Examination of influence of CO_2 concentration by scientific methods in the laboratory

László Kajtár*, Levente Herczeg, Eszter Láng

Department of Building Service, Budapest University of Technology and Economics, Budapest, Hungary

ABSTRACT
The goal of the present study was to examine the influence of CO_2 concentration in the air of indoor spaces on human well-being and intensity of mental work. Ten experimental subjects were used in four experimental conditions with different CO_2 concentrations (600, 1500, 3000, 4000 ppm). Microclimatic parameters (CO_2 concentration, temperature and relative humidity of the air, surface temperature of walls) were measured. Well-being of subjects has been evaluated with the aid of subjective scales, physiological variables were recorded and mental performance of subjects was measured by a standard test. It was checked that indoor climate parameters—temperature, relative humidity—remained the same under exposure of different CO_2 concentrations. Thus, the obtained results are related to the effects of CO_2. Results revealed that human well-being as well as capacity to concentrate attention are declining when CO_2 concentration in the air is increasing up to 3000 ppm.

INDEX TERMS
Air quality; Carbon dioxide; IAQ assessment; Measurement technique; Mental work

INTRODUCTION
The comfort in closed spaces is usually understood as thermal, air quality, acoustical and illumination engineering comfort. The office plays a special role in providing adequate comfort as workers spend a longer time in closed spaces performing intellectual work. In the air-conditioning of comfort spaces the primary task is to provide a pleasant indoor microclimate for the people staying in the room. In addition to thermal comfort, air quality is also regulated by international requirements and standards. In the occupied zone a sufficient amount of fresh air of appropriate quality must be provided for the people staying in the room. Hungarian technical regulations do not fully cover these aspects yet—hence the complaints frequently heard from employees working in air-conditioned spaces: the air has an unpleasant 'smell', they experience 'lack of air' or perhaps have headaches. Among pollutants carbon dioxide, a by-product of the human metabolism, is regarded as one of the key factors. The carbon dioxide content of exhaled air is higher than that of the outdoor air, leading to an increase in the carbon dioxide concentration in the closed space. CO_2 concentration influences human well-being. In closed spaces the allowed CO_2 concentration may be ensured by supplying the adequate amount of fresh air. The exact volume of fresh air varies in Hungarian and international literature, ranging from 20 to 120 m^3/person. This is also a matter of economic efficiency as the volume flow of fresh air has an impact on the energy use of the air conditioning system.

In the framework of the OTKA research topic (topic nos. T 029451 and T 037596) at the Building Services Department of the Budapest University of Technology and Economics we conducted studies concerning the impact of CO_2 on human performance and well-being, at the same time determining the necessary fresh air demand.

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* Corresponding author.

SUBJECTS AND PROCEDURE

To carry out the measurements described in the Introduction, a measuring stand was constructed to examine the performance and well-being of subjects performing office work. Ten subjects participated in the study (four males and six females, mean age = 21.3 ± 1.5 years). Each subject participated in four experimental sessions with different pre-set CO_2 concentrations (600, 1500, 3000 and 4000 ppm). The circuit diagram for the laboratory measurements is shown in Figure 1.

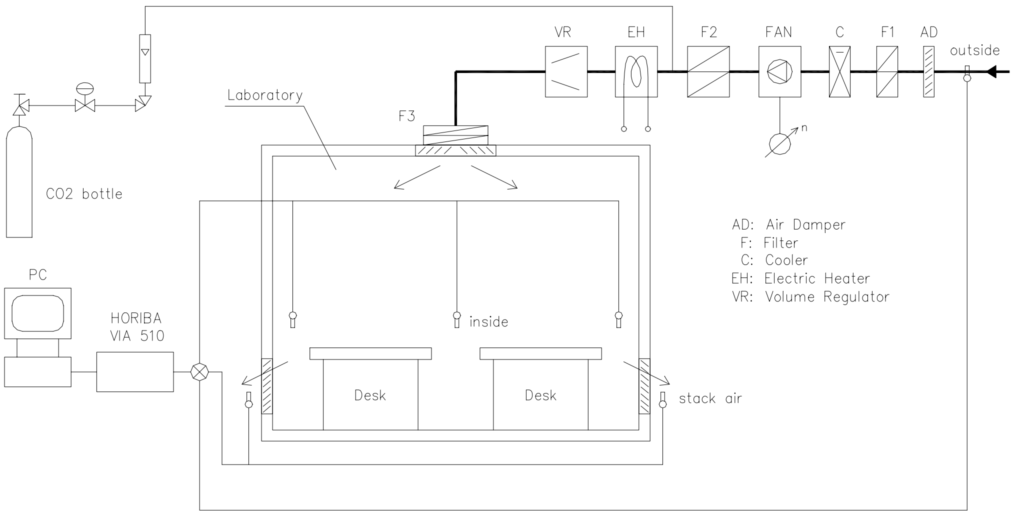


Figure 1 Circuit diagram of the laboratory measurements.

