The Environmental Radiation Pollution in Urban Buildings

تلوث البيئة الإشعاعي في الأبنية الحضرية

By:

Wajih Basem Al Smadi

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Dissertation Supervisors

Dr. Alaa A-Ameer

Dr. Haşim Altan

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Abstract

Indoor environmental quality is essential in urban buildings. Health of occupants depends greatly on factors related to air quality and space maintenance. However, a new form of pollution has emerged in developed nations due to the excessive use of electric and electronic products. This pollution is caused by the unavoidable emanation of electromagnetic fields in the free air and space penetrating the living organisms and causing adverse health effects over the long term. The design and construction studies do not sufficiently account for the radiation-intoxication issues within the indoor environments due to the lack of awareness on the importance of the electromagnetic radiation field. This dissertation reviews the latest literature on the indoor environmental radiation and its health implications. The research experimental study gives an overview on simple procedures to measure, identify and discuss the RF radiation in two residential apartments. Results of this study are compared to the international standards on exposure limits and addressed accordingly in the analysis. The findings discussion and research outcomes should urge project planners to initiate guidelines and recommendations in order to mitigate radio-frequency fields in indoor environments throughout the design phases. The end-users should also be capable of using measurement methodologies to perform a preliminary assessment of the radiation exposure level at their own premises.

نبذةٌ عن الدّراسة

جودة البيئة الدّاخليّة هو أمرٌ أساسيٌّ في الأبنية الحضريّة. تعتمد صحّة القاطنين بشكل كبير على عواملَ مرتبطة بجودة الهواء وصيانة الفراغ. بَيْد أنّ شكلاً جديداً من أشكال التلوّث ظهرَ في الدّول المتقدّمة بسبب الاستخدام المُفرط للمنتجات الكهربائيّة والالكترونيّة. ويُعزى سببُ هذا التلوّث، الذي لايمكن اجتنابُه، إلى انبعاث الحقول الكهرومغناطيسيّة في الأثير والفضاء الحُرّ مخترقاً الكائنات الحيّة ومسبباً آثاراً سلبية على الصّحة على المدى البعيد. لا تُعنى الدّراسات التّصميميّة والهندسيّة بشكل كافٍ بموضوع التّلوّث الإشعاعي للبيئة الدّاخليّة نتيجة نقص الوعي بأهميّة مجال الإشعاعات الكهرومغناطيسيّة. هذه الأطروحة هي مراجعة للمؤَلفات العلميّة التي تتعلق بالإشعاعات في البيئة الدّاخليّة وتأثيراتها على الصّحة. تعطي الدّراسة التّجريبيّة ملخّصاً حول إجراءاتٍ بسيطة لقياس، تحديد ومناقشة الإشعاعات الرّاديويّة في شقّتين سكنيّتين. قورنت نتائج هذه الدّراسة بالنّسبة إلى المعايير العالميّة لحدود التّعرّض للإشعاع و تمَّ تحديدها بموجب ذلك في التّحليل. تساعدُ نتائج المناقشة على وضع خطوطٍ توجيهيّةٍ وتوصياتٍ لمخططي المشاريع من أجل تخفيف الحقول الرّاديويّة في البيئات الدّاخليّة خلال مراحل التّصميم. كما باستطاعة القاطن العادي استخدام منهجيّات القياس لعمل تقييم أوّليٍّ لدرجة التّعرّض للإشعاع في منشآتهم الخاصّة.

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To my family.

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List of Abbreviations

AC	Alternate Current
AI	Artificial Intelligence
AM	Amplitude-Modulated
ASTM	American Society for Testing and Materials
BA	Building Automation
BAS	Building Automation System
BIM	Building Information Modeling
BMS	Building Management System
CA	Communication Automation
CCTV	Closed-Circuit Television
CO2	Carbon Dioxide
DC	Direct Current
DNA	Deoxyribonucleic Acid
EA	Environment Assessment
EAS	Electronic Article Surveillance
EHS	ElectroHyperSenstivity
EIBG	European Intelligent Building Group
EIS	Environmental Impact Statement
ELF	Extremely Low Frequency
EM	Electromagnetic
EMF	Electromagnetic Fields
EMI	Electromagnetic Interference
EMR	Electromagnetic Radiation

FCC	Federal Communications Commission
GPS	Global Positioning System
HF	High-Frequency
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
IARC	International Agency for Research on Cancer
IB(s)	Intelligent Building(s)
ICNIRP	International Commission of Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
INIRC	International Non-Ionizing Radiation Committee
IRPA	International Radiation Protection Association
ITU	International Communications Union
LAN	Local Area Network
MF	Medium-Frequency
MPE	Maximum Permissible Exposure
mRNA	Messenger RNA
NEPA	National Environmental Policy Act
NIR	Non-Ionizing Radiation
NOEL	No Observed Effects Level
OA	Office Automation
OET	Office of Engineering and Technology
PCB	Printed Circuit Board
RAIA	Royal Australian Institute of Architects
RF	Radio-Frequency
RFR	Radio-Frequency Radiation

RNA	Ribonucleic Acid
TRA	Telecommunications Regulatory Authority
UN	United Nations
UNEP	United Nations Environment Program
VOC	Volatile Organic Compound
WHO	World Health Organization
WIFI	Local area wireless computer networking

List of Symbols

dB	Sound Noise in Decibel
λ	Wavelength in Meter (m)
f	Frequency in Hertz (Hz)
h	Constant equal to 6.63×10^{-34} Jsec.
Ω	characteristic impedance of the media environment or free space
E	Electric field strength in Volts per Meter (V.m-1)
S	Power flux in Watt per square Meter ($W.m^{-2}$)
H	Magnetic field strength in Amperes per Meter ($A.m^{-1}$)
B	Magnetic flux density in Tesla (T) or milliGauss (mG)
μ	magnetic permeability and is equal to: $\mu = 4\pi \times 10^{-7}$ Henry per Meter ($H.m^{-1}$)
SAR	Specific Absorption Rate in $W.kg^{-1}$

Chapter 1

INTRODUCTION

1.1 Research Background

As cities grow and expand, more technologies are being employed to facilitate the societies' life and mitigate the consequences of the excessive population affluence and energy consumption in early 21st century. However, these technologies, which are represented through electric and electronic products, are increasingly becoming significant sources of an invisible form of environmental pollution called the Electromagnetic Radiation (EMR). These products include household appliances such as refrigeration equipment, stoves incl. cookers and microwave ovens, washing machines, air-conditioners and water heaters. The introduction of wireless devices made the information transmission and control technology more resilient at home by automating the essential building services such as air-conditioning, lighting, and heating. The usage of wireless and WIFI devices such as mobile phones, network routers and smart meters to control these services, filled up the indoor environment with unavoidable radio waves, referred to as Radio-Frequency Radiation (RFR).

On 31st of August 2012, Rajasthan state of India shut down 200 cell towers which were located near to schools, and banned another 500 towers near to jails and hospitals (Shetty, 2012). This action has come into effect after an expert committee submitted a report to the Ministry of Environment and Forest. This report included a review of 919 studies on the effects of mobile towers on animals, insects, humans and plants, where the panel found that 65% of these studies showed harmful effects (Shetty, 2012). Similarly, the Chilean congress has passed a Towers Act in June 2012 to strictly limit the power of antennas, and establish mitigation in areas saturated with antenna towers that are close to homes or institutions, such as schools, healthcare centers or kindergartens (United Press International Inc., 2012). In the same year, the German environment Minister has issued a 10 point plan, where point 6 is concerned about improving the protection from electromagnetic fields (Lang, 2012). Other developed countries has also taken similar steps to limit the radiation in urban areas.

The international concerns about the health risks of living in proximity to radio frequency emitting technologies such as cell towers, antennas attached to buildings, cell phones and wireless devices, were explicitly expressed. Nevertheless, it's still questionable how significant the relationship between the exposure to radio and microwave fields, and the consequent negative health effects over the long terms would be. While a number of studies conducted on the non-thermal effects of RF radiation showed no robust evidence of any effect (Vecchia et al., 2009), other reports indicated that there is a four-fold increase in cancer rates among people living over a decade within 350m of a cell tower (Wolf and Wolf, 2004). The tower exposure studies have also shown neurobehavioral malfunction, and lower than average performance tests for attention, memory and problem solving. In addition to a host of inexplicable illnesses such as headaches, fatigue, dizziness, heart palpitations, anxiety, insomnia, and difficulty breathing. (Abdel-Rassoul et al., 2007).

Given the serious situation, It's essential that the professionals in the construction industry learn to measure, monitor, detect and calculate the exposure hours to radiation based on the building location and spaces orientation in relation to the cell towers, in order to plan out remediating solutions and prevent as much as possible such harmful exposures. Such measures help to reduce the resultant risks of carcinogenic effects and other associated cumulative illnesses which build up by the time. The aim of this study is to explore and identify the indoor radiation pollution levels in a selection of residential and office spaces located in Dubai. The results should be helpful to propose potential techniques such as spatial design, special shielding paints, window films, aluminum foil, etc. during the design and specification stages in order to prevent the external radio frequency waves from penetrating the interior spaces and affect the occupants' biological and physiological performance.

Results of this study aim at spreading the awareness among the project planners on the importance of addressing the exposure to radio frequencies deliberately and economically at the project site, and hence, protecting the end-users from future potential health risks.

1.2 Statement of Research Problem

The lack of consideration and knowledge about the indoor environmental radiation within the construction community requires serious actions to spread the awareness and educate the building stakeholders on the importance of accounting for radiation-conscious design throughout the project life cycle. Simple methods were introduced to quickly measure, evaluate and address the exposure levels in urban buildings, and in turn, plan suitable remediation strategies.

1.3 Aim and Objectives

This dissertation aims to reduce the environmental radiation pollution by spreading the awareness within the design and construction community on the importance of mitigating the radio-frequency electromagnetic fields in indoor environments. The objectives of the research can be summarized as follows:

a. Review the available scientific literature on the automation of intelligent buildings, Radio-Frequency (RF) radiation and the biological health implications on humans.

b. Perform an initial evaluation of RF radiation levels in two urban building units.

c. Analyze and discuss findings in light of the international standards, where the research outcomes should be helpful to draw the attention of project planners and building end-users to the radiation issues.

1.4 Dissertation Framework

The dissertation structure is organized and categorized as per the following the chapters:

Chapter-1: This chapter encompasses the introduction to the subject study, the thesis aim, objectives of the study, the statement of the research problem and the dissertation structure.

Chapter-2: This chapter comprises of the definitions of intelligent buildings, and discusses some of the related design aspects in addition to an overview on Building Information Modeling (BIM). Building automation systems and performance mandates are also discussed in light of the integration between the elements. The review will then discuss the vitality and safety aspects of the employment of Intelligent Buildings in urban buildings, and eventually, the environmental radiation section introduces concerns over the electromagnetic radiation expressed in public newspapers and a general categorization of electromagnetic fields sources.

Chapter-3: This chapter comprises of the type of electromagnetic radiation in the subject study, measurement methods, hardware instrumentation, units, calibration, measurement procedures and considerations. International standards and regulations are also incorporated in this chapter. Then, the biological health implications are included, where negative effects from recent researches are listed and supported with available resources up to the date of this report.

Chapter-4: This chapter introduces the research experiments study and the related methodology conducted in two residential flats to address the problem and examine the objectives of this thesis. Physical measurements are taken and compiled in a schedule for analysis

Chapter-5: Results of the research experiments study are analyzed against the international standards and guidelines and discussed through the existing conditions.

Chapter-6: This chapter encapsulates the research conclusions and recommendations for future work, as well as the research practical outcomes in the new construction and existing buildings.

Chapter 2

INTELLIGENT BUILDINGS AND ENVIRONMENTAL RADIATION

2.1 Definitions

Following the progressive technology development within the building construction industry, the concept of Intelligent Buildings (IBs) has ever evolved over the time with no definite description as yet. The term "Intelligent" or "Smart" Building has since been receiving more attention throughout the diverse specialties, making it always open to discussion on its origin and what this term does cover. However, a plethora of attempts to define IBs has led to three categories (Wang, 2010):

2.1.1 Performance-Based

As the title suggests, the building intelligence is determined by stressing on the performance aspects and user demands, rather than the technologies or systems involved. The European Intelligent Building Group (EIBG) considers that buildings which provide the most efficient environment to its occupants, reduces the operational costs of hardware and facilities, and manages resources in considerate manners can be called "intelligent" (Wang, 2010). As a reflection on the real-life platform, the level of intelligence greatly depends on the building function and its response to the occupant needs, as well as the ability to quickly adapt to the internal or external conditions, and satisfying the changing user demands over the time.

2.1.2 Services-Based

In this perspective, the Japanese version, for instance, accentuates on four services provided by an Intelligent Building (Wang, 2010):

1- Reception and transmission of information, as well as efficient management Ssupport.

2- Assurance that the workers are satisfied and convenient indoors.

3- Rationalization of management expenses, with an enhanced performance.

4- Quick and cost-effective adaptation to the sociological surrounding changes, intricate working demands and the business plans in effect.

2.1.3 System-Based

Intelligent Buildings in this part are defined through the technology systems that are incorporated. The Chinese IB Design Standard suggests that an IB encompasses the Automation of Office (OA), Building (BA), and Communication (CA) network systems, labeled as (3A) (Wang, 2010). The deliberate integration amongst the structure, management, system and service improves the building's efficiency, comfort, convenience and safety.

2.2 Intelligent Building Design

Since successful architectural engineering requires clear and accurate documentation of the project requirements, the design tools has been improving over the centuries to analyze and cope with the interlaced construction needs throughout the diverse disciplines involved. As energy prices rise, and the world becomes more environmentally-conscious, the need for an entirely new set of building practices and considerations is a priority to handle the higher complexity of design requirements. The evolution of architectural tools has recently made a massive leap by exploring the software capabilities to resolve complex geometrical riddles. In turn, the designers were more able to document flexibly and clearly the project requirements.

One of these tools is the parametric design modeling, where relationships are established between elements, in such a way that allows to reflect changing or adjusting the parameters of one element into the other elements of design dynamically whenever it happens. The Building Information Modeling (BIM) broadened the horizons to explore new design capabilities through the experimentation of virtual environments before taking off the physical site construction. With the help of the parametric tools, the user can make his own set of rules and relationships, based on which the geometry is generated implicitly, where simple tasks can be automated, managing the complexity of tracking individual instances. Revit is one of the outstanding software examples in this respect. Materials, areas, dimensions and attachments can all be controlled by means of live feedback. Any kind of change in the geometry configuration triggers an auto-update to the associated set of information database (Halamka, 2012).

