Development of an Electromagnetic Pollution Rating Index for Buildings

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Abstract

Rapid technological development and the intensive use of electrical energy in buildings create electromagnetic pollution. This pollution is further intensified by external radiation from base stations and transmission lines. The World Health Organization (WHO) classifies electromagnetic field (EMF) exposure as a Class 2B carcinogen. To address this, this study proposes a novel electromagnetic pollution rating index (EPRI). This index integrates into green building certification systems, such as leadership in energy and environmental design (LEED) and building research establishment environmental assessment method (BREEAM). The EPRI methodology applies risk reduction factors (10–1000×) to international commission on non-ionizing radiation protection (ICNIRP) reference limits. A case study conducted in a 7,600 m² municipal building involves 760 measurements at extremely low frequency (ELF) and radio frequency (RF) ranges. Results reveal maximum values of 4.9 V/m and values of 0.43 μT. These qualify for the highest A+++ rating, demonstrating the practical applicability of EPRI in certifying electromagnetically clean indoor environments.

Keywords: electromagnetic radiation, green building, electromagnetic pollution rating index (EPRI), indoor environmental quality, green building certificate

1. Introduction

In recent years, Berniak-Woźny and Rataj [1], Parise et al. [2], and Hu et al. [3] studied eco-friendly and energy-efficient buildings, addressing sustainability frameworks, energy performance, and building assessment approaches. Designing green buildings is a key initiative to ensure the efficient and sustainable use of resources such as energy, water, and materials. Eco-friendly, energy-efficient buildings are generally regarded as sustainable structures. Ye et al. [4] highlighted the role of renewable energy applications in improving resource efficiency within green buildings.

Rathebe et al. [5] emphasized the importance of evaluating residential exposure to electromagnetic fields (EMFs) due to potential health impacts. Exposure to electromagnetic radiation (EMR) from various wireless communication devices is commonly assessed using the specific absorption rate (SAR). This metric represents the rate at which electromagnetic energy is absorbed by biological tissue. Carlberg et al. [9] associated long-term exposure to EMFs with potential health risks, highlighting the importance of SAR-based assessments.

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EMFs are physical phenomena that extend over space and may affect objects and living organisms within their range. Since all electrical and electronic devices are potential sources of EMR, it's important to consider the levels of EMR in residential areas when designing green buildings. Rathebe [8], Feizi and Arabi [10], and Carlberg et al. [9] reported that in some cases, field levels in residential environments can reach high levels and cause adverse health effects.

Indoor communication base antennas installed on floors and ceilings in large commercial buildings represent another significant source of indoor EMR. As electromagnetic waves can penetrate common building materials, Rathebe [8] suggested that appropriate shielding solutions should be applied in environments where exposure cannot be effectively reduced at its source.

2. Materials and Methods

2.1. Study area and data collection

This research evaluates EMR pollution at the Ümraniye district municipal building in Istanbul. The study includes systematic EMF measurements inside and outside the building. Data are classified using the electromagnetic green building index, and all levels remain below the international commission on non-ionizing radiation protection (ICNIRP) limits. This compliance aligns with the as low as reasonably achievable (ALARA) principle.

An initial assessment identifies potential EMF sources, their characteristics, and frequencies in all interior spaces and the building's surroundings. The methodology involves documenting the initial findings on the building schematic and formulating a detailed measurement plan. The implemented plan prescribes a measurement density of five locations per 100 m^2. Furthermore, the protocol requires subdividing larger areas into mapped grid sections, with five measurement points allocated to each. Establishing a formal measurement schedule and allocating adequate resources secures the project's timely completion. Ultimately, identification of the highest-signal locations in each area enables the determination of maximum individual exposure.

Measurements are taken at heights of 1 m, 1.5 m, and 1.7 m above ground using a field meter for 6-minute intervals, with average values recorded for each point. All measurements use a wooden tripod to minimize operator influence. The operator adjusts the source frequencies, levels, bandwidth, and equalizer settings and employs antennas sensitive to environmental signals when using a spectrum analyzer. If the broadband signal is insufficient or undetectable, the frequency band is controlled using the spectrum analyzer.

