Health risk assessment in atrium-type buildings

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Abstracts— In the study the indoor air quality assessment in office-rooms is given. The present investigation includes three atrium-type buildings (A built in 2003, B – in 2009, C- in 2010) where accordingly 120 (building A), 360 (building B), 90 (building C) scientific and administrative workers work. The workers' opinion on the existing work conditions was assessed. The atrium's (floor area 15x15 metres) roof in the buildings (A) is tightly covered with glass, the windows of the building towards the atrium are closed-type. So the office-workers, whose rooms' windows are towards the atrium, never feel fresh air. The other building (B) with atrium inside (15x30 metres) was built with opened windows closed to the atrium. The roof of this atrium is also built from glass but there is a 2 to 5-metre break between the walls and the roof. It gives the possibility for office-workers to open the windows and have the fresh air. The third building (C) is fourth-storeyed and the windows are large, but cannot be opened. The atrium (30x30 metres) is comfortable, the workers use it during the rest-time. The main results of the investigation: the indoor air is too dry in winter season (relative humidity 10-20%); the air temperature in the workrooms depends on the rooms' location in the building and the relaxation time of the temperature is too high (the rooms are not heated or cooled with enough speed according to the sudden changes of the outdoor air temperature); if the room area is smaller than 10 m^2 per worker, then the concentration of CO_2 is over the limits (>800 ppm); noise is a problem when the ventilation is working in a very high capacity. The concentration of dust is low and the moisture in the rooms (causing bad smell) is observed only in the first floor closed to the atrium.

Keywords— atrium-type buildings, carbon dioxide, dust, indoor air.

I. Introduction

The indoor climate quality at residential or industrial buildings is related to the inhabitants' and workers' wellbeing including job satisfaction, motivation and productivity, as found in many studies [1-4]. The European Standard EN 15251:2007 sets the new demands for previously Socialist-countries for indoor climate (IC) quality: for air temperature, humidity, velocity (ventilation), carbon dioxide concentration, noise and lighting in office and research-rooms. The investigation and modelling [5,6] of the air quality in the office and residential rooms has become a very important issue in many countries of different climate (in cold and warm area [7,8]). The prevention of rising the concentration of carbon dioxide (CO_2) over the norms (800 ppm over the out-door CO_2 concentration) and ventilation of the rooms have new approaches to improve the situation [9-11].

During the 1970s energy crisis, buildings were designed to be airtight, conserving as much warm air during the winter and cooled air during the summer as was possible. Windows that could not be opened became a common part 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. The results can range from nose, eye and throat irritation and aggravation of asthma to an increased risk of lung cancer. Biological sources of indoor air pollution include mould, mildew, fungi and bacteria. 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. Each year there are news reports of buildings being evacuated because of "sick building syndrome," a group of health symptoms listed above that stem from poor air quality inside a building and usually subside after leaving the building. Long-term exposure to some indoor air pollutants can lead to damage of the central nervous system, kidneys and liver. Although anyone can have problems because of indoor air pollution, most susceptible is the ageing workforce, people who have respiratory ailments such as bronchitis, asthma or emphysema. Nowadays, the airtight windows are used in the office-rooms in the atrium-type buildings around the atrium. The previous-mentioned problems arose again.

The physical environment of the workroom is important as it may induce stress on individuals and thereby reduce the results of their cognitive endeavours of scientific and office workers overall. EN 15251:2007 originates from different (I to IV) categories of comfort. The risk assessment levels for occupational hazards are given in BS8800; a flexible risk assessment (RA) method has been developed in Tallinn University of Technology [12-14]. Figure 1 gives the basis for risk assessment of indoor climate in office-rooms and gives the possibility to determine the level of comfort of the room

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(EN15251:2007) that has links with the previous methods (BS8800, the flexible RA method).