The main reason behind the quick development of BIM technology is that building information models are authoritative representation of facilities where every piece of information is incorporated into the database throughout the project life cycle (Smith, 2007). This mechanism helps to consistently simulate and resolve any conflicts between the disciplines before any physical problems happen on actual terms. Another aspect of the BIM is the ability to maintain, extract and modify the information database following future changes. For instance, maintenance schedules and invoices can all be stored for payment and accounting affairs. The strength of BIM system comes from its unlimited capacity which can cover every aspect of the project, from the inception throughout design and construction phases, in addition to the occupancy period. The database is flexible to any updates by all assigned disciplines and the model can be further locked or exported to apply additional analysis where required, such as environmental and energy performance tests. Understanding the capabilities of BIM technology opens the door for elaborate works to be coordinated, controlled and produced efficiently saving 50-80% of the time and efforts required to perform the same tasks using ordinary tools (Smith, 2007). It is suggested that the existing site level of radiation can be stored within the BIM database of the buildings which are under construction, so that the project team is always aware of any clashes that may occur between the design approach and the considerations made to avoid radiation exposure based on the building orientation, cladding, interior furniture and other aspects. Further elaboration on this point may be carried out by other researchers as convenient.

2.3 Building Automation Systems

Building Automation Systems (BAS) are centralized and interlinked networks of hardware and software parts (KMC Controls, 2014). The benefits of the employment of Building Automation Systems are abundant due to their increased reliability to plan preventive and remediating maintenance plans. Other advantages are represented by the fact that a BAS-outfitted facility offsets considerable expenses related to the operation and management personnel, and enhances the staff productivity by allotting more time to maintain the equipment, and thus, reducing the fixing and replacement tasks. BAS, or sometimes referred as BMS, for Building Management System, could sometimes incorporate the protection of people and equipment in scope (Wang 2010). Automation Systems can be assigned for the safety and security of building occupants, and therefore, they should be carefully planned and adjusted to suit the occupants' needs. Wong et al. (2004) shows that the key to an efficient operation of IBs is not attributed to the sophistication of the services systems, but rather to the integration among the sub-components. For instance, the vertical transportation would be interfaced with the fire alarm and security systems in order to determine how many elevators are required to satisfy an evacuation plan, the operation mode to cope with the emergency level, and in some cases, the floor levels accessible for exit. Similarly, Wong et al. (2004) outlines another example of a fire alarm program linked to access-control systems in order to release specific doors under emergency conditions.

One of the recent innovative systems concerned about the Indoor Air Quality (IAQ) are the CO2 sensors. These devices, which can be attached to the walls or the ceiling of interior spaces, have closed feedback loop to the central HVAC system. Any difference of Carbon Dioxide (CO2) levels in a certain space environment triggers an error signal that alters the Air Handling Units operation in order to cope with the changing demands for fresh air supply in that space. This helps to prevent respiratory problems and associated physical health effects due to the lack of required amount of Oxygen in the indoor make-up and/or supply air. The BAS, which manages the HVAC service sub-system, would have to be carefully calibrated to initiate an emergency set of actions in case the latter fails to react adequately to the received feedback. The application of BIM technology in this respect definitely facilitates the maintenance and management processes providing a significant platform for ongoing and future records.

2.4 Building Performance Mandates

The total building performance helps to understand the critical balance required to make sure that all building performance mandates are met adequately. This is accomplished by comprehensively evaluating the objective and subjective fields in all performance areas simultaneously. The building mandates definition can be categorized into two areas: The building enclosure integrity and the interior occupancy requirements (Davis, 1986).

In a secondary school in Singapore built in 1997, Wong and Jan (2003) conducted a research and showed that some of the building performance mandates which fall within the recommended criteria had an impact onto the students health, and thus, the learning process integrity. The instrumental measurements in a selected sample of classrooms showed, for instance, that the Indoor Air Quality (IAQ) -determined by CO2 levels and dust concentration- was at values acceptable by the ENV guidelines for schools, meanwhile, the subjective survey data revealed a significant percentage of physical health problems such as headaches, coughs, cold and eye irritation. In the author's opinion, it was the thermal and occupancy density factors which play an important role in spreading the germs. Even if all the mandates are acceptable objectively within the corresponding guidelines, one component which is not tolerated by the occupants can cause trade-off consequences on the total building performance.

In this research, an interesting fact was noted concerning the acoustical performance. The measurement devices recorded an average value of sound noise over 72.6 Decibels (dB) in one of the sample classrooms, which drastically exceeds the Singaporean guidelines by 17dB and the international standards (25-40dB), Nevertheless, 82.2% of the survey respondents considered the noise level acceptable, while the author found surprisingly that 89.5% of the occupants in that classroom have to shout and to strain their ears to hear one another. The classrooms were noisier than the external environment. A situation that potentially lead to communication issues, stress, disturbance and the development of poor conversational habits due to the lack of speech clarity (Wong and Jan, 2003). Perhaps, the negative effects of the overwhelmingly excessive noise levels in schools have not received their adequate share of attention by the industry professionals -in that specific case- and this school research helped to spread the awareness and draw the attention to an important "invisible" performance mandate which affects the building's safety and convenience to adolescent occupants who are in a sensitive age of learning and social development.

2.5 Safety Issues in Planning

Intelligent building systems have earned a considerable attention within the construction industry in the recent years. Ever since that, it became trendy to specify sophisticated networks of hardware equipment and software programs in order to automate the control of every possible function in buildings making them sound "intelligent". Sometimes, the design and commissioning processes overlooked the fact that a building performance is highly affected by the interlinked cohesion between its components, in addition to the building's interaction with the surrounding outdoor environment. Transdisciplinary integration through the workflow processes at every detail is of a prime importance to ensure that the building will function efficiently or "smartly" with minimum clash of benefits and more synergistic operation and management. Wong et al. (2004) indicated that there has been recently a growing interest in IB investment within the Asia Pacific region, quoting from a number of authors, this move which was credited to benefits at the financial, ergonomic, convenience, efficient operation and marketability aspects. However, as intelligent enclosures, they have to cope with the design target performance requirements and adapt to the changing organizational and operational environment, I-buildings also have to keep their occupants safe and protected. The excessive inclusion of equipment into the system is an unnecessary financial and operational burden which should be avoided. Simplicity and effective approaches should be sought to achieve the expected performance criteria.

The side effects of intelligent buildings were not sufficiently addressed in researches. The impact onto the employment industry and career opportunities cannot be overlooked. Inspection, maintenance and operation personnel who were used to be contracted to channel extensive tasks in multiple size establishments in the past, are now replaced with low-cost intricate systems to get most of these tasks done according to programmed schedules. There are expectations that Artificial Intelligence (AI) and robotics will overtake more jobs than they provide by 2025 (Smith and Anderson, 2014). The web-based connectivity gave a flexible and instantaneous ability to adjust or alter the system functionality through a wide range of cellular and smart devices. However, the downside is that, the buildings performance are more than ever at stake of being hacked by outsiders and controlled in unexpected manners which could possibly manipulate and jeopardize the physical environment, and thus, put the life of people and equipment in danger. One example, would be an illegitimate access to the security CCTV cameras from the web (Kelion, 2014), door card readers, or perhaps, the fire alarm system. The building can be switched to a set of conditions where it's not required, and subsequent actions can trigger unnecessary processes which could result in a public mess and false calls for an emergency situation.

Numerous studies have shown a relationship between the electromagnetic fields and the human physical health, where electronic and wireless products are increasingly employed throughout the i-systems. The concept of artificial communication between the subcomponents and the feedback loops by means of electrical pulses or digital signals has filled the surrounding environment with excessive amounts of man-made radiation. This type of environmental pollution is of an emerging concern in the pathophysiology, genetic toxicology and many other disciplines which are trying to decipher and address the vocabulary of that bio-electro-chemical relationship with more evidence and demonstrations. Chapter 3 reports thoroughly some of these researches.

2.6 Environmental Radiation

In early 2013, The National newspaper reported a public anger over a mobile phone mast placed near Abu Dhabi school. The antenna tower was located 40 meters away, which raised the fears of hundreds of parents that the long-term exposure to electromagnetic emissions was a gamble with their children's life (Ahmed, 2013). Similarly, the strong energy fields from high-voltage power lines in Jebel Ali have sparked question marks about their health implications on the neighboring residents in the Gardens area. There was a lack of field measurements to the electromagnetic density nearby the cables, consequently, experts were not aware if the people in that area were exposed to dangerous levels of Electromagnetic Fields (EMF). The utility company asserted that zones within 50 meters to either side of the high-voltage lines were not allowed to accommodate any buildings (Hadid, 2006). However, tools to take field measurements, and plans to analyze and study the results in light of the international standards - Please refer to chapter(4) for more details in this regard - seem to have been absent during the implementation stages.

Human beings are exposed naturally to Electromagnetic Fields (EMF) from the beginning of history. Terrestrial and extraterrestrial sources such as earth, sun, sky and lightning are the main sources of radiation. Characterized as having a very broadband spectrum, the natural EMF is considered extremely small at Radio Frequencies (RF) when compared to man-made fields. The 21st century has seen an enormous scientific development accompanied with the need for faster delivery of information through various means of communication. Man-made fields can be briefly attributed to the telecommunication and broadcasting technologies such as medium and short wave stations, mobile and wireless networks, and myriads of medical, industrial and domestic products, in addition to those implemented in the safety, navigation and radar applications (Vecchia et al., 2009).

Chapter 3

RADIATION AND HEALTH IMPLICATIONS

3.1 Radio-Frequency Radiation and Measurement

As a form of radiant energy, the Electromagnetic Radiation (EMR) classically comprises of electromagnetic waves generated from the synchronized oscillations of electric and magnetic fields propagating at the speed of light. Accelerating the charged particles is the production method of electromagnetic waves which carry energy and momentum away from their source particle (Crowell, 2015). When these waves absorb sufficient energy to propagate freely, or so-called "radiate" in this case, without the continuous influence of the moving charges which emanated them, the Electromagnetic Radiation (EMR) is then classified as "far field". On the other hand, near field radiation remains close to the producing charges such as ordinary magnets and static electricity phenomena. The former, far-field EMR, is of this research's concern and will be further narrowed down to focus onto the concerned frequency range. In the quantum theory of electromagnetism, EM interactions are direct results of elementary components called photons. The photon's energy according to this theory is quantized and provide an additional source to the electromagnetic radiation by the transition of electrons to lower energy levels in atomic orbits. The energy and frequency of photons are related by Planck's equation (Crowell, 2015):

$E = \mathrm{h}.f$, where E is the energy per photon, f is its frequency and (1)

h is a constant equal to 6.63×10^{-34} Jsec.

The bigger the frequency is, the more energy the photon possesses. On the other hand, electromagnetic waves propagation is represented in a sinusoidal wave form featuring troughs and crests, where the distance between two neighboring troughs or crests (peaks) is defined as the wavelength. According to the physical equation (Crowell, 2015):

$$v = f.\lambda \tag{2}$$

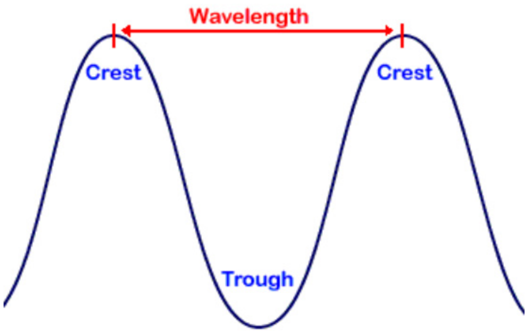


Figure (1) - Schematic representation of RFR wavelength (Netting, 2007)

The EMR frequency is inversely proportional to wavelength λ, inferring that the electromagnetic radiation waves which have shorter wavelengths exhibit higher frequency and possess larger energy than the longer-wavelength low-frequency radiation. However, the latter has less penetrating abilities and is often called non-ionizing radiation because the energy it carries is insufficient to ionize atoms/particles.

3.1.1 Radiation Spectrum

Characterized by either the frequency (f) or wavelength (λ) of their oscillations, the electromagnetic waves stretch across a large spectrum range, which essentially consists by order of increasing frequency (or decreasing wavelength) of Radio waves, microwaves, infrared radiation, optical radiation (visible range), Ultra-violet radiation, x-rays and gamma rays. In general terms, the electromagnetic radiation is classified by frequency character as shown in Figure (2).

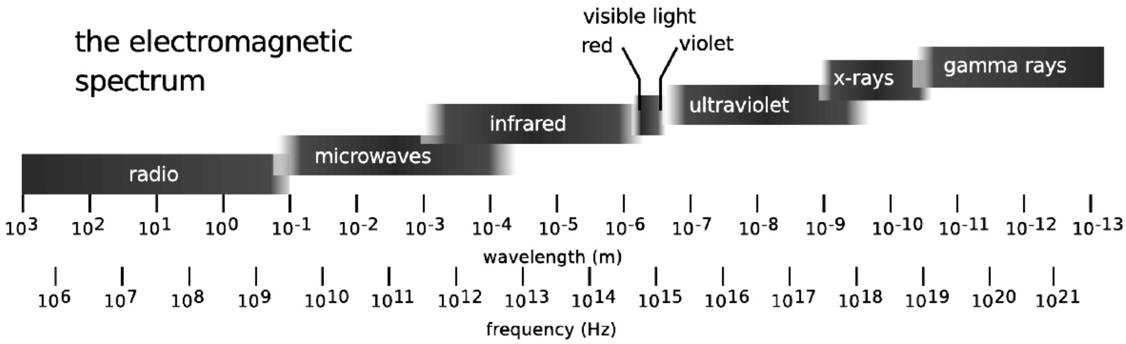


Figure (2) - Scheme of radiation spectrum
(Crowell, 2015)

The scope of this thesis will be concentrated on the range between 3MHz - 300GHz, succinctly referred to as HF range radiation in the upcoming chapters. The aim is to explore the relevant sources and go through the terms and regulations associated with these frequencies. The radiation spectrum is generated by two general sources:

A. Natural Fields

At radio frequencies below 30MHz, the electromagnetic radiation is mainly generated from the lightning discharges either between clouds or when flashes strike the ground during thunderstorms. The EM radiation, entering from the space, at below 30MHz frequencies is reflected back by the ionosphere layer. Whilst, the electromagnetic fields originated from the warm earth and extraterrestrial radiation, in particular the sun and the cosmic sky, penetrate the earth's atmosphere efficiently between 30MHz and 30GHz in a very broadband blackbody spectrum radiation. Extraterrestrial frequencies above 30GHz face high attenuation by the earth's atmosphere (Vecchia et al., 2009). On the other hand, electromagnetic radiation is naturally emitted by the spontaneous disintegration of radioactive elements. These elements are either chemically combined in the soil and earth rock minerals, or in the form of gases that are radioactive daughter products of other elements. Radon is a clear ionizing radiation example in this regard, where extremely small size particles of the Radon gas can be carried easily through a relatively static environment causing contamination to the building indoor air volume (Radon.com, 2009). an issue which is increasingly becoming of a concern urging societies, such as the American Society for Testing and Materials (ASTM), to issue a standard of practice to mitigate Radon radiation in residential areas (US Environmental Protection Agency, 2010).

