MONITORING OF INDOOR ENVIRONMENTAL QUALITY IN A PRINTING COMPANY – CASE STUDY

Silvia Vilcekova[1], Ludmila Meciarova[1]*

[1]Technical University of Kosice, Faculty of Civil Engineering, Vysokoskolska 4, Kosice 042 00, Slovakia

Abstract

Indoor environmental quality in a workplace is a very sensitive issue according to the fact that people spend a substantial part of their day here and also it is not always possible to ensure their full protection against harmful substances. The first measurement of indoor air quality in the printing company was conducted in spring 2015. Another measurement was carried out several months later in winter 2015 and focused to more parameters of indoor environmental quality. The aim of this study was to compare the results of these measurements, and find out whether there are changes in the levels of total volatile organic compounds and in the presence of individual volatile organic compounds in this type of workplace. An electronic nose was used for qualitative analysis of volatile organic compounds. The mean TVOC and total PM concentrations were 66.1 mg/m^3, and 211.3 μg/m^3, respectively. Operative temperature was also higher than optimal value for this type of workplace. Other parameters of indoor environmental quality were normal. Analysis of VOCs showed occurrence of many types of VOCs and eight of them were detected also during first measurement.

Key words

indoor environment; pollution; volatile organic compounds; workplace

To cite this paper: *Vilcekova, S., Meciarova, L. (2016). Monitoring of indoor environmental quality in a printing company – case study, In conference proceedings of People, Buildings and Environment 2016, an international scientific conference, vol. 4, Luhačovice, Czech Republic, pp. 83-90, ISSN: 1805-6784.*

*Corresponding author: Tel.: +421-055-602-4262,
E-mail address: ludmila.meciarova@tuke.sk

1 INTRODUCTION

The indoor environmental quality (IEQ) is defined by the following environmental factors: thermal comfort, indoor air quality (IAQ), visual comfort and acoustic comfort [1]. High IEQ is associated with company and employee productivity gains. On the other hand poor IAQ is related to sick-building syndrome (SBS) [2]. The term „SBS" is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to the time spent in a building but no specific illness or cause can be identified. SBS seems to be related to inadequate ventilation, temperature and humidity changes, and biological and chemical contaminants from outdoor and indoor sources [3].

The pollution of indoor air is common to all built environments. Such contamination is most pronounced in industrial environments, which pose unique exposure concerns and are subject of occupational safety and health programs in most developed countries [4]. The concentrations of indoor pollutants depend on the relationship among the volume of air contained in the indoor space, the rate of air exchange, the outdoor pollutant concentrations, and the rate of production or the release of the sources [5]. Volatile organic compounds (VOCs) and carbonyls belong to the most important categories of chemicals that occur in the indoor air. VOCs are classified as the organic compounds that have boiling point between 50°C and 260°C [6]. VOCs have many sources in the environment; therefore, result in very complex scenarios of human exposure that are not fully understood. Even low concentrations of these substances have been associated with irritation, discomfort, and disease [7].

However, most studies were focused on IEQ in the office building while only a small part of them studied IEQ in the industry workplaces. Therefore, the aim of this study was to assess the indoor air quality in printing company focused on offset printing and compare the results with previous monitoring performed in this type of workplace.

The main sources of VOCs in the printing industry are organic solvents, inks, fountain solutions, and cleaning agents [5]. Besides printing operations, VOC emissions also may be caused by proofing ink mixing, cleaning, binding, laminating, and chemical storage [8]. Printing techniques can be categorized to offset, gravure, letterpress, screen printing, and flexography. Each of these processes uses different chemicals, and equipment but they all produce images on a substrate by carrying out the same basic procedures which can be classified into imaging, pre-press, printing and post-press [9]. The graphic image is applied from an ink-covered printing plate to a rubber-covered "blanket" cylinder and then transferred onto the substrate in the offset printing. The substrate in offset lithography can be either a web or sheets. A web substrate can be used with either heat set or non-heat set inks. Sheets are used with non-heat set inks only [10]. The inks used for publication work contain about 40% solvent, while ink used for newspaper work contains 5%. In both cases, the solvents are usually petroleum-derived hydrocarbons [9].

