ELECTRO-SMOG MITIGATION FOR ACHIEVING HEALTHY BUILDINGS: INVESTIGATING THE RELATIONSHIP BETWEEN ARCHITECTURAL DESIGN PARAMETERS AND EMR LEVELS

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ABSTRACT

ELECTRO-SMOG MITIGATION FOR ACHIEVING HEALTHY BUILDINGS: INVESTIGATING THE RELATIONSHIP BETWEEN ARCHITECTURAL DESIGN PARAMETERS AND EMR LEVELS

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Modern technologies have made daily life easier, but they also have some side effects; the most important are those on human health. With the spread of information and communication technologies (ICT) and electronic devices, the level of electromagnetic radiation (EMR) is also increasing. In addition, new approaches, such as the smart city concept in which technology is one of the main components, increase the number of sources to emit EMR. Considering that a significant part of human life is spent indoors, buildings should be designed considering the effects of EMR on human health. EMR has been studied in different fields such as medicine, engineering, and physics. Interest has recently been increased in EMR in building science, which is already dealing with related subjects such as sick or healthy buildings, indoor air quality (IAQ) and indoor environmental quality (IEQ). Unfortunately, knowledge is not yet sufficient to design spaces considering the effects of excessive EMR on health. This study investigates the mitigating and control of excessive EMR with building design parameters. It tests the effect of design decisions on building envelope, window wall ratio, room size, and proportions, finishing materials, furniture materials and planimetric layout on shielding through in-situ measurements and computer-aided simulations. As a result, it points out to the influence of design decisions for producing healthier interior spaces in terms of EMR. In this way, it is aimed to create a reference for theory and practice in the field of architecture and to increase awareness of the relationship between EMR and healthy space design.

Keywords: Healthy Building Design, Electromagnetic Radiation, Electro-Smog Mitigation, Sensitive Places, Dielectric Properties of Building Materials.

ÖZ

SAĞLIKLI BİNA HEDEFİYLE ELEKTRO-SİSİN AZALTILMASI: MİMARİ TASARIM PARAMETRELERİ VE EMR SEVİYELERİ ARASINDAKİ İLİŞKİNİN İNCELENMESİ

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Teknolojiler günlük hayatı kolaylaştırırken aynı zamanda bazı yan etkileri de beraberinde getiriyor. Bu yan etkilerden en önemlileri insan sağlığı üzerindeki etkilerdir. Bilgi ve iletişim teknolojilerinin ve elektronik cihazların gelişmeleriyle birlikte yaydıkları elektromanyetik radyasyon (EMR) seviyesi de artış göstermektedir. Buna ek olarak akıllı şehir gibi teknolojiyi ana bileşenleri haline getiren yeni yaklaşımlar EMR yayacak kaynak sayısını da attırmaktadır. Hayatın önemli bir bölümünün iç mekanlarda geçtiği dikkate alındığında binaların, iç mekanların EMR'nin insan sağlığı üzerine etkisi dikkate alınarak tasarlanması gereklidir. Sağlık, mühendislik ve fizik gibi farklı alanlarda çalışılan EMR; sağlıklı bina ve iç mekan ortam kalitesi (IEQ) gibi konulara aşina olan yapı bilimlerinde de son zamanlarda yöneldiği bir konudur. Yapıların EMR'un sağlık üzerine etkileri dikkate alınarak tasarlanmabilmesi konusunda bilgi birikimi henüz yeterli değildir. Bu çalışma aşırı EMR'un bina tasarım elemanları ile kalkanlanması ve kontrolünü araştırmaktadır. Yapı kabuğu katmanları, pencere duvar oranı, oda ebat ve oranları, kaplama malzemeleri, tefrişler gibi mimari elemanların kalkanlamaya etkisi vaka analizi olarak yerinde ölçümler ve bilgisayar destekli sümulasyonlar aracılığıyla test edilmiştir. Sonucunda ise oluşturduğu veri tabanını kullanarak mimarlari

elemanların etki ağırlıklarını ortaya koymayı hedeflemektedir. Bu sayede bu alanda teori ve pratik için referans oluşturulurken aynı zamanda EMR ve sağlıklı mekan tasarımı ilişkisi üzerine farkındalığın tasarımcılar arasında arttırılacağı öngörülmektedir.

Anahtar Kelimeler: Sağlıklı Bina, Elektromanyetik Radyasyon, Elektro-Sis Azaltılması, Duyarlı Mekanlar, Bina Malzemelerinin Dielektrik Özellikleri.

To My Family

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
5G	the fifth-generation technology standard for cellular networks
ALARA	As Low as Reasonably Achievable
ASBC	The Austrian Sustainable Building Council
BREEAM	Building Research Establishment Environmental Assessment Method
EC	European Commission
EF	Electric Field
EHS	Electromagnetic Hypersensitivity
EMF	Electromagnetic Fields
EMO	Chamber of Electrical Engineers in Türkiye
EMR	Electromagnetic Radiation
EU	European Union
FCC	The U.S. Federal Communications Commission
ICT	Information and Communication Technologies
IEQ	Indoor Environmental Quality
IoT	Internet of Things
LEED	Leadership in Energy and Environmental Design
MF	Magnetic Field
NATO	The North Atlantic Treaty Organization

RFR	Radiofrequency Radiation
SAR	Specific Absorption Rate
SBS	Sick Building Syndrome
TEMPEST	Telecommunications Electronics Materials Protected from Emanating Spurious Transmissions
TQB	The Total Quality Building Assessment Tool
TSI	Turkish Standard Institute
WHO	World Health Organization
WIFEEB	Wireless friendly energy-efficient buildings

Note: Definition of Terms are given in the Appendices section.

LIST OF SYMBOLS

SYMBOLS

ε_R:	Relative Permittivity
μ:	Permeability
σ:	Conductivity
η':	The Real Part of the Relative Permittivity
η'':	The Imaginary Part of the Relative Permittivity

.

CHAPTER 1

INTRODUCTION

This chapter presents four sections concerning the argument for the study, the research problem, research questions, objectives, and methodology of the study as well as the disposition of the dissertation.

1.1 Argument

In past few decades, information & communication technologies (ICT) and electronic devices have overwhelmingly infiltrated into daily life. Consequently, the electromagnetic (EM) and radiofrequency (RF) pollution caused by the increasing use of electrical and electronic equipment present new environmental challenges. The term "electro-smog" is used in a generalized way for the various electromagnetic fields of different frequencies and strengths that are present in our environment and are emitted from sources such as electrical cables, power lines, electrical appliances, mobile phones, computers, and telecommunication antennas (Bernhardt, 2005). A broad base of literature underlines the fact that the excessive electromagnetic radiation (EMR) from such technologies is an invisible threat to health and safety in addition to information security. With technological developments, especially within the smart city (SC) concept, the use of ICT and electronic devices both in indoor and outdoor environments is expected to increase further (Clegg et al., 2020). Since, people spend more than 86% of their time indoors (Klepeis et al., 2001) they are continually exposed to EMR. The importance of health, one of the most critical assets for human life, was once again remembered during the COVID-19 pandemic. The negative impacts of electro-smog on human health are the main motivation to acquire a deeper understanding of the relationship between EMR and the built environment, in order to ensure a healthy space.

So far EMR has been studied commonly in the field of medicine, physics, and engineering within their specific context and from their individual perspectives. The field of building science within its interdisciplinary sphere is familiar with health issues in buildings referring to indoor environmental quality (IEQ), indoor air quality (IAQ), healthy building, and the sick building syndrome (SBS). However, EMR and healthy space design is an almost unexplored topic at present, and consequently there is very limited information available for architects and planners to design healthy buildings. Nevertheless, there are 5 theoretical studies that draw attention to the importance of this issue and offer theoretical suggestions (Abdorahimi & Sadeghioon, 2019; Belyaev et al., 2016; Clegg et al., 2020; Gustavs, 2008; Korur et al., 2010). Also, there are 4 studies that provide measurement-based data on the effect of architectural decisions (Algumbari & Nagy, 2022; Glaria et al., 2018; Hakgudener, 2015; Khalfan et al., 2018). One of them focuses on a study desk in a home (Algumbari & Nagy, 2022). The other one focuses on relationship between influence of geomagnetism into building and rainwater streams (Glaria et al., 2018). Another one focuses on effect of furniture and transmission coefficients of some building materials individually in laboratory environment with a proportional model (Hakgudener, 2015). The last one focuses on shielding effectiveness of historic buildings (Khalfan et al., 2018). There are two studies that provide simulation-based data. The first one simulated the effect of roof forms such as domes, vaults, and flat slabs for 2.4 GHz frequency in a hypothetical room with brick, plaster, and paint as the envelope materials (Wahba et al., 2021). This study evaluates EM power density. The second one by Vizi & Vandenbosch, (2016) simulated four features in a hypothetical room, which were: room forms such as circular, hexagonal, rectangular; curvilinear and right-angled corners; effect of adding a window in one wall (1.5mx1.5m); and the effect of furniture instead of empty room. The room was assumed to have only concrete as the building envelope and was evaluated for the electric field distribution in it for a single radiation frequency of 1.0 GHz (Vizi &

Vandenbosch, 2016). Although these studies are very valuable as a first step, they provide very limited knowledge on the issues at hand. There is an enormous gap in the literature that needs to be filled urgently.

There are several reasons for the need to further studies: Firstly, the parameters applied for the reduction of EM radiation may produce different results for each frequency. Therefore, many studies focusing on various frequencies are needed, and more work needs to be done step by step to account for the varied frequencies. For the time being, the first step should be to determine the architectural variables affecting EMR shielding at a current frequency level. Secondly, EMR consists of two components: electric and magnetic radiation. The tested parameters may produce different results for electric field strength, magnetic field strength or EM power density. Therefore, it is necessary to analyze the electric and magnetic aspects separately. Finally, more effort is needed to collect data on EMR specific to the field of architecture. There is no database in existence. For example, dielectric properties are not published for all building materials. In fact, a study covering the entire wall, floor, ceiling systems that can be created with materials with existing dielectric properties has not yet been carried out. The data set that is related to architecture also needs to be compiled. Eventually, developing new building codes for healthy building environments may help to promote and accelerate awareness about EMR-free design for healthy environments (Hakgudener, 2015). These are important knowledge gaps that may be a critical step towards producing a building code for EMR related healthy design.

While it is important to know the current EMR levels indoors, it is also important to remember that the number of EMR sources will increase rapidly soon with developing ICT-based technologies such as the Internet of Things (IoT). In addition, mobile network technology is starting to use higher frequency ranges with each generation. While 4G operates in the 2-8GHz range, 5G has increased to the 3-300Ghz range. The range of 30-3000GHz is planned for 6G. The increase in smart equipment will also affect indoor EMR densities.

Meanwhile, Architecture aims at providing shelter, safety, and comfort in different climatic and geographical conditions as well as, healthy interiors. Even if it is not possible to completely prevent radiation, reducing the exposure time of people to EMR can be an important step in terms of health. If there is a solution that architecture can offer in this regard, it should be investigated.

Electro-smog is invisible, but it is a measurable phenomenon. Its presence can be captured and visualized with several tools including measuring devices and computer-based simulations. It may not be possible to use these opportunities widely and integrate them into the architectural design due to many factors such as the designer's lack of technical knowledge in the field of EMR, the lack of specialized data for architecture, restricted project design durations, and project economy. Considering that it is not possible for the studies and examples in the literature to form a guideline individually, gathering and developing the existing information and presenting it in a form that will support the decision-making capability of the architects at the early design stage will be an important step in designing healthy spaces. While this is important for new buildings, it should be remembered that the existing building stock is much larger in number than new buildings. For this reason, it is important to provide data and tools in a form that is simple enough for the users of existing buildings to utilize. In this way, they can have data to determine the function of the rooms, the location of the furniture or the renovations to be made.

Adverse health effects depend on factors such as EMR frequency, power / strength, duration of exposure, age, and gender of the exposed person. There are some factors that need to be considered while dealing with electro-smog in buildings:

Firstly, children and especially babies are more affected by EMR because their skulls are thin, and their body size is small. Already in many countries, nurseries, schools, and children's rooms are defined as EMR sensitive places. Lower limits have been defined for such sensitive areas.

Secondly, it would be logical to divide architectural spaces into zones according to the EMR levels related to their function. In other words, some areas require a large number of devices or wireless network access due to their function. For example, in the kitchen there are appliances such as electric hobs, ovens, dishwashers, boilers, microwave ovens, toasters, refrigerators and other gadgets like mixers, grinders etc. In the living room, where many devices such as smart TVs, computers, game consoles, Wi-Fi routers are used, there are already EMR sources in the room. However, when places such as children's rooms and bedrooms are considered, there is a dire need to eliminate or lower the use of devices and wireless network. For this reason, it is more practical to reduce electro-smog intensity in places such as children's rooms and bedrooms.

Thirdly, the duration of exposure is an important factor in the occurrence of adverse health effects. It is therefore reasonable to focus primarily on activities where people spend long periods of time. For example, sleeping or working at a desk.

Fourthly, the intensity and density of EMR in a volume can vary due to height. This is a challenge in the assessment and solution generation process.

Taking these four factors together, this study proposes to assess the height of the bed (70cm above the floor) in children's rooms where sleeping activity takes place. People are in the same position for a long time in the sleeping state. Even, children spend at least a third of the day asleep. Also, all sensitive organs, such as the heart and brain, are exposed to EMR at a similar height range, minimizing the age and gender differences in terms of height when the sleeping position and bed level are considered.

Currently, the knowledge is quite limited and far from presenting how parameters of architectural design affect EMR distribution and density in the building interiors. Hence, this study explores the impacts of architectural decisions on EMR propagation. The study will also transfer and transform EMR related information from various fields into building science. This doctoral research, therefore, aims to develop an EMR level-based prediction model to support early design stage decision for healthy design of children’s rooms. This work will include a literature survey, case study, computational simulations, and measurements by using EMF-Meters for validations of the model. Due to resource limitations, evaluations are conducted at 1GHz, to determine which architectural variables are influential and to compare their level of influence.

1.2 Objectives

This study aims to determine whether architectural design is effective for mitigating radiation exposure in indoor spaces. If effective, a secondary aim is to provide an early design stage decision support model for architects to design healthy spaces by mitigating electro-smog. Since the essential underlying aim is to raise awareness about an EMR safe and healthy building design, the following objectives form the backbone of this research:

- To assess outdoor and indoor EMF levels by on-site measurements and literature review.
- To compile dielectric properties of common building materials from various interdisciplinary studies in the literature.
- To compare the EMF limit for healthy interiors by studying international/national regulations, suggestions in literature for EMR limits, and scoring criteria in building rating systems for the built environment.
- To transform EMR related data from various practices, such as TEMPEST, material research, propagation of electromagnetic waves, into building design.
- To compile the recommendations and the data in the literature related to architecture on EMR.
- To list architectural parameters which have the potential to mitigate excessive EMR.

- To calculate the effects of architectural parameters on EMR mitigation and to grade their weights.
- To design a decision support framework.

1.3 Procedure

In the light of literature, known theoretical rules and data related to EMR were analyzed and associated with building design. In addition to literature in the field of architecture, appropriate data from studies in various disciplines were transferred to the field of building science. These were presented in a table form including spatial suggestions, dielectric properties of building materials, data related with EMR and buildings from various studies. These tables are a base to be expanded and add on to, in order to compose a guideline for EMR safe and healthy design. Also, international regulations and limits for the built environment are presented in table form.

To create a decision support model, it is necessary to first create a database. To achieve this end the effect of architectural variables such as wall thicknesses, wall materials, floor finishings, ceiling materials, room depth, room width, room height, window size, window position, furniture density, furniture material and door position on indoor EMR mitigation were identified by using a simulation tool normally used in engineering problem solving. Consequently, a 4-stage study was carried out to create the database. In the first stage, not only the current EMR levels in the outdoor areas of the selected sensitive buildings were determined by on-site measurements, but the results were compared with other studies in literature and international limits. In the second stage, the interior EMR levels of a flat in Ankara city center were assessed by on-site measurements. These measurements were also used for the calibration and validation of the simulations results. A room in the flat where indoor EMR levels were assessed is selected as the case study for sensitive interior spaces.

The room, which is a nursery (baby's room), is modelled in simulation environment with respect to its properties such as materials, sizes, openings, furniture. Results from simulation of this model were compared with on-site measurements of the room. In the third stage, shielding ability of various wall types were assessed through both on-site measurements with an experimental installation and simulations. In the fourth stage, the effects of different architectural decisions were tested in the simulation environment through the room selected as the case study.

The flow chart in Figure 1.1 presents a conceptual framework. First of all, EM strength in the environment needs to be defined or assumed for different exposure levels related with the type of EMR sources, location, distance, intensity, wavelength parameters. The presence of important external sources such as railways, base stations, transformer stations and EMR sources such as indoor household appliances should be considered. Within the scope of this study, the focus is on the part associated with the building shown in Figure 1.1 and the assessment of the EMF level in the outdoor environment is done for only a few locations, including the case study flat. The EMR levels emitted by household appliances were also measured only in the case study flat and compared with data in literature. Establishing a database on the determination or estimation of EMF levels in the environment could be the subject of another study. For example, a recent study proposes to produce a prediction system based on measured values recorded in a city (Sakacı & Çerezci, 2019). This is an important step towards creating electromagnetic field maps of cities, updated over time due to the change of internal and external sources, and used as a database for architectural design. This prediction system presented by the authors can be used in combination with the architectural tool proposed here.

After the exposure level has been assessed, the building properties were defined. While determining the priority status, areas such as children's rooms, bedrooms, nurseries will be defined as sensitive places, the other areas such as living rooms will be defined as normal areas, and areas such as offices and kitchens will be defined as resource spaces because they need EMR sources. Within the scope of this study, only sensitive places are being focused upon.

Since reducing the exposure time of the users is one of the important steps for health, the occupancy time is a parameter to be considered. These functional properties of the building may be used as a coefficient for rating. Within the scope of this study, only the sleep activity, which is subjected to long-term exposure, is the focus. The baby's room was preferred as it is a sensitive place. However, the plane to be exposed to EMR during sleeping activity was determined as 70cm from the floor, taking into account the standard bed height. This level is also a valid level for adults.

The physical building properties include many parameters such as room shape, room size, room height, room proportions (aspect ratio), facade area, window to wall ratio, wall materials, wall thickness, floor and ceiling finishes, furniture density, and furniture materials. Each of these parameters consists of subordinate variables. The effects of 50 cases developed by the combinations of these variables were derived by simulation. Simulation results were also used to define the impact weights of architectural parameters through correlation and multiple regression analyses.

The decision support model was developed by using the database. A case study building was selected to test the decision support model. For the case study building, the prediction model was applied. Validation was done by comparing simulation results and the predicted value.

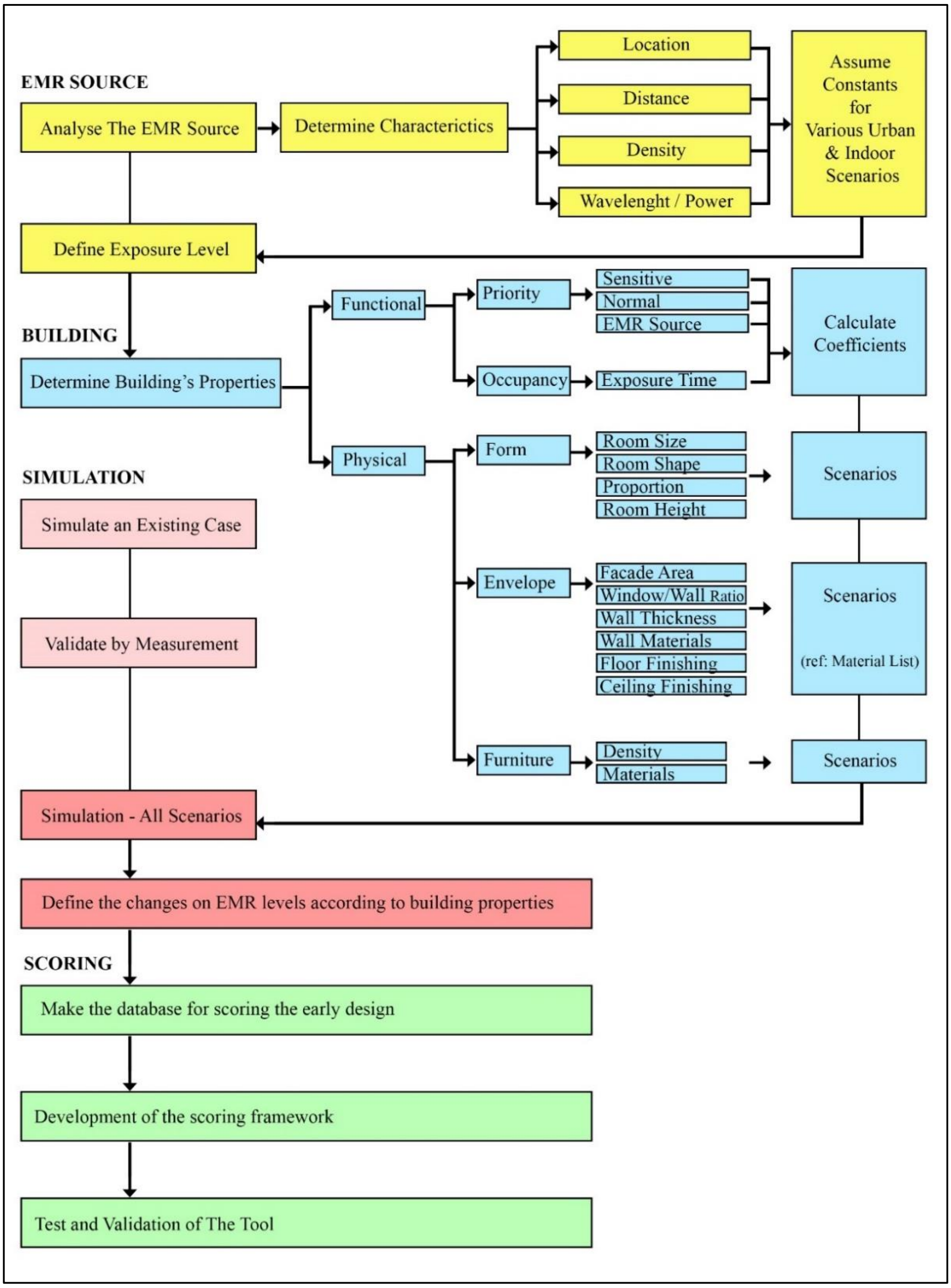


Figure 1.1. Flowchart to present procedure of the study.

1.4 Disposition

This study consists of five chapters. In Chapter 1, the argument, the objectives, and an outline of the procedure are presented. The chapter concludes with disposition of the dissertation.

In Chapter 2, literature survey covering the basics about EMR, EMR-related risks, EMR levels in smart city vision, international EMR regulations, and data derived from literature is presented. Literature survey depends on 160 published sources and 7 web pages.

In Chapter 3, the research material and the methodology are presented.

In Chapter 4, the results are presented and discussed.

In Chapter 5, the dissertation is concluded with the presentation of research results and recommendations based on research findings.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a literature review on EMR and EM pollution in the built environment. It consists of topics on EMR-related risks, EMR regulations, EMR shielding theory, and data derived from literature. In addition, all accessed studies dealing with EMR in building science (architecture) are presented. To clarify the presentation especially for architects, and general definitions and basic principles of EMF have been given.

2.1 Defining EMR

In order to understand the electro-magnetic radiation (EMR) phenomenon and its impacts in the built environment, we first need to define other phenomena like electric fields, magnetic fields, and electromagnetic fields. These are explained below for the benefit of architects and designers who are unfamiliar with these concepts:

An Electric field (EF) is an invisible line of force that surrounds a charged particle or device (NIEHS, 2002). The intensity of an electric field at a specific location is expressed quantitatively as "electric field strength." (Sheldon, 2022); the unit of measurement is volts per meter (V/m). EF which is produced by the flowing current can be easily shielded by objects like trees and buildings (NIEHS, 2002).

A Magnetic field (MF), similarly, is an invisible vector field that has magnetic influence on an object in space.(NIEHS, 2002). A MF, which is produced by an electric current, has an influence on moving electric charges, electric currents, and magnetic materials (Feynman, 2011). The MF strength is a measure of the intensity of a magnetic field in a given area of that field; and its unit of measurement is tesla (T) or gauss (G). Although, it is harder to shield MF than EF, there are possibilities to weaken it (NIEHS, 2002). A brief comparison of EF and MF can be seen from Figure 2.1.