B. Man-Made Fields

The advances in modern communications technology has entered into many areas of science applications and contributed to the speed of information delivery and handling of tremendous amounts of data without compromising on the quality of connections, but rather affecting the human body which is increasingly exposed to higher levels of power density than any time before. Whenever Radio Frequency (RF) man-made fields are in focus, the telecommunications and broadcasting industries are considered stakeholders in distributing a great deal of the electromagnetic energy over large areas around the transmitting sources. In fact, according to Vecchia et al. (2009), the most powerful continuous emitters of RF radiation into the space are the broadcast stations. As much as 600kW are radiated within the MF and HF bands, while the TV and FM radio frequencies operate their antennas at a typical range of 10 to 50kW. In most of these cases the transmitters are placed relatively away from the occupied regions. however, workers and maintenance personnel may be well exposed to significant amounts of radiation during their work on actual site or inside operation cabinets. According to the function of distance law, the power density and currents are reduced drastically, as confirmed through a series of site measurements on MF vertical monopole 185m high antenna in the Pori area in Finland (Jokela et al., 1994). Nevertheless, other hazardous transmitters of radiation could not be away from human beings (sometimes less than 2cm), and the distance here is negligible in relation with the radiant energy through the voice and data transmission systems, which are enhanced over the time with extra amounts of energy in order to maintain the speed and capacity of data transmission. Mobile and wireless communication technologies are rapidly growing with higher frequency bands and more radiant energy allocated throughout the progressive generations. Different techniques were employed to assimilate the ever-increasing number of users. The analog 1G systems were introduced in 1980s followed by the GSM systems which was based on digital signal modes, the subsequent generations focused on enhancing the velocity of connections as a consequence of the gained mobile phone popularity in accessing internet and messaging platforms through the web. The most recent goal of the International Communications Union (ITU) is to achieve 100Mbits/s for general environments and 1000 Mbits/s for indoors. A goal that implies using wider bandwidth requirements and more radiant energy (Vecchia et al., 2009). A fact that suggests more stringent measures to mitigate the increased adverse effects on the biological life of humans and the living organisms. Other everyday's man-made fields include mobile telephony networks, mobile transmitters inclusive of the handsets, wireless LANs, Bluetooth, microwave ovens, radio-frequency identification systems such as wireless card readers, and the Electronic Article Surveillance (EAS) for theft protection at the merchandise store (Vecchia et al., 2009). Medical, industrial and safety applications depend heavily on wireless connections to facilitate the data transmission and enhance the design performance.

3.1.2 Non-ionizing Radio Frequency Radiation

The electromagnetic radiation has very wide bands encompassing diverse levels of energy based on their frequency and spectral power density. While the radiant non-ionizing waves possess sufficient energy to move atoms around or make them vibrate, this amount of energy is not enough to extract electrons from their orbits. Therefore the non-ionizing radiation was confined to inducing high currents and thermal effects within the microwave and high frequency range, however, as shown in previous sections, various researches were conducted to assure and explore the non-thermal impact for such waves on living organisms.

3.1.3 Radiation in the Building Design and Construction

RIBA plan of work 2013 guide included in its latest version two new stages which will be henceforth essential milestones in any building project plan, stage (0) defined as the strategic definition and stage (7) for in-use phase (Sinclair, 2014). The importance of this addition comes out from the fact that every project needs a proper identification of the case, and a serious measurement and verification of the results. The methodology, based on which construction plans were initiated, is always subject to quality controls in order to enhance the sub-results by the end of each assigned task. The client, accompanied with the adviser and project leader, discuss the business case and address the goals behind the desired investment and the related feasibility aspects (Sinclair, 2014). This initial strategic planning is a real platform for the architect within the preparation and brief stage to assimilate and convert into pragmatic steps. It's stage (0) wherein the client decides to designate the land or location for a specific project type.

Be it a school, a hospital, a residential tower or any other facilities where individuals are expected to spend a great deal of time within the building enclosure. This enclosure is the only protection skin against the outdoor environment and weather conditions. The location of the project has an important impact onto the nature of business and the lifestyle of occupants. For instance, the urban planning that contains landscape features, sufficient car parks, smooth circulation layouts and services available at few blocks can progressively enhance the well-being of residents and their social life. Additionally, the safe roads and pathway connection to the educational establishments provide alternative and safe routes for everyday's commuters without possibly having to use fuel-burning engines. The client, and his team, should carefully choose the urban space within the vicinity, not only from an investment perspective, but more importantly, considering the health and safety of the end-users.

Since industrial areas are not allowed in most jurisdictions to accommodate residential houses, the equation has to be consistent on the opposite direction. For instance, the use of formaldehyde-emitting adhesives in carpets and closets, VOC-containing materials, uncertified polymer components in areas exposed to higher-than-average temperature and humidity levels are considered some of the many industrial trespasses into the indoor environment. The awareness of the project team about the vicinity elements and their integration makes the client's decision smarter, and protects the project end-users from the location implications. Bearing in mind how the radio-frequency radiation can affect the life of humans over the long term, the building site should be as far as possible from any existing or potential radiation emitters within the surrounding. The architect in stages (1) and (2), i.e. preparation and concept design respectively, defines the building geometrical shape and the distribution of materials within the outer skin. The desired outlook should be a minimal quest against the building shape harmony with its orientation. The selection and distribution of functional spaces and services affects the watt-hours resident exposure to a nearby cell tower emissions.

Considering within the design process that health and safety of occupants is a prime objective, the lead designer should be able to channel the design process intelligently. The earlier he thinks of a radiation-conscious design, the more efficient and cost-effective the next stages will be in terms of materials selection and implementation methods onsite. The site exposure to radiation emissions can be effectively mitigated by the synergistic integration between the design and specification aspects. Some protective materials might become dangerous and counteract the intended objective if designed and implemented in wrong manners. The project team should exchange the technical requirements and collaboratively follow up on the radiation-conscious design, implementation and measurement actions. For optimal communication and management quality, it is recommended to assign this task to a commissioning authority delegated to assure that the expected radiation protection performance is achieved throughout the project phases. The commissioning authority, preferably appointed as a third-party consultant, helps to maintain the prescribed high-quality materials specification from the value-engineering procedures. For instance, the cost-to-function ratio analysis should not downgrade or reduce the quantity of electromagnetic protection shielding paint, or the EMF-reflective glass films. Certain concessions at value-engineering phases are a compromise on the quality design efforts and a gamble with the EMF-protected life of the end-users.

3.1.4 Radiation Measurement

A. Instruments

The surrounding electromagnetic fields, or sometimes referred to as ambient or background, are measured using EMF meters. These instruments contain sensors or probes which receive the signal and then forwards it to the main processor for data-logging and analysis. There are many ways to measure a radio-frequency radiation depending on the desired settings and the results required. This research will conveniently select and focus on potential simple and economic ways which can be conducted to acquire initial understanding of the radiation coverage within a selected space. Human body induced currents and fields will not be covered within this thesis. This subject has other sophisticated biological implications and the capacity of relevant methods cannot be accommodated within this limited study. Similarly, accurate and professional field measurements should be performed by specialized personnel/consultants to ensure that the results are thoroughly addressed. In general, there are two types of measurements which can be performed (Vecchia et al., 2009):

a) Broadband measurements of the electric/magnetic fields through a wide extent of frequencies. This is simply done using an EMF meter equipped with mono-axial or tri-axial antenna.

b) Frequency-selective measurements: Where the interest is navigating a selected frequency range using a field antenna and a frequency-calibrated sensor or spectrum analyzer.

EMF measurements can also be classified as either near-field or far-field, where on a case-by-case basis, conditions of the emitted signal and the media environment affect the received values. The spatial distributions of the electric (E) and magnetic (H) fields, in addition to the corresponding amplitudes and phases, differ greatly based on the distance from the sources. This is also affected by the media environment where the signal travels, couples, interferes or reflects. Every field measurement should preferably account for both (E) and (H) components of a signal to draw a comprehensive picture about the radiation criteria in a selected space. However, in the far-field region measurements, the magnetic (H) field can be concluded by entering the electric field strength values in this equation (Vecchia et al., 2009):

$$|E|/|H| = 377\Omega \quad (3)$$

where Ω is the characteristic impedance of the media environment or free space.

The electric and magnetic vectors at a far distance from the source become distributed uniformly in a plane wave signal transverse to the direction of propagation. (Vecchia et al., 2009)

EMF meters can be either mono-axial or isotropic. Mono-axial meters use short dipoles to sense and detect E and H fields in either X, Y or Z axis direction. three measurements have to be performed at each point in order to get the lump sum value

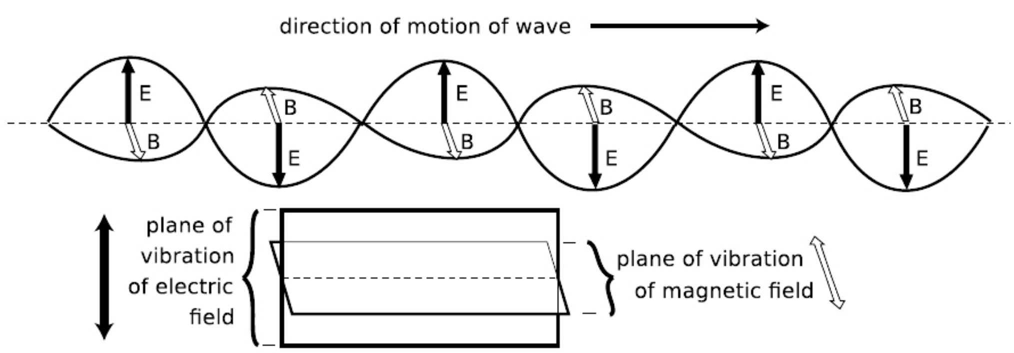


Figure (3) - Electric (E) and Magnetic (H) fields propagation
(Crowell, 2015)

Figure (4) - Single-Axis Meter
(EXTECH Instruments, 2015)

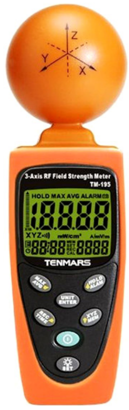


Figure (5) - Isotropic Meter
(Tenmars, 2015)

Using Isotropic (tri-axis) meters facilitates the processes and provides the instant sum of values without repeating the measurements. Mono-axial meters are more affordable but can take approximately triple the time required to address the measurements. Besides, their accuracy is less when compared to isotropic instruments. The major components of any EMF instruments can be summarized as follows (Vecchia et al., 2009):

a) Field sensor: A detection device, which incorporates an antenna or probe, sends a low-freq. signal, which is proportional to the field strength magnitude, to the data collection processor.

b) Data link: carries the signal from the reception device to the display or data collection processor. This is usually a highly resistive wire at RF frequencies under study. Fiber optics are also reliably used as data links in this regard.

c) Data processor and results display: Upon arriving to the collection unit, the signal gets filtered, amplified, summed, and digitized through the Printed Circuit Board (PCB). This unit can also feature other processes such as averaging, encrypting and transfer of measurement data to other computing machines for further analysis. The aforementioned components can be integrated into one single device with a digital display and an instant-on show of field results quantified in the desirable units (Vecchia et al., 2009). For more information on the units of measurement and the calibration methods of measurement instruments, please refer to appendix B & C respectively.

B. Measurement Procedures and Considerations

As presented earlier, electromagnetic fields encompass two major components: electric and magnetic vectors. While the electric fields are produced by stationary charges, the latter is generated by the moving currents. The relationship between these two components is better understood through the Maxwell equations and Lorentz force law. The scope of this research is confined to the basic understanding of these aspects to keep in line with the objectives and the main intent. Certain rule-of-thumb procedures should be taken into consideration before and while performing site surveys:

a) The selection of instruments depends considerably on the allocated budget, level of research detail, time deadline to hand-over the analysis, the accuracy of the EMF-model, and the user awareness of the multiple EMF emitters in the subject space. In general, isotropic meters are significantly more expensive than the single antenna versions, but they save a lot of time by taking the data measurements without having to repeat the step three times (for X, Y, and Z axes) at the selected points. The accuracy is further enhanced by avoiding manual adjustments and calculation. Other types of instruments include: Frequency-weighted, Non-weighted flat frequency and the extended range broadband versions (Haney, 2009).

Like the other commercially available EMF meters, the frequency-weighted type is designed to measure the EMF levels within the frequency range which is absorbed by human body. However, the scope of these types is always limited and cannot give right values across most, esp. higher, frequencies. If the data obtained is subject to further analysis and scientific research, non-weighted frequency instruments can validate the results with more accurate field measurements (Haney, 2009).

b) Detection of hot spots within the house or the building, where the field measurement is taking place. Identification of HF and ELF emitters such as faulty wires, fuses, switch boxes, transformers, smart meters, Wi-Fi devices, microwave ovens, refrigerator engines generating high magnetic fields, etc. helps to address the sources and understand the "background" electromagnetic activity. Later, preventive stages will consider the circulation and functional areas within the furniture and architectural layouts according to the perceived exposure time and limits. Action plans can include fixing and removing unnecessary radiant items indoors, as well as shielding other equipment. They may also include protection claims against radiation waves that emerge from the public and neighboring premises.

c) It is worth to mention that the measurement results should not be misinterpreted throughout the quantity units. Many surveyors don't pay attention to the actual units and might end up recording values on a different scale. Using deliberate conversion tables prevents such unwanted confusion and enhances the accuracy of comparison with the international standards and guidelines.

d) Recording EMF data measurements is recommended to be conducted using more than one meter with the same model -at least part of the survey- to make sure that the instruments are well-calibrated and the uncertainty levels are minimal. Repetition of the site surveys helps to address any false readings esp. those resulted from the pulsed/burst modulation signals.

e) As mentioned earlier, man-made electromagnetic field strengths are inversely proportional to the square distance, and therefore are reduced drastically if the meter is more than 2-3 feet away from the source. Measurements should target the areas where longer exposure periods are experienced, such as the bed and sitting areas, table desk, kitchen counter, etc. Recognizing the hidden sources requires close and slow-motion scanning of the surfaces until the respective locations are addressed accordingly.

f) The field surveyor should be aware of the battery capacity of the EMF meter and should keep it always at high levels of charge. Low-energy batteries can skew the result values.

The experimental studies in the next chapter should give a fair methodology derived from real-life practical know-how experiments which can be conducted by casual users at their own properties. This is for the general awareness of the importance to detect, measure, monitor and mitigate the high frequency non-ionizing radiation within the existing buildings. The radiation safety standards should be effectively circulated within the project team from the early stages in order to achieve an EMF-free -or perhaps a significantly lower-than-permitted radiation levels- environment upon the project completion and hand-over.

3.1.5 International Regulations and Guidelines

Unlike the other aspects of electromagnetic fields radiation science, the standardization and threshold tolerance levels between the issuing bodies shows a real gap in reporting methodologies and safety considerations. Moreover, this gap is not about few fractions between the permissible exposure limits, but rather multiplied by a factor of 10, 100 or even more (Foster, 2002). For instance, the currently allowed Maximum Permissible Exposure (MPE) in the United States stated by the Federal Communications Commission (FCC) is 10 W/m^2. While in China, Russia and Switzerland the corresponding values were set at 0.1, and this goes further down by other bodies such as the Ecolog-Institute reaching 0.01 W/m^2 . According to Mr. Foster (2002), Department of Bioengineering in the university of Pennsylvania, the huge disparity among the results is attributed to the rationale behind those limits. This rationale, from the U.S. lenses, is a result of extensive review works done on quality research papers published in peer-reviewed journals. The research experiments were often focused on a short-term - (6-20 minutes) on average - exposure to Electromagnetic Fields (EMF) radiation in order to address the resultant heat in living tissues. There was obviously no evident accountability to the hitherto non-thermal effects, based on which the Russian and Eastern Europe standards were stipulated. Experiments which were achieved on chronic exposure to EMF radiation in the Russian, Chinese and Eastern Europe reports helped to identify symptoms of radiation-intoxication related diseases, many of which are still considered vague, yet non-falsifiable, in the western medicine (Foster, 2002).

