ELECTROMAGNETIC FIELD EXPOSURE IN THE PUBLIC SPACE OF THE SLOVAKIAN CITY

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Resume

The main objective of our research was to map the exposure to electromagnetic smog in the frequented space of shopping centres in the city of Bratislava and to compare our results to the actual hygienic limits. The measurements of the low- and high-frequency electromagnetic fields were performed at different places in shopping centres. Our results did not exceed the Slovak current limits in any of the measurements. However, almost all of them markedly exceed new permitted limits according to EUROPAEM. Based on our results, stricter limits in many European countries and increasing evidence on possible harmfulness of long-term exposures to artificial electromagnetic fields, preventive carefulness can be recommended - to support the research in this field, to prepare professional public education and possibly to prepare the stricter Slovak exposure limits.

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1 Introduction

Exposure of humans to electromagnetic fields (EMF), low-frequency (LF) within the frequency range from 1 Hz to 100 kHz, high-frequency (HF) within the frequency range from 100 kHz to 300 GHz is not a new phenomenon. However, during the twentieth century, environmental exposure to man-made electromagnetic fields has been steadily increasing. Technical technological innovations constantly provide new sources, especially high-frequency electromagnetic fields, even directly in homes and public spaces (transport, Wi-Fi network, wireless energy meters, wireless games etc.). In connection with this, there are also growing concerns today about the possible negative effects of such high and continuous long-term exposure to artificial electromagnetic fields [1].

In an effort to protect the public health, many countries have tightened their health and safety limits in this area and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), established by the European Commission, has also addressed the issue of protection strategies [2]. Research in this area has brought new safety warnings and indications concerning, in particular, the nonthermal effects of electromagnetic smog.

It is also worth noting, for example, that the International Agency for Research on Cancer (IARC), a part of the World Health Organization (WHO), has included electromagnetic fields in Group 2B among possible human carcinogens [3] and the WHO has organized in 2004 an international workshop on Electrical Hypersensitivity, where this has been defined and recognized as a real problem [4-5].

There are many different guidelines and recommendations in the world that also set health and safety limits for human exposure to electromagnetic radiation, namely, the electromagnetic fields. However, many of them are now outdated and expired (dated back to the beginnings of research in this area). In many European countries, including Slovakia, the recommendations developed by the International Commission for Nonionizing Radiation Protection, abbreviated ICNIRP [6], are currently valid. In Slovakia, these recommendations were applied in practice in 2007 [7]. However, new recommendations, with significantly lower exposure limits, should also be mentioned, e.g. those published by the European Academy of Environmental Medicine - EUROPAEM [8] or BioInitiative [9]. These new recommendations are based on several researches in recent years and correspond to the effort for the so-called "Preventive measure", as the effects of long-term exposure to electromagnetic radiation from artificial sources are now difficult to estimate more accurately and several studies point to its potential harmfulness.

The purpose of our research was to map the exposure to various types of artificial electromagnetic fields in the public areas of the major shopping centers in Bratislava and to compare the values to the current health and safety limits according to ICNIRP and EUROPAEM.

2 Materials and methods

2.1 Study design

Exposure measurements to electromagnetic fields were made in three selected large shopping centres located in three different districts of Bratislava. We marked them in the text with e letters A, B and C, to maintain anonymity. The measurements in the shopping centers were made at a height of 1.5 meters in the middle of the shopping route. The measurement locations in the shopping centers (SC) were distributed symmetrically on each floor along the shopping routes. Total number of measurement locations n = 90 (SC-A: n = 40, SC-B: n = 30, SC-C: n = 20). The different numbers of measurement locations are related to different lengths of shopping routes of individual SCs. The average values were then calculated for each SC.

2.2 Procedure

All the measurements were performed during the working days in the afternoon between 2:00-5:00 PM. Exposure to the both low-frequency (LF) within the frequency range from 20 Hz to 50 kHz and the high-frequency (HF) within the frequency range from 50 MHz to 3,500 MHz electromagnetic fields was measured in all shopping centres locations.