During experimental session volume flow of supply air was held constant (120 m^3/h). Constant CO_2 concentration was obtained by dosing CO_2 into the chamber (see Figure 1).

Sessions succeeded each other in the following manner: session no. 1 (600 ppm CO_2), no. 2 (1500 ppm), no. 3 (600 ppm), no. 4 (4000 ppm). Two sessions (with 1500 and 4000 ppm concentrations) consisted of 2 × 70 min mental work periods. Two sessions (with 3000 and 600 ppm CO_2 concentrations) consisted of 3 × 70 min mental work periods. The mental work involved the reading of a text manipulated for this purpose and the search for typographic errors. Performance of subjects was characterized by the number of rows read by the subjects (quantity aspect), and percentage of misspelled words found by them (quality aspect). Prior to and following work periods questionnaires were to be filled in for evaluating subjective comfort and well-being; also, physiological tests were carried out and measures of skin temperature were taken.

Due to some technical and economic limiting factors the exposure time was longer only for two levels of CO_2. The following was considered during analysis: periods with corresponding exposure time were compared. The same is true for the sequence of exposure conditions. Learning effect was taken into consideration during the analysis.

Measurement of Objective Microclimatic Characteristics

The following objective microclimatic parameters were examined:

- Measurements of CO_2 concentration were carried out with the aid of a HORIBA VIA 510 infrared gas analyser for which the Department has developed a data collector to be connected to a computer. Measurements were carried out during the entire experimental session with 30-s sampling intervals. CO_2 concentrations were set at: 600 (no CO_2 supply), 1500, 3000 and 4000 ppm.

- PMV (Predicted Mean Vote), PPD (Predicted Percentage of Dissatisfied) values: objective measurements concerning thermal comfort were conducted with a PMV meter. Data were read every 70 min in a work period.
- Temperature of the ventilated air, as well as temperature of exhaust air were measured with two temperature data collectors. The temperature and relative humidity in the occupied zone were also measured with the aid of a temperature and humidity data collector. Measurements were carried out during the entire experimental session, with 30-s sampling intervals.
- The surface temperature of four side walls of the floor and the ceiling has been measured using a laser surface thermometer. Sampling was done at the start of the session, before the breaks and at the end of the session.

Evaluation of Subjective Comfort

The following parameters were examined in the evaluation of subjective comfort:

- Fanger scale: subjects had to report whether they find air quality acceptable or unacceptable by marking +1 (clearly acceptable) and –1 (clearly unacceptable) on a scale.
- Hedonic scale: subjects' comfort was measured in the range of pleasant (5) and unbearable (1).
- Air quality scale: analogue scale for evaluation of freshness of the air. The endpoints of the scale were fresh (0) and very unpleasant (+1) sensation.
- In the examination of human well-being changes in subjects' freshness, calmness, tiredness and concentration were surveyed.

The above measurements were carried out in each session at the beginning, at the end, and in the breaks between the 70-min working periods. This way questionnaires were filled in three times during session no. 1 (1500 ppm CO_2) and session no. 4 (4000 ppm CO_2) consisting of two working periods, while during sessions consisting of three working periods (session no. 2 with 3000 ppm CO_2, and session no. 3 with 600 ppm CO_2) measurements were carried out four times.

The following measurements were carried out at the beginning and at the end of each session:

- Subjective evaluation of surface temperature of human skin: subjective thermal comfort was recorded with the help of a seven-grade scale (very hot: –3; pleasant: 0; very cold: –3) at five different points: forehead, nose, chest, right hand and left hand.

Subjective evaluation of general thermal comfort: subjects' thermal comfort was examined using an analogue scale.

Study of Objective Physiological Parameters for Humans

The following physiological and psychophysiological parameters were measured and computed: systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse rate, heart period (HP) beat by beat, spectral components of the power spectra of heart period variance (HPV), skin temperature.

During each session, SBP, DBP, pulse rate has been taken at the beginning and at the end of the session, as well as in the pause between two working periods with the aid of a wrist digital sphygmomanometer. The surface temperature of the human skin was measured with a surface thermometer at the beginning and at the end of the session (measured points: forehead, nose, chest and both hands).