Another factor which apparently widens the gap between the set value standards is the science-based versus precautionary measures. According to Mr. Foster (2002), Switzerland can be considered one of the countries which lowered the MPE thresholds to stringent levels way below the FCC or ICNIRP guidelines based on precautionary considerations " to minimize the hitherto unknown health risks" (Foster, 2002). The author points out to fact that public concerns over possible health effects from exposure to EMF radiant energy had an impact on these regulations. On either case, harmonizing the Maximum Permissible Exposure (MPE) values can be achieved by converging the opinions over traditional medicine concepts and standardizing the methods of demonstration and proof. (Foster, 2002). A great leap that requires considerable time and efforts in this relevance. The following literature focuses on few well-known important bodies /agencies which have made considerable amounts of experimental and scientific contribution in the non-ionizing radiation field.

3.1.6 International Organizations on EMF Radiation

A. International Commission on Non-Ionizing Radiation Protection

In 1974, a working group was established to look into concerns raised about the protection measures against Non-Ionizing Radiation (NIR). It didn't take long until this group was converted into the International Non-Ionizing Radiation Committee (INIRC) as a scientific affiliate of the International Radiation Protection Association (IRPA) (ICNIRP, 1998). Thereafter, A set of documents were issued to address the health criteria related to Non-Ionizing Radiation (NIR). These criteria were thoroughly incorporated from the physical and electrical perspective, in addition to a literature review on its biological effects and an assessment of the health risks associated with NIR exposure (ICNIRP, 1998). Sponsored by the United Nations Environment Program (UNEP), these criteria became an initial database for further researches and findings in NIR discipline.

Following the 8th international congress of the IRPA in Montreal, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which encompasses four main committees: Epidemiology, Biology, Physics and Optical Radiation, was founded to study the NIR-related health and biological hazards, and develop a set of guidelines on exposure limits to the non-ionizing EMF radiation (Vecchia et al., 2009).

B. BioInitiative Working Group

In 2006, a group of scientists and public health experts attended a small symposium convened during the Bioelectromagnetics society's annual gathering. These scientists were exposed to the current science-based Knowledge over the biological effects of Electromagnetic Fields (EMF) and Radio-Frequency Radiation (RFR) as well as the relevant preventive measures conducted by some countries around the world. As a consequence, the BioInitiative working group emerged from this conference and decided to write a report that reviews the recent researches about the biological health risks of exposure to EMF and RFR radiation and convert them into a public policy (Sage, 2008). The aim was to warrant the precautionary and preventive measures in order to mitigate the increasing exposure to radiation, and reduce the existing Maximum Permissible Exposure (MPE) levels. The BioInitiative intent was to alert people about the radiation-intoxication risks occurring at levels that are way below the existing standards. The initial report issued in 2007 received a considerable amount of different responses and criticism by governmental health authorities and other expert bodies. However, as an independent group composed of 29 highly academic and prestigious authors -among whom are former presidents of international societies-, the BioInitiative group maintains that the credibility of the BioInitiative report comes from the fact that it has been achieved without the influence of any governmental authorities or existing bodies which remained attached to the outdated standards. As a result, The BioInitiative report should be considered as a robust science-based public health policy. (Carpenter and Sage, 2012).

C. Federal Communications Commission

As a U.S. governmental agency, the FCC developed a set of guidelines within the revised OET Bulletin 65 in order to assist the operators in evaluating whether the proposed/existing facilities or devices are compliant with the exposure limits adopted. However, following the National Environmental Policy Act (NEPA) issued in 1969, the Federal Communications Commission (FCC) has since adopted several rules and requirements to assess the effects of construction of any transmitting facilities over the quality of human environment, such as the submission of an Environment Assessment (EA) followed by an Environmental Impact Statement (EIS) through a long series of procedures to ensure that the suspected significance of impact is at acceptable levels (Federal Communications Commission, 1997). The FCC OET publication is quite helpful enabling the applicant to determine compliance and thus avoid any further delays caused by these precautionary processes. Furthermore, in 1996, new guidelines and procedures were set to measure and analyze the environmental effects of radio frequency emissions. These guidelines account for two categories of exposure limits: "Occupational controlled" and "general uncontrolled" situations. The former controlled case is confined to the operators and workers in transmitting centers whether inside cabins or at site for maintenance, on either case, the worker is made aware of the radiation levels he is exposed to, and therefore, should exercise caution and take necessary protection equipment (Federal Communications Commission, 1997). The latter situation where most of the population fall therein, is uncontrollable and therefore, lower permissible levels should be followed to avoid any adverse effects resulted from the lack of awareness to use precautionary protection. The experimental study in the next chapter is conducted and analyzed against the uncontrollable exposure category.

D. Telecommunications Regulatory Authority

All Telecommunication and network providers in the United Arab Emirates (U.A.E) including cell phone services within the bands of GSM-900 MHz, GSM- 1800MHz and UMTS-2100 MHz must obtain their license from the Telecommunications Regulatory Authority (TRA) and therefore must show compliance with the corresponding requirements. As a part of these requirements, the licensee's equipment should comply with one or more of the radiation safety standards. The TRA policy states that the applicant should adhere to the general public exposure limits to non-ionizing radiation mentioned in the ICNIRP guidelines, whichever is more stringent. The licensee should ensure that general public don't have access to areas where exposure limits are set out as per the controlled occupational standards. It's worth to note that the requirements urge the licensees to use their best efforts to avoid installing any transmitting antennas near to schools, hospitals and university campuses. The regulatory includes a table on minimum antenna distance from public areas based on the frequency of radio-frequency emissions. Clause 6.2 exhibits that TRA will survey and measure the transmitting sites to check compliance with ICNIRP guidelines. An immediate deactivation will take place against any violations in this respect (Telecommunications Regulatory Authority, 2010). The regulatory document policy version 1.0, which was issued on 21st June 2010, was crystal clear about the safety threshold that should be followed by the telecom and mobile network providers with reference to ICNIRP guidelines. However, such regulations should be circulated among the design and construction community to protect the indoor environments from excessive electromagnetic field emissions.

3.1.7 Criteria of Measurement Standardization

The general regulations depend greatly on the scientific literature review of a significant body of researches and peer-reviewed publications to setup the rationale for such regulations. However, given the huge difference within the electromagnetic radiation concerned bodies and organizations over the validity of various researches and methodologies used to document the findings, there was a drastic impact as a consequence of this disparity. In turn, inconvenient exposure limit values were issued, accompanied with an unfortunate deviation of 10, 100-fold or more. A plethora of factors led to the non-harmonious values, some of them can be summarized as follows (Foster, 2002):

a. Scientific vs. Precautionary-based: The science-based guidelines consider the observed well-documented biological effects resulted from exposure of living organisms to the least possible intensity in order to trigger significant physiological responses. While, the precautionary regulations are based on the principle of avoiding risk of yet unknown hazards of EMF radiation exposure. The latter is mostly influenced by the economic and political factors and maintains a rationale balance between such factors along with the technical and economic feasibility (ICNIRP, 1998).

b. Thermal vs. Non-thermal Effects: ICNIRP guidelines published in 1998 insists that "the literature on a thermal effects of AM [Amplitude-Modulated] electromagnetic fields is so complex, the validity of reported effects so poorly established, and the relevance of the effects [on] human health is so uncertain". These factors make the generation of EMF exposure limits for human, based on the available amount of researches, impossible (ICNIRP, 1998). In contrary, the 2014- updated report of the BioInitiative working group confirms that exposure values which are way below the safety standards can cause cellular stress responses which is represented by the cellular protective mechanism against harmful radiation (Black, 2012). The BioInitiative report concludes that the scientific support for the electromagnetic fields safety limits is not valid when the biological mechanisms, in the Extremely-Low-Frequency (ELF) and Radio-Frequency (RF) ranges, are activated at greatly different levels of the Specific Absorption Rate (SAR). At a non-thermal SAR level, the amount of ELF required to stimulate the activation of DNA in order to synthesize stress proteins (referred to as the stress response) is over a billion fold less, comparing to RF stimulation for the same process at the thermal level (Black, 2012).

c. Short-term vs. Chronic Exposure: The existing FCC/IEEE, ICNIRP and other bodies' regulations are based on short-term exposure limits. The occupational radiation limits are set out at 6 minutes and the general uncontrolled public exposure is standardized at 30 minutes (ICNIRP, 1998). Chronic exposure which might cause cancer or increase the chances of its occurrence were not accounted within the 1998 edition due to insufficient information at that time. However, the BioInitiative group points out to the fact that the existing regulations are outdated and need to consider reviewing the recent researches concerning the long term exposure to radiation (Bioinitiative, 2014).

d. In-Vivo and In-Vitro: ICNIRP In 1998 edition states that the in-vitro effects caused by the short-term exposure to Extremely-Low-Frequencies (ELF) or pulsed Electromagnetic Fields (EMF) were summed up. Although the transient cellular and tissue reactions to EMF exposure have been documented, there was no clear association between the EMF-exposure and the response of subjects. Due to the fact that many of the responses were not exhibited in-vivo, these studies are of a limited reliability in the evaluation of health implications. Consequently, ICNIRP concludes that in-vitro studies alone cannot be accounted to give necessary information which can be used as a substantial basis for evaluating potential EMF-health effects (ICNIRP, 1998). On the other hand, it is suggested that international legislative bodies should not wait until the unknown risk surfaces in real life, especially if it was established scientifically. A lesson to learn from is the smoking phenomena, where it took a significant time to realize that cigarettes are carcinogenic. Consequently, this phenomena exacerbated and raised mortality rates over the years.

e. Other Factors include the difference perspectives in modern day medicine concepts, where some EMF-diagnosed diseases in eastern countries, such as asthenia and hypothalamic syndromes, is still considered ambiguous and non - justifiable in western medicine (Foster, 2002). Additionally, political pressures and the magnitude of technological impact onto the economic wheel of every country signals the difficulty of determining a united set of standards among the nations.

3.1.8 International Actions and Plans

The ELF-EMF radiation is classified as group B2 (possible human carcinogen) by the International Agency for Cancer Research (IARC) (Sage, 2014). In result, more efforts should be spent to analyze and understand the radiation pollution by the International community. The EMF project, established in 1996 by Geneva-based World Health Organization (WHO), is a real long-term invitation to foster more researches in the field of the non-ionizing EMF radiation. The results of the frequent academic reviews to these experimental studies helps to advise the international health governments on the newly required mitigation exposure levels (World Health Organization, 2015). The focus of these studies should flow into the chronic exposure levels, which are not accounted as yet within most of the guidelines. A concern that has to be addressed at earliest before irreversible health effects take place in the current and future generations. The BioInitiative report points out to the fact that averaging MPE limits among the studies is not a wise methodology especially that they differ in strength, equipment, date, tolerance and radiation scope. Further to the result of "No Observed Effects Level (NOEL)" associated to the proposed lower power densities, it is recommended to consider a tenfold reduction in limits as a rationale approach to establish precautionary standards accounting to the yet-unknown risks (Sage and Carpenter, 2012).

3.2 Health Implications

In 1996, the World Health Organization (WHO), headquartered in Geneva, launched the EMF project in response to the increasing concerns over the exposure to the environmental radiation and its impact onto the population health over the short and long terms. The Electromagnetic Fields (EMF) project was a great initiative to coordinate a plethora of international studies, funded by the WHO member states and many non-governmental organizations, in order to assess the scientific evidence over the health effects from each of the irradiation frequencies. WHO, as a UN affiliate, set a number of key objectives to achieve tangible results in this project. One of which, was to identify gaps in knowledge that need further research to make better assessments. More importantly, the WHO scope encompasses facilitating the development of EMF exposure standards that are acceptable world-wide, and thus, providing information and advice to national authorities and other institutions to communicate, manage and mitigate the EMF exposure hazards in residential and work places (World Health Organization, 2015).

A clear objective of the international EMF project is to evaluate the health and environmental effects caused by the exposure to static and dynamic electric and magnetic fields within the frequency range of 0-300GHz which can be divided into the following categories (World Health Organization, 2015):

a) Static at 0 Hz.

b) Extremely Low Frequency (ELF): 0-300KHz.

c) Intermediate Frequencies (IF): 300KHz-10MHz.

d) Radio Frequencies (RF): 10MHz-300GHz.

The scope of this dissertation is concentrated on the RF range, which is one of the most prevalent in many facets of everyday life from the radio and TV transmission through the telecommunications as well as within the medical and industrial devices. The intended scope will be explored through a selection of corresponding researches and laboratory experimentations. The literature review will objectively reflect different scientific evidences and discussions in this relevance.

3.2.1 Potential Effects of Electromagnetic Fields

The International Commission of Non-Ionizing Radiation Protection ICNIRP report in 2009 reviews the scientific evidence on dosimetry and biological effects, in addition to the epidemiological observations and health implications related to the exposure to increased EMF fields ranging between 100KHz to 300GHz (Vecchia et al., 2009). According to this report, the hitherto findings of epidemiological studies showed no consistent or persuading demonstration of causal relations between radio-frequency exposure and any negative health implications. Due to many inherent difficulties, it was not possible to replicate some of these studies to justify their results by other bodies (Vecchia et al., 2009). However, the BioInitiative Group (2014), has made enormous efforts by the contributions of 29 academic authors from ten countries of highly distinguished entities, to study, review and address the growing health issues of short-term and chronic exposure to radiation. Circa one thousand eight hundred recent studies have been published in the last five years. The majority of these studies reported health implications at exposure levels, which fall below the safety standards by ten to hundred or thousand fold in most of the countries (Sage, 2014). Hardell and Sage (2008) point out that precautionary and preventive measures took a long period of time to be considered until early warnings were initiated based on scientific evidences. The precautionary principle should always be implemented in case there is a rational cause for concerns.

On the other hand, the BioInitiative report compiles, in addition to other extensive reviews, a list of up-to-date 106 papers which were conducted as free radical studies on RF radiation. Interestingly, 88% of these paper provide evidence on effects resulted from the exposure to radiation well within the current safety standards (BioInitiative Working Group, 2014).