The validation process involves verifying the selected measurement values against theoretical calculations. Assessments include both EMF strength and power density. The complex field structure in the near-field region requires separate electric- and magnetic-field probes for broadband devices. All relevant sources are active during measurements to capture cumulative effects. Isotropic probes are employed for broadband measurements to record instantaneous, active, maximum, and time-averaged values. The measurement device logs the average power density (W/m^2, mW/cm^2), the average electric field (V/m) or its square root, and the average magnetic field (A/m, μT) or its square root. Probes are selected to match the bandwidth of environmental signals. Multiple probes are used as needed, depending on the characteristics of the electromagnetic sources.

The average measurement duration is 6 minutes, with repetitions at various intervals as required. Long-term measurements are conducted using field monitors on tripods and are monitored remotely to minimize environmental interference. The process includes the careful consideration of measurement uncertainty at every stage. Sources of uncertainty include the device, probe, operator actions, and unpredictable events. Device and probe uncertainties are determined from calibration certificates, while additional uncertainties arise from human and environmental factors, including equipment positioning, weather, and communication traffic. To address experimental uncertainties and improve robustness, measurements are repeated under consistent conditions. Comparison with previous experimental data validates the results.

2.2. Determination of the electromagnetic pollution rating index (*EPRI*)

For EMF measurement values obtained during green building inspections, the total limit values in Table 1 of the ICNIRP are used. The assessment methodology, guided by the ALARA principle, involves applying the electromagnetic risk-reduction factor (r) values from Table 2 to the data in Table 1. This process yields the EPRI, which uses the indices A+++ through B- to rate permanent living spaces according to the established evaluation categories.

The measurement procedure flow chart is shown in Fig. 1. The process includes the necessary technical evaluation and measurement steps. It specifies whether the measurement results meet the limits and which category they fall into. Based on the results obtained, the level of electromagnetic pollution is determined.

Table 1 ICNIRP reference levels for general public exposure to time-varying electric and magnetic fields (1 Hz – 3 kHz) [12]

Frequency Range	Electric Field (V/m)	Magnetic Field (A/m)	Magnetic Flux Density (T)
1 Hz-8 Hz	5000	$3.2\times10^4/f^2$	$4\times10^{-2}/f^2$
8 Hz-25 Hz	5000	$4\times10^3/f$	$5\times10^{-3}/f$
25 Hz-50 Hz	5000	1.6×10^2	2×10^{-4}
50 Hz-400 Hz	$2.5\times10^2/f$	1.6×10^2	2×10^{-4}
400 Hz-3 kHz	$2.5\times10^2/f$	$6.4\times10^4/f$	$8\times10^{-2}/f$

Table 2 EPRI risk reduction factors (r) applied to ICNIRP reference

Frequency Band	EMR Type	Ris Factor rA	EPRI Type A	Risk Factor rB	EPRI Type B
ELF	Magnetic Field	1000	A+++	200	B+++
ELF	Magnetic Field	500	A++	100	B++
ELF	Magnetic Field	250	A+	50	B+
ELF	Magnetic Field	100	A-	10	B-
RF	Electric Field	1000	A+++	200	B+++
RF	Electric Field	500	A++	100	B++
RF	Electric Field	250	A+	50	B+
RF	Electric Field	100	A-	10	B-

