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INDOOR AIR QUALITY IN INDUSTRIAL PREMISES

MIKROKLIMATA KVALITĀTE RAŽOŠANAS TELPĀS

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1.Introduction

The indoor air quality for workers can be defined as an optimal indoor environmental condition containing the lowest possible levels of air pollutants to satisfy the health, comfort, and wellbeing of the vast majority of workers in any type of buildings at any given time. In industry, it mainly depends on the air temperature, relative humidity, and air velocity at workplace; and on the content of a large variety of chemicals that appear to the environment from the technological processes carried out in the industrial premises or outdoor environment. The occurrence of exposure to chemicals is mainly due to insufficient awareness, lack of human and financial resources and deficiencies in access to information. At times, the office-rooms are situated near to the industrial departments and the odours of chemicals or dust may disturb the white-collar workers through olfactory symptoms.

This study focuses on manufacturing: wood processing, printing, clothing, plastic, and mechanical industries, where the main hazards at the workplace air include variety of chemicals, high air temperatures in warm season, low relative humidity in central-heated rooms in cold season, etc.

The workplace risk assessment is a tool to help create a safer environment and a process for identifying hazards, their risks levels and possible negative influence to the workers' health [1]. The imperative to identify approaches to risk assessment that are both accurate and simple has led to the development of various schemes for evaluating and controlling risks, including COSHH (Control of Substances Hazardous to Health) and Chemical Control Toolkit which are designed for assessing chemical risks in working firms [2,3,4,5] and PRHI (Process Route Healthiness Index) what is developed for analysing new processes, which have not yet been implemented [6].

The desire for both accuracy and consistency assessing all occupational hazards has resulted in the development of the current systemic approach where the risk assessment can be undertaken and progressed. In many countries, employers are legally obliged to carry out systematic, documented workplace risk assessment, which sets special requirements to the method used: (i) it should be sufficiently flexible to adapt to the changing patterns of industry and the evolving regulatory demands of society and (ii) for confidence of accuracy, it should be based on the measurements of occupational hazards in the workplaces and the potential health impairment data.

2. Methods

The study includes of the following activities:

1. To connect risk levels and health complaints, the simple/flexible risk assessment method worked out by the authors in 2002 (Fig. 1, [7]) is used. The method is based on two-step model that could be enlarged to a six-step model, and uses (no/yes) or (corresponds to the norms/does not correspond to the norms) principle. In this study, the five-step simple/flexible risk assessment method is used. The motivation to use five risk levels is derived from BS 8800:2004 standard, which also recommends five risk levels and is therefore familiar and easy to understand to employers and occupational health and safety specialists.

