IMPROVEMENT OF WORKPLACE ERGONOMICS IN ATRIUM-TYPE BUILDINGS

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The aim of the study was to improve the indoor quality and ergonomics of workplaces in atrium-type buildings. The investigated atrium-type building has the atrium (15×30 metres) inside. The roof of the atrium is built from glass and there is a break between the walls and the roof. It gives the possibility for workers in rooms closed to the atrium to have some fresh air. Nevertheless, there are problems caused by shortage of natural light, high concentrations of CO_2 and low room temperature in winter. The main results of the investigation were: the design of the workplaces needs to be carried out in parallel to the construction of the building; later it is difficult to improve conditions in the workplace; the air temperature in workrooms depends on the room location in the building and in winter, rooms closed to the atrium are cold; the concentration of CO_2 exceed limits in rooms where windows cannot be opened. Workers are endangered by developing sick building syndrome. The concentration of dust is under the limits, but the problem of dusty air was raised by the workers. Some ergonomic improvements are possible and corresponding recommendations were given to the employers.

Key words: *atrium-type buildings, natural lighting, microclimate, sick-building syndrome, concentration of CO_2, workplace design.*

INTRODUCTION

The world practice of designing atrium-type buildings to improve the indoor climate is used both in cold and warm climate countries (Voeltzel *et al.*, 2001; Sharples and Lash, 2007; Song, 2007; Pan *et al*., 2009; Yunus *et al*., 2010; Sadrzadehrafiei *et al.*, 2011). The atrium-type buildings are mainly used as commercial centres, but also as large educational buildings (Tint and Traumann, 2012a).

In the present study, the indoor climate, lighting and ergonomic design of workplaces in the workrooms of an atrium-type building (built in 2009) of a university were investigated.

In the Estonian Standard EVS-EN 15251:2007, the demands for indoor climate (IC) quality in office-rooms are given for the air temperature, humidity, velocity (ventilation), carbon dioxide concentration, noise, and lighting. The Estonian standard EVS 894:2008 (Daylight in dwellings and offices) gives more attention on the importance of natural lighting and possibilities to overcome shortages of natural lighting. The investigation of the air quality in offices and in residential buildings has become more and more important. The concentration of carbon dioxide (CO_2) has in-

creased outdoors and therefore the indoor concentrations have also have become more uncomfortable to the people working inside (Stavova *et al*., 2007). Mechanical ventilation (Woods *et al*., 2009) no longer satisfies the comfort demands of workers. The windows in the office-rooms of atrium-type buildings have to be openable.

During the 1970s energy crisis, buildings were designed to be airtight and windows that cannot be opened became a common practice of building design. It is now clear that such airtight buildings create problems. Because of inadequate ventilation to the outside, the air pollutants inside the buildings have to be removed. Health problems due to indoor air pollution can range from nose, eye, and throat irritation and aggravation of asthma to increased risk of lung cancer. Biological sources of indoor air pollution include mould, mildew, fungi, and bacteria (Schleibinger *et al.*, 2008). Exposure to small amounts of indoor air pollutants can cause minor irritations, such as dry, scratchy eyes and throats, or headaches. However, in large concentrations pollutants can lead to dizziness, tiredness, and nausea, and rashes. Although anyone can suffer from indoor air pollution, the most susceptible groups are the ageing workforce, and persons with respiratory ailments like bronchitis, asthma, or emphysema. Nowadays, airtight windows are

used in the office-rooms close to the atrium in atrium-type buildings (Tint and Traumann, 2012a). The physical environment of the workroom is important as it may induce stress in individuals and thereby reduce the overall results of cognitive endeavours of scientific and office workers. EVS-EN 15251:2007 originates from different (I to IV) categories of comfort.