However, in the case of well-shielded electric circuits, the electric component of low-permeability is almost zero and there exists practically only a magnetic component. The three orthogonal strength components (X, Y and Z) of the magnetic field were measured at each location, from which the final value of magnetic induction (μT) was subsequently calculated. The HF electromagnetic fields were characterized by a power density (W.m^{-2}) that best expresses the exposure to these fields.

2.3 Measurement equipment

Three devices were used for the measurements. An "EXTECH EMF450" multi-field EMF meter (Extech Brand, Nashua, NH) was used to measure exposure to LF and HF electromagnetic fields. The device measurement range in the mode of measurement of magnetic induction is 0.02 - 200 μT and in the mode of measurement the electric field intensity is 50 - 2000 V.m^{-1} in the frequency range of 50/60 Hz. The device measures the power density for frequencies 50 - 3,500 MHz in the range 0.02 μW.m^{-2} - 554.6 mW.m^{-2}.

A "PF5 Pocket Power Frequency Meter" (EMFields Solutions, Sutton, United Kingdom) was used to measure exposure to LF electromagnetic fields. The device measures in the frequency range 20 Hz - 50 kHz. It can be used in the magnetic induction measurement mode in a measuring range of 0.02 - 2 μT or the electric field measurement intensity mode in a measuring range of 5 - 200 V.m^{-1}.

The "HF-Analyzer Gigahertz, HF35C" (Gigahertz Solutions, Furth, Germany) was used to measure exposure to HF electromagnetic fields. The device measures the power density for frequencies 800 - 2,700 MHz in the measurement range 0.1 - 2,000 μW.m^{-2}. To measure very high exposures, an electronic element attenuator DG20 is attached that reduces the sensitivity of the measuring device by a factor of 100 (= 20 dB). The device then measures in the range of 10 - 200,000 μW.m^{-2}. This device measures in two modes. The RMS (Root Mean Square) mode represents the quadratic average of all the pulses, often called the effective value and in the PEAK mode, which senses the peak (maximum) values of the pulse signal.

All the broadband EMF meters were self-calibrated before measurement.

2.4 Statistical analyses

We present the data as the mean ± SD and (range). The differences in the categorical variables between the three groups were analyzed using Kruskal-Wallis Test with the Post-Hoc Mann Whitney U test. All the tests were carried out at a significance level of $\alpha = 0.05$. (In Kruskal-Wallis Test p-value of < 0.05 was considered statistically significant). The IBM SPSS Statistics 25 statistical program was used for the statistical processing of measured data.

Table 1 *Exposure to electromagnetic fields in shopping centres. LF = low frequency; HF = high frequency.*

Place of measurement (number of measurements)	LF electromagnetic field magnetic induction [μT]			HF electromagnetic field power density [μW.m^{-2}] RMS mode			HF electromagnetic field power density [μW.m^{-2}] PEAK mode		
	mean	max	min	mean	max	min	mean	max	min
Shopping centre A (40)	0.09	0.25[†]	0.01	79	450[†]	10	305[†]	750[†]	70
Shopping centre B (30)	0.18[†]	0.43[†]	0.05	265[†]	725[†]	20	1 904[†]	10 950[†]	20
Shopping centre C (20)	0.11[†]	0.29[†]	0.02	180[†]	1 100[†]	7	1 115[†]	3 500[†]	70
Limit ICNIRP		100 ^			10 000 000 ¦			- ‡	
Limit EUROPAEM		0.1			100			100	

† *The resulting value means exceeded limits of EUROPAEM.*

^ *The resulting value of the magnetic induction is in this case calculated according to the formula 5/f (kHz) (that is, for 50 Hz the resulting value of the magnetic induction is 100 μT).*

¦ *The resulting value of the power density is, in this case, calculated according to the formula f (MHz)/200 (i.e. for example for 2,000 MHz the final value of the power density is 10,000,000 μW.m^{-2}).*