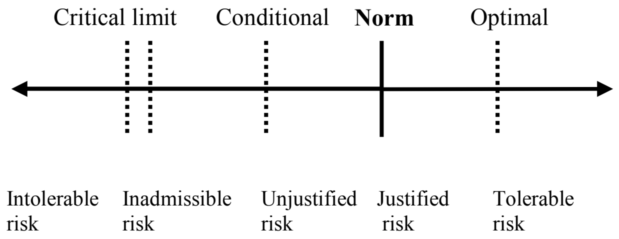

Fig. 1. Five-step simple/flexible risk assessment method

2. The criteria for risk levels of occupational hazards were acquired from regulative norms, standards, directives and scientific literature.
3. To describe the main impact of chemicals on workers' health, the European Unions Risk-phrases (R-phrases) of chemicals were used [8]. Most R-phrases do not have toxicological dose criteria, but are based on a critical toxic effect, such as irritation or sensitisation, reproductive toxicity, cancer etc. Chemicals that were present in the examined industries were formaldehyde (R23/24/25, R34, R40, R43) in the textile and the wood processing industries, toluene (R11, R38, R48/20, R63, R65, R67), xylene (R10, R20/21, R38), butanol (R10, R22, R37/38, R41, R67), styrene (R10, R36) and benzene (R11, R45, R48/23/24/25) in the wood processing industry, hydrogen fluoride (R26, R27, R28, R35, R41) in the plastic industry, isopropanol (R11, R36, R67) in the printing industry and welding gases in the mechanical industry. Two chemicals - formaldehyde and carbon dioxide - were also measured in offices.
4. 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 482:1994 "Workplace atmospheres – General requirements for the performance of procedures for the measurement of chemical agents"; EN 689:1996 "Workplace atmospheres – Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy"; EN 481:1993 "Workplace atmospheres- Size fraction definitions for measurement of airborne particles"; EN ISO 10882-1:2001 "Health and safety in welding and allied processes- Sampling of airborne particles and gases in the operator's breathing zone – Part 1: Sampling of airborne particles"; EVS-EN 1231:1999 "Workplace atmospheres – Short term detector tube measurement systems – Requirements and test methods"; WCB method 1150:1998 "Particulates (total) in air" and 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". The parameters of indoor climate were measured with TESTO 615 (air temperature, relative humidity) and TESTO 415 (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. Triplicate readings were recorded for each measurement and the average was presented. Chemicals were measured with the express method using a Dräger-Accuro Gas Detection Pump and the indicator tubes (specific for each chemical measured). The number of pumping was determined by the express method, e.g. for formaldehyde 10 or 20 times (depending on the range of measurement), followed by the change of the colour of the indicate tube that detected the amount of the examined chemical in the air of the work environment. Three similar measurements were performed and the average presented.

3. Results of measurements

The summary of the results of measurements are presented in Table 1 and Table 2.
The Estonian health protection norms on microclimate [9] divide the values of microclimate factors (air temperature, relative humidity, air velocity and thermal radiation intensity) into two categories: optimal microclimate parameters and permitted microclimate parameters. The minimal permitted air temperature in the workrooms is 12 ^0C (cold season (the mean temperature of ambient air is below

10 ^{0}C). The maximal permitted air temperature is 28 ^{0}C (warm season (the mean temperature of ambient air exceeds 10 ^{0}C). Both these temperatures create the conditions that may harm the human body if exposed for a long time. Therefore, these temperatures are permitted only at non-permanent workplaces and non-permanent working activities. The optimal relative humidity is 40-60%, while permitted humidity is up to 70%.

Table 1

The results of measurements of indoor climate

Industry	**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**
	Cold season	**Warm season**	**Cold season**	**Warm season**	
Clothing	20.0…26.7	22.7…26.7	33.0....38.0	48.2…53.0	0.01…0.04
Printing	21.7…22.4	22.5…24.3	38.2…52.2	44.2…62.4	0.01…0.26
Wood	21.2…24.0	24.3…26.5	34.2…42.6	35.1…47.6	0.02…0.30
Mechanical	10.8…21.4	17.6…23.2	31.3…39.9	41.4…48.7	0.01…0.21
Plastic	14.0…22.4	18.6…25.5	26.1…40.7	36.5…45.7	0.02…0.07
Offices	18.7…23.0	22.4…26.7	32.6…47.9	39.5…54.6	0.01…0.17

Table 2

The results of measurements of chemicals

Industry	**Chemicals, ppm or mg/m^3 U = 10…30%**	**Exposure limits for chemicals, ppm or mg/ m^3 [10]**
Clothing	formaldehyde – n.d.	0.6 mg/ m^3
Printing	isopropanol - 100 ppm	150 ppm
Wood	formaldehyde - 0.5 mg/m^3 toluene - 1- 941 mg/ m^3 xylene- 2.5-347 mg/ m^3 butanol- 0.5- 285 mg/ m^3 styrene- 1-208 mg/ m^3 benzene- 0.8-1 mg/ m^3	0.6 mg/ m^3 192 mg/ m^3; 221 mg/ m^3 150 mg/ m^3 90 mg/ m^3 1.5 mg/ m^3
Mechanical	ozone – 0.2 ppm carbon monoxide – 0.1…0.2 ppm carbon dioxide – 120…200 ppm nitrogen oxides – n.d.	0.1 ppm 35 ppm 5000 ppm 25 ppm
Plastic	hydrogen fluoride – 0.5 ppm	1.8 ppm
Offices	formaldehyde- n.d. carbon dioxide-800...3000 ppm	0.6 mg/ m^3 5000 ppm

(Abbreviations: n.d. - not detected)

In most investigated companies, the air temperature was at an acceptable level or very close to it. Some problems were encountered in the warm season in the clothing, wood processing and plastic industry, where the temperature in departments was higher than optimal due to deficiencies in ventilation systems or their lack, however, it remained between the limits of permitted temperature. In the cold season, the temperature fell to a lower level than permitted in the mechanical company due to deficiencies or lack of a heating system, opened doors and poor insulation of the industrial building.

