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Health impact of energy use in buildings: Radiation propagation assessment in indoor environment

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Abstract

Energy has become an essential part of today's lifestyle, especially for using the electronic appliances in homes, offices and other built environments in a daily basis. Although in modern life, electronic devices have become ubiquitous, the excessive electromagnetic radiations from these appliances may cause potential health effects. Realizing this significance, a systemic and comprehensive assessment was performed to study the radiation propagation generating from the energy based electric appliances. Along with measuring the radiation exposure in buildings, this study examined how the radiation propagation varies with different construction materials. Moreover, radiation associated human health impacts were also investigated. Evaluation of five building environment demonstrated that drywall acted as the best shielding object (transmission coefficient: 18% electric field strength) whereas lumber and glass wall acted as the poor shielding material (96% and 97% electric field strength respectively). Comparison with the standard values specified by international authorities showed lower field strength values for some regulatory institute, although these values were higher compared to some more restricted safety levels in some countries, indicating the possible human health impacts in the assessed built environment. Hence, this study recommends utilization of proper shielding materials, maintaining exposure distance along with exposure duration reduction.

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Keywords: Green building; Indoor environmental quality; Human health; Electromagnetic radiation; Spatial design

1. Introduction

Energy has become an essential part of today's lifestyle, especially for using the electronic appliances in homes, offices and other built environments in a daily basis. In case of EU households, nearly a quarter of total energy use is attributed to the electronic appliances, even more for the case of Sweden (almost near to the half of the total energy in house) [1]. Although in modern life, energy use for the purpose of electronic devices has become ubiquitous, the excessive electromagnetic radiations from these appliances may cause potential health effects [2]. Possible associations between exposure to electromagnetic fields (EMFs) and human health have been examined by

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several epidemiologic studies [3–5]. Few studies found that extremely low frequency (ELF) fields are carcinogenic [6,7]. Continuous review of the epidemiological studies has revealed the link between minimum radiation exposure for children and the increased risk of severe diseases, such as leukemia [8,9].

In most Green Building Rating Systems, indoor environmental quality (IEQ) has been recognized as one of the credit categories to provide a better and healthy environment for the occupants [10]. Currently, the electromagnetic field (EMF) aspect of indoor environment for conventional as well as green building occupants is largely overlooked [11]. People living in extreme weather zones (excessive hot and cold regions) generally tend to spend more time in indoor spaces compared to the people in countries with better weather pattern. Currently, the standard regulations available for radiations in built environment do not completely protect the occupants from the biological as well as the other health impacts caused by the EMFs, and the focus has been largely on avoiding electric shocks [6]. Non-ionizing electromagnetic radiation sources can have clinical importance because a small increase in exposure can cause health hazards [12,13]. Incorporating issues of EMF radiations in the design of built environment can minimize the impact of energy use in buildings as well as can have significant improvement in reducing the health hazards of the occupants [14]. This study quantifies the EMF concentration in several built environments including green buildings, examines the human health hazards, and develops strategical frameworks to enhance the building IEQ.

2. Materials and methods

2.1. Non-ionizing radiations

The entire electromagnetic spectrum encompasses several energy forms including electricity and microwaves at higher wavelength end (low frequency end) and x-ray and gamma ray at lower wavelength end (high frequency end). These extremely low frequency radiations (non-ionizing radiations) are invisible form of energy that can be found in household electricity [2,15]. Both electric and magnetic fields are produced in different built environment as a result of electric transmission for different electronic appliances. These two fields together form EMFs where electric field can be easily blocked by construction materials, however, magnetic fields have highly penetrating nature. EMF radiation can propagate from any external as well as internal sources in a building environment. In this research, we focus on a range of low frequency to high frequency radiation propagation, defined as 50 MHz to 3.5 GHz respectively.

2.2. Case study selection

This research considered residential (R), hospital (H), office (O), and school (S) and entertainment centers (E) building environments inside Qatar Foundation, Doha as the case studies to assess the importance of spatial design. Both conventional and green buildings were investigated in this study. To understand the propagation nature of EMF fields, several building materials were investigated e.g. plain concrete, glass, lumber, drywall which are mainly used for partition purpose.