‡ *ICNIRP does not specify the PEAK limit.*

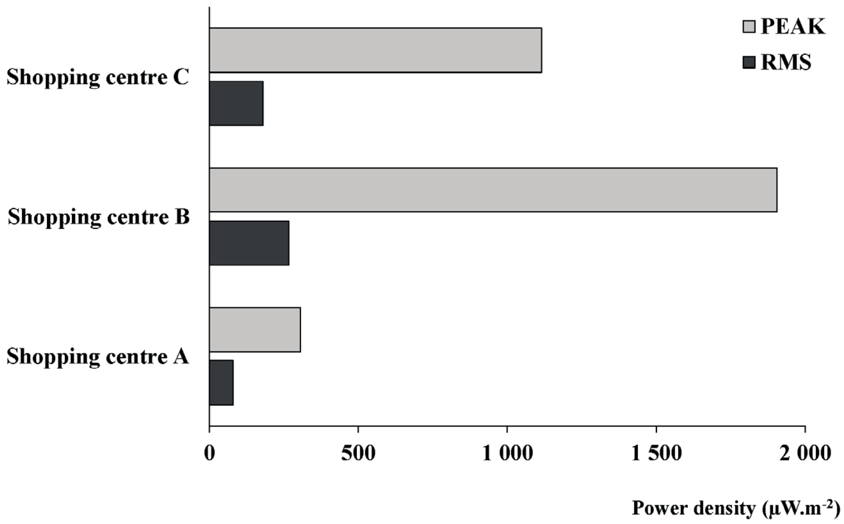

Figure 1 *Mean values of exposure to electromagnetic fields in shopping centres displayed in different modes*

3 Results

The results of the statistical processing of the measured data (mean, maximal and minimal values) are presented in table 1 and graphically. Table 1 contains data on the exposure to LF and HF electromagnetic fields in the large shopping centres in Bratislava and Figure 1 shows differences in measured LF electromagnetic fields exposures in different modes.

In the shopping center A (40) the magnetic induction was 0.094 ± 0.010 μT, the power density in the RMS mode 78.75 ± 13.41 μW.m^{-2} and the power density in the PEAK mode 304.78 ± 24.07 μW.m^{-2}. In shopping centre B (30) the magnetic induction was 0.184 ± 0.019 μT, the power density in the RMS mode 265.40 ± 28.89 μW.m^{-2} and the power density in the PEAK mode 1904.49 ± 565.01 μW.m^{-2}. In Shopping centre C (20) the magnetic induction was 0.111 ± 0.018 μT, the power density in the RMS mode 179.75 ± 65.92 μW.m^{-2} and the power density in the PEAK mode 1114.80 ± 238.51 μW.m^{-2}.

We compared individual parameters in all the shopping centers and found significant differences in the measured values between individual shopping centers. In the measurement of the electromagnetic field LF - magnetic induction, the Kruskal-Wallis H test indicated that there is a significant difference in the dependent variable between the different groups, $\chi^2(2) = 16.88$, $p < .001$. The Post-Hoc Mann Whitney U test, using an alpha of 0.05, indicated that the mean ranks of the following pairs are significantly different (SC-A vs. SC-B and SC-B vs. SC-C). In measurement of the power density of the electromagnetic field HF - RMS mode, the Kruskal-Wallis H test indicated that there is a significant difference in the dependent variable between the different groups, $\chi^2(2) = 28.23$, $p < .001$. The Post-Hoc Mann Whitney U test, using an alpha of 0.05, indicated that the mean ranks of the following pairs are significantly different (SC-A vs. SC-B and SC-B vs. SC-C). In measurement of the power density of the electromagnetic field power density - PEAK mode, the Kruskal-Wallis H test indicated that there is a significant difference in the dependent variable between the different groups, $\chi^2(2) = 30.45$, $p < .001$. The Post-Hoc Mann Whitney U test, using an alpha of 0.05, indicated that the mean ranks of the following pairs are significantly different (SC-A vs. SC-B and SC-A vs. SC-C). Upon closer examination of the technical documentation of individual installations in shopping centers, we discovered that each shopping center has different parameters of unified access points (signal strength, performance etc.).

In all the measurements of LF and HF fields in shopping centers, older limits according to ICNIRP and still valid in Slovakia were not exceeded even once. The new limits, according to EUROPAEM, were exceeded only slightly in the LF electromagnetic fields. The average values of exposure to the electromagnetic fields of LF in shopping centers, in one case only slightly exceeded and in one case reached the value of 0.1 μT of the EUROPAEM limit. However, the average values of exposure to HF electromagnetic fields exceeded the EUROPAEM limit (100 $\mu W.m^{-2}$) in the Peak mode several times, in all three shopping centres. In two centers, this limit was significantly exceeded in the normal RMS measurement mode, as well and the maximum value was even at the level of 1100 $\mu W.m^{-2}$.