In the present study the indoor climate characteristics in the atrium-type buildings' [15-19] office rooms are given. The investigations on ventilation and indoor air quality show the problems and advantages of this construction style [13, 20]. The present investigation includes three atrium-type buildings where accordingly 120 (building A), 360 (building B) and 90 (building C) scientific and administrative workers work. The workers' opinion on the existing work conditions was assessed. The atrium's roof of two of the buildings (A, C) is tightly covered with glass, the windows of the building towards the atrium are closed-type (they cannot be opened). The 6-storeyed building (A) for administrative and research needs was built in 2003 when the construction costs where very high and it was important to save money. Therefore the working conditions of office-workers were left in the background. So the office-workers, whose rooms' windows are towards the atrium never feel fresh air (Fig 2). The house is quadrangular, without any beetling construction parts. The floor area of the atrium A is 15x15 metres. It is a good place for students' relax during the breaks (Fig 3) .

< 300	300	500	1000 - 1500[1]	Lighting, lx
< 4	< 4	> 7	> 10	Ventilation, l/s per person
< 20	> 20	> 25	> 30	Humidity, %
> 800	< 800	< 500	< 350	CO_2, ppm
more	19 - 27	20 - 26	21 - 23.5	Operative temperature, ºC
> 15	< 15	< 10	< 6	PPD[2]
< - 0.7; > + 0.7	-0.7< PMV< +0.7	-0.5< PMV< +0.5	-0.2< PMV <+0.2	PMV[3]

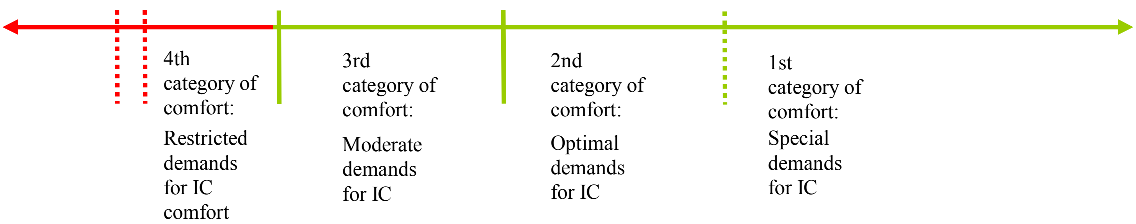

Figure 1. The categories of comfort for different hazardous factors in office rooms for administrative and research personnel.

[1] Lighting 1500 lx is demanded for carrying out special interior areas with higher demands for illumination (industrial activities etc.).

[2] predicts the mean value of the thermal votes of a large group of people exposed to the same environment. PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm (ISO 7730:2005).

[3] index that predicts the mean value of votes of a large number of persons on the 7-point thermal sensation scale (o-neutral; -1: slightly cool, -2: cool, -3: cold; +1: slightly warm, +2: warm, +3: hot), based on the heat balance of the human body (ISO 7730:2005).

The other building (B) with atrium inside (15x30 metres) was built in 2009 when the construction costs were low. It was possible for the university to install the office-rooms with opened windows closed to the atrium. The roof of this atrium is also built from glass but there is a break between the walls and the roof (Fig 4). It gives the possibility for office-workers to open the windows and have the fresh air. The negative influence of that type of building occur in the changeable climate conditions when in winter snow is coming through the break and falling on the floor of the atrium where the rooms' windows of the first floor are very near to the floor. Some of the rooms are excessively humid (possible development of mycobacterium). The rooms are mostly meant for 2-3 persons. The new buildings also create the psychological problems (constricted workplaces, less good possibilities to carry out scientific work etc.) for workers. There are also some problems with indoor air temperature in the rooms outside the atrium, in the opposite side of the atrium offices, having two glass walls opening outdoors and the empty space (design problems) under the floor (the air temperature in these office-rooms is very low in the winter season (Fig 5). The third investigated building is three-storeyed (built in 2010, Fig 6). The windows towards the atrium cannot be opened, but they are large and the work conditions inside the laboratories are good due to good ventilation and there are few workers in one room. The atrium (building C) is used as lobby-room (Fig 7).

Figure 2. Atrium-type building (A) that is tightly covered with glass roof. Only the workrooms beginning from the 4th floor are sun-lighted.