The health effects caused by exposure to different types of non-ionizing radiation, especially the radio frequency emissions can be summarized as follows:

A. Brain Tumors and Acoustic Neuroma

Khurana et al. (2009) conducted a review of studies attempting to address the question on whether there is an epidemiological evidence for a relation between long-term use of cell phones and the risk of brain tumor development. Methods used in the review of Khurana et al. (2009) represented a strict selection of papers to meet certain quality and relevant criteria such as:

> **a)** The publication in a peer-reviewed journal.
>
> **b)** Sample participants in these researches have used their mobile phones for not less than ten years (to account for latency).
>
> **c)** The consideration of "laterality" in the analysis, where the side of brain tumor being examined corresponds to the head side that is exposed during the cell-phone calls.

Results of this study showed surprisingly that a ten year usage of cell-phones was enough to double the risk of brain tumor diagnosis. Statistics concluded a significant link between the long-term use of cell-phones and the risk of developing glioma and acoustic neuroma (Khurana et al., 2009). Similarly, the BioInitiative report (2014) asserts, based on the extraordinary body of work produced by Lennart Hardell, Orebro University in Sweden, that there is a consistent pattern of increased risk for tumors that arise from glial cells in the brain (Glioma), as well as those growing on the vestibulocochlear nerve, which runs alongside the facial nerve carrying information from the brain to the facial muscles (Acoustic neuroma), that can lead to problems with hearing and balance (NHS Choices, 2014).

B. Childhood Cancer and Leukemia

Childhood Leukemia is a frequent malignancy that occurs mostly in the critical age group of 2 - 5 years. It was exhibited from the epidemiological scope researches that there is a higher level of risk with increasing exposure to magnetic fields between 3-4 mG (Hardell and Sage, 2008). According to Prof. Michael Kundi, head of the Institute of Environmental Health in the Medical University of Vienna, it's still contended, by the International Agency for Research on Cancer (IARC), that the observed relationship between the children's Leukemia and exposure to ELF fields is attributed to confounding factors, exposure misclassification, selection and other biases, rather than being causally interpreted. Due to the weak evidence on such a link between Leukemia and the exposure to ELF fields, The World Health Organization (WHO) proposed that very cheap precautionary measures should be undertaken to avoid compromising on the health advantages, social benefits and the economic aspects of electric power (Kundi, 2012). However, a scientific review was conducted by Calvente et al. (2010) on publications between 1979 and 2008 to examine the relation between the exposure to RF radiation and the risk of developing childhood Leukemia. Calvente et al. (2010) confirms in his review from the epidemiological perspective, that the evidences reviewed were sufficient to reveal a consistent pattern of increased Leukemia incidence in children exposed to low electromagnetic fields greater than 0.3uT. Nonetheless, a conclusive causal relationship need to be further justified by more researches with limited confounding variables (Calvente et al., 2010). In the summary for public 2014 edition, the BioInitiative working group argues that an average of ca.1mG or lower should be applied to the transmission and distribution lines as a part of precautionary measures to reduce the exposure to ELF radiation (Sage, 2014).

C. Breast Cancer

Kim et al. (2010) conducted an in-vitro experiment using various techniques in order to monitor the protein expression profiles of human breast cancer cells by using two-dimensional gel electrophoresis. There were no significant alterations observed in the cells mRNA nor in their protein levels (Kim et al., 2010). It's contended that many similar studies are inconclusive due to the different experimental conditions applied, as well as their focus on the short-term exposure levels. On the other hand, in a separate review of 13 published epidemiologic residential and occupational researches, 11 papers showed positive evidence on the decreased melatonin production caused by high ELF Magnetic Fields (MF) exposure (Sage, 2014). A fact which suggests that the frequency fields act like promoters to cancer than being direct causes. Nevertheless, Davanipour and Sobel (2012) conclude that this effect on the melatonin production exhibits an important longitudinal evidence for the risk factor that it represents, at least for the post-menopausal breast cancer. Laboratory studies on animals has shown that ELF levels, that are not higher than the current stipulations, can significantly inhibit the melatonin production and thus speed up the growth process of breast cancer cells over the long run. An evidence that deserves more attention to warrant the existing preventive regulations (Hardell and Sage, 2008).

D. Immunological Changes

Roux et al. (2008) made an interesting investigation into the irradiation on other biological systems. using an especially designed facility, the scientists exposed tomato plants to 900MHz EMF radio frequency for a period of 10 minutes. The measured results were astonishing. Typical to an environmental stress response, three specific mRNA substances were observed accumulating after the stimulation in a rapid, large and 3-phase manner. The response, which encompasses several chemical processes, was very similar to wound responses. The exposure to Radio frequency radiation was suggested to be perceived as an injurious stimulus by the tomato plants (Johansson, 2009).

The human immune system is divided into two major types: The innate and the adaptive immune systems. The former is the primary body defense against the microbes, using the pattern-recognizing surface receptors, digestion and degradation techniques, the innate system can react quickly to pathogens and bacteria. The latter, the adaptive immune system, is often at rest until it's recruited for the battle when the primary defense fails to stop the invasion. Although it requires 7-10 days to fully mobilize, the adaptive immune system has a very effective pathogen recognition mechanism and a molecular memory, in addition to the response improvement capabilities (Johansson, 2009).

Besides its high defensive performance, the human immune system reacts differently to the invading bodies depending on various factors. Thus, this system can sometimes respond in excessive manners causing disruption to the local tissue or the entire body. Scientists call such events as hypersensitivity reactions. These reactions mostly happen in response to three different stimuli: infectious agents, environmental disturbances and self-antigens. A direct effect of exposure to electromagnetic radiation was for the first time observed in the 1980s persons with the functional impairment ElectroHyperSenstivity (EHS). In his conference presentation at WHO international workshop, Cox (2004) reported on the ElectroHyperSenstivity in the United Kingdom. Symptoms of mobile phone users included headaches (85%), burning (61%), dizziness (27%), fatigue (24%), nausea (15%), itching (15%), redness (9%), and cognitive problems accounting for 42% (Johansson, 2009). Other research reviews revealed a cause-and-effect relationship between the EMF exposure and the disruption of the autonomic nervous system, in which some of the papers found that the EHS people have the heart rate variability impaired (Sage, 2014).

E. Genotoxic Effects

In an in-vitro experimental study funded by the European Union and the Verum Foundation in Munich, Diem et al. (2005) found that after exposing the human fibroblast and rat granulosa cells to 1800 MHz Radio-Frequency Radiation (RFR) at different signal modulations, the DNA single- and double-strand breaks were significantly higher at the intermittent pulse as well as the talk modulation than the continuous exposure. The scientists concluded that, if the temperature increase was the culprit, the continuous exposure to RFR would have had a stronger impact. A result inferring that there is an obvious non-thermal factor involved in the DNA strand breaks under the existing different cell-phone modulations (Diem et al., 2005). In a 101 publications review on in-vitro and in-vivo studies conducted by Prof. Hugo Ruediger, from the Division of Occupational Medicine in the Medical University of Vienna, there were 49 positive results versus 42 of no-effect, while 8 researches failed to detect a genotoxic effect, but rather showed an enhanced genotoxic effect of other chemical or physical agents. Dr. Ruediger (2009) discusses that despite the unusual sensitivity of cells to electromagnetic fields through the observed destabilized H-bond of cellular macromolecules, the energy of weak EMF is not sufficient to break DNA. Therefore, it is suggested that these genotoxic effects are mediated by indirect mechanisms, besides the debatable microthermal processes, the generation of Oxygen radicals, or the disturbance of DNA-repair processes (Ruediger, 2009).

The latter two factors are supported by a review of hundreds of papers reporting cellular oxidative damage, which increases with the aging factor due to the decline of anti-oxidants, as well as the failure to repair DNA damage. 65% of 114 academic papers published in the period 2007-2014 showed genotoxic effects of RFR (Sage, 2014). A significant percentage that should call upon more considerate regulations for the exposure limits to radiation.

F. Nervous System and Brain Function

EMF exposure studies has provided evidence that medium to high exposure to ELF, which are far below public safety standards, can increase the amyloid beta substance in the brain while reducing the melatonin production. These effects are significant risk factors for Alzheimer's disease. Laboratory researches have shown that the nervous system related to humans and animals is sensitive to the Extremely Low Fields (ELF) and Radio Frequencies (RF). Although changes in the brain function and behavior depend on specific exposure levels, besides, the existing studies emphasized on the short term effects, evidences on the changes that occur on the brainwave activity affecting memory and learning, should warrant the current regulations on exposure limits (Hardell and sage, 2007).

G. Fertility Review

Gutschi et al. (2011) conducted a study on human sperm obtained from 2110 patients who attended the clinic through the period 1993 to 2007. It was shown from the sperm analysis that patients who use cell-phones had the serum free testosterone significantly higher accompanied with lower luteinizing hormone than those who do not use mobile phones. Findings of this study and similar researches assert that the Radio Frequency Radiation (RFR) affects the semen quality and sperm motility. The scientists found that the resultant cumulative effects will have a serious impact on the male fertility in the future generations (Behari and Rajamani, 2012). On the other hand, the BioInitiative working group report a significant reduction in size of ovaries and a decreased ovarian development, as well as premature cell death of ovarian follicles and nurse cells in Drosophila melanogaster (Sage, 2014). Conclusions raise various public health questions over the fertility in women and miscarriage incidents. Furthermore, studies on exposure levels caused by keeping mobile phones on the belt, in the trousers pocket, or resting WIFI laptops on the lap, showed irreversible damage of sperms in humans and animals. A fact that leads to real concerns about fertility conditions and the reproduction health of future generations (Sage, 2014).

Summary

This chapter, which encompasses the radiation and health implications from exposure to electromagnetic fields, exhibits the increasing intensity of the problem. Actions need to be initiated to counteract these effects over the long run. The radio-frequency measurement part introduced many definitions and considerations related to the field assessment aspects which will be experienced within the following experimental case studies. The outlined regulations and international standards gave an overview on outstanding organizations in this relevance, in addition to different considerations associated with the exposure limits criteria. This chapter was a key introduction to identify hidden health risks, and therefore, emphasize on the need to conduct EMF-radiation measurements in new and existing facilities. The analysis of the readings against the international standards gives a sincere assessment of the indoor radiation-intoxication levels.

Chapter 4

RESEARCH STUDY

Having discussed about the Electromagnetic Fields (EMF) which scientists classify as an indoor environmental pollutant or toxin (Richman, Munroe and Siddiqui, 2014), the scope of this chapter will be focused on a real-life experimental study. This study is conducted individually by the researcher, where EMF measurements are taken, addressed and analyzed in light of the background literature. This field study does not endeavor to explore the EMF epidemiological aspects but rather invites the building construction stakeholders to account for the low-exposure-to-radiation methods through the design and specification phases of indoor environments. The tools used are domestic equipment, which any household can purchase and operate at his own ease without any technical assistance required. The point of this generic assessment of EMF levels inside the subject spaces is to give simple and quick guidelines for the regular occupants to employ for a preliminary evaluation. Detailed assessment of diverse radiation aspects as well as accurate measurements should be sought through an EMF - services specialist/consultant who has the sophisticated devices to elaborate on specific aspects of EMF radiation. Such services are highly recommended in critical buildings such as hospitals, schools and kindergartens, where further researches should be considered, such as the Electromagnetic Interference (EMI) of medical devices, e.g. heart pace-makers with specific range of radio-frequency radiation. Some houses might need deliberate identification of EMF depending on their location exposure, age, the health status and the ElectroHyperSenstivity (EHS) symptoms of occupants, and other factors where necessary.

Results of this study are intended to set the first milestone for further detailed researches. Additionally, occupants should be able to determine suitability of dwellings before moving in by performing quick and easy measurements within a reasonable time and affordable budgets. In case the end-user is settled, such measurements should help in redefining and arranging the space circulation and furniture in an EMF-radiation-conscious manner.

4.1 Research Experiments Design

The subject study comprises of two residential apartments, A and B. Flat A is located in Discovery Gardens, Al-Zen district, a 1.5km walking distance from Ibn Battuta mall. Flat B is situated in Dubai Marina besides "Damac Properties" metro station. The reason behind choosing these locations is that both apartments are located in highly-developed urban areas exhibiting all transport and telecommunications facilities which implies that wireless systems have been intensively incorporated within these areas. The infrastructure is well-maintained by the developers through a preset schedule of works year-round. Traffic problems are continuously being mitigated by constructing a series of road extensions in addition to the recently inaugurated tram line which gave some breath to the Marina dense side. It's expected that these areas are the next urban hubs due to their proximity to Dubai World Central (DWC), Maktoum new airport, the expo 2020 site and the free zone areas. The second reason is that construction in Jebel Ali zone is moving forward steadily with more electric and electronic systems which are being employed to facilitate and enrich the urban setting with more care and services. However, the downside encompasses the exposure to more and more radio-frequency emissions within the controlled and uncontrolled occupancy zones. One can realize the number of telecom antennas, which are aimed in all directions, installed on top of each establishment. In some other cases, due to the height difference between the buildings, a pile of dipoles are erected on one roof next to residential balconies, overlooking the health risks to which the residents are exposed. it's been speculated that the dense distribution of those equipment will have an impact onto people's lives, however, it is supposed that demonstrations were never performed to assess the radiation levels in order to justify such concerns. Claims cannot be taken unless there is a scientific evidence behind them. Nevertheless, some newspapers such as the National and Gulf-News, as stated in chapter 2, have drawn the attention to the public's discomfort over the installation of new antennas esp. near to schools. Addressing the radiation exposure demands a swift action to mitigate the environmental radiation pollution.

The scope of this field experiment will be confined to the indoor environment of the aforementioned flats inclusive of the terraces. Outdoor measurements in public areas, which are way higher, may be further collected in other research studies. A questionnaire survey was not considered in this research as it requires further collaboration with other disciplines and may exceed the designated aim of this research. A plethora of areas can be explored in future studies depending on the aspects of interest. One of which would be the comparative relationship of the EMF epidemiological aspect between different neighborhoods in light of international previous benchmark data provided by peer-reviewed scientific papers. Results of this experimental study are for indication purposes only. Further verification and measurements should be conducted in order to acquire reliable data for statistics and other transdisciplinary usages. Moreover, findings do not necessarily give an assessment of the radiation level and human exposure at the macro-level of these districts. Further extensive studies are recommended to satisfy this respect.