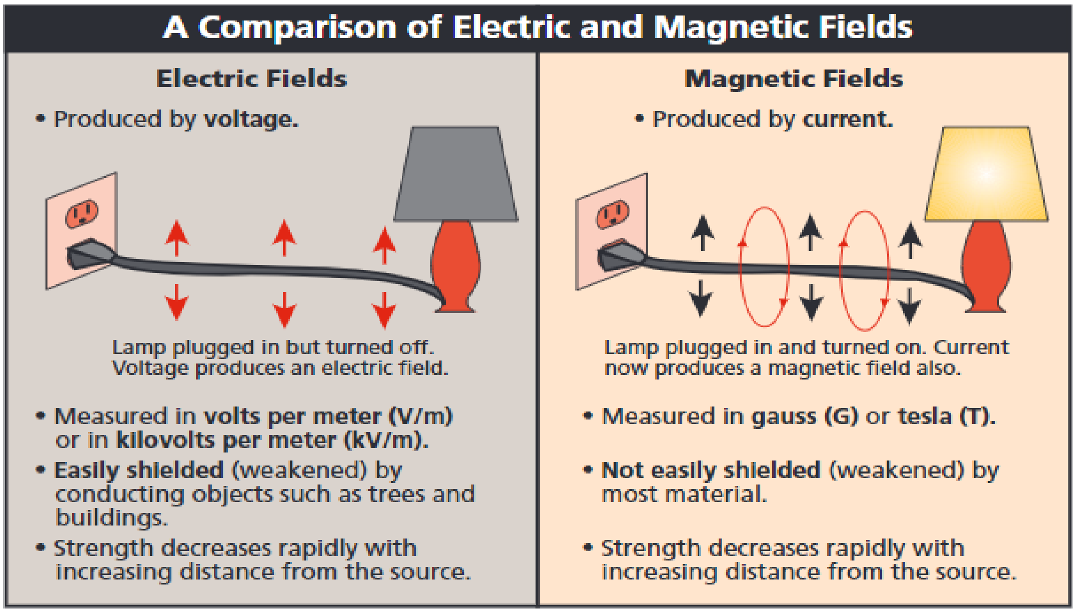


Figure 2.1. A Comparison of electric and magnetic fields (NIEHS, 2002).

Tesla and gauss units are used in milli (m:10^{-3}), micro (μ:10^{-6}), and nano (n:10^{-9}) scales in the international system of units (SI). Micro-tesla (μT) and milli-gauss (mG) are commonly used for measurements (NIEHS, 2002). The relationship between the two units can be determined by the conversion formula (NIEHS, 2002) given below:

$$\mathbf{1\ \mu T = 10\ mG = 0.795774\ A/m}$$

International EMR limits, which will be discussed in the following sections, are mostly given in μT. Since it is sometimes necessary to convert between units within the scope of this study, the conversions for 1 μT are shown in Table 2.1.

Table 2.1 Unit conversion table for MF strength.

G	**Gauss**	0.01 G
mG	**milliGauss**	10 mG
µG	**microGauss**	10,000 µG
T	**Tesla**	0.000001 T
mT	**milliTesla**	0.001 mT
µT	**microTesla**	1 µT
nT	**nanoTesla**	1,000 nT
A/m	**Ampere/Meters**	0.795774 A/m

Electromagnetic field (EMF) is the combination of EF and MF. It is created by electrically charged particles in their environment (Purcell & Morin, 2013). It can be defined as a space consisting of a series of waves oscillating at a certain frequency with a certain distance (wavelength) between them (Patermann, 2005).

The strength of an electromagnetic field is determined by the combined strength of EF and MF. In other words, it is a multiple of the current, which is the amount of electricity in use and the voltage, which is the electrical potential (Ward, 2022); *i.e.*

Electromagnetic Field (V.A/m²)= Electric Field (V/m) x Magnetic Field (A/m)

The vector product of the EF and MF of a propagating EM wave can also be defined as the electromagnetic power per square meter (EMRP) (Hayt & Buck, 2012).

EF and MF strengths decrease with increasing distance from the source. This is "the inverse-square law" that defines the relation between EMF strength and distance (Voudoukis & Oikonomidis, 2017). Hence, distance can be considered as a natural shielding possibility. Especially for designing indoor layout, this law can help to balance the ever-increasing need for wireless networks in buildings and the need for a healthy indoor environment. Figure 2.2 shows how EM intensity weakens within 120 cm distance from the source (NIEHS, 2002).

Electromagnetic radiation (EMR) is a form of energy that moves through space at the speed of light (Percuoco, 2014), and consist of EMF (Belyaev et al., 2016). EMR is present almost everywhere in the environment. It is used in a variety of applications, including electrical power generation, telecommunication, and medical imaging (Clegg et al., 2020).

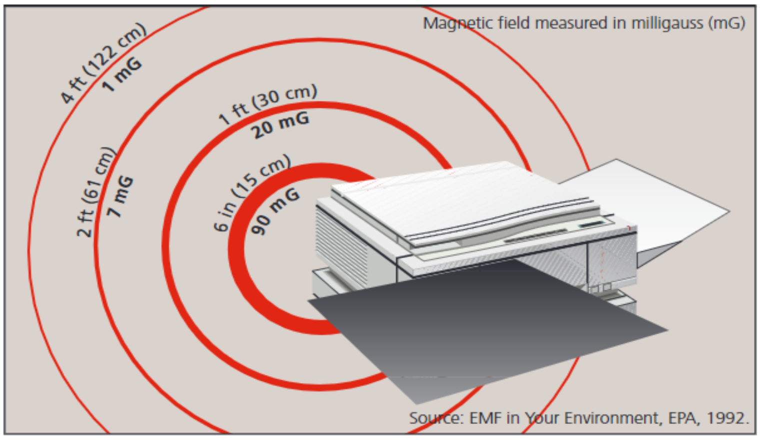


Figure 2.2. Magnetic field strength and distance relation fields (NIEHS, 2002).

Electromagnetic radiation is a broad term that encompasses a wide range of frequencies, including radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. The characteristics of electromagnetic radiation depend on its frequency, wavelength, and amplitude (strength) (NIEHS, 2002; Purcell & Morin, 2013). The different types of electromagnetic radiation have different uses and effects on matter as seen from Figure 2.3 and Figure 2.4.

According to its effect, EMFs are examined under two main titles as ionized, which occurs where the voltage is higher than 12eV, and non-ionized electromagnetic radiation (EMR), which occurs where voltage is lower than 12 eV (Erdoğan et al., 2019). Each type has adverse effects on human health.

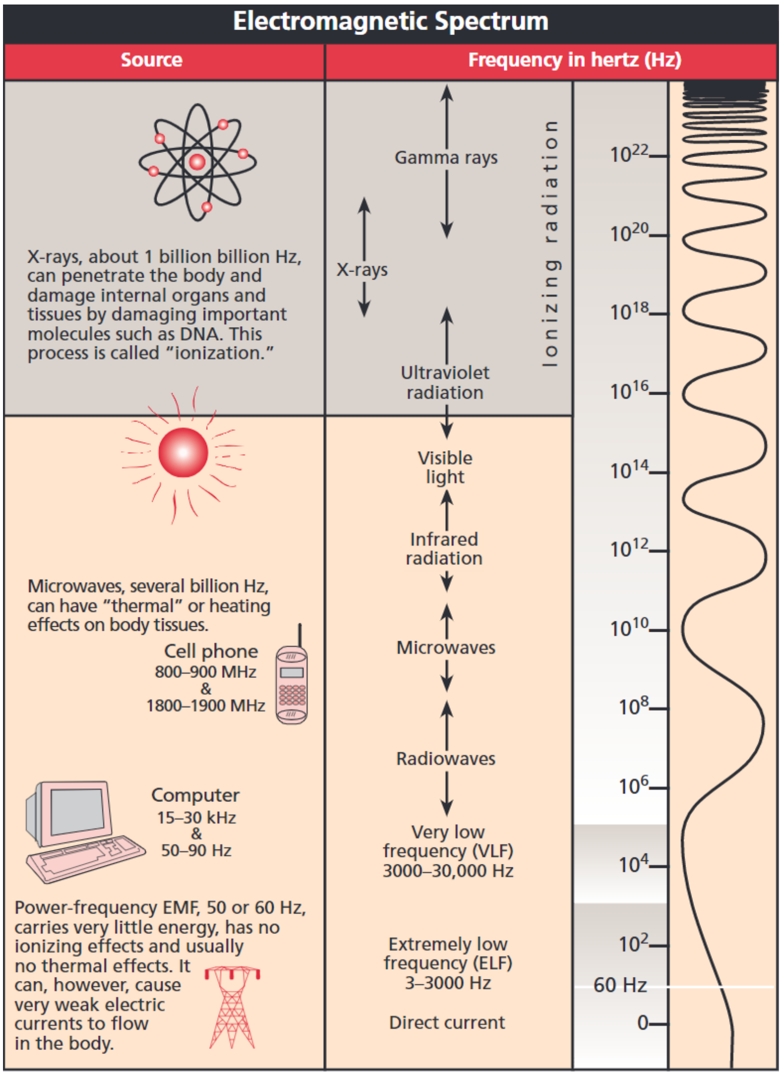


Figure 2.3. Electromagnetic Spectrum (NIEHS, 2002).

Radio Frequency (RF) is the range of frequencies within the electromagnetic spectrum that are used for communication technologies, such as radio and television broadcasting, mobile phones, and Wi-Fi. The RF range is typically defined as frequencies between 3 kilohertz (kHz) and 300 gigahertz (GHz) (Belyaev et al., 2016). The classification of radio frequency according to frequency ranges can be seen in Figure 2.4. While current widespread technologies are located in the ultra-high frequency (UHF) band, future wireless technologies, which will form the basis of smart cities, will serve in much higher frequency ranges (Clegg et al., 2020).

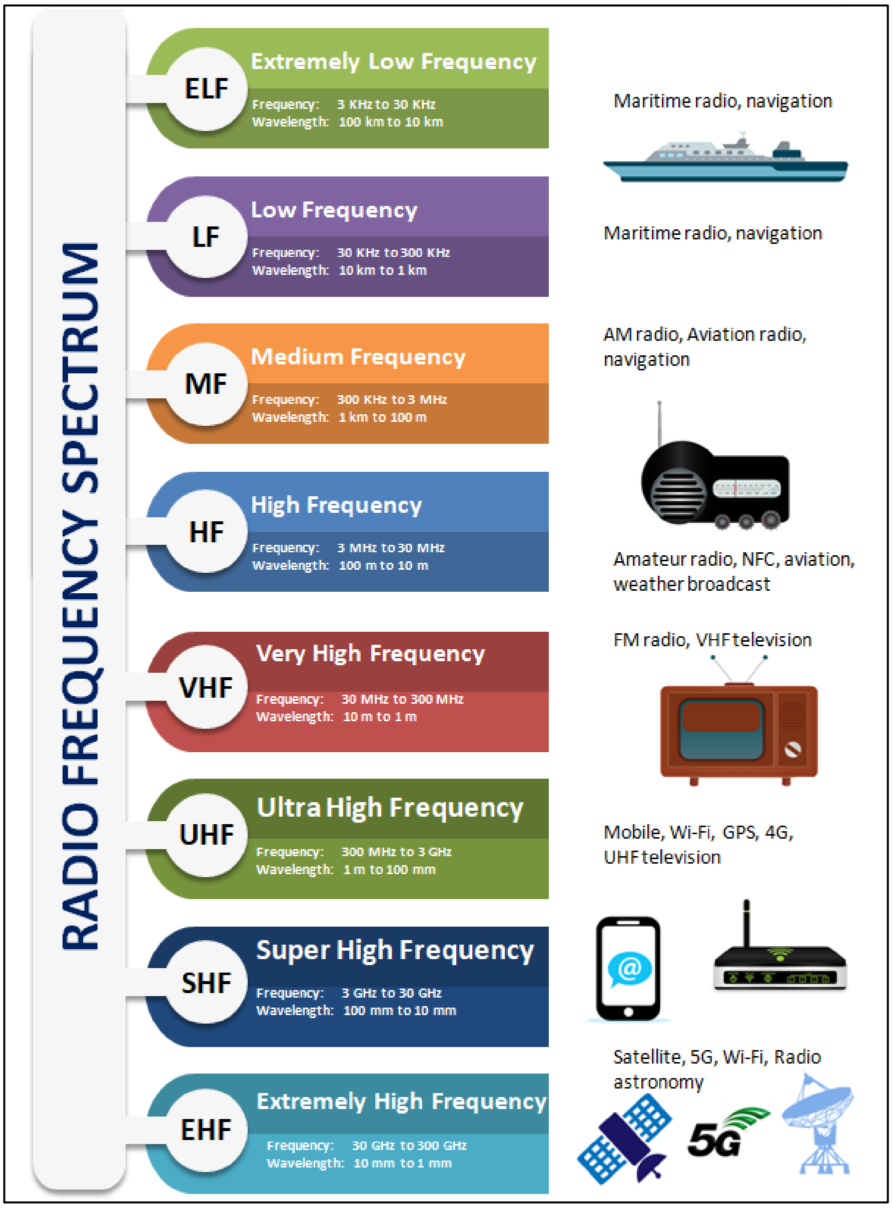


Figure 2.4. Radio frequency bands and applications (Rajiv, 2022).

Frequency is measured in hertz (Hz), and 1 Hz refers to the number of repeating waveforms in 1 second (Ozen et al., 2013). This means that 2 times more waveforms occur at a frequency of 2Hz compared to 1Hz in a fixed time interval. "*Wavelength is the distance between two adjacent crests of the wave*" (Ozen et al., 2013) and it is measured in units of length (Figure 2.5).

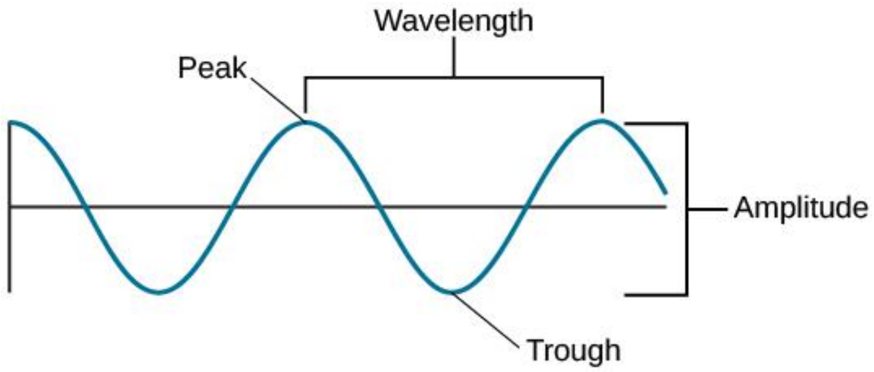


Figure 2.5. Wavelength, frequency, and amplitude (Jhangiani, 2017).

Frequency and wavelength are inversely proportional; and the conversion formula for wavelength and frequency is given as:

$$\textbf{Frequency or f (Hz)} = \frac{\textbf{Speed of light or c (m/s)}}{\textbf{Wavelength or } \boldsymbol{\lambda} \textbf{ (m)}}$$

where c is the speed of light (299,792,458 m/s), f is the frequency in Hz, λ is wavelength in m. Wavelengths for some frequencies are given in Table 2.2.

Table 2.2 Frequency and Wavelength

Frequency (GHz)	Wavelength (cm)
0.01 GHz	2,997.92458 cm
0,1 GHz	299.792458 cm
1 GHz	29.9792458 cm
2 GHz	14.9896229 cm
5 GHz	5.99584916 cm
10 GHz	2.99792458 cm
30 GHz	0.99930819333 cm
100 GHz	0.299792458 cm

The magnetic field values emitted by some of the electrical devices in households are presented in Table 2.3.

Table 2.3 Magnetic fields generated by electrical devices depending on the distance (Türkkan & Pala, 2009).

Electrical Device	3cm (μT)	30cm (μT)	100cm (μT)
Hair Dryer	6-2000	0.01-7	0.01-0.03
Electric Shaver	15-1500	0.08-9	0.01-0.03
Vacuum Cleaner	200-800	2-20	0.13-2
Fluorescent Light	40-400	0.5-2	0.02-0.25
Microwave Oven	73-200	4-8	0.25-0.6
Mobil Radio	16-56	1	<0.01
Oven	1-50	0.15-0.5	0.01--0.04
Washing Machine	0.8-50	0.15-3	0.01-0.15
Iron	8-30	0.12-0.3	0.01-0.03
Dishwasher	3.5-20	0.6-3	0.07-0.3
Computer	0.5-30	<0.01	
Refrigerator	0.5-1.7	0.01-0.25	<0.01
TV	2.5-50	0.04-2	0.01-0.15

2.2 EMR-related risks

Human life is surrounded by EM radiation produced by various electronic signal emission sources, which is associated with EM wave interference, harm to human health, information security violations, pollution of the home environment and other issues (Clegg et al., 2020).

The EMR-related risks on health, information security and structural system is briefly mentioned in this section to enhance an idea behind why EMR should be taken notice of in our living environment.

2.2.1 Health risks

Electromagnetic pollution receives less attention than other environmental pollution because it is invisible, and its harmful effects are not immediately apparent (Şeker & Çerezci, 2010). In fact, EMR (100 MHz–300 GHz) is classified as a Group 2B cancerogenic by the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) in 2011 (Baan et al., 2011). Recently, in 2019, the advisory group within the WHO recommended that this classification be re-evaluated with animal experiments (Marques et al., 2019). Various studies have already suggested to re-classify EMR as Group 1 known human carcinogen (Hardell & Carlberg, 2019; Miller et al., 2018) on par with tobacco smoke and asbestos (Clegg et al., 2020).

Although it must be acknowledged that correlation does not always mean causation, literature in medicine widely point out to the negative effects of EMR on health. While some studies establish a relationship between RF/EMR and their adverse effects, some others do not. Cucurachi *et al.* (2013) questions the possibility of a geographical bias in this regard by comparing the number of studies that conclude that there is a correlation between EMR and health versus those that declare there is none, according to the countries of the authors. Although there are many more studies showing that EMR has harmful health effects, these studies are not yet used as a reference for setting precautions and limits; this too has led to controversy (Cucurachi et al., 2013; NIEHS, 2002; Odac et al., 2016; Torres-Duran et al., 2007).

Because it is a search for a balance between the pursuit of technological / economic development and health concerns, WHO recently published a series of protocols for a systematic review on various health effects of EMR (Henschenmacher et al., 2022; Marques et al., 2019; Mevissen et al., 2022; Pacchierotti et al., 2021; Röösli et al., 2021). Under the umbrella of the European Union (EU), the European Commission (EC) still supports not only studies investigating the relationship between EMR and health but also many projects to reduce or eliminate the negative effects of EMR on health (Patermann, 2005).

Some studies have already reported various adverse effects. Some of them are on sperm quantity and quality, as well as DNA damage from everyday EMR exposures (Houston et al., 2016). Also, high levels of EMR absorption during pregnancy have been associated with slowing or halting embryonic development (Han et al., 2010); increased risk for premature birth (Tsarna et al., 2019), and an increased risk of behavioral problems, particularly in the form of hyperactivity/inattention in children

(Birks et al., 2017). Children absorb much more EMR doses than adults (Fernández et al., 2018) as seen in Figure 2.6. While for children up to seven years old, some studies have correlated wireless technology use with addictions and depression (Jun, 2016), fatigue (Zheng et al., 2015), altered baseline thyroid hormone levels (Geronikolou et al., 2015), and poorer well-being (Redmayne et al., 2016). Increases in cerebral hemorrhage and heart attack risks at young ages are also associated with EMR (Bold et al., 2003).

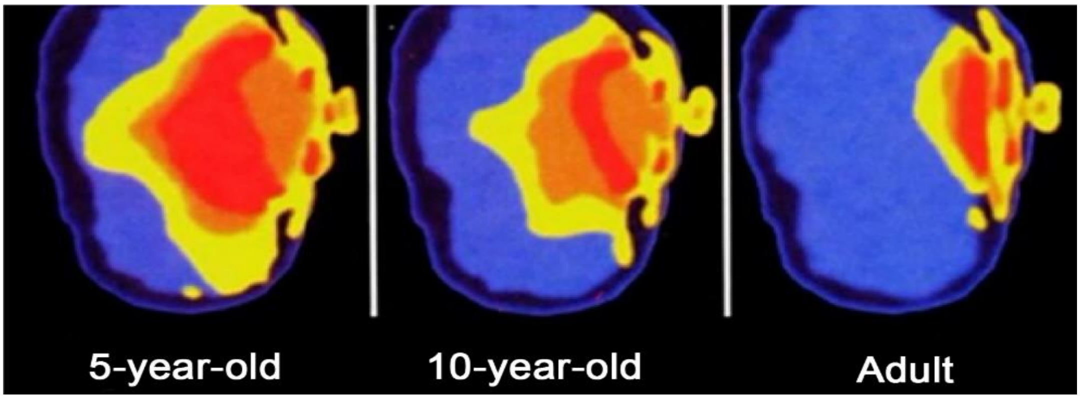


Figure 2.6. Demonstration of EMR impact on brain for ages (Gandhi et al., 1996; Sweidan et al., 2017).

There are also studies present on adverse effects on plants and animals such as mammals, fish, birds, insects, amphibians, etc. (Cucurachi et al., 2013; Fernie et al., 2000; Shende & Patil, 2015). Example of these adverse effects are that the side of the plants facing the antenna is less healthy and plants close to the antenna die earlier (Waldmann-Selsam et al., 2016). EMR emitted from WiFi at 2.4GHz (2420mW/kg, 1 g average) affects reproductive parameters of male rats (Dasdag et al., 2015). The authors suggest that it is necessary to avoid long term Wi-Fi exposure.

On the other hand, Electromagnetic Hypersensitivity (EHS), which is being more sensitive or intolerant to EMR, includes symptoms such as "headaches, cognitive difficulties, sleep problems, dizziness, depression, fatigue, skin rashes, tinnitus, and flu-like symptoms" (Genuis & Lipp, 2012). A recent study on EHS, considering the WHO's causality criteria, shows the association of man-made EMR with EHS and suggests considering EHS-associated health issues as a pandemic (Belpomme & Irigaray, 2022).

According to a frequently cited study conducted in United States (U.S.), people in cities spend 86.9% of their time indoors (Klepeis et al., 2001). Although it may vary regionally, this high percentage enhance the importance of providing healthy interiors.

Beyond biological variability (*e.g.* age, gender) and environmental factors (*e.g.* air temperature, humidity, ventilation), adverse health effects are related with intensity of radiation and exposure time (ICNIRP, 2020).

In addition, it is needed to draw attention to a critical point (Panagopoulos & Chrousos, 2019), *i.e.* the natural non-polarized EMR which is responsible for the biological rhythmicity and well-being of humans and animals (Dubrov, 1978; Presman, 1970; Schumann, 1952; Tesla, 1904; Wever, 1979). Not only excesive man-made EMR exposure but also lack of natural EMR may cause health issues (Panagopoulos & Chrousos, 2019). Technologies such as ICT and 5G use high frequencies (Clegg et al., 2020), while natural EMR is at very low frequencies mostly between 7.8–13 Hz (Persinger, 2014). Although shielding is one of the effective ways to control man-made polarized EMR; unfortunately, common shielding methods (metal plates, etc.) block both types of EMR (Panagopoulos & Chrousos, 2019).

2.2.2 Information security risks

Although this PhD study is health orientated, to date there are not many studies on building design considering the health risks of EMR. For this reason, it may be instructive to examine studies on EMR for different purposes. At this point, information security in buildings is directly related to EMR shielding. Also, it is already an important issue in smart cities.

It has been known in literature since the 1980's that even data transmitted by cable can be scanned with the help of EMR around the cables, *i.e.* the so-called information leakage (van Eck, 1985). On the other hand, information transferred by wireless technology is an EMR open to eavesdropping, so easier to steal as part of the "side-channel attack" (Sayakkara et al., 2019). Transient Electromagnetic Pulse Emanation Standards (TEMPEST) were published by The North Atlantic Treaty Organization (NATO) for its member countries to use for counterintelligence purposes in the 1960's (Easter, 2020). Until this decade, measures such as TEMPEST considered the information security of military and government buildings. Now it is also a critical challenge in the smart city concept (Silva et al., 2018). All data including citizens' sensitive personal information, which are open to various security threats, such as side channels, cross-site scripting, and data leakage, will be stored in the urban network in smart cities; so, protecting these data is a key concern (Rejeb et al., 2022; Rizi & Seno, 2022; Sharifi, 2019; Silva et al., 2018). In smart cities, this issue can be extended to the questioning of electronic voting applications within the scope of e-democracy which may be interfered by EM leakage. However, practices for information security can also shed light on the efforts to control EMR for a healthy environment and these two issues can mutually support each other.

2.2.3 Structural and EMI risks

A recent study points out that ionizing radiation has an adverse effect on the reinforced concrete structure, causing up to 60% of the structure's strength to be lost in time (Ibragimov et al., 2022). It should be noted that the volume of buildings exposed to ionizing radiation is less than the volume of those exposed to non-ionizing radiation. The authors also point out that non-ionizing radiation has an influence on reinforced concrete structures in the emergence of a corrosion process by an electrochemical mechanism, along with a reduction in the mechanical strength of the reinforced concrete structure. EMR play role in both the "start" and progression of corrosion in reinforced concrete structures that can actually be directly destroyed by microwave radiation with an energy of about 50 J/g (*i.e.* 50 VAsec/g) (Ibragimov et al., 2022). The concrete also is in danger of micro-scale destruction by electromagnetic pulses, which principally weaken the bond strength at the boundary of the cement paste and aggregate (Ibragimov et al., 2022).