Figure 3. The atrium in building (A) is used as lobby room by students. The window of atrium-side office-room is seen in the back. The window cannot be opened.

Figure 4. As there is a slot between the roof and walls in the building (B), the snow is falling on the atrium floor in winter.

Figure 5. The office-room in the 2nd floor (building B), directed to the south.

Figure 6. Three-storeyed atrium-type building (C).

Figure 7. The lobby-room in the building C.

The aim of the study was to clear-up the shortages in the work environment in atrium buildings, to give recommendations for improvement of ventilation of the rooms, for improving the heating system. The connections between the indoor climate quality and the satisfaction of workers with working conditions was cleared-up with the questionnaires given to the workers in the course of the risk assessment visits. The relationship between the air quality (including sick building syndrome-SBS), ventilation, work area magnitude, lighting conditions, noise and stress phenomena was investigated.

II. Material and Methods

The measurements were carried out in 137 office-rooms meant for 1-4 people.

The criteria for risk assessment at workplace were derived from regulative norms, standards, directives and scientific literature [12-14]:

1.To perform the measurements of occupational hazards, the following standard methods were used: ISO 7726:1998 "Thermal environments – Instruments and methods for measuring physical quantities"; 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", EN 12464-1:2002 "Light and lighting- Lighting of work places- Part 1: Indoor work places", EVS 891:2008 "Measurement and evaluation of electrical lighting in working places", ISO 9612:1997: "Acoustics – Guidelines for the measurement and assessment of exposure to noise in a working environment", WCB method 1150:1998 "Particulates (total) in air"; EVS-EN 1231:1999 "Workplace atmospheres- Short term detector tube measurement systems- Requirements and test methods".

2.The parameters of indoor climate were measured with TESTO 435 (air temperature, relative humidity, air velocity) in 4 points of the workroom (8 if the surface area was over 100 m^2), at a level of 1.0 metres (sitting position) or 1.5 metres (standing position). Triplicate readings were recorded for each measurement and the average was presented. Before sampling, the doors between the rooms in the departments were closed for at least 1 hour and the doors to the corridors were close all the time. TESTO 435 enables also the measurements of CO_2. The measurements of room temperature were carried out in the cold season.

3. Measurements of lighting the workplaces and screen were performed using the light-metre TES 1332 (ranges from 1-1500 lx). The lighting was measured on the worktable, on the screen and on the keyboard. Lighting was measured at the local workplaces (normally at a height of 0.80 m above floor level), where a suitable measuring grid was applied. The arithmetic mean, $\overline{E}$, was presented. A digital luxmeter TES 1332 was used. To exclude the stray light, the measurements were carried out either in the dark or where possible, the windows were covered with blinds.

4. Noise, measured as equivalent continuous A-weighted sound pressure level (L_{eq}(A)), was evaluated under normal operating conditions using a hand-held Type II Sound Level Meter (TES 1358).

5. Dust in the work-rooms was measured with Haz-Dust EPAM-5000 (10 µ filter).

The questionnaire used for investigation of the satisfaction of workers with occupational health hazards, was compiled considering the previous risk assessments in the university buildings and the shortages emerged during the discussion with the workers.

III.Scientific Basis

According to the EN 15251, the hazards determining the comfort class of the office-room are as follows: the performance of atrium type administrative buildings addressing indoor air quality, thermal environment, lighting and acoustics.

Office lighting and health: people prefer to have windows in many spaces. Boyce et al. [31] found that workers in windowless offices spend a small but statistically significant greater amount of time talking to others, either directly or by telephone; and a small but statistically significant lesser amount of time working on their computer, relative to workers in windowed offices. An office desk situated near a window typically receives five times as much light from daylight as it would from electric lighting alone. The workers in windowless offices do not receive sufficient daylight to entrain their circadian system, and therefore seek additional daylight and social interactions. There are other health damages that could be happened (even cancer) [21]. The colour of the light is also very important [22]. The cool fluorescent light has negative effect on individuals' health. The luminous flicker of fluorescent lamps, which can be reduced or eliminated by replacing magnetic ballasts with digital ballasts, has shown to have affected visual performance, caused visual comfort and general stress [23].

