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Air quality as an important indicator for ergonomic offices and school premises

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Abstract. The health risk assessment model for office rooms contains the physical indoor air factors and the risks connected with the use of computers. Four comfort classes have been postulated. Indoor air quality is the main risk factor at workplaces such as office rooms and schools besides non-ergonomic use of computers. High levels of carbon dioxide (CO_2) could be observed due to poor ventilation systems and inadequate air exchange due to inoperable windows. Overcrowded classrooms could also be the reason for a high CO_2 level. Lowering the occupancy and increasing the breaks between classes could alleviate the high CO_2 concentrations in schools and offices. The data of Estonian investigators are analyzed. Experiments for determination of the adequacy of ventilation rate and the respective build-up of CO_2 are carried out by the authors of the paper.

Key words: ergonomic workplace**,** indoor air**,** carbon dioxide, schools, offices.

INTRODUCTION

There are numerous hazards in the work environment (low temperatures, draught, high concentration of carbon dioxide, noise, etc.) that affect office workers and can damage the peripheral and central nervous system. Different hazardous factors (indoor climate, static posture, etc.) are influencing on the computer-workers. Workers and students spend about half of their waking hours at work or school (Koistinen et al., 2008). Therefore, the adequate air quality in schools and workplaces is a top priority for facility managers and building operating managers. The study of Myatt et al. (2002) found a relationship between sick leave absences and carbon dioxide concentrations in office buildings.

Computer-workers are under pressure as increasing amounts of work have to be done within limited time. Intensive use of computers causes major health problems like tissue damages, imbalance in blood flow, formation of the carpal tunnel syndrome (Oha et al., 2010). The interaction between the body and the work environment is complicated and four important systems (central nervous, automatic nervous, endocrine, and immune) are involved in this network (Raja et al., 1996). Stuffy air, noise, temperature, lighting deficiency might be the supplementary risk factors for developing musculoskeletal disorders (MSDs) and psychosocial stress at workplaces

(Tint et al., 2012a). The main physiological and psychological stress factor is a poorly designed workplace (Tint & Traumann, 2012b).

Stressors like time limits, too much work demanded by the employer are considered to be the factors that can cause fatigue in upper extremities (Feuerstein et al., 2004; Kulin & Reaston, 2011; Panari et al., 2012).

If improvement methods in the working environment are implemented, the level of stress of workers has to decrease.

The increasing amount of computer work and workers in the society is a supplementary source for developing the MSDs. The workload is increasing, but the working conditions are not developing so fast. The preventive measures in occupational safety and health are often not used as these measures cause supplementary costs for the employers (Tint et al., 2010). An investigation of 295 computer workers (Tint et al., 2014) showed that Estonian computer workers assess their health status as considerably high. They are optimistic in solving the problem that the monotonous work with computers will continue and believe that their health status in the future will stay on the same level using the steadily enhanced rehabilitation means. Considering the fact that people begin to work with computers at ever younger age, according to the current investigation, more MDSs are observed by young people (< 40 years of age) than by older workers (> 40 years of age). The positive result is that 43.4% of older workers consider their health status good. Vision disorders were diagnosed for groups A and B almost at the same rate. It shows that eyes get tired and the eyesight is worsening already at a young age.

In occupied rooms, including classrooms, the concentration of carbon dioxide (CO_2), a colourless, odourless gas, can be used as an indicator of the ventilation rate per occupant and the removal of pollutants in the air (Geelen et al., 2008). Indoors, complaints of poor air quality are unusual if CO_2 concentrations are under ca. 700 to 800 ppm. The carbon dioxide emissions from a medium-sized human doing easy physical work are estimated to be around 20 L h^{-1} (Laht, 2010).

If the occupancy and ventilation rate are stable enough, the time required to reach a steady state depends on the ventilation time constant which is the reciprocal of the air exchange rate of the space (e.g., if the air exchange rate is 0.4 h^{-1}, the time constant is 2.5 h). To reach a carbon dioxide concentration of 95% of the steady state value, a period of three time constants with a stable occupancy and ventilation rate could be required (Seppanen et al., 1999).