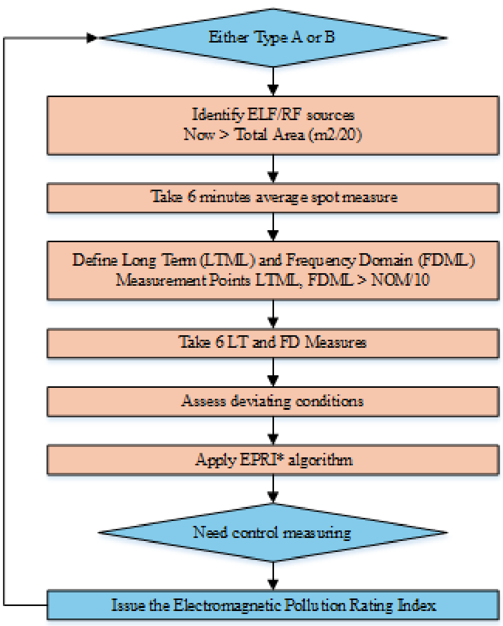

Fig. 1 Flowchart of the EMF measurement protocol and EPRI-based evaluation
(NoM: Number of Measurements)

According to the flow chart, after analyzing and defining the environment, a "Type" assessment is performed (Type A and Type B). This flowchart aims to ensure that the measurement procedure is repeatable and controllable. When the necessary control and process blocks are followed, the procedure can be applied consistently across different environments (hospitals, elderly care centers, kindergartens, etc.) as outlined in Table 2. The flowchart procedure is the same for both types.

Additionally, in environments where this process is not mandatory, responsible authorities may request a more detailed assessment by selecting the Type A option. Table 3 shows the minimum number of measurements required for Type A and Type B. According to the algorithm, the minimum number of spot measurements is determined by dividing the total covered area by 20 for Types B and A, respectively. For large areas, this assumption yields reasonable values. The methodology defines distinct risk factors for two building categories: Type A for sensitive buildings (e.g., hospitals, nurseries) and Type B for non-sensitive ones (e.g., residences, offices). Obviously, the risk factor in sensitive areas is higher than in non-sensitive areas.

Table 3 Minimum number of spot measurements required based on total covered area

Total Covered Area (m²)	Minimum Number of Measurements
Area ≤ 100	5
101 ≤ Area ≤ 200	10
201 ≤ Area ≤ 400	20
401 ≤ Area ≤ 600	30
601 ≤ Area ≤ 800	40

These rating indices are determined by dividing the values in Table 1 by the risk factor. The magnetic field effect, especially at extremely low frequency (ELF) levels, is a significant concern for human health and a key parameter for EMF measurements. Consequently, the application of higher risk reduction factors targets the magnetic field reference levels. For example, if the measurement frequency in a building is 2100 MHz, one-hundred of the ICNIRP reference level for 2100 MHz (61 V/m) is calculated (>0.61 V/m) and compared with the measurement values. If the measurement values are less than 0.61 V/m, this building attains the highest performance value, A+.

3. Results

3.1. Green building certification according to measurement results

The Umraniye Municipality Building in Istanbul, spanning 7,600 m², is selected as a case study to assess electromagnetic pollution in green buildings. The assessment follows the measurement procedure flowchart in Fig. 1. Initial observations identify that no significant external or internal EMR sources, such as base stations or high-voltage power lines, are present. These factors are deemed insufficient to influence the building's environment.

Following site identification, measurements at ELF and low frequency (LF) are performed using wide-band (1 Hz–400 kHz; 100 kHz–6 GHz) and selective frequency-separation (27 MHz–6 GHz) methods. The measurement equipment is detailed in Table 4. This assessment adopts the ICNIRP reference levels to define the exposure limits for ELF and radio frequency (RF) frequencies. The applicable limits are as follows: at 50 Hz, the public exposure magnetic field limit is 200 µT (Table 1), and at 6 GHz, the RF limit is 61 V/m. The assessment methodology applies EPRI risk index values to these exposure limits.