Values exceeding the stricter EUROPAEM limits are marked in the tables in bold.

(Note: the electric component of LF electromagnetic fields in the shopping centres was assumed to be almost zero in all places - therefore we do not list it in Table 1 and we only present the magnetic component of the LF electromagnetic fields).

4 Discussion

According to the effects, electromagnetic radiation can be divided into two groups: ionizing and non-ionizing. Ionizing radiation has enough energy to ionize, that is, to release an electron from an atom or molecule, or to break a chemical bond. The population is not exposed to stronger sources of ionizing radiation, but today is surrounded by various sources of artificial nonionizing radiation, e.g. electromagnetic smog (electric systems, radio and television transmitters, networks of mobile operators, WIFI etc.). The effects of non-ionizing radiation can be divided into thermal and non-thermal.

Although the thermal effect leading to tissue overheating has been known for a long time, currently, thanks to new methodological possibilities, nonthermal effects and their mechanisms are the subject of research. One of these mechanisms is, for example, the ability of the electromagnetic field to activate voltage-gated calcium channels. The increased intracellular calcium concentration activates the calcium signaling pathway, thereby stimulating nitric oxide synthesis. Nitric oxide then reacts with superoxide, forming an extremely reactive peroxynitrite. Its decomposition produces free radicals responsible for oxidative stress and carcinogenesis [10-11]. Another possible mechanism is a direct effect on cellular organelles and microtubules of the cytoskeleton, which could be damaged by the mechanism of the so-called resonant absorption [12] or even by the direct effect on DNA, which behaves as the so-called fractal antenna [13].

Despite the fact that the nonthermal mechanisms of electromagnetic radiation have not yet been sufficiently investigated, there is a growing evidence and indications that truly long-term and continuous exposure to relatively weak artificial electromagnetic fields can contribute to development of various health problems and serious diseases. The impact of the electromagnetic field is mentioned in particular in connection with neurological diseases, such as Alzheimer's and Parkinson's disease [14-16] or brain tumors [17]. A contribution to the development of certain forms of autism cannot be excluded. In this context, leukemia is also mentioned in the literature [18-19].

The IARC (International Agency for Research on Cancer) has classified HF electromagnetic fields as possible human carcinogen [20]. Exposure to a high-frequency electromagnetic field can also cause a variety of neurobehavioral changes in susceptible individuals, particularly fatigue, mood swings, headaches, sleep disorders and concentration [21].

Research in this area is very complicated, since electromagnetic radiation is a factor, whose consequences appear to manifest itself in humans only after a very long time. In addition, other simultaneous factors (genetics, the presence of other diseases, lifestyle, level of stress, exposure of the body to toxic substances etc.) are acting.

The findings obtained in experiments on cells and animals can suggest a lot, but their direct transfer to humans is problematic. Therefore, it is likely that the definitive confirmation or rejection of the negative effects of electromagnetic smog on humans will not be possible for a longer period of time. It is currently reasonable to take the position of the so-called precautionary measures - to support research in this area, to sensitively inform the public about possible risks, about levels of electromagnetic smog exposure at different locations and about possible measures to reduce the level of exposure.

Our research provides information on the levels of population exposure to electromagnetic smog, respectively, artificial electromagnetic fields in frequently visited public spaces of the Bratislava city. We compared the results of our measurements to the limits of the most important European recommendations for exposure to electromagnetic fields, ICNIRP and EUROPAEM. The European Union and the Slovak Republic [22] have also taken over the ICNIRP limits that are still the official limits in Slovakia. These limits do not take into account extreme pulse fluctuations (peaks) and are based only on influence of the contact currents induced in the body and the thermal effects of HF electromagnetic fields [6]. Recent EUROPAEM recommendations already take into account the nonthermal effects of HF electromagnetic fields and their recommended limits already take into account the magnitude of the intensity and power density measured in the Peak pulse mode. The Peak measurement mode, unlike the conventional RMS mode, also records extreme pulse fluctuations, thus providing a more accurate picture of the “activity” of the electromagnetic field.