Relative humidity posed a problem during the cold season when in some companies, the air dried due to heating system and no conditioner system existed to balance the relative humidity of the air. A certain proportion of the employees complained about lippitude of eyes, skin xeric and dryness of

mucus membranes, which may be caused by the low value of relative humidity during the cold season. However, no lower limit for relative humidity is fixed by Estonian regulations; any value below 70% is permitted. The values of air velocity were acceptable, except shortage of air during the warm summer days in rooms where the ventilation system was not regulated to produce higher air velocity values in the warm season than in the cold one.
The results of measurements of chemicals revealed that the main concern in the current case studies is wood processing industry where several chemicals were detected over exposure limits established in Estonian regulations. In other industries, the chemicals were not exceeding the exposure limits.
Therefore, the four chemicals of major concern (toluene, butanol, xylene and styrene) were used to develop the criteria for risk assessment model. Besides chemicals presented in the scheme hereafter, the phenol-formaldehyde varnish is a source for allergic reactions of workers in wood-processing industry. Benzene vapours were also found. The exposure limits for formaldehyde (0.6 mg/m^3) and benzene (1.5 mg/m^3) were not exceeded, but the welfare of workers has to be considered especially since benzene and formaldehyde are known to be associated with cancer risk and are classified as carcinogenic to humans [9]. Therefore, safety measures are crucial to protect the workers, and the hierarchy of control measures should be applied starting with 'safe place' and 'safe systems' strategies such as eliminating or isolating the chemical hazards, mitigating the hazards by engineer control methods followed with 'safe person' strategies such as use of personal protective equipment, equip the person with the knowledge of skills to avoid creating dangerous scenarios, etc. However, proposing the most appropriate safety measure is beyond the scope of this article.

4. Inconvenient indoor quality, chemicals and health risks

The relative humidity may influence the worker's health and comfort as too dry air can cause local irritation of mucosa, eyes and skin. The overall symptoms are dizziness and headache. In the case of too humid air, the sensitiveness to the odours (gases, vapours) from the finishing materials will increase [12]. The chemicals with the major concern in the study were toluene, xylene, butanol and styrene. Next, a short review is presented of these 4 chemicals and their toxic effects as well as concentrations in order to be able to integrate their hazards to a workplace risk assessment model.

Health hazards of toluene

Inhalation of toluene vapour can affect the central nervous system (CNS). No toxicity was observed in human beings repeatedly exposed to toluene levels of less than 188 mg/m^3 (50 ppm) for short periods of time or exposed once to a level of 375 mg/m^3 for a few hours [13].
At approximately 188 mg/m^3, subjective complaints such as slight drowsiness and very mild headache have been reported [13, 14]. Mild irritation of the nose, throat, eye and respiratory tract has occurred between 375 to 750 mg/m^3. Concentrations of about 375 mg/m^3 have caused also fatigue, dizziness but probably no observable impairment of reaction time or coordination; over 750 mg/m^3 has caused symptoms similar to drunkenness, numbness, and mild nausea; and over 1875 mg/m^3 has caused mental confusion, staggering gait, incoordination, lack of self-control and nervousness [13,14, 15]. Dose levels of 37500 mg/m^3 and higher are associated with narcosis and can results in unconsciousness and death within a few minutes [13].
Slight eye irritation may start at 1125 mg/m^3 during extremely short exposure (3 to 5 minutes); and at 375 or 562 mg/m^3 during longer exposures (6 to 7 hours). Repeated or prolonged contact may cause dermatitis (red, itchy, dry skin) because of its defatting action [14, 15].