2.3. Experimental details

Triple axis RF meter (HF-B3G) has been employed in this study to investigate both electric and magnetic field strength in the above-mentioned indoor environments. For high frequency radiations, the power density has also been measured in building spaces where power density can be defined as the power (time rate of energy transfer) per unit volume. When an occupant is exposed in the EMF field, power density indicates the amount of power absorbed by the occupant.

The triple axis RF meter installation followed the rule of device placement at 1.5 m above the ground and 0.5 m away from nearby electronic appliances under investigation, by securing the device in a tripod to avoid any risk. In case of outdoor EMF measurement, the device was horizontally positioned 5 cm away from the partition wall. The maximum average value was considered which indicates the median of the all highest intensities found at different times and locations. Moreover, these intensity value measurements were performed for six minutes. In addition, different building materials were assessed to determine the permeability. Permeability, or the transmission coefficients, indicates the construction material's ability to propagate the EMF radiation. Comparison of the inside and outside intensities provides the permeability value for the reference building space.

Table 1. Maximum average intensity level in surveyed building spaces for mid to high frequency.

Building space	Type of investigated electronic appliances in indoor environment	Electromagnetic emission intensity					
		Electric field strength (mV/m)		Magnetic field strength (mA/m)		Power density (mW/m^2)	
		High	Low	High	Low	High	Low
H1	Wi-Fi devices, cell phones, cordless telephones, smart meters, and portable wireless devices	7454	2449	19.77	6.496	85.32	10.00
H2	Wi-Fi devices, cell phones, cordless telephones, smart meters, and portable wireless devices	3416	701.60	9.061	1.861	23.09	1.24
H3	Wi-Fi devices, cell phones, cordless telephones, smart meters, and portable wireless devices	1886.9	1485.5	5.005	3.940	6.401	5.98
H4	Wi-Fi devices, cell phones, cordless telephones, smart meters, body scanners, diagnostic X-ray radiography equipment, and computers	4102	2,81	10.88	7.459	29.01	19.10
H5	Wi-Fi devices, cell phones, cordless telephones, smart meters, radiography, CAD/CAM, delivery systems, treatment centers, and computers	2117	1699.7	5.615	4.508	9.202	5.29
O1	Wi-Fi devices, cell phones, cordless telephones, and portable wireless devices	9148	6250	24.26	16.580	130.8	61.20
O2	Wi-Fi devices, cell phones, cordless telephones, and portable wireless devices	1883	1065	4.995	2.825	8.451	1.77
O3	Wi-Fi devices, cell phones, cordless telephones, smart meters, and portable wireless devices	1742.3	1067.3	4.621	2.831	5.701	1.85
O4	Wi-Fi devices, cell phones, and portable wireless	1634	982.90	4.334	2.600	4.594	1.66
R1	Wi-Fi devices, ovens, cell phones, cordless telephones, smart meters, radio and television signals, and computers	13,913	6687	36.90	17.74	297	71.30
R2	Wi-Fi devices and smart meters	7525	818.7	19.96	2.172	100.6	1.29
R3	Wi-Fi devices, ovens, cell phones, cordless telephones, radio and television signals, and computers	4120	490.5	10.93	1.301	28.26	0.38
R4	Wi-Fi devices, cell phones, radio and television signals, and computers	1991.2	1415	5.282	3.753	8.845	3.12
S1	Wi-Fi devices, cell phones, smart meters, spy cameras, and computers	18,122	1267.4	48.07	3.362	503.9	3.00
S2	Wi-Fi devices, cell phones, smart meters, spy cameras, and computers	3789	1780.7	10.05	4.723	26.54	6.48
E1	Wi-Fi devices, cell phones, cordless telephones, smart meters, and radio and television signals	2555	1255.9	6.778	3.331	10.61	2.65

Note: H: Hospital; O: Office; R: Residential; S: School, E: Entertainment.