5 Conclusions

Although the values of HF and LF electromagnetic fields measured in the shopping centers in Bratislava city did not exceed the limits currently valid in the Slovak Republic (corresponding to the ICNIRP limits), this should not be a reason for complete satisfaction, as they significantly exceeded the limits of the new recommendations according to EUROPAEM. In several countries are stricter limits in this area and the growing evidence of possible harmful effects of long-term exposure to the artificial electromagnetic fields would reqiured to formulate preventive measures. Therefore it should be considered to strengthen limits for this area in the Slovak Republic. Moreover, the neighboring countries gradually adjust these limits. At the same time, it would be appropriate to support research and raise public awareness of this issue.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] KOHAN, M., SPRONGLOVA, M., VISNOVCOVA, N., MISEK, J., SPANIKOVA, G., JAKUSOVA, V., JAKUS, J. Monitoring of data transmission and changes in values of electromagnetic field in living environment. *Communications - Scientific letters of the University of Zilina* [online]. 2020, **22**(1), p. 71-76 [accessed 2022-18-03]. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.c.2020.1.71-76

[2] Scientific committee on emerging newly identified health risks. Opinion on potential health effects of exposure to electromagnetic fields. *Bioelectromagnetics* [online]. 2015, **36**(6), p. 480-484 [accessed 2022-15-02]. ISSN 1521-186X. Available from: https://doi.org/10.1002/bem.21930

[3] World Health Organization (WHO). *Non-ionizing radiation. Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields.* Lyon, France: IARCPress, 2002. ISBN 92-832-1280-0.

[4] HAVAS, M. Radiation from wireless technology affects the blood, the heart and the autonomic nervous system. *Reviews on Environmental Health* [online]. 2013, **28**(2-3), p. 75-84 [accessed 2022-21-02]. ISSN 0048-7554. Available from: https://doi.org/10.1515/reveh-2013-0004

[5] HANSSON M. K., BERGLING, R., HORNSTEN, R. Heart rate variability and magnetic field exposure among train engine drivers-a pilot study. *Bioelectromagnetics* [online]. 2021,**42**(3), p. 259-264 [accessed 2022-16-02]. ISSN 1521-186X. Available from: https://doi.org/10.1002/bem.22329

[6] ICNIRP. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). *Health Physics* [online]. 2020, **118**(5), p. 483-524 [accessed 2022-18-02]. ISSN 1521-186X. Available from: https://doi.org/10.1097/HP.0000000000001210

[7] VERKASALO, P. K., KAPRIO, J., VARJONEN, J., ROMANOV, K., HEIKKILA, K., KOSKENVUO, M. Magnetic fields of transmission lines and depression. *American Journal of Epidemiology* [online]. 1997, **146**(12), p. 1037-1045 [accessed 2022-22-06]. ISSN 0002-9262. Available from: https://doi.org/10.1093/oxfordjournals.aje.a009232

[8] BELYAEV, I., DEAN, A., EGER, H., HUBMANN, G., JANDRISOVITS, R., KERN, M., KUNDI, M., MOSHAMMER, H., LERCHER, P., MÜLLER, K., OBERFELD, G., OHNSORGE, P., PELZMANN, P., SCHEINGRABER, C., THILL, R. Europaem EMF guideline 2016 for the prevention, diagnosis and treatment of

EMF-related health problems and illnesses. *Reviews on Environmental Health* [online]. 2016, **31**(3), p. 363-397 [accessed 2022-28-02]. ISSN 0048-7554. Available from: https://doi.org/10.1515/reveh-2016-0011

[9] SANTINI, R., SANTINI, P., DANZE, J. M., LE RUZ, P., SEIGNE, M. Symptoms experienced by people in vicinity of base station: I/Incidences of distance and sex / Enquete sur la sante de riverains de stations relais de telephonie mobile: i/incidences de la distance et du sexe (in Spanish). *Pathologie Biologie* [online]. 2002, **50**(6), p. 369-373 [accessed 2021-22-02]. ISSN 0369-8114. Available from: https://doi.org/10.1016/S0369-8114(02)00311-5