Knowing that reinforced concrete buildings are increasingly exposed to electromagnetic radiation in the environment; scientific techniques and methodologies must be developed to insulate reinforced concrete structures from electromagnetic radiation of various frequencies (Ibragimov et al., 2022). This issue is discussed here to drawn attention to and raise awareness about the risks of prevailing EMF to structures; and though it is one of the dimensions of the relationship between EMR and buildings, it has not been included within the scope of this research.

Apart from the structure, the operation of electronic and mechanical systems inside buildings can also be affected by EMR. An electromagnetic pulse (EMP), also a transient electromagnetic disturbance (TED), is a burst of electromagnetic radiation that can be produced by a variety of sources, such as solar storm and lightning (DOH, 2003). An EMP can cause a wide range of effects on electronic equipment, depending on the strength and frequency of the radiation and the distance from the source (DOH, 2003). At high levels, an EMP can damage or destroy electronic devices and systems, causing malfunctions or complete failures; and at lower levels, an EMP can cause interference or temporary disruptions in the operation of electronic equipment. Electrical devices can also produce brief EMF bursts (sometimes known as "transients") when they are turned on or off (NIEHS, 2002). The effects of an EMP can be mitigated by applying shielding and other protective measures.

Electromagnetic interference (EMI), also called radio-frequency interference (RFI), is the disruption of operation of an electronic device or system by electromagnetic radiation from an external source, *e.g.,* another equipment or device. Electronic devices are increasingly being used in environments where they are surrounded by other electronic equipment and devices that may generate EMI (Maddocks, 2003). This can cause problems such as malfunctions, errors, and reduced performance in the affected equipment, which can be particularly problematic in sensitive electronic equipment, such as medical devices or aircraft navigation systems (Maddocks, 2003). To prevent or reduce the impact of EMI, a variety of techniques such as shielding and filtering can be applied (Kunkel, 2020).

Sometimes a compatibility system is applied to ensure that the devices work without harming each other. The capability of electronic equipment to operate properly in its intended environment without generating unacceptable levels of electromagnetic interference (EMI) is known as electromagnetic compatibility (EMC) (Maddocks, 2003). EMC can be achieved through design techniques, testing, and the use of EMI mitigation measures such as shielding and filtering (Maddocks, 2003).

Beyond device-based measures, spectrum management is applied to ensure that users serving different purposes can coexist and work effectively without interfering with each other. Spectrum management is the process by which governments or organizations regulate the use of the electromagnetic spectrum, including EMR frequencies used for communication technologies such as radio, television, and mobile phones (Cave, 2006). It aims to increase efficiency, promote innovation and economic growth, and provide protection against harmful interference. The EM spectrum is a finite resource and the demand for access to this spectrum is constantly increasing as new technologies are developed and adopted (Cave, 2006). To summarize, since spectrum management groups together different functions when frequency sensitive shielding alternatives are developed, EMR intensity can be reduced by completely preventing non-essential frequencies from penetrating indoors.

2.3 International EMR regulations

The metrics of radio frequency radiation (RFR) limits, international reference levels for RFR, current EMR levels in built environment and discussions on limits are mentioned in this section.

The U.S. Federal Communications Commission (FCC) defined RFR limits for public exposure with regard to three metrics: 1) the "Specific Absorption Rate" (SAR), which is the rate of RF energy absorption by human tissue; 2) power density (PD), which is the rate of deposition of energy per unit area and is a function of the electrical and magnetic fields at a particular frequency; and 3) the electrical field strength (EFS) (Clegg et al., 2020). SAR is mostly related to devices while PD and EFS are directly related to the environment. So, PD and EFS is subject to space design considerations.

2.3.1 International limits

The World Health Organization published a guideline for developing health-based EMF standards as a framework for countries who prefer to make their own standards (WHO, 2016) but they did not set health-based EMF limits or standards. According to health-based exposure guideline the EMF standards must address frequency, exposure level, exposure duration and whole-body/partial-body exposure.

Although WHO recognizes that long-term exposure to MF of 0.3 μT and above in residential areas is associated with childhood leukemia, it states that the population exposed to this value in 2000 was very limited (WHO, 2007). WHO still believes that more studies are needed on various adverse health effects to re-identify the limits.

WHO formally recognize the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which is founded by the International Radiation Protection Association (IRPA). The limits in the ICNIRP guidelines are variable depending on public-occupational status, frequency, and duration of exposure. Various limits from ICNIRP are presented in tables below. The limits for exposure, averaged over 30 min and whole body, to EMF from 100 kHz to 300 GHz can be seen from Table 2.4. The reference level quantities relevant to ICNIRP 2020 guidelines are incident electric field strength (E_{inc}) in V/m and incident magnetic field strength (H_{inc}) in A/m, incident power density (S_{inc}) in W/m^2, and plane-wave equivalent incident power density (S_{eq}) in W/m^2. In formulas given frequencies (f_M) are in MHz. Although there is no data about 6 to 30 minutes exposure in the ICNIRP 2020 guideline for above 2 GHz, formulas are also given for this level in the ICNIRP 1998 guideline.

Table 2.4 Reference levels for exposure, averaged over 30 min and whole body, to EMF from 100 kHz to 300 GHz (ICNIRP, 2020).

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	61	0.16	10
	>400 – 2000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	NA	50
General public	0.1 – 30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30 – 400 MHz	27.7	0.073	2
	>400 – 2000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	NA	10

According to the formula in the Table 2.4, the reference level at 1Ghz frequency for 30 minutes public exposure is 43.48 V/m for incident EF, 0.117 A/m (0.146 μT) for incident MF and 5 W/m2 for incident power density.

Reference levels for local exposure, averaged over 6 min to EMF from 100 kHz to 300 GHz can be seen from Table 2.5. The reference level at 1Ghz frequency for 6 minutes local exposure is 92.03 V/m for incident EF, 0.24 A/m (0.3 μT) for incident MF and 22.05 W/m2 for incident power density.

Table 2.5 Reference levels for local exposure, averaged over 6 min to EMF from 100 kHz to 300 GHz (ICNIRP, 2020).

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$1504/f_M^{0.7}$	$10.8/f_M$	NA
	>30 – 400 MHz	139	0.36	50
	>400 – 2000 MHz	$10.58f_M^{0.43}$	$0.0274f_M^{0.43}$	$0.29f_M^{0.86}$
	>2 – 6 GHz	NA	NA	200
	>6 – <300 GHz	NA	NA	$275/f_G^{0.177}$
	300 GHz	NA	NA	100
General public	0.1 – 30 MHz	$671/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	62	0.163	10
	>400 – 2000 MHz	$4.72f_M^{0.43}$	$0.0123f_M^{0.43}$	$0.058f_M^{0.86}$
	>2 – 6 GHz	NA	NA	40
	>6 – 300 GHz	NA	NA	$55/f_G^{0.177}$
	300 GHz	NA	NA	20

In the ICNIRP 1998 guide, the reference level at frequencies between 400MHz – 2Ghz for public exposure is same as the ICNIRP 2020 guide. Also, reference levels above 2 GHz public exposure is given as 61 V/m for EF, 0.16 A/m (0.20 µT) for MF and 10 W/m2 for power density as seen from Table 2.6.

Table 2.6 Reference levels for general public exposure, to time varying EF and MF (ICNIRP, 1998).

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (µT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

For exposures below 6 minutes, it can be seen in the Table 2.7 where higher reference levels are presented.

Table 2.7 Reference levels for local exposure, integrated over intervals between >0 and <6 minutes to EMF from 100 kHz to 300 GHz (ICNIRP, 2020).

Exposure scenario	Frequency range	Incident energy density; U_{inc} (kJ m^{-2})
Occupational	100 kHz – 400 MHz	NA
	>400 – 2000 MHz	$0.29 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>2 – 6 GHz	$200 \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>6 – <300 GHz	$275/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$100 \times 0.36[0.05+0.95(t/360)^{0.5}]$
General public	100 kHz – 400 MHz	NA
	>400 – 2000 MHz	$0.058 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>2 – 6 GHz	$40 \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>6 – <300 GHz	$55/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$20 \times 0.36[0.05+0.95(t/360)^{0.5}]$

The guideline on exposures by ICNIRP is widely accepted in the world for EMF safety. However, different national limits are also used around the world. EMF limits are determined by frequency; Table 2.8 shows the limits in different countries for low frequency (50Hz). Some countries directly use the ICNIRP limits, while some are more sensitive, and some are worse. Countries marked in green have stricter limits than ICNIRP values for both EF and MF. Blue ones indicate stricter limits for either EF or MF.

Although the MF limit for 50Hz was defined as 100 μT (ICNIRP, 1998), the ICNIRP guide 2010 allows up to 200 μT (ICNIRP, 2010). In European Countries, the permissible upper limit for the electric field is mostly 5kV/m, and for sensitive areas such as schools, hospitals, and daycare centers, it is 0.5kV/m for 50Hz frequency. Similarly, the permissible upper limit for the magnetic field is 100 μT (0.2 – 0.4 and 1 μT in sensitive areas) in European Countries.

Australia, Belgium, Finland, France, Italy, and the Netherlands have specifically set lower values (mostly 0.2 to 0.4 μT) for sensitive locations such as dwellings, schools, kindergartens, and hospitals. In the definition of sensitive places, particular emphasis is placed on places where children under 15 years of age spend time; thus, schools, dwellings, and hospitals are defined as sensitive and priority spaces for EMR; because they are used by children who are thought to be more affected by EMR than adults, and hospitals have the ubiquity of electronic devices that cause EMR leakage, such as magnetic resonance imagining devices.

Table 2.8 MF and EF limits in different countries for 50Hz.

		Low-frequency (50Hz)			
		Electric field (kV/m)	Magnetic flux density (microT)	Guidence	Reference
ICNIRP	1998	5	100	ICNIRP (1998)	(ICNIRP, 1998)
ICNIRP	2020	5	200	ICNIRP (2020)	(ICNIRP, 2020)
Argentina	2017	3	25	Local	(WHO, 2018)
Australia	2017	[5]/[10]	[0.4]/[100]/[1000]	Local + ICNIRP	(WHO, 2018)
Austria	2017	[5]	[100]	ICNIRP (1998)	(WHO, 2018)
Bahrain	2017	5	100	ICNIRP (1998)	(WHO, 2018)
Belgium	2017	[5]/[7]/[10]	[0.2]/[0.4]/[10]/[100]	Local	(WHO, 2018)
Brazil	2017	4.17	83	Local	(WHO, 2018)
Croatia	2018	2/5	40/100	Local + ICNIRP	(WHO, 2018)
Cyprus	2017	5	100	ICNIRP (1998)	(WHO, 2018)
Denmark	2018	[5]	[0.4]/200	ICNIRP (1998)	(WHO, 2018)
Finland	2017	[5]/[15]	[0.4]/[100]/[500]	Local	(WHO, 2018)
France	2017	5	[1]/100	Local + ICNIRP	(WHO, 2018)
Germany	2017	5	100	ICNIRP (1998)	(WHO, 2018)
Greece	2020	3 / 3.5	60 / 70	Local	(Kiouvrekis *et al.* , 2020).
Hungary	2018	5	100	ICNIRP (1998)	(WHO, 2018)
Iran	2017	5	100	ICNIRP (1998)	(WHO, 2018)
Israel	2017	[5]	[0.2]/[0.4]/[100]	Local + ICNIRP	(WHO, 2018)
Italy	2017	5	0,2/ 3/ 10/ 100	Local + ICNIRP	(WHO, 2018) (EMFs,2019)
Japan	2017	3	200	Local	(WHO, 2018)
Netherlands	2017	[1]/[5]	[0.4]/[200]	Local + ICNIRP	(WHO, 2018)
New Zealand	2017	5	100/[200]	ICNIRP (2020)	(WHO, 2018)
Norway	2017	5	[0.4]/200	Local + ICNIRP	(WHO, 2018)
Peru	2017	4.16	83	Local	(WHO, 2018)
Philippines	2017	4.17	83.33	Local	(WHO, 2018)
Poland	2019	1	48	Local	(EMFs, 2019)
Korea	2017	[4.17]	[83.33]	Local	(WHO, 2018)
Russia	2017	0.5	5	Local	(WHO, 2018)
Singapore	2018	[5]	[100]	ICNIRP (1998)	(WHO, 2018)
Slovenia	2018	0.5/10	10/100	Local + ICNIRP	(WHO, 2018)
Sweden	2017	[2.5]	[100]	Local	(WHO, 2018)
Switzerland	2017	5	1/100	Local + ICNIRP	(WHO, 2018)
Türkiye	2017	[15]	[200]	Local + ICNIRP	(WHO, 2018)
United Kingdom	2017	[5]/[9]	[100]/[360]	Local + ICNIRP	(WHO, 2018)
Florida	2019	2	15/20	Local	(EMFs, 2019)
Newyork	2019	1.6	20	Local	(EMFs, 2019)

Croatia and Slovenia have extended this definition of sensitive locations to include areas around hospitals, residential areas, educational facilities, public recreation grounds, nursing homes, children's playgrounds, retail/business/commercial areas.

France, Finland, Norway, and the Netherlands apply higher limits for existing settlements and stricter limits for new settlements or propose them on a voluntary basis. Also, edge of a right-of-way and proximity to sources such as power lines have also been taken into consideration in some countries. On the other hand, Israel applies limits of 0.4 µT for daily average MF exposure and 0.2 µT for annual average

MF exposure in all locations for long-term exposure beyond ICNIRP limits. However, in countries where more than one value is presented beyond sensitive areas, different limits are defined based on the duration of exposure. While there are local practices in some states of the USA, there is no federal legal limit. The limits presented for Florida and New York are low compared to ICNIRP values.

Similar to low frequency limits, different national limits are also used around the world for radiofrequency. Table 2.9 shows the electric field and power density limits in different countries for RF (900M - 1800Hz).

Even if European Standards (ENs) follow the same numeric values as ICNIRP 1998 guideline (WHO, 2017), the European Union (EU) promotes the “As Low As Reasonably Achievable” (ALARA) principle (Clegg et al., 2020); hence, some European countries have local limits also.

In Greece, 70% of the EU recommendation is used as the power density limit. Also, 60% of the EU recommendation is used as the limit value within 300 meters of sensitive areas such as schools, kindergartens, hospitals, or eldercare facilities (Kiouvrekis et al., 2020; WHO, 2017).

Italy has stricter limits. Moreover, in sensitive areas such as homes, schools, playgrounds, and places where people may stay for longer than 4 hours, the "attention value" of 0.1 W/m^2 is applied. This value is also averaged over any 24-hour period for all areas. Italy has set a quality goal target especially for new installations.

Table 2.9 Power density and EF limits for 900-1800MHz (WHO, 2017).

		Radiofrequency						
		Electric field (V/m)		Power density		Specific absorption rate (SAR)		
		900 MHz	1800 MHz	900 MHz	1800 MHz	Whole body	Head and trunk	Limbs
Argentina	2017	41.25	58.36	4.5	9	0.08	2	4
Australia	2017	41.1	58.1	4.5	9	0.08	2	4
Austria	2017	41.25	58.34	4.5	9	0.08	2	4
Bahrain	2017	41	58	4.5	9	0.08	2	4
Belgium	2017	6	8,5	0.096	0.192			
Brazil	2017	41.25	58.34	4.5	9	0.08	2	4
Bulgaria	2017	6.14	6.14	0.1	0.1			
Canada	2017	32.1	40.07	2.74	4.4	0.08	1.6	4
Chile	2017			0.1/1.0	0.1/1.0	1.6/2	1.6/2	1.6/2
Cyprus	2017	41	58	4.5	9	[0.08]	[2]	[4]
Finland	2017	41.4	58.55	4.5	9	0.08	2	4
France	2017	41	58	4.5	9	0.08	2	4
Germany	2017	41.25	58	4.5	9	0.08	2	4
Greece	2017	31.9/34.5	45.1/48.8	2.7/3.15	5.4/6.3	0.048/0.056/0.08	1.2/1.4/2.0	2.4/2.8/4.0
Iran	2017	41.25	58.34	4.5	9			
Israel	2017	[13.0]	[18.0]	[0.45]	[0.9]	[0.08]	[2]	[4]
Italy	2017	6/20	6/20	0.1/1.0	0.1/1.0	0.08	2	4
Japan	2017	47.55	61.4	6	10	0.08	2	4
Malaysia	2017	41.25	58.34	4.5	9		2	
Netherlands	2017	41.25	58.34	4.5	9	0.08	2	4
New Zealand	2017	41.25	58.34	4.5	9	0.08	2	4
Norway	2017	41.25	58.34	4.5	9	0.08	2	4
Peru	2017	41.25	58.34	4.5	9	0.08	2	4
Philippines	2017	41.25	58.34	4.5	9	0.08	2	4
Korea	2017	41.25	58.34	4.5	9	0.08	2	4
Russia	2017			1	1			
Saudi Arabia	2017	41.25	58.34	4.5	9	0.08	2	4
South Africa	2017	[41.0]	[58.0]	[4.5]	[9.0]	[0.08]	[2]	[4]
Sweden	2017	[41.25]	[58.33]	[4.5]	[9]	[0.08]	[2]	[4]
Switzerland	2017	4/41.25	6/58.34					
Tunisia	2017	41	58	4.5	9	0.08	2	4
Türkiye	2017	3/10.23/41.0	3/14.5/58	0.27	0.55		2	
United Kingdom	2017	[41.25]	[58.34]	[4.5]	[9.0]	[0.08]	[2]	[4]
USA	2017	47.6	61.4	6	10	0.08	1.6	4
Zambia	2017	41	58	4.5	9	0.08	2	4

Similarly, lower values are applied in Switzerland, where the use of these total limit values is divided equally among the 3 existing GSM operators. In other words, each of them can use at most one third of this value.

Israel uses 10% of the ICNIRP limit as the maximum permissible value. In addition to this requirement, a special authorization is required for each base station to ensure that it does not cause further radiation after providing the required coverage.

2.3.2 Current EMR levels in built environment and discussions on limits

Although the effect of radiation on health is the same worldwide, different limits are applied in different countries as seen in the tables above. On top of this, some research in the medical field indicates values different from ICNIRP limits. This situation causes debates. WHO recently published a series of protocols for a systematic review on various health effects of EMR (Henschenmacher et al., 2022; Marques et al., 2019; Mevissen et al., 2022; Pacchierotti et al., 2021; Röösli et al., 2021).

Various studies have been done to assess level of EMF/RF levels for indoors and outdoors. Measurements taken from 697 points in four different companies in Türkiye that together employ 5,632 workers/operators show that about 72% of the staff is under the risk of developing health problems according to IARC and WHO 2001 classifications (Seyhan, 2010). The level of EM in factories is also related to the area of operation of the factory and the equipment used. Measurements recorded in another factory manufacturing cleaning products are below the ICNIRP limit (Cerezci et al., 2022).

According to measurements made in 24 different schools in a Turkish city, in 15 of the schools MF strength was above 0.4 μT, which is associated with childhood leukemia. EF strength was also above 1V/m in 45% of the schools (Yener et al., 2017).

On the other hand, radiation levels in Greek primary and secondary schools are below 60% of the highest limit set by ICNIRP as regard to sensitive land use recommended by EU (Kiouvrekis et al., 2020). Similarly, measurements for indoor dwellings in different parts of Greece are below ICNIRP, the European and domestic limits (Kottou et al., 2015).

Also, Outdoor EMF/RF measurements in Amsterdam, Basel, Ghent, and Brussels are below the ICNIRP limits (Urbinello et al., 2014). The mean total RF-EMF exposure for spot measurements in European “Homes” and “Outdoor” microenvironments was 0.29 and 0.54 V/m, respectively according to data reported in the literature between 2005 and 2013 (Sagar et al., 2018).

In the measurements made in a region of Ankara in Turkey, although EF strength was below 1V/m at most of the measurement points, the average EF intensity was determined as 2.61 V/m, while the maximum EF intensity was determined as 7.84 V/m (Kurnaz & Aygün, 2018).

Nevertheless, it is necessary to consider the limits applied by different countries and the adverse health effect threshold values, and not only the ICNIRP limits. A study focused on hospitals, offices, residences, and schools in Qatar (Mannan et al., 2020), and the researchers compared their results with the regulations in Russia, Bulgaria, Poland, and Switzerland also, in which standards are stricter. It was seen that the measured data mostly exceeded these stricter national limits for electric field, magnetic field, and power density, even though they were within the ICNIRP limits.

In countries like Turkey, which do not have a definition of "sensitive places", legal arrangements should be made to provide a safe and healthy environment for children who are still in the developmental period and are more sensitive than adults (Yener et al., 2017).

In view of such discrepancies Kottou *et al.* (2015) make a very critical point: Lower limits need to be set. The main justification for this idea is the possibility of biological harm from extended human exposure to low intensity fields (non-thermal effects). The authors note that all maximum values measured during their study were close to or above the indoor 'no thermal impact' limits for sensitive people.

Hardell *et al.* (2017) draw attention to various studies in literature and argue that even if outdoor RF/EMF measurements in Stockholm are within the ICNIRP limits, various studies in the literature contain findings that these values are associated with some health problems due to exposure duration (Hardell et al., 2017).

Negative health effects of low-intensity (non-thermal) radiation have been pointed out at levels significantly below existing exposure standards (Fragopoulou et al., 2010; Hardell & Sage, 2008); therefore, new health-based EMF/RF exposure standards should be defined for public health. Fragopoulou *et al.* (2010) refer to the Seletun Scientific Panel and suggest that extremely low frequency (ELF) exposure limit as 0.1 μT (1 mG) max. 24-hour average and limit of 1.7 mW/m2 (also = 0.00017mW/cm2 = 0.17μ W/cm2) for whole body RF exposure.

Some authors suggest 0.001 μT (1nT or 0.01mG) daytime and nighttime arithmetic mean exposure as magnetic field limit in areas where people spend more than 4 hours per day (Belyaev et al., 2016; Vignati & Giuliani, 1997). They also suggest 0.0003 μT (0.3nT or 0.003mG) for sensitive populations. Their suggestion on electric field limit is 0.1V/m for daytime, 0.01V/m for nighttime exposure and 0.003V/m for sensitive populations.

2.3.3 Assessment approach

Another comment in literature is about measurement methods. Considering the methods used for measurement, there are significant discrepancies between studies, making it impossible to compare studies across nations or analyze temporal patterns. To accurately determine average RF-EMF exposure levels in daily environment, a comparable RF-EMF assessment approach is required (Sagar et al., 2018). As an example, a study did not find any correlation between distance (0m to 350m) from source and EMR values (Kiouvrekis et al., 2020), despite “the inverse-square law” mentioned previously. Such a result may be due to the method or the measuring material. WHO (2016) addresses the Institute of Electrical and Electronic Engineers (IEEE), the International Electrotechnical Commission (IEC), the European Committee for Electrotechnical Standardization (CENELEC) and the International Telecommunications Union (ITU) for measurement standards. The International Telecommunication Union (ITU) is the United Nation’s specialized agency for information and communication technologies – ICTs.

“TS EN 50413 - Basic standard on measurement and calculation procedures for human exposure to electric, magnetic, and electromagnetic fields (0 Hz - 300 GHz)” and “IEEE recommended practice for measurements and computations of electric, magnetic, and electromagnetic fields with respect to human exposure to such fields (0 Hz-300 GHz)” are followed in this dissertation.

On Site, laboratory and computation are the 3 assessment approaches defined by IEEE as follows:

- On Site approach covers “cases (e.g., assessment of an installation) where exposure is being evaluated at a specific location or area with one or more sources of EMF. Typically, the assessor has limited or no control of these sources.”
- Laboratory covers “cases (e.g., approval of an equipment under test) where typically the equipment under test and the test environment are both subject to control of the assessor. Commonly the evaluation is performed at a specialized test facility.”
- Computation covers “cases where the relevant parameters are determined, and the exposure is estimated by calculation.”

2.4 EMR Shielding

Electromagnetic shielding (ES) is the practice of surrounding an area, device, or object with a material that absorbs or reflects electromagnetic fields, in order to protect it against the effects of electromagnetic interference (EMI) (Hemming, 1991). EMI can cause electronic devices to malfunction or behave erratically and can be caused by a variety of sources such as electric motors, fluorescent lights, and cell phones (Kunkel, 2020). Although shielding is often used in sensitive electronic equipment, such as medical devices and military equipment, to protect against the effects of EMI (Kunkel, 2020), in this study the same application is considered for the purpose of providing healthy environments in buildings. Shielding is already used at the building scale, for example in the shielding of X-ray rooms with faraday cages.

Shielding can be achieved by using materials that are electrically conductive, such as metal or metal-coated materials, which can absorb or reflect the electromagnetic radiations (Frenzel et al., 2007; Kovar et al., 2017; Majcher et al., 2020; Pavlík, 2019; Suresh et al., 2014). The effectiveness of the shielding depends on the conductivity and thickness of the material, as well as the frequency of the electromagnetic radiations or intensity of their fields (Kunkel, 2020).