Numerous studies both in Europe and North America have indicated that non-specific symptoms related to occupancy in office buildings (Bako-Biro *et al.*, 2004; Fang *et al.,* 2004; Saari *et al.*, 2006) and attributed to poor air quality are common among office workers and that there is considerable variation in the prevalence of symptoms among buildings (Jones, 1999; Seppänen *et al.*, 1999). These symptoms are generally referred to as sick building syndrome (SBS) symptoms. The SBS has become common due to the construction of buildings designed to be energy-efficient with air conditioning systems and unopenable windows (Berardi *et al.*, 1991). SBS is characterised by: eye, nose and throat irritation, sensation of dry mucous membranes and skin erythema (skin redness), mental fatigue, headaches, high frequency of airway infections and cough, hoarseness, wheezing, itching and non-specific hypersensitivity, nausea and dizziness. SBS is often also characterised by other non-specific symptoms, such as nasal dryness, nasal congestion (stuffy, blocked nose), nasal excretion (runny nose), pharyngeal symptoms, difficulty in concentration, and difficulty in breathing and tight chest (Seppänen *et al.*, 1999). The term 'SBS' is used primarily when the agents causing the symptoms are unidentified and the symptoms do not indicate a specific known disease. SBS symptoms/complaints appear during the workday and improve or disappear on the weekend. Despite several studies aimed at establishing the pathogenetic role of microorganisms, chemical pollutants and microclimate in such environments, the aetiological factors are usually difficult to identify (Berardi *et al.*, 1991).

Natural ventilation in the workrooms is as important as the natural lighting. There are of course problems in winter as we have to preheat the air (Woods *et al.*, 2009).

Natural light is associated with lower fatigue and reduced eyestrain. With natural lighting of the rooms the contact with outdoor environment remains for the worker (DeKay, 2010).

The body uses natural light similar to food and water, as it stimulates essential biological functions (nervous and endocrine system).

There are a number of factors that can limit visual functions of the worker, such as artificial lighting or daylight deficiency, visual correction, visual angle and distance, flicker, contrast etc. Workers are influenced psychologically and physiologically by different spectrums provided by natural and the artificial lighting. The atrium roof profile and structure influence very much the natural light transmittance: the

roof lets through 20% and 80% of the light (Rennie and Parand, 1998).

The aim of the study was to survey indoor climate quality and workplace management to provide recommendations for improving working conditions and ergonomics of workplaces (Graves and Tardiff, 2006) for office workers.

MATERIALS AND METHODS

Characteristics of the building and the workrooms investigated are given in Figures 1–2.

Measurements made in the work environment are based on ISO, EN DIN, EVS standards: 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 work places. Part 1: Indoor work places", EVS 891:2008 "Measurement and evaluation of electrical lighting in working places". The measuring equipment used for microclimate: TESTO 435. The device TESTO 435 also enables

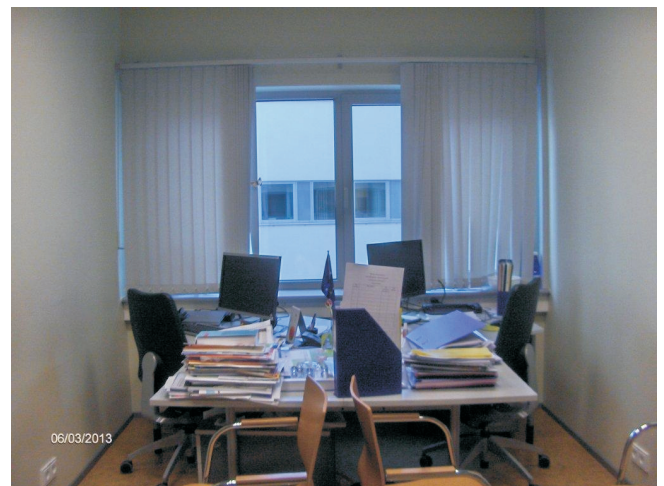*Fig. 1*. Non-ergonomically designed workroom.

Fig. 2. The investigated workroom *A* in the building, closed to the atrium.

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measurement of CO_2 concentration. Measurements of lighting in workplaces and from monitors were performed using the light-metre TES 1332 (ranges from 1–1500 lx). Lighting was measured on the worktable, on the monitor and on the keyboard. Lighting was measured at local workplaces (normally at a height 0.80 m above floor level), where a suitable measuring grid was applied. Dust was measured with a HazDust EPAM-5000.

RESULTS

Indoor climate conditions (bad microclimate, lighting problems, ergonomics of the workplace) can cause the health problems for office workers. Therefore, these three indoor climate components were investigated thoroughly.