Health hazards of xylene

The main effect of inhaling xylene vapour is depression of the CNS, with symptoms such as headache, dizziness, nausea and vomiting. The psychophysiological tests have shown no effects up to 300 mg/m^3 (70 ppm) [16] exposed for 4 hours. Volunteers have tolerated 435 mg/m^3, but higher concentrations become objectionable [17]. At the concentration of 900 mg/m^3, prolonged reaction times, minor

effects on EEG and impairment of vestibular and visual function have been observed [16]. Exposures estimated at 3000-3045 mg/m^3 have caused dizziness, nausea and vomiting [16, 17].
Xylene vapour becomes irritating at relatively high levels. Eye irritation has been reported after exposure to 2000 or 3000 mg/m3 of xylene for 15 minutes [16].
Extremely high concentrations (approximately 43000 mg/m^3) may cause incoordination, loss of consciousness, respiratory failure and death. In some cases, a potentially fatal accumulation of fluid in the lungs (pulmonary edema) may result. Symptoms of pulmonary edema, such as shortness of breath and difficulty breathing, may be delayed several hours after exposure. However, these effects are rarely seen since xylene is irritating and identifiable by odour at much lower concentrations [17].

Health hazards of butanol

Occupational exposure to butanol may result in depression of the CNS and may cause severe eye irritation and moderate skin irritation. N-Butanol shows a low order of toxicity in single-dose exposures to laboratory animals [18] and is mainly associated with effects on the CNS [19]. The minimal information available suggests that occupational human exposure to air concentrations below 300 mg/m^3 (98 ppm) is not associated with any adverse symptoms. However, studies on human volunteers indicate that the light-sensitivity of dark- adapted eyes and electrical activity of the brain may be influenced by air concentrations as low as 0.092 mg/m^3 [19].
The most important effects of n-butanol inhalation are symptoms of alcohol intoxication and narcosis. Following exposure to 1-butanol vapours, the signs of poisoning in human beings, may include irritation of the nose, throat, and eyes, the formation of translucent vacuoles in the superficial layers of the cornea, headache, vertigo, and drowsiness [19]. Prolonged excessive exposure may cause other serious adverse effects, and even death.
Exposure to butanol liquid or vapour may cause severe eye irritation manifested as a burning sensation, lachrymation, blurring of vision, and photophobia. Repeated skin contact may aggravate preexisting dermatitis and result in absorption of harmful amounts through the skin. In most cases, n-butanol is quickly metabolized to carbon dioxide (CO_2) [18].

Health hazards of styrene

Acute exposure to styrene in humans results in respiratory effects, such as mucous membrane irritation, eye irritation, and gastrointestinal effects while chronic exposure affects the CNS with symptoms such as headache, fatigue, weakness, depression, CNS dysfunction, hearing loss and peripheral neuropathy.
Styrene induced subjective symptoms of irritation of the mucous membranes at concentrations exceeding 420 - 840 mg/m^3 (100 - 200 ppm). In the same concentration range, subjective symptoms of the CNS, such as dizziness, lightheadedness, headache, and drowsiness may occur. Reaction time, performance, and body balance tend to be impaired by short-term inhalation exposure to styrene at concentrations of 630 - 840 mg/m^3 and definite impairment occurs at concentrations exceeding 1470 mg/m^3 [20].
The level defined as immediately dangerous to life or health is 21000 mg/m^3 [21]. Inhalation Lowest Lethal Concentration = 42000 mg/m^3/30 minutes and Inhalation Lowest Toxic Concentration = 2520 mg/m^3 [22].

5. Modelling of the connections between the hazards and health disturbances

Considering data from scientific literature (case reports, occupational studies, and studies on volunteers) [12-22], international standards (EN 481:1993; EN ISO 10882-1:2001) and regulative norms for chemicals in the work environment air [11] and using the simple/flexible risk assessment method, the connections between risk levels and health complaints of selected chemicals in wood processing industry are determined.

The schemes are developed by the chemical ability to cause typical occupational disease such as cancer, short-term high risk effects, nervous system disturbances, respiratory effects, hematologic disturbances etc as classified in OSHA Instruction CPL 2.45B [23] and is specific for each risk group (20 groups in total, 1 representing the most severe health effects). Current scheme is for toluene, xylene, butanol and styrene which cause nervous system disturbances and are classified in risk ranking as groups 6-8.