Reflection vs. absorption for shielding: EM Shielding by reflection and absorption are two common methods against EM Pollution (Liu et al., 2022). Electromagnetic shielding by reflection has long been used for eavesdropping and device protection (Kunkel, 2020). The reflection causes secondary electron density in the source direction; therefore, it produces a secondary effect for human health and EM pollution (Liu et al., 2022; Xie et al., 2018). For example, a room with furniture presents a high level of EMR than an empty room because reflected radiation from metal parts of furniture doubles wave strength in specific areas (Hakgudener, 2015). On the other hand, Absorption is basically based on energy conversion to absorb EM Waves (Liu et al., 2022; Xie et al., 2020). At this point, absorption stands out as a more efficient method in terms of health. However, depending on the case, shielding by reflection is still a practice to consider.

(i) **Shielding Effectiveness (SE)** is the capacity to prevent electromagnetic radiation (Kunkel, 2020), and is calculated by using the following formulae in terms of EF, MF and power.

$$SE = 20 \log E_0/E_1 \quad \text{………… Eq.1}$$

$$SE = 20 \log H_0/H_1 \quad \text{………… Eq.2}$$

$$SE = 10 \log P_0/P_1 \quad \text{………… Eq.3}$$

where E0, H0 and P0 are the strength of EF, MF and power respectively at a selected point in the space while there are no shielding materials as can be seen from Figure

2.7. E1, H1 and P1 are respectively the strength of EF, MF and power in the same point while there are shielding materials (Frenzel et al., 2007; Pavlík, 2019; Kumar et al., 2014) as can be seen from Figure 2.8. Its unit is decibels (dB) which are typically used to measure RFR reductions. Because of the non-linear, logarithmic scale, a signal that is 10 dB weaker than another signal has a signal intensity that is one tenth that of the reference signal (Kosatsky et al., 2013). Shielding effectiveness depends on the signal frequency, thickness, temperature, humidity, and other factors for each building material (Hakgudener, 2015). It also depends on the style of masonry construction (Khalfan et al., 2018).

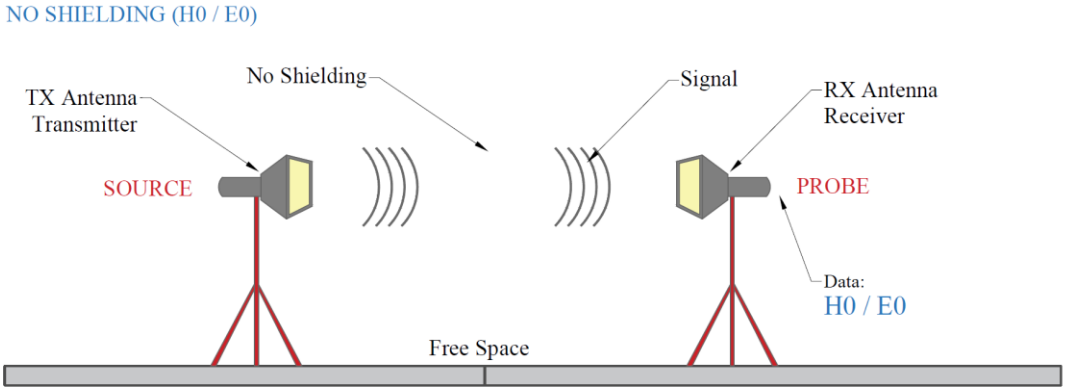


Figure 2.7. Illustration of H0 and E0 measurement for shielding effectiveness (Stone, 1997); redrawn by author.

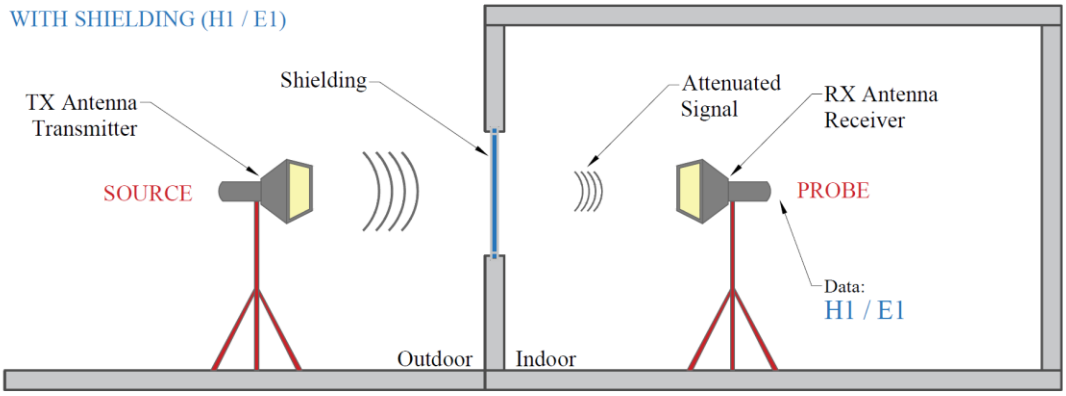


Figure 2.8. Illustration of H1 and E1 measurement for shielding effectiveness (Kovar *et.al*,2016; Stone, 1997); redrawn by author.

If the shielding plane is assumed to be infinite and the direction of the incident wave is perpendicular to the shielding plane, the SE can also be calculated by the following formula based on Schelkunoff's shielding theory:

$$SE = A + B + R \text{............ Eq.4}$$

where SE is the shielding effectiveness, A is the absorption loss, R is the reflection loss, and B is the multiple reflection loss (Hemming, 1991; Zhang et al., 2011) as seen in Figure 2.9.

Shielding effectiveness of a materials depends on (a) dielectric properties like the conductivity and the permeability, (b) its thickness and (c) the frequency of the incident wave (Zhang et al., 2011).

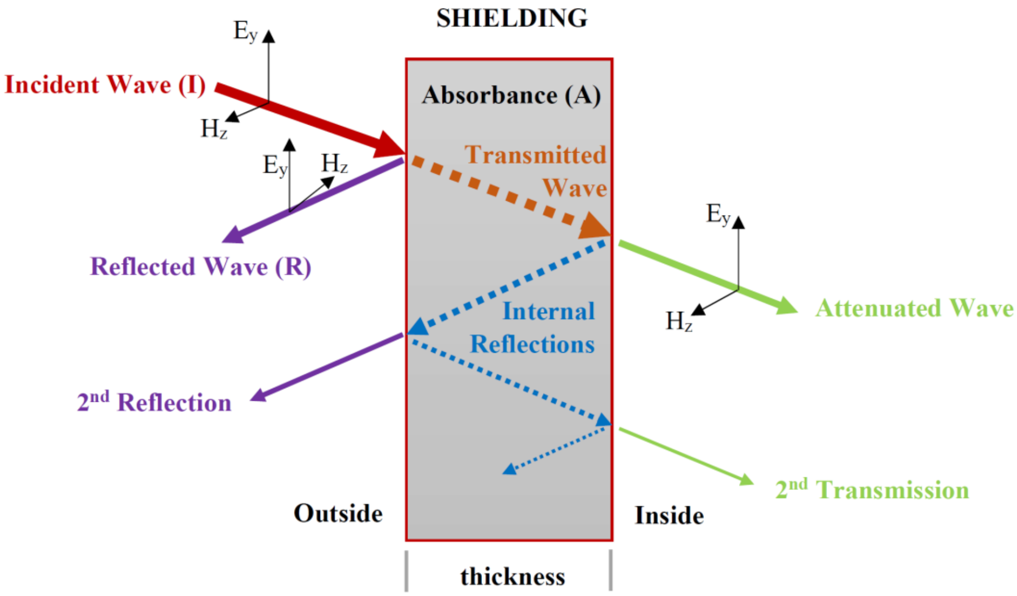


Figure 2.9. Principle attenuation by shielding (Yener. & Çerezci, 2016); redrawn by author.

2.5 EMR in architecture

The relationship between EMR and building science, the impact of smart city vision on EMR and architectural projects designed by considering EMR-related issues are presented in this section.

2.5.1 Healthy building

A healthy building can be defined as "a new generation green building that supports the physical, psychological, and social health, well-being, and performance of people" in addition to environmentally sensitive and resource-efficient building concepts (Ramanujam, 2014). According to Harvard University, the 9 Foundations of healthy building are as follows: air quality, thermal health, moisture control, dust and pest control, safety and security, water quality, acoustic comfort, lighting and views, ventilation (Allen et al., 2017). In addition to these, the healthy building concept also includes offering activity opportunities and a no-smoking environment for its users.

On the other hand, the sick building syndrome (SBS) is one of the widely studied issues in building science to prevent buildings and building support systems from causing diseases (Gao et al., 2021; Sarkhosh et al., 2021; Sharma & Tiwari, 2014; Suzuki et al., 2021).

Although it is not common knowledge, EMFs in the built environment also have negative effects on human health (Korur et al., 2010). So, EMR has been identified as a part and potential cause of SBS (Sharma & Tiwari, 2014). Various studies conducted at hospitals also pointed out to the statistically significant correlation between EMF levels caused by building services (including work equipment) and medical disorders such as weakness, headache, forgetfulness, nervousness, fatigue, and sexual anorexia problems in employees (Dökmeci & Aksan, 2019; İlhan et al., 2017).

Cities in near future with their wide range of electronic equipment and wireless connections will shoot up the electromagnetic radiation levels in urban areas. It is predicted that soon electromagnetic interference will need much more consideration in the design and planning of cities, like air flows, sound levels, pollution control simulations (Akcin et al., 2016).

Clegg *et al.* (2020) underline the fact that there is a critical need to apply EMF shielding strategies and EMR-free or low EMR technologies in building design and renovation. The authors also refer to building science to cope with this new challenge since it has been dealing with design & operational efficiency and sustainability guidelines.

Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) include indoor air quality (IAQ) section which is related to health. Even if LEED and BREEAM do not assign any points for EMR, The Total Quality Building Assessment Tool (TQB) which is published by the Austrian Sustainable Building Council (ÖGNB) has included low-intensity EMFs and radiation as a criterion for assessment. Also, EUROPAEM suggest some precautionary values.

Precautionary guidance for RFR exposure levels in TQB rating tool (ÖGNB, 2023) and EUROPAEM guide (Belyaev et al., 2016) can be seen from. Within the TQB tool, which is an evaluation system with a total of 1000 points, 20 points are related to EMF. See "Appendix B" for details of these items.

While the reference value for power density at 1GHz is 5 W/m2 in the ICNIRP manual, the highest score in the TQB tool targets 0.00001 W/m2; and EUROPAEM recommends 0.0001 W/m2 during daytime and 0.00001 W/m2 during sleep as shown in Table 2.10.

Table 2.10 Precautionary guidance for power flux density levels in TQB and EUROPAEM rating tools (Clegg et al., 2020).

		Exposure to 900–1800 MHz RFR (mW/m^2)
TQB Tool	Planning stage	
	10 points (best)	≤ 1
	5 points	≤ 3
	0 points	> 3
	Final stage	
	10 points	$S \leq 0.01$
	8 points	$0.01\ mW/m^2 < S \leq 0.1$
	6 points	$0.1\ mW/m^2 < S \leq 1$
	4 points	$1\ mW/m^2 < S \leq 3$
	0 points	> 3
EUROPAEM 9001800 MHz		
	Daytime	0.1
	During sleep	0.01
	Sensitive Populations	0.001
Natural Background		0.000000001

At 50 Hz extremely low frequency (ELF), the ICNIRP limit is 200 T, while TQB shows 0.1 T as the target for the highest score. Likewise, EUROPAEM recommends a value of 0.1 T as can be seen from Table 2.11

Table 2.11 Precautionary guidance for magnetic flux density levels in TQB and EUROPAEM rating tools (Belyaev et al., 2016; ÖGNB, 2023).

		Exposure to 50Hz ELF (µT)
TQB Tool	Final Stage	
	10 Points (Best)	$B \leq 0.1$ µT
	8 Points	$0.1 < B \leq 0.2$ µT
	6 Points	$0.2 < B \leq 0.4$ µT
	4 Points	$0.4 < B \leq 1$ µT
	0 Points	$B > 1$ µT
EUROPAEM		Arithmetic Mean
	Daytime	0.1 µT
	During Sleep	0.1 µT
	Sensitive Populations	0.03 µT

These recommended values for 50Hz are similar to the values set for 1GHz in the ICNIRP guideline. In other words, it is possible to say that there is a serious gap between ICNIRP guidelines, TQB and EUROPAEM.

2.5.2 EMR levels and Smart City vision

The Smart City vision presents a techno-utopia which is information & communication technology (ICT) based and knowledge-intensive with innovation primacy. Smart cities with their technological backbone promise to solve urban issues including mobility, energy, sustainability, pollution, and health (Sharifi, 2019). The key elements of this techno-utopia are the smart mobility, smart environment, smart services, smart governance, smart people, smart living, smart economy, and smart infrastructure (Anthopoulos, 2017); while all these elements mostly depend on ICT (Yigitcanlar et al., 2019).

Despite all the attractive promises, smart cities are prone to increasing electromagnetic radiation (EMR) because ICT, electric utilities, Internet of Things (IoT), and other systems/devices radiate EMR; hence, it can become an invisible threat to the environment and human health (Clegg et al., 2020).

The 4th generation mobile network (4G) used between 2013-2020 operates in the 2-8 Ghz frequency range, while the 5th generation mobile network (5G), which was started to be used in 2020, operates in the 3-300Ghz frequency range (Gupta et al., 2019). On the other hand, the 6th generation mobile network (6G), which will be activated in the future, is planned to operate in the 95-3000Ghz frequency range and many functions of smart cities will be based on the 6G network (Kumari et al., 2021). In addition, many objects from autonomous cars to daily devices will be connected to these networks. Developments in the mobile network and the increase in the number of devices connected to this technology will create a level of EMR that has not been experienced before (Clegg et al., 2020). This level of increase will affect many cities with use of 5G/6G networks even if they are not a smart city.

As the number of electrical devices will increase day by day, it can be predicted that the EMR level will increase (Türkkan & Pala, 2009). A study conducted in a city between 2010 and 2012 showed that EF strength and power density strength values increased significantly over a 3-year period, even though the values measured in residential buildings were well below ICNIRP limits (Çerezci et al., 2015).

2.5.3 Architectural projects for EMR related issues

It should be noted that of the four projects found on the worldwide web only two are real buildings while the other two are exhibits. Additionally, the aim of the two building projects was essentially to provide data security; and occupants' health or IEQ were not the concern. The first building is the National Security Agency (NSA) Headquarters was constructed in 1986 in Maryland, USA. The architectural design of two rectangular prisms with dark, opaque, and reflective facades represents the idea of hiding what happens inside from the outside as seen in Figure 2.10.

Figure 2.10. NSA Headquarters in Maryland, USA designed by Eggers & Higgins Architects (Capps, 2017).

This facade cladding is not just a visual statement. It is also a solution that meets TEMPEST requirements and offers shielding against eavesdropping with its copper layer (Capps, 2017).

Various faraday cages have been formed as electromagnetic shielding to reach EM-blind spaces or buildings (Savic, 2018); and the building called The Signal Box, constructed between 1991-1994, is such an example. It is a Pritzker prize-winning project designed by architects Herzog & de Meuron and built as a railway utility building in Basel, Switzerland. To protect the electronic equipment inside from external low frequency (60Hz) EM impulses caused by electrical infrastructure for railway, The building's outer cladding of copper strips acts as a Faraday cage, and it is also possible to let in daylight by bending these strips in certain sections as can be seen from Figure 2.11.

Figure 2.11. The Signal Box railway utility building in Basel, Switzerland designed by Herzog & de Meuron (Savic, 2018).

The RAM house, a home prototype, was designed by Space Caviar in 2015 and built as an installation for exhibition in Genoa, Italy. The RAM (radar-absorbent material) house proposes an “Airplane Mode” for homes. The RAM house which can be seen from the Figure 2.12 questions the concept of privacy in the age of smart devices and smart homes. Walls and customizable curtains provide visual privacy. Similarly, this project advocates the need for a shelter that can also control electromagnetic signals on demand. The important point in this project is that it is not a permanent faraday cage but a selective one. It ensures this by employing a reconfigurable grid, organized by movable shields which act as a faraday cage to filter electromagnetic radiation in the interior (Space Cavier, 2015).

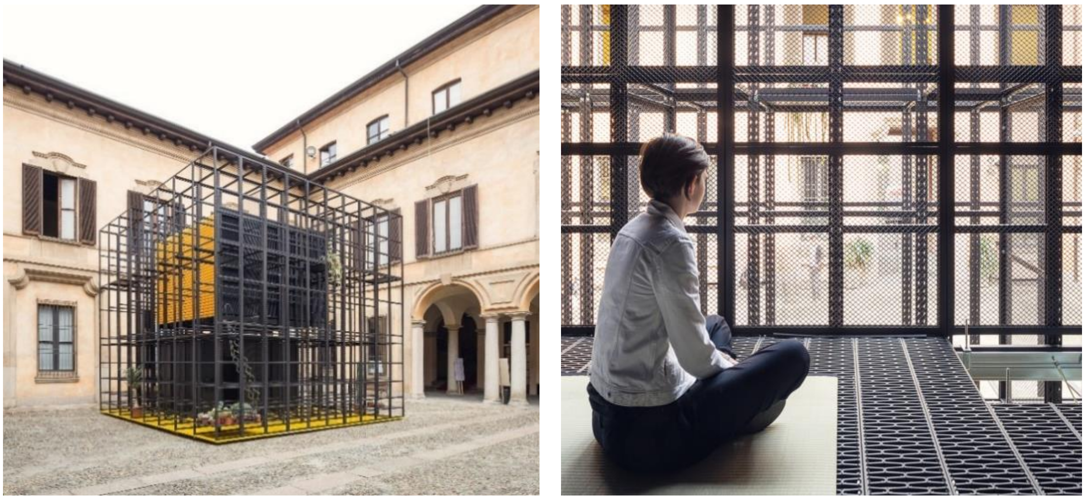


Figure 2.12. The RAM house project installation exhibited in Genoa, Italy (Space Cavier, 2015).

Another example, “404: Space Not Found” shown in Figure 2.13 was designed by Mathieu Bujnowskyj in 2017 as a critical pavilion for the H3K Basel, Switzerland. This design offers a counter view to ICT-based ideas such as “all-connected” and smart infrastructure. This small and portable tent shaped mobile pavilion offers the user a space free from any digital signal thanks to its fabric properties (Bujnowskyj & Chapouly, 2017). The designers draw attention to issues such as electro-smog, data-privatization of public space, information overload, and digital mass surveillance.

Figure 2.13. 404 - Space Not Found pavilion project in Basel, Switzerland (Bujnowskyj & Chapouly, 2017)

While mentioning fabric, it is important to note that there is ongoing research in the literature on the effect of different parameters of fabrics such as weaving properties, pores, and materials on EM shielding (Bilgin et al., 2011; Gözde, 2014; Tamam et al., 2016; Yılmaz, 2014). In addition, some commercially available curtains and fabrics can also be effective for shielding (Yener. & Çerezci, 2016).

These architectural works are impressive as individual answers to the problem, but they are far from serving as a design guideline. Each of them gives an idea about how architecture can deal with EMR. These works also represent a new kind of aesthetic as a result of being a shelter from EMR.

2.5.4 Impact of architectural features on EMF

The projects presented in the previous section were based on treating the envelope as a faraday cage; however, they do not dwell on the geometry of the architectural space. In this regard two studies on the impact of spatial geometry on EMFs can be considered as pioneering examples. Both of these studies (Vizi & Vandenbosch, 2016; and Wahba *et al.*, 2021) are based on computer simulations of EMF in a single space.

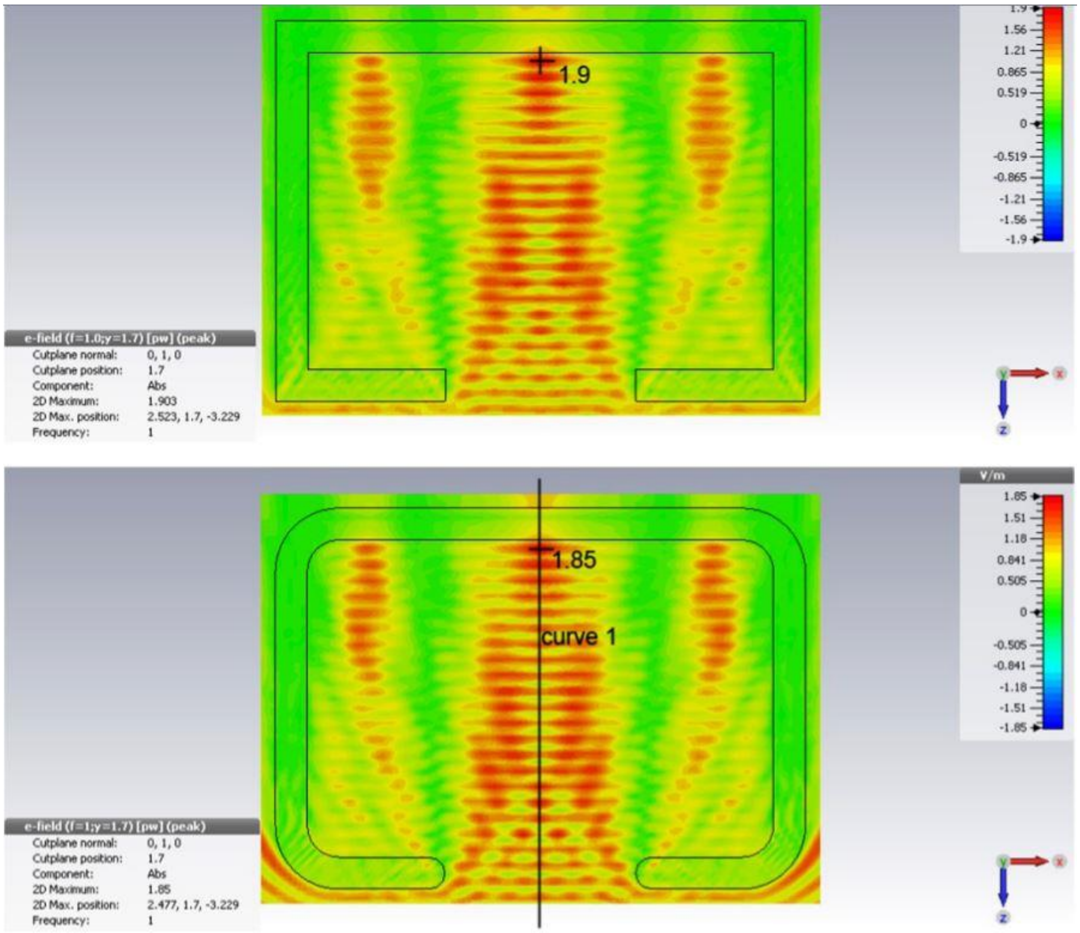


Figure 2.14. Comparison of the effect of room shapes on EMF, through computer simulations (Vizi & Vandenbosch, 2016).

In the first study by Vizi & Vandenbosch, (2016) the impact of the room shape, wall thickness, wall materials (brick, concrete, and reinforced concrete) and glass on EF were simulated. The room properties remaining the same the geometry was changed to compare the behavior of a room with orthogonal or rounded corners. Even if it is limited work, it presents important information to show the impact of architecture as a prelude. This study compares cases by electric field (V/m) values for 1 GHz frequency as seen in the Figure 2.14.

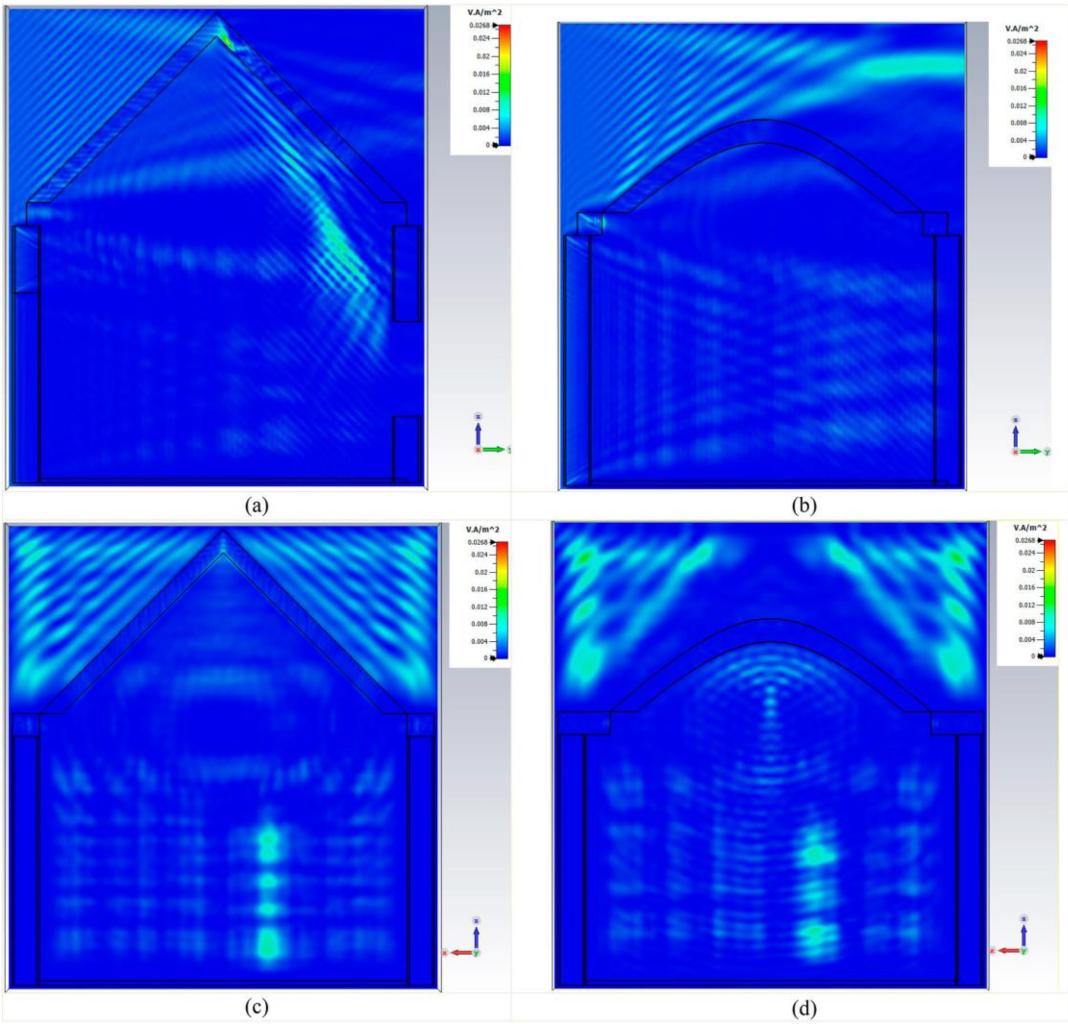


Figure 2.15. Comparison of the effect of roof shapes on EMF, through computer simulation (Wahba et al., 2021).