Since the early 1980s, the printing industry has made efforts to reduce the exposure to VOCs. Chlorinated hydrocarbons, toluene, and xylene have been replaced by paraffins and cycloparaffins with high boiling points, and to some extent with terpenes and water-based solvents. Despite these improvements, exposure to VOCs is still present in this type of industry [8]. Special airborne particulate pollutants are also present in this environment. The paper dust generated during paper cutting and folding processes can be suspended in the air. The starch powder used to separate printed paper sheets is also an airborne particulate pollutant. Ink can be found in a form of droplets suspended in the air, apart of its presence in a form of vapour. All of these particulate pollutants are known to cause occupational health problems [11].

2 MEASURING SITE

The measurement of IEQ parameters was carried out in a building of printing company, which was built approximately in 1970s. It is a steel hall while parts of the envelope with windows are built of burnt brick. Partitions are created from gypsum boards. The whole building is thermally insulated with glass wool. This building has central heating with own heat source (gas caldron). The measurement was performed in a part of building with floor area of 144.3 m^2 and volume of 533.91 m^3 during normal operation (Figure 1). This workplace was equipped with epoxy flooring, aluminium windows, one printing machine, one machine for paper cutting, one strapping machine, 62 wooden pallets, five tables from particleboard, one wooden and twelve upholstered chairs, several tons of different types of paper and cardboard, sealed canisters with cleaning chemicals and printing inks.

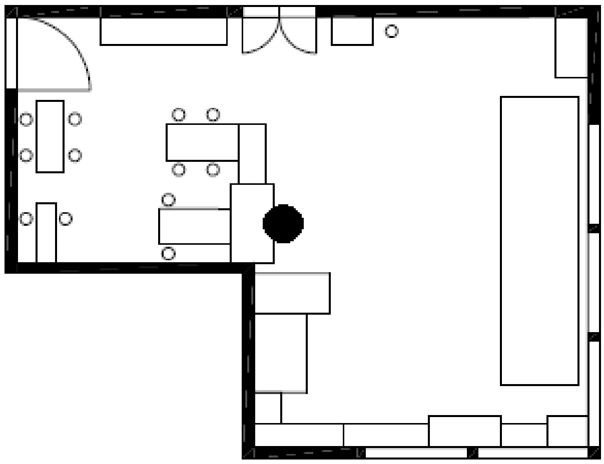

Fig. 1: Plan view of the studied space (black circle – measuring instruments)

3 METHODS

The concentrations of total volatile organic compounds (TVOC) were determined using photoionization detector with UV lamp (ppbRAE 3000). This device has measuring range from 1 ppb to 10,000 ppm, three-second response time [12] and specified accuracy (isobutylene) from 10 to 2000 ppm: ±3% at calibration point [13]. Two-point field calibration of zero and standard reference gases were carried out one day before measurement. Qualitative determination of VOCs was carried out with electronic nose (zNose 4300). The manufacturer of this device specifies the precision of 5% RSD, 10% accuracy and sensitivity at low ppb level for most compounds [14]. The system was calibrated to the alkane response with a solution of C6-C22 in methanol before measurement. The method used for measurement included the inlet temperature of 200°C, valve temperature of 165°C, column temperature from 40 to 200°C, sensor temperature of 20°C, sampling time of 10 seconds (0.5 ml/s) and analysis time of 20 seconds. Sampling with electronic nose was repeated 10 times in four cycles; therefore, the total amount of analysed air was 200 ml. A detailed description of the apparatus has been described in the study Meciarova et al. [15]. Air velocity, air temperature and relative humidity were determined with multifunctional device Testo 435-4. Measuring range and accuracy for air velocity is from 0 to 20 m/s and ±0.03 m/s, for temperature is from -20 to +70°C and ±0.5°C, and for humidity is from 0 to 100%RH and ±2% RH [16]. The mass concentrations of particulate matter for fractions of 0.5, 1.0, 2.5, 5.0 and 10.0 micrometres were measured with a Hand Held 3016 Airborne Particle Counter. This instrument detects the minimum particle size of 0.3 microns with a flow of 0.1 CFM. The sound pressure levels were measured with a handheld analyser - Brüel and Kjaer Type 2250. Mean radiant temperature was measured with Vernon-Jokl globe thermometer. All measuring devices were placed approximately in the centre of the studied space in the height of 1.3 m above the floor. Four employees were working in this space during measurement. Measurement lasted 8 hours and was carried out during normal operation (employees opened the windows and door at their own discretion) and during heating season.