According to current Estonian legislation, the concentration of carbon dioxide considered to be hazardous is 5,000 ppm or 0.5%. The Estonian standards connected to building construction state that the maximal amount of carbon dioxide in rooms can be 2,500 ppm or 0.25%, of which 1,500 ppm (0.15%) can be emitted by human organism activities (EVS-ES 15251, 2007). As the standards do not bear legal power, the amounts of carbon dioxide in classrooms are regulated by Resolution no. 109 issued by the Ministry of Social Affairs on August 29, 2003, according to which carbon dioxide concentration in classrooms at the end of the day's last lesson must not be higher than 1,000 ppm (Resolution nr 109, 2003).

The Estonian Health Protection Inspectorate (EHPI) has monitored the internal climate of school classrooms over the years. In 2005–2006, 158 schools took part in a respective survey. The results showed that the situation was rather unsatisfactory: 66% of the classrooms examined did not meet the necessary demands (EHPI, 2006). In

2009, the EHPI undertook a similar survey with 117 kindergartens, which revealed that 62% of rooms had carbon dioxide concentrations over 1,000 ppm. It should be stated here that the results show a positive temporal trend: while in 2004 only 31% of kindergartens met the legislative demands in terms of carbon dioxide amounts, then in 2006 the respective figure was 44%, and in 2007 – 52% (EHPI, 2009). The main reasons for the elevated carbon dioxide amounts were found to be somewhat insufficient room volumes per child, and ventilation – when increased, both resulted in a decrease of CO_2 concentrations.

Besides the EHPI, the Tallinn University of Technology and the University of Tartu have undertaken similar surveys as well. In 2005, Kõiv conducted a survey of carbon dioxide concentrations in 9 schools in Tallinn, publishing the respective data in 2007 (Koiv, 2007). The results showed that due to deficient ventilation, carbon dioxide concentrations could reach as high as 3,300 ppm. In the work of Plangi (2007), a similar survey was undertaken in Tartu schools, showing that in general the CO_2 concentrations measured were between 432 and 2,954 ppm, whereas 89% of classrooms did not meet the demands imposed by the legislation in this issue.

A thorough survey was undertaken lately by Laht (2010) considering the internal climate of four schools in Tartu (December 2009 to March 2010) and a kindergarten in Valga (October 2009). It was shown that in school classrooms the measured CO_2 concentrations ranged from 400–800 ppm at the beginning of the day to 1,300–2,300 ppm during the course of the day, with temporary drops to 400–1,000 ppm upon ventilation. In the kindergarten rooms, carbon dioxide concentrations were shown to increase from 200 to 1,650 ppm during the day.

The experimental part of the present study focuses on monitoring IAQ in offices and school buildings, where the main hazards of the workplace are high air temperatures during the warm season, possible low temperatures in the winter, low relative humidity in centrally-heated rooms in the cold season, and high concentrations of CO_2.

It is possible to calculate the concentration of CO_2 at the end of the lesson or the needed air exchange rate to keep the CO_2 level within the frames of the norms using the equation (Zogla & Blumberga, 2010):

$$n_{av} = \frac{\ln C(t_1) - \ln C(t_2)}{t_2 - t_1},$$

where: n_{av} – air exchange rate, h^{-1}; $C(t_1)$ – CO_2 level in the beginning (with subtracted background CO_2 level), ppm; $C(t_2)$ – CO_2 level in the end (with subtracted background CO_2 level), ppm; t_2–t_1 – time between CO_2 level measurements, h.

The authors of the present paper have been engaged in the measurement of CO_2 in schools since the autumn of 2005. The elevated content of CO_2 in indoor air has been a problem in schools, particularly in computer classes in the years 2005–2008, when there were small numbers of computers available for schoolchildren and they queued in the classes waiting for a free computer. Also, the problem in old school buildings was that the rooms had no mechanical ventilation. A large number of elementary schools, kindergartens and hobby schools were renovated during 2008–2012 and now the conditions are expected to be improved.