Office noise and health: unnecessary noise is perceived to be more harmful [24]. Sounds that are generated by others or unpredictable sounds (e.g. telephone rings) are considered uncontrollable, and more stressful. People talking in the background and telephones ringing have been cited most frequently as the primary sources of annoyance in offices. The noise hinders the performance of complex tasks more than it hinders of performance of simple tasks [25]. Most annoying sources of sounds in offices include people, telephones. Intrusive sounds, noise, make people tired and irritable. It has a negative effect on the performance, especially when working on tasks that depend on short-term memory. Those working in noisy office environments have also been found to be less cognitively motivated, and to have higher stress levels, according to a Cornell University study [26]. Noise pollution has been linked with health problems such as heart disease, high blood pressure, and stroke. It's also been linked with musculoskeletal problems, as a Cornell University study on office noise found that those working in noisy office environments can also be less likely to ergonomically adjust their workstations for comfort, which can contribute to physical problems.

Ambient temperature, air quality (SBS) and ventilation: ambient temperature is a predominant stressor in office buildings. Witterseh et al. [24] have reported that if the temperature in offices increased from 22^0C to 26^0C the participants in the study reported increased difficulty of thinking and concentrating. In the Northern European workplace studies, a linear relationship between the symptoms of sick building syndrome (SBS) and room temperatures above 22^0C has been a consistent finding. Air supply, odour, and pollutants determine the air quality within a building. Numerous workplace studies [2, 19, 27] have shown that air quality can cause stress among workers. The quality of indoor air could be improved with well-organized ventilation: Seppänen et al. [28] found that ventilation rates below 10 l/s per person in all building types were associated with significant worsening in one or more or perceived air quality outcomes, also with increased symptoms of SBS. The risk of SBS symptoms continued to decrease significantly with decreasing carbon dioxide concentrations below 800 ppm. There are some other not-exactly determinable pollutants (from carpets, carpet clues, wall-paints), which concentration is low and the determination of the exact volatile component is difficult and expensive. Chamber experiments show less dry throat and less difficulty thinking clearly with increased velocity of the air (>1 m/s) at workplace. Northern European studies show that temperatures above 23^0C increase SBS [29]. Airway infections seem also to be associated with dampness indoors [30].

Satisfaction with working conditions: the needs for ergonomic workplace design are nowadays very important as the workforce is ageing. Older people may be more affected by noise and lighting conditions than younger people. Some cognitive needs may be more pressing for highly educated (researchers) individuals. Time may be an additional factor determining the potency of environmental stressors. In some contexts, people may simply get used to a stressor if exposed to it for an extended period. Stress is primarily a psycho-physiological phenomenon that arises from an individual's perception of balance between environmental demands and response capabilities. From the job-demand perspective, stress results the joint effect as of the demands of work and the range of freedom (control) available to the worker facing those demands.

Table 1. Overall results of measurements of indoor climate in atrium-type buildings

Room type	Indoor air temperature, ^{0}C, U = 0.6 ^{0}C		Indoor air humidity, %, U = 2.0%		Air velocity, workplace, m/s, U = 0.01 m/s	Lighting, lx, U = 10.4%	Concentration of carbon dioxide	Concentration of dust in the air
	Cold season	Warm season	Cold season	Warm season			CO_2, ppm U= 10%	mg/m^3 U=10%
Building A, towards the atrium	21.2..22.5	22.7..25.6	24.3..25.7	48.2..53.0	0.02…0.17	457..847	585..935	0.0017
Building A, towards the outdoors	20.4…23.1	22.5..31.6	23.7..24.6	44.2..62.4	0.02…0.33	300..915	462..744	0.0011
Building B, towards the atrium	21.0…22.8	24.3..26.5	24.0..32.5	35.1..47.6	0.02…0.19	433..1160	541..897	0.0015
Building B, towards the outdoors	10.8…21.4	21.0...32.0	14.0..33.1	41.4...48.7	0.01…0.25	690..1209	478…1152	0.0011 * 0.099 in the smoking room
Atrium A (Fig 4)	21.8..22.7	23.0..27.0	20.0..29.1	45.1..48.9	0.01..0.05	350….360	572…678	0.0016
Building C, towards the atrium	20.0..20.5	22.5..23.9	24.0..29.0	50.8...55.7	0.01...0.23	340….583	459…512	0.0013
Building C, towards the outdoors	21.9..22.0	21.5..23.0	23.0..30.0	51.5..56.0	0.02..0.12	264....892	521…707	0.0011
Atrium C (Fig 6)	18.0..18.2	25.0..26.0	35.0..36.0	60.0..61.0	0.3..0.45	360..362	450…452	0.0014