The second study by Wahba *et al.* (2021) simulates the effect of roof form on electromagnetic power density, as shown in Figure 2.15. In addition, the effect of façade openings and the effect of different materials added to the cement mixture, on shielding were investigated by the authors. This study presents results for 2.4GHz frequency by electromagnetic power density (V.A/m2) values. The authors found no connection between the EMP distribution levels at the interior and the height of the walls. They underline that the proportion of the roof surface exposed to radiation and the focusing power, depending on the roof geometry, are the two main aspects that can be related to the effect of roof form on EMP. Therefore, architectural parameters such as surface area, slope, shape and curvature of the roof surface facing the incident radiation were found to be effective.

2.6 Knowledge derived from literature

Recommendations for reducing EMR levels and data on the dielectric properties of building materials compiled from the literature are presented in this section.

2.6.1 Recommendations to reduce EMR levels

According to Clegg *et al.* (2020), the first step to reduce EMR may include “re-installing wired (not wireless) internet networks, corded rather than cordless phones, and cable or wired connections in building systems (e.g., mechanical, lighting, security)”. It should be noted that wires also produce EMR at different frequencies. The authors define the goal to be achieved for EMR exposures as ALARA, “As Low As Reasonably Achievable.” While ALARA is an initial approach to solve the problem at its source; technological advances become a physiological addiction and habit in people’s daily life (Konok et al., 2016; Shoukat, 2019).

Also, the scale of cities and buildings makes it hard to design without technology (Shengwei. Wang, 2010). In this case, while determining the "Reasonably Achievable" target according to the function of the space, it is also necessary to have a health-oriented approach. For example, we should exclude priority spaces such as kindergartens, primary schools, children's rooms in homes from the coverage area of wired and wireless networks. Even places where people spend a long time without the need for technology, such as bedrooms, should be excluded.

There is much effort to deliver wireless radiation to all points in buildings and cities without interference, to provide access to Wi-Fi connected devices and services. For example, a study focuses on the design of buildings and interiors that do not block wireless radiation (Krzysztofik, 2018). On the other hand, awareness in architecture and urban design on the health impacts of EMR has been increasing in recent years.

The EU-funded project, “WIFEEB (Wireless friendly energy-efficient buildings)” is focused to form and validate “the wireless-friendly, energy-efficient building concept” (Rigelsford et al., 2015). In the project, access points placed on walls switch between transmission and reflection modes to allocate more bandwidth only to the occupied part of the building that need access. This reduces the radiation level in other spaces. Intelligent walls, which are reconfigurable to EM propagation needs and scenarios, are dynamic and active elements of architecture (Rigelsford et al., 2015).

Similarly, another study introduces a concept called *"friendly buildings"* with the intention of solving design concerns such as *“energy efficiency, wireless connectivity and human health”* together (Habash et al., 2019). The authors argue that the use of emerging nanomaterials and metamaterials in structures could facilitate software-based control of the EM waves emitted by Wi-Fi. In other words, they propose to build "programmable wireless networks" that are controlled via software and use building surfaces as transmission/insulation elements. In this way, Wi-Fi levels can be set for different spaces in the interior and changed as required.

According to Wahba et.at. (2021):

- When assessing EM performance inside a building, it makes more sense to focus on the SE and maximum EMFP in the occupied space rather than on the maximum EMFP in the volume.
- The amount of radiation received is proportional to the surface area of the roof form exposed to radiation. The geometric properties of the roof are effective on the amount of radiation entering the building and its distribution in the interior.
- Some roof forms, such as domes, concentrate the EMFP density close to the roof and offer a cleaner occupied space.

- Openings, whether in the wall or on the roof, have a significant impact on the EMR dispersion.
- The effect of the orientation depends on the location of the openings, the angle of incidence of EMR and the exposed surface area of the building.
- The SE is strongly impacted by the material layers utilized for envelope.

On the other hand, it is claimed that paint colors, furniture placement, materials, usage of shielding techniques are parts of the interior design to achieve permissible radiation levels (Gustavs, 2008).

Contrary to common belief, a recent study has shown that Aloe Vera, snake plant and cactus on the desk do not have a measurable effect to reduce radiation levels (Algumbari & Nagy, 2022). The authors, at the end of their experimental study focused on a measuring EMR on a desk, suggest:

- Preferring natural materials such as wood with anti-static properties for flooring.
- Using paints or wallpapers with EM shielding properties.
- Choose furniture made of non-magnetic materials to avoid secondary reflections.
- Choose light-colored finishings.
- Synthetic finishes cause electrostatic charges and should therefore not be used on walls, floors and furniture.
- Keep distance from the source (electrical wiring or devices) while positioning furniture.
- Use low-EMF emitting lighting equipment. Improve natural ventilation and natural lighting.

Some of those suggestions are supported by other studies also (Belyaev et al., 2016; Vignati & Giuliani, 1997). Belyaev *et al.* (2016) recommends to:

- Turn off wi-fi, mobile data, near field communication (NFC) when they are not necessary.
- Minimize the use of “wireless devices such as home entertainment, headphones, baby monitors, game consoles, printers, keyboards, mice, home surveillance systems” by preferring wired connections whenever possible.
- In case wireless devices have to be used, position them away from long usage areas such as beds, armchairs, tables.
- Place furniture such as beds, armchairs and tables at least 30 cm away from the wiring in the wall. Keep minimum distance of 1.5m from running motors such as washing machines.
- Especially for children's rooms and bedrooms, it should not be adjacent to EMR sources in the building section and plan.
- Metal furniture should be avoided in the bedroom.
- Do not design electrical devices in bedrooms.
- Prefer lighting equipment emitting less EMR.
- Avoid using synthetic surfaces for walls, floors, and ceiling to avoid static electricity.
- Electrical installations in buildings should be grounded and shielding should be preferred for cables. Especially in lightweight structures such as wood and drywall.
- Shielding materials should be preferred for all surfaces in the envelope of the space and elements such as doors and windows.
- Locate buildings away from power lines and radiation sources.

Also, Clegg *et.al.* (2020) suggest similar precautions, such as:

- Use shielding for cables and wiring.
- Use wired connection for HVAC, LAN and communications.
- Locate new building away from external sources “(cell towers, radio and TV broadcast towers, and radar sites (e.g., airports)”.
- Zone the building by access need to wireless network.

- Place Wi-Fi access point away from places such as bedrooms and children's rooms.
- Use shielding materials for buildings.
- Coat the windows with a transparent layer of metal oxide that reflects the RFR.
- Use solutions that provide shielding in the building envelope *"*such as metal siding or roofing, metal window and door frames, metal or metal clad doors, low-E windows, shielding curtains, RF window film, and thin metal mesh or radiant barrier foil integrated into the building envelope*"*.
- Use carbon-based shielding paints or fine metal mesh on walls.
- Apply RF protective covers/curtains.
- All shielding materials (including paint) must be grounded.

Additionally, the authors predict that vegetation will absorb some RFR due to its water mass (Clegg et al., 2020). Frequency, terrain effect, humidity, size and shape of leaves, branches and stems can cause signal attenuation (Çerezci et al., 2022). On the other hand, Aloe Vera, snake plant and cactus on the desk do not have measurable effect to reduce radiation levels (Algumbari & Nagy, 2022).

Korur *et.al.* (2010) recommend:

- When making the plan layout, blind-fronted spaces such as bathrooms, WC, storage rooms can be preferred in the direction of external sources.
- Evergreen trees, higher than buildings and with water mass can be used as shields against electromagnetic pollution.
- Lightning rods should be used for buildings built higher than natural elevations.
- Copper, aluminum, and iron tiles used in the building envelope, space frame systems, metal door and window connections must be grounded.
- Electrical cables inside walls and suspended ceilings must be carried in metal conduits and the entire system must be earthed.

- Wooden natural building products should be preferred over materials that cause electrostatic charge such as Plexiglas, rubber, PVC, or metal. If metal is to be used due to the architectural concept, the products should be grounded.
- In building design, electrical installations should be away from head level, even if they are grounded.
- Electrical appliances must not be left plugged in.

Areas in valleys may be partially protected from regional RFR sources, depending on the surrounding hills and humidity levels (Abdorahimi & Sadeghioon, 2019). Similarly, underground structures can be protected by the surrounding soil and moisture. Since, soil conductivity and permeability increase with moisture content (ITU-R, 2021). So, water absorbs EM radiation significantly.

Another study investigates the effect of the vertical spatial organization in the various floors of the building on the geomagnetic field distribution (Glaria et al., 2018). According to this study, the layout of the parking areas and the arrangement of the metal masses in the basement of the building and the amount of groundwater flow affects the geomagnetic field in the building cross section.

Frequency selective surfaces (FSS) are remarkable option to secure buildings from various frequencies while allowing some intervals (Roberts, 2014). Also, in modular 3D FSS design, it is also possible to determine the rate of permeability by changing the angle of the FSS modules (Roberts, 2014).

Reflection, diffraction, and scattering are the three primary impacts of EMW propagation. Radio waves become distorted because of each. Since EM waves do not interact with any materials, these typical effects are not present in empty areas of buildings (Hakgudener, 2015). The strength of the propagation reduces through surfaces like floors, walls, and roofs. Particularly, corners encourage diffraction and multipath propagation (Hakgudener, 2015). This phenomenon could be explained in terms of physics by the formation of standing waves. Studies present in the literature shows the difference between furnished and empty room in terms of EMR levels

(Hakgudener, 2015; Vizi & Vandenbosch, 2016). Two or more separate reflected waves combine to create the higher values.

2.6.2 Dielectric properties of building materials

The dielectric properties of materials are an important variable for building envelope calculations. They are frequency dependent and vary according to the ratio of the components in the material. For better understanding, Figure 2.16 shows shielding effectiveness of aluminum at different frequencies.

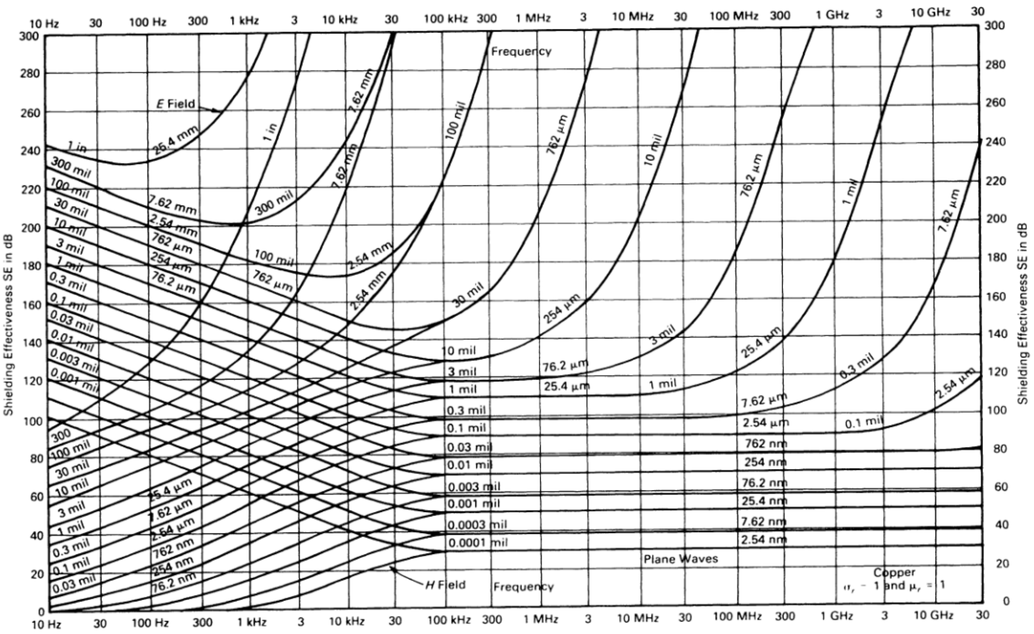


Figure 2.16. Shielding effectiveness of aluminum. Source distance of 1km (Hemming, 1991).

Although it is not possible to find all dielectric properties at different frequencies for all materials, it is possible to find various dielectric properties of some building materials in different frequency ranges in the literature. Since dielectric properties for building materials are not available as a data set, they are compiled from different studies in the literature and presented in the results section. Dielectric properties of concrete, brick, glass, autoclaved aerated concrete (AAC), marble, thermalite blocks, limestone, ceramic tiles, plexiglas, blind, carpet, fabric, linoleum, paint with carbonyl iron, gypsum plaster, stucco, PVC, gypsum ceiling board, rockwool ceiling board, plasterboard, EPS, XPS, mineral wool, aluminum, air, wet & dry ground, wood and wood-derived materials such as plain wood, wood-cement board, hardboard, MDF, chipboard, plywood, floorboard was compiled from 18 sources (Bandyopadhyay et al., 1980; Cuiñas & Sánchez, 2002; Ellingson, 2023; Folgueras et al., 2009; ITU-R, 2015, 2021; Landron et al., 1996; Pinhasi et al., 2008; Pisa et al., 2017; Rudd et al., 2014; Wilson & Crawford, 2002; Xie et al., 2016; Zhekov et al., 2020).

Beyond dielectric properties, the shielding capability of materials against EMR is often evaluated with proportional parameters such as transmission coefficient (H. Guan et al., 2006; Mannan et al., 2020; Vizi & Vandenbosch, 2016; Yılmaz, 2014), absorption or reflection rates (Gandolfo et al., 2017; H. Guan et al., 2006; Maxwell et al., 2018) and shielding effectiveness (Frenzel et al., 2007; Hemming, 1991; Khalfan et al., 2018; Pavlík, 2019; Pavlík et al., 2018; Suresh et al., 2014). This proportional evaluation approach, which simplifies a complex calculation, will often be more applicable in the multivariate space of architecture.

As seen from Table 2.12; Concrete, brick, brick-faced concrete walls, and brick-faced masonry block present better transmission percentage than wood, plywood, glass, drywall to reduce the impact of EMR (Hakgudener, 2015). Materials in this table mostly present higher performance to block EMF/RF for higher frequencies (Hakgudener, 2015). So, it can be assumed that building materials may react differently against RFR at higher GHz frequencies planned for 5th generation (5G) technologies compared to radiation in the current lower frequency ranges (Vizi & Vandenbosch, 2016).

Table 2.12 Common building materials average maximum transmission field percentages (Hakgudener, 2015).

Building Material	Thickness (mm)	Average maximum transmission field (0.5-2.0 GHz) %	Average maximum transmission field (3.0- 8.0 GHz) %
Brick	271	76%	13%
Brick faced concrete wall	271	19%	0.1%
Brick faced masonry block	284.4	38.5%	4%
Plain concrete	203	15%	4%
Drywall	9.5	98%	100%
Glass	12.5	87%	86%
Lumber (dry)	113	76%	34%
Lumber (wet)	113	75%	32.5%
Plywood (dry)	11.8	97%	98%
Plywood (wet)	11.8	86%	76%
Reinforced concrete	203	52%	0.3%
Rebar grid	19 (70X70 mm^2 grid)	64%	88%

In the light of this table, to improve EM safety Hakgudener (2015) suggests some alternatives, such as (1) Mesh and cage, which can be applied to the facade and interior walls, (2) RF shielding paint containing carbon-based and corrosion-resistant materials for façade and walls, (3) RF shielding window film for windows or curtain walls in residential buildings in case of excessive exposure.

Similarly, Table 2.13 presents maximum transmission coefficient values. These values are not based on a single frequency but are measured over a range of frequencies from a variety of sources such as “Wi-Fi devices, cell phones, cordless telephones, smart meters, body scanners, diagnostic X-ray radiography equipment, and computers” (Mannan et al., 2020). In this table, “EFS is electric field strength, MFS is magnetic field strength and PD is power density”. Also, measurements from different environments are represented by the initials of the building types, i.e: “H: Hospital, O: Office, R: Residential, S: School, E: Entertainment”.

Table 2.13 Permeability of building materials (Mannan et al., 2020)

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

Additionally, the transmission and reflection coefficient of some tested construction materials at 2.4 GHz are presented in

Table 2.14.

Table 2.14 Transmission and reflection coefficient of some materials at 2.4GHz (Koppel *et al.*, 2017)

No.	Material	Transmission coefficient	Reflection coefficient
01	Foamed polystyrene thermal insulation board (Tenapor EPS)	0.87	0.02
02	Graphitized foamed polystyrene thermal insulation board with (Tenapor Neo EPS)	0.69	0.00
03	Flexible insulation board made from natural wood fibres (Steico Flex)	0.79	0.08
04	Waterproof plywood (Latvijas Fineris)	1.03	0.26
05	Composite peat-wood plate	1.10	0.10
06	Natural fiber concrete pressed plate (Knauf Heraklith C50)	1.30	–0.03
07	Gypsum panel (custom made)	1.25	0.13
08	Aerated concrete (Aeroc)	0.92	–0.11
09	Lightweight expanded clay aggregate (LECA) concrete block	1.06	–0.11
10	Gypsum board (Knauf)	0.45	0.17
11	Oriented strand board (OSB)	0.48	0.17
12	Particleboard with veneer	0.69	0.25
13	High performance concrete plate, round shape	0.71	0.38
14	High performance concrete plate	0.34	0.35
15	Fibreboard (MDF)	0.87	0.12

Beyond existing building materials, the production of composite materials may also be a solution to the EMR issue. Shielding effectiveness of building materials such as cement, gypsum and mineral wool can be increased with various fillings (B. Guan et al., 2017; X. Wang et al., 2022; Xie et al., 2016). In addition, fabrics with shielding properties can also be developed (Gözde, 2014; Tamam et al., 2016; Yılmaz, 2014).

Table 2.15 shows the reflection loss values of some building materials when produced with different fillers. In this table, the frequency column indicates the frequency at which the tested material shows the highest efficiency. The fraction column shows the ratio of the material used as filler in the main material. The T-column shows the thickness of the material. The RL column shows the reflection loss, and the negative magnitude of this value indicates the higher absorption property.

Table 2.15 Absorption properties of construction materials and composites gathered from 15 sources in literature (Compiled by the author).

Material	**Filler**	**Frequency (GHz)**	**BW (GHz)**	**Fraction (wt. %)**	**T (mm)**	**RLmin (dB)**	**References**
Cement	Graphite	13.5	3.5 (11.5-15)	15	20	-21.35	(Jia et al., 2013)
Cement	Graphite	10.7	3 (9.5-12.5)	15	30	-15.64	(Jia et al., 2012)
Gypsum	Graphite	13.8	1 (13.2-14.2)	25	10	-19.53	(Han, 2017)
Cement	Carbon Fiber (3mm Length)	17	1 (16.5-17.5)	0.3	31	-10.5	(Ou et al., 2006)
Cement	Carbon Fiber (6mm Length)	8.2	2.3 (6.6-7.7, 8-9.2)	0.4	10	-19.3	(Li et al., 2007)
Cement	Helical Carbon Fiber	4	11.7 (3.6-4.4/6-7.7 /8.8-18)	1	20	-22.7	(Xie et al., 2018)
Cement	Carbon Black	18	14.5 (12-26.5)	0.5	30	-16.5	(Dai et al., 2010)
Mineral Wool	Carbon Black	5.2	6.5 (4-6.5/14–18)	3	10	-27	(Xie et al., 2016)
Mineral Wool	Carbon Black	18	12 (2–3/7-18)	3	20	-12.5	(Xie et al., 2016)
Cement	Carbon Nanotubes	2.8	10.1 (2.5-3/4.5-5/ 6.2-7/8-8.5/10-13.8 /14.2-17.8)	0.9	25	-17	(Wang et al., 2013)
Double Layer Cement-based Panel	Nano-Fe2O3 / Nano-NiO / Carbon Nanotubes / Superplasticizer / Dispersant / Ceramicite	3.7	2-18		14+14	-13.4	(Yafei et al., 2017)
Triple Layer Cement-based Panel	Nano-Fe2O3 / Nano-NiO / Carbon Nanotubes / Superplasticizer / Dispersant / Ceramicite	4.5	2-18		6+11+11	-22.4	(Yafei et al., 2017)
Porland Cement	Magnetite	3.7	2.6-3.95	15	5	-28	(Guan et al., 2017)
Porland Cement	Magnetite	15.1		15	5	-16	(Guan et al., 2017)
Cement	Fe3O4	14	6-18/25-42	3.5	5	-22.6	(Wang et al., 2017)
Epoxy Foam Pyramid Board	Carbon Fiber	4-18	4-18	0.5	20+3	-30	(Méjean et al., 2017)
Foamed concrete	an admixture of organic inclusions	10	2-18	52	40	-34.9	(Xingjun et al., 2015)
Carbon-fiber lattice structures	foam	11	8-12	-	40+4	-25	(Xu & Xu, 2013)
TetraPak Recycle	aluminium	4.46	0.8-6	30	10	-42.48	(Kaya et al., 2020)
TetraPak Recycle	aluminium	4.81	0.8-6	20	10	−39.08	(Kaya et al., 2020)
TetraPak Recycle	aluminium	3.36	0.8-6	10	10	−35.61	(Kaya et al., 2020)

In addition, Table 2.16 presents the thermal and mechanical properties of some building materials.

Table 2.16 Mechanical and thermal properties of some building materials gathered from 3 sources in literature (Compiled by the author).

Material class	Rho	Thermal Cond.	Heat Capacity	Diffusivity	Young's Modulus	Paisson's ratio	Thermal Expan	Reference
	kg/m^3	W/K/m	kJ/K/kg	m^2/s	kN/mm^2 (GPa)		1e-6/K	
Vacuum (≈ air)	1204	0.026	1.005	2.14872e-005	Na	Na	Na	CST MWS
Concrete	2400	1.7	0.8	8.85417e-007	30	0.2	13	CST MWS
Brick	1920	0.72	0.84	5.2x10^-7	25	0.25	4.7(10-6 m/(m °C))	CIBSE
Plasterboard	950	0.16	0.84		1	0.3		CIBSE
Wood	500	0.2	2	2e-07	Na	Na	Na	CST MWS
Glass	140	0.048	0.84		70	0.22	9 (10-6 m/(m °C))	CIBSE
Gypsum Ceiling Board	800	0.16	0.84		1	0.3	0.07 (10-6 / °C)	CIBSE
Chipboard	630	0.12	2.26		2.8	0.18		CIBSE
Plywood	700	0.15	1.42	0.14×10-6	18	0.39	4.0 µm/m-K	CIBSE
Marble	2750	2.9	0.84	1.3×10-6	54	0.2	21 µm/m-K	CIBSE
Floorboard (timber)	650	0.14	1.2		7	0.3		CIBSE
Metal (iron)	7870	79.5	0.45	2.24481e-05	200	0.291	12	CST MWS
Aerated Concrete	850	0.29	0.84	3.58e-007	1.85	0.25	13	CIBSE
LW Concrete	670	0.21	0.84	7.5e-007	14	0.2	13	CIBSE
RF Concrete	2400	2.5	1				13	ISO10456
Ceramic (tiles-dry)	2000	1.2	0.85		200	0.2	5 (10-6 / °C)	CIBSE
Aluminium	2700	237	0.9	9.75309e-005	69	0.33	23	CST MWS

CHAPTER 3

MATERIAL AND METHOD

This chapter includes details on the research material and methodology. The material section includes information on the sources used in the data collection, the software and devices used in the measurements and simulations, and the environmental and architectural characteristics of the flat selected as case study. Methodology includes the procedure of data collection, on-site measurement, and simulation.

3.1 Research Material

First of all, a thorough literature review was conducted to establish the conceptual framework, which is shown in Figure 1.1 in the first chapter, and to gather data on different building and finishing materials. Then, the study used various materials that are presented in the following sections, to achieve the planned objectives.

