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Research Article

Measurement and Risk Assessment of Extremely Low Frequency Magnetic Fields around Transformers in a Working Place

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Abstract

Transformers present the most common source of exposure to excessive extremely low frequency (ELF) magnetic fields (MFs). A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Nowadays, the effects of extremely low frequency electromagnetic (EM) fields on health were discussed frequently, but there is few measurement studies performed around various transformers for workers. In this study, the leakage fields around transformers and enclosures site were measured in Ankara and evaluated in terms of standards. It was observed that people were exposed to ELF-MFs above International Agency for Research on Cancer (IARC) cancer limits. Workers reported health complaints such as being tired in most working hours, immunological complaints, dizziness, some cancer cases are also observed there. In these systems areas safe distances or areas for people should be realized and precautions should therefore be taken to minimize the fields exposed.

Keywords: Transformers, Extremely Low Frequency Magnetic Fields, General Public, Workers, Exposure Limits

Bir Çalışma Ortamında Bulunan Trafo Etrafındaki Oldukça Düşük Frekanslı Manyetik Alanların Ölçümü ve Risk Değerlendirilmesi

Öz

Transformatörler, aşırı düşük frekanslı (ELF) manyetik alanlara (MF'ler) maruz kalınan en yaygın kaynak türü olarak karşılaşılmaktadır. Transformatör, elektromanyetik indüksiyon yoluyla iki veya daha fazla devre arasında elektrik enerjisini aktaran elektrikli bir cihazdır. Günümüzde oldukça düşük frekanslı elektromanyetik (EM) alanların sağlık üzerindeki etkileri sıkça tartışılmıştır, ancak işçiler / çalışanlar için çeşitli transformatörler etrafında yapılan birkaç ölçüm çalışması vardır. Bu çalışmada, Ankara'da bulunan bir işyerinde trafo ve pano sahası etrafındaki EM alanları ölçülmüş ve standartlar açısından değerlendirilmiştir. Bu işyerinde çalışan insanların Uluslararası Kanser Araştırmaları Ajansı (IARC) kanser limitleri üzerindeki ELF-MF'lere maruz kaldığı görülmüştür. Birçok çalışan mesai saatleri içinde yorulma, immünolojik şikâyetler, baş dönmesi gibi sağlık şikâyetleri olduğunu bildirmiştir, ayrıca çalışanlar arasında bazı kanser vakaları da mevcuttur. Benzeri sistemlerin bulunduğu alanlarda çalışanlar için güvenli mesafeler veya alanlar oluşturulmalı, maruz kalınan alanları en aza indirmek için önlemler alınmalıdır.

Anahtar Kelimeler: Transformatör, oldukça düşük frekans, manyetik alan, halk sağlığı, çalışanlar, maruziyet limitleri

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1. Introduction

Gazi Non-Ionizing Radiation Protection (GNRP) Center was founded in 2005 in Gazi Biophysics Department. Center performed studies on the biological effects of electromagnetic radiation and performed other studies via mapping residential and workplace electromagnetic field levels between 0 – 10 GHz. GNRP deals with training programs on non-ionizing radiation, protection from non-ionizing radiation and electromagnetic fields consultancy, too. Centre has reported measurements of high electromagnetic field strengths. After these measurements, counseling and training programs for public / workers were recommended by GNRP. Sirav et al. (2014) performed another GNRP measurement study related with transformers. In this study, the leakage magnetic fields around a transformer were measured in an apartment building in Küçükçekmece-Istanbul, and the measurement results were evaluated with respect to the international exposure standards. The transformer station was on the bottom floor of a three-floor building. It was found that people living and working in the building were exposed to ELF magnetic fields higher than the threshold magnetic field value of the International Agency for Research on Cancer (IARC). Many people living in this building reported health complaints such as immunological problems of their children. There were child-workers working in the textile factories located in the building. Dielectric heaters and sealers present the most common source of occupational exposure to excessive radio frequency (RF) fields. These systems are used industrially to heat or melt dielectric materials. GNRP performed 27.12 MHz radio-frequency radiation measurement study in Gazi Rocket Factory in 2010 (Sirav et al., 2010). It has been observed that operators exposed to same RF fields with occupational exposure limits. Many workers have health complaints such as elevated body temperatures in the factory. Safe distances or areas for workers should be recommended in these systems. After these measurements counseling and training programs for public/workers were recommended by GNRP.