4.2 Research Instrumentation

The hardware, which was used to collect the measurement values, is called "Electrosmog meter". Manufactured by CORNET Microsystems Inc. in the United States, the selected and online - purchased meter has the following specifications:

a. Model code: ED-78S

b. Sensor type: Electric field sensor and magnetic field sensor

c. Frequency range and sensitivity:

Radio Frequency (RF): 100MHz to 8GHz

(-60dBm to +5dBm), (0.5μW/m^2 to 1.8W/m^2)

(14mV/m to 26.2V/m)

Low Frequency (LF1): 50Hz to 10KHz (0.1μT to 60μT) / (1mG to 600mG)

Low Frequency (LF2): 50Hz to 1KHz (0.01μT to 1μT) / (0.1mG to 10mG)

d. RF peak power measurement: 0.5μW/m^2 to 1.8W/m^2

e. Display type: Digital LCD graphic display

f. Units of measurements: decibel-milliwatts (dBm), milliwatts per square meter (mW/m^2), volts per meter (V/m), microTesla (μT), milliGauss (mG)

g. LCD back light: 15 seconds auto-off and manual on-off control

h. Display of data: LCD 4 and 5 digit, 8 LED color segment, moving Histogram (level/time) of previous 30 recorded data, Analog segment bar

i. Data update rate: Sampling rate: 3500/sec.

j. Display update rate: 2/sec.

k. Error rate: ±3.5 dBm

l. Functions: Hold, Max, Average, Sound signature, Alarm

m. Sound & Alarm: Audio sound ON/OFF control, programmable alarm triggering Level

n. Safety standard indication: 3 safety range indication by 3-color LED

o. Battery used: 9V alkaline battery

p. Battery life: > 20 hours

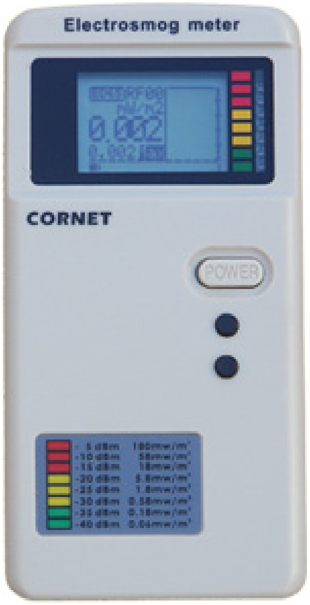


Figure (6) - Electrosmog Meter by CORNET Microsystems Inc.

This equipment was selected after a careful review was carried out by the researcher over the market and professional products used to measure radio-frequency levels. Practitioners in this field, such as Mr. Lloyd Burrell who is the author of "Beating Electrical Sensitivity - The Path to Tread", have recommended this equipment through a series of blogs and videos on measurement of EMF radiation (Burrell, 2010).

The instructions manual recommends using the meter for personal and reference use only. Official RF safety procedures should be conducted by trained technical personnel with lab instruments. The dual mode meter allows to measure both electric and magnetic fields. However, only electric fields were taken to concentrate on the subject evaluation study. Since most mobile phone base stations emit radio-frequency waves in a vertical position, the meter was held all the time in a vertical position at 1.5m height from the floor so that the receptor beam is right-angled with the EMF plane, thus, better results are obtained in the most effective direction. Given that the indoor environment is filled with different ranges of electromagnetic fields, it would be cumbersome to distinguish the source of each type of waves, but rather the combined strength of these waves. More intricate equipment can be used by researchers to analyze the spectra and define the EMF wavelength properties. The measurements assist in defining rough location of sources and the strength of burst signals with reference to the receptor orientation. It's worth to mention that, as described in the previous chapters, signals fade down quickly in relation with the square distance, and that's why some hidden wireless devices may not account within the measurements esp. If they are placed in undetected positions aiming in different distribution angles.

4.3 Case Studies

4.3.1 Case Study 1: Flat (A)

Within a cluster of eight-floor-high buildings -Figure (7)- at the third floor, flat (A) location at the corner allows to evaluate the east-south-west angle covering 75% of the directions due to the building rotated position. On the opposite rooftop, a cell phone antenna tower is installed 40m away from the subject balcony. The flat plan has been drawn in addition to the furniture distribution which is important to identify areas with the most occupancy levels around-the-clock. For instance, the kitchen is where most of the households spend in daytime, while beds are critical when it comes to the long hours sleep during the night. The field study took about 90 minutes, where spot and trawling measurements were taken between 8pm and 10pm at preset points marked on the studio-type plan layout (Figure 8).

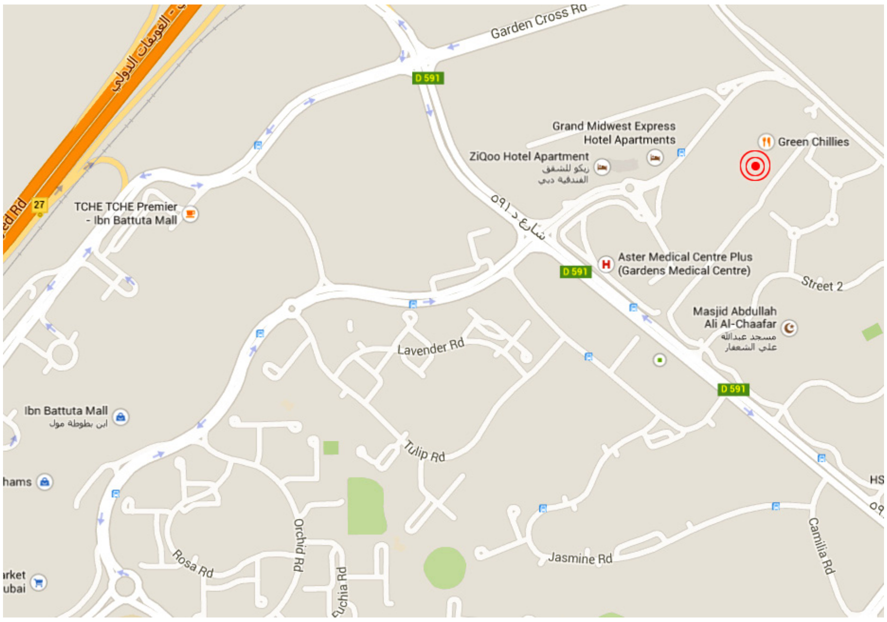


Figure (7) - Vicinity plan of case study 1 - Flat A

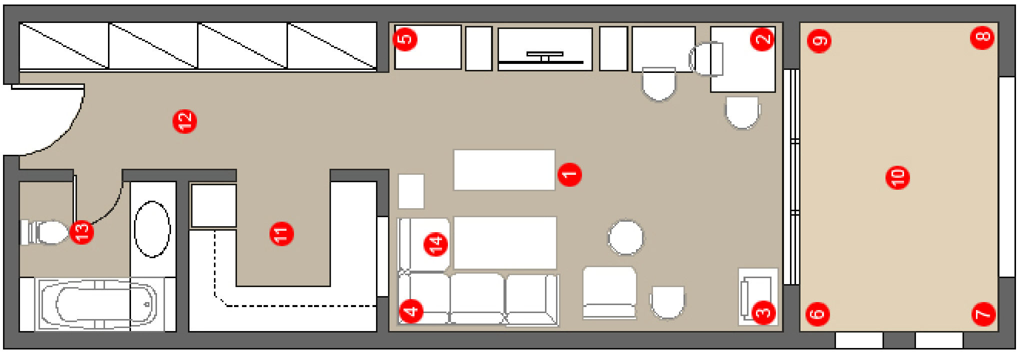


Figure (8) - Flat A plan layout: indication of measured points

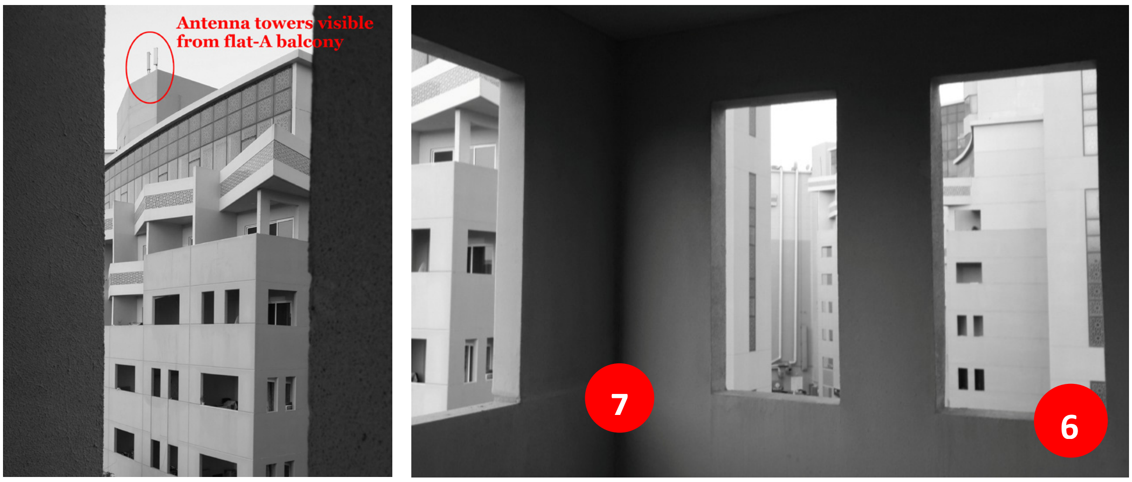


Figure (9) - Flat A balcony with indication points

Measurement points address the four corners and the center of the main living room and the balcony as well as the center of the kitchen, corridor, bathroom and over the bed pillow. Before starting the test, it was necessary to make sure that most wireless LAN devices were switched off (including WIFI and GPS features in the cell phones). The mobile phone was not switched off, but rather set on a standby mode without making any calls that disrupt drastically the display values. TV, receiver and radio devices were all unplugged. The field test had to have minimal impact from local emitting equipment as rational as possible while avoiding the ideal irrelevant situations where none of the electric or electronic products is operating, which is not the case in the actual life. Since the pulsed signals change in strength over the time, a short while was spent at each of the measurement points in order to obtain significant reading values that represent RF radiation levels in milliwatts per square meter (mW/m^2) accordingly. The instrument was then configured to take the field strength in volts per meter (V/m). Measured values were then compiled in a table and analyzed.

4.3.2 Case Study 2: Flat (B)

This apartment is located in floor 4 at the diamond building assembly, it has a balcony that views the podium level swimming pool, a part of Marina walk and more importantly, a bunch of antenna towers erected on a lower height building not further than 20m from the edge of the terrace. The owner of this flat expressed his concerns about the emissions his living space and bedroom might be exposed to. The field test visit was conducted in 60 minutes between 5 PM and 6 PM. Most wireless devices were set off including TV, receiver and radio devices. The critical exposure of flat location to adjacent mobile phone towers undoubtedly raises question marks on how those antennas have been designed and implemented within such a residential vicinity and whether compliance with local regulations was sincerely addressed on actual terms. The centre and corners of spaces were identified, measured and compiled for the study analysis.