Table 4 Specifications of the EMF measurement equipment used in the case study

Meter Equipment	Brand	Model	Measurement Range
ELF-LF Exposure Level Tester	Narda	ELT 400	1 Hz - 400 kHz
Broadband Field Meter	Narda	NMB 550	100 kHz - 6 GHz
E Field Probe	Narda	EF 0691	0.1 Hz - 6000 MHz
Selective Radiation Meter	Narda	SRM 3006	9 kHz - 6000 MHz
E Field Probe	Narda	E-Field, T-A	27 MHz - 3 GHz
E Field Probe	Narda	E-Field, T-A	420 MHz - 6 GHz
ELF-LF Survey Meter	Holaday	HI-3604	30 Hz - 2 kHz

This study yields a dataset of 760 measurements covering both RF and ELF frequency ranges. Electric and magnetic field values are provided in Table 5. The highest electric field value, 4.9 V/m, is recorded during a 6-minute measurement at the Human Resources Office on the 8th floor, adjacent to the Ç amlica Tower. This value corresponds to the frequency modulation (FM) radio broadcasting signals. Fig. 2 presents the frequency distribution of the EMF measurements taken at the Urban Renewal Office on the 3rd floor, and Fig. 3 presents the frequency distribution of EMF measurements taken at the Deputy Mayor's office on the 5th floor.

Table 5 Low and high-frequency electromagnetic radiation spot measurement values

Floor	Location	Number of Measurements	Magnetic Field (ELF)	Electric Field (RF)
-2	Car parking area	40	0.43 µT	2.9 V/m
-1	Drivers' lounge, cafeteria	30	0.28 µT	2.9 V/m
0	Finance department, property assessment office, security office	30	0.19 µT	2.0 V/m
1	Head of the municipal enforcement office, deputy mayor office	30	0.21 µT	3.8 V/m
2	Urban renewal, planning, and mapping office, structural and mechanical office	30	0.17 µT	2.9 V/m
3	Urban design department, public works office, transportation services	25	0.22 µT	3.9 V/m
4	Business and affiliates department	25	0.18 µT	0.7 V/m
5	Support service, deputy mayor office II, Strategy Development Department	20	0.17 µT	3.7 V/m
6	Contraction control office, social support services	20	0.13 µT	3.2 V/m
7	Library, legal affairs department, cleaning service	30	0.17 µT	0.4 V/m
8	Department of media and communications, human resources office	25	0.13 µT	4.9 V/m
9	Veterinary services department, tender unit, feasibility and project development office, international relations office	30	0.11 µT	3.8 V/m
10	Department of planning and projects, deputy mayor's office III, board of inspection	25	0.15 µT	2.8 V/m

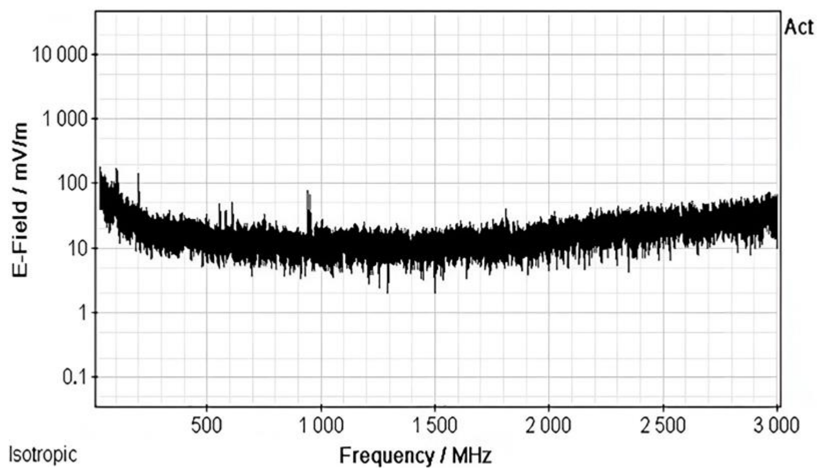

Fig. 2 EMF spectrum measurement at the Urban Renewal Office (5th Floor)

