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Case Report

ELF-MF Exposure, Actual and Perceived, and Associated Health Symptoms: A Case Study of an Office Building in Tel Aviv-Yafo, Israel

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Abstract: Empirical studies link exposure to extremely low frequency magnetic fields (ELF-MFs) to several health symptoms. However, it is unclear whether these symptoms are associated with actual or perceived exposure. In this study we attempted to answer this question by studying the health complaints of employees working in a multi-story office building located near a major high-voltage power line. ELF-MF measurements were conducted in the building using a triaxial sensor coil device on all 15 floors. In parallel, questionnaires were administered to evaluate the prevalence of various health symptoms among the employees. Multivariate logistic regressions were used next to quantify the associations between actual and perceived ELF-MF exposure and the employees' health complaints. The analysis revealed that feelings of weakness, headache, frustration, and worry were associated with both measured and perceived ELF-MF exposure ($p < 0.01$), while perceived ELF-MF exposure was also found to be associated with eye pain and irritation (OR = 1.4, 95% CI = 1.2–1.6), sleepiness (OR = 1.3, 95% CI = 1.1–1.5), dizziness and ear pain (OR = 1.2, 95% CI = 1.0–1.4). We conclude that high-voltage power lines produce both physiological and psychological effects in nearby workers, and, hence, proximity to such power lines should become a public health issue.

Keywords: work exposure; extremely low frequency magnetic field (ELF-MF); health complains

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1. Introduction

Electricity supply improves standards of living and life quality [1]. However, it also increases public concerns about potential health hazards related to exposure to extremely low frequency magnetic fields (ELF-MFs) [2,3].

The association between ELF-MF exposure and childhood leukemia has been well-documented since the late 1970s [4,5], and, in 2002, the International Agency for Research on Cancer classified ELF-MF as a Group 2B (possible) carcinogen [6].

Recently, the phenomenon of elevated sensitivity to ELF-MFs (generally below regulated levels) has been defined as an idiopathic environmental intolerance (IEI), also known as electromagnetic hypersensitivity syndrome [7,8]. This syndrome is characterized by a wide range of nonspecific symptoms, such as skin redness, itching, sleepiness, tiredness, difficulty concentrating, dizziness, and several others [8]. However, the pathophysiological mechanisms of the impact of ELF-MFs on humans remain largely unclear, with most studies carried out to date falling short of suggesting that IEI-EMF symptoms are correlated with actual ELF-MF exposure or that those complaining of IEI symptoms could detect ELF-MF exposure more accurately than unaffected individuals [7–9].

Nevertheless, according to several recent studies, living or working near a high-voltage power line has adverse effects on people who are exposed, or perceived to be exposed, by adding physiological and psychological stress to their daily routine [2,10–12]. The association of ELF-MF exposure with nonspecific health symptoms, such as fatigue, headaches, skin rashes, and insomnia, is also well documented [13]. However, these symptoms are not a part of any specific syndrome recognized by the World Health Organization (WHO), which recently stated that "despite extensive research, . . . there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health" [14]. It is also not clear whether the *abovementioned symptoms result from actual or perceived exposure to ELF-MF, or whether both play a role* [11,15,16].

The present study was aimed at bridging this knowledge gap by investigating the association between actual and perceived ELF-MF exposure and health symptoms reported by employees working in a large 15-floor office building located in close proximity to a major high-voltage power line in the city of Tel Aviv-Yafo, Israel. The study produced a fully matched dataset incorporating both measured and perceived ELF-MF exposures, as well as individual attributes of the employees and their health symptoms that enabled us to analyze the associations between different ELF-MF exposure metrics and the employees' health complaints.

2. Methods

2.1. ELF-MF Measurements

The ELF-MF measurements were performed between June and August 2012 on all 15 floors of a large office building located in the central part of Tel Aviv-Yafo, the second largest city in Israel. The building belongs to the Israel Ministry of Education and about 620 employees work there. The building is located about 10 m away from a major 161 KV power line (Figure 1).

Figure 1. Office building under study and nearby high-voltage power line.

For the field measurements, we used a SPECTRAN NF-5030 v.5 (NF-5035) spectrum analyzer, manufactured by Aaronia AG (Euscheid, Germany), and a TM-192D EMF meter, manufactured by Tenmars Electronics Co., Ltd. (Taipei, Taiwan) (see Appendix A). The NF-5030 instrument was used to analyze ELF-MF frequencies, so as to ensure that ELF-MF readings came from the 50 Hz power line and not from other sources. Concurrently, the TM-192D device was used to measure ELF-MF levels. Both devices measured the ambient ELF-MF [17] in milli-Gauss (mG), with an accuracy of ±0.1 mG, and the measurements were stored in a data logger [18].

A total of 487 measurements were performed by a certified engineer using 40 measurement devices simultaneously on each floor. Appendix B features plans of all 15 floors of the building showing the locations in which measurement devices were placed. The measurement protocol followed the guidelines prepared by the Commissioner of the Environmental Radiation Office, Israel Ministry of Environmental Protection [19]. Each morning, the instruments were moved to another floor. The instruments were placed on employees' desks, as far as possible from electrical appliances (such as radios, power supplies, electric transmitters, internal power lines, microwave ovens, speakers, etc.) to avoid interference. Appendix B shows examples of the measurement devices located on typical building floors.

At each location, 24 h measurements were performed in 1 min intervals. The total exposure was then evaluated for each location by averaging the data recorded between 7 a.m. and 7 p.m.; that is, during the employees' typical working hours. If ELF-MF values were not detected, new measurements were performed in the same location. In total, there were nine such repeated measurements (1.84%).

Based on information from the Israel Electric Company, the load on the power line during working weekdays varies in the range of ~10%, mainly due to changes in electricity demand during summer. Therefore, every day, before starting a new set of daily measurements, a single measurement was made in the lobby of the 6th floor to ensure that measurements performed on different days were comparable.

2.2. Questionnaires

To assess perceived ELF-MF exposure and record health symptoms, we used a questionnaire based on the WHOQOL-BREF of the WHO 1997 survey instrument [20–23], while questions related to general health and specific symptoms were adopted from the Short Form 36 Health Survey Questionnaire (SF-36), used in the UK Omnibus Survey, and the Oxford Healthy Life Survey [24].

The questionnaire contained 75 questions divided into 6 sections: (1) work location (floor, office, and desk number); (2) evaluation of perceived ELF-MF; (3) general health and health symptoms; (4) quality of life assessment; (5) lifestyle and behavior; and (6) socioeconomic attributes (gender, age, education level, monthly income, etc.). The answers were limited to a fixed set of responses, depending on the question type, either yes or no, or on a 10-point Likert scale (e.g., "In your view, what is the magnetic field level in your office?" Please rate from none (0) to very high (9)). Prior to the survey, the employees were not informed about measured ELF-MF levels at their workplace to avoid triggering health symptom reporting due to a known exposure. Over 600 questionnaires were collected (with a response rate of 97%), of which 487 questionnaires (81%) were fully completed and used in the analysis (sampling power = 89%). The study was approved by the Ethics Committee of the Israel Ministry of Education, Israel. Written informed consent was also obtained from all the employees surveyed.

2.3. Statistical Analysis

The assembled data were analyzed in two stages. First, bivariate correlations were estimated to assess the relationship between perceived and measured ELF-MF exposures. Next, binary logistic regressions were used to examine the associations between reported health symptoms and ELF-MF exposure, either perceived or measured, while controlling for potential confounders, such as age, gender, sociodemographic characteristics, smoking, number of years of working in the building, and average number of daily work hours. Both types of analysis were performed using IBM SPSS v.27 software.

3. Results

3.1. ELF-MF Measurements and Their Associations with Perceived Exposure

The results of the ELF-MF measurements on separate floors of the building are reported in Table 1, while socio-demographic characteristics of the respondents are reported in Table 2.

Table 1. Magnetic field measurements by floor, in mG.

Floor	Min	Max	Mean	SD	N
1	0	1	0.43	0.51	14
2	0	2	0.45	0.63	29
3	0	5	1.39	1.55	36
4	0	6	2.25	1.76	28
5	0	6	2.44	1.8	39
6	0	5	2.77	1.54	43
7	0	5	2.65	1.93	43
8	0	6	2.3	1.91	33
9	0	5	1.54	1.58	35
10	0	5	1.53	1.46	36
11	0	4	1.46	1.14	28
12	0	5	1.06	1.37	33
13	0	3	1.03	0.8	31
14	0	4	0.79	1.01	29
15	0	3	0.48	0.74	29

Table 2. Descriptive statistics of the survey respondents.

Age	N	% of Total
18–24	52	11%
25–34	92	19%
35–49	151	31%
50–69	178	37%
70+	14	3%
Seniority (years)		
<6	73	15%
7–11	73	15%
12+	341	70%
Household income (NIS per month)		
<10 K	38	8%
10–15 K	90	18%
15–20 K	123	25%
20–30 K	220	45%
>30 K	16	3%
Years of schooling		
<10	33	7%
11–12	78	16%
13–14	77	16%
15–18	224	46%
18+	75	15%

As can be seen in Table 1, the highest ELF-MF levels of 5–6 mG were recorded between the 3rd and 12th floors at a distance of about 10 m from the power line, with the magnetic flux peaking between the 4th and 6th floors (see Figure 2). As further shown in Figure 2, the maximum exposure was recorded on the building's northwestern side, which faces the power line and passes by it between the 4th and 6th floors, and exposure decreases with distance from the wires.