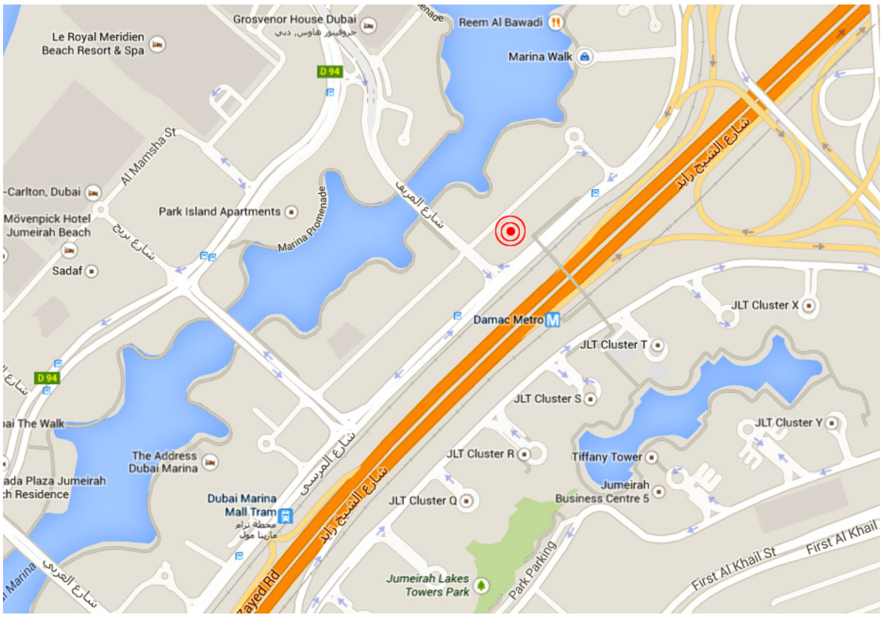


Figure (10) - Vicinity plan of case study 2 - Flat B

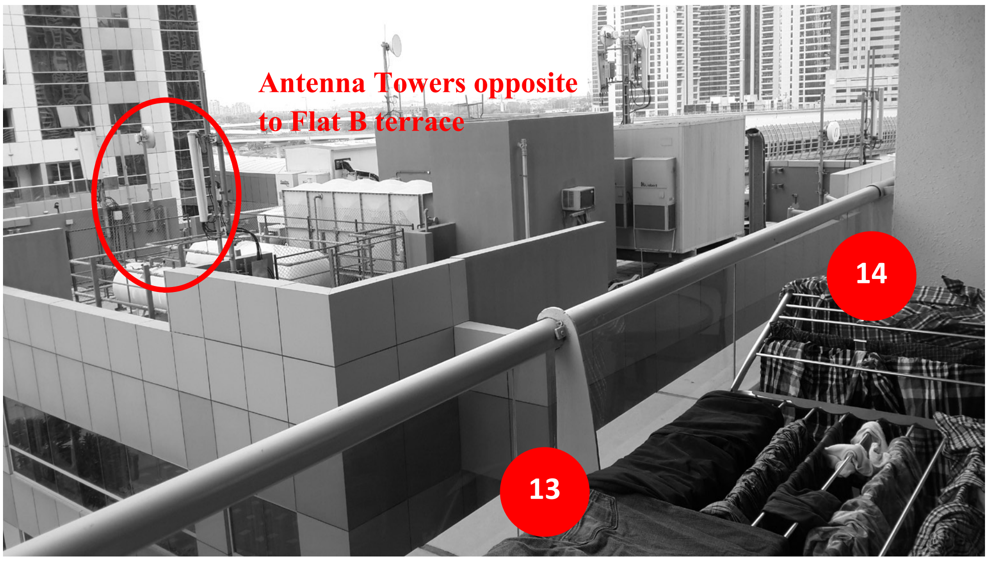


Figure (11) - Flat B Balcony with indication points

Figure (12) - Flat B Corridor and living space with indication points

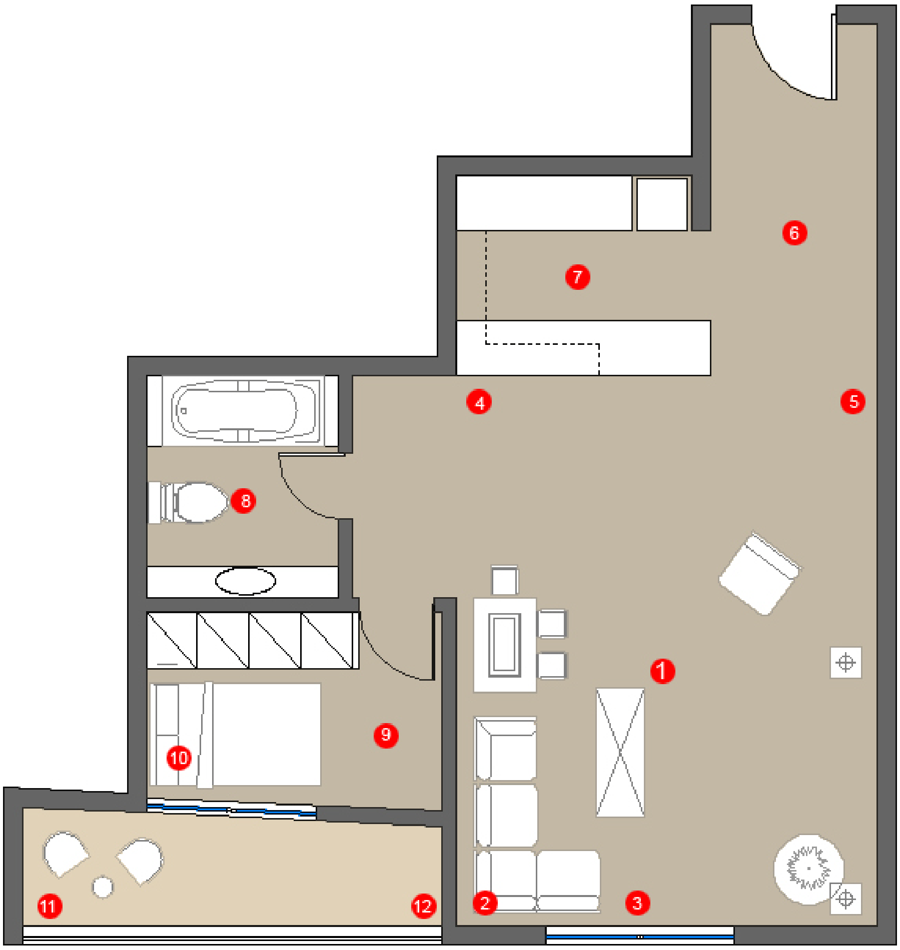


Figure (13) - Flat B plan layout: indication of measured points

Chapter 5

RESEARCH RESULTS AND DISCUSSION

5.1 Case Studies

5.1.1 Case Study 1: Flat (A)

The reading average of the points identified on the plan layout should give a general idea about the radiation level spill into the indoor environment. As it shows in the tabulated values schedule, some of these points can be considered as "hot spots" where immediate concern is raised. Due to the lack of international consensus over the EMF-exposure limits (Foster, 2002), comparison was established against the most hitherto stringent values represented by the Bioinitiative group standards issued in 2012, as well as the guidelines of year 2007, which are similar to Salzburg resolution for pulsed signals (Appendix-A). It was obvious that there was a tremendous deviation between the average and maximum values due to the burst nature of signals. However, Table (1) shows that more than 30% of the Max. values of field Intensity (mW/m^2) exceed the Bioinitiative 2007 limits, while none of them complies with the 2012 standards. Please refer to Appendix-A for general overview on current standards.

On the other hand, only ca. 15% of the average values of field intensity accord with the set guidelines. The field strength follows the same rhythm with a bit of difference, 1 out of 13 average value points comply with 2007 limits, while none of the Maximum recorded amounts concerts with the Bioinitiative standards issued in 2012.

Table (1) - Flat A Reading Values

	Reading Values (Flat-A)		
	Measurement Points	RF Radiation mW/m^2	Field Strength V/m
Average	1	0.0195	0.091
Max.		1.786	0.74
Average	2	0.0159	0.0784
Max.		0.2465	0.2907
Average	3	0.0663	0.175
Max.		0.3104	0.3621
Average	4	0.0317	0.0714
Max.		0.1555	0.1943
Average	5	0.0032	0.0511
Max.		0.1127	0.1813
Average	6	0.1705	0.2714
Max.		0.816	0.567
Average	7	0.4591	0.388
Max.		2.147	0.802
Average	8	0.0916	0.2594
Max.		1.914	0.869
Average	9	0.027	0.0859
Max.		0.761	0.4888
Average	10	0.0895	0.2155
Max.		5.271	1.214
Average	11	0.0091	0.1069
Max.		0.1745	0.2562
Average	12	0.0039	0.0383
Max.		0.2831	0.2714
Average	13	0.0162	0.0784
Max.		0.1745	0.2388
Average	14	0.034	0.1081
Max.		0.1451	0.218

Figure (14) shows the reading values relative to the severity of concern which is based on the Bioinitiative 2007 guidelines (Appendix-A). Apparently, points 1, 6, 7, 8, 9 and 10 can be considered the real hot spots in this apartment falling under the immediate concern zone, where remediation strategies should take place at the soonest. It's also apparent that the center of each space (points 1 &10) is located within the highest strength of the field, the living space and the balcony respectively, due to the lack of any obstacles around them. Looking at the furniture plan, there is low occupancy level, yet high circulation, in these points, an issue which draws the attention to have more limited and conscious stay in these areas. The next chapter will introduce possible ways of reducing EMF spill to indoor environments.

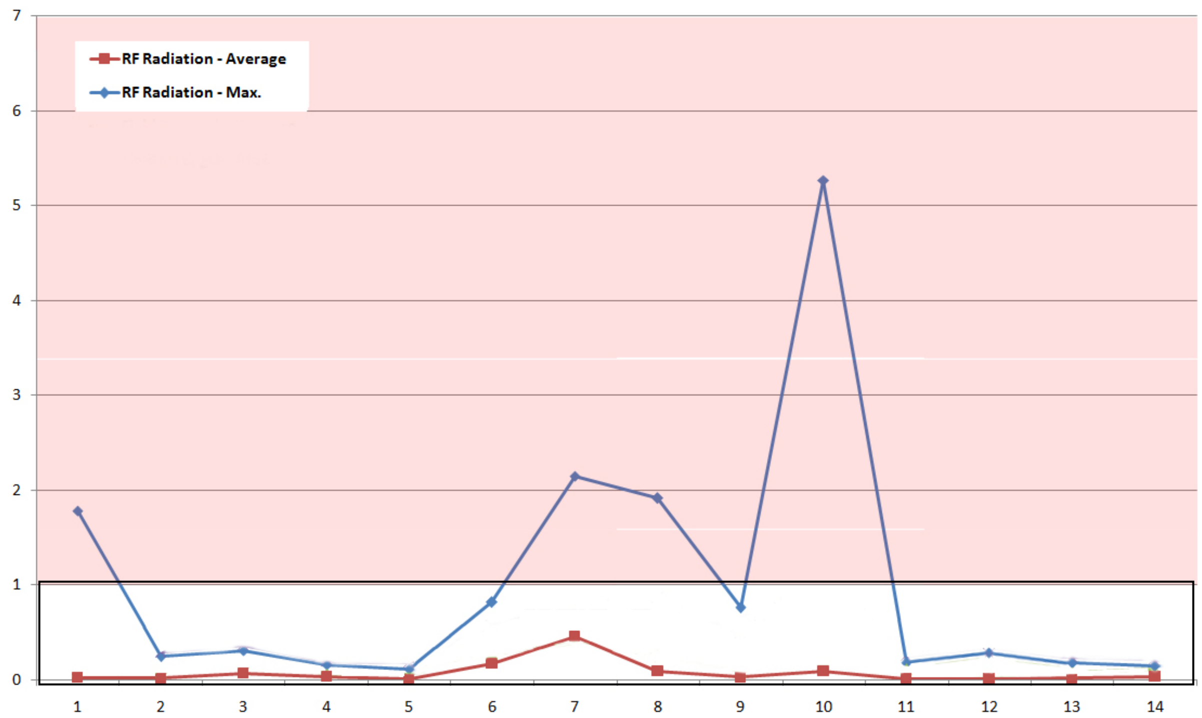


Figure (14) - Flat A - Values vs. Severity of concern

Immediate Concern   Slight Concern

The minimum average levels achieved in flat-A were at points 5, 12, 11, 2 and 13 respectively, indicating that the interior facilities such as the kitchen, corridor and bathroom are the least exposed to Electromagnetic Fields (EMF). This can be explained by the thickness of the partition walls protecting these spaces from a higher potential exposure. In contrast, the highest values acquired on average, were attributed to the terrace space. One 250x135mm opening at the southeast direction and two 60x135mm openings at the southwest allow a free access of EMF waves from the adjacent building antenna installed on the rooftop. It's worth to note that reading values at the outer side of the wall, i.e. points 6 & 9, are about 2.5 higher than their counterparts at the inner side of the wall, 3 & 2 respectively. This implies that the glass reflective properties block the radio waves within the Infrared range and above, besides the aluminum profile which plays a significant insulation role against heat and radiation. The electromagnetic fields intensity and strength are culminated at point 10 centered in flat-A terrace space. On the other hand, It's worth to mention that EMF-values amount at Max. 0.1451 mW/m^2, 0.218 V/m, averaging at 0.034 mW/m2, 0.1081 V/m over the bed pillow which tremendously exceed the Bioinitiative 2012 standards.

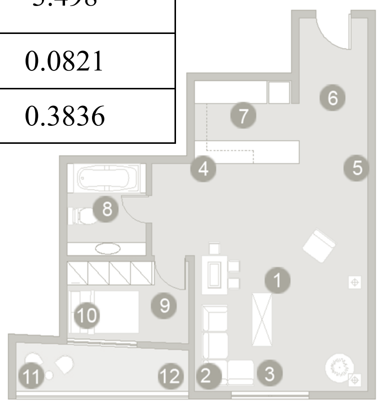
5.1.2 Case Study 2: Flat (B)

The general impression on the tabulated values is not positive comparing to flat-A case. The living space and the adjacent balcony are exposed to considerably higher radiation levels. About 43% of the Max. readings exceed the Bioinitiative 2007 guidelines while none of the average measurements falls under the limits issued in 2012 except points 7 & 8, the kitchenette and the bathroom respectively. The field strength follows approximately the same statistical significance with ca. 35.7% of the 2007 non-compliant peak values, while 78.6% of the average readings exceed the Bioinitiative standards of year 2012.

Figure (15) gives an overview on the recorded values and the corresponding severity of concern. EMF mitigation methods against this case will be addressed within the next chapter. The terrace overlooks the rooftop of the opposite tower and is exposed directly to the mobile phone antennas recording the highest value in this research at point 12 where the display read 5.52 mW/m^2 on Avg. and 39.99 mW/m^2 at Max. while Table (2) shows that the field strength peaked at 3.498 V/m and averaged at 1.12 V/m in point 12. Such results call for extreme concerns especially that the balcony is used occasionally by the apartment end-users for sitting and relaxation. The closeness of dipoles sparked a lot of concerns by the tenant, and the obtained data justify his claims and call upon action plans by contacting the Telecommunications Regulatory Authority (TRA) in order to file a complaint and ask for professional assistance to evaluate and mitigate the radiation levels in the terrace.

Table (2) - Flat B Reading Values

	Reading Values (Flat-B)		
	Measurement Points	RF Radiation mW/m^2	Field Strength V/m
Average	1	0.205	0.2035
Max.		0.981	0.622
Average	2	0.727	0.2309
Max.		2.581	0.91
Average	3	0.1264	0.2129
Max.		0.959	0.554
Average	4	0.0459	0.083
Max.		1.451	0.4559
Average	5	0.017	0.0731
Max.		0.048	0.548
Average	6	0.2197	0.511
Max.		2.465	1.081
Average	7	0.0013	0.0511
Max.		0.619	0.2907
Average	8	0.0012	0.0349
Max.		0.0129	0.3008
Average	9	0.0303	0.1813
Max.		1.207	0.3457
Average	10	0.0079	1.009
Max.		0.1101	2.205
Average	11	2.523	1.12
Max.		15.92	3.498
Average	12	5.52	0.0821
Max.		39.99	0.3836



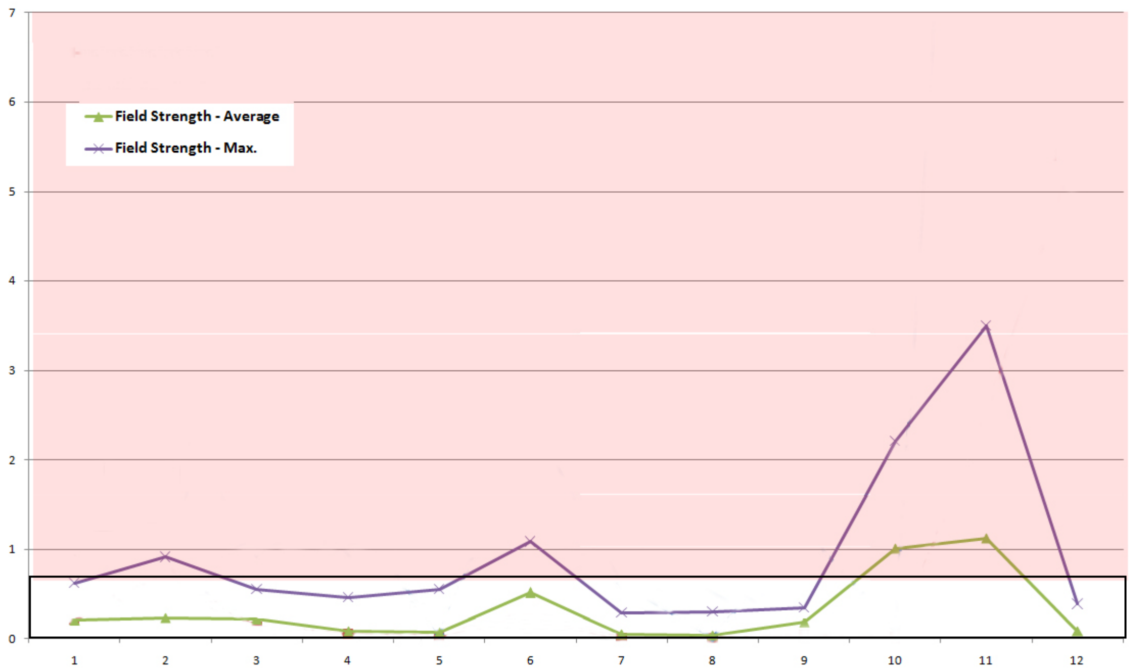


Figure (15) - Flat B - Values vs. Severity of concern

Immediate Concern   Slight Concern

On the other hand, It's worth to mention that the EMF radiation was reduced drastically indoors, yet exceeding the limits. That can be implicitly attributed to the aluminum profile of the door, IR-reflective glass and the thickness of the balcony wall. Nevertheless, there is still a concern that the bedroom -as it shows in the plan layout- receives an intolerable amount of electromagnetic fields requiring immediate remediation strategies to take place.

An unexpected result sprung from point 6 in the middle of the entrance corridor recording a value of 2.465 mW/m^2 indicates clearly that these radio-frequency emissions were generated from devices attached inside the stairs and/or the elevator shaft of the building. The thickness of walls and the finishing layers were not sufficient to block such a considerable spill towards the private premises. It was noted that point 2 at the inner side of the wall receives around 5.8 times the amount of radiation at point 3 which faces the window. This finding points out to the fact that reflective window films might be more efficient in mitigating the EMF levels than the block walls. A finding that requires further justification in other potential researches. The lowest average ever recorded in flat-B was inside the bathroom where point 8 indicates 0.0012 mW/m^2. It would not seem too strange to obtain such a value, especially, by looking at the amount of barriers separating this space from the terrace and making it an EMF-protected little fortress. Such results should be targeted in all over the apartment space to achieve a healthy and safe environment with respect to "uncontrolled occupancy" levels. Due to the disconcerted design of this apartment in relation with the surrounding antenna towers, unexpected results were exhibited at different locations suggesting that incident waves are reflected from some of the furniture objects, such as mirrors and metal hardware, which might have worsened the situation by increasing the exposure of some areas. Consequent to the worrisome results, the tenant of this apartment was advised to seek immediate assistance from a trained EMF specialist to further map and analyze the radiation levels deliberately.