3. Results and discussions

3.1. Monitored emission intensity level

A total 5 types of building (16 different buildings) were assessed to investigate the EMF radiation propagation and approximately 480 measurement data were collected. Within the investigated buildings, EMF radiation intensities fluctuated significantly. Therefore, the location and time averaged median values have been represented in this study. Both highest and lowest values for electric and magnetic field strength as well as power density values have been listed in Table 1. Analysis of the intensity data revealed the comparatively lower EMF emission intensity in investigated office buildings, except for the case O1. Generally, the limited number and variation of electronic appliances within the office spaces were indicated as the reasons for the lower EMF intensity levels in those office premises. On the other hand, much higher EMF radiation intensities were found in household, health care and educational institute buildings compared to the office buildings. Table 1 data indicated that among the similar building category, the lowest intensity value found in one building can be greater than the highest intensity value of another building and vice versa. This variation of intensities is due to the different type of radiation emission sources in each indoor spaces of the investigated buildings. Health care buildings generally require a large number of various electronic appliances and thereby, investigation of such buildings resulted in higher power density levels.

Significantly higher electric and magnetic field strength as well as much higher power density was found for the case S1 compared to the all investigated indoor spaces. The reason was indicated as the use of high-frequency radiation sources such as security camera, projectors, Wi-Fi devices and computers in S1. Similarly, investigation of S2 showed comparatively higher power density due to the presence of security cameras, smart meters for lab set-up, and large number of computers. Moreover, higher values of EMF radiation intensity in R1 and R2 raised high concern as these two buildings are recognized as the 'Green Buildings' which indicates that the green buildings are also responsible for radiation exposure and cannot always provide health safety in terms of EMF emissions.

3.2. Spatial design response to radiation propagation

In any building environment, variation in location and use pattern of electronic appliances results in different exposure levels. In this section, permeability of different construction materials was assessed employing the methodology of comparing indoor and outdoor building intensities (Table 2). The external building environment was controlled by keeping it to minimal radiation source almost in all surveyed areas. Compared to the controlled environment, emission in indoor spaces was found much higher which indicates the necessity of exterior shielding material that ensures lower intensity level for controlled environment.

Table 2. Permeability of building wall materials (EFS: Electric field strength, MFS: Magnetic field strength, PD: Power density).

Study	Type of building envelope/wall	Thickness (cm)	Maximum transmission coefficient			Study	Type of building envelope/wall	Thickness (cm)	Maximum transmission coefficient		
			EFS (%)	MFS (%)	PD (%)				EFS (%)	MFS (%)	PD (%)
H1	Plain concrete wall	20	66	66	41	O4	Lumber wall	6	96	96	97
H2	Lumber-faced concrete wall	56	86	86	77	R1	Ceramic-faced lumber wall	5	23	23	7
H3	Glass wall	1	97	97	71	R2	Lumber wall	6	95	95	84
H4	Concrete-faced lumber wall	63	88	88	76	R3	Drywall	20	23	23	5
H5	Concrete wall	20	78	78	51	R4	Tile-faced drywall	25	64	64	43
O1	Drywall	24	18	18	4	S1	Lumber wall	33	70	71	57
O2	Glass-glazed drywall	24	73	73	57	S2	Drywall	25	72	72	43
O3	Glass wall	2	74	79	59	E1	Masonry-faced concrete wall	43	60	60	37

In contrast, the intensity measured at the external environment for the cases of O3, O4, and R3 was greater than the indoor environment. This was caused by waves propagating to the uncontrolled space from adjacent emission sources. Analysis of data in Table 2 revealed that the transmission coefficient significantly differed among building areas. Response analysis of construction materials showed the response of R1, R3, R4, H1, O1 and E1 were better compared to the rest of the building spaces. On the other hand, in the case of S2 the propagation of power density was significant. However, the response of construction materials applied in the case of O4, H2, H3, and R2 were not strong enough as these materials permitted passing of significant amount of EMF across the controlled external building environment. These events indicate that in the case of EMF propagation a much improved shielding condition can be achieved by using drywall, tile-faced drywall, ceramic faced wall, masonry or plain faced concrete walls, whereas glass wall and lumber wall showed the opposite nature. Hence, construction of sensitives areas in indoor spaces which demand lower EMF radiation propagation, should always avoid the use of lumber or glass walls.