In recent years there is several epidemiological measurement studies related with transformers and related exposed electromagnetic fields. Röösli et al. (2011) evaluated extremely low frequency magnetic fields (ELF-MF) based on the location of the apartment relative to the transformer room. They completed measurements in 39 apartments in 18 buildings. Measured arithmetic mean ELF-MF was 5.9 mG in eight apartments that were adjacent to a transformer room, either directly above the transformer or above touching the transformer room wall-to-wall. In apartments that only partly touched the transformer room at corners or edges, average ELF-MF level was 1.4 mG. Li et al. (2007) monitored 121 children attending 14 schools with nearby high voltage transmission lines - HVTL (exposed group) and 123 children of 18 schools at least 100 m away from HVTL (unexposed group) by using personal ELF-MF exposure meter. They noted that 17.8% of the exposed children had a personal mean exposure greater than 4 mG during school hours significantly ($p=0.011$) higher than that (6.5%) estimated for the unexposed children. Kandel et al. (2013) performed ELF-MF measurements around and above three stand-alone 22/0.4-kV transformer stations. They reported that these results support the exposure assessment method used in the Trans Expo epidemiological study, i.e. classifying only

those apartments located right above a transformer station as highly exposed to MFs.

Maluckov et al. (2014) presented the results of measurements of ELF magnetic induction dating from the household electric devices and transformer stations suited near the residential areas. They strongly recommended necessity to relocate the transformer stations to the safe distance from residential areas.

International Agency for Research on Cancer (IARC) classified ELF magnetic fields as a possible human carcinogen (2B classification) in June 2001 (IARC, 2002) based on "inadequate evidence" for carcinogenicity of ELF-MF in rodent bioassays and "limited" epidemiologic evidence for a link between ELF-MF exposure and childhood leukemia. Epidemiologic evidence was evaluated independently by two pooled data analyses. Greenland et al. (2000) pooled data from 12 studies with a total of 2656 cases and 7084 controls. They used a cut off value of 0.3 μT for exposed children and found an odds ratio (OR) of 1.7 (95%- CI: 1.2–2.3) based on 99 exposed cases. Ahlbom et al. (2000) included nine studies with a total of 3203 cases and 10,338 controls. With a cut off 0.4 μT they observed an OR of 2.0 (95%-CI: 1.3–3.1) based on 44 exposed cases. These results were recently confirmed in a pooled analysis of 7 studies on childhood leukemia and residential magnetic fields published after 2000 including a total of 76 cases being exposed to magnetic fields of 0.3 μT or higher (Kheifets et al., 2010).

The biological effects of extremely low frequency (ELF) magnetic and electric fields have been evaluated at Biophysics Department of Gazi University since 1990. The effects of 50 Hz magnetic field exposures on collagen synthesis, epilepsy, electrolytes, lipid peroxidation (MDA), Nitric Oxide (NOx), respiratory burst system (MPO), antioxidant defense system (GSH), and immune system in spleen, skin, lung, kidney, brain and plasma tissues have been evaluated and these studies indicate that ELF magnetic fields have significant effects on these tissues (Canseven et al., 2008; Canseven et al., 2006; Seyhan et al., 2006). Effects of static and 50 Hz ELF electric (E) fields on free radical synthesis, antioxidant enzyme level, collagen synthesis have also been analyzed in such as brain, liver, lung, kidney, spleen, testis and plasma of guinea pigs (Guler et al., 2009). The results show that the effects of E fields on the tissues depend on the type and magnitude of the field and exposure period. RF studies are also being carried out at Gazi Biophysics. Evaluation of radiofrequency radiation (RFR) in a chosen pilot area - Yenimahalle Şentepe – Dededoruk Hill in Ankara- was realized first time in Turkey in 2001 by Gazi Biophysics. Radio Frequency (RF) radiation at that region, which has 64 different TV and radio towers and one base station, was found to be 4 times higher than the permitted standards of Turkey. The base station and some TV and radio transmitters were not included in the calculations, since their technical information were not available (Sirav & Seyhan, 2009b). There are also many biological effects of RF radiation studies that are performed in Gazi Biophysics Department. RF at non-thermal levels could have significant effects on the permeability of blood-brain barrier (Sirav & Seyhan, 2009a). The effect of mobile phone radiation at different frequencies and strengths and the effects of RFR on tissue hydroxyproline level were examined (Ozgur, 2006). Mobile phone exposure based RF dosimetry was determined by using Finite-Difference Time-Domain (FDTD) method (Tuysuz, 2007). The influence of 1800 MHz GSM-like signals on hepatic oxidative DNA

