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Reducing exposure to extremely low frequency electromagnetic fields from portable computers

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Abstract. The relevance of this article can be described by the rapid development in computer technology which has resulted in widespread use of laptop computers. Consequently the population is now more exposed to the electromagnetic fields, emanating from such devices. The aim of this article is to test various intervention measures which would help to reduce the exposure. The authors focus only on the measures easily applicable by the general public. The effectiveness of the interventions is measured by reduced electric and magnetic field. This study focuses on the electromagnetic fields in the range of 50 Hz to 400 kHz. The importance of minimizing exposure to the electromagnetic fields is also stressed by the high level European bodies. Reduction of environmental risk factors, where possible, is in fact the corner stone of European occupational health legislation. The measurements are conducted using a novel 14-point model, covering the entire body of the user. Measurements from 46 laptop computer workplaces provided data about 156 unique exposure instances. The measurement results show that the least exposure scenario comprises of a laptop computer working on battery, having external input devices and display, the casing of the computer being properly grounded and power wires and adapters are positioned away from the user's body.

Key words: electromagnetic fields, ELF, extremely low frequency, computer, laptop.

INTRODUCTION

In this study, laptop personal computers (PCs) are in the focus from the aspect of electromagnetic fields (EMFs). Laptop computers produce a wide range of electromagnetic fields. The main source for EMFs from laptop PC's are 1) low and intermediate frequencies from power processing both inside (mainboard) and outside (power adapter) and 2) radio frequencies from wireless data transmission. This study deals with electromagnetic fields at the lower end of the spectrum, within a range from 50 Hz to 400 kHz. This encompasses extremely low frequencies (ELF), ultra-low frequencies (ULF), very low frequencies (VLF), low frequencies (LF) and some of medium frequencies as classified by the International Telecommunications Union (ITU)(ITU, 2005). This bandwidth was selected as, with the exception of radiofrequency fields, most all other electromagnetic emissions from mobile PC lay within that range. This study does not deal with EMF radiation utilized by PCs for wireless data transmissions (WLAN, 3G/4G etc.).

In this study different exposure scenarios were investigated, intervention measures applied and their efficiency measured. The selection criteria for intervention measures was based on easy applicability by PC users.

The relevance of the subject is prescribed firstly by the exponentially increased use of mobile computing devices in the past years, which in turn have increased the levels of EMFs in the working and learning environments.

The relevance can also be described, as the public is increasingly interested in reducing their exposure to the EMFs in everyday life. The danger from EMFs below the currently effective safety limits still remains debatable. The general precautionary principle, used in occupational and public health, however requires to reduce environmental risk factors to as low as possible. Therefore this study provides solutions on how to reduce electromagnetic fields from laptop computer use, and at the same time retain the functionality of a PC as a working and learning device.

Laptop computers, like any other electrical consumer products, must comply with the standards of electromagnetic compatibility which in turn would automatically ensure the compliance with the legal safety limits for the EMFs. Therefore it is highly unlikely that a modern PC would produce levels above of such safety limits.

However, as new data from dosimetric and clinical studies suggests, there may be other biological mechanisms induced by the electromagnetic fields that are currently unaccounted for in the safety limits (Bioinitiative report, 2007; 2012).

Although these newly proposed health implications cannot be unnoticed, a great uncertainty still exists amongst the scientific community. New biological effects are yet not well known and therefore there is a problem with replicating many of such studies. Also, it remains unclear, if the mentioned biological effects also have health consequences. Reports ordered by the EU have concluded: there is limited or inadequate evidence for such new effects (EFHRAN, 2010). The main aim of the legally established safety limits is to protect the public and workforce from levels of electromagnetic fields that are known to cause adverse health effects (ICNIRP, 1998; EP, 1999; EP&EC, 2004 and 2013).