The concentrations of CO_2 in schools and kindergartens on Saaremaa Island (in the west of Estonia) in autumn 2005 were measured in the range between 450 ppm and 3,000 ppm (Tint et al., 2011); the measurements of CO_2 concentration (in winter 2010) in a 1984 built school-building in Tallinn gave the following results: 438 to 1,205 ppm. The measurements were carried out in 12 classrooms. The building has been out of use since the end of 2012 (Fig. 5) (Traumann et al., 2012).

The aim of the study was to give recommendations for improvement of indoor air quality and to work out a health risk assessment (HRA) model for office-rooms, including ergonomic principles for work with computers. The HRA model connects the risks in the work environment and medical examinations (ME) according to the risk level in offices.

MATERIAL AND METHODS

Indoor air in schools and offices was investigated. The data from the investigation of indoor climate quality in schools with natural ventilation (based on Laht, 2010) and mechanically ventilated rooms (based on the data of the authors of the current paper) were compared. The measurement equipment and the standard were as follows: EVS-EN-ISO 7726:2003 'Thermal environments – Instruments and methods for measuring physical quantities'; EVS-EN 15251:2007 'Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics', EVS-EN 12464-1:2011 'Light and lighting – Lighting of workplaces – part 1: Indoor work places', EVS 891:2008 'Measurement and evaluation of electrical lighting in working places'. The measurement equipment used for microclimate: TESTO 435. TESTO 435 also enables the measurements of CO_2. The measurement of CO_2 was carried out according to EVS-EN 1231:1999, EVS-EN 15251:2007 and EN 13779:2010.

Workplace lighting and screens were measured using the light-metre TES 1332 (ranges from 1–1,500 lx). Lighting was measured on the desk, on the screen, and on the keyboard. Dust was measured with HazDust EPAM-5000.

Figure 1. Office in an institution 1.

Figure 2. Office in an institution 2.

Figure 3. Office in an institution 3.

Figure 4. Office in an institution 4.

Figure 5. Computer class in an old school building.

Figure 6. Computer class in a renovated school building.

RESULTS

Table 1 shows the results of the measurements in the work environment of the offices shown in Fig. 1–4. In winter, the humidity of the air is too low. By the norms (EVS-EN 15251:2007), relative humidity of 40–60% is required for the worker to feel comfortable. The level of carbon dioxide ~1,000 ppm is felt by the workers as poor microclimate. The lighting of workplaces equipped with computers is usually good, in the frames of the norms (300–500 lx), but sometimes information technologists prefer working in the dark (without electrical lighting). However, this situation must be avoided.

Table 1. Results of the measurements indoors in offices (2012–2013)

Room type	T, °C Cold/warm season	R, % Cold/warm season	L, lx	CO_2, ppm	Dust, mg m^{-3}
	U = 0.6°C	U = 2.0%	U = 10.4%	U = 10%	U = 10%
Office 1, Fig. 1	20–22/28–30	22–23/35–65	495–890	537–998	0.030
Office 2, Fig. 2	20–22/24–28	15–25/35–75	200–250	500–750	0.020
Office 3, Fig. 3	18–22/20–24	20–30/40–74	350–600	350–1,200	0.015
Office 4, Fig. 4	17–20/22–28	15–30/40–70	690–1209	478–1,152	0.011

U – uncertainty of measurements; T – temperature of the air; R – relative humidity; L – lighting; CO_2 – concentration of carbon dioxide in the air; Dust – dust concentration in the air

The ventilation rate and concentration of CO_2 in a new school-building (Fig. 6) in Tallinn in January 2013 are given in Table 2.