and lipid damage in non-pregnant, pregnant, and newly born rabbits have been studied by Gazi Biophysics (Tomruk et al., 2010). The study showed that the whole-body 1800 MHz GSM-like RF radiation exposure may lead to oxidative destruction as being indicators of subsequent reactions that occur to form oxygen toxicity in tissues.

The objective of the present study was to evaluate the ELF magnetic field exposures in an office building due to transformer at the bottom floor in a central part of Ankara.

2. Explanation of Case Study

The ELF magnetic fields around the transformers (33/0.4 kV, 1250 kVA) and enclosures was conducted with calibrated Narda EFA-300 in the Ankara, Turkey. The transformers and enclosures were located in the ground floor of the office building (Figure 1). Four measurements were conducted periodically at the corridors and offices inside of the building between years 2010 – 2012 during working hours by the GNRP Center.

Narda EFA-300 ELF meter had a built-in isotropic magnetic field probe. External B-field probe was used for increasing sensitivity of the measurement. EFA-300 and probe was received a calibration certificate according to standards. The frequency of the measurement was auto-selective. During measurement the meter was positioned one meter above the ground. The points in the offices were selected desks and working area except corridors. The measurements at the corridor helped us to figure out decreasing/increasing ELF value for years. The measurement places were changed by a few decimeters if electrical appliances were close to the regular measurement locations in order to avoid influence on the measurement results from local sources.

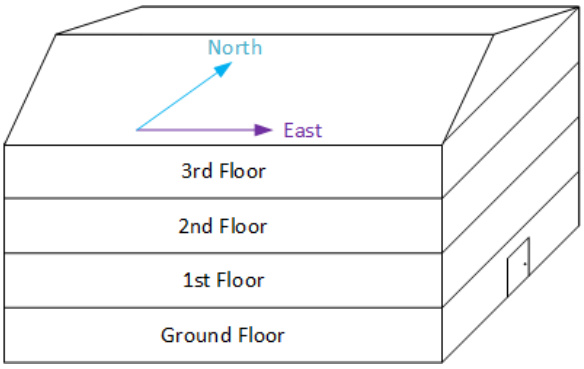


Figure 1 The building plan and location of the transformer in the building

International Commission on Non-Ionizing Radiation Protection (ICNIRP) provides a two-tier set of electromagnetic field exposure limits (ICNIRP, 1998 & 2009). The higher tier is referred to as occupational while the more restrictive tier is referred to as for General Population. The ICNIRP standard is used in most European countries and is gaining acceptance in many other countries throughout the world. Table 1 represents the occupational and general public ICNIRP 50-Hz magnetic field limits and International Agency for Research on Cancer - IARC's threshold for ELF magnetic fields.