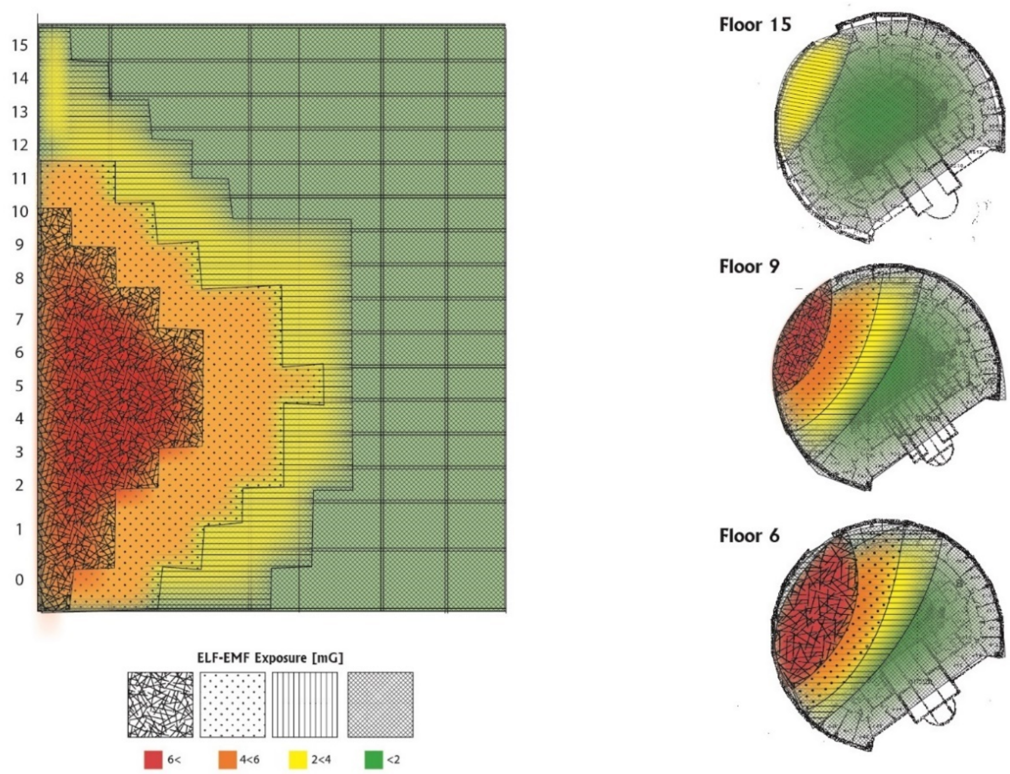

Figure 2. Magnetic flux on typical building floors according to field measurements.

In Figure 3, we compare average perceived exposure, measured on a 5-point Likert scale (from 1 to 5, low to high), to the actual measured exposure in mG at the workers' desks. As evidenced in this figure, the distribution looks fairly uniform, showing similar average levels of perceived exposure within the whole range of actual exposure (r = 0.06 ns).

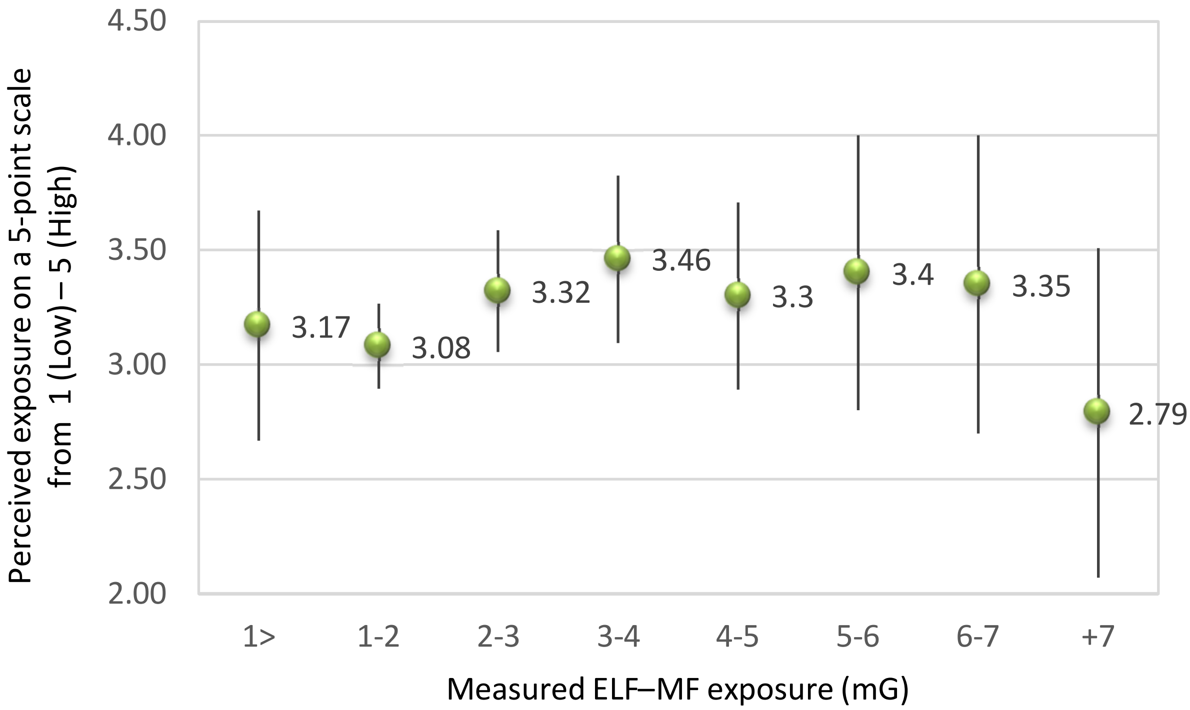

Figure 3. Average levels of perceived exposure and their 95% confidence intervals across different levels of measured exposure (in milli– Gauss, mG).

3.2. Regression Analysis

Regression estimates for measured and perceived ELF-MF exposures are reported in Table 3 and visualized in Figure 4. Horizontal bars in this figure that do not intersect the vertical line at 1 and marked in red are statistically significant. The models in Table 3 were estimated using the logistic regression method for each health symptom separately (yes/no), while controlling for age, sex, country of birth (Israel/other), income, education, presence of domestic pets, smoking status, number of years of working in the building, and average number of daily work hours.

Table 3. Associations between measured and perceived ELF-MF exposure and health symptoms (method: ordinary logistic regression).

Health Complaint	Measured Exposure			Perceived Exposure		
	OR	95% CI		OR	95% CI	
Abdominal pain	1.005	0.897	1.125	1.097	0.950	1.267
Blurred or double vision	0.956	0.849	1.076	1.108	0.958	1.280
Cough	1.069	0.956	1.194	0.950	0.823	1.095
Cramps—hips	1.024	0.916	1.145	1.007	0.875	1.159
Cramps—legs	1.111	0.994	1.241	1.074	0.931	1.239
Cramps—neck	1.012	0.906	1.130	1.067	0.928	1.226
Dizziness or ear pain	1.009	0.905	1.125	1.185 *	1.032	1.361
Dyspnea	0.960	0.856	1.077	1.049	0.911	1.208
Eczema skin rash or burning	1.097	0.984	1.224	0.972	0.846	1.117
Exhaustion and weakness	1.201 **	1.076	1.341	1.323 **	1.146	1.528
Eye pain or irritation	1.002	0.900	1.116	1.381 **	1.199	1.591
Fast or irregular heartbeat	1.085	0.972	1.210	1.140	0.990	1.313
Feeling of lack of control over life	1.005	0.895	1.129	1.149	0.990	1.333
Fever or cold	0.972	0.865	1.092	1.019	0.883	1.176
Frustration/sadness	1.095	0.977	1.226	1.003	0.868	1.159
Frustration/worry	1.236 **	1.107	1.380	1.318 **	1.142	1.520
Headache	1.288 **	1.149	1.443	1.288 **	1.124	1.475
Hearing problems or ear bleeding	0.998	0.895	1.114	0.980	0.854	1.124
Loss of consciousness	0.996	0.885	1.120	1.053	0.909	1.220
Nervousness	1.028	0.918	1.152	1.130	0.977	1.306
Runny nose or allergy	0.944	0.844	1.056	0.957	0.834	1.099
Sleepiness	1.029	0.922	1.147	1.282 **	1.114	1.476
Sore throat, hoarse voice	1.034	0.915	1.168	1.113	0.953	1.300
Swelling of hands and/or legs	1.045	0.931	1.173	0.943	0.814	1.093
Taking allergy drugs	1.032	0.920	1.159	0.887	0.767	1.026
Unbalanced walk	1.102	0.983	1.236	0.994	0.859	1.151

* $p < 0.05$, ** $p < 0.01$. Models are controlled for the number of years working in the building, average number of work hours, smoking, income, education, presence of domestic pets, country of birth (Israel/other), age, and gender. OR, odds ratio; CI, confidence interval.

As can be seen in Table 3, measured ELF-MF exposure appears to be positively associated with three health symptoms: headache (odds ratio (OR) = 1.3, 95% confidence interval (CI) = 1.1–1.5; $p < 0.01$); frustration/worry (OR = 1.2, 95% CI = 1.1–1.4; $p < 0.01$), and exhaustion/weakness (OR = 1.2, 95% CI = 1.1–1.3; $p < 0.01$). The estimated ORs are similar for all three symptoms (OR = 1.2–1.3), indicating that an increase in ELF-MF by 1 mG tends to increase their prevalence by ~20–30%, all other factors being equal.