Table 3 presents the essential data of investigated four chemicals (such as boiling point, odour threshold, exposure limit and IDLH value) to determine the risk levels. Odour threshold is an important factor to consider in risk assessment model since the olfactory symptoms or hypersensitivity towards chemicals odours may be distracting and interfere with job performance and safety or induce cacosmia (i.e., feeling ill from the odour of xenobiotic chemicals) [24,25]. Odour threshold is used as the 'optimal limit' in the current scheme.

Worker exposure concentration is an estimate of the chemical concentration that is potentially inhaled by the workers in the workplace. Occupational exposure limits [11] are specifications for the maximum airborne concentration of substances, averaged over a reference time period (in our case 8-h shift) in workplace air and are used as the 'norm' in the current scheme. They have been the primary expression of workplace risk management expectations and are suitable to divide the acceptable and unacceptable risk area (e.g green and red area in the scheme).

The 'conditional limit' is determined using the highest exposure value which is not is not associated with any adverse symptoms, yet, derived from toxicological profiles [12,13,16,17,19,20].

For the 'critical limit', half of the IDLH (immediately dangerous to life or health concentration) values are used. The purpose for establishing IDLH was to determine a concentration from which a worker could escape without injury or without irreversible health effects in the event of respiratory protection equipment failure and a concentration above which only "highly reliable" respirators would be required. The IDLH values have been determined considering the toxicity data of a chemical and applying suitable safety factors [26,27].

Table 3

Odour thresholds, exposure limits, lethal concentrations of investigated solvents

Solvent	**Boiling point, ^0C**	**Odour threshold, mg/m^3** [26]	**Exposure limit, mg/m^3**[11]	**IDLH, mg/m^3** [27]
Toluene	110.6 [13]	11.1	192	1900
o-Xylene	144.4 [16]	4.9	221	4000
n-Butanol	117.6 (1-butanol) [19] 98.5 (2-butanol) [19]	3.1 (1-butanol) 7.7 (2-butanol)	150	4300
Styrene	145.2 [20]	4	90	3000

The five-stage simple/flexible risk assessment model, where the relationship between exposure concentration and potential health impairment is presented, is shown in Figure 2.

The occupational illness stages are developed using statistical data of diagnoses of occupational diseases by occupational health doctors. In the case of styrene, butanol, xylene and toluene, the main health impairments are divided into two different groups - irritating and neurotoxic effects.

According to the proposed scheme, all the four investigated chemicals fall to red, unacceptable risk area. The exposure to toluene poses intolerable risk (risk level V), xylene and styrene inadmissible risk (risk level IV) and butanol unjustified risk (risk level III). Without any additional control measures applied, the risk for occupational diseases caused by these chemicals is significant.