3.1.1 Locations for EMF level assessments outdoors

This dissertation has the aim to focus on the protection of interior space from excessive radiation. However, the EMR values at a point outside the building closest to the external wall and at the boundary wall are also considered in the regulations for sensitive spaces. Nursery and primary school buildings are sensitive and priority spaces that need protection from EMR due to their function. Children's rooms in residential buildings were also considered as sensitive spaces in this study.

Figure 3.1. Outdoor measurement locations.

To observe the EMR level in outdoor areas, 4 different locations were selected. Two of them are in suburban (a nursery and a primary school) and the other two are in the city center (a nursery and a residential building).

The first of the selected buildings is the nursery building located in suburban area. This building has a reinforced concrete structure and brick walls. There is a playground for children in the garden. There are two transformer stations located towards the south of the building, while the underground energy transmission cables from these transformer stations pass through a protective channel under the nursery building. The nearest base station is located on the roof of another building in the east of the building. The distance between the transformer station and the garden wall is 10.8m, while the distance between nursery building and nearest base station is 160m.

The second building is the primary school building in the same suburban area. This building has a reinforced concrete structure, and its walls are made of plaster and paint on brick. The school has a garden for children's activities. There is a transformer station adjacent to the garden wall of this building.

The third building is a kindergarten building located in the city center among the residential buildings in a dense urban area, unlike the first two. This building is also located on the same urban island with the residential building that houses the flat unit which is used as a residential case study; and they are diagonally neighboring buildings.

The fourth and last location is the flat unit in the urban residential building, which will also be used for the interior case study and measurements of EMR for determining the SE of selected building materials.

3.1.2 Case study for interior EMF level assessments

The building where the flat was selected as a residential case study is located in Ayrancı neighborhood of Çankaya district in Ankara, as seen from Figure 3.2.; it is used as the venue to run the testing and validation process also. The building is surrounded by residences, offices, and embassy buildings.

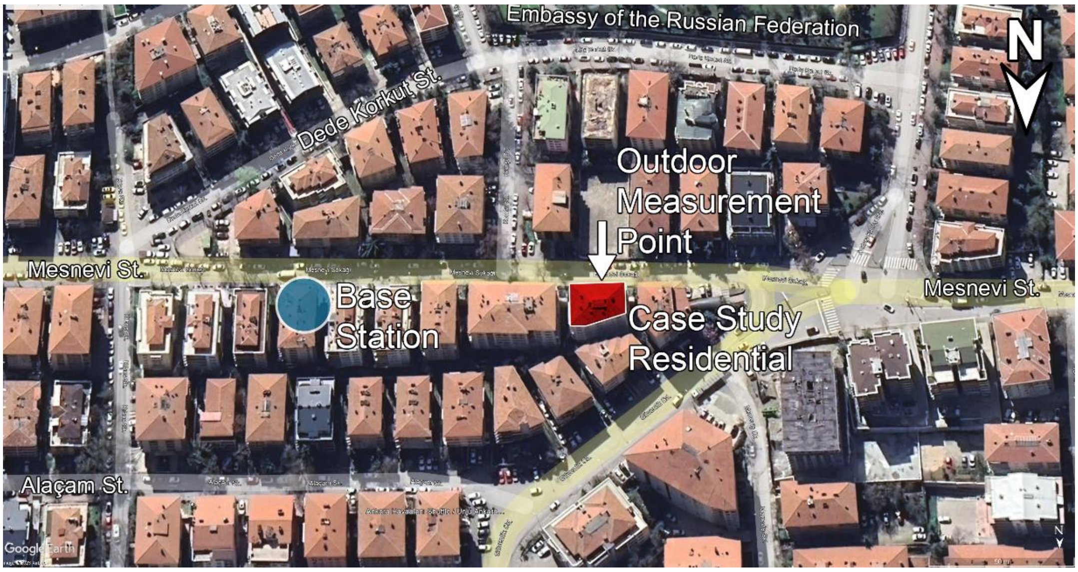


Figure 3.2. Map showing location of the base station and case study residential building in Ankara.

According to the Information and Communication Technologies Authority (BTK), the official organization that regulates, authorizes, and supervises ICT in Türkiye, there are 2 base stations around the case study building. The second base station should be on the roof of the building south of the case study building. However, it was determined that there is no base station at this location during the on-site examinations. When the building is taken as the center, there is only 1 base station in a circle with a radius of 150 meters. As can be seen from Figure 3.2, this base station is 110m away from the building in the east and is located on the roof of another building. According to BTK data, the EF intensity measured at this base station is 1.214 V/m. BTK has specified the safety distance for the base station as 24 meters.

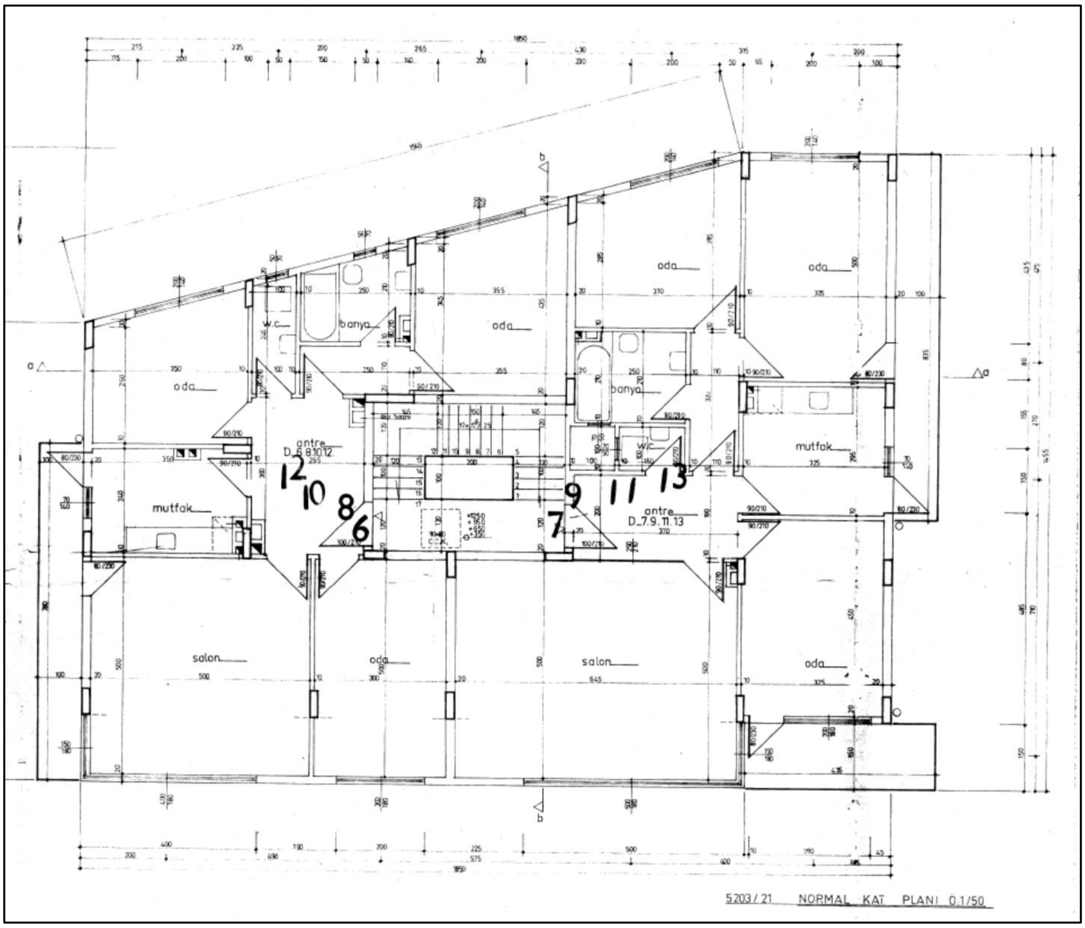


Figure 3.3. Plan taken from Çankaya municipality for case study flat.

According to the official records of Çankaya Municipality, this building was built in 1977 with reinforced concrete frame system. The walls of the building are hollow red brick. Brick thickness is 19cm on the exterior walls. In 2004, thermal insulation was applied to the exterior of the building. The applied carbon-added expanded polystyrene (EPS) thermal insulation board is produced in accordance with thermal insulation materials standard TS EN 13163. It has a declared thermal conductivity coefficient of 0.032 W/mK. On EPS, 2 layers of thermal insulation plaster was applied with mesh support. As the last layer, grainy exterior rendering was applied on the primer.

Figure 3.4. Furniture layout of case study flat.

The fenestration of the building has been changed lately and there are PVC windows/doors with 4+16+4mm double glazing. The window dimensions and plan layout can be seen from Figure 3.4 and Figure 3.6.

The south, west and north facades of the flat face outwards. On the east side, it is adjacent to the circulation hall and the neighboring flat. While the flat is neighboring another flat with the same plan on the lower floor, there is an attic above it.

The floor of the flat is 10cm thick reinforced concrete. The floor finishing is 33cmx33cm ceramic in the toilet and bathroom area. There is a 45cmx45cm ceramic floor finishing in the entrance hall and kitchen area. In all other areas, there is laminate parquet placed on 1cm acoustic insulation layer. Net floor to ceiling height is 280cm.

The reinforced concrete thickness of the roof slab is 10cm and 10cm thick glass wool thermal insulation is laid on it. On the wooden hip roof skeleton, wooden boards, membrane waterproofing, and roof tiles cover the unoccupied attic space.

The interior walls are made of 10cm thick hollow red brick. When both sides are covered with plaster and paint, the total thickness is 15cm. The walls of the bathroom and toilet areas are covered with 25cmx40cm ceramic tiles. All other walls in the flat are plastered and painted, except for the countertop wall in the kitchen that has mosaic tiles.

3.1.3 Tools used for measurements

The tools used in this research are a triple axis EMF Meter, a tripod, a digital thermometer and humidity meter, EMF simulation software and a microwave oven.

i. The triple Axis EMF Meter (Figure 3.5-a) is used for EF, EMF, and RF measurements on-site. The model used is GQ EMF-390 which can measure EMF up to 500mG by 0.1 mG resolution. It can also measure RF radiation up to 10GHz and EF up to 1000V/m by 1V/m resolution. This device can record data by specifying the measurement time and date. The RF spectrum power analyzer in the device operates in 5 different frequency bands as given in its manual:

- “Frequency band 1: 50MHz to 65MHz (Frequency step: 100KHz, Frequency span: 100KHz)”
- “Frequency band 2: 65MHz to 76MHz (Frequency step: 100KHz Frequency span: 100KHz)”

- “Frequency band 3: 76MHz to 108MHz (Frequency step: 100KHz Frequency span: 100KHz)”
- “Frequency band 4: 240MHz to 1040MHz (Frequency step: 1KHz to 10KHz Frequency span: 50KHz to 4000KHz)”
- “Frequency band 5: 2.4Ghz to 2.5GHz (Frequency step: 25KHz to 405KHz Frequency span: 58KHz to 812KHz)”

Figure 3.5. Tools used for measurements.

ii. A tripod (Figure 3.5-d) which is Digipod TR560AN model is used to stabilize the GQ EMF-390 to keep it away from environmental influences. The tripod used is adjustable in height from 30 cm to 170 cm. With the help of 3 separate spirit levels on the tripod, it is possible to fix the device in the plane.

iii. A laser meter (Figure 3.5-b) which is Bosch PLR 50C model was used to determine the measurement positions and heights. The meter can measure from 0.05m to 50m with an accuracy of ±2mm.

iv. A device with thermometer and hygrometer features (Figure 3.5-c) was used to note the humidity and temperature values in the room where the EMR measurements were taken. The Xiomi miaomiaoce meter model can measure temperature with ±0.3°C accuracy between 0°C and 60°C and relative humidity with ±3% accuracy between 0% and 100%.

v. A microwave (MW) oven (Figure 3.5-e), in addition, was used as the source for the measurements on wall types. The MW oven that is Arçelik MD 674S model works in 2.45 GHz.

3.1.4 Materials used for measurements on wall types

Measurements were made on 10 different wall composition as can be seen from Figure 3.8 in detail. The first 6 of these measurements were made on the existing wall types in the flat. Measurement points are presented in Figure 3.6. The last 4 were measured with insulation boards added on an existing wall. These wall types are identical to 10 of the cases in the parametric SE simulations with the wall piece and are coded in the same way. W07, W08, W09, W14, W15, W21 are existing walls in the flat. In W10, W11, W12 and W13, different insulation materials were placed on the surface of the existing wall coded as W7 and measurements were made.

Insulation materials added to the wall surface can be seen in Figure 3.7. The size of the aluminum sandwich panel used in W10 is 50x50cm. The size of the carbon EPS board used in W11, XPS board used in W12 and styrofoam board used in W13 is 60x120cm. Thicknesses for all walls are given in Figure 3.8.

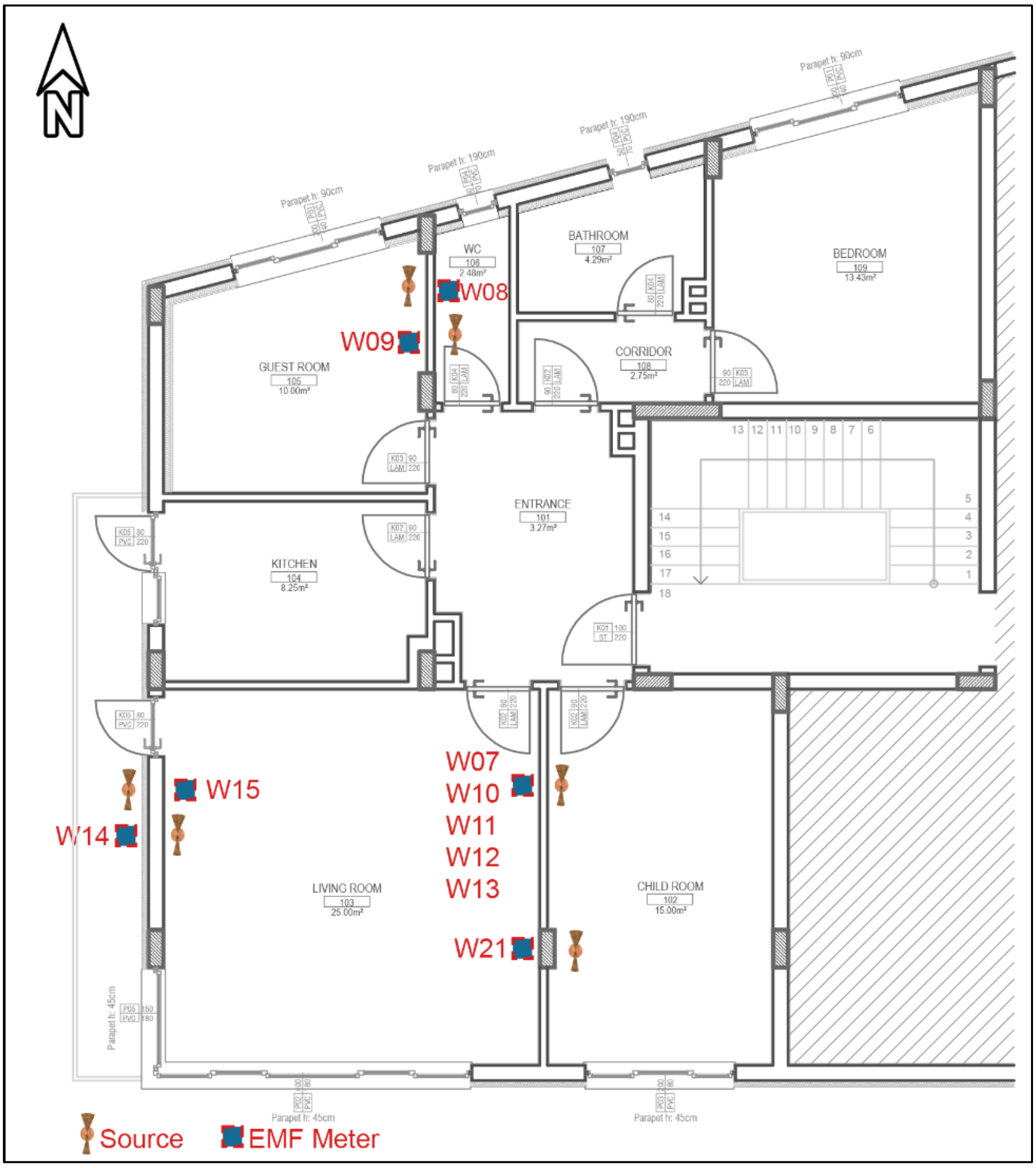


Figure 3.6. Assessment points for measurements on wall types.

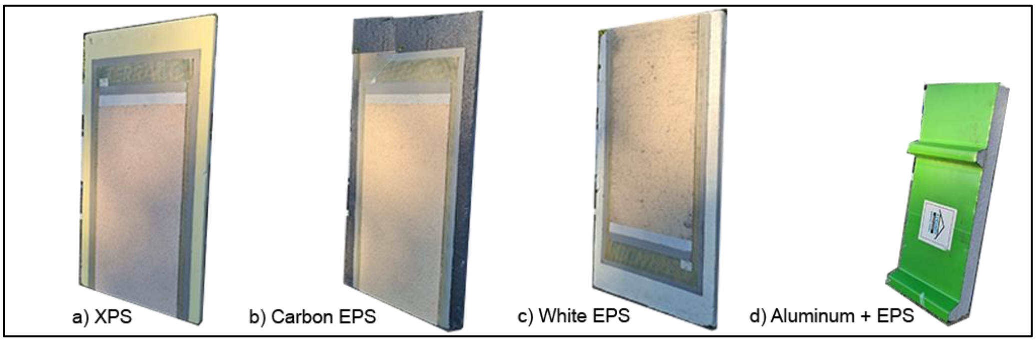


Figure 3.7. Insulation panels placed on the surface of the existing wall.

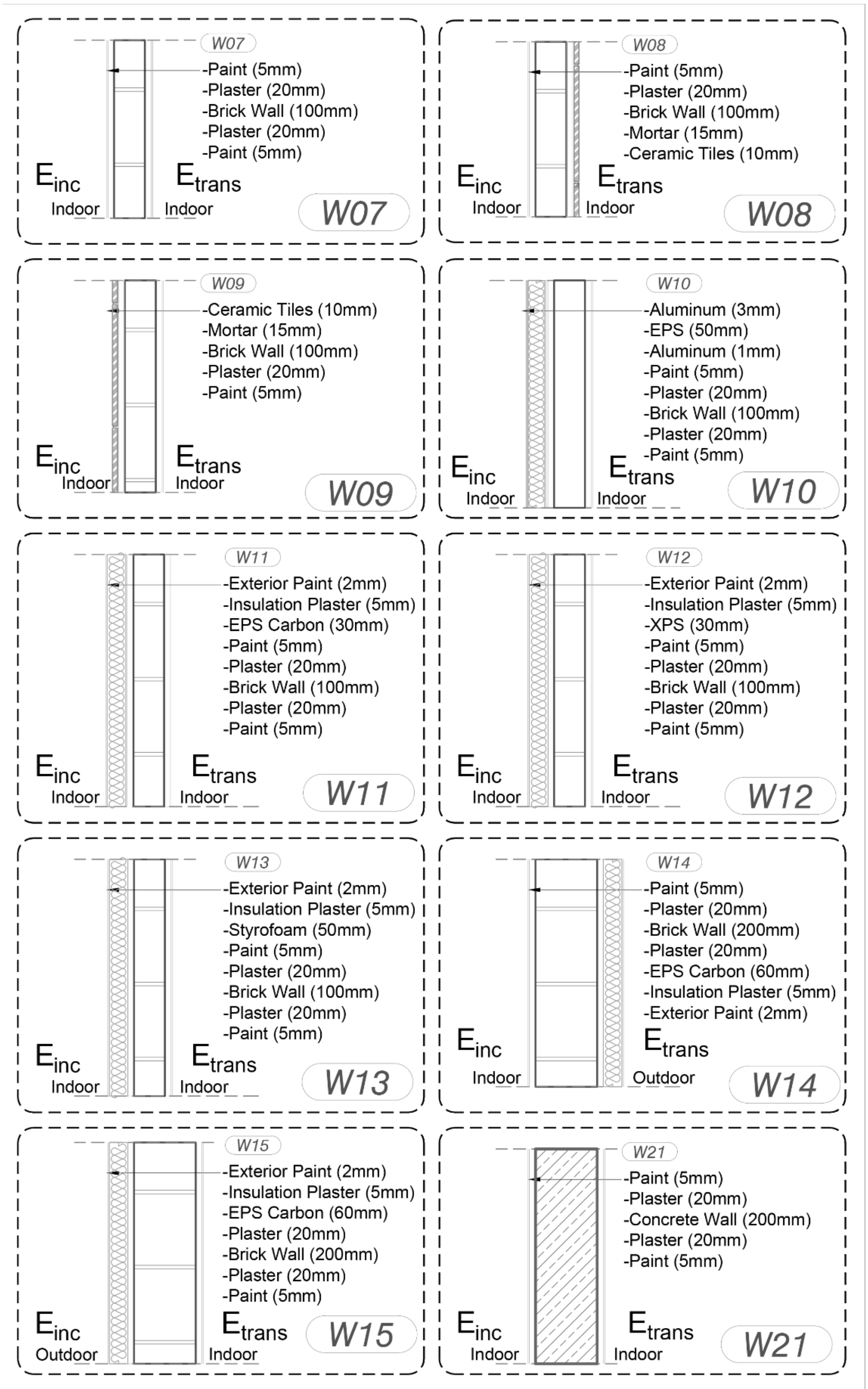


Figure 3.8. Details of the wall types measured for shielding effectiveness.

3.1.5 Tools used for simulations

Simulation Software is used for EMR calculations for various architectural decisions. The software used is CST Microwave Studio (CST-MWS) 2019 educational version. It was preferred because it has the capability to work with built environments and building materials for RF frequencies.

The accuracy of the simulation software is tested in some studies related to electrical engineering (Chevalier et al., 2003). Also, the percentage errors calculated were reported to be from 0.9% up to 6.5% between the measured and simulated values, in a recent study regarding impact of roof form on EMR (Wahba et al., 2021). So, it remains within an acceptable error range for EM power density levels.

3.2 Method

This thesis focuses on children's rooms, which are considered sensitive and prioritized spaces. Inside children's rooms, different activities can take place at different points. Considering that the duration of exposure is an important factor, it is most critical to organize the area where the activity takes place at a fixed point for a long time, *i.e.*, sleep. With reference to a standard bed level and body thickness, the working plane was set at a height of 70cm from the floor.

Choosing the bed level as the working plane also has other benefits. For a standing person, the brain, heart, and other sensitive parts are each at a different height level. In the lying position, they are approximately at the same height level. In addition, the bed level eliminates differences in the use of space due to age, gender, and body size. The plane at 70cm above the floor can be applied to every person. On the other hand, it should be noted that the difference in exposure due to age and gender is not only related to the point in the space. For example, because their skulls are thinner and their heads are smaller in size, a much larger part of children's brains are exposed to radiation. This increases the intensity of risks.

For the reasons listed above, all measurements and simulations performed within the scope of this study focused on the EMR intensity at a height of 70cm above the ground.

3.2.1 Calibration

The 0-value calibration of the EMF Meter was performed in the isolation created by wrapping the device in 8 layers of aluminum foil. The measurement values of the device were tested on the EF strength value published by BTK for base stations. BTK has published only EF strength value for base stations. It was observed that the measurements made around the selected base stations were compatible with the BTK data.

Incident wave magnitude defined for the plane wave to which the model is exposed in the simulations has a multiplier effect on the results with a linear proportion. This multiplier effect was observed by testing with 5 different simulations.

The results of the measurements taken at the points determined with the EMF meter were evaluated. Afterwards, the room selected as a case study was modeled in CST-MWS. The first simulation results were analyzed. To calibrate the on-site measurement data with the simulation results, the incident wave magnitude value was set to 1V/m for all cases.

3.2.2 Measurement standards and procedure

In the controlled environment of a laboratory or simulation, conditions such as source direction and intensity can be determined. In a real-life environment, however, there are case-specific conditions that are difficult to predict.

In this study, first of all, the current situation under the simultaneous effect of different sources and frequencies in a real case was assessed by on-site measurements.

These EMF measurements were made in 2 different ways for 2 different purposes. The first one is to determine the current EMR levels of indoor and outdoor spaces; the other one is to compare the "shielding effectiveness" for different wall material configurations that are frequently used in building construction.

3.2.2.1 Measurements for outdoor and indoor

Measurements by EMF Meters were done with respect to “IEEE recommended practice for measurements and computations of electric, magnetic, and electromagnetic fields with respect to human exposure to such fields (0 Hz-300 GHz)”. EF strength, MF strength and RFR power values were recorded.

EMR sources such as telecommunication base stations, electricity power plants were determined for each building. The online base station map published by the BTK (https://www.turkiye.gov.tr/baz-istasyonlari) was used as a reference when determining the source locations. In addition, the presence of base stations was confirmed by on-site checks. Other resources such as transformer stations and power lines were identified through on-site observations. Before starting the measurement, the number of Wi-Fi networks affecting the measurement point was determined by using a computer.