3.3. Health impacts

Safety limits and guidelines indicate the emission intensity limit tends to protect humans from the harmful exposure to EMFs [16]. Developed countries such as USA, Canada and some countries in Europe follows

Table 3. Measured exposure levels compared to safety levels (E: Electric field; H: Magnetic field; S: Power density).

Building	Surveyed spaces			Compared to ICNIRP			Compared to Russia, Bulgaria, Poland			Compared to Switzerland		
	E (mV/m)	H (mA/m)	S (mW/m^2)	E (mV/m)	H (mA/m)	S (mW/m^2)	E (mV/m)	H (mA/m)	S (mW/m^2)	E (mV/m)	H (mA/m)	S (mW/m^2)
H1	7454	20	85	53 546	140	9915	−6234	62	15	−1354	−12	−40
H2	3416	9	23	57 584	151	9977	−2196	73	77	2684	−2	22
H3	1887	5	6	59 113	155	9994	−667	77	94	4213	2	39
H4	4102	11	29	56 898	149	9971	−2882	71	71	1998	−4	16
H5	2117	6	9	58 883	154	9991	−897	76	91	3983	2	36
O1	9148	24	131	51 852	136	9869	−7928	58	−31	−3048	−17	−86
O2	1883	5	8	59 117	155	9992	−663	77	92	4217	2	37
O3	1742	5	6	59 258	155	9994	−522	77	94	4358	3	39
O4	1634	4	5	59 366	156	9995	−414	78	95	4466	3	40
R1	13 913	37	297	47 087	123	9703	−12 693	45	−197	−7813	−30	−252
R2	7525	20	101	53 475	140	9899	−6305	62	−1	−1425	−13	−56
R3	4120	11	28	56 880	149	9972	−2900	71	72	1980	−4	17
R4	1991	5	9	59 009	155	9991	−771	77	91	4109	2	36
S1	18 122	48	504	42 878	112	9496	−16 902	34	−404	−12 022	−41	−459
S2	3789	10	27	57 211	150	9973	−2569	72	73	2311	−3	18
E1	2555	7	11	58 445	153	9989	−1335	75	89	3545	1	34

the regulations of EMF emission developed by International Commission on Non-Ionizing Radiation Protection (ICNIRP) [16–18]. However, in Russia, Poland and Bulgaria the safety standards are more rigorous compared to ICNIRP [16,19]. Table 3 represents the exposure values collected from the investigations and some international standards for comparison. Compared to the ICNIRP standard values, all case study data showed considerably lower intensities, indicating safe indoor environment. However, the measured electric field strengths were found much higher compared to the limits set by the other European countries (Poland, Russia and Bulgaria) where the magnetic field strengths were within the limit. Moreover, for some cases such as S1, O1, R1, R2 the power density values exceeded the standard limits. Hence, the measured EMF intensity values have significant importance to prevent the occurrence of any health hazards due to radiation propagation. Again, the exposure intensities for some case studies were higher compared to Switzerland standard limits, which implies health concerns.

4. Conclusions

The use of electronic appliances and its impact in built environment is receiving considerable attention in recent years. This study aimed to present a novel perspective that will help to understand the linkages that connect the IEQ and EMF exposure in buildings. Hence, this work included different building environments (conventional as well as green buildings) to study and develop a novel approach. Study results summarized that relatively lower EMF emission intensity was found in office premises and comparatively higher power density values were found in hospitals. Moreover, green building assessment resulted in high EMF emission that indicated the significance of this novel approach to examine and thereby reducing the EMF radiation propagation. Examination of different building materials revealed that materials such as ceramic faced lumber, drywall, tile-faced drywall, and masonry or plain faced concrete showed high shielding effect while glass and plain lumber wall showed the opposite. Therefore, this study highly recommended the design of sensitive areas in building's with drywall or ceramic or plain/masonry faced concrete walls. Also, this study listed some strategies to improve IEQ including utilization of proper shielding materials, maintaining exposure distance along with exposure duration reduction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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