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Assessment of Population Exposure to Extremely Low Frequency Magnetic Fields and Its Possible Childhood Health Risk in the Czech Republic

Vitezslav Jirik[a,b] Ludek Pekarek[c] Vladimir Janout[a]

[a]Department of Epidemiology and Public Health, Faculty of Medicine, University of Ostrava, Czech Republic
[b]Laboratory of Biophysics, Faculty of Science, Palacky University Olomouc, Czech Republic
[c]National Institute of Public Health, Prague, Czech Republic

Key Words
Extremely low frequency magnetic field · Power distribution network · Housing in Czech Republic · Health risk · Childhood leukaemia

Abstract
The purpose of this study was to estimate exposure of children to power frequency magnetic field and its possible variability in the main types of houses. Spot measurements with a number of additional measurements were used for exposure assessment. The objective was to find out how many children in the Czech Republic are exposed to low-frequency magnetic field above 0.4 μT – level, hypothetically associated with the increased risk of childhood leukaemia.

Introduction

The assessment of exposure to extremely low frequency magnetic field (ELF MF) in residential zones in the Czech Republic (CZ) was provoked by three reasons. First, publications have been appearing for many years allegedly providing evidence that exposure to ELF MF (50 or 60 Hz) with magnetic flux density exceeding 0.4 microtesla is weakly associated with increased incidence of leukaemia in children [1–5]. This induced the International Agency of Research on Cancer (IARC) to classify ELF MF as a "possible carcinogen" [6], in spite of some reports which did not confirm this suspicion [7,8]. Second, data on Electromagnetic fields exposure of general public in countries of the former Eastern Europe have not yet been collected, while the style and types of housing have been for considerable time different in these countries in comparison to Western Europe and Overseas due to different social politics, economy and technical standards determining the used technologies in the mentioned two parts of Europe. In the Czech Republic, ELF MF problems connected with possible health impairment were not included in the hygienic limits (Ministry regulation No. 408/1999 Coll. and earlier documents) valid in CZ up to 2000. Only in 2000, limits recommended by International Commission on Non-Ionising Radiation

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Vitezslav Jirik,
Faculty of Medicine, University of Ostrava, Syllabova 19, 703 00 Ostrava – Zábřeh, Czech Republic. Tel: +420 597 091 791,
E-Mail vitezslav.jirik@email.cz

Fig. 1. The special-manufactured three orthogonal coils used for spot measurements, connected with oscilloscope by three shielded cables. Three coils have the dimensions $540 \times 600 \times 540\,mm^3$ and the effective areas $15.3 \times 15.0 \times 14.7\,m^3$. Resistance is 10.6–11.0 Ω and self-inductance 6.6–7.2 mHz in 120 Hz. The relative error of an electric-parameter measurement is about 5%.

Protection (ICNIRP) [9,10], were adopted in the Czech Republic for the full range of frequencies from 0 to 300 GHz.

The third stimulation for accomplishing the ELF MF measurement in the Czech Republic was the WHO recommendation [11] contained in the "Recommendations for research in the field of sources, measurements and exposures" characterised as "The further characterisation of homes with high ELF exposure in different countries", which encouraged the realisation of this work.

Materials

Measurements of magnetic field were realised with three orthogonal coils (Figure 1) connected to four-channel oscilloscope type Tektronix TDS 3054 – Tektronix Inc., 14200 S.W. Karl Braun Drive, Beaverton, Oregon, USA. Voltages induced in the three coils were separately recorded and the vector of magnetic flux density B was constructed from the three stored components. In addition, the small (pocket) magnetometer NoRad – NoRad Corp., 1160 E. Sandhill Ave., Carson, Calif., 90746, USA was sometimes used for personal measurements, and software program Axum 7 (Mathsoft Engineering & Education, Inc., since 2006 Mathsoft) obtained from PTC Corporate Headquarters, 140 Kendrick Street, Needham, MA 02494, USA was used for processing the stored data. Regression analysis, analysis of variance and correlation were performed using Excel (Microsoft Corp., Worldwide, USA) and Stata (Stata Corp., Release 9, College Station, Texas, USA).