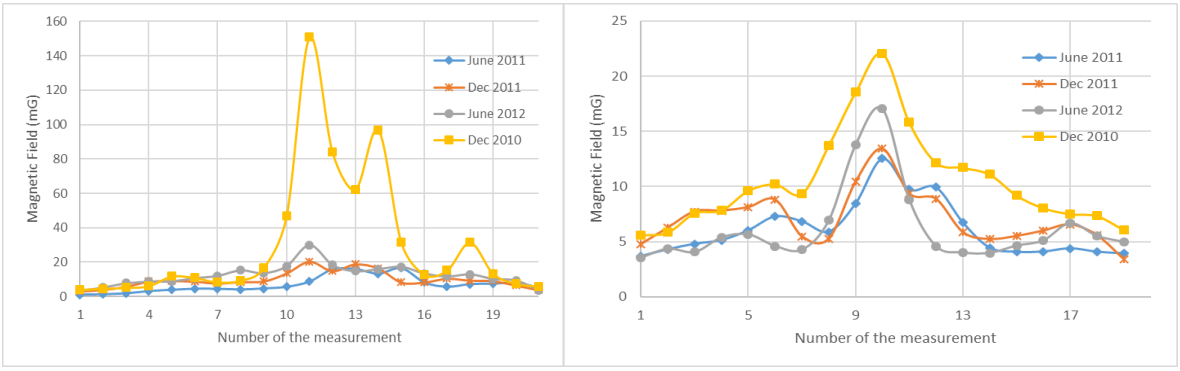
Table 1 Occupational and General Public ICNIRP 50 Hz magnetic field limits and IARC's threshold for ELF magnetic fields (IARC, 2002; ICNIRP, 2009; Kheifets & Shimkhada, 2005)

Category	ICNIRP (B Field)	IARC * (B Field)
Occupational Exposure	5 G	3 mG
General Public Exposure	1 G	

3. Results and Discussion

After the first ELF measurement performed in December 2010, the main part of the transformer was moved depending on recommendation of the GNRP measurement report. Since first measurement, some enclosures were added to the electrical distribution system cause of increasing of the electricity energy demand. It is obvious that the ELF values were increased day by day.

Figure 2a and 2b illustrates ELF values at ground and first floor corridor, respectively. The ELF values at the ground floor corridor were decreased dramatically after moving transformers. The maximum ELF value was conducted in December 2010 both of the figures. The results of the measurements around the transformers and enclosures are summarized in Figure 3 as a cumulative distribution of ELF values. First measurement curve is the top the distribution as expected.



(a) (b)

Figure 2 Magnetic field values a) ground floor corridor b) first floor corridor

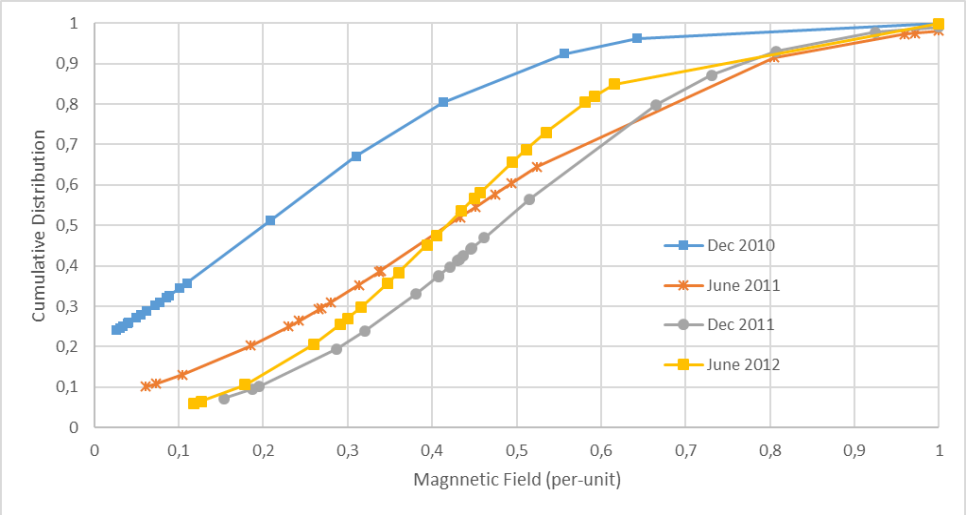
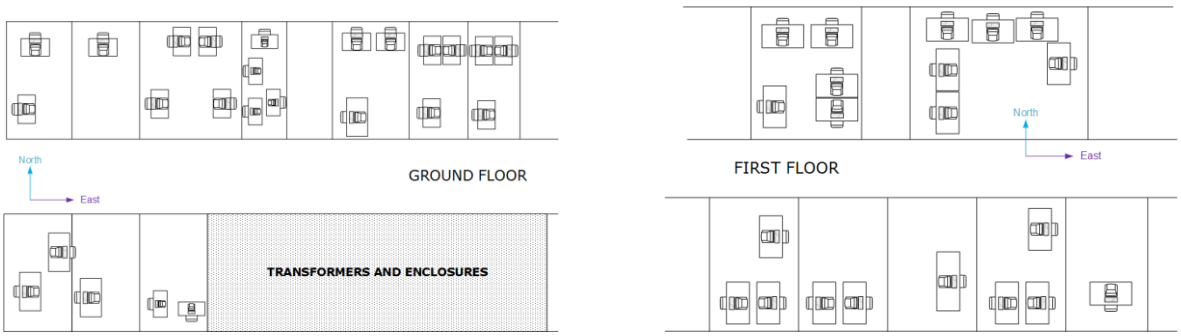