Therefore, the lawmakers have not yet hastened to lower the safety limits but suggested the public and working people to follow a precautionary approach, until the science has made it more clear, what levels can be considered as harmful (EEA, 2007). The precautionary principle is voluntary in nature and prescribes that electromagnetic fields should be reduced to as low as reasonably possible. Also the current safety guidelines refer that the obligation of the employer is not only to assure the workplace's compliance with the limits but also to ensure that EMFs are reduced to the minimum. Special risk groups should also be considered – pregnant women and people wearing passive or active medical implants (EP&EC, 2013).

Whereas this study mainly deals with laptop PCs in office workplaces, there are many other places where people in work or in public are exposed to the EMFs. An international study done in several European countries, monitored peoples overall exposure to the EMFs, and it was found that the highest exposures were encountered in transportation vehicles (e.g. people using mobile devices simultaneously in a closed metal casket), followed by exposure in outdoor urban environments (wireless transmission antennas), and then in offices, followed by urban homes (Wout et al., 2010).

Modern office environment consists of a many EMF propagating appliances: some produce EMFs as a by-product (e.g. ELF EMFs from a PC); others use EMFs intentionally (e.g. wireless data link). Many of such types of products are new and not fully covered by compliance standards, therefore may create exposures to the EMFs that are currently unaccounted for in the guidelines (Kühn et al., 2007).

In the area of ELF and VLF EMFs, less research has been done in regard to mobile computers than in the domain of radiofrequencies. Whereas radiofrequencies in the portable PCs are created intentionally – to establish wireless data transmission link, low frequency EMFs can be considered as a side product of the operation of the PC. Computer components such as power supply modules, mainboard, video card, display, etc. all process signals and consume power which also generate electric and magnetic fields (MF) in the ELF and VLF range. Whereas the emanating magnetic field mostly depends on the processed electrical current, the strength of the electric field radiation is determined by the design and application of the portable PC. If the circuits and wires are enclosed in a shield and the casing is grounded, then the electric field values may be very low. Therefore, given that the laptop computers are with proper metal casing, the main factor determining the strength of the electric fields should be whether the casing is grounded or not (Fig. 1).

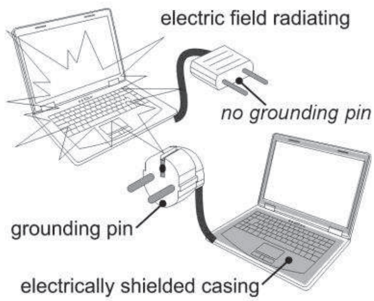

Figure 1. Plug type CEE 7/16 (left) is lack of the grounding pin, whereas plug type CEE 7/7 can ground the PC casing. Source: authors' drawing.

Frequencies of the electromagnetic fields produced by the laptop computers also vary from model to model. Besides typical sinusoidal waveforms, the EMFs have also an impulsive nature forming a complex waveform (Zopetti et al., 2011). Switching mode power supplies should be considered as main contributors to the impulse EMFs in the PC usage. A study by Zopetti et al. (2011) concluded that power supply units are the main source of high EMFs (Zopetti et al., 2011).

Bellieni et al. (2012) reported that next to the power supply unit, also the laptop PC's body itself (being in contact with a human body) gives off nearly the same levels of EMFs, and these can be higher than these found in the proximity of high tension power lines, transformers and domestic video screens (Bellieni et al., 2012).

The authors utilize a recently developed 14-point measurement protocol and a format of graphical representation, allowing easy understanding of the measurement results, by those not accustomed to the EMF issues. Unlike in some measurement protocols, where only one (maximum) reading is recorded from the worker's body position, this newly developed protocol provides better exposure assessment, picturing a detailed view of exposure levels in different body regions.

The aim of the paper is to identify high and low exposure scenarios, where various set ups of laptop computers, (including wiring) produce different exposure levels to the electromagnetic fields. This study is set to test the effectiveness of several intervention measures in actual office work environments. The results provide recommendations on how to use mobile computing devices by minimizing user's exposure to the EMFs.

A long term perspective of this study is to produce results that can be utilized in drawing up PC usage exposure assessment model. Such model is to use self-reported data (a questionnaire) of usage of electrical appliances and assess the exposure to various ranges of EMFs.

MATERIALS AND METHODS

In the ELF and VLF range of the electromagnetic spectrum, field strength measurements were conducted for both electric and magnetic fields. We investigated four factors that typically affect the exposure levels from laptop PC use in office environments: 1) battery or external power, 2) internal or external keyboard/mouse, 3) internal or external display 4) grounded or ungrounded casing and 5) distance to peripheral electrical wires and power adapter. Based on the combination of these determinants, tens of practically possible exposure scenarios could be deduced. Most common scenarios were selected for this study, as presented in Table 1.

Each of the exposure scenarios required a separate EMF measurement run. Scenario A, i.e. a PC setup without any intervention was studied first. A special wall socket plug was used to connect the laptop PC to external power without establishing a grounding connection for the PC casing. This would ensure comparable results for all PCs under testing, since some establish grounding via power supply unit. Secondly, intervention measures were tested independently from each other – only one determinant was changed (scenarios AG, AK, AW). Then, different combinations of interventions were tested. The authors selected the combinations that were most often used in practice.

Table 1. EMF exposure and intervention scenarios investigated in this study

Power source	Casing grounded	Ext.keyboard, mouse	Ext. monitor	Peripheral wiring, adapter
A	-	-	-	-
A	G	-	-	-
A	-	K	-	-
A	-	-	-	W
B	-	-	-	W
A	G	K	-	W
B	G	K	-	W
B	G	K	M	W

Abbreviations: A on external power source; B on battery power; K on external keyboard (otherwise on internal keyboard); M on external monitor (otherwise on internal monitor); G casing grounded (otherwise ungrounded); W wires routed away from body; (-) no intervention, which in case of 'peripheral wiring' means that power wires and/or adapters are right next to the body.

This study was set to investigate above mentioned exposure scenarios in actual work environments. Each workplace is unique by its laptop, peripheral devices and other inventory that makes up the overall electromagnetic field that the user is exposed to. While lab measurements are useful in determining the absolute exposure values and intervention effectiveness, the aim of the authors was to provide an overview of actual EMF levels present at places where office staff work daily. This allows encompassing also ambient EMFs, which are necessary to take into account when assessing the end result of an intervention. Perfect application of interventions can be achieved in the lab, but actual office environments are often confined by neighboring desks, preset wiring etc. that are likely to hinder the intervention outcome.

Fig. 2 describes exposure scenario A – laptop powered from a wall socket. This occurs most often when working with laptop PCs. Intervention BW would mean switching from external power (wall socket) to battery power. This would also remove the power adapter from the scene and create distance to any power wires.

Another intervention scenario, where external power is retained, would remove the power adapter and wires from beneath and next to the worker's feet (scenario AW). This means rerouting the adapter and wires to create maximum distance to them (usually 0.7 to 1.5 m).

Another intervention to increase user's distance to the EMF source (the PC), is using external keyboard and mouse (K). Also, connecting an external display unit to the laptop PC could result in additional distance (M). However, since external displays are also powered from the wall socket, secondary EMF source will be introduced into the scene.

Another way to reduce electric fields from the laptop PC, is to see that the casing is properly shielded and grounded (G). To make sure the shielding is adequate, in this study grounding was applied by two means: 1) connecting a grounding cable into laptop's USB-port's (Universal Serial Bus) grounding pin and 2) connecting power adapter's wall plug's third pin to ground (if applicable).

A new 14-point model of a human body (developed by Koppel) was used to conduct the measurements – altogether 14 points, distributed across the body, were measured for both electric and magnetic field (Fig. 2) (Koppel & Tasa, 2013). Unlike most workplace exposure measurements, where often only one reading is produced, encompassing 14 points, allows recording detailed readings. This in turn gives an overview of the exposure situation and to determine, which body regions are most exposed to the EMFs. Therefore intervention measures can be directed more efficiently.

The 14 p model is based on a sitting PC user, since the office personnel mostly spend their day behind the desk. On each of the 14 points, EMF meter was directed into different directions to obtain the strongest field reading. By going through the 14–point model, the whole body area was scanned The PC was set into operating mode, without any active software operations. The portable computers were on a chipboard office table. In case of power adapter and wires being positioned right at the worker's feet, point no 9 reading was taken right at the adapter/wires. Similarly point no 14 (the palms) reading was taken by scanning the PC casing for the highest field value. Therefore points no 9 and 14 represent the highest possible exposure point for the palms and the feet.

An average exposure was calculated based on the 14 points for each intervention. The results were grouped based on intervention scenarios. For each group average, maximum and minimum sets were determined, e.g. maximum of group A would indicate a PC that produced a highest average exposure across 14 points, in that group.

The equipment used for conducting the measurements, consisted of a low-medium frequency analyser ME3951A from Gigahertz Solutions, with a frequency span from 5 Hz to 400 kHz. Readings were taken in RMS (root mean square) values.

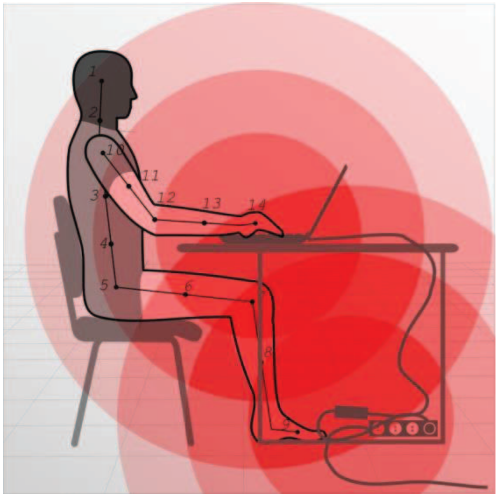

Figure 2. 14-point measurement model used in this study (Koppel, 2013), with exposure scenario A.

RESULTS

Altogether 156 unique exposure instances were investigated, each resulting in 14 readings for both electric and magnetic field (the entire sample consisted of 4,368 manually taken readings). Measurements were taken in office environments from 46 laptop PC setups.

Fig. 3 presents average, minimum and maximum values, classified per exposure scenario across the sample.

As this study conducted measurements for both electric and magnetic field, different propagation ways for these separate aspects of the electromagnetic field must also be taken into account when analyzing the results.

The highest exposure levels were characteristic to scenario A where no intervention was applied: 1) the laptop PC was connected to the wall socket, 2) using internal input devices (keyboard and mouse), 3) using internal monitor, 4) having an ungrounded casing and 5) with wires and power supply unit loosely positioned next to the user's body. For illustration purposes a PC was selected from the sample, that produced average field levels as compared to the rest of the sample, both in pre and post intervention measurements. Fig. 4 pictures a scenario A (no intervention) measurement for that PC.

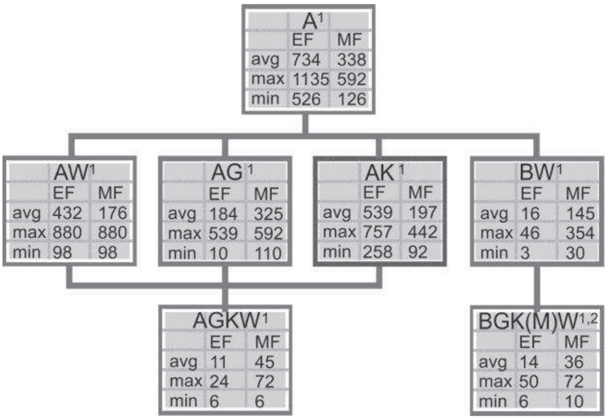

Figure 3. The effectiveness of various intervention scenarios, expressed as average (avg), maximum (max) and minimum (min) values for each intervention group's electric field (EF; V m^{-1}) and magnetic field (MF; nT); 1 see table 1 for scenario descriptions; 2 scenarios BGKW and BGKMW presented as one group due to their similarity in results.

Fig. 5 represents field strength values for the same PC when intervention scenario AGKW was implemented. The electric field strength as averaged over the body had decreased from 680 V m^{-1} (scenario A) to 9 V m^{-1} (scenario AGKV).

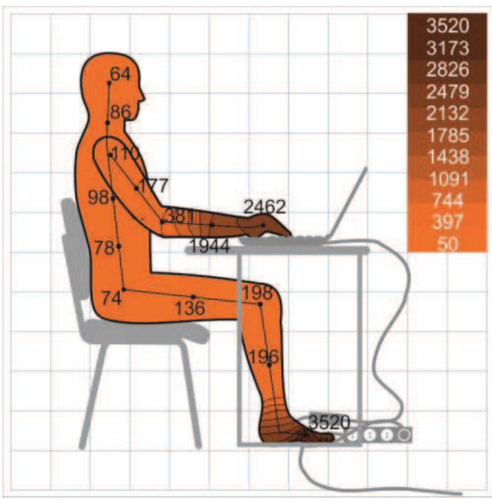

Figure 4. Scenario A for a selected PC, which represents typical field strength values for a computer without any intervention. Electric field values in V m^{-1}.

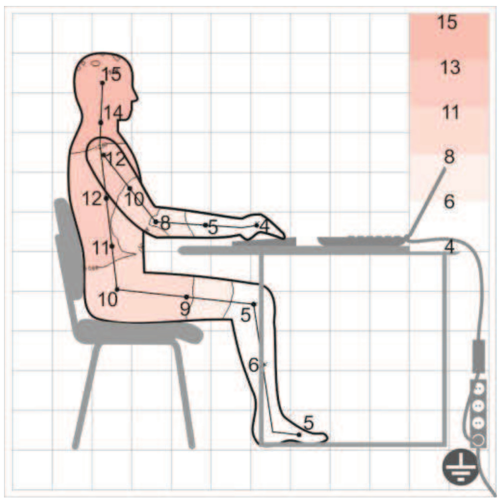

Figure 5. Scenario AGKV for the same selected PC, with typical field strength values for that intervention class. Electric field in V m^{-1}.

The first level intervention included testing each intervention measure separately (AW, AG and AK). Measurements indicated large variations in exposure levels across the sample. Any of the investigated four factors was seen to have a significant impact on overall exposure formation, but eventually did not produce satisfactory results alone itself.

Grounding the computer (AG) would somewhat reduce the electric field, but magnetic field remains unaffected due to the differences in propagation of these two fields.

Weakest electric fields we measured at the business class laptop PC's with an extra outer metal casing and with PC's casing properly connected to ground. Contrariwise, high E-filed levels were detected where the PC was lacking ground connection for casing. Such exposure scenarios are encountered in daily life where power plug lacks the third (casing grounding) connector (see Fig. 1) and if ground also cannot be established via external display unit or other peripheral device connected to ground.

Positioning of the PC's power adapter (AW) was also seen to largely increase the exposure levels. Often the adapters together with the wires were lying loosely on the floor, right next to or below the user's feet. Other peripheral wires, such as extension cords, while placed in close proximity of the user's body, were also measured to abruptly raise the exposure levels.

The usage of external keyboard and mouse (AK), was also seen to greatly affect the maximum exposure level. This can be explained by the user's increased distance to the PC if external input devices are used.

First significant reduction in electric field was noticed, when the laptop PC was on battery power and peripheral wires positioned away from the user's body (BW). Some PC models were seen to be unaffected irrespectively whether the PC was powered from the wall socket or from the battery. Whereas other models produced many folds greater exposure in electric field when connected to external power (AC). This is mainly to do with the PC mainboard's power module design, but also to do with the quality of switching power supply unit – whether the power adapter was equipped with adequate noise suppression filters or not.

Significant reduction of both electric and magnetic field could only be seen when multiple interventions were implemented simultaneously i.e. scenarios AGKW and BGK(M)W. Although BGK(M)W has a slightly lower magnetic field and AGKW with a bit lower electric field (see Fig. 3), the difference is marginal. Both scenarios produced satisfactory results and could be therefore recommended to the general public.

Involvement of external display unit, did not allow any significant change in EMF exposure, than using laptop PC's internal display. Although using an external display would allow placing the PC unit further away from the body, the external display unit also contains a live circuit itself which radiates EMFs.

The most exposed body parts were the user's hands and feet. Almost in all cases significant reduction in exposure could be achieved by utilizing external input devices (keyboard and mouse), since using the PC's internal input devices, places the user in close contact with the PC mainboard. Elevated exposure of the feet was encountered every time when the PC's power supply unit and/or peripheral power wires were arranged loosely, close to the user's body (most often the feet). The weakest exposure levels were detected in points 1 and 2 representing the head and neck.

CONCLUSIONS

This study has indicated that the user of a mobile PC can extensively control his/her exposure to the EMFs, without any significant extra effort or investment. Simple rearrangement of devices and adoption of new usage habits can reduce exposure to the EMFs even by factors of scale. Interventions, applied by this study, can broadly be divided to measures that reduce exposure by 1) increasing the distance to the EMF source, 2) shielding the EMF source and 3) using alternative power supply modes.

It was found that not all laptop PCs submit to interventions similarly. This is due to the PC design e.g. casing. Exposure levels are also dependent on the quality of accompanying power supply units. Some, cheap looking power adapters were seen to produce elevated levels of EMFs, both from the adapter itself, the power cable and consequently the PC unit. Few, good quality power adapters were equipped with a third wire for a casing ground – this effectively shielded the adapter, the power wire and the PC casing. Quality and design of a PC casing was also seen to be a determinant in how much electrical field was propagated out from the enclosure. The design of the PC also determines which parts of the PC radiate the most EMFs and whether the user is to be in close contact with these.

The overall conclusion - in order to effectively reduce the exposure levels, one should apply a combination of various intervention measures. Applying just one, may reduce some aspects of EMFs and/or reduce exposure only from a certain body area. The best reduction of EMFs was achieved when at least three intervention measures were applied: the whole body average exposure to the magnetic field was lowered by 89% (scenario BGKMW) and to the electric field by 99% (scenario AGKW).

As a general rule, the more distance were created between the user and the portable PC, the weaker the EMFs got. External input devices (mouse, keyboard) and output devices (monitor), together with rearrangement of power cords, can be viewed as means to create greater distance to the PC. The usage of such peripheral devices at the same time retains the full functionality of the PC or even improves it: 1) utilizing ergonomic mouse and keyboard alleviates ergonomic issues and allows better control of the cursor, 2) larger display reduces eye strain while images become larger and text more clear to read.

The results of this article are applicable for the general public, where users of mobile PC’s seek to reduce the exposure to the EMFs. This study provides several ways, on how to reduce the EMF levels and to avoid excess exposure. However, the effectiveness of intervention measures should always be tested. As found in some instances in this study, some USB-sockets’ grounding pin did not produce an effective grounding effect, whereas using other USB-port on the same computer achieved a good result. Also the power adapters may lack the third (grounding) pin or be of faulty design or working order.

DISCUSSION

The results of this study are in line with the work of Ekman et al. (2012), who also concluded a wide variation in the strengths of the electric field: the mean electric field of a PC was measured to lie between 10 and 678 V m^{-1}, with the maximum detected field of 1,050 V m^{-1}. For the PCs with high electric field, the underlying cause was the lack of grounding for the PCs casing (Ekman et al., 2012). The PCs with proper grounding were having electrical field strength tens of times lower. The main determinant was seen to be the power adapter unit, where some models were lacking a third pin for casing ground (Ekman et al., 2012).

This study found the strongest exposure to the MF to occur in point no 14 (the palms) and in point no 9 (the feet). Similar results were measured by Zopetti et al. (2011) and their follow up study by Bellieni et al. (2012), where magnetic field right at the power supply units was measured to be the strongest of the setup (from .28 to 4.7 µT RMS) (Bellieni et al., 2012; Zopetti et al., 2012). The authors of this study measured magnetic field at the same place (point 9 in scenario A) ranging from 30 to 3.6 µT. When analyzing the magnetic fields right at the laptop PC, Zopetti et al. (2011) recorded lower values (from .55 to 1.1 µT RMS) than this study (from .2 to 5.4, averaging at 2.7 µT for scenario A at point no 14) (Zopetti et al., 2012). This can be understood, as a difference in measurement setup - the height of the sensor from the object being measured. While this study scanned the computer at the height of ~1 cm, Bellieni et al. (2012) from a height of 5 cm. Also, this study used point no 14 to measure the EMFs from on top of the laptop PC i.e. palms, Zopetti et al. (2011) and Bellieni et al. (2012) measured from beneath the laptop PC, where they reported getting the highest readings. Therefore, considering the difference in measurement protocols, and acknowledging the concurrence of power supply unit measurements, the results of this study provide a good representation of the EMF levels produced by modern laptop computers.

Comparing our results from laptop PCs to desktop PCs, we would conclude that there is no difference in electric field. In this study points 3 and 4 from scenario AGKW averaged in 12 V m^{-1}, whereas Baltrenas et al. (2011) measured at the same relative body position 12 V m^{-1} in average for the desktop computers with LCD monitors and 15 V m^{-1} with CRT monitors (Christiane, 2011).

Measurements of magnetic field conducted in this study, were subject to fluctuations, due to variations in electrical power demand in neighboring facilities. Ambient magnetic field also varied from site to site. Since this study was conducted in actual work environments, such influences are inevitable even during the period when one laptop PC was investigated under various interventions. Per authors' evaluation, such variations in magnetic field remained mostly within the range of 40nT and therefore do not pose a role in comparing the exposure scenarios, except the multiple intervention scenarios AGKV and BGK(M)V. With the last two scenarios the magnetic field reaching the user's body from the PC was so low that remained below the ambient magnetic field level. Meanwhile, electric field, that is mostly shielded by walls, remained constant, unaffected by neighboring activities.

In order to completely control the workers' exposure to the EMFs, attention must also be paid to the elements of the work desk and any accompanying furniture. The focus should be on the arrangement of power cables and position of metal parts of the furniture. An ordinary power cable below the desk plate (at a distance of 3 mm from the worker's thigh) can produce an electric field of 40 kV m^{-1} on the surface of the skin (if the person is grounded) (Van Loock, 2007). Therefore, to minimize discomfort at the office desk, one should keep away from metal parts and electric wires (Van Loock, 2007). Van Loock recommends keeping a distance of at least 30 cm from the metal frame.

Complemented by authors' earlier work in the high frequency range of the EMFs (Koppel & Ahonen, 2013), the results of this study can be utilized in drawing up an exposure assessment model based on users' self-reported data (an online questionnaire). Although methodically questionnaire assessment is not as accurate as on-site measurements, a great number of people can be reached, who are interested in reducing their exposure to the EMFs. Such online-assessment model also serves as an educational tool since a vast portion of public are unaware of how the electromagnetic fields are propagated – a conclusion made by the authors after talking with the people from the workplaces. This finding is also supported by public studies which show that precaution as a way to manage EMFs has not been seen relevant for the majority of the public: they don't think about the measures (only 15% think) and they do not implement any measures (only 7% implement) (Christiane, 2011). Therefore, the authors emphasize the need to educate the public about electromagnetic fields as environmental risk factors.

With a diverse range of electrical office appliances and advancements in computer technologies, new methods of work have emerged e.g. working at distance via laptop. These developments have also brought along elevated levels of EMFs the worker today is exposed to. This paper has offered solutions on how to greatly reduce such exposure. The measures pointed out are both easy to implement and effective.

REFERENCES

Baltrenas, P., Buckus, R. & Vasarevicius, S. 2011. Modelling of the Computer Classroom Electromagnetic Field. *Electronics and electrical engineering* **109**(3), 75–80.

Bellieni, C.V., Pinto, I., Bogi, A., Zopetti, N., Andreuccetti, D. & Buonocore, G. 2012. Exposure to Electromagnetic Fields From Laptop Use of 'Laptop' Computers. *Archives of Environmental & Occupational Health* **67**(1), 31–36.

BioInitiative Working Group 2007. Bioinitiative report: A Rationale for a Biologically Based Public Exposure Standard for Electromagnetic Fields.

BioInitiative Working Group, Editors Cindy Sage and David O. Carpenter 2012. BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Radiation – http://www.bioinitiative.org

Christiane, P. 2011. Mobile Telecommunication: Current Knowledge on Risk Perception and Risk Communication. 2011. *8th International Symposium on Wireless Communication Systems* Aachen, 894–897.

EEA – European Environment Agency 2007. Radiation risk from everyday devices assessed – http://www.eea.europa.eu/highlights/radiation-risk-from-everyday-devices-assessed

EFHRAN – European Health Risk Assessment Network on Electromagnetic Fields Exposure, Report on the level of exposure (frequency, patterns and modulation) in the European Union Part 2: Extremely low frequency (ELF) fields

Ekman, P., Hagström, M., Hallio, J., Auranen, J., Hänninen, O. & Huttunen, P. 2012. Personal computers may cause symptoms related to low frequency electric fields in users. *5th European Conference of the International Federation for Medical and Biological Engineering*. Budapest, 14-18.09.2011. IFMBE Proceedings, **37**, 1148–1152.

EP-European Parliament 1999. Directive 1999/519/EC on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). *Official Journal of the European Communities* 30. 7. 1999.

EP&EC – The European Parliament and the Council 2004. Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). *Official Journal of the European Union* 30.04.04.

EP&EC – The European Parliament and the Council 2013. Directive 2013/35/EC of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). *Official Journal of the European Union* 26.06.13.

ICNIRP-International Commission of Non-Ionising Radiation Protection 1998. Guidelines for limit-ing exposure to time-varying electric, magnetic and electromagnetic fields – http://www.icnirp.de/documents/emfgdl.pdf

ITU Nomenclature of the frequency and wavelength bands used in telecommunications, Recommendation ITU-R V.431-7, Approved 2005-05, http://www.itu.int/rec/R-REC-V.431-7-200005-I/en.

Koppel, T. & Tasa, T. 2013. Electromagnetic fields in contemporary office workplaces. *Agronomy Research* **11**(2), 421–434.

Koppel, T., Ahonen, M. 2013. Radiofrequency electromagnetic fields from mobile devices used for learning and working. *Electronics and Electrical Engineering* **19**(6), 65–70.

Kühn, S., Lott, U., Kramer, A. & Kuster, N. 2007. Assessment Methods for Demonstrating Compliance With Safety Limits of Wireless Devices Used in Home and Office Environments. *IEEE Transactions on Electromagnetic Compatibility* **49**(3), 519–525.

Van Loock, W. 2007. Lipoatrophia Semicircularis: An Electromagnetic Myth. *7th International Symposium on Electromagnetic Compatibility and Electromagnetic Ecology* 319–322.

Wout, J., Frei P., Roösli, M., Thuróczy, G., Gajsek, P., Trcek, T., Bolte, J., Vermeeren, G., Mohler, E., Juhász, P., Finta, V. & Martens, L. 2010. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. *Environmental Research* **110**(7), 658–663.

Zopetti, N., Andreuccetti, D., Bellieni, C., Bogi, A. & Pinto, I. 2011. Evaluation and characterization of fetal exposures to low frequency magnetic fields generated by laptop computers. *Progress in Biophysics and Molecular Biology* **107**, 456–463.