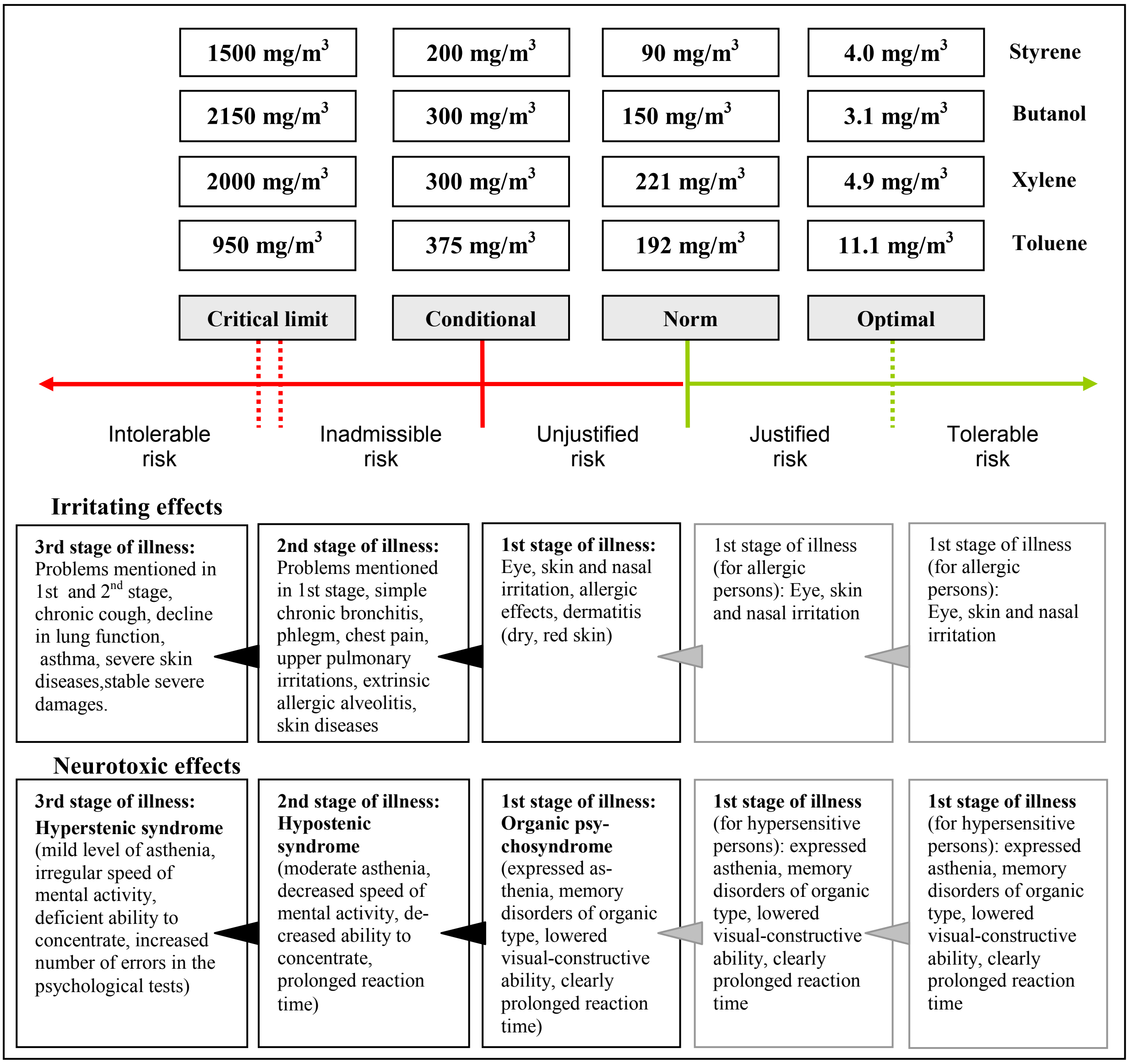

Fig. 2. Chemicals and risk criteria

6. Conclusions

Based on the study, the following conclusions can be drawn:

1. Assessing chemicals risks with simple/flexible risk assessment method is an attempt to provide coherent guidance through targeting necessary information for small and medium sized enterprises to manage chemical risks and track performance more effectively. It is an alternative method to support companies in fulfilling governmental legislation of handling chemicals in occupational settings. Since the method has been worked out to assess other occupational hazards as well, it keeps a consistent manner for approaching hazards in the workplace.
2. The method is suitable for enterprises processing materials or handling chemicals in some stages, but cannot be applied for chemical plants where several other factors should be taken into account while assessing the risks for safety, health and environment. The risk of major hazards is not covered by simple/flexible risk assessment method.
3. In the investigated Estonian enterprises, most of the examined indoor quality hazards (air temperature; relative humidity; chemicals in printing, mechanical and clothing industry) were

under control. Some problems were detected with air temperature due to deficiencies in ventilation systems or their lack and the low relative humidity value in winter season when the air dried due to heating system and no conditioner system existed to balance the relative humidity. Some chemicals present in indoor air in wood processing industry posed a very high risk for workers. The risk levels assessing with simple/flexible risk assessment were III to V which was not acceptable. Immediate safety measures are necessary.

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K. Reinholde, P. Tint, R. Munters. Mikroklimata kvalitāte ražošanas telpās.