Figure 3 Cumulative distributions of ELF values

The ground and first floors' view from above were given in Figure 4a and 4b. Second and third floor plans were same as first floor except for desk locations and number of desks. It was observed that there were offices around transformers and enclosures room. The measurements were performed on workers' desk and their other working areas.



(a) (b)

Figure 4 The plan of the ground (a) and first floor (b)

The statistical analysis of measurements is summarized in Table 2. The number of the spot measurement, arithmetic mean, maximum and minimum ELF exposure level of the workers are given for per area separately. It shows that the highest exposure was conducted in December, 2010 cause of the transformers were still located. After the first measurement, the levels decreased in June 2011. It was increased with time. Last measurements were performed in June 2012. The last measurement proved that the ELF exposure levels of workers were still higher than ICNIRP standards.

In the ground and first floor corridor measurements were conducted with one-meter range. These measurements (21 on the ground floor, 19 on the first floor) were performed to figure out ELF values of the transformers and enclosures differences between years. On the ground floor the average value in December 2010 was more than twice as much as that measured in June

2012 (30.26 mG vs 12.45 mG). The maximum ELF value (150.81 mG) was conducted in the closest point of the transformers. The ELF exposure on the first floor corridor in December 2010 was also significantly higher than in June 2012 (10.49 mG vs 6.21 mG).

Table 2 Comparisons of ELF-MF exposure (in mG) between 2010 and 2012

Measurement Area		Dec 2010	June 2011	Dec 2011	June 2012
Ground Floor Corridor	n	21	21	21	21
	Mean	30,25	6,99	9,76	12,45
	Max	150,81	16,65	20,39	29,84
	Min	3,98	1,01	3,13	3,50
1st Floor Corridor	n	19	19	19	19
	Mean	10,49	6,12	7,07	6,21
	Max	22,08	12,53	13,41	17,05
	Min	5,59	3,68	3,40	3,55
Offices (ground floor)	n	18	18	18	18
	Mean	7,26	3,65	4,86	5,40
	Max	35,29	18,17	14,39	30,35
	Min	2,66	1,42	1,76	1,76
Offices (1st floor)	n	28	28	28	28
	Mean	15,64	9,84	11,49	14,06
	Max	69,39	51,88	60,34	68,98
	Min	2,40	1,57	1,62	1,64
Offices (2nd floor)	n	30	30	30	30
	Mean	3,98	2,34	2,77	3,46
	Max	10,13	4,35	7,55	7,96
	Min	1,59	0,91	1,16	1,14
Offices (3rd floor)	n	11	11	11	11
	Mean	5,47	3,46	5,00	4,92
	Max	7,88	5,50	6,97	7,01
	Min	4,13	2,26	2,81	2,93

The offices on the ground floor the average of ELF values (n=18) was 5.40 mG (Standard deviation, SD= 6.48) in June 2012 and 7.26 mG (SD=7.29) in December 2010. As seen in Figure 4 offices were located south side of the first floor that is above of the transformers

room. It is obvious that the average value on the first floor around three times higher as much as that measured on the ground floor (14.06 mG vs 5.40 mG). For first floor the average exposure among in 2012 (14.06 mG, SD=14.67) was similar to that (15.64 mG, SD=15.71) of in 2010.