Indoor air measurements. The exposure limits given in the standard EVS-EN for the indoor climate in three comfort classes 15251 are presented in Table 1. Data on estimated indoor climate conditions are given in Table 2. The air temperature in the offices was sometimes (in winter) under the norm (< 20–22 °C). Each of the investigated rooms had mechanical ventilation above the door (5 metres from the window). The mechanical ventilation in the rooms has been monitored for three years and the best results have been attained (cold air is no longer blowing on the workers). The relaxation time for heating the indoor air with the pre-heating ventilation systems in cold outdoor temperatures was too long, and therefore it was continuously cold in the rooms. The rooms are equipped with radiators, but in the rooms closed to the atrium they do not switch on until the room temperature is below 16 degrees. The relative humidity in winter was very low (10–15%), which caused dry skin problems to workers. There was a bad smell in some of the rooms on the first floor that is closed to the atrium (biological tests were carried out, but fungi were not found). The indoor air was not dusty (measurement results were under the limit 0.0050 mg/m³), but not fresh (felt by the workers). Therefore, the rooms needed to be ventilated naturally by opening windows in the beginning of the workday and during lunch break.

The atrium-facing rooms were very comfortable in summer when compared to those that were closed to the outside wall. The atrium-facing rooms were not over-heated in summer. Natural lighting in winter was at intensity 50 lx to 100 lx in rooms closed to the atrium. For workroom *A* (Fig. 2) the opposite windows were very close (other staff were working there), and the researchers in this room often worked with blinds-covered windows. This reduced the entrance of the natural light into the room even more.

The ergonomics of workplaces. Figure 3a, 3b, and 3c show the layout of tables and chairs in rooms. The workspace is small for two persons. Tables and chairs were purchased for the entire four-storey building at the start of operation in the building. All tables and chairs have the same size, regardless of the workers' anthropological features. The best of these three possibilities can be considered that depicted in Figure 3b. In this case, light enters from the left side for both of the workers (which is the optimal condition if they are right-handed); it is possible to open the window. In the present arrangement of the tables shown in Figure 3a, it is not possible to open the window, because the window stop is in the middle of the large window-wall and short workers reach the window to open it (the indoor interior was designed without consideration of the anthropological features of the workers). Such a conclusion was made based on the fact that the educational staff members were not

Table 1

PERMITTED INDOOR CLIMATE NORMS IN OFFICE-ROOMS (EVS-EN 15251:2007)

Category of comfort of the room (I- assessed as the best room)	Indoor air CO_2 concentration (measured), ppm	Indoor air CO_2 concentration considering the mean measured outdoor CO_2 level 400 ppm	Air temperature, °C summer/winter	Air humidity, %	Lighting, lx
I	350	750	25.5/21.0	> 30	500
II	500	900	26.0/20.0	> 25	500
III	800	1200	27.0/19.0	> 20	500

Table 2

RESULTS OF MEASUREMENTS INDOORS IN ATRIUM-TYPE BUILDINGS (2012–2013)

Room type	Indoor air temperature, °C, U = 0.6 °C		Indoor air humidity, %, U = 2.0%		Lighting, lx, U = 10.4%	Concentration of carbon dioxide, measured	Concentration of dust in the air
	Cold season	Warm season	Cold season	Warm season		CO_2, ppm U = 10%	mg/m³ U = 10%
Rooms close to the atrium	18–20	20–24	10–21	35–65	433–1160	541–897	0.0015
Rooms closed to outdoors	17–20	22–28	15–30	40–70	690–1209	478–1152	0.0011

U, the uncertainty of measurements

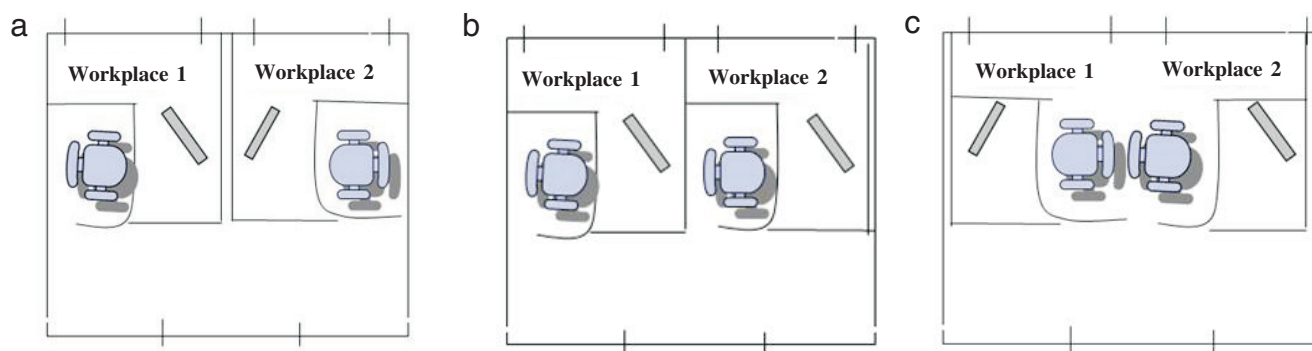The dust concentration in the smoking room was 0.099 mg/m³

Fig. 3. Workroom *A* with two workplaces (area 12 m^3). The ergonomic solutions (a, b, c)

present in the same time in the room. Simultaneous presence of workers in a room takes place 2–3 times a week and not for the whole working day.