4 RESULTS

The results from measurement of indoor air temperature, relative humidity, air velocity, concentrations of TVOC, and sound pressure levels are shown in Table 1. Operative temperature calculated according to STN EN ISO 7726 was 24.1°C. According to Decree of the Ministry of Health of the Slovak Republic No. 259/2008 Coll., optimal temperature for this type of workplace should be from 15 to 20°C and permissible temperature should be from 12 to 22°C for cold part of year. Therefore, operative temperature was by 17.01% higher than optimal temperature and by 8.7% higher than permissible temperature. Air velocity should be ≤ 0.3 m/s and relative humidity in the range of 30 to 70%. As can be seen, these parameters were normal. According to Regulation of the Government of the Slovak Republic No. 115/2006 Coll. sound pressure level should be ≤ 80 db. This requirement was also fulfilled. There are no limit values for TVOC concentrations. According to Mølhave [17], TVOC concentrations higher than 25 mg/m^3 belong to toxic range in the view of health and comfort. In previous measurement (in second part of the studied printing company), mean TVOC concentration was 2.6 mg/m^3. However, the volume of the room was by 76.3% smaller in this measurement than in the first measurement. Thus, air dilution was much lower. Also, it should be noted that air handling unit was broken during measurement. Correlation analysis did not confirm TVOC concentrations dependence on temperature or relative humidity in this space.

Tab. 1: The results from objective measurements of IEQ parameters

	Air temperature [°C]	**Relative humidity [%]**	**Air velocity [m/s]**	**TVOC [mg/m^3]**	**Sound pressure level [dB]**
Mean	24.5	31.6	0.03	66.2	74.7
Min.	23.4	29.8	0.00	31.2	68.5
Max.	26.1	35.3	0.36	138.9	76.8
S.D.	0.6	0.9	0.04	23.2	2.8

Limit for 24 hour exposure to $PM_{10.0}$ is 50 μg/m^3 according to Decree of the Ministry of Health of the Slovak Republic No. 259/2008 Coll. In this study, concentrations of $PM_{10.0}$ were measured only 8 hours, thus it is not possible to compare these values. However, mean concentrations of $PM_{10.0}$ was 174.8 μg/m^3 and this value is three-fold higher (Table 2). Guideline value for concentrations of $PM_{2.5}$ according to WHO [18] is 25 μg/m^3 but also for 24 hour exposure. Mean value of $PM_{2.5}$ concentrations was 30.2 μg/m^3, which is also higher than the guideline value.

Tab. 2: The results from measurement of PM concentrations

	$PM_{0.5}$ [μg/m^3]	$PM_{1.0}$ [μg/m^3]	$PM_{2.5}$ [μg/m^3]	$PM_{5.0}$ [μg/m^3]	$PM_{10.0}$ [μg/m^3]	Total PM [μg/m^3]
Mean	12.2	19.5	30.2	81.4	174.8	211.7
Min.	5.2	8.3	11.2	21.8	36.2	38.0
Max.	23.1	33.3	58.4	240.7	665.9	1165.9
S.D.	4.3	5.7	11.0	56.1	141.9	182.1

Figure 2 shows the course of TVOC concentrations during 8 hours. As can be seen, TVOC levels fluctuated throughout the day and the highest levels were measured approximately from 7th hour. This was caused by the final cleaning of printing machine with special organic solvent for offset printing machine, which was carried out during this time. The course of air temperature, relative humidity, and total PM concentrations during measurement are shown in Figure 3 and Figure 4.