Table 2. Concentration of CO_2 and ventilation efficiency in a renovated school building in Tallinn (Fig. 6)

Room description	Concentration of CO_2 corresponding to time, ppm; U = 10%									Mechanical ventilation rate, $m^3\ h^{-1}$
	8.00	9.00	9.30	10.15	10.50	12.00	13.35	14.00	14.20	
Computer class 1 (45 m^2)	575	635	600	650	591	730	621	710	673	20
Computer class 2 (40 m^2)	502	560	540	671	580	682	610	720	653	22
Computer class 3 (45 m^2)	543	653	632	733	640	730	621	699	580	21
Laboratory equipped with computers (40 m^2)	501	729	680	1,067	699	854	730	850	630	18
Ordinary classroom (20 m^2), without windows	480	523	520	521	522	632	520	658	533	20
Ordinary classroom (35 m^2)	487	727	601	721	540	663	540	680	533	20
Ordinary classroom (45 m^2)	508	650	520	673	523	688	533	698	512	20

When no ventilation of a class during breaks by opening the windows was undertaken, the CO_2 content increased from 700 to 1,500 ppm during the lessons (Fig. 7), decreasing due to natural ventilation only when a low enough number of students was in the room. However, when ventilation by opening the windows during the breaks is applied, the accumulation of CO_2 is kept under control with a slightly varied CO_2 build-up in classes almost independent of the number of students (Fig. 7, curve 1). However, CO_2 concentrations of 1,200–1,800 ppm were still obtained by the end of the lesson. The duration of the lesson is 45 min. and the break 10 min. (the lunch-break between the 3rd and 4th lesson is 15 min (Fig. 7).

The measurements in the new building (Table 2; Fig. 7, curve 2) equipped with mechanical ventilation (natural ventilation through the windows is not possible) were 550–750 ppm and higher concentrations were measured in an overcrowded classroom (30 people; CO_2 concentration 1,067 ppm). It only takes 15 minutes to balance the CO_2 concentration to the level of 550 ppm.

The health risk assessment (HRA) model worked out by the authors of the current paper is presented in Fig. 8. Concentration of carbon dioxide is one of the indicators of the impurity of indoor air. Other important indicators (shown in Fig. 8) are: lighting of the workrooms, temperature, and air humidity. Dust concentration in office air by comfort classes is determined considering the Estonian regulations (Resolution, 2011), measurements of dust, and the feeling of dust in the air by workers. Comfort at workplaces is also determined with ergonomic indicators, like workplace design, the time spent at the computer per workday. The frequency of medical examinations (ME) is determined by the investigation results of computer-equipped workplaces (Tint et al., 2014).

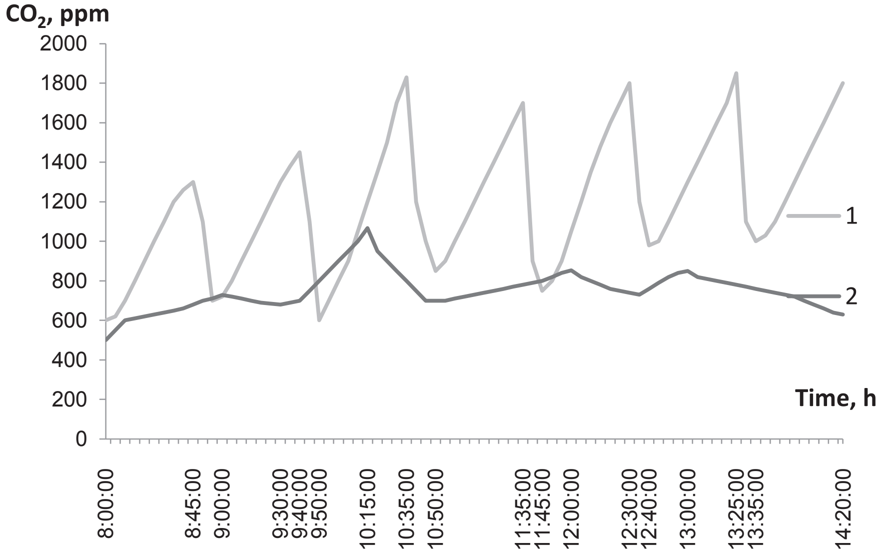

Figure 7. Change of CO_2 concentrations during the lessons and breaks at schools: 1 – School 5 (based on Laht, 2010); 2 – School in Tallinn (new data of the authors of the current paper).