HP, HPV were collected continuously during sessions. An integrated system (ISAX) designed for spectral analysis of HPV has been used as mental effort monitor, since suppression of MF (mid-frequency component of HPV) reflects the effort invested by the subjects.

Statistical Analysis

Statistical analysis on the above variables was performed using SPSS 10.00 for Windows. Differences between sessions, as well as changes appearing during the same session were revealed by analysis of variance with repeated measurements using appropriate contrasts.

RESULTS, CONCLUSIONS

Measurements were completed at the end of October 2002. In the present study performance during mental workload and results concerning evaluation of subjective comfort are presented. Concerning other recorded variables due to the large number of measurements data processing is still in progress.

Since such indoor climate parameters as temperature of the air, temperature of the walls and relative humidity of the air remained the same under exposures of different CO_2 concentrations obtained results are related to the effects of CO_2.

Results Concerning Evaluation of Subjective Comfort

Changes appearing during the same session

Fanger scale: Analysis of variance with repeated measurements revealed significant differences between measurements of the same session. Subjects evaluated air quality less acceptable at the end of the session than at the beginning of the same session. In the case of session with 600 ppm CO_2 subjects evaluated air quality less acceptable only after the second working period while well-being of subjects declined already following the first 70 min of working period during other sessions.

Differences between sessions

Fanger scale: When comparing corresponding measurements of different sessions analysis of variance showed that significant differences appeared between sessions only following the second working period, that is, after 140 min. Subjects evaluated air with 3000 and 4000 ppm CO_2 significantly less acceptable than air with 600 ppm CO_2. Air with 1500 ppm CO_2 concentration has been judged as significantly more acceptable than air with 4000 ppm CO_2. In the case of sessions with 600 and 3000 ppm CO_2 three 70-min working periods were used. After the third working period, that is, after 210 min air was denoted significantly less acceptable during session with 3000 ppm CO_2 as compared to session with 600 ppm CO_2 (as it was the case already after 140 min).

Figure 2 shows the results of measurement with the Fanger scale.

Evaluation of air quality using the Fanger scale (acceptable{+1}, unacceptable {–1}) during experimental sessions with different CO_2 concentrations.

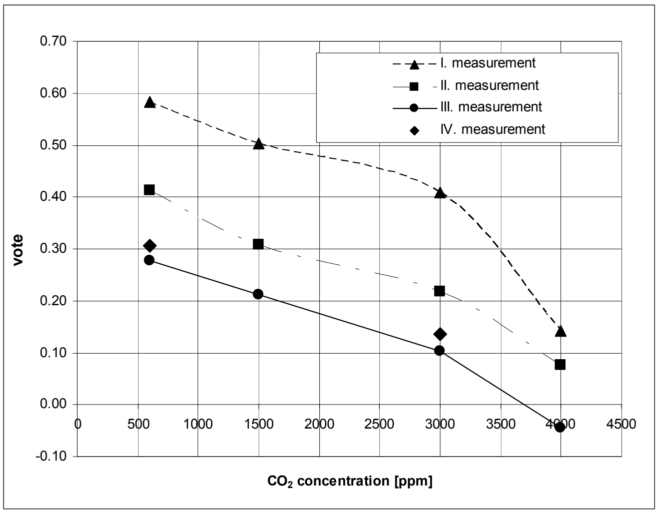


Figure 2 Results of measurements with the Fanger scale.

Air quality scale: Similar results were found as in the case of FANGER scale, with the only advantage that after 140 min air with 1500 ppm CO_2 concentration has been judged as significantly more fresh than air with 3000 ppm CO_2 concentration. Figure 3 shows the results of measurement with the Air quality scale.

Evaluation of air quality using Air quality scale (fresh {0}, very unpleasant sensation {+1}) during experimental sessions with different CO_2 concentrations