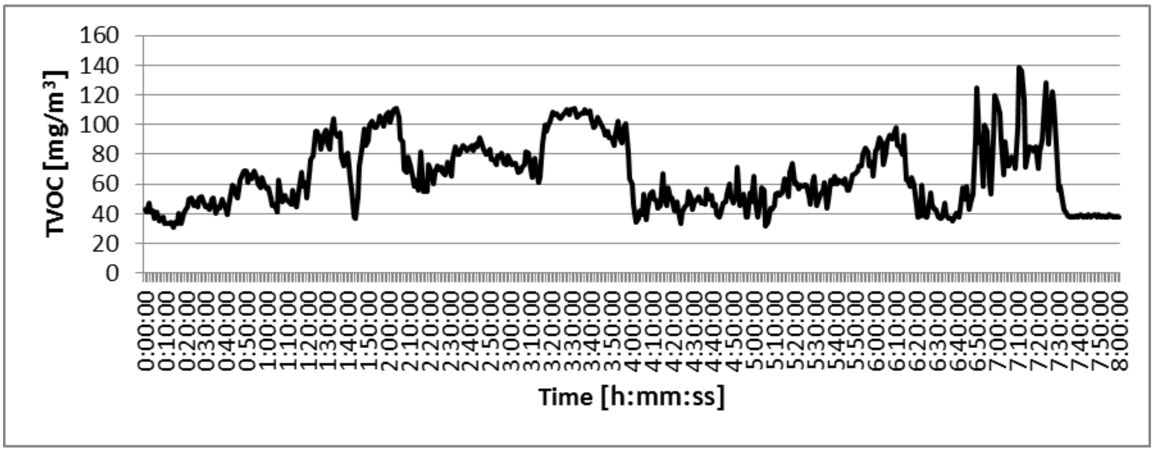

Fig. 2: The course of TVOC during 8 hours

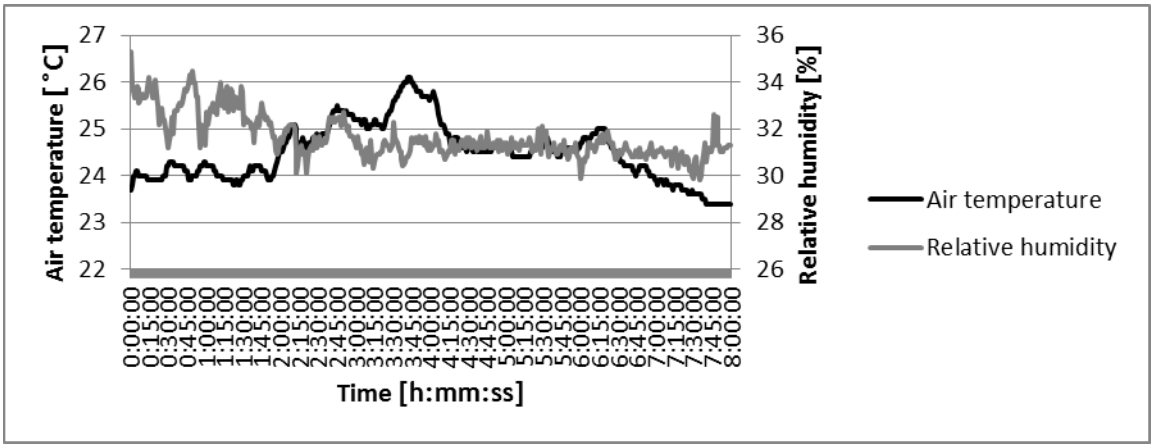

Fig. 3: The course of air temperature and relative humidity during 8 hours

As can be seen, the total PM concentrations also fluctuated during the working hours. Higher concentrations from the time of 1:45:00 to 6:00:00 can be explained by that during printing process anti set-off powder was used.