To record EMF measurements, sampled points were selected according to the importance of locations with regard to the possibility of excessive exposure due to duration of occupancy. Also, outdoor measurements were taken not only at close points to the façade but also next to the garden boundary wall. This is required for sensitive buildings such as schools and hospitals. Similarly, indoor measurements were recorded at several sample points in each room. Temperature and humidity information was taken at the measurement points, concurrently.

The EMF meter was fixed on a tripod during the measurements. With reference to the information in the technical documentation of the EMF meter, only the handle areas were fixed to the tripod in order not to cover the sensors of the device. No devices such as cell phones, computers, smartwatches that can be considered as internal sources were kept near the measurement points.

Figure 3.9. Typical setup for interior measurements.

As in the case of building interiors, all measurements were performed for 7 minutes. The first and the last 30 seconds were excluded from the evaluation to eliminate the situation where the assessor was near the device. During the 6-minute measurement, EF -MF strength and RFR power were recorded every second.

Technical drawings of the flat selected as a case study for indoor measurements were obtained from Çankaya Municipality. In addition, the materials and measurements were checked on site and the existing plan of the flat was drawn. Interior EMR sources (such as wireless modems, microwave ovens, HVAC equipment, printer) and measurement points were marked on this plan which is presented in Chapter 4.

In the light of the information in the user manual of GQ EMF390; the RF sensitivity and RF browser scale of the device was set to "normal", and the RF density gain was set to "10".

No frequency filtering was performed in the measurements. All frequencies affecting the selected locations were included in the measurements. Source characteristics such as antenna patterns, duty factors, modulation, operational cycles, automatic power control, and other factors related with waveform were neglected. On the other hand, multiple paths due to reflection, diffraction and refraction effects from the environment were taken into consideration while evaluating results. Similarly, spatial variations were considered during evaluation.

3.2.2.2 Measurements on wall types

Measurements on wall types were made in the flat selected as the case study. Since the measurements were made in an existing apartment unit, a household appliance was chosen as the source. Therefore, the results presented here are not intended to provide a precise numerical description of the transmission coefficient or shielding effectiveness of the materials. The results obtained from this additional experiment are used to compare the materials both among themselves and with the simulation results, in order to validate the data obtained.

A Wi-Fi extender was previously used as a source in the measurements. The results were not significant because the intensity of the radiation emitted by the Wi-Fi extender is very variable and unstable over time. Only one EMF meter is available to record the measurements. Since it was not possible to measure the value of the source simultaneously with the measurement at the probe point, this setup was abandoned.

A microwave oven, which emits radiation more constantly, was chosen as the source. The MW oven was placed on a wooden stand on one side of the wall as shown in Figure 3.10. The MW oven was positioned at a distance of 3cm from the wall surface in all cases. The EMF meter was placed on the surface of the wall in all cases. The EMF meter was placed on the same wooded stand on the other side of the wall, centering the microwave oven to measure the strength of the transmitted wave

(E_{trans}). The alignment of the placement was ensured with the help of a laser meter. In all measurements, the temperature and humidity values of the measurement point during the measurement were also noted. The MW oven was operated for at least 6 minutes each time and all measurements were recorded for a minimum of 6 minutes.

a) +White EPS b) +Carbon EPS c) +XPS d) EMF Meter

Figure 3.10. Typical setup for measurements on wall types.

In cases W10, W11, W12 and W13, the insulating materials shown in Figure 3.10 were added between the MW oven and the wall. These materials (except W10) are wide enough to completely cover the front face of the MW oven. The material sample used in W10 was able to cover less than half of the front surface of the microwave oven.

In addition to the measurements made on the wall types, measurements were also made at a distance of 3cm from the microwave oven without any obstacle in between measure the amplitude of the incident wave (E_{inc}).

The current EMF level was also recorded at all measurement points without a source to determine if there were any environmental influences that could affect the results.

To ensure measurement accuracy, the same precautions as for indoor measurements were applied for wall measurements. Wi-Fi was off during measurement and there is no other device near measurement point.

The mean value of the measurements for 6 minutes was calculated for evaluation. Transmission coefficient (Γ) is calculated as follows by using mean values:

$$\Gamma = E_{trans}/E_{inc}$$

3.2.3 Compiling dielectric properties of common building materials

Since the dielectric properties of common building materials are needed to define the cases in the simulation environment, all the data available from the literature review were gathered and presented as groups in tables for use in calculations and simulations. These groups are listed below:

Dielectric properties of concrete compiled from 7 sources (ITU-R, 2015, 2021; Pinhasi et al., 2008; Rudd et al., 2014; Zhekov et al., 2020).

Dielectric properties of various types of brick for various frequency ranges compiled from 9 sources (Cuiñas & Sánchez, 2002; ITU-R, 2015, 2021; Landron et al., 1996; Pinhasi et al., 2008; Pisa et al., 2017; Rudd et al., 2014; Wilson & Crawford, 2002; Zhekov et al., 2020).

Dielectric properties of plexiglass compiled from 4 sources (Pinhasi et al., 2008; Pisa et al., 2017; Wilson & Crawford, 2002; Zhekov et al., 2020).

Dielectric properties of wood and wood-derived materials such as plain wood, wood-cement board, hardboard, MDF, chipboard, plywood, floorboard was compiled from 7 sources (Cuiñas & Sánchez, 2002; ITU-R, 2021; Pinhasi et al., 2008; Rudd et al., 2014; Wilson & Crawford, 2002; Zhekov et al., 2020).

Dielectric properties of gypsum ceiling board compiled from 3 sources (ITU-R, 2015, 2021; Wilson & Crawford, 2002).

Dielectric properties of rockwool ceiling board compiled from 2 sources (Pinhasi et al., 2008; Rudd et al., 2014).

Dielectric properties of plasterboard compiled from 7 sources (Cuiñas & Sánchez, 2002; ITU-R, 2015, 2021; Pinhasi et al., 2008; Rudd et al., 2014; Wilson & Crawford, 2002; Zhekov et al., 2020).

Dielectric properties of EPS (Bandyopadhyay et al., 1980), polystyrene (Zhekov et al., 2020), XPS (Ellingson, 2023) and Mineral wool (Xie et al., 2016) is presented. Dielectric properties of autoclaved aerated concrete (AAC) compiled from 2 sources (Pinhasi et al., 2008). Dielectric properties of marble compiled from 2 sources (ITU-R, 2021; Pinhasi et al., 2008).

Dielectric properties of ceramic tiles and limestone were taken from only one source (Landron et al., 1996). Dielectric properties of tremolite blocks were found only from a source (Pinhasi et al., 2008). In addition, various materials including blinds, carpet, fabric, linoleum, stucco (Wilson & Crawford, 2002), paint with carbonyl iron (Folgueras et al., 2009), PVC (Pisa et al., 2017), gypsum plaster (Zhekov et al., 2020) are presented.

3.2.4 Simulation procedure

EMR calculations are the main subject of electrical engineering and physics, and not architecture. This study approaches the subject from an architectural point of view. It aims to observe the influence of architectural variables by comparing one variable at a time on the cases.

Just like the measurements, the simulations were run in 2 different ways for 2 different purposes. The first one was to calculate the shielding effectiveness values of common wall types used in buildings in the range of 0.5-10GHz. The second was a series of space simulations to observe the effect of different architectural variables including wall thickness, wall materials, floor finishings, ceiling materials, room depth, room width, room height, window size, window position, furniture density, furniture material and door position on indoor EMR intensity and dispersion.

It may be useful to describe the simulation environment before the cases tested in the simulations, considering the scarcity of studies for architectural spaces. CST MWS uses a 3D Cartesian grid for calculations. As the simulated volume increases or the frequency is increased, the number of cells to be calculated increases. Although the software is capable of calculating larger buildings and higher frequencies, this requires both longer computation times and more powerful devices than personal computers, such as supercomputers. For this reason, for the time being, space simulations are run at 1GHz frequency on a room module selected as a case study.

In addition, it was possible to study the shielding effectiveness of wall types at frequencies used by technologies such as 4G and 5G by working with a piece of wall that is very tiny compared to space.

In real life, EMR will impact the room from various directions with different intensities. In order to reduce the computational memory size, the cases are irradiated with an ideal plane wave from one direction. In the CST MWS environment, different from the usual CAD space, the Y axis represents the height. The Z axis represents depth, and the X axis represents width.

The input variables that need to be defined and entered into the simulation software as well as the output variables obtained after the simulations are run, are presented in Figure 3.10 below.

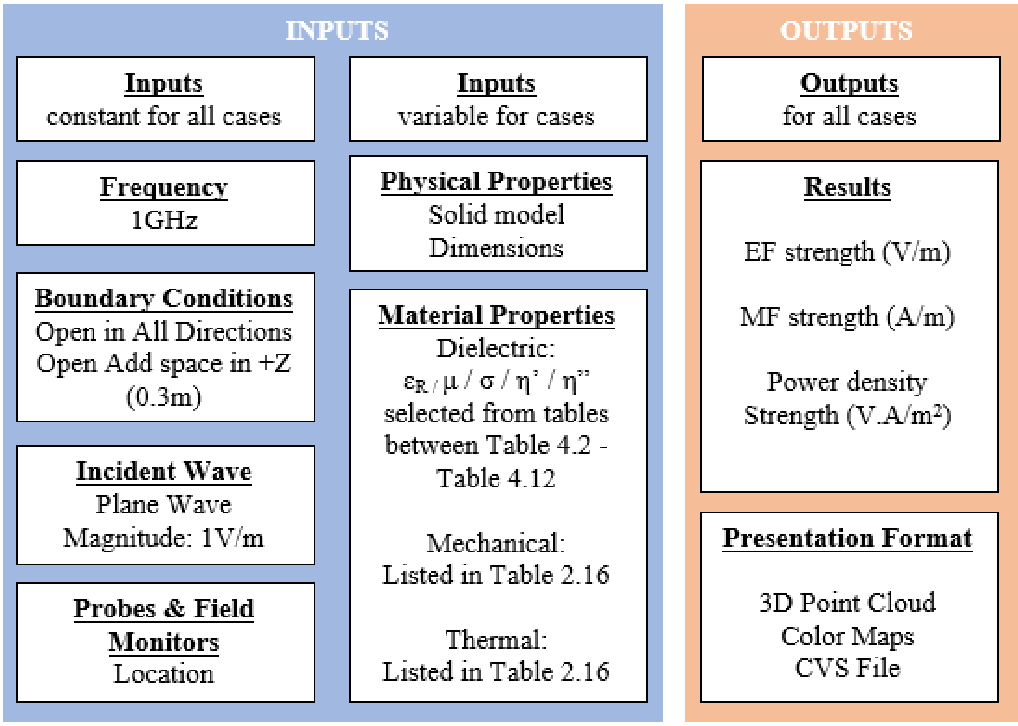


Figure 3.11. Inputs and outputs for simulations.

3.2.4.1 Parametric simulations of wall samples

To assess parametric shielding effectiveness SE (dB) values of materials in the 0.5-10GHz frequency range, simulations are made on a 10cm x 10cm wall section.

X and Y boundaries were defined as open while Z boundaries as open-add space. 30cm distance in both +Z and -Z direction is added, as seen from Figure 3.12. The plane wave was placed 30 cm from the end of the wall in all cases. The measuring probe was placed at 10 cm on both sides of the wall. To compare the results, a case with no walls was tested first. The data from this case was used in the SE calculation.

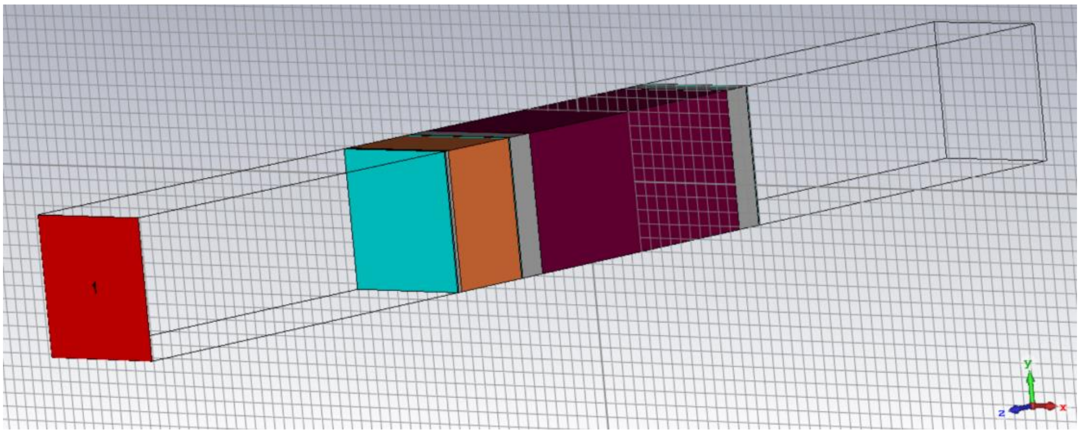


Figure 3.12. Model for parametric SE simulations of materials.

10cm brick wall in W1, 10cm AAC wall in W2 and 10cm concrete wall in W3, 20cm brick wall in W4, 20cm AAC wall in W5 and 20cm concrete wall in W6 were examined.

In addition to W21, the cases between W7 and W15 are the same as the on-site wall types, as can be seen from Table 3.1 and Figure 3.8. In this way, it is also possible to compare simulation and measurement results.

In W16, compared to W15, a marble cladding scenario was presented instead of plaster and paint on the exterior facade. In W17, wood cladding was applied on the exterior façade, while in W18 PVC cladding was present.

Furthermore, the use of aerated concrete instead of brick was tested in W19 compared to W14. A reinforced concrete external wall was tested in W20. Although reinforced concrete walls are required to be minimum 30cm by current Turkish regulations, concrete walls in case study flat are 20cm since it was constructed in 70's. This also represents the situation in the existing building stock.

In W22 a dry wall system with plasterboard was simulated. In W23, a dry wall system with MDF boards was tested.

Table 3.1 Simulation scenarios for transmission coefficient.

	Case	Code	Detail	Thick (m)	
	W00	W00	No Shilding	0	
	W01	Bw1	Brick (100mm)	0.10	
	W02	Aw1	Aerated Concrete (100mm)	0.10	
	W03	Cw1	Concrete (100mm)	0.10	
	W04	Bw2	Brick (200mm)	0.20	
	W05	Aw2	Aerated Concrete (200mm)	0.20	
	W06	Cw2	Concrete (200mm)	0.20	
	W07	PpBw1Pp	Paint & Plaster (21mm) + Brick (100mm) + Plaster & Paint (21mm)	0.14	
	W08	PpBw1Cr	Paint & Plaster (21mm) + Brick (100mm) + Mortar (10mm) + Ceramic (10mm)	0.14	
	W09	CrBw1Pp	Ceramic (10mm) + Mortar (10mm) + Brick (100mm) + Plaster & Paint (21mm)	0.14	
	W10	AsEsAsPpBw1Pp	Aluminium (3mm) + EPS (50mm) + Aluminium (1mm)+Paint & Plaster (21mm) + Brick (100mm) + Plaster & Paint (21mm)	0.20	
	W11	PpEcPpBw1Pp	Plaster & Paint (4mm) + EPS carbon (30mm) + Paint & Plaster (21mm) + Brick (100mm) + Plaster & Paint (21mm)	0.18	
	W12	PpXsPpBw1Pp	Plaster & Paint (4mm) + XPS (30mm) + Paint & Plaster (21mm) + Brick (100mm) + Plaster & Paint (21mm)	0.18	
	W13	PpEsPpBw1Pp	Plaster & Paint (4mm) + EPS white (50mm) + Paint & Plaster (21mm) + Brick (100mm) + Plaster & Paint (21mm)	0.20	
Source	W14	PpEcPpBw2Pp	Paint & Plaster (4mm) + EPS carbon (60mm) + Paint & Plaster (21mm) + Brick (200mm) + Plaster & Paint (21mm)	0.31	Receiver
	W15	PpBw2PpEcPp	Paint & Plaster (21mm) + Brick (200mm) + Plaster & Paint (21mm) + EPS carbon (60mm) + Paint & Plaster (4mm)	0.31	
	W16	MfEcBw2Pp	Marble (30mm) + EPS carbon (60mm) + Brick (200mm) + Plaster & Paint (21mm)	0.30	
	W17	TfEcBw2Pp	Timber (20mm) + EPS carbon (60mm) + Brick (200mm) + Plaster & Paint (21mm)	0.30	
	W18	PfEcBw2Pp	PVC (10mm) + EPS carbon (60mm) + Brick (200mm) + Plaster & Paint (21mm)	0.29	
	W19	PpEcPpAw2Pp	Paint & Plaster (4mm) + EPS carbon (60mm) + Plaster (21mm) + Aerated Concrete (200mm) + Plaster & Paint (21mm)	0.31	
	W20	PpEcPpCw2Pp	Paint & Plaster (4mm) + EPS carbon (60mm) + Plaster (21mm) + Concrete (200mm) + Plaster & Paint (21mm)	0.31	
	W21	PpCw2Pp	Paint & Plaster (21mm) + Concrete (200mm) + Plaster & Paint (21mm)	0.25	
	W22	GpPbWmPbGp	Gypsum Plaster (10mm) + Plasterboard (12mm) + Mineral Wool (100mm) Plasterboard (12mm) + Gypsum Plaster (10mm)	0.13	
	W23	GpMbWmMbGp	Gypsum Plaster (10mm) + MDF (12mm) + Mineral Wool (100mm) + MDF (12mm) + Gypsum Plaster (10mm)	0.13	
	W24	Cw1Cr	Concrete Slab (100mm) + Mortar (10cm) + Ceramic (10mm)	0.17	
	W25	Cw1XsFb	Concrete Slab (100mm) + XPS (10mm) + Floorboard (10mm)	0.17	
	W26	Cw1Mf	Concrete Slab (100mm) + Mortar (20mm) + Marble (20mm)	0.17	
	W27	Cw1AgGb	Concrete Slab (100mm) + Air gap (100mm) + Gypsumboard (12mm)	0.21	
	W28	Cw1AgAs	Concrete Slab (100mm) + Air gap (100mm) + Aluminium (3mm)	0.21	
	W29	Cw1AgPf	Concrete Slab (100mm) + Air gap (100mm) + PVC (8mm)	0.21	
	W30	Cw1AgTf	Concrete Slab (100mm) + Air gap (100mm) + Wood (10mm)	0.21	

In the scenario called as W24, a 2cm thick ceramic layer was tested on a 15cm thick reinforced concrete slab. Floorboard layer was tested in W25 and marble coating on the floor was tested in W26.

W27 presents a scenario with 20cm air gap and gypsum board ceiling under reinforced concrete floor, W28 presents a scenario with aluminum, W29 with PVC and W30 with wood suspended ceiling.

3.2.4.2 Simulations for indoor space

The room model in simulation environment was irradiated by an ideal plane wave at frequency = 1 GHz and wavelength = 299.79 mm. The incident plane wave is positioned one wavelength (30cm) away from the outer wall of the room in the +Z direction in the XY plane. Boundary condition is defined as open in all directions. A space of 30cm from the outer wall in the direction of the incident wave source is added to the background boundaries. In all other directions, the background is aligned with the outer face of the walls. The origin was taken at the center of the space in each case. All the *X-Y-Z*-direction have both negative and positive parts in the model.

EF strength, MF strength and EM power values were obtained as a result of simulations. The comparison of the cases was based on the shielding effectiveness (SE) values calculated from the EM power density (PD) results. SE, which is used in the literature for the comparison of shielding materials, is now being used to define shielding from EMR in architectural spaces also. Not only the effect of materials, but also the effects of different parameters such as height, depth, width, window position, window dimensions were reflected as SE results. In this way, all different parameters could be easily compared.

To obtain the H_0/E_0 value to be used in the SE calculation, the probe and source were placed in the same position in the simulation environment having the same boundary conditions but not closed as shown in Figure 2.7 in the previous chapter.

3.2.4.3 Calibration and validation Case

In this case, coded as C00, all of the existing materials and dimensions of the room selected as a case study are defined as they are in reality. This case has 3m x 5m net interior dimensions and 2.8m net height. There is a 6cm carbon EPS insulation board on top of a 20cm brick wall facing the exterior (radiation source). Both sides of the wall are plastered. In the center of this wall there is a 2 x 1.7m window. The PVC frames of the window are neglected in the simulation. The window glazing is defined as 4mm glass + 16mm air gap + 4mm glass. There is a 30cm high, 200cm wide aluminum radiator under the window. The side and back walls are 10cm brick, plastered on both sides. The ceiling is 10cm thick reinforced concrete slab and plaster finished. Reinforced concrete floor is defined simply as concrete in the simulation. Reinforcements are neglected. Likewise, the floor slab is defined as 10cm concrete and there is 1cm thick timber floorboard on 1cm XPS on the floor. There are 2 carpets on the floor of the room, the first one is 150cm x 230 cm and the second one is 90cm x 130cm. The 90cm x 210 cm wooden door on the back wall of the room, which is 85% glass, is defined as fully glazed in the simulation. The wooden furniture inside the room; wardrobe, 3-seater sofa, baby bed, and a console with drawers which should not be there are also defined in the simulation model in the size they are. Objects such as accessories and books in the room and marble windowsills are neglected.

3.2.4.4 Simulation Cases

Some of the physical building properties were grouped within the scope of this study as room shape, room size, room height, room proportions, facade area, window-to-wall ratio, wall materials, wall thickness, floor and ceiling finishes, and furniture density, and furniture materials. Each of these groups consists of further variables. As can be seen from Table 3.2 and Table 3.3 briefly; 50 different cases were constructed by variations on the room module to observe the effect of architectural interventions at 1GHz EMR frequency.

Since EMR has frequency-specific wavelengths and materials have variable shielding effectiveness according to frequency, it was preferred to perform simulations on a real-size model. In doing so, the reference case was kept as small and simple as possible to enable the simulations to run on a personal computer and relatively shorten the long simulation times.

In the base-case, the dimensions and characteristics of the room chosen for the measurements were applied. The first case, **case 1** coded as **C1**, can be considered as a reference case. In this case the height was kept constant at 2.8m. The size of the room was set to 3x5m. A 20cm thick brick wall was defined on the façade facing the radiation source and 10cm thick on the other sides. No cladding was added on the wall. Similarly, reinforced concrete with a thickness of 10cm was defined on the floor and ceiling, but no cladding material was added. There are also no windows and no furniture in this case. Subsequent cases were derived by modifying this simple case. In this way, it was possible to observe the isolated effects of the variables individually; which are wall thickness (4 scenarios), wall material change (13 scenarios), floor finishings (4 scenarios), ceiling materials (4 scenarios), room depth (2 scenarios),.room width (2 scenarios), room width and depth (2 scenarios), room height (3 scenarios), fenestration size (5 scenarios), position of window with respect to EMR source (5 scenarios), furniture density and material (3 scenarios), and door position (2 scenarios). The results of these scenarios which are described in detail in the following paragraphs were compared with each other.

(i) Changing wall thicknesses:

In case 2, the thickness of the brick wall in the direction of the radiation source was increased to 30cm. **In case 3**, the thickness of the brick wall facing the radiation source was reduced to 10cm so that all walls were 10cm. **In case 4**, all walls were increased to 20cm, the same as the wall facing the radiation source. In **case 5**, the thickness of all walls was increased to 30cm, including the wall facing the radiation source. These cases were used not only to measure the effect of wall thickness on shielding, but also to observe how the thickness of the walls surrounding the space and the secondary waves from reflection affect the EMR intensity in the space.

(ii) Changing wall materials

The group from Case 6 to Case 18 measures the effect of different wall types. In these cases, the material change was applied only on the wall facing the radiation source. The other walls were left unchanged as 10 cm thick bricks. **In Case 6**, an uninsulated building wall was tested. The core is made of 20cm brick, and the inner and outer faces are covered with 2cm plaster and paint. **In Case 7**, a 10cm air gap was left between two 10cm thick brick walls facing indoors and outdoors, covered with 2cm plaster and paint. **In case 8**, a 6cm thick EPS board was added to the outer face of the 20cm brick wall. Both sides of this wall are covered with 2cm thick plaster and paint. **In Case 9**, a reinforced concrete wall was applied instead of a brick wall compared to Case 8. **In Case 10**, aerated concrete wall was used compared to Case 8. In **Case 11**, mineral wool board was used instead of EPS board compared to Case

8. In **Case 12**, XPS board was used instead of EPS board compared to Case 8. **In Case 13**, 3cm thick marble facade cladding was applied instead of 2cm plaster and paint on the exterior compared to Case 8. Mechanical cladding system should be preferred for the application of natural stone claddings on thermal insulation. In this study, the metal elements of the mechanical cladding system were neglected in the simulations. **In Case 14**, compared to Case 8, 3cm thick wooden facade cladding was applied instead of 2cm plaster and paint on the exterior facade. **In Case 15**, 1cm thick ceramic wall cladding was applied instead of paint on the interior facade compared to Case 8. **In Case 16**, compared to Case 8, 2cm thick ceramic wall cladding was applied on the exterior instead of paint. **In Case 17**, 1cm thick PVC cladding was applied instead of 2cm plaster and paint on the exterior compared to Case 8. **In Case 18**, a dry wall of plasterboard and mineral wool was tested in the source direction. In this case, as in the other cases, the back and side walls were left as 10cm brick walls.