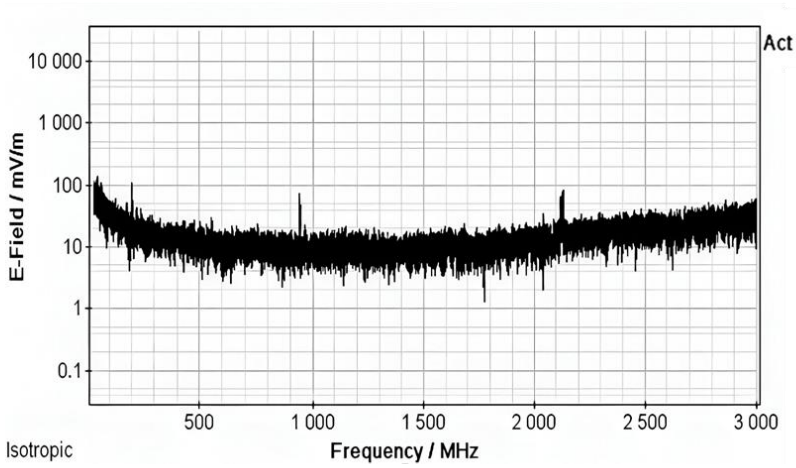

Fig. 3 EMF spectrum measurement at the Deputy Mayor's Office (3rd Floor)

4. Discussion

The development and implementation of a novel EPRI framework demonstrates its practical application in a real-world municipal building. The discussion interprets these findings, contextualizes them within the broader literature, and examines the implications of the proposed methodology.

Transforming the precautionary ALARA principle into a concrete assessment tool represents a key contribution to green building science. International guidelines such as those from ICNIRP [12-14] and the EU Directive 2013/35/EU [15] establish exposure limits based primarily on thermal and electrostimulation effects. However, they do not directly address the long-term biological concerns raised by agencies like IARC (Group 2B classification) or the BioInitiative Working Group [17].

By introducing significant reduction factors (r=10-1000), the EPRI bridges this regulatory gap. This approach aligns with the calls from researchers such as Lai and Singh [18,19] and Levitt et al. [24,25]. They recommend treating ambient EMF as environmental pollution requiring proactive management, particularly in sensitive environments such as sleeping areas, hospitals, and schools.

Evidence from the case study supports the framework's feasibility. All measured EMF values remain substantially below the A+++ rating thresholds. The highest measured electric field value of 4.9 V/m, attributed to FM broadcasting, is considerably lower than the ICNIRP public reference limit, confirming that low-EMF indoor environments can be achieved using current construction practices.

The framework's methodological strength lies in its replicable measurement protocol, which differentiates between area types (sensitive vs. non-sensitive) and ensures comprehensive spatial sampling. Nevertheless, the index currently relies exclusively on ambient field measurements. Future refinements could incorporate dosimetric metrics such as SAR, while further toxicological and epidemiological research could help refine frequency-specific reduction factors.

5. Conclusions

This research addressed a critical gap in green building certification systems by developing and validating the EPRI. The study integrated principles from the ALARA framework and biological effects research to establish exposure thresholds. Through systematic EMF measurements in a 7,600 m^2 municipal building, the practical applicability of the EPRI methodology was successfully demonstrated. Based on these findings, the following conclusions can be drawn:

(1) Gap in current standards: Most green building rating tools do not consider EMF pollution as part of indoor environmental quality. This study highlights and addresses this gap, recommending the inclusion of EMF control in sustainable building design.

(2) Novel precautionary framework: The proposed EPRI adopts a precautionary approach by prioritizing non-thermal biological effects. It sets stricter exposure limits than the thermally-based ICNIRP guidelines, reducing them by factors of 100 to 1000 for sensitive areas and by 10 to 200 for other building zones.

(3) Practical and applicable tool: The index offers a transparent methodology for measuring, evaluating, and rating EMF levels in buildings. Its successful use in a municipal building case study validates its practical value.

(4) Validation through case study: Field measurements from the municipal building confirmed the framework's effectiveness. The building's low EMF levels earned an A+++ rating, showing how the EPRI can benchmark and recognize electromagnetic cleanliness.

(5) Broader implications: Including the EPRI in major green building certifications, such as BREEAM or LEED, can encourage the design. This integration promotes the construction of buildings that are both energy-efficient and support long-term occupant health related to EMF exposure.

Conflicts of Interest

The authors declare no conflict of interest.

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