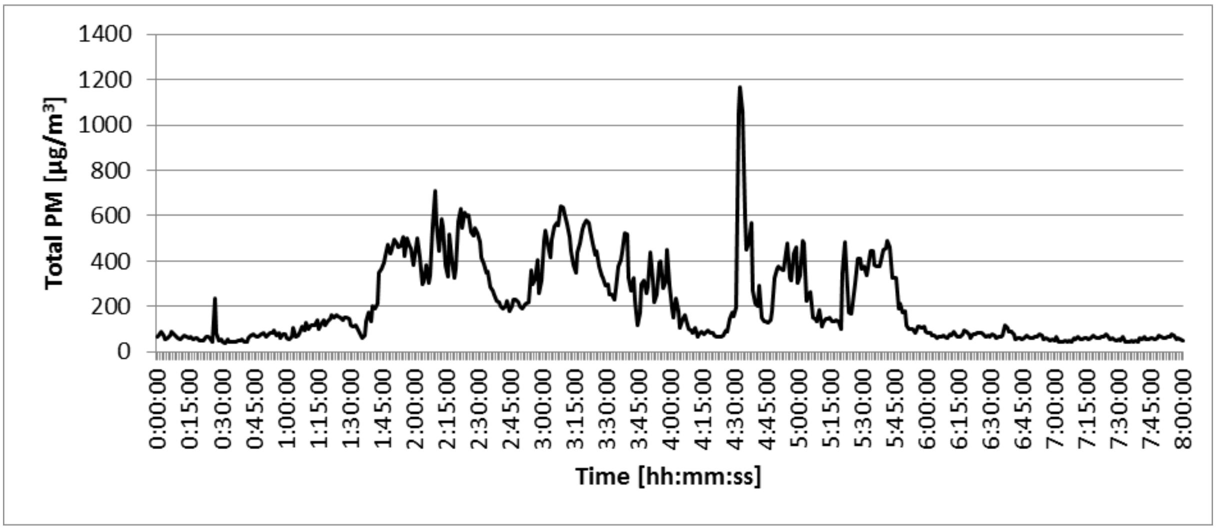

Fig. 4: The course of total PM concentrations during 8 hours

The results from analysis of individual VOCs with electronic nose are shown in Table 3. The most occurring compound was isophorone, 5-methylindane and longifolene. Isophorone is a common compound present in the printing inks. The following compounds were also found in the previous study [19]: norbornane; o-xylene; 1,3-diethylbenzene; nonanal; undecane; undecanal; 2,3-dimethylbenzeamine; and 2-phenoxyethanol.

Tab. 3: Analysis of individual VOCs with electronic nose

Compound	**CAS**	**1st cycle**	**2nd cycle**	**3th cycle**	**4th cycle**
norbornane	279-23-2			✓	✓
1,1,4-trimethylcyclohexane	7094-27-1	✓	✓	✓	
o-xylene	95-47-6	✓		✓	✓
β-pinene	127-91-3		✓		
bis(2-chloro-1-methylethyl) ether	108-60-1		✓	✓	✓
p-cymene	99-87-6	✓			
1,3-diethylbenzene	141-93-5			✓	✓
1,2-diethylbenzene	135-01-3	✓	✓		
nonanal	124-19-6	✓		✓	✓
undecane	1120-21-4		✓		
isophorone	78-59-2	✓	✓	✓	✓
5-methylindane	874-35-1	✓	✓	✓	✓
5-methylundecane	1632-70-8			✓	
undecanal	112-44-7	✓			✓
4-methyl undecane	2980-69-0		✓		
2,3-dimethylbenzeamine	not available			✓	✓
dodecane	112-40-3		✓		
5-methyldodecane	17453-93-9			✓	✓
2-phenoxyethanol	122-99-6	✓		✓	✓
butoxyethanol acetate	112-07-02	✓			
longifolene	475-20-7	✓	✓	✓	✓

5 CONCLUSION

The results of this study showed that relative humidity, sound pressure level, and air velocity meet the legislative requirements. On the other hand, air temperature, concentrations of TVOC and particulate matter are high in this company and much higher in the second studied space. Operative temperature was higher by 8.7% than permissible temperature for this type of workplace. Mean TVOC concentration was higher by 99.7% than recommended value, mean concentration of $PM_{10.0}$ was higher by 71.4% and mean concentration of $PM_{2.5}$ was higher by 17.2% than guideline values. Since natural ventilation is insufficient, despite the measures in the printing industry mentioned above. Therefore, planned replacement of air handling unit throughout the company is the best possible solution for protection of employees' health. Analysis with electronic nose showed occurrence of many species of VOC in the indoor air. The strongest sources of VOCs was printing inks and cleaning agents that are used throughout working hours. The use of the results gained in this paper is limited due to the fact that it is a small case study. However, these results highlight the need to pay attention to the indoor environmental quality also in industry.

REFERENCES

[1] Sarbu, I. and Sebarchievici, C. (2013). Aspects of indoor environmental quality assessment in buildings. Energy and Buildings, **60**, pp. 410-419. http://dx.doi.org/10.1016/j.enbuild.2013.02.005

[2] Heinzerling, D., Schiavon, S., Webster T. and Arens E. (2013). Indoor environmental quality assessment models: A literature review and a proposed weighting and chlassification scheme. Building and Environment, **70**, pp. 210-222. http://dx.doi.org/10.1016/j.buildenv.2013.08.027

[3] Environmental Protection Agency (EPA). (1991). Indoor air facts no 4: sick building syndrome. Available at: http://www.epa.gov/iaq/pubs/sbs.html (accessed 25 May 2016).