DISCUSSION

The indoor air etc. problems in the same workplace can very much differ (Mergi, 2007; Geelen *et al*., 2008; Tint *et al*., 2012b). Therefore, an individual approach for every workplace has to be carried out considering the anthropological features etc. of the worker who will work in the specific workplace (Tayyari and Smith, 1997; Fernandez, 2002).

Info-technology workers often work in under-lighted working conditions although there are possibilities to increase (artificial) lighting to normal limits (400–500 lx).

The ergonomic use of laptops is achieved with docking stations, such that the worker will also use a large monitor. Some young workers like to use laptops in the dark (without artificial lighting), which can have negative impact on worker health years later (Brooks, 2005; Middlesworth, 2015).

If a workplace is designed ergonomically, it is possible to reduce the possibility of developing musculoskeletal disorders (MSDs), as strain in the body decreases. These diseases (MSDs) are the most common reason for a decrease of productivity of employees in the workplace (Lee, 1999; Oha *et al*., 2013). Chairs need to provide lumbar support; otherwise, the workers' body leans toward the table causing strain in the neck, shoulders and back (Hägg, 2000).

As ceiling lamp placement usually cannot be rearranged to avoid glare and inconvenience of workers regarding the illuminance sources (usually only the number of lamps turned on can regulated), then the workstation placement in relation to windows and ceiling lamps needs to be planned. Good ergonomic planning can increase visual comfort of workers and have a positive effect on their muscle- and joint comfort (Vilcane *et al*., 2015).

Occupational illnesses develop by stages. In the first stage, the rehabilitation is effective and the worker can return to work after some weeks after treatment. In the second stage, treatment is possible, but it takes more time and sometimes the worker has to change the work character to avoid being disabled in the future. Recovery from the third stage of the disease is not possible, but it is possible to use some rehabilitation methods to alleviate the suffering of affected persons. Managers and work environment specialists can influence the prevention of MSDs by the improvement of workplace ergonomics, which needs to be done before health disturbances occur.

The indoor air and other problems in the same workroom are specific to the particular case. Therefore, an individual approach for every workplace has to be implemented, considering the anthropological and other features of the worker who will work in the specific workplace.

The 1st (the best) category of comfort (EVS-EN 15251) is achieved when the workers themselves can design the workplace and work with computers occurs as a part of alternative other work activities. Medical examinations are obligatory in case of work with computers once every three years (Anonymous, 1999). If the computer workers do not adhere to legislation on computer work, by taking work home, then the risk for developing MSDs is high already at a young age.

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DARBA VIETU ERGONOMIKAS UZLABOŠANA ĀTRIJA TIPA ĒKĀS

Pētījuma mērķis bija uzlabot iekštelpu gaisa kvalitāti un ergonomiku darba vietās ātrija tipa ēkās. Ātrija tipa ēkai ir raksturīgs taisnstūrveida, slēgts pagalms ar izmēru 15 × 30 metri iekšpusē. Pagalma pusē jumts ir veidots no stikla un ir pārtraukums starp sienām un jumtu. Tas dod iespēju darbiniekiem ātrija slēgtās telpās elpot svaigu gaisu, tomēr pastāv problēmas, ko izraisa dabiskās gaismas trūkums, augsta CO_2 koncentrācija un zema temperatūra ziemā. Pētījuma galvenie rezultāti: dizains darba vietās ir jāveic paralēli ēkas būvniecībai, vēlāk ir grūti uzlabot apstākļus darbavietā; gaisa temperatūra darba telpās ir atkarīga no istabas vietas ēkā; ziemā telpas slēgtajā ātrijā ir aukstas; CO_2 un putekļu koncentrācija pārsniedz pieļaujamās robežas. Darba ņēmēju veselība var tikt apdraudēta, attīstoties slimo ēku sindromam.