U- the uncertainty of measurements

IV. Results of Measurements And Questionnaire

The results of measurements of the air temperature, humidity, velocity at workplace, lighting, CO_2 and dust concentration are given in Table 1.

The work conditions in the building A: lighting norms in the office rooms located on 1st-2nd floor closed to the atrium is guaranteed with artificial sources only; the workrooms are airless; the mechanical ventilation does not guarantee the comfort of people; at the end of the workday, the CO_2 concentration is over the limits (>800 ppm).

The work conditions in building B (1st floor): in winter there is no daylight in the cabinets (located on very low level). The conditions of lighting are better in spring and autumn seasons. The workers in the 1st floor cabinets never see the sunlight. The workers in the 2nd-4th floor cabinets with windows directed north also never see the sunlight. During autumn, summer and spring the conditions are better depending on whether the direction of the cabinets windows of the rooms are sometimes sun lit. The rooms outside the atrium are very cold in winter, but in summer the indoor air is too hot (over 30^0C). There are shortages in surveillance of the ventilation systems.

The work conditions in building C (2^{nd} and 4^{th} floor) are very good. The house is the newest from the three investigated. The workers are satisfied with the ventilation and lighting of the rooms.

The lighting of the rooms corresponds to the norms (400-500 lx). It is possible to furnish the workplaces with the local lighting source if it is needed to gain the lighting norms. The problem is the insufficient knowledge of ergonomics and possible health damages working in dark (without electric lighting with computers). That kind of experience is very common for the info-technology specialists (they are mostly young, with excellent eye-sight).

The concentration of carbon-dioxide is near to the upper limit in the rooms where there is less than 10 m^2/person, it means that there are two persons working in the room meant for one worker.

The outdoor concentration of CO_2 in Tallinn town measured during April-May 2012 was 350-450 ppm.

The questioning of workers about their work conditions gave varying results. The administrative workers who are working with computers during 8-hour workdays, complained about cold air blowing on their legs. They were also more sensitive to the temperature changes in the room (that are dependent on the sudden changes of the outdoor air temperature). So the heating system of the buildings has a long relaxation period. The biggest problem for 50% of people was too dry air in winter during the heating period. Some of the people have turned off the ventilation system (in the building B) as the air blows on them straight and causes health problems (sick throat, dryness in the nose, headache). Too hot workrooms are the problem for administrative workers from June to August. The noise is not a great problem in the investigated buildings. Some of the workers complain about noise from the upper floors (from the 4^{th} to the 3^{rd} in building B).

IV. Discussion

Recently more and more attention is paid to the questions of indoor climate quality and improvement of ventilation and air-conditioning systems both in cold and hot climates [10]. The modelling of indoor air quality parameters gives the possibility beforehand guarantee the best results and raise the wellbeing of people in the work environment [6,7].In the course of modelling the values of air pollutants are transformed into dimensionless number characterizing the state of air pollution. Air quality assessment depends on strictly given limits without taking into account specific local conditions and synergic relations between air pollutants and other meteorological factors.

Good design of workrooms calls for an integrated approach. The temperature, humidity, lighting, acoustic comfort and chemicals in the workroom (including the content of carbon dioxide) have all to be taken in mind in the designing stage if we want to get good results. The ventilation systems are improving with every year, but the problem is yet the expensive surveillance of the systems and also the shortages of good specialists in this field. The process is multidisciplinary and until now the work conditions have not been taken into consideration in the stage of design in considerable degree.