(iii) Changing floor materials

Case 19 to Case 22 examine the impact of floor finishings. **In Case 19**, compared to Case 1, 2cm plywood sheeting was added over the reinforced concrete slab on the floor. **In Case 20**, 2cm timber floorboard was added over the reinforced concrete slab. **In Case 21**, 1cm ceramic tile was added on the floor. **In Case 22**, 2cm thick marble was added on the reinforced concrete floor. The mortar layer required for laying the marble was neglected in this study.

(iv) Changing ceiling materials

Case 23 to Case 26 test the effect of ceiling materials. **In Case 23**, compared to Case 1, a 0.5cm thick aluminum sheet was added to the ceiling slab to evaluate the effect of an aluminum suspended ceiling. To avoid a change in room height, no suspended ceiling cavity was created. The modulation of the aluminum suspended ceiling and the acoustic fabric with perforated holes on the modules were neglected in this study. Similarly **in Case 24**, 1.2cm thick gypsum board was added to the ceiling to evaluate the effect of plasterboard suspended ceiling. **In Case 25**, 0.7cm thick PVC was added to the ceiling to observe the effect of PVC suspension. **In case 26**, a 2cm thick wooden layer was added to the ceiling to observe the effect of wooden ceiling finishes, which can be seen in more traditional buildings.

(v) Changing room depth

Case27 and Case28 investigate the effect of the depth of the chamber with respect to the radiation source. **In Case 27**, compared to Case 1, the depth of the chamber was increased to 4m and **in Case 28** to 5m. The dimensions given are the net internal dimensions of the room.

(vi) Changing room width

Case 29 and Case 30 test the effect of the width of the chamber relative to the radiation source. **In Case 29**, compared to Case 1, the width was increased to 4m and **in Case 30** to 5m.

(vii) Changing room depth and width

Case 31 and Case 32 increase the width and depth simultaneously. Both width and depth are increased to 4m **in Case 31** and 5m **in Case 32.**

(viii) Changing room height

Case 33, Case 34, and Case 35 observe the effect of the height of the room on the EMR intensity. The net height was increased from 2.7m in Case 1 to 3m **in Case 33**, 3.2m **in Case 34** and 3.5m **in Case 35**.

(ix) Changing window size

The group from Case 36 to Case 40 observes the effect of window size. **In Case 36**, a 1.3x1.3m window was placed in the center of the wall facing the radiation source. The window is defined as double glazing on the model. Fenestration frames are neglected. **In Case 37**, a window of 1.7x1.3m was added to the same wall in the same way. **In Case 38**, a 1.7x1.7m window was added to the same wall in the same way. **In Case 39**, a 2x1.7m window was added to the same wall in the same way. **In**

Case 40, a glass façade was created with a 2.4x2.4m window. Double glazed window (4mm glass + 16mm air + 4mm glass) used for all cases.

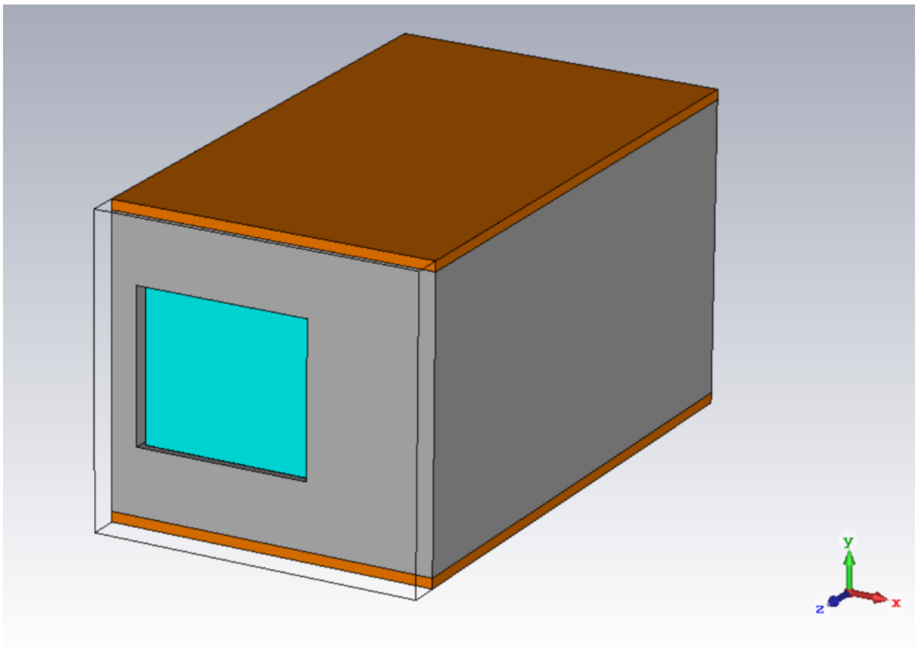


Figure 3.13. Model of case 43 in which window is not centered in the direction of the radiation source.

(x) Changing window position

Case 41 to Case 45 test the effect of the position of the window relative to the source. **In Case 41**, the 1.3x1.3m window was centrally inserted in the wall in the opposite direction to the radiation source. **In Case 42**, the 1.3x1.3m window was centrally inserted in the side wall in the +X direction with respect to the radiation source as seen from Figure 3.14. **In Case 43**, the 1.3x1.3m window was inserted into the wall in the direction of the radiation source, but instead of being centrally positioned horizontally, it was aligned in the +X direction of the wall as seen from Figure 3.13. **In Case 44**, the 1.3x1.3m window was again placed on the wall in the direction of the radiation source but was aligned vertically upwards instead of centrally. **In Case 45**, unlike Case 44, it was aligned downwards.

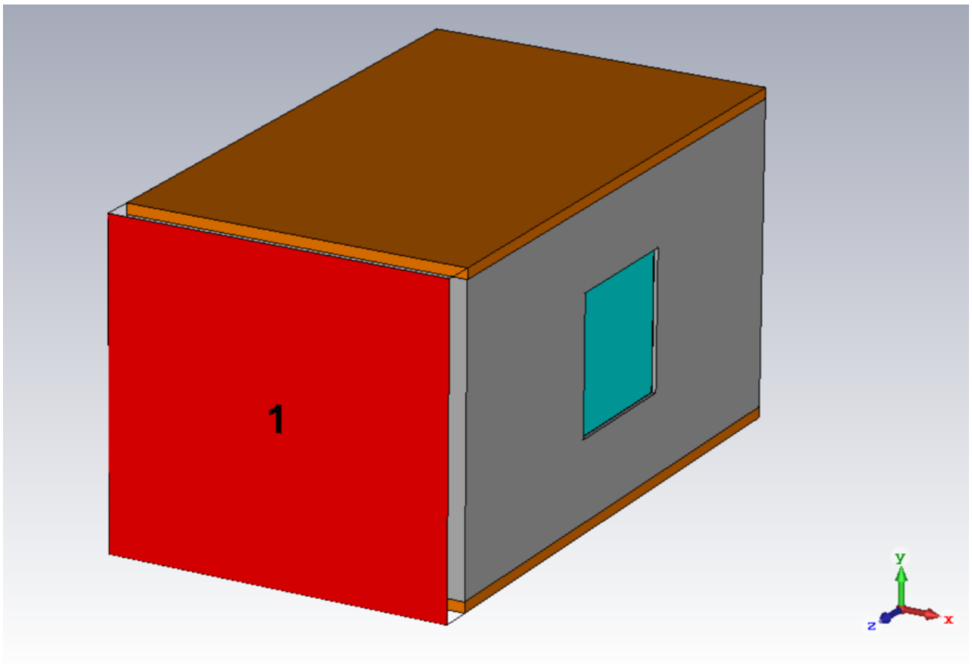


Figure 3.14. Model of case 42 in which a window is placed at the side wall.

(xi) Changing furniture density and material

Case 46, Case 47 and Case 48 measure the effect of furniture density and furniture materials. **In Case 46**, metal furniture was added to fill 40 per cent of the space in the plan compared to Case 1. **In Case 47**, wooden furniture was added to fill 40 per cent of the plan. **In Case 48**, wooden furniture was added to fill 60% of the plan.

(xii) Changing door position

In case 49, a door was added to the edge of the wall opposite the wall facing the source. Since 85% of the added door leaf is glass, it is defined as all glass in the simulation model. **In Case 50**, the same door was moved to the side wall.

Table 3.2 Simulation Cases

Parameters	Case No	Wall Material	Thic. (m)	Floor	Ceiling	Room Size (m)	Height (m)	Window (%)	Furniture (%)	Door
Validation	c0	Paint + Plaster + EPS + Brick (0,2m) + Plaster + Paint	0.3	timber floor board 2cm	Plaster + Paint	3*5	2.8	2*1.7	timber -0,6	Back Left
Wall Thickness	c1	Brick 20 cm (Facing the Source)	0.20	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c2	Brick 30 cm (Facing the Source)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c3	Brick 10 cm (Whole Envelope)	0.10	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c4	Brick 20 cm (Whole Envelope)	0.20	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c5	Brick 30 cm (Whole Envelope)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
Wall Materials	c6	(Paint + Plaster) + Brick + (Plaster + Paint)	0.24	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c7	(P + P) + Brick + Vacuum + Brick + (P + P)	0.34	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c8	(P + P) + EPS + Brick + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c9	(P + P) + EPS + Concrete + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
		(P + P) + EPS + AAC + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c11	(P + P) + Mineral Wool + Brick + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c12	(P + P) + XPS + Brick + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c13	Marble (3cm) + EPS + Brick + (P + P)	0.31	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c14	Timber (3cm) + EPS + Brick + (P + P)	0.31	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c15	(P + P) + EPS + Brick + Plaster + Ceramic (2cm)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c16	Ceramic (2cm) + Plaster + EPS + Brick + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c17	PVC (1cm) + EPS + Brick + (P + P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c18	(P+P) + Plasterboard + Mineral Wool + Plasterboard + (P+P)	0.30	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	0
Floor Covering	c19	Brick 20 cm (Facing the Source)	0.2	carpet 2cm	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c20	Brick 20 cm (Facing the Source)	0.2	XPS 1cm + floorboard 1cm	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c21	Brick 20 cm (Facing the Source)	0.2	Mortar 1cm + ceramic 1cm	Concrete Slab (0,1m)	3*5	2.8	0	0	0
	c22	Brick 20 cm (Facing the Source)	0.2	Mortar 2cm + marble 2cm	Concrete Slab (0,1m)	3*5	2.8	0	0	0
Ceiling Material	c23	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	aluminium	3*5	2.8	0	0	0
	c24	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	gypsumboard	3*5	2.8	0	0	0
	c25	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	PVC	3*5	2.8	0	0	0
	c26	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	wood	3*5	2.8	0	0	0
Depth	c27	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*4	2.8	0	0	0
	c28	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*3	2.8	0	0	0
Width	c29	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	4*3	2.8	0	0	0
	c30	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	5*3	2.8	0	0	0

Table 3.3 Simulation Cases (continued)

Parameters	Case No	Wall Material	Thic. (m)	Floor	Ceiling	Room Size (m)	Height (m)	Window (%)	Furniture (%)	Door
D x W	c31	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	**4*4**	2.8	0	0	0
	c32	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	**5*5**	2.8	0	0	0
Height	c33	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	**3**	0	0	0
	c34	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	**3.2**	0	0	0
	c35	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	**3.5**	0	0	0
Window Ratio	c36	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) centered**	0	0
	c37	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.7) centered**	0	0
	c38	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.7*1.7) centered**	0	0
	c39	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(2*1.7) centered**	0	0
	c40	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(2.4*2.4) glass facade**	0	0
Window Position	c41	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) opposite wall**	0	0
	c42	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) side wall**	0	0
	c43	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) left**	0	0
	c44	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) above**	0	0
	c45	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	**(1.3*1.3) below**	0	0
Furniture	c46	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	**metal-0,4**	0
	c47	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	**timber-0,4**	0
	c48	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	**timber -0,6**	0
Door	c49	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	**back left**
	c50	Brick 20 cm (Facing the Source)	0.2	Concrete Slab (0,1m)	Concrete Slab (0,1m)	3*5	2.8	0	0	**side**

3.2.5 Evaluation procedure

The values resulting from the on-site measurements are presented in the results section. Also, results for parametric simulations on wall samples are presented. These two results are compared with each other.

The simulation setup for space simulations was calibrated and validated with the results of the on-site measurements taken in the flat, selected as the case study. Simulations were run according to the scenarios determined by the author on the room selected as case study. The results of the simulations were obtained as EM power; and shielding effectiveness (SE) values were calculated from equation 3.

$$SE= 10 \log P_0/P_1 \qquad \text{Eq.3}$$

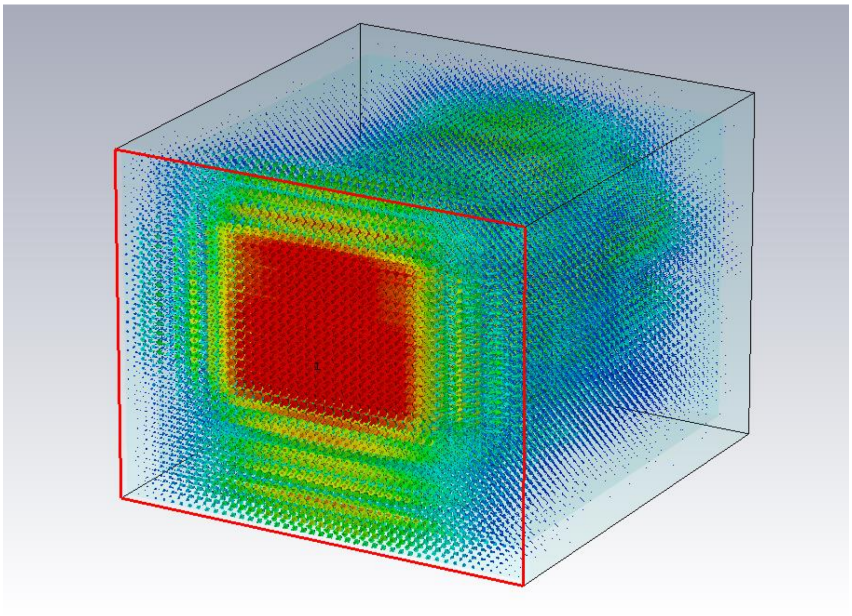


Figure 3.15. Electro-smog visualization in CST MWS by EMFP vectors.

Electromagnetic radiation is three-dimensional (see Figure 3.15) and repetitively moving. Since this study focuses on the sleep period, data at a height of 70cm above the ground are observed. Y axis indicates height. Plans showing the distribution of EM PD values at 70cm above the ground in color were used to compare the distribution and strength in the area.

In addition, SE results were calculated by EM PD (V.A/m2) results on the line extending at the center of room (X:1.5m) from Z:0.0 to Z:5.0m at 70cm hight from the floor (Y:+0.7m) to evaluate the change in depth as well. See Figure 3.16. Exceptionally, in C43, C46, C47, the highest PD values were not centered, so the evaluation line was shifted over the section with the highest PD.

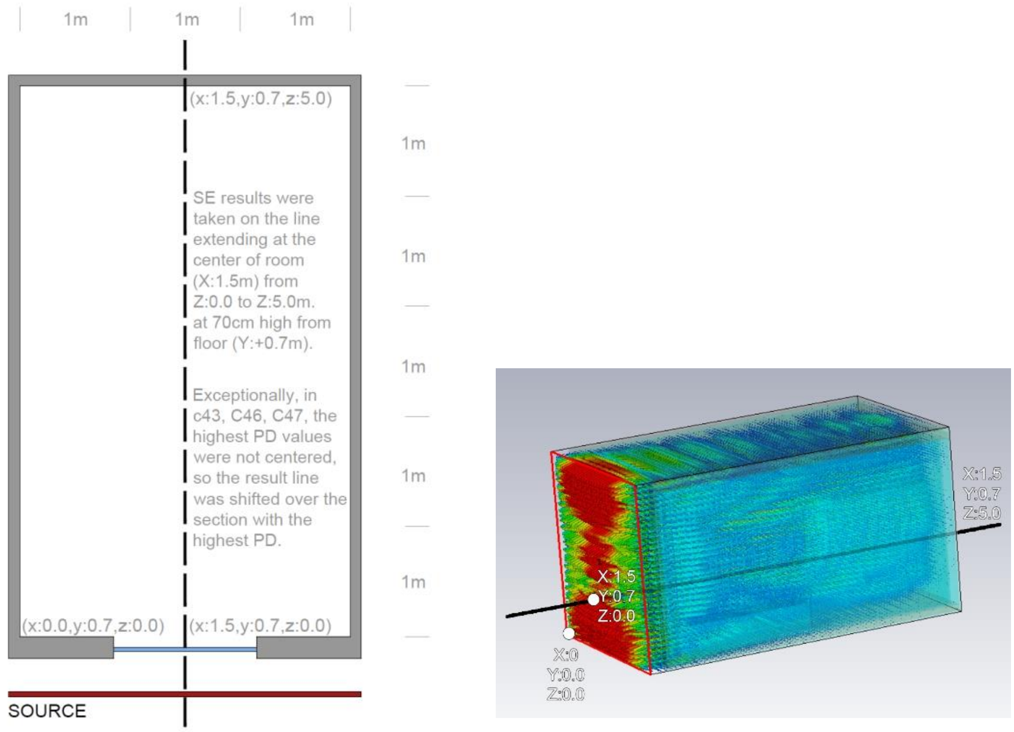


Figure 3.16. Position of result line for SE calculations.

The effects of many possibilities created by the combinations of these variables were calculated by simulation; and the results were used to define the effective weights of the architectural parameters by correlation analysis and a prediction model was obtained by multiple regression analysis.

CHAPTER 4

RESULTS AND DISCUSSION

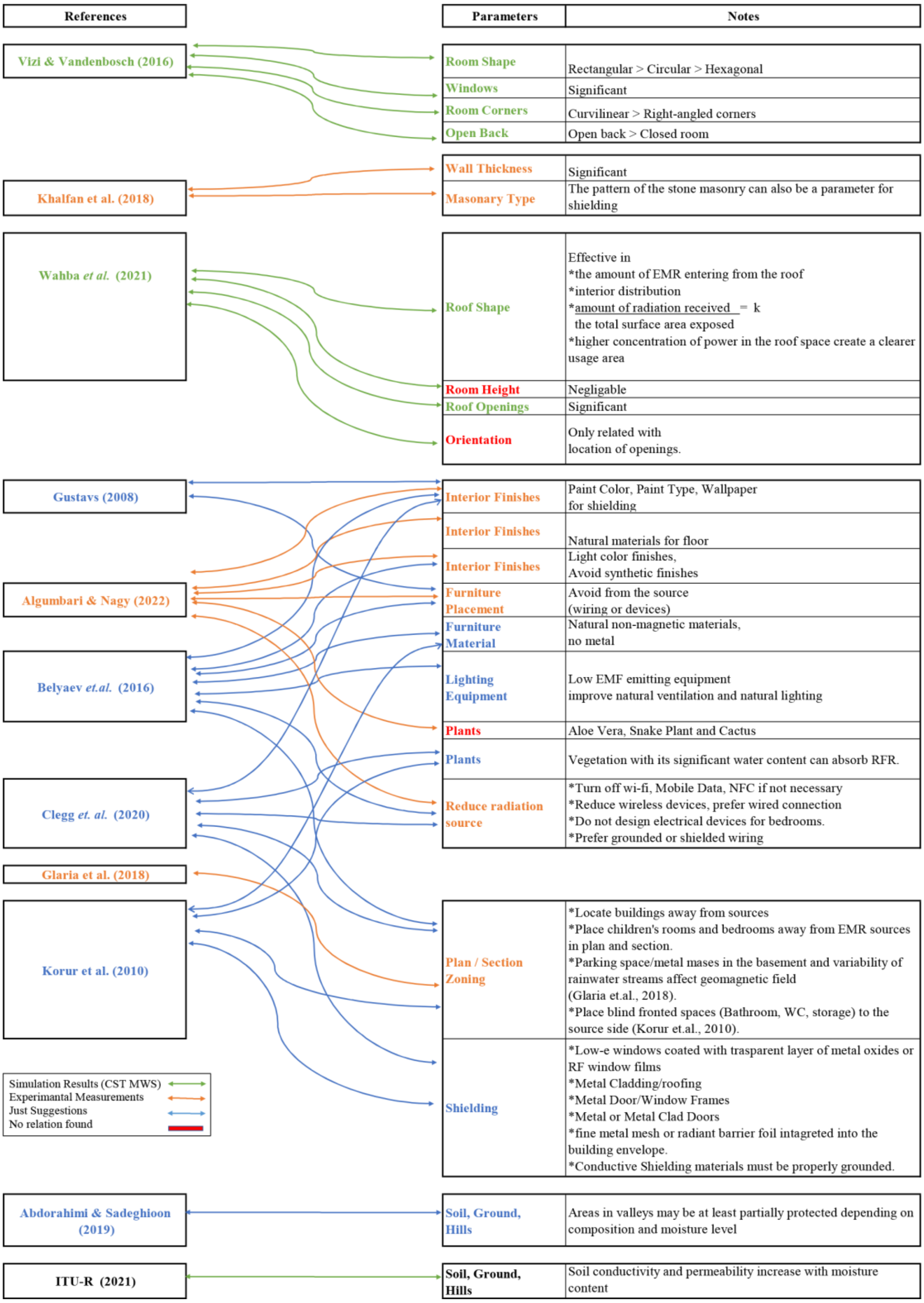
Results and discussion are presented in this chapter for EMR level assessments including on-site measurement and simulation procedure to define the current situation and the effect of architectural design variables selected within the scope of this study.

4.1 Discussion on literature

There are 5 theoretical studies that offer theoretical suggestions. Additionally, there are 4 studies that provide measurement-based data and two studies that provide simulation-based data. The recommendations and findings of these studies are compiled and presented in Table 4.1. Some of them have common recommendations or findings. As a result of the review on these studies, variables that have not been studied or whose results can be discussed despite being studied were identified and the cases presented in the previous chapter were prepared.

There are some solutions in the literature that include active technologies such as smart switches to mitigate excessive electro-smog. At this point, it should be noted that EMR and RFR levels will increase with smart city and smart building concepts but 5G Technologies, wireless modems, microwave ovens, smart meters, electricity power plants, railways, and other EMR sources may also separately penetrate the built environment. Employing advanced solutions for every residential unit, in every country, may not be possible because of financial limitations. If it is possible to discover a passive way in which these objectives and functions can be achieved without increasing EMR and RFR risks. It may be a good way to ensure health and well-being, reduce inequality, encourage responsible consumption and production, and other UN 2030 Targets.

Table 4.1 Illustration of suggested EMR related parameters in the literature gathered from 11 sources in literature (Compiled by the author).



Since it is almost impossible to ignore modern technology in cities and buildings, it is necessary to look for ways to eliminate its side effects while taking advantage of the opportunities. Among the benefits and side effects of ICT-based approach, rethinking buildings and infrastructures may introduce a transformation in architecture. Buildings are designed by producing the most reasonable composition with current possibilities to meet the occupants' needs. For example, the endeavor to produce solutions with respect to the climatic conditions affects the roof form, window sizes, wall thicknesses, room heights etc. Sunshades and eaves become a design element by aesthetic concerns at the same time. Similarly, the endeavor to produce solutions to mitigate excessive EMR can also affect architectural forms. Within this perspective, FSS modules that are still being studied in the literature can be both used for EMF/RF shielding and sun shading in future, for example.

The literature mentions the possibility of simultaneous shielding of man-made and natural EMF. Natural EMF with a low frequency of 7.8-13 Hz is responsible for the biological rhythmicity and well-being of humans and animals. This is an important challenge that hasn't been investigated yet in architecture. It may be possible to solve this issue with frequency sensitive shielding.

There are different results in the literature on the mitigation of EMR exposure by plants. Algumbari & Nagy (2022) found shows that aloe vera, snake plant and cactus in small pots do not reduce EMR power density strength at a work desk. On the other hand, Korur *et al.* (2010 predicts that trees can absorb RFR due to their water bodies. In the study conducted by Çerezci *et al.* (2022) for telecommunications coverage through forest shows that trees reduce radiation by the depth with their different parameters. This can be explained by the scale of the plant in the space. It may be useful to consider plants as a barrier rather than as an air purifier in a single location.

4.2 Dielectric properties of building materials compiled from literature

The next step was to compile the dielectric properties of the materials needed to define the cases in the simulation environment. Although dielectric properties for all building materials are not available, material lists compiled from the literature make it possible to calculate the impact of commonly used wall, floor, and ceiling systems. In this way, SE calculations will be possible for surfaces of different thicknesses at certain frequencies within the scope of this study.

On the other hand, further studies on the properties of materials are still needed for different frequency ranges and different material types. There are many building materials, and the sources penetrating the buildings have various frequencies. So, it is obvious that a very complex data set is needed for materials. Although the data set