On the second floor the average values (n=30) were dramatically lower (around five times) than first floor measurements. The standard deviation of the measurement on the second floor in 2010 and 2012 were calculated 2.29 and 1.86, respectively. On the third floor the measurements were conducted only in the south side offices resulting higher average value than second floor. In 2012 the average value and standard deviation were 4.92 mG and 1.12.

The exposure assessment of the measurements as percentage based on comparison in December 2010 and June 2012 are given in Table 3. The assessment criteria are selected as 3 mG and 4 mG according to limits in the standards. It also summarizes how many points are higher than standards. These are working area points and so the workers expose these ELF values during working hours and days.

Classifying measurements in the office building was given in Table 3. The proportion of the workers who exposed greater than 3 mG was significantly higher than limits. The minimum proportion (46.67%) was measured in second floor offices in June 2012. In this assessment the measurements both north and south side of the building were evaluated. The proportion of the ELF values in North and South side were 82.35% and 0.0%, respectively. The proportion of the third floor measurements greater than 3 mG and 4 mG were 90.91% and 81.82%, respectively. It is clear that the offices located above of the transformers were affected even if it were in third floor.

Table 3 Comparison of the exposure assessment based on years with measured (true) exposure, using 3 mG and 4 mG cut-point

	Dec 2010				June 2012			
	> 3mG		>4mG		> 3mG		>4mG	
	n	%	n	%	n	%	n	%
Ground Floor Corridor	21	100,00%	20	95,24%	21	100,00%	19	90,48%
1st Floor Corridor	19	100,00%	19	100,00%	19	100,00%	16	84,21%
Offices (ground floor)	15	83,33%	11	61,11%	10	55,56%	8	44,44%
Offices (1st floor)	25	89,29%	21	75,00%	23	82,14%	20	71,43%
Offices (2nd floor)	17	56,67%	10	3,33%	14	46,67%	9	30,00%
Offices (3rd floor)	11	100,00%	11	100,00%	10	90,91%	9	81,82%

International Agency for Research on Cancer (IARC) classified ELF magnetic fields as a possible human carcinogen (2B classification) in June 2001 (IARC, 2002), based on

"inadequate evidence" for carcinogenicity of ELF-MF in rodent bioassays and "limited" epidemiologic evidence for a link between ELF-MF exposure and childhood leukemia. Due to this classification measurement studies are very popular interest area for many researchers. Transformer measurement studies in buildings have already been conducted in different countries. In 30 Finnish apartments average exposure in the high exposure category was 0.62 μT (Ilonen et al., 2008); similar results were observed in the eight Swiss apartments that were fully adjacent to a transformer room. In 31 Hungarian buildings mean magnetic flux density in the high exposure category was 1 μT (Szabo et al., 2007; Thuroczy et al., 2008). In ten buildings in Israel the mean value was 0.40 μT in apartments above transformers (Hareuveny et al., 2011). However in a large measurement study among 1314 controls of a German childhood leukemia study, 0.2 μT was exceeded in only 1.9% of all 24 h ELF-MFs measurements in children's bedrooms (Schuz et al., 2000).

Although some epidemiologic studies were performed several decades ago on ELF-MFs in residential places, the biological and health effects of ELF-MFs in humans and exposed field levels are still an emerging area of investigation. In this measurement study, it has been observed that measured average levels of ELF-MFs for the transformer unit is high with respect to IARC threshold, however measured values are far below than ICNIRP exposure limits. Results showed that ELF magnetic field measurement values could be announced as safe. However, when compared with the IARC's threshold levels based on childhood leukemia epidemiologic studies (Kheifets & Shimkhada, 2005), it can be seen that the people are exposed to ELF magnetic fields higher than the limit. Studies on women in workplaces suggest breast cancer for long term exposures to 10 mG and higher (Hardell & Sage, 2008). Magnetic field levels measured in this study are also below breast cancer thresholds. To minimize the risk of adverse health effects ELF-MFs must comply with the international recommendations. Further studies using different configurations, shielding materials and methods will be needed.

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