Methods

Different housing and schools were chosen for the main measurements, in different types of locations (i.e. big cities with more than 100,000 inhabitants, small towns and villages) and with several different constructions of buildings, typical for CZ. The houses were divided into three categories (by type dwelling) in compliance with published housing statistics in the European Union [12], i.e. for high-rise housings (built-up of concrete panels, generally with more than four floors and several tens of flats, Figure 2), multi-family housings (constructed of panels or bricks up to four floors with a smaller number of flats, Figure 3) and family housings (generally single or double-storey houses, built-up of bricks or blocks with one or two apartment accommodation, Figure 4). According to this statistics, 33.8% of total dwelling stocks of CZ are high-rise dwellings, i.e. in high-rise housings, 55.6% are multi-family dwellings. Most of the last category housings are probably multi-family housings (more detailed statistics is not available), because family housings would mostly contain up to two apartments (two-dwelling buildings are not included in the above-mentioned statistics). It can be estimated, that one or two family dwelling represented only 9.7% of total dwelling stocks in CZ. Nursery and primary school buildings are mostly similar to the multi-family housings.

Methodology of exposure assessment is usually based on estimates of exposure assessed by calculation, i.e. from distance from electric wires, wire codes or calculation of historical fields, and on estimates of exposure assessed by measurement, i.e. spot measurements, long-term measurements and personal exposure monitoring. In this study, the method of spot measurement was chosen even though there are some drawbacks of this measurement strategy due to errors resulting from variability of magnetic fields [11]. On the other hand, this simple method takes into account the possibility of unjustified misgiving and fear from magnetic field, which could be induced by seeing the measurement. Most of inhabitants would not notice the measurement and therefore they would not be disturbed by the results. Addresses have been kept in confidence for privacy protection. Another advantage of the used method was the oscilloscopic recording of the time course of the field and hence the knowledge of its full frequency spectrum.

Fig. 2. An example of high-rise housing in the Czech Republic.

Fig. 3. An example of multi-family housing the Czech Republic.

Fig. 4. An example of family housing in the Czech Republic.

One measurement lasted from 15 to 45 min and was performed on several places (from three up to six places) in immediate house vicinity (from 1 up to 5 m). These sampling locations were selected in random time of the day accomplished minimally 1.5 m over ground, because the ELF MF values directly above underground power lines; these would be significantly higher than at any place beside or inside dwellings.

Besides the main measurements, additional measurements were carried out in order to increase the credibility of exposure estimates from the spot measurements. The measurement was repeated in different seasons to estimate seasonal variability and some of them were conducted continuously for several days at the same place to estimate a short-term variability. Parallel measurements were made beside and inside the housings to estimate the difference of ELF MF values outside and inside the housings. In addition, several measurements were performed in the vicinity of high voltage cables (220 and 440 kV) and also as a personal exposure measurement on a school child's body.

The individual results of measurements in the vicinity of the housings showed the log-normal distribution. Therefore, the logarithmic data transformation was used. All statistical parameters were calculated from transformed data, and the inverse transformation was applied afterwards. The geometric mean (GM) was used as average value:

$$GM = 10^{AM}$$

The lower margin of variability (L) has been expressed as

$$L = 10^{AM-SD},$$

and the upper margin of variability (H) as

$$H = 10^{AM+SD}$$

In the above expressions, AM is the arithmetic mean of logarithmic data, SD the standard deviation of logarithmic data and n the count of data.

Results

Spot Measurements Beside Houses Using Oscilloscope Recording

Results of measurement according to individual types of housing are given in Table 1. There were statistically significant differences between family housings and high-rise housings and between family houses and multi-family

Table 1. The results of the extremely low frequency magnetic field measurements according to individual types of housing in CZ

Type of housing	High-rise housing	Multi-family housing	Family housing
Number of measured sites	55	35	73
GM	0.236 μT	0.203 μT	0.072 μT
Variability (*L–H*)[a]	0.097–0.577 μT	0.095–0.432 μT	0.026–0.198 μT
Distribution[b]	33.8%	56.6%	9.7%
Weighted average	0.193 μT		
Variability (*L–H*)	0.084–0.442 μT		

[a]The expression of variability (*L–H*) is described in "Materials" and "Methods" sections.
[b]Distribution means how much inhabitants live at the mentioned types of housing in the Czech Republic [12].

houses ($p < 0.05$). Differences between ELF MF levels in multi-family housings and high-rise housings were not significant ($p > 0.05$).

The Content of Higher Harmonics

The three-coil probe with oscilloscope was used to determine the content of higher harmonic components in the signal. Magnetic induction values almost never gave a shape of an ideal 50 Hz sinusoid curve (Figure 5).

Figure 6 shows average relative ELF MF levels of higher harmonic frequencies in proportion to the first (fundamental 50 Hz) harmonic for each of the three types of housings. Statistically significant ($p < 0.05$) differences in the content of higher harmonic frequencies were found between ELF MF results beside the family housings and other types of housings (i.e. between high-rise housings and multi-family housings). Abundance (level of relative distribution) of the first and third harmonics was higher for multi-family housings and for high-rise housings. Relative abundance of other frequencies was higher for family housings.

Seasonal Variability of Results of Spot Measurements

Validity of the above-mentioned results was confirmed by additional measurements, which included repetitive measurements in a number of the same locations near houses during different seasons. If the first measurement was performed in summer, then the recurrent measurement was accomplished in winter and *vice versa*. The verification was undertaken in randomly selected houses representing all three types of housings. Regression analysis and correlation of results for winter and summer seasons (Figure 7) showed insignificant ($p > 0.05$) differences between the measurements during various seasons ($y = 0.9225x - 0.0184$, where y represents the winter results and x, the summer results at the same sites) and statistically significant ($p < 0.05$) correlation between these measurements ($R^2 = 0.7358$).

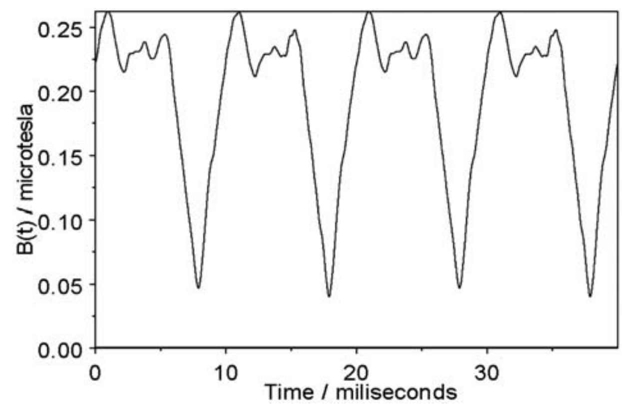

Fig. 5. Example of measured, a typically distorted signal. A time response of magnetic flux density vector.

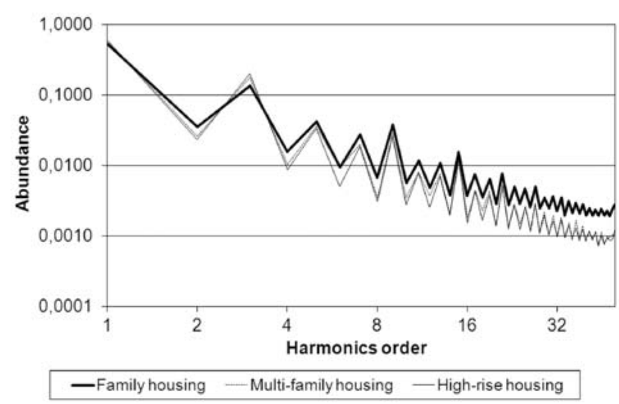

Fig. 6. The average of relative magnetic field levels (abundances) of higher harmonics in proportion to fundamental frequency (50 Hz) for each of the three types of housing. Upper (thick) broken-line belongs to the family houses, lower two broken-lines (hide each other) belong to the high-rise houses (thin line) and to the multi-family houses (dotted line). First harmonic has 50 Hz, second harmonic 100 Hz and third harmonic 150 Hz, etc.

Variability of Spot Measurements During a Day and in Different Days

The changes of ELF MF values were measured in randomly selected locations during a period of few days.

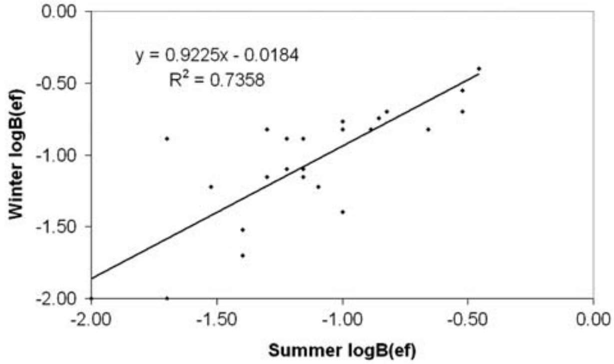

Fig. 7. The linear regression of measurement results (extremely low frequency magnetic flux density) in winter and in summer at the same places. Coefficient of regression 0.9225 has the confidence interval 0.7067–1.1411 with the statistical significant correlation ($p < 0.01$). R^2 is coefficient of determination (R is coefficient of correlation).

Short-term variability was calculated from the time changes of ELF MF inside and outside of several housings (one place inside and one place outside of two high-rise housings and likewise of two family-housings). These were measured continuously for 4 days. Relative standard deviations were approximately ±35% inside and ±31% outside of the high-rise housings and ±41% inside and ±35% outside of the family housings.

Differences in Results of ELF MF Measurements Beside and Inside the Housings

For each of the three types of housings, several parallel measurements were accomplished beside and inside in randomly selected places. Differences between the average effective MF value in the vicinity of the housings (outside) and average effective MF value in all the premises were evaluated for all types of housings. GM of the ELF MF values for selected high-rise housings was 0.122 μT outside and 0.147 μT inside, for multi-family housings – 0.184 μT outside and 0.161 μT inside, and for family housings – 0.038 μT outside and 0.045 μT inside. For all types of housings the statistical analysis showed that differences in results of spot measurements in the vicinity of housings (outside) and inside the housings were not significant ($p > 0.05$).

Personal Exposure

Measurement of daily (24-h) exposure was performed by two ways, suitable for assessing the difference between directly measured personal exposure and stationary measured values in various places of a typical living environment (i.e. at home or in a flat, on the way of the child to school, at school, i.e. in classroom and corridors, and outside of house). Evaluation of the stationary measurements and of three personal measurements were carried out on a 12 years old school boy under assumption that a school child spends 18 h at home (spot measurement 0.072 μT) or around the house (spot measurement 0.075 μT) and 6 h at school (spot measurement 0.181 μT). Calculated daily personal exposure was 0.100 μT and average 24-h directly measured personal exposure was 0.094 μT.

Measurements in the Vicinity of Power Lines

The highest long-term ELF MF values were found in the vicinity of very high voltage lines. Reported results directly under wires were 2.46 and 3.33 μT from the wires of 220 and 440 kV, respectively and 0.89 and 1.13 μT within 30 m from the wires. Our efforts to acquire data of the number of housings located in the vicinity of very high voltage power lines in CZ were not successful; therefore we could not assess the population living at this maximum ELF MF exposure.

Distribution of Exposure Levels of General Public in the Czech Republic

The distribution of ELF MF exposures in categories determined by WHO [11] was estimated on the basis of published data [12] about the inhabitant distribution in individual types of housings in CZ. Estimate of the ELF MF exposure distribution is given in Table 2.

Units and Symbols

Magnetic flux density (magnetic field, magnetic induction) B in μT (microtesla).

ELF MF is below 300 Hz.

Discussion

When comparing the results against the WHO published ELF MF values [11] of GMs (0.025–0.07 μT), the measurements obtained in this study were higher. The estimate of weighted GM in the vicinity of all types of housings in CZ was 0.193 μT (0.072–0.236 μT, Table 1). This higher level may be due to different types of housing in CZ and how the housings are wired electrically in comparison to the housings found elsewhere in other European countries. A considerable proportion of high-rise and multi-family housings have a variety of relevant electric wiring and lines. In addition, panel housings have steel-concrete framing. The estimated GM of ELF MF levels was 0.236 μT for high-rise housings and 0.203 μT for multi-family housings (Table 1). On the other hand, GM

Table 2. Estimates of relative distribution of the extremely low frequency magnetic field exposures in CZ

Exposure distribution	Category[a] $<0.1\,\mu T$	Category[a] $>0.1-\leq 0.2\,\mu T$	Category[a] $>0.2-\leq 0.4\,\mu T$	Category[a] $>0.4\,\mu T$
Percent of population	19.7	27.6	28.3	24.4

[a]The categories are divided according to WHO [11].

of effective ELF MF levels of family housings had an estimated value of 0.072 μT (Table 1) and this was statistically different. Therefore, only results for family housings were consistent with the published values [11]. Approximately three times higher exposure level was found in other types of housings in CZ (i.e. in high-rise housings and in multi-family housings).

For individual types of housings, the differences among the average contents of higher harmonic frequencies (Figure 6) were small, but these were statistically significant. We have no explanation for the slightly higher relative content of the basic frequency 50 Hz, third harmonic frequency 150 Hz and the lower relative content of remaining frequencies beside the high-rise and multi-family housings.

The resented results of ELF MF measurements during winter and summer that were measured at the same places had considerable stability. The regression analysis of these data showed no statistically significant differences, while their correlation was significant (Figure 7). The short-term variability of spot measurements at the same location during several days was relatively low (max 41%) and therefore these facts should not significantly influence the applicability of the spot measurement results on longer-term period. Therefore we suppose that the results of spot measurements can be used for long term exposure assessment.

Significant differences were not found between average ELF MF levels beside and inside the housings. But the distribution of ELF MF levels within the houses was not uniform. Higher levels were observed at the lower floors and lower levels at higher floors in the high-rise housings. In multi-family housings and family housings the distribution was more uniform. These findings confirmed the idea that measurements in the immediate outside vicinity of the housings could be representative for assessing exposures inside the housings (of course except very short term exposures from electric appliances or close to incoming electric power lines in the building). This is supported by other studies [1] which used distances between dwelling and outside power lines to calculate the ELF MF exposures inside the housings.

Substantial difference has not been found between the result of personal exposure measurement on a school child living in a family housing and the calculated time-weighted average from stationary measurements. The measured 24-h personal exposure average 0.094 μT corresponds with WHO [11] published data (0.042–0.134 μT). This result was slightly higher than spot measurement in the vicinity of the housings (0.075 μT). The reason for the higher personal exposure level found was probably due to the 6 h-presence in higher ELF MF exposure (0.181 μT) at the school. Though the number of personal measurements was very low, it seems likely that real ELF MF exposures for children living in family housings could be slightly higher than ascertained by the spot measurements, but for children living in high-rise or multi-family housings the exposure should be similar to the results presented in this paper.

Though it is necessary to consider higher short-term ELF MF exposures in vicinity of electric appliances or in vicinity of underground power lines (these short-term exposures usually take seconds or minutes at a maximum level) for inhabitants including children, long-term exposures should not be influenced by these exposures. However, long-term exposures can occur in the vicinity of very high voltage lines. Measured levels under wires or in a short distance from them (30 m) are in order of few microtesla and correspond to published data [11]; whereas the number of exposed persons on a long-term basis is not likely to be influenced to a great extent (exact data about the number of housings in the vicinity of very high voltage were not available).

Dwellings in CZ are different in comparison with Western Europe, because for example in Great Britain only 2.4% of dwellings are in high-rise buildings (33.8% in CZ), 18.7% dwellings are in multi-family housings (55.6% in CZ) and 78.9% of dwellings are in family housings (9.7% in CZ) [12]. By generalisation of these data to the whole population in the CZ, it is possible to approximate the average exposures (0.193 μT) in Table 1. Exposures above 0.4 μT, which are associated with a slightly increased risk of childhood leukaemia [6] can be expected up to 24% of children (i.e. with about 400,000 children) of total number of about 1,700,000 children with 0–14 years of age in CZ (Table 2). Whether these increased exposures (according to WHO the average of odds ratio from selected studies is 2.0 for exposed children above 0.4 μT) was related to the enhancement of childhood leukaemia incidence in CZ, would remain open to debate and consideration. These exposure values were higher than published data from industrial countries of Western Europe and Overseas, where a maximum 4% of children are estimated to be exposed by level above 0.3 μT, and a maximum 2% could be exposed by level above 0.4 μT on a long-term basis [11].

Conclusion

The results of ELF MF spot measurements in the vicinity of 163 housings in Czech Republic have shown some differences in the average values according to the type of housing (high-rise, multi-family and family houses). These results could approximately correspond to exposures of people (and children) on a long-term basis because no significant differences among seasons, day-times or ELF MF levels beside and inside the housings were ascertained.

For family housings, the GM of ELF MF values, which did not include contributions from electric appliances or underground power lines, was 0.072 μT. This value was consistent with data published in the industrial countries of Western Europe and elsewhere, with higher proportion of the population living in such family housings. Exposures of the Czech population, frequently living more in the typical high-rise or multi-family housings, were approximately three times higher than observed in the family housings.

It is possible that up to 24% of children in the Czech Republic are being exposed to ELF MF above 0.4 μT on a long-term basis. It could mean, that according IARC – WHO data, a higher risk of childhood leukaemia.

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