The concentration of carbon dioxide in the work-rooms is depended on many factors: the outdoor concentration of CO_2, the number of persons working in one room, the state of windows etc. The recommended CO_2 levels in the workrooms according to the standard EVS-EN-15251are given in Table 2. The outdoor air CO_2 concentration is taken as average from the measurements 400 ppm; the authors [10] refer to the number 350 ppm. The concentration of carbon dioxide is also related to indoor air relative humidity: the higher is the concentration of CO_2 [11]. The concentration measured in the current study shows that the concentration is higher in towns due to car transport and heating of houses with wood and oil shale.

50% of the buildings in Estonia have yet old-type windows. From one side the replacement those with new tight type of windows saves energy and money, but from the other side it causes a lot of indoor climate problems particularly when the new type window cannot be opened. The studies show that the indoor air concentration of carbon dioxide increases and this renovation process has to be accompanied with the renovation of ventilation system [1,10].

Some authors argue that the air-proof windows lead to higher indoor air humidity [11]. This phenomenon was generally not observed it the investigated rooms, to the contrary, in the most rooms the air was dry during the heating season, except in the first floor (building B), were the snow from the atrium floor penetrated through the floor and walls. This caused the bad smell in the rooms and possible occurrence of molds resulting in allergies and asthma [11].

Table 2. The permitted concentration of CO_2 in the workrooms by EVS-EN-15251 and measured outdoor CO_2 concentration

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
I	350	750
II	500	900
III	800	1200
IV	>800	>1200

VI. Conclusions

1. The investigation gave the conclusion that the workrooms in the atrium-type buildings mostly belong to the 4th category of comfort (according to Fig 1). To get better working conditions for workers it is necessary to improve the surveillance of ventilation and heating system overall.
2. It is recommended to use supplementary heating sources (air-pumps), when the air temperature in the rooms is below 19^0C (in winter).
3. Use window blinds and efficient ventilation in summer.
4. Use modern equipment for increase the humidity of the air in the rooms.
5. To provide a good day-lighting practice in offices where it is possible (it is not possible in the rooms close to the atrium).
6. The right ventilation and building care can prevent and fix IA quality problems. The concentration of a pollution component in the naturally or even artificially ventilated offices linked to glazed atria may be very low, but the odour might be strong. In such cases usually the cause is in the repair work where new, unknown glues were used. It takes some time for all volatiles to odour. If the odour does not disappear then the remove of the floor covering (carpet-type), glue and sometimes even a concrete layer from the floor will be necessary to get smell-free indoor conditions.
7. The ventilation and air-conditioning systems are used both in cold and hot regions all-around the year. The cost of equipment and energy spent for their handling is quite high. In this situation a lot of money is spent for electricity. The surveillance of equipment and regimes is needed to get the better cost-effectiveness results.
8. The change of old windows to new ones began in Estonia from the year 2000 and this caused the indoor CO_2 concentration increase over the limits (800 ppm over the outdoor concentration).
9. In big towns, where the car-transportation is highly used, the concentration of carbon dioxide is high (400-450 ppm). Therefore in Tallinn, the capital of Estonia, the measures to reduce the concentration of CO_2 are: electric cars and trolleys; public transport free of charge (as it is planned by the Tallinn municipal government from 2013).
10. To satisfy the needs of workers in summer-time, the glazing of windows is very important. The temperature in the workrooms glazed with ordinary glass is over 30 ^{0}C. Therefore solar-reflecting glazing materials are needed accommodating the observable part of solar radiation.
11. Against noise from the street double pane glazing and even triple pain glazing is used in Estonia. It also contributes to the energy consumption during winter-time. There is an air gap between the two or three glass panels.
12. The application of advanced glazing will lead to a saving of energy consumption in 3.4 to 6.4% [16], but in the same time the concentration of carbon dioxide is increasing for 200-400 ppm.

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