[4] Godish, T. (2000). Indoor environmental quality. Boca Raton, Florida: CRC Press LLC. ISBN 1-56670-402-2.

[5] Caselli, M., de Gennaro, G., Saracino, M.R. and Tutino, M. (2009). Indoor contaminants from newspapers: VOCs emissions in newspaper stands. Environmental Research, **109**(2), pp. 149-157. http://dx.doi.org/10.1016/j.envres.2008.10.011

[6] Sarigiannis, D.A., Karakitsios, S.P., Gotti, A., Liakos, I.L. and Katsoyiannis, A. (2011). Exposure to major volatile organic compounds and carbonyls in European indoor environments and associated health risk. Environmental International, **37**(4), pp. 743-765. http://dx.doi.org/10.1016/j.envint.2011.01.005

[7] Schlink, U., Thiem, A., Kohajda, T., Richter, M. and Strebel, K. (2010). Quantile regression of indoor air concentrations of volatile organic compounds (VOC). Science of the Total Environment, **408**(18), pp. 3840-3851. http://dx.doi.org/10.1016/j.scitotenv.2009.12.002

[8] Viegas, S. (2011). Occupational exposure to volatile organic compounds in the Portuguese printing industry. Environmental health and biomedicine, **15**, pp. 233-239. http://dx.doi.org/10.2495/EHR110211

[9] Lin, W. K. (2011). Volatile organic compounds (VOCs) emission estimate of printing industry in the Pearl River Delta Region, HKU Theses Online (HKUTO). Available at: http://hub.hku.hk/bitstream/10722/144198/3/FullText.pdf?accept=1 (acessed 25 May 2016).

[10] EPA Victoria. (2004). Minimising VOC emissions from Victoria's printing industry. Available at: http://www.epa.vic.gov.au/~/media/Publications/940.pdf (accessed 25 May 2016).

[11] OSH Research Report. (2016). Indoor Air Quality for Printing Plants. Available at: http://www.oshc.org.hk/download/research/36/2/IAQeng.pdf (accessed 25 May 2016).

[12] RAE Systems. (2014). Understanding and operating the ppbRAE 3000, Technical Note TN-150. Available at: http://www.raesystems.com/sites/default/files/content/resources/Technical-Note-150_Understanding%20And%20Operating%20The%20ppbRAE%203000_08-14.pdf (accessed 25 May 2016).

[13] RAE systems. (2010). ppbRAE 3000, User's Guide. Available at: http://www.enviroequipment.com/rentals/PDF/ppbRAE3000_manual.pdf (accessed 25 May 2016).

[14] Electronic Sensor Technology. (2008). 4300 Ultra fast GC analyser, Operation Manual, MicroSense 5. Document No. DOC004300. Updated February 14, 2008. 1077 Business Center Circle, Newbury Park, CA 91320.

[15] Meciarova, L., Vilcekova, S. and Balintova, M. (2014). Measurement of VOCs with a portable GC/SAW detector. Chemical Engineering Transactions, **40** (Special Issue), pp. 283-288. http://dx.doi.org/10.3303/CET1440048

[16] TESTO. (2016). testo 435-4 – Multifunction meter w/memory, software, and differential pressure. Available at: https://www.testo.com/product/0563+4354/testo-435-4-Multifunction-meter-w-memory-software-and-differential-pressure (accessed 25 May 2016).

[17] Mølhave, L. (1990). Volatile organic compounds, indoor air quality and health. Indoor Air, In Proceedings of the 5th International Conference on Indoor Air Quality and Climate. Toronto, Canada, July 29 – August 3, pp. 15-33.

[18] WHO. (2006). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Summary of risk assessment. Available at: http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf (accessed 25 May 2016).

[19] Meciarova, L. and Vilcekova, S. (2015). Analysis of volatile organic compounds in the building of printing company. In Conference Proceedings Indoor climate of buildings 2015, Slovakia, Strbske Pleso, December 8.-9.,pp. 93-98 (In Slovak). ISBN 978-80-89216-85-7.

Acknowledgments

This study was financially supported by Grant Agency of Slovak Republic to support of projects No. 1/0307/16.