Pētīta gaisa kvalitāte (mikroklimats, ķīmisko savienojumu koncentrācija gaisā) ražošanas un tām blakus esošajās administratīvajās telpās. Noteikti veselības riski. Piedāvāts skaitlisko kritēriju modelis, lai novērtētu profesionālos veselības riskus (iekštelpu klimatu un gaisa kvalitāti), izmantojot vienkāršo/elastīgo risku novērtēšanas metodi. Doti piemēri un mikroklimata parametru mērījumi (temperatūra, mitrums, gaisa plūsmas ātrums), kā arī ķīmisko savienojumu koncentrācija gaisā darba zonā piecās rūpniecības nozarēs (metālapstrādē, poligrāfijā, kokapstrādē, plastmasu un šūšanas ražotnēs). Noteiktas sakarības starp riska līmeni un potenciālajiem veselības bojājumiem. Konstatēts, ka šķīdinātāju koncentrācija – toluola robežās no 1-941 mg/m^3*, ksilola – no 2,5-347* mg/m^3*, butilspirta – no 0,5-285* mg/m^3 *un stirola – no 1-208* mg/m^3 *ir nepieļaujams veselības riska faktors kokapstrādes rūpniecībā. Piedāvāts modelis risku novērtēšanai, kas ņem vērā ķīmisko savienojumu koncentrāciju gaisā darba zonā un to iespējamo negatīvo ietekmi uz veselību. Mikroklimats šo nozaru ražotņu telpās ir kontrolējams, izņemot ļoti karstās vasaras dienās. Ķīmisko savienojumu koncentrācija gaisā ir uzturama pieļaujamās robežās poligrāfijas, metālapstrādes (izņemot metināšanu slēgtās telpās) un apģērbu ražotnēs. Vienkāršā/elastīgā risku novērtēšanas metode ir izmantojama materiālu pārstrādes uzņēmumos vai uzņēmumos, kuros atsevišķās operācijās tiek izmantotas ķimikālijas, bet ne ķīmiskajā rūpniecībā, kur vērā ir jāņem vēl citi faktori.*

K. Reinhold, P. Tint, R. Munter. Indoor air quality in industrial premises

The study focuses on indoor air quality (microclimate, chemicals) in industrial premises. The health risks are determined. A model with numerical criteria is offered to assess the level of occupational hazards (indoor air climate) using a simple/flexible risk assessment method. Practical examples and the results of measurements of microclimate (temperature, humidity, and velocity of the air) and chemical concentrations in the workplace air in five industries (mechanical, printing, wood, plastic and clothing industries) are presented. The connections between risk levels and possible health damages are presented. In the wood processing industry the concentration of solvents: toluene (1- 941 mg/ m^3); xylene (2.5-347 mg/ m^3); butanol (0.5- 285 mg/ m^3) and styrene (1-208 mg/ m^3)) is considered to be unacceptable risk for workers' health. The model is presented for taking into consideration the concentration of chemicals in the air of the work environment and possible negative health effects. The microclimate is under control except during very warm climate in summer. The chemicals are under control in printing, mechanical (except welding in closed workrooms), and clothing industry. The simple/flexible risk assessment method is suitable for enterprises processing materials or handling chemicals in some stages, but cannot be applied for chemical plants where several other factors should be taken into account.

К. Рейнхольд, П. Тинт, Р. Мунтер. Качество внутреннего микроклимата в промышленных помещениях

Исследование фокусируется на качестве микроклимата и химических веществ в промышленных помещениях и в примыкающих с ними административных помещениях. Определен риск влияния неблагоприятного микроклимата на здоровье рабочих. Представлена модель математическими критериями для оценки уровня производственных опасностей с использованием простого/гибкого метода для оценки риска. Представлены практические примеры и результаты измерения микроклимата (температуры, влажности и скорости движения воздуха) и концентраций химических веществ в рабочей зоне в пяти отраслях промышленности (в металлообрабатывающей, печатной, дерево-обрабатывающей, пластмассовой и швейном производстве). Представлены связи между уровнями риска и потенциальными повреждениями здоровья. Концентрация растворителей: толуола (1-941мг/$м^3$), ксилола (2.5-347мг/$м^3$), бутанола (0.5- 285 мг/$м^3$) и стирена (1-208 мг/$м^3$) считается неприемлимым риском в зоне дыхания рабочего и возможно негативное действие на здоровье рабочих в дерево-обрабатывающей промышленности. Микроклимат в пределах нормы за исключением температуры воздуха в чрезвычайно жаркий период летом и ниже нормы влажность воздуха в помещениях с центральным отоплением в холодный период.