[10] PAVICIC, I., TROSIC, I. In vitro testing of cellular response to ultra high frequency electromagnetic field radiation. *Toxicology in Vitro* [online]. 2008, **22**(5), p. 1344-1348 [accessed 2022-15-04]. ISSN 0887-2333. Available from: https://doi.org/10.1016/j.tiv.2008.04.014

[11] TAGHI, M., GHOLAMHOSEIN, R., SAEED, R. Effect of radio frequency waves of electromagnetic field on the tubulin. *Recent Patents on Endocrine, Metabolic and Immune Drug Discovery* [online]. 2013, **7**(3), p. 252-256 [accessed 2022-21-04]. ISSN 1872-2148. Available from: https://doi.org/10.2174/18722148113079990007

[12] ROOSLI, M., LORTSCHER, M., EGGER, M., PFLUGER, D., SCHREIER, N., LORTSCHER, E., LOCHER, P., SPOERRI, A., MINDER, CH. Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees. *Occupational and Environmental Medicine* [online]. 2007, **64**(8), p. 553-559 [accessed 2022-07-05]. ISSN 1351-0711. Available from: https://doi.org/10.1136/oem.2006.030270

[13] BLANK, M., GOODMAN, R. DNA is a fractal antenna in electromagnetic fields. *International Journal of Radiation Biology* [online]. 2011, **87**(4), p. 409-415 [accessed 2022-21-04]. ISSN 1362-3095. Available from: https://doi.org/ 10.3109/09553002.2011.538130

[14] HUSS, A., SPOERRI, A., EGGER, M., ROOSLI, M. Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population. *American Journal of Epidemiology* [online]. 2009, **169**(2), p. 167-175 [accessed 2022-28-02]. ISSN 0002-9262. Available from: https://doi.org/10.1093/aje/kwn297

[15] VERGARA, X., KHEIFETS, L. GREENLAND. S., OKSUZYAN, S., CHO, Y. S., MEZEI, G. Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: a meta-analysis. *Journal of Occupational and Environmental Medicine* [online]. 2013, **55**(1), p. 135- 146 [accessed 2022-08-03]. ISSN 1536-5948. Available from: https://doi.org/10.1097/JOM.0b013e31827f37f8

[16] VAZAN, R., BELICA, I., OSTATNIKOVA, D. Etiopathogenesis of autism - current state of knowledge. *Lekarsky Obzor*. 2018, **67**(7-8), p. 234-238. ISSN 0457-4214.

[17] KHEIFETS, L. I. Electric and magnetic field exposure and brain cancer: a review. *Bioelectromagnetics* [online]. 2001, **22**(5), p. 120-131 [accessed 202-21-12]. ISSN 0197-8462. Available from: https://doi.org/10.1002/1521-186x(2001)22:5+<::aid-bem1028>3.0.co;2-y

[18] DRAPER, G., VINCENT, T., KROLL, M., SWANSON, J. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. *BMJ* [online]. 2005, **330**(7503), p. 1290 [accessed 2022-12-04]. ISSN 1468-5833. Available from: https://doi.org/10.1136/bmj.330.7503.1290

[19] SAGE, C., CARPENTER, D. BioInitiative report: a rationale for a biologically-based public exposure standard for electromagnetic radiation. BioInitiative Working Group [online] [accessed 2022-11-03]. Available from: https://bioinitiative.org/

[20] World Health Organization (WHO). *Non-ionizing radiation. Part 2: Radiofrequency electromagnetic fields.* Lyon, France: IARCPress, 2013. ISBN 978-92-832-1325-3.

[21] MISEK, J., VOJTEK, J., VETERNIK, M., KOHAN, M., JAKUSOVA, V., SPANIKOVA, G., BELYAEV, I., JAKUS, J. New radiofrequency exposure system with real telecommunication signals. *Advances in Electrical and Electronic Engineering* [online]. 2018, **16**(1), p. 101-107 [accessed 2021-12-12]. ISSN 1804-3119. Available from: https://doi.org/10.15598/aeee.v16i1.2768

[22] Collection of Laws (CL) no. 534. Decrees of the Ministry of Health of the Slovak Republic [online] [accessed 2021-10-10]. Available from: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2007/534/20071201