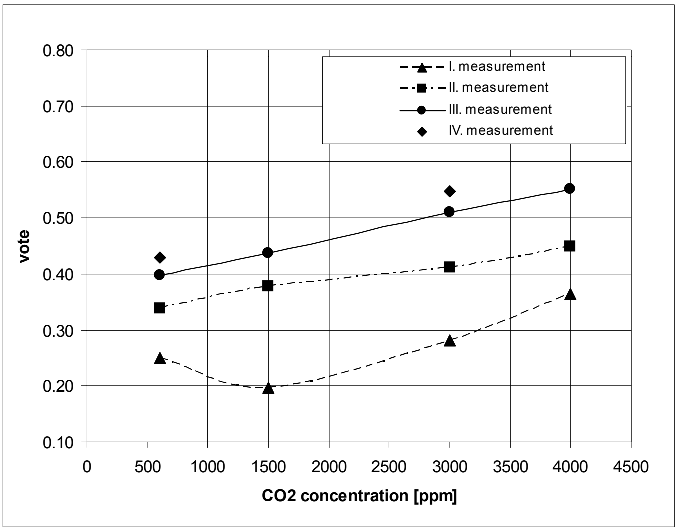
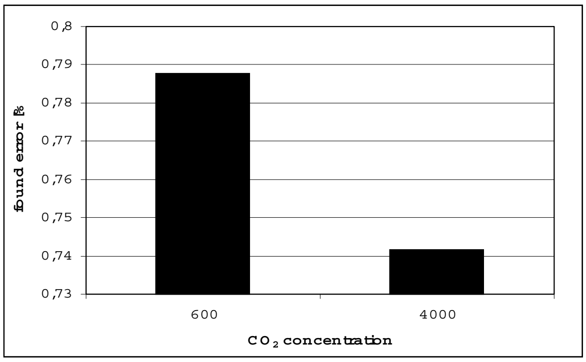


Figure 3 Results of measurement with the Air quality scale.

Results Concerning Mental Workload

Performance of subjects characterized by the number of rows read during the session (quantity aspect) was not significantly impacted by the degree of CO_2 concentration. Concerning this variable 'time effect' (learning) has been found: subject's performance related to the quantity of read rows increased from the first to the last session. The quality aspect of performance (percentage of mistakes found by the subjects), however, proved to be more sensitive to the concentration of CO_2. Analysis of variance revealed that during the second 70-min working period percentage of mistakes found by the subjects was significantly higher in session with 600 ppm CO_2 than in the corresponding working period of session with 4000 ppm CO_2 concentration. Moreover, during the third 70-min working period of session with 600 ppm CO_2 the percentage of mistakes found by the subjects was nearly significantly higher than in corresponding period of session with 3000 ppm CO_2 concentration. In this case the number of rows read by the subjects in the session with 600 ppm CO_2 also exceeded the number of rows read in the corresponding period of session with 3000 CO_2 concentration. That means that the third working period with 600 ppm CO_2 proved to be more advantageous for both aspects of mental performance than 3000 ppm CO_2 concentration (Figures 4 and 5).



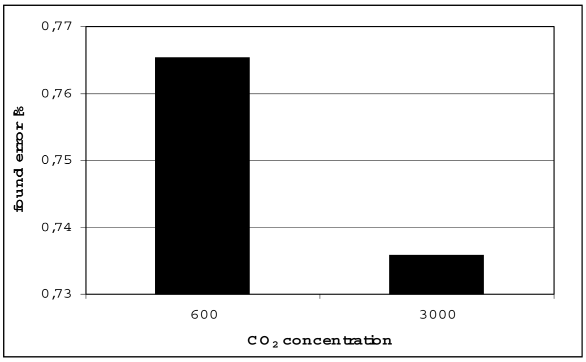


Figure 4 (Left) Influence of CO_2 concentration on percentage of errors found by subjects in the second 70-min work period.
Figure 5 (Right) Influence of CO_2 concentration on percentage of errors found by subjects in the third 70-min work period.

The quality aspect of mental work express the ability to concentrate attention.

It looks like human well-being as well as capacity to concentrate attention is declining when CO_2 concentration is increasing up to 3000 ppm.

REFERENCES

Bánhidi, L. and Kajtár, L. (2000). *Komfortelmélet*, 436 pp. Budapest: Egyetemi Kiadó (own part: pp. 187–352).

Kajtár, L., Erdősi, I. and Bakó-Biró, Zs. (2001). Thermal and air quality comfort in the Hungarian office buildings. *Proceedings of the Second NSF International Conference on Indoor Air Health*, Miami Beach, USA, pp. 270–278.

Herczeg, L. and Kajtár, L. (2002). *Measurement of Air Quality Comfort in Closed Spaces*. Budapest: Gépészet.

Kajtár, L., Herczeg, L. and Láng, E. (2001). Influence of CO_2 concentration on office work intensity and human well-being. *International Conference Indoor Climate of Buildings*, Slovakia, Kiadvány, pp. 111–120.

Láng, E., Horváth, Gy. and Slezsák, I. (1997). Integrated system for ambulatory cardio-respiratory data acquisition and spectral analysis. *World Congress on Medical Physics and Biomedical Engineering*, Nice, France, 14–19 September. Abstract: *Medical and Biological Engineering and Computing*, Vol. 35, Supplement, Part I, p. 118.