Chapter 6

CONCLUSIONS AND FUTURE RECOMMENDATIONS

6.1 Research Conclusions

Exposure to Electromagnetic fields radiation in public and private premises is unavoidable. The research study identified high levels of radiation-intoxication in the subject apartments suggesting that action plans should be initiated from the early stages of the architectural and environmental design of urban buildings. Preliminary evaluation of the EMF levels encroaching onto the project site and designed spaces must be performed so that technical advice and further investigation can be planned according to the severity of situation. Buildings, that are designed to be intelligent, do not only enhance the occupants lifestyle and controllability over the services, but more importantly, prevents the excessive use of energy and maintains the occupants health and security. The environmental radiation protection requires that the construction community, including the project developers and designers, are aware of the negative health effects of the electromagnetic fields onto humans and living organisms. Most of urban areas are considered "uncontrolled exposure zones" and require careful planning of wireless and EMF infrastructure in relation with the human activity areas. Easy access to measurement equipment facilitates the initial assessment of exposure levels and enhances the radiation-conscious design.

To conclude, The research study is a pragmatic example to measure and understand the EMF reading values in light of the international guidelines and standards. Results of this research showed a significant spill of radio-frequency waves into the subject spaces. The proximity of cell phone antennas to the case study units exhibited real concerns which were justified by the measurements taken at different points in the respective plan layouts. Findings and discussion should magnify the importance of considering, and hence mitigating, the site exposure to radio-frequency radiation, especially if the project encompasses education or medical facilities such as schools, kindergartens or hospitals (Dhami, 2011). Elaborate analysis of the site radiation-intoxication must be deliberately conducted in this case. Several techniques can be employed to reduce the increased exposure levels inside urban buildings depending on the situation identified. Shielding paint, reflective glass films, aluminum foil, etc. can effectively reduce the spill of exterior waves into the indoor environments in existing buildings (Burrell, 2010). Proactive considerations in the new construction projects help to offset expensive remediation strategies in later stages and foster the indoor protection from EMF radiation more efficiently.

6.2 Recommendations for Future Work

The focus of this thesis can be further elaborated by other researchers to include a survey on the biological health implications along with the case studies to better understand the relationship between exposure to intolerable levels of EMF radiation and the Sick Building Syndrome cases. Future studies may also develop a code of practice in a handbook form to implement protection techniques from radio-frequency radiation inside urban buildings and open spaces within current design processes. Magnetic fields, which were not covered in the course of this study, are important components of indoor radiation-intoxication and are therefore worth to analyze and explore further in light of the construction industry practices. Techniques to mitigate and reduce exposure levels indoors and outdoors can be further detailed to show the specification sheets of materials and planning of elements within the architectural context. Urban planning is one of the important disciplines that accounts for the usage zones, demographic density and activity levels on a cityscape level. Therefore, the distribution of power lines and antenna towers can be preplanned at the master plan study stage to further avoid the excessive exposure of densely occupied areas to electromagnetic fields radiation.

6.3 Research Practical Outcomes

The experimental research study gave a clear overview on the Electromagnetic Fields (EMF) readings inside two of urban buildings in Dubai. The results were concerning especially that a considerable percentage of EMF-radiation level is escaping towards the indoor environment. Maisch et al. (2006) in the BDP Environment design guide, published by the Royal Australian Institute of Architects (RAIA), confirms that there is sufficient evidence to take steps ahead within the early stages of design to mitigate unnecessary exposure levels. Such actions should be accomplished by the collaboration of all project stakeholders, primarily architects, designers and planners. Early considerations accounted into the design processes will definitely save future costs on shielding and implementing protection techniques from Electromagnetic Fields at the occupancy period (Maisch et al., 2006).

Some of the professional radiation-conscious practices are literally sophisticated and very expensive compared to the overall expenses, and might involve profound techniques which have to be conducted by a specialized EMF-consultant. However, the scope of this research is focused on spreading the awareness on the importance of evaluating and mitigating EMF exposure levels using simple and cost-effective methods and equipment. Elaborate detailing in this respect should be sought from professional consultants in the electromagnetic fields. The recommendations derived from the case studies can be categorized in two parts based on the building project type: new construction and existing renovation.

6.3.1 New Construction

Architects and designers, who proactively consider and plan radiation-conscious projects within the early stages of design, can significantly save potential expenses from the allocated budget. Simple and quick measurements of the Electromagnetic Fields (EMF) can be conducted to determine the site radiation-intoxication levels. These measurements should be focused on radio-frequency levels in case mobile phone antennas are distinguished within the close vicinity. Additionally, magnetic fields should also be measured, especially if power lines cross near the site construction. Distribution map of electric stations and dipole locations should be sought from local authorities and telecommunication agencies if the site investigation reports a significant number of EMF sources. Internet satellite maps are nowadays handy to locate and measure the distance from those sources. Dual-frequency meters, such as the device used in the experimental study, that can measure the magnetic and electric strengths are available in consumer products within affordable prices. These equipment should allow to evaluate preliminarily the radiation levels and determine if further elaboration on this subject is required by a specialized consultant.

The study can swiftly be conducted and the results can effectively be reflected on the early design layouts. Then, if the taken measurements are of a concern, the architect should accommodate changes in the environmental and/or functional architecture setting in order to mitigate the EMF-trespass to the project site. Such changes should preferably be communicated with the client in case of any major concerns. The design team highlights the areas where EMF levels exceed the norms in order to strategically protect them and avoid allocation of high-occupancy spaces throughout the exposed zones. Some of the solutions, which can be inferred on the functional aspect, are the allocation of non-occupied warehouses and general storage rooms in the exposed areas. Access will be temporary and short-term exposure will only be experienced. Highly-occupied areas such as office desks, kitchens, service counters, bedrooms, living spaces, etc. should be carefully planned within well-shielded zones. The wall thickness and constituent materials affect the partition/separator resistance to EMF spill. Specification of these elements should carefully be made in collaboration with reliable manufacturers. Some of these materials include the insulating aluminum foil which can be stuck using wallpaper paste (Burrell, 2010), or other methods to blend it within the wall structure.

The deliberate allocation of electrical rooms including the drivers, transformers, ballasts, junction boxes, etc. helps to keep the low-frequency fields away from the occupants. Shielding these equipment reduces significantly the induced spills. Similarly, the accommodation of WIFI devices, wireless meters and Bluetooth accessories away from high activity areas certainly is essential, especially if that is accounted on the overall plan, where the equipment location of one flat does protect the relevant owner and does not impact the neighboring premises through the separating walls.

6.3.2 Existing Renovation

The situation in this category is more difficult to tackle due to the restraints and other complications imposed by the urban building location and occupants. Nevertheless, many solutions can be proposed in this relevance to mitigate the existing exposure levels, such as using window films and shielding paint.

As the experimental study showed, the reading values behind the glass were significantly lower than outside. A result that suggests that glazed doors were already equipped with films to reflect the radiation waves beyond the optical range such as Ultra-violet and Infrared waves. Nevertheless, due to the proximity of antenna towers, a fair amount of radiation still escapes through the glazing components towards the indoor environment. Extra layers of EMF-resistant films can be added to maximize protection. In case of opaque walls, water-based shielding paints can be applied on the outer surface of the wall (Figure 14). Further measurements should always be conducted to ensure the efficiency of these solutions.

Figure (16) - Electromagnetic Fields Radiation (EMR) protection paint (Burrell, 2010)

Care should be taken while implementing these techniques indoors, because they may reflect the Radio-Frequency waves internally and cause the amplification of Electromagnetic Fields instead of mitigating them. Accent protection to critical areas such as the bed can be considered such as Faraday bed canopy which is an ultra-fine metal composite mesh suspended over the bed space (Burrell, 2010).

Figure (17) - Faraday bed canopy
(Burrell, 2010)

The application of shielding materials turns the space walls into a conductive enclosure, therefore, grounding should always be performed on these materials with the assistance of an electrician. Being thorough and methodical about EMF-protection strategies is a key role to effectively reduce the exposure to radiation within affordable time and budget constraints (Burrell, 2010).

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Appendix - A

Table (3) - Overview on International Guidelines for General Population Exposure

Country or Organization	Thermal	Non-thermal	Regulatory	Advisory	Power Density nW/cm²	Field Strength V/m
US FCC - OET Bulletin 65 (1900 MHz)	X		X		1,000,000	61.4
Canada - Canadian Safety Code 6 (1900 MHz)	X		X		1,000,000	61.4
ICNIRP[1] Much of Western Europe, others (1900 MHz)	X		X		950,000	59.8
Italy[2]		X	X		9,500	6.0
Russia, China, Poland[3]		X	X		10,000	6.1
Switzerland[4]		X	X		4,300 - 9,500	4.0 - 6.0
Ecolog-Institut[6] (Germany, 2000)		X		X	1000	1.9
Salzburg Resolution[5] (non-pulsed signals)		X		X	10,000	6.1
Salzburg Resolution[5] (pulsed signals)		X		X	100	0.6
The BioInitiative Working Group (2007) [7]		X		X	100	0.6
The BioInitiative Working Group (2012) [8,9]		X		X	0.3 - 0.6	0.034 - 0.048

1. International Commission for Non-Ionizing Radiation Protection (functions under the auspices of the World Health Organization).
http://www.icnirp.de/PubEMF.htm

2. Decree No. 381 of the Italian Ministry of the Environment, 10 September 1998. (Decreto 10 settembre 1998 n.381). Applies to fields from fixed (permanently installed) communications antennas, and in locations used for stays of 4 hours or more.
www.ambiente.it/impresa/legislazione/leggi/1998/dm381-98.htm

3. Foster, K. 2001. *Exposure Limits for Radiofrequency Energy: Three Models.* Proceedings of the Eastern European Regional EMF Meeting and Workshop. Varna, Bulgaria : 28 April - 3 May 2001.
http://www.who.int/peh-emf/meetings/en/day2Varna_Foster.pdf

4. Ordinance regarding protection against non-ionising radiation (NISV), Swiss Federal Council, 23 December 1999.
[For sensitive use areas: schools, hospitals, residential areas. Level is frequency dependent.]

5. International Conference on Cell Tower Siting. 2000. *Salzburg Resolution.* Salzburg, Austria, June 7-8, 2000.
Resolution and Signatories: http://www.salzburg.gv.at/salzburg_resolution_e.pdf
Summary: http://www.salzburg.gv.at/proceedings_(01)_title_and_summary.pdf
Full proceedings, access to individual papers: http://www.salzburg.gv.at/celltower_e

6. ECOLOG-Institut. 2000. *Mobile Telecommunications and Health - Review of the current scientific research in view of precautionary health protection.* [Scientific review commissioned by T-Mobil (DeTeMobil Deutsche Telekom MobilNet GmbH).]
Summary: http://www.hese-project.org/hese-uk/en/niemr/ecologsum.php
Full Report: http://www.hese-project.org/hese-uk/en/papers/ecolog2000.pdf

7. The BioInitiative Working Group. 2007. *BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields ELF and RF.*
Website: www.bioinitiative.org/

8. BioInitiative Working Group, Cindy Sage and David O. Carpenter, Editors. 2012. *BioInitiative Report: A Rationale for Biologically-based Public Exposure Standards for Electromagnetic Radiation.*
Website: www.bioinitiative.org

Appendix - B

Units of Radiation Measurement

As mentioned earlier, the electromagnetic (EMF) radiation measurement encompasses two EMF elements: Magnetic and Electric charge components. Instruments can be designated to measure either of these fields or both of them based on the specified characteristics. It should be noted that electromagnetic fields can be generated by means of AC or DC currents. Measurement units are considered as follows:

a) Electric field strength E is expressed in Volts per Meter (V.m-1)

b) In the far field of radiation source, the HF EMF is often quantified as power flux S, and defined in units of Watt per square Meter ($W.m^{-2}$). A thousandth is expressed in milliWatt per square Meter (**m**$W.m^{-2}$). A millionth is expressed in micro (**µ**$W.m^{-2}$) and a billionth refers to nanoWatt per square Meter (**n**$W.m^{-2}$).

$$1\ W.m^{-2} = 10^{+3}\ mW.m^{-2} = 10^{+6}\ \mu W.m^{-2} = 10^{+9}\ nW.m^{-2}$$

$$1\ nW.cm^{-2} = 10^{+4}\ nW.m^{-2} = 10^{-2}\ mW.m^{-2}$$

c) Magnetic field strength H is expressed in Amperes per Meter ($A.m^{-1}$)

d) Magnetic flux density (B) is expressed in units of Tesla (T), $B = \mu.T$

where μ is the constant of proportionality or defined as the magnetic permeability and is equal to: $\mu = 4\pi \times 10^{-7}$ Henry per Meter ($H.m^{-1}$) (in vacuum, air, and non-magnetic -incl. biological- materials) (ICNIRP, 2010).

e) A unit widely-used to describe EMF emanated from appliances, power lines and interior electrical wiring is milligauss, abbreviated as mG.

$$1\ \mu T = 10\ mG$$

A well-known unit that is very often used to determine dosimetric measures esp. in experimental researches on EMF radiation effects on biological systems, is called the

Specific Absorption Rate (SAR) and expressed in $W.kg^{-1}$. The SAR unit is the time derivative of the incremental energy δW, which is absorbed by, or dissipated in, an incremental mass, δm (Vecchia et al., 2009):

$$SAR = \frac{\delta}{\delta t}\left(\frac{\delta W}{\delta m}\right)$$

Where the incremental mass can be contained in a volume, δV, with a given density ρ:

$$SAR = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho.\delta V}\right)$$

Appendix - C

Calibration Methods of Measurement Instruments

Based on the EMF instruments and their configuration, calibration methods should be taken into account before any site measurements, to avoid false readings and reduce the uncertainty factors associated. Achieving reliable measurements requires primarily setting the EMF instruments at the frequencies under study. While the out-of-band frequencies should be accounted in order to mitigate potential reproduction of additional signals. The calibration processes should preferably be done inside zero-EMF facilities where signal interference and coupling to objects (including users) are avoided to the best possible. However, in-vivo experiments might involve a significant deal of harmonics, reflection, scattering and other external effects which may perturb the incident field. Therefore, the surveyor should be aware of the multiple radiation sources and their ramifications on the resulted values. Care should be taken while taking near-field measures because the sensor, and possibly the unit PCB and chips, can potentially be affected by the electromagnetic field, inducing currents and signal perturbations within the device due to the interaction and coupling with the surrounding objects. Isotropic (or trifield) electromagnetic field meters are insensitive to the direction of propagation, but using mono-axial versions may sometimes result in drift effects due to the manual location adjustment and probe rotation with relation to the field axes (Vecchia et al., 2009).