< 100	< 300	300–500	500–600	Lighting, lx
RH< 20 or RH >70	20<RH<70	25<RH<60	30<RH<50	Humidity (RH), %
More	19–27	20–26	21–23.5	Operative temperature, °C
v < 4	4 ≤ v <7	7≤ v ≤10	v > 10	Ventilation, (v) l s^{-1} per person
> 800	**< 800**	**≥ 500**	**350–500**	**CO_2, ppm (over the outdoor level)**
0.09–0.1	**0.06–0.09**	**≥ 0.05**	**0.01–0.05**	**Dust, mg m^{-3}**
Over 8 hours/day	8 hours/day	6 hours/day	4 hours/day	Work with computers
Old chairs, static posture, no natural lighting	Standard workplace for everybody, static posture	The desires of workers have been taken into account in some points (the chair)	The workers have designed the workplace themselves	Workplace ergonomics
		Norm		
4th health risk level **ME** twice a year**	3rd health risk level **ME** once a year**	2nd health risk level **ME**once in 3 years**	1st health risk level **ME** once in 3 years**	Variables

Medical examinations (*ME***)

Figure 8. Health risk assessment model for computer-workers in office rooms.

DISCUSSION

Based on the literature review, the air in the classrooms and offices in Europe and North America is often polluted and the ventilation systems are not working correctly. In practice, application of a mechanical ventilation system or improvement of the existing natural ventilation is not always feasible. As an alternative, the ventilation behaviour of the occupants in schools and offices can be improved by the combination of a CO_2 warning device and teaching package for specific ventilation advice, while giving the ventilation advice alone is usually not effective (Geelen et al., 2008).

A CO_2 warning device is a measuring instrument with a display and red light-emitting diode (LED) which turns on when the CO_2 concentration exceeds 1,200 ppm (Geelen et al., 2008). This informs the workers, teacher and pupils of the CO_2 concentration being too high. Along with use of the warning device, a ventilation teaching package was specifically developed for 7–10-year-old pupils by Geelen et al. (2008) as specific behavioural instructions for the teachers and their pupils. The teaching package consisted of three lessons and in each lesson a different theme was discussed with the help of a cartoon character called 'Outdoor air'. The first theme, 'Moisture in the air & Ventilation', described a regular school situation with the occurrence of moisture in the air, emitted from the skin and the lungs. It explained that continuous ventilation was needed to remove the moisture from the classroom. Although other pollutants in the classroom are of importance, moisture was used to simplify the situation for the pupils. The second theme, 'Dirt in the air & Airing of the classroom', described that more pollutants, like glues or paints, were emitted into the air during handicraft lessons. Furthermore, it explained that extra ventilation of short duration, like airing, was needed to remove these extra pollutants from the classroom and offices. The third theme, 'Dust mite & Cleaning', described the need for a clean environment, for example to avoid the growth of dust mites (Geelen et al., 2008).

CONCLUSIONS

Indoor air and other problems in the same workroom could be defined individually in quite different ways. Therefore, an individual approach has to be implemented for every workplace considering the anthropological and other features of the worker who will work in the certain workplace. Information technology workers often work in under-lighted working conditions although there is a possibility to raise the (artificial) lighting to the normal limits (400–500 lx).

The carbon dioxide measurements showed that there is the 4^{th} level health risk in educational institutons and office-rooms in cities near intensive transport roads in particularly, if the windows cannot be opened and the mechanical ventilation is not working. The all-wall glass windows make the conditions even worse if the temperature outdoors is high (> 25°C) and in this case nearly 30°C inside the office-room.

The concentration of carbon dioxide outside the buildings in towns has increased. In a hot season (May, June), the measurements showed that the content of CO_2 in the street (in towns) was 492 ppm. Considering this, the concentration of CO_2 in office-rooms without mechanical ventilation close to the street was 866…1,986 ppm. The complaints from the side of the workers were enormous. The situation in countryside is better.

The 1st (the best) category of comfort is gained when the workers themselves can design the workplace and work with computers alternates with other work activities. Medical examinations are obligatory in this case once in 3 years. If computer workers do not follow the legislation on computer work as it often happens (work is taken home), then the risk for developing the MSDs is high in the young age already.

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