Concurrently, perceived ELF-MF exposure is found to be significantly associated with more health symptoms: headache (OR = 1.3; 95% CI = 1.1–1.5; $p < 0.01$); frustration/worry (OR = 1.3; 95% CI = 1.1–1.5; $p < 0.01$); exhaustion/weakness (OR = 1.3; 95% CI = 1.1–1.5; $p < 0.01$); dizziness or ear pain (OR = 1.2; 95% CI = 1.0–1.4; $p < 0.05$); eye pain or irritation (OR = 1.4; 95% CI = 1.2–1.6; $p < 0.01$); and sleepiness (OR = 1.3; 95% CI = 1.1–1.5; $p < 0.01$).

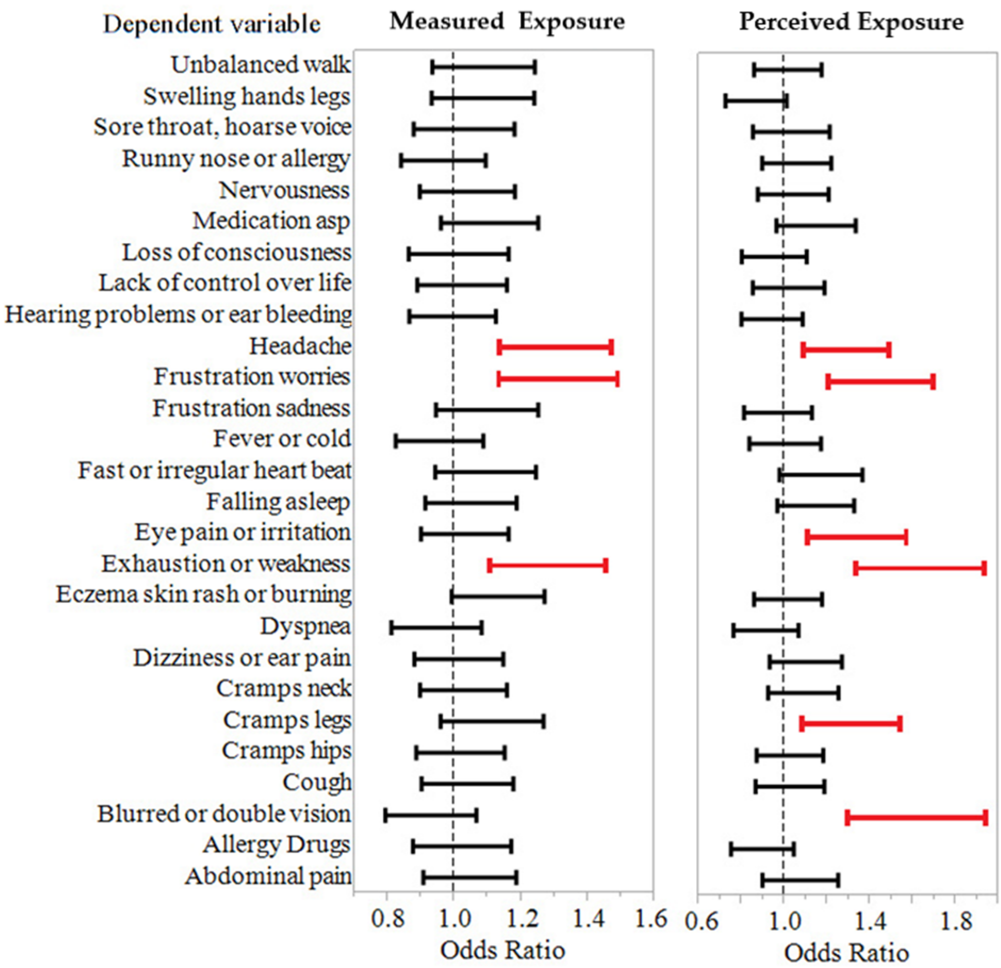

Figure 4. Odds ratios and 95% confidence intervals measured and perceived ELF-MF exposure. Notes: Based on estimated reported in Table 3; controlled for the number of floors (linear and squared terms), number of years of work in the building, number of working hours, income, education, existence of domestic pets, country of birth, age and gender; red lines indicate significant association, black lines indicate insignificant associations.

4. Discussion

In this study, we analyzed health symptoms reported by employees working in a multistory building located near a major (161 kV) power line. We compared the frequency of such symptoms with both instrumentally measured and perceived ELF-MF exposure, with the latter obtained from a questionnaire. The study produced a fully matched dataset, which enabled us to analyze the association between health complaints and different exposure metrics. As the study revealed, several health symptoms, including exhaustion and weakness, headache, and frustration and worry, were found to be positively and significantly associated with both actual and perceived exposure ($p < 0.01$). In addition, perceived EMF exposure was found to be a significant predictor of eye pain and irritation, sleepiness, and dizziness or ear pain ($p < 0.01$). The study also revealed that measured exposure correlated poorly with perceived exposure (r = 0.06 ns), meaning that people could *not* accurately estimate the ELF-MF levels they were actually exposed to.

Our results are generally in line with the results of other studies that reported tiredness, headaches, dizziness, insomnia, increased heartbeat, and skin problems occurring in the presence of ELF-MF, primarily related to electromagnetic hypersensitivity [4,8,23,25,26]. Anxiety, hostility, headache, fatigue, difficulty concentrating, vertigo, weakness, dizziness, attention disorders, and nervousness associated with electromagnetic hypersensitivity are also well documented [7,13,26].

However, our results are different from those reported by Baliatsas et al. [27], who found no significant associations between measured ELF-MF exposure and health outcomes but did find significant associations between perceived exposure and health symptoms [27]. The apparent differences between these findings may be due to the fact that they modeled exposure from RF-EMF sources, such as mobile phones, DECT, and radio/TV monitors with relatively low emission levels, while our study was carried out in a building near a major power line with higher levels of measured exposure (0.9–7 mG), depending on the floor.

To the best of our knowledge, this study is the first that links nonspecific health symptoms with both perceived and actual exposure to ELF-MF, whereas other studies did not reveal statistically significant associations between health symptoms and measured ELF-MF exposure [8,28]. The meta-analysis by Baliatsas [28] is not fully comparable with our study, because that study analyzed health effects from RF sources (such as mobile phone base stations, shortwave broadcast transmitters, computer monitors, mobile phones, etc.), while we investigated the presence of health symptoms in the immediate vicinity of a major power line with higher levels of ELF-MF exposure.

Health symptoms associated with perceived exposure revealed in our study are likely to be attributed to the abovementioned idiopathic IEI-EMF phenomenon [7,29]. According to the European Academy for Environmental Medicine (EUROPAEM) EMF working group, possible underlying mechanisms of IEI-EMF include the formation of free radicals or oxidative and nitrosative stress, which might be related to multiple chemical sensitivity or chronic fatigue syndrome and are associated with a potentially higher risk of cancer [4].

Several limitations of the present study need to be mentioned. First, the ELF-MF exposure of study participants might not be only from the power line, but also from various other EMF sources (such as mobile phones, computers, monitors, etc.), or they may have multiple sensitivities to, for example, odor or noise [30,31]. Moreover, we could not examine EMF-ELF exposure in the workers' homes. Furthermore, due to technical limitations, measurements on different floors of the building were made on different days, which might have introduced some variation. Future studies should thus attempt to address these issues by employing a simultaneous measurement scheme and sampling strategies [32].

5. Conclusions

The main findings of this study can be summarized as follows:

- The analysis revealed no significant association between instrumentally measured and perceived ELF-MF exposure, which implies that individuals cannot detect actual ELF-MF exposure accurately;
- The analysis revealed that feelings of weakness, headache, frustration and worries were associated with both measured and perceived ELF-MF exposure, while perceived ELF-MF exposure was also found to be associated with eye pain and irritation, sleepiness, as well as dizziness and ear pain.
- As we conclude, working near a high voltage power line appears to produce not only psychological but also physiological effects, and should thus become a public health concern.

As several reported symptoms (including headache, frustration/worry, and exhaustion/weakness) were found to be significantly related to measured exposure, not just perceived exposure, the results should lead to revisiting ELF-MF exposure standards. Moreover, follow-up studies should attempt to estimate other effects of ELF-MF exposure, such as its effects on employee productivity, the number of visits to physicians, absenteeism, and medication intake.

Author Contributions: L.S.R.-S.—measurements, data processing and analysis, paper writing; J.D.—help with results' interpretation, writing and editing; S.G.—measurement methodology; P.J.—help with results' interpretation; B.A.P.—conceptualization, methodology, formal analysis, help with writing and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was approved by the Ethics Committee of the Ministry of Education (2 September 2012, #40555543), in Israel Written informed consent was also obtained from all the employees surveyed).

Informed Consent Statement: The study was approved by the Ethics Committee of the Ministry of Education (2 September 2012, #40555543), in Israel Written informed consent was also obtained from all the employees surveyed).

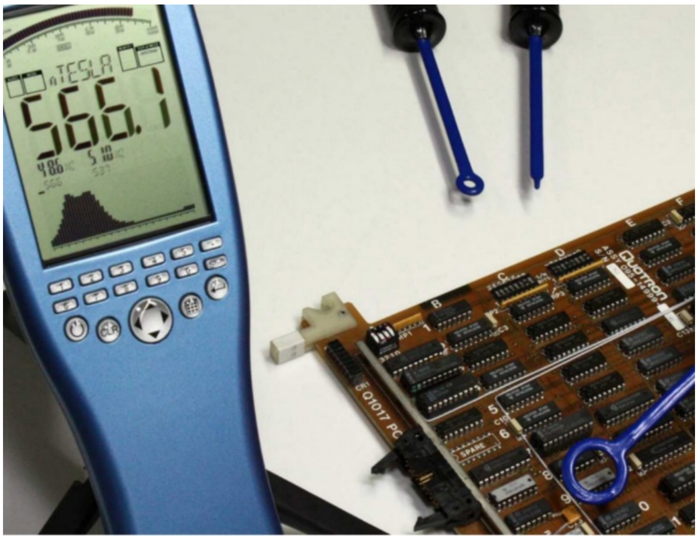
Data Availability Statement: The data were collected during this study case.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Measurement equipment used in the study.

A. Aaronia NF-5035 Spectrum Analyzer



Features:

- Frequency range: 1 Hz–1 MHz;
- 3D magnetic-field measurement coil;
- Typical level range: 1 nT to 2 mT;
- Filter bandwidth (min/max): 0.3 Hz (min)/10 MHz (max);
- Typical precision base unit: 3%;
- Range analog input (typical): 200 nV (min)–200 mV (max);
- FFT (resolution in points): 1024;
- Vector power measurement (I/Q) and true RMS: Yes;
- Weight: 430 g;
- Tripod connection: 1/4".

B. Tenmars TM-192D Field Meter

Features:

- 30 Hz to 2000 Hz frequency range;
- For triple-axis measurements of low-frequency electromagnetic fields;
- Quick and easy measurement with three-channel measurement sensors;
- Built-in USB communication for data-logging; capacity of 500 or 9999 datasets;
- Magnetic field unit is Tesla (T) or Gauss (G);
- Data hold (HOLD), maximum hold (MAX), and minimum hold (MIN) functions;
- Auto range or manual range select mode;
- Easy and safe to use;
- Low-battery detector;
- Overload indication;
- Auto-power off function.

Specifications:

- Display: 4-digit, triple liquid crystal display;
- Measuring range: 20, 200, 2000 mG; 2, 20, 200 uT;
- Resolution: 0.01, 0.1, 1 mG or 0.001, 0.01, 0.1 uT;
- Frequency response: 30 Hz to 2000 Hz;
- Sensor: triple-axis (X, Y, Z);
- Accuracy (20 mG/2 uT): $\pm$ (3.0% + 30 dgt) at 50/60 Hz; $\pm$ (2.5% + 5 dgt) at 50/60 Hz; $\pm$ (5.0% + 5 dgt) at 30/2000 Hz;
- Sample rate: 2.5 times/s;
- Overload (LCD): OL displayed;
- Power supply: 9 volt battery, NEDA 1604, IEC 6F22, or JIS 006P;
- Battery life: approx. 100 h.

Appendix B

Maps of typical building floors showing locations where measurement devices were placed.

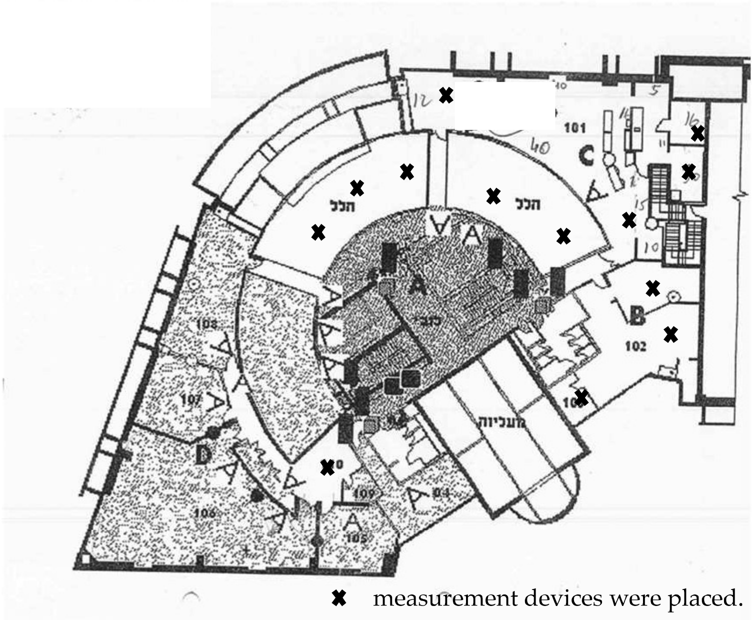


Figure A1. Floor 1.

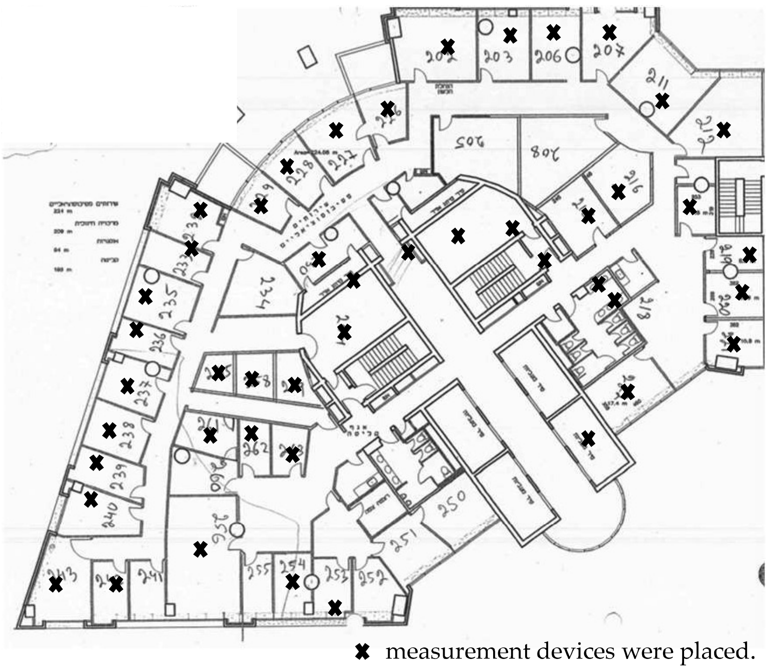


Figure A2. Floor 2.

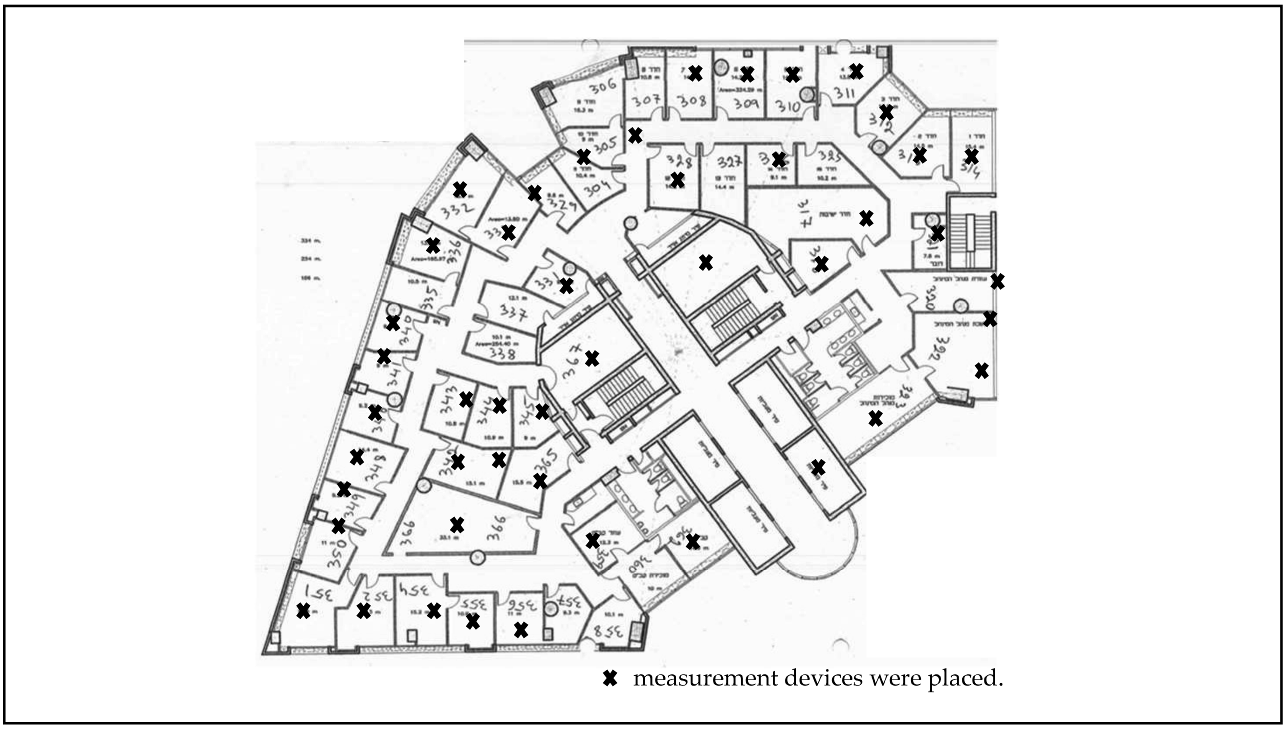


Figure A3. Floor 3.

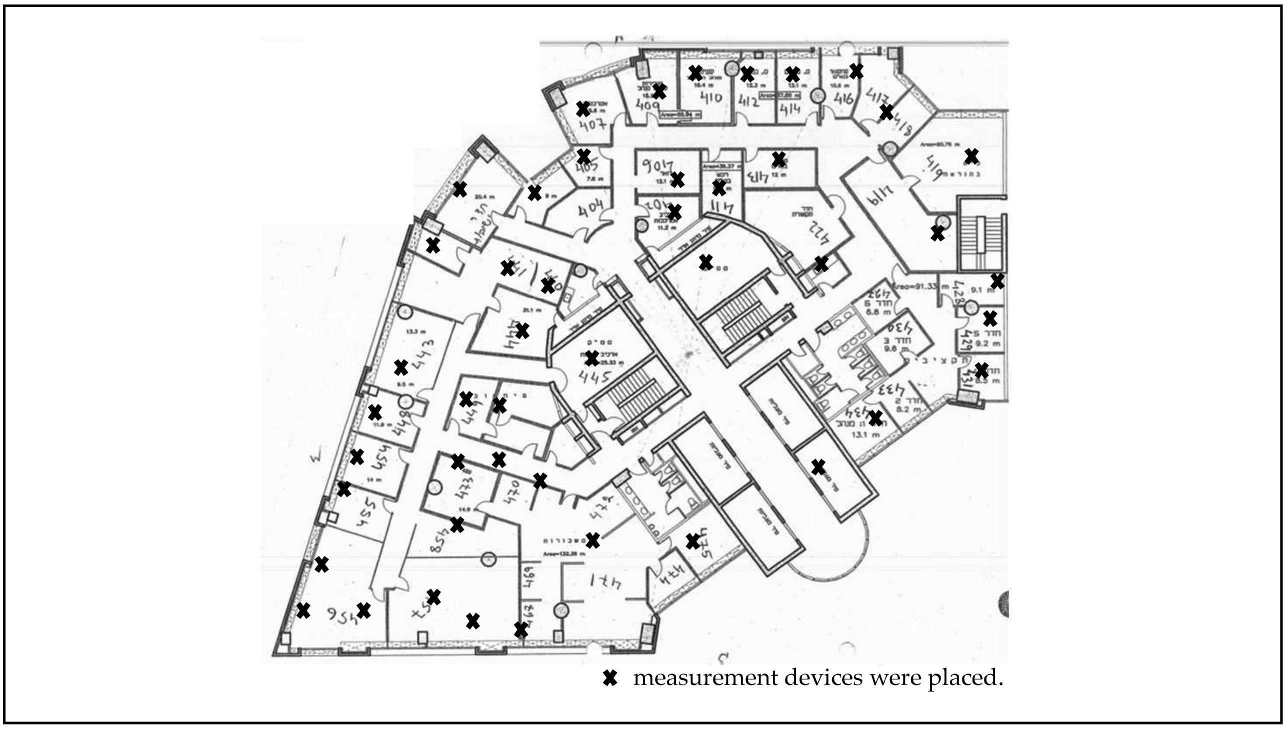


Figure A4. Floor 4.

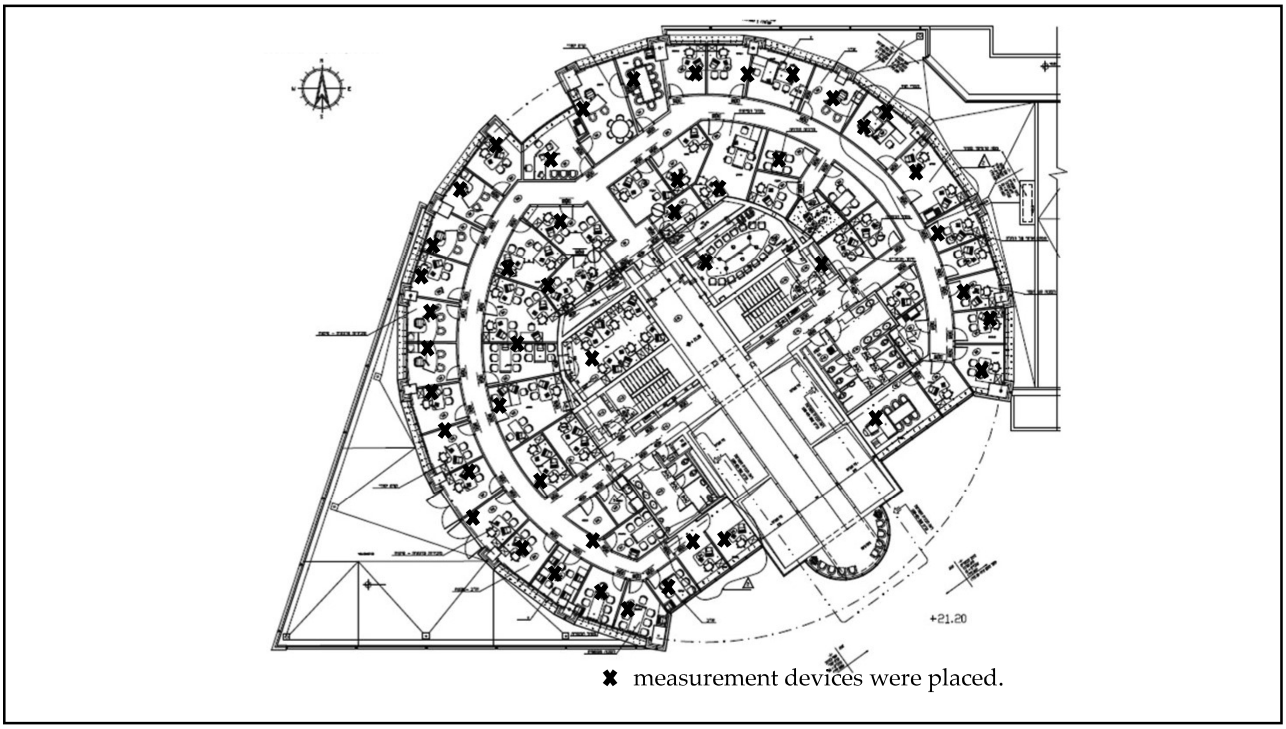


Figure A5. Floor 5.

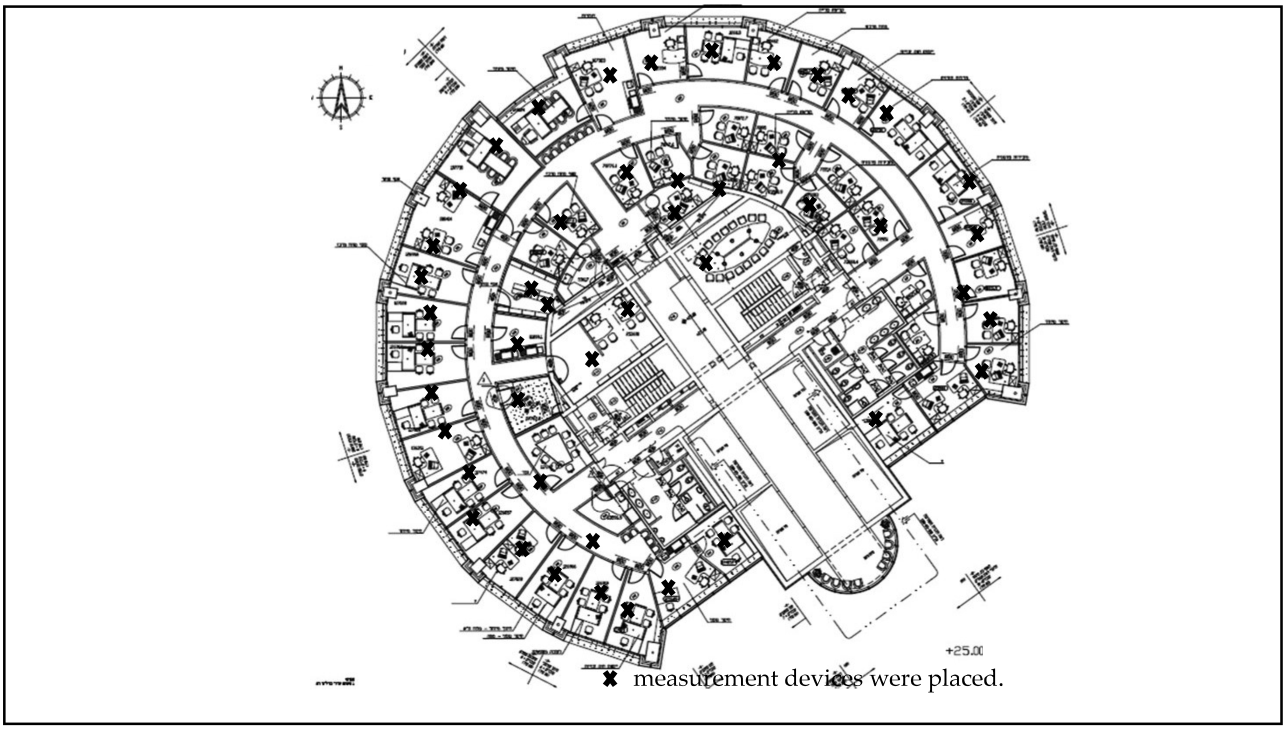


Figure A6. Floor 6.

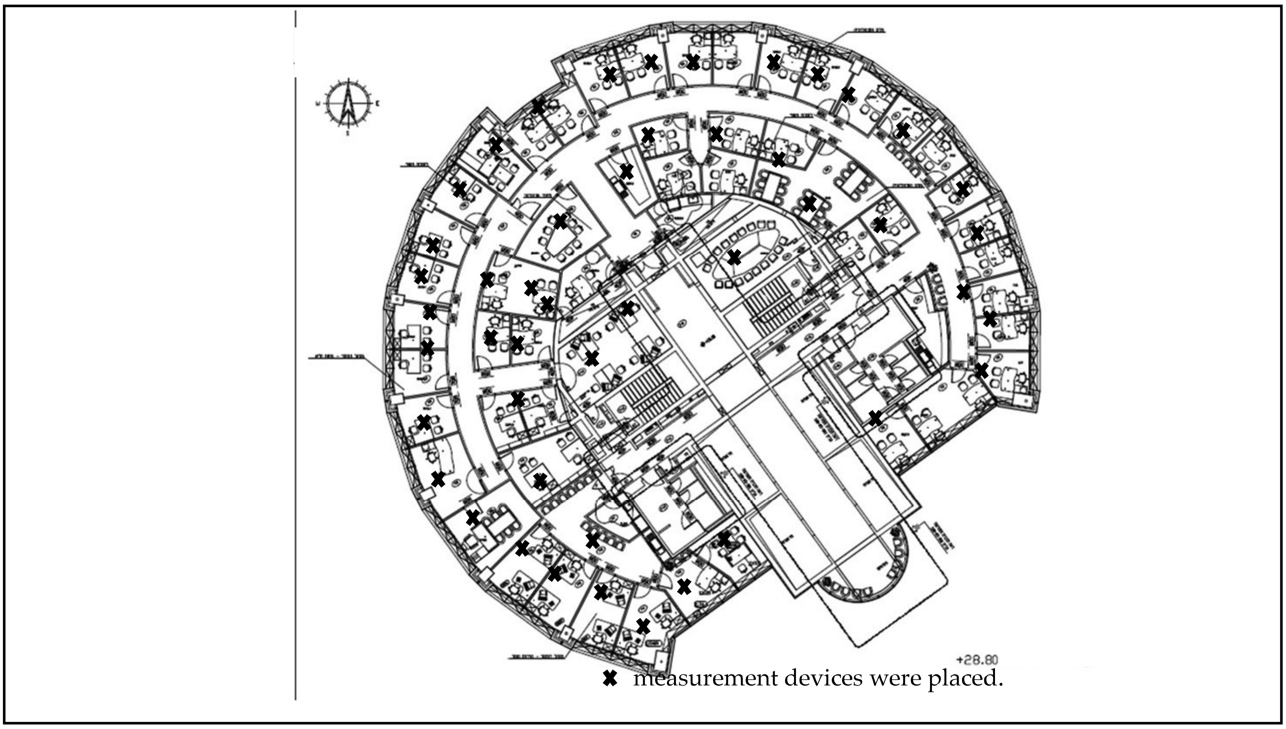


Figure A7. Floor 7.

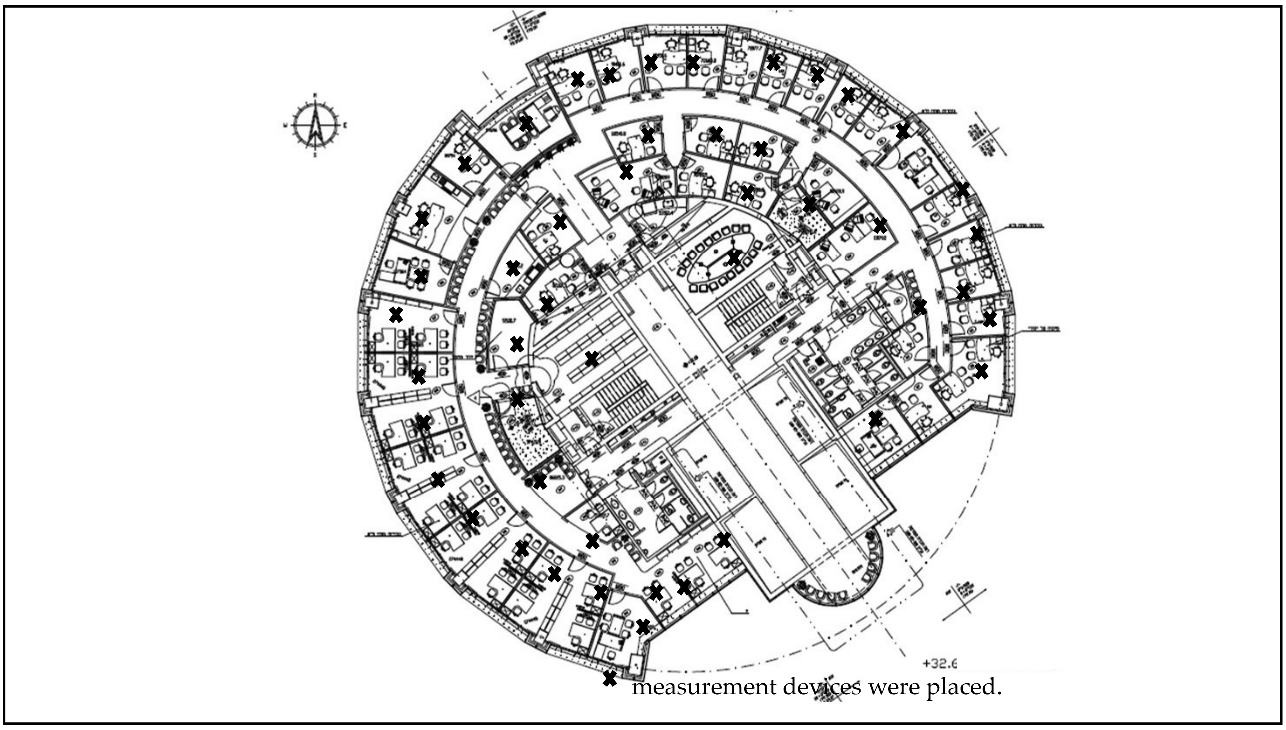


Figure A8. Floor 8.

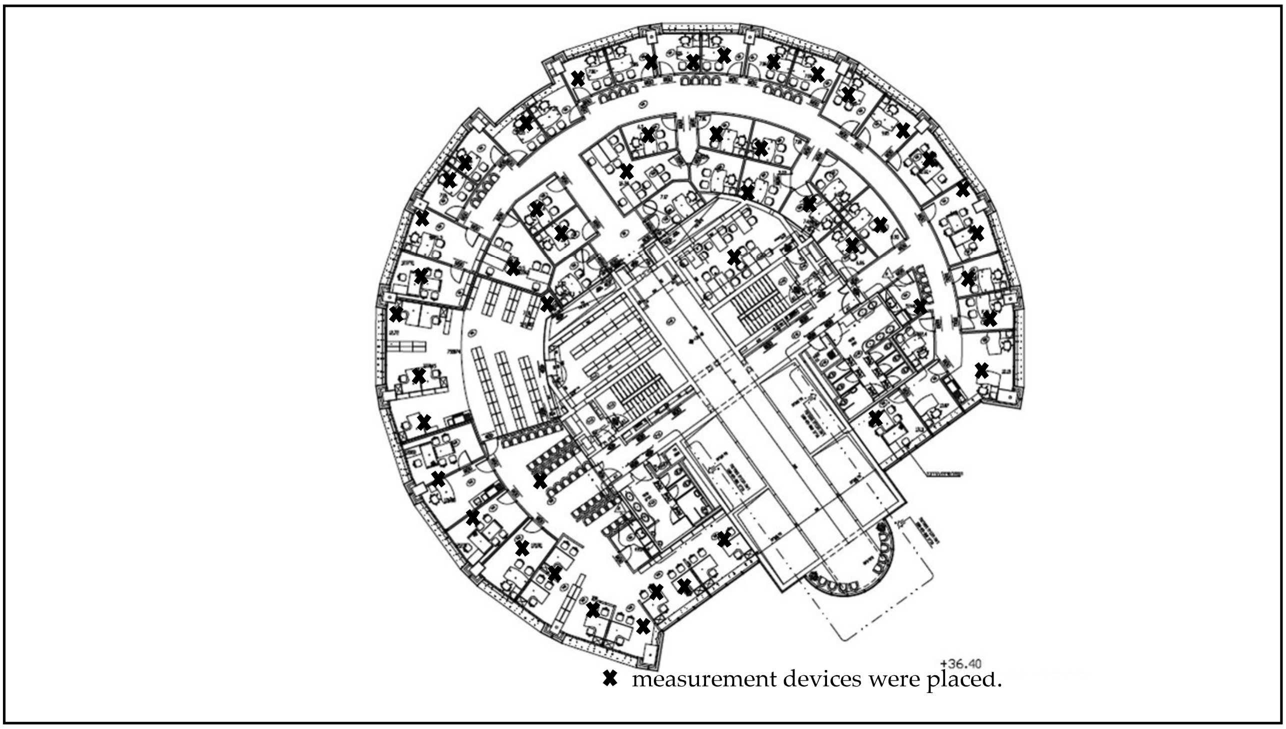


Figure A9. Floor 9.

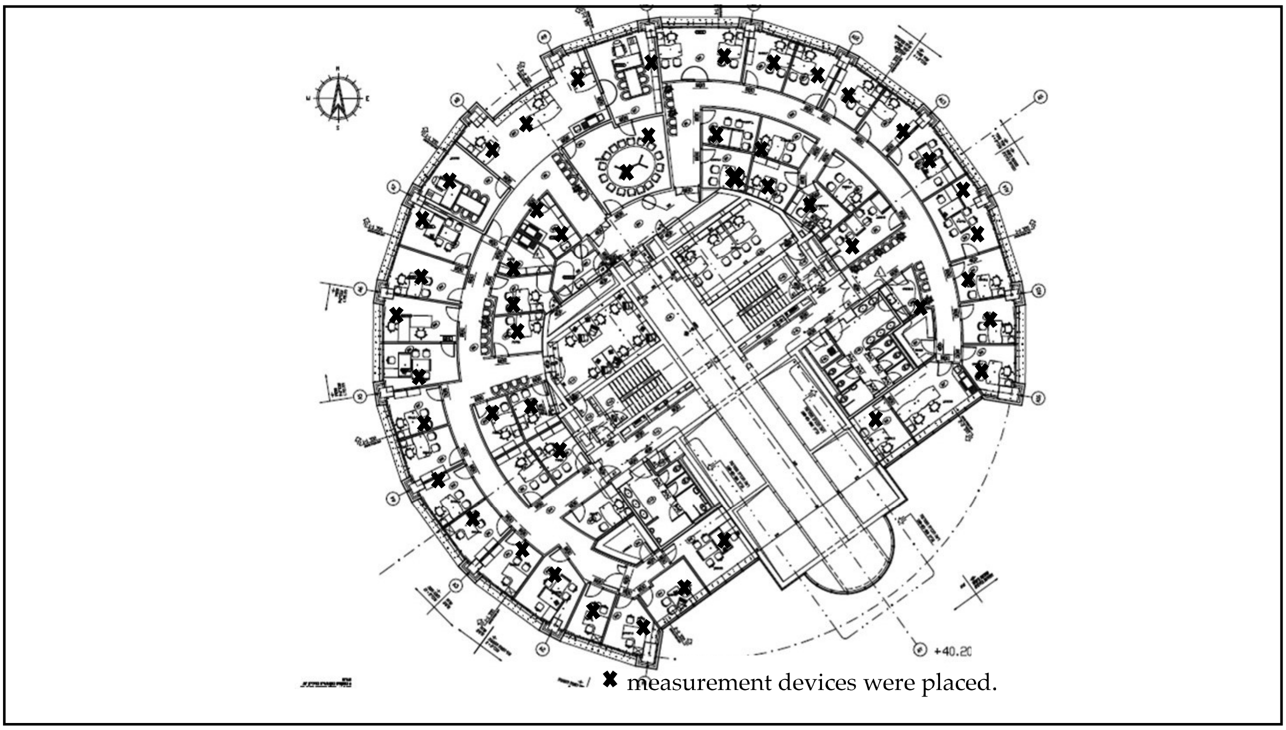


Figure A10. Floor 10.

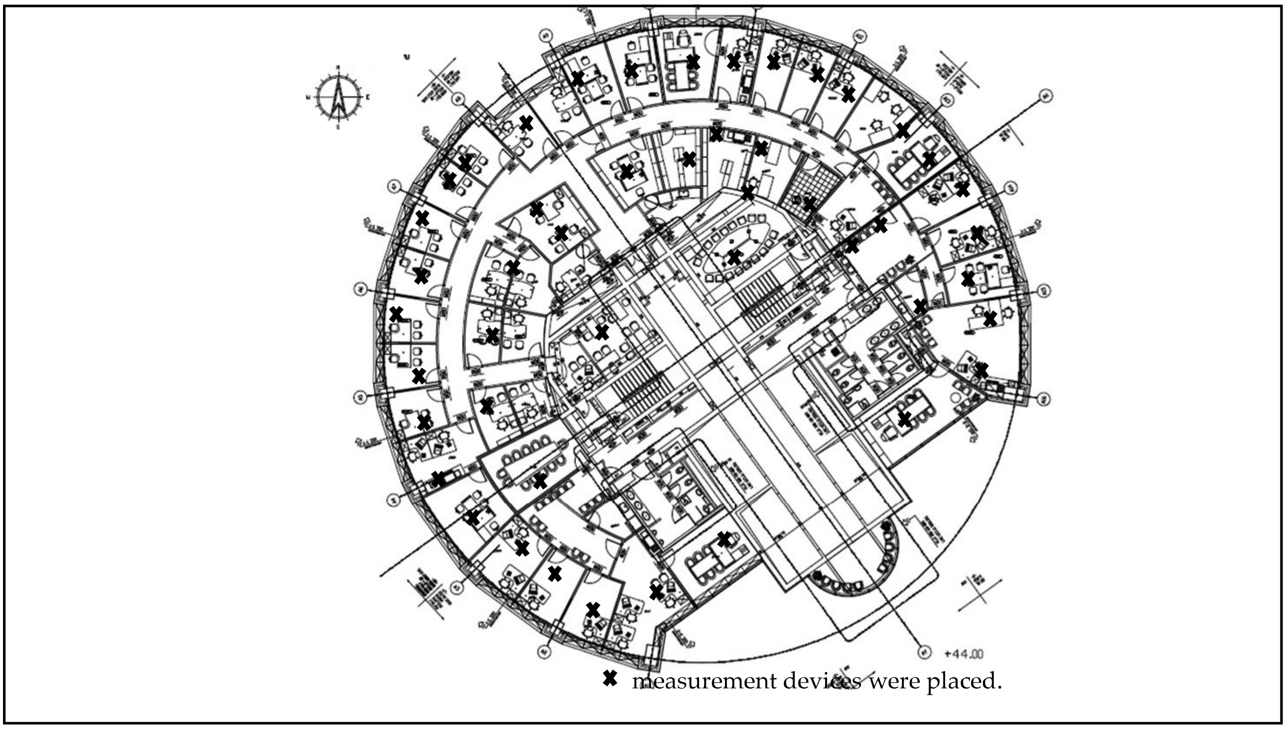


Figure A11. Floor 11.

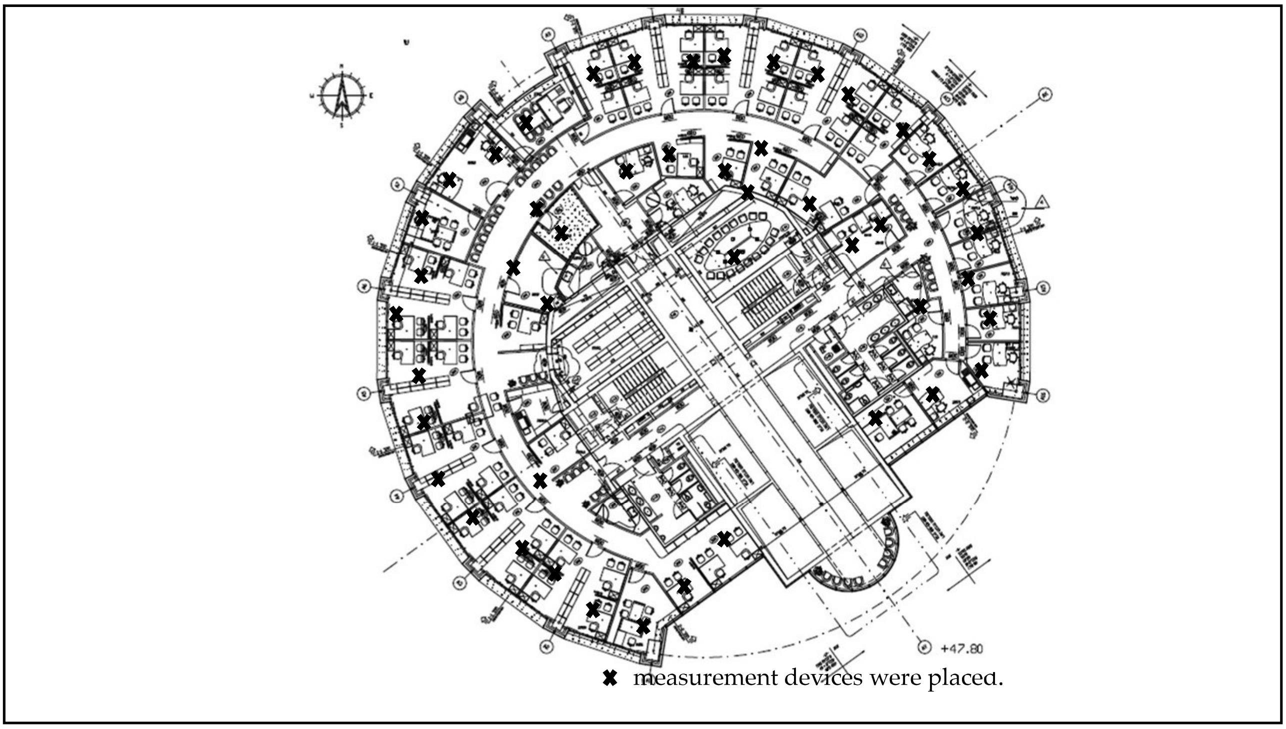


Figure A12. Floor 12.

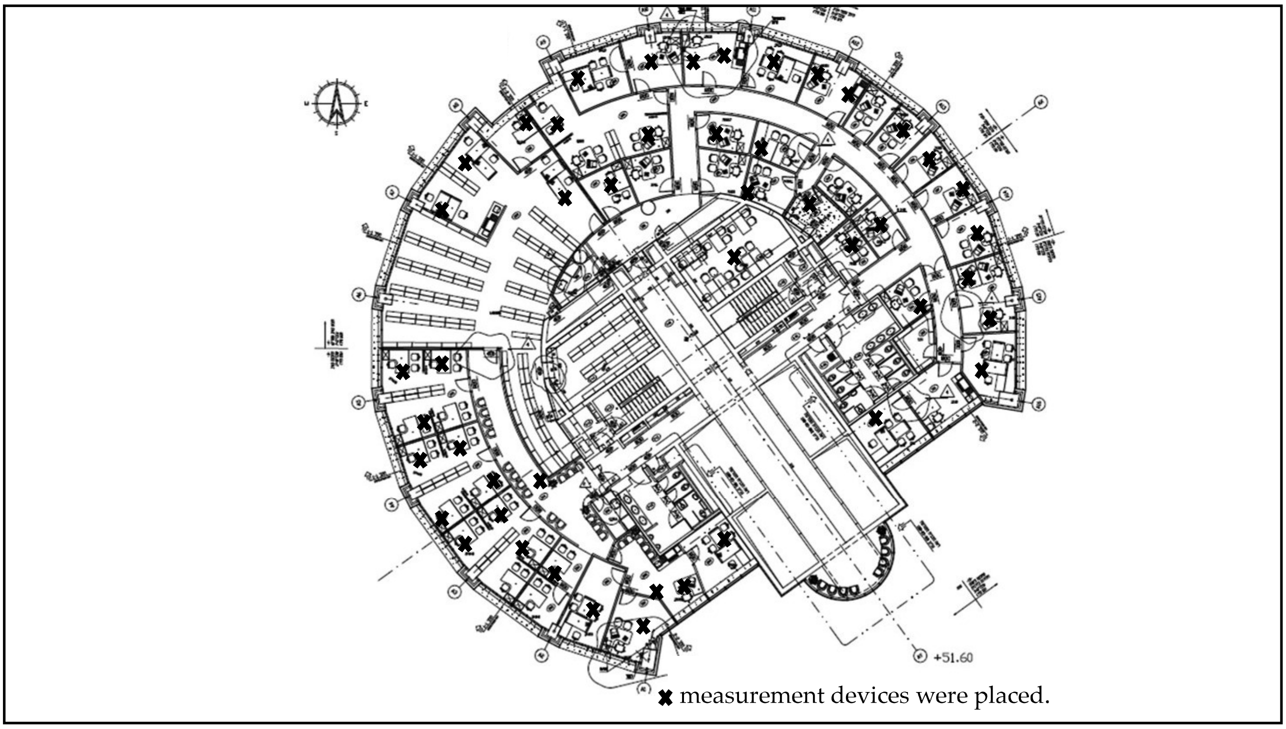


Figure A13. Floor 13.

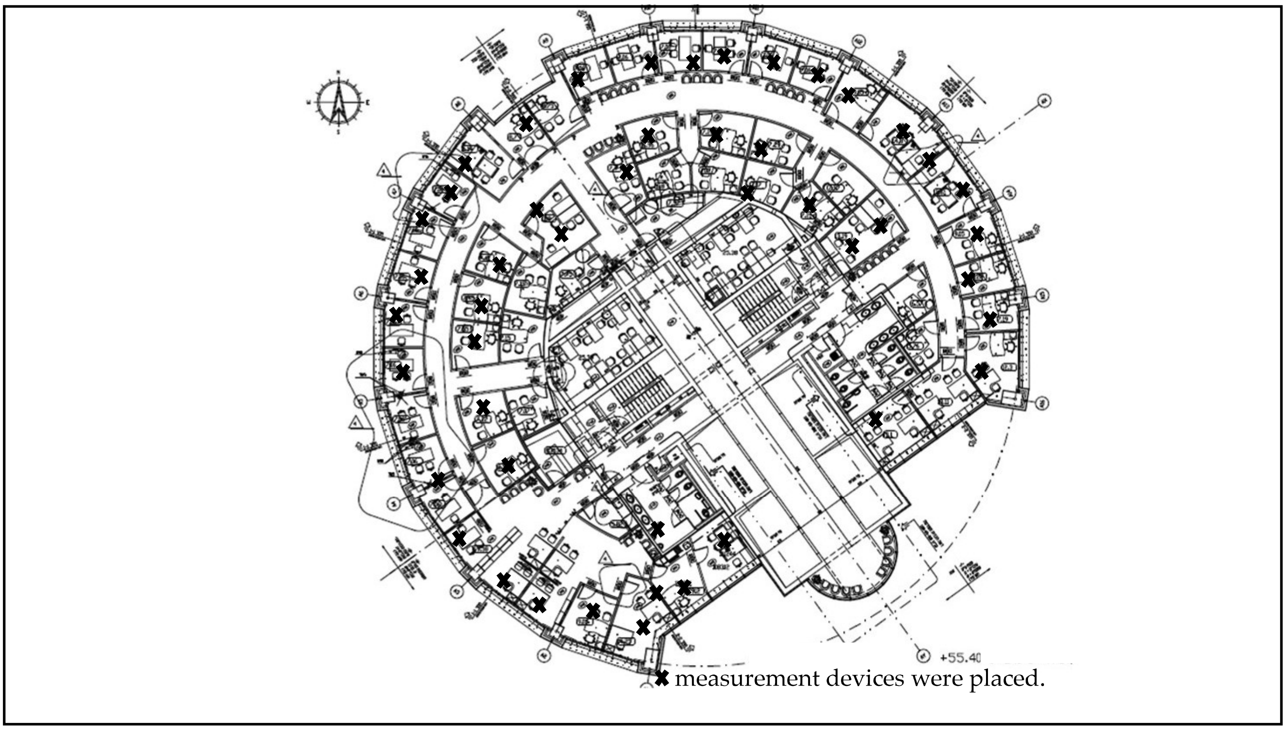


Figure A14. Floor 14.

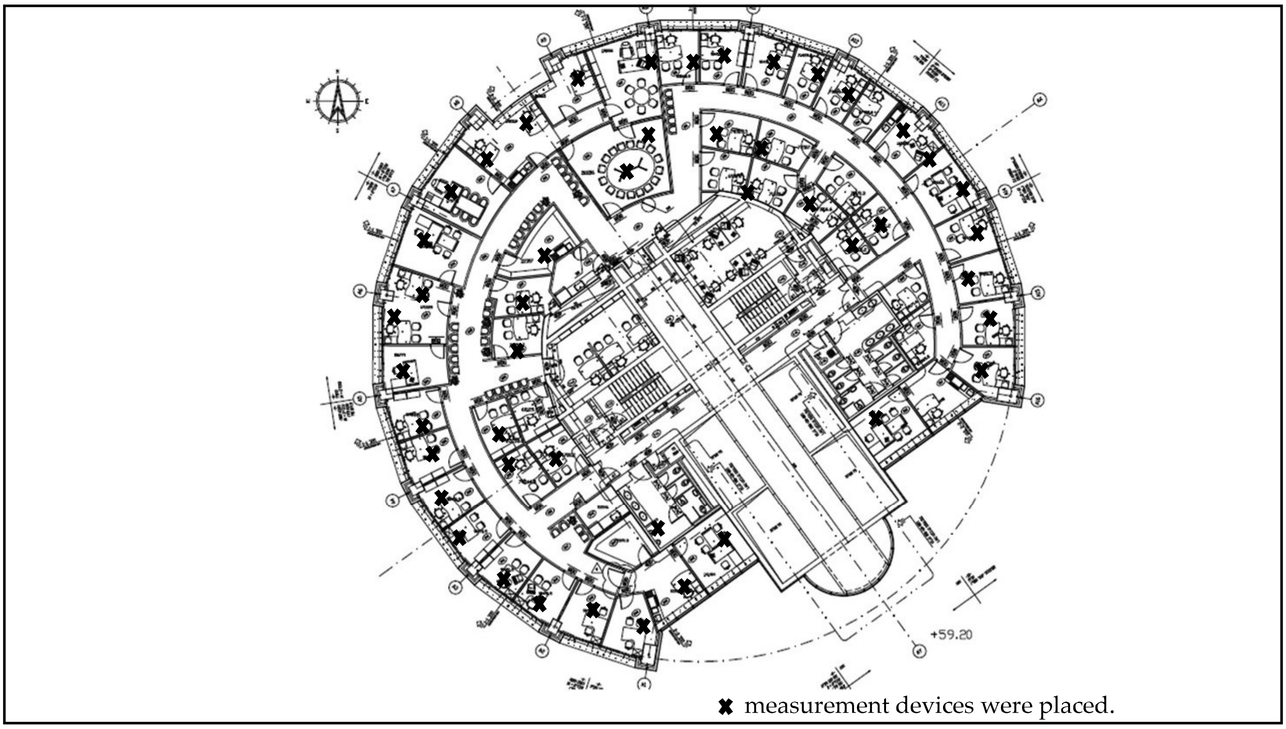


Figure A15. Floor 15.

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