Agronomy Research **11** (2), 421–434, 2013

Electromagnetic fields in contemporary office workplaces

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Abstract. Technological progress and widespread use of electronics has rapidly increased levels of electromagnetic fields (EMFs) in workplaces during the last decade. Today's workers are exposed to levels of EMFs unprecedented in history. This has caused concern amongst the general public. Although the EMF levels of such modern devices fall within current safety limits, the recent studies have still raised questions regarding the biological effects well below the safety limits. The European Union and the World Health Organization have called for scientists to conduct more studies in this field and to investigate all aspects of EMFs. The aim of this study was to quantify the actual levels of the EMFs in contemporary workplaces. As most of studies have only addressed a certain frequency range, this study covers all the spectrum of low (LF), intermediate (IF) and high frequency (HF) EMFs. Altogether 69 workplaces were investigated. Great variations were detected across the workplaces, depending mainly on the computer set-up configuration. Exposure levels proved to be affected by the nearby electrical equipment, arrangement of wires or faulty appliances. At the end of the paper the authors discuss different network connection technologies and provide the results which suggest solutions for lower HF EMF exposures that allow for following of the precautionary principle.

Key words: electromagnetic fields, occupational exposure, office, reduction, mitigation.

INTRODUCTION

Electromagnetic fields (EMFs) are probably among the most imperceptible environmental factors. A human being is not able to see, hear, taste or sense them directly in any way. When a worker is exposed to a loud noise, he or she will notice it momentarily and seek protection. In general, the same can be said of most other stressors with the exception of biological risk factors and some odourless chemicals that also can pose an inconspicuous danger. Therefore, the only way to guarantee safety is to have strict control mechanisms over such indiscernible environmental factors and to educate personnel. Being aware of dangers in the workplace and knowing the safety practices is the core of modern occupational hazard prevention.

Electromagnetic fields have become a debated topic, mainly attributed to the emergence of new wireless technologies. As new technical solutions provide us with a new level of comfort and mobility it is also accompanied by an increase in ambient EMFs. This is especially the case for radiofrequency (RF) EMFs − the core of wireless communications such as Wi-Fi (also called WLAN), Bluetooth, 3G and 4G protocols.

Bolte and Eikelboom (2012) found in their population dosimetric study that the total exposure to RF EMFs is mainly influenced by other people calling and therefore dependent on population density. Also, the time of the day and season of the year play a role in this equation. Such dense areas might be considered work and shop areas during daytime (Bolte & Eikelboom, 2012).

As the authors undertook this study it was known beforehand that encountering EMF above the safety limits is highly unlikely since all the office electrical equipment must comply with the standards of electromagnetic compatibility which automatically ensures the accordance with legal safety limits.

However, as new data from dosimetric and clinical studies indicates, there are other biological mechanisms induced by the electromagnetic fields that are currently unaccounted for in the safety limits (Bioinitiative report, 2007 and 2012). Despite the proposed health implications, a great uncertainty still exists amongst the scientific community. These new biological effects are still not well known therefore replication of such studies is not always successful. Some scientists think that discrepancies between the results are due to the various genetic backgrounds of the research subjects, as suggested by some animal studies – not all individuals are susceptive to the EMF related health consequences in the same way. The uncertainty also remains if such effects having a biological influence also have health consequences. The main aim of the legal safety limits is to protect the public and workforce from levels of EMFs that are known to cause adverse health effects (EP, 1999; EP, 2004; ICNIRP, 1998). Therefore, even if these debated non-thermal effects are confirmed by the following studies, attention must be paid if and to what extent these effects prove adverse to human health. Also, when the adverse health effects are identified, it is unlikely that society will back away from wireless technologies since it has been interconnected into the many aspects of the operativeness of the economy and overall everyday life. Then discarding the wireless devices would be challenged by the benefits of such technologies and the question deduced to an optimisation task: what is the best ratio of costs (possible adverse health implications) and returns (benefits from the mobility).

Therefore, the institutions have not yet hurried to lower the safety limits but suggested a precautionary approach to be followed until science has clearly demonstrated what levels are considered harmful (EEA, 2007). The precautionary principle is voluntary in nature and states that electromagnetic fields should be reduced to as low as reasonably possible. Even the current safety guidelines point out that the obligation of the employer is not only to assure the workplace's compliance with the restriction limits but also to see to it 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, 2004).

Whereas this study focuses on office workplaces, there are also other places where people are exposed to the EMFs. An international study done across several European countries, monitoring people's overall exposure to the EMFs, found that the highest exposures occurred in transportation vehicles (many people are using mobile devices simultaneously in a closed metal casket), next in an outdoor urban environment (wireless transmission antennas), and then in offices, followed by urban homes (Wout et al., 2010).

Today's office environment consists of a variety EMF generating devices: some generate EMFs as a byproduct; others utilise (RF) EMFs to conduct wireless data transmissions. Many such product types are new and are not fully covered by compliance standards and therefore may create exposures that are currently unaccounted for in the guidelines (Kühn et al., 2007). For example, although the emissions from a DECT phone are relatively low, the maximum field from 1m distance of some of these devices are considered higher than from the near vicinity of base stations (Kühn et al., 2007).

Considering the emergence of RF technologies high level European bodies and other institutions have also indicated concern in regard to the safety of the population. Given that the present safety guidelines were issued when the electromagnetic surroundings were quite different – public health EMF directive in 1999 and occupational health directive in 2004 – it has been argued whether the current electromagnetic climate can be considered safe.

A resolution issued in 2009, by the European Parliament pointed out that 1) the public safety limits are outdated, 2) these limits don't take into account the developments in info- and communication technology and 3) the limits don't consider such sensitive groups as pregnant women, newborns and children (EP, 2009).

In 2011, the Council of Europe, having reviewed the latest scientific evidence, published a report naming wireless technologies potentially harmful to humans. The need to follow the precautionary principle was stressed. The precautionary principle was defined 'as low as reasonably achievable' (CE, 2011).

Although at the present time, the question remains what type of individuals are most affected by the EMFs, it is becoming more obvious that children are much more in danger than adults. The Russian National Commission of Non-Ionizing Radiation Protection (RNCNIRP) has twice in the past years issued warnings with children in mind. They concluded that chronic exposure at levels presently considered safe by the safety limits, may lead to psychosomatic disorders in adult years, especially in the case of usage of mobile devices begun in childhood. The RNCNIRP identified these health hazards as follows: 1) in the nearest future (after starting the use) – memory problems, attention deficit, decline in learning and cognitive abilities, increased irritability, sleeping problems, increased sensitivity to stress and increased probability of epileptic seizures; 2) at the age of 25–30yrs – brain tumors, acoustical and vestibular nerve tumors; 3) at the age of 50–60 yrs – Alzheimer's disease, dementia, depression and a variety of degenerative problems connected to the nerve structures of the brain (RNCNIRP, 2008; RNCNIRP, 2011).

The European Union has also ordered scientific reviews on the literature to determine if RF EMFs can be considered. These reports tend to be more conservative than previously mentioned ones. The European Health Risk Assessment Network on Electromagnetic Fields Exposure (EHFRAN, 2010) produced a report concluding that the scientific knowledge from RF EMF exposure is still inconclusive, and the newly proposed adverse health effects occurring below the official safety limits are not well established (EHFRAN, 2010).

The European Commission ordered a report that examined the existing scientific evidence in regard to the health effects of EMFs and also concluded that the scientific body is lacking solid proof that would implicate current safety limits obsolete. But it was also concluded that many of the research are biased: the studies were conducted impartially or had methodological shortcomings (SCENIHR, 2009).

While investigating EMFs it is quite necessary to encompass all major EMF regions from the spectrum: low, intermediate and high frequencies. Different frequencies have different effects on the body. While low frequencies penetrate the body and by doing so induce electrical currents inside the body, high frequencies are mainly absorbed by the body and converted into heat.

The aim of this paper is to provide a quantified overview of electromagnetic fields in today's office environments and to identify their main sources. The results of this study help to point out technical solutions that help office workers to reduce their exposure to the EMFs.

MATERIALS AND METHODS

This study investigated EMFs at computer equipped office workplaces. The workstations consisted usually of a desktop or laptop PC, with nearby peripheral devices (i.e. printers, scanners). Other office equipment, such as desk lamps, telephones, extension cords and sometimes lock-boxes, server cabinets, i.e. are also encountered.

The authors used a new 14–point measurement protocol (Fig. 1), developed by Koppel. 14–point protocol encompasses the entire body of an office worker (head, torso and limbs), providing a comprehensive view of the electromagnetic fields the worker is exposed to. The model is based on a sitting person whereas also the office personnel typically spends a major part of their day behind the desk. On each of the 14 points, the meter was moved around horizontally covering the possible positions of the workers body. Also, the meter was directed into various directions to capture the strongest field which is then recorded. As the measurement is taken on a specific time, this does not represent the daily average. However, as mostly the exposure is induced by the office equipment in the immediate vicinity of the workstation, the authors made certain that all the relevant equipment were turned on while conducting the measurements.

By following the 14–point model, the entire body area is scanned so that no signal will remain unaccounted for. The data for 14 points allows for a comprehensive exposure assessment which might become useful also in later investigations when exposure characteristics and adversely affected body regions are studied. Out of 14 points three body regions can be averaged: head, torso and limbs. In some cases, safety limits are also different for the same body areas, because of the different vulnerability. Sometimes head, eyes and reproductive organs are brought forward as most vulnerable body parts, mainly because of their weaker ability to counteract stress effects. The authors consider it important to record such detailed data as this can also be linked to the questionnaire data in proceeding studies. Archived 14 points data may also become useful if a person develops a chronic illness in a certain part of the body which then can be analysed if a higher exposure was present in that area.

The instruments used were Gigahertz Solutions HF59B radiofrequency analyser, connected to a directional antenna HF800V2500LPE174 (Germany) and low-medium frequency analyser ME3951A from the same manufacturer. The high frequency meter encompassed frequencies from 800 to 2,500 MHz whereas the low frequency meter covered from 50 Hz to 400 kHz. These settings allowed registering mostly all EMF sources in the premises and nearby. Distinguishing high frequencies from lower frequencies is relevant, since they are primarily absorbed by the body, unlike low frequencies (Presman, 1970; Newton & Jolesz, 2008).

HF readings were recorded in RMS (root mean square) mode using the meter's normal or pulse mode, depending on the signal type. Utilising such specialised measurement modes is necessary to obtain adequate RF EMF readings since much of the contemporary wireless data is transmitted in short pulses, often unnoticed or underestimated by other measurement devices, not suitable for such investigations.

If higher than average EMFs were detected in workplaces, an attempt was made to identify the source. This was achieved by switching off electrical appliances, one by one till the field level was reduced. If the mitigation attempt was successful, a secondary measurement round was often conducted to register the effect of the intervention measures.

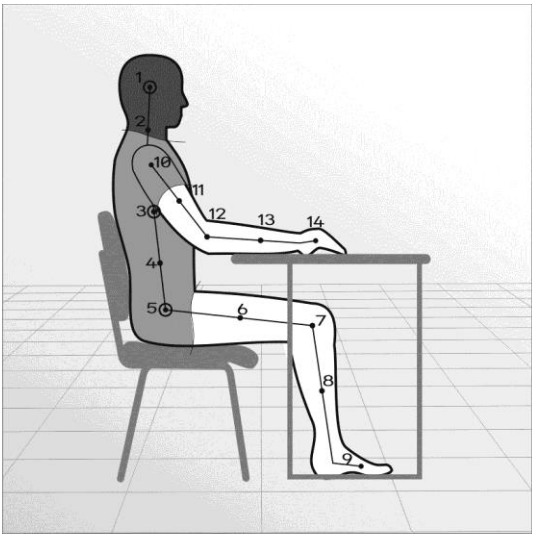

Figure 1. The 14–point measurement system by Koppel. Points are distributed into body regions as characterised by the vulnerability to the EMFs: head, torso, limbs.

RESULTS

Altogether 69 computer workstations with different set-up configurations were metered. Different workstation set-up configurations were seen to affect the overall worker's exposure. Such main configuration factors that had the greatest role were: 1) using a laptop or a desktop computer, 2) internal or external keyboard, 3) internal or external monitor, 4) AC or battery power, 5) wireless or wired network connection, 6) positioning the computer case close or further away from the body, whereas the latter options were producing the weaker exposure. In addition, a workplace's surroundings also played a role in forming the EMF exposure levels: most common exposure elevator was due to loosely arranged power wires and extension cords boxes close to the worker's body on the floor or beneath the table. Other office equipment was also seen to elevate the exposure levels when in close vicinity of the worker. If the workstation was next to the facilities main power cables or the switch box (i.e. below the floor or behind the wall), this also resulted in much higher exposure levels. From the point of view of HF EMFs, the greater exposure was attained when the workplace was situated on the 2nd floor or higher and other buildings or transmitting stations were in the vicinity. Besides loosely positioned power wires and extension cords, this study also identified server cabinets, printers and copiers placed right next to the worker's body as significant exposure magnifiers. Some of the office premises metered were still having old two-wire cable without an additional ground wire. Thereby where electrical equipment is drawing power from such old outlets, the device's metal casing had no or opposite effect in screening out the electric fields of the electro technical components inside the device. Electric field readings nearby some such devices exceeded 2,000 V m^{-1} which was the limit of the meter.

14–point measurements provided a detailed view of exposure conditions throughout the body. In the case of magnetic and electric fields, most frequently the top exposure was recorded in points 14, 13, 9, 8 and 7 which represent the limbs. This can be explained as most often hands or feet were in close proximity to electrical office equipment or power wires. The weakest exposure levels were detected in points 1 and 2 representing the head (and neck). Different exposure scenarios were unveiled when analysing high frequency measurement data – the head (and the neck) were the most exposed body parts, followed by the upper torso. This is due to the narrow wavelengths of the HF fields which require a line of sight for proper propagation. Therefore, the feet were the least exposed body parts – the closer to the floor, the weaker the HF field. Fig. 2 presents field strengths as averaged over the sample and classified by the body regions exposed.

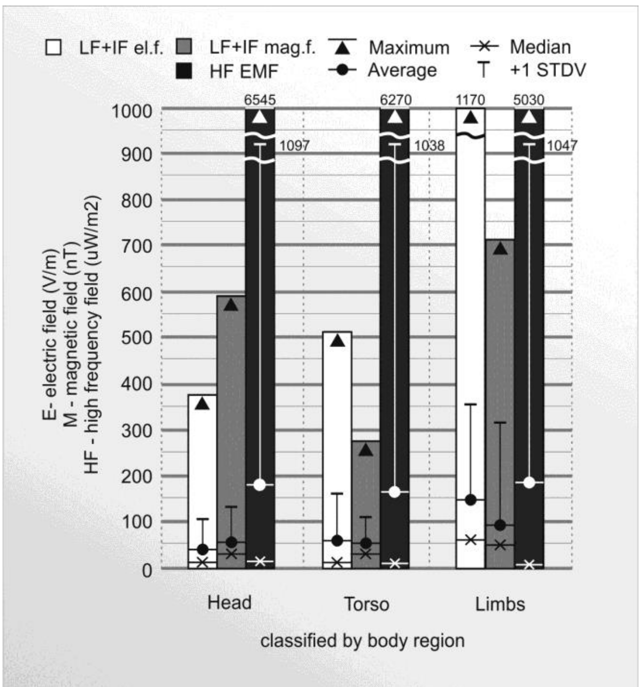

Figure 2. EMFs as averaged according to the exposed body region (n = 69).

For example, a faulty or aged power supply provided the worker with an average of 523 V m^{-1} (maximum 1,925 V m^{-1}) exposure condition; the readings dropped to 4 V m^{-}1 in average (maximum 7 V m^{-1}) over the worker's body, when the source was removed.

A large variation of HF EMF levels in workplaces was detected whether or not wireless data transmission was utilised by the office staff. For example, an ambient background of average 29 μW $(m^2)^{-1}$ (maximum 56 μW $(m^2)^{-1}$) was replaced with an average of 5,138 μW $(m^2)^{-1}$ (maximum 6,930 μW $(m^2)^{-1}$) when wireless data adapters (3G) were activated from neighbouring computers. However, exposure levels from wireless adapters monitored were to be greatly dependent on the transmission mode.

A lab test, as shown by Fig. 3 and 4 along with Table 1 express the relative differences in RF EMF exposure between three network connections: 1) cable LAN, 2) WLAN and 3) 3G/4G. The cabled connection provides a RF-free environment, whereas WLAN and 3G/4G produce radiofrequencies for wireless data transmission protocols. In the case of weak network coverage, the highest exposure levels can be attributed to 3G/4G systems, since these adapters need to establish a connection to a cell tower maybe kilometres away, whereas WLAN needs to contact its corresponding router usually within 20 m.

Table 1. Exposure to the radiofrequency electromagnetic fields from an office worker's sitting position under various Internet activities, power density (mW $(m^2)^{-1}$). A lab measurement test

	Using LAN (ambient field)		Using WLAN		Using 3G/4G	
	Mean	Max.	Mean.	Max.	Mean	Max.
Connected to network	0.07	0.09	0.14	2.09	5.41	10.07
Reading the news	‘	‘	0.13	1.59	4.60	64.03
Watching videos	‘	‘	0.17	1.59	25.30	61.40
Uploading files	‘	‘	7.88	10.46	51.36	69.46

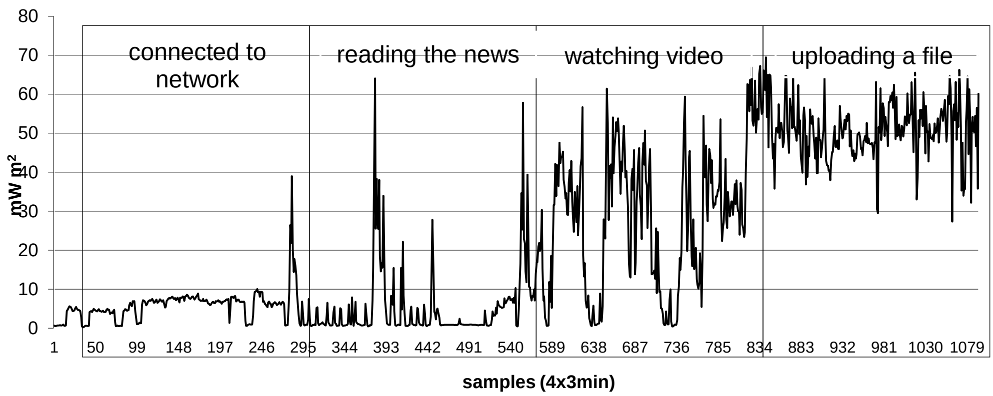

Figure 3. HF field levels' dynamics from a measurement point with neighbouring computers using 3G/4G-network connection, engaging different types of online activities. The highest levels are obtained while the computers were uploading files mW $(m^2)^{-1}$.

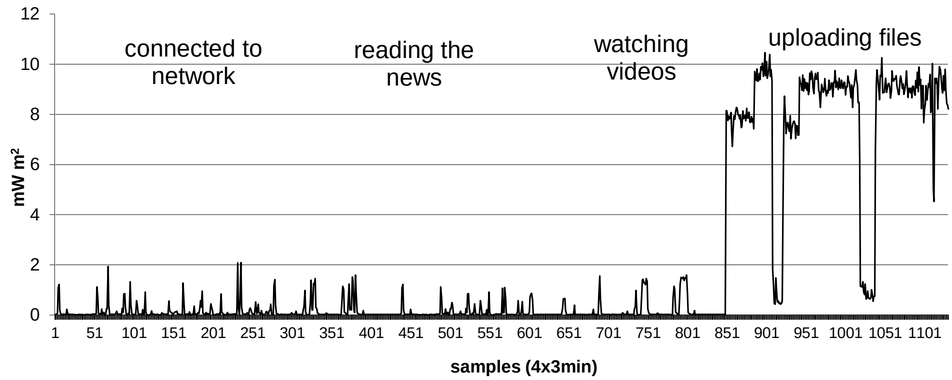

Figure 4. A measurement point with neighbouring computers using WLAN connections.

Limitations do apply to the interpretation of this measurement data as 3G/4G measurements were taken under poor network connection conditions in order to detect above average exposure levels. Tests done under perfect network connection conditions showed occasionally lower output radiation than WLAN-adapters, whereas in other instances, the same network conditions provided high exposure conditions. This is due to the adapter switching transmission protocols or regulating power output according to the reception quality. Under the same network reception, variations in 3G/4G wireless adapter power outputs were also detected from model to model. As demonstrated by Fig. 5, the highest exposure conditions in actual office environments are only intrinsic to the last 10^{th} decile of the entire sample measured and even then they do not come close to the worst case scenario test runs. It must also be noted that the measurement readings obtained at each workplace, at each body point do not necessarily mean that the person is exposed to such levels all day long, as one tends to move around the workstation and have other tasks too.

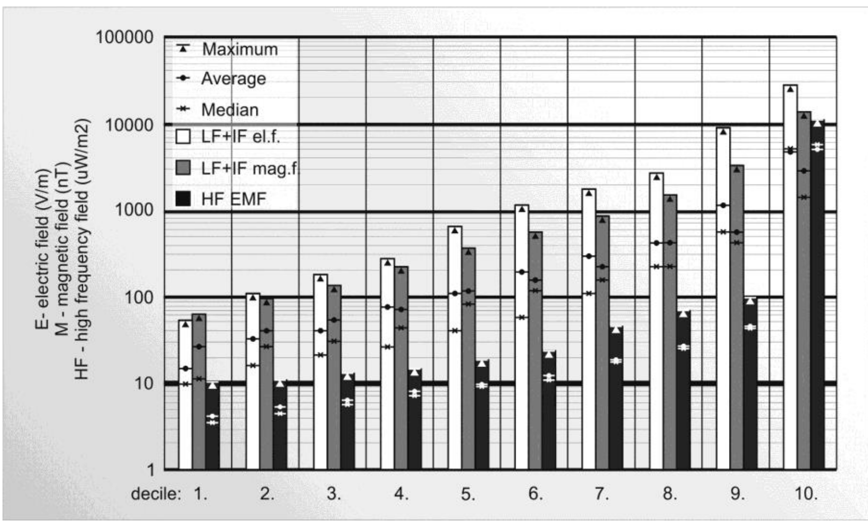

Figure 5. Distribution of the workplaces (n = 69) into deciles based on the exposure type.

When comparing workplaces based on the computer type, based on the sample average laptop computer workplaces had a significantly higher exposure to the high frequency electromagnetic fields than desktop computer workplaces (Fig. 6). The highest readings were obtained in the workplaces where other nearby computers were using 3G/4G wireless network adapters and were engaged in active data transmission. High readings were also recorded when the computers in the close vicinity used WLAN adapters to perform the same active data transmission tasks. Still, looking at the overall picture, the laptop computers' typical HF emissions (11.6 μW $(m^2)^{-1}$) proved to be similar to the desktop computers' (8.6 μW $(m^2)^{-1}$) as indicated by the medians in Fig. 6. No large variations in between the laptops and desktops were also noted in electric and magnetic field readings, although desktop computers tended to have a slightly higher electric field (median 53 V m^{-1}) than laptop computers (median 22 V m^{-1}), but in case of the magnetic field the situation was reversed with desktop's having a lower field (median 35nT) than laptops (median 53nT), as averaged over the entire body.

A typical higher than average exposure was usually due to the power wires positioned close to the worker's body or the electrical appliances in the immediate vicinity of the workplace. In one such instance when a worker showed initiative and repositioned the (desktop) computer case and several power wires to create distance to her body, the magnetic field levels showed a dramatic decrease: average over the entire body from 352 to 26nT and maximum over the entire body from 1,829 to 34nT.

A similar case was encountered with a laptop computer where loosely positioned power cables, both below and on top of the worktable, were creating higher than average exposure levels. Both power cables were rearranged, unnecessary cables disconnected and relevant ones attached to the wall. The electric field levels decreased from 381 to 101 V m^{-1} (averaged over the entire body) and from 2,000 to 569 V m^{-1} (maximum over the body).

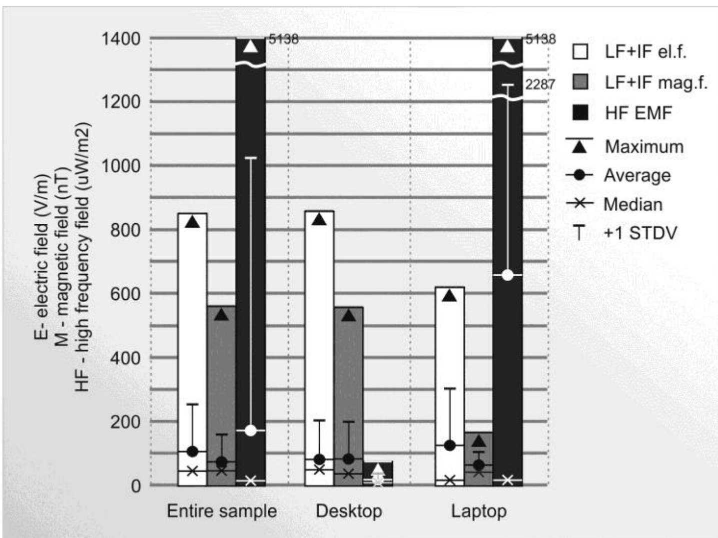

Figure 6. Exposure to the EMFs, as averaged according to the computer type (n = 69).

Faulty, aged or otherwise poor quality power adapters were also identified to produce higher than average exposure levels. Fig. 7 illustrates a case with a desktop lamp power adapter contributing significantly to the overall magnetic field levels. After disconnecting the power adapter from the wall socket, the magnetic field levels (as averaged over the entire body) dropped from 567 to 105nT with a maximum field level decreasing from 2,000 to 127nT. The most affected body region were the hands, as the worker could possibly place his hands right next to the lamp's power adapter. But also the entire rest of the body was somewhat affected by the fields generated by the adapter. But it must be noted that it is unlikely for the worker to be in such close vicinity to the adapter, therefore the measured field levels only represent the worse case scenario, as with the rest of the measurements presented in this study.

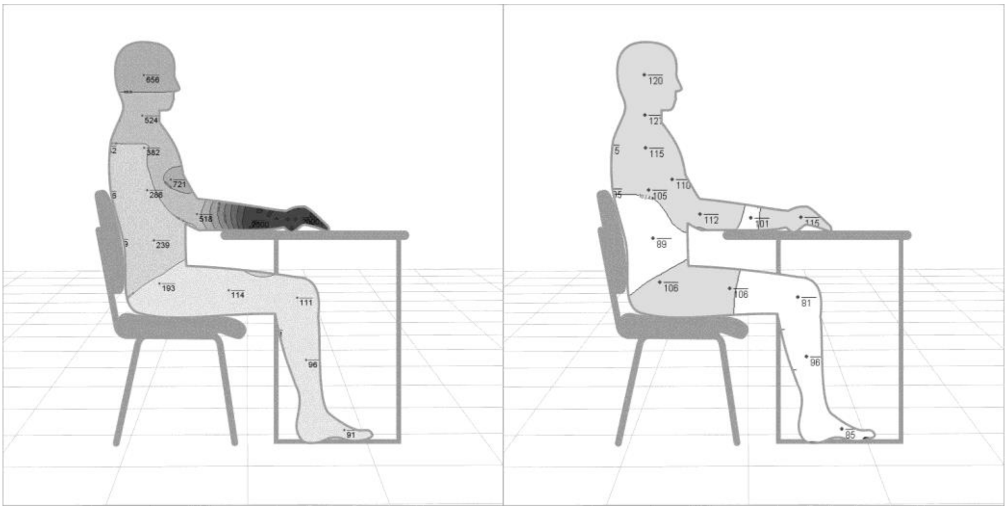

Figure 7. Exposure to the low frequency (LF) and intermediate frequency (IF) magnetic field before (left) and after (right) the intervention: A poor quality power adapter was removed from the work environment which dropped the average exposure level more than five fold.

Along with the encountered computer setups, several controlled intervention tests were done with laptop computers, seeking solutions to minimise the exposure to LF electric and magnetic fields. Using the laptop on battery power or/and utilising an external keyboard were seen to significantly reduce the worker's exposure to the EMFs (Figs 8, 9). Connecting the external keyboard proved to significantly lower the worker's exposure to both low frequency electric and magnetic fields. As the laptop's internal keyboard requires the individual to place their hands on the computer surface, other EMFs generated by the computer (motherboard, battery charger, etc.) will also have a better reach into the human body. Unlike the desktop computer where all the electronics and power circuits are closed in the metal casket and placed away from the body, the laptop computer requires the user to be in close vicinity with the case, with all the electronics placed under the hands or on the lap. In addition, when the laptop is powered from the wall socket, the electric field increases due to the battery charging and other processes.

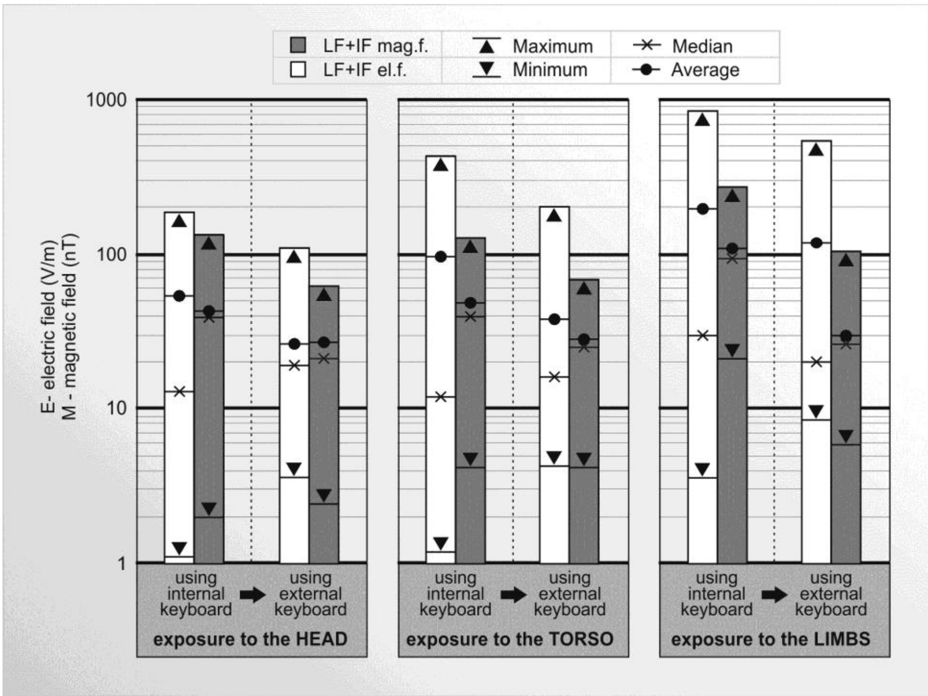

Figure 8. Using laptop with external keyboard instead of internal keyboard allowed reduction of exposure to both electric and magnetic fields in all body regions.

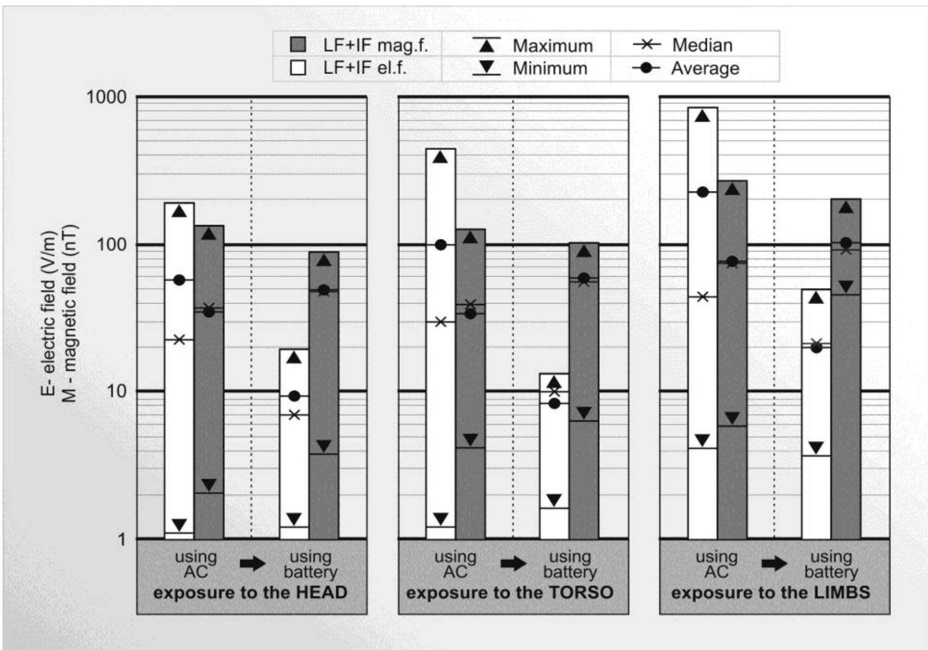

Figure 9. Using laptop computer on battery power allowed reducing the average and median electric field levels but increased the magnetic field levels in all body regions.

CONCLUSIONS AND DISCUSSION

This study presented measurements results of electromagnetic fields from office workplaces. EMFs proved to exhibit significant variations both in space and time domains. It must be noted, that the encountered EMF levels were well below the occupational safety limits and do not come close to those encountered in some of the industrial processes. As this was known beforehand, the aim of this article was to determine the average ambient levels at office workplaces, to identify the sources creating above average EMFs and based on this to reveal technical solutions and computer setups that would minimise the exposure. Minimising one's exposure is relevant if the precautionary principle is to be followed. The principle of the best practice in occupational health and safety is not only to comply with the legal requirements but to reduce risk factors to as low as reasonably possible. This article has presented the measurement results that will help not only to determine if particular office workplaces are above or below the average levels, but also provides the information on how to reduce the exposure.

Next to low and intermediate frequency electromagnetic fields, this study tested three network connections (cabled LAN, WLAN and 3G/4G) to measure their contribution to the office ambient electromagnetic fields. By far, the 3G/4G solution provided the highest exposure level which is explainable as these adapters needed to contact cell towers kilometres away, also the connection was poor, which resulted in maximum power output. All connection types underwent 4–stage testing to determine exposure characteristics from the most widely used network protocols: 1) connected without the activity, 2) surfing and reading the news, 3) watching an online video, 4) uploading a file. The latter of which provided the highest exposure level. However, a person is hardly likely to upload files all day long, indicating such a high level will only occur occasionally. Wout et al. (2012) studied WLAN duty cycles and also determined that the largest duty cycles were common to file transfer (duty cycle of 47.6%) while surfing and audio streaming used the wireless medium less intensively (duty cycles below 3.2%). Therefore, when assessing exposure from wireless transmitters, it is essential to account for the nature of the computer work, which in turn prescribes the overall exposure level.

A study by Khalid et al. (2011) metered WLAN in schools and came up with duty cycles far smaller: 0.08% for laptops and 4.8% for access points. The study simulated that based on these actual on-site results, assuming a room with 30 laptop PCs and access point emitting at maximum power, from a distance of 0.5 m, operating with maximal duty factors, the personal exposure could reach 16.6 mW $(m^2)^{-1}$ (Khalid et al., 2011).

Bolte and Eikelboom (2012) equipped subjects with HF exposimeters and averaged the 24 h results to 0.180 mW $(m^2)^{-1}$ which is much more than the average results of this study. As Bolte and Eikelboom describe, the main contribution to exposure was from nearby people using mobile phones (37.5%), cordless DECT phones (31.7%) and their docking stations (12.7%) (Bolte & Eikelboom, 2012). The authors' study omitted such sources and recorded the constant background levels only.

Similar levels to Bolte and Eikelboom (2012) were also found in Frei et al. (2009) study, where the mean weekly exposure of the individuals was 0.13 mW $(m^2)^{-1}$. Unlike Bolte and Eikelboom, the major contributors to the RF exposure were found to have come from mobile phone base stations (32.0%), followed by mobile phone handsets (29.1%) and DECT phones (22.7%) (Frei et al., 2009).

In regard to LF EMFs, as per authors' measurements, elevated readings were often taken beneath the working desk. The desk, a centerpiece of a typical office workspace is usually re-enforced by a metal framework. Often power cables run underneath the desk plate or on the floor.

A regular power cable below the desk plate (at a distance of 3 mm from the worker's thigh) could produce an electric field of 40 kV m^{-1} on the surface of the skin (if the person is grounded) (Van Loock, 2006). The effect is limited to the outer layer of the skin but may disturb the worker. Therefore, to avoid discomfort behind the office desk, one should keep away metal parts and live electric wires (Van Loock, 2006). Loock recommends keeping a distance of at least 30 cm from the metal frame.

The workers could significantly reduce their exposure levels by rearranging wires on the floor and behind the desk, to create maximum distance to the body.

Authors questioning the occupants of the office workplaces realised that very few people are aware of the mechanisms of EMFs propagation. This notion is also backed by population studies which indicate that precaution as a safeguard in regard to EMFs has not been considered relevant for the vast majority of the public: they neither think about the measures (only 15% think) nor do they implement any (only 7% implement) (Christiane, 2011). Therefore, the authors see the need for the governmental and third sector organisations to educate the public about these environmental factors that indeed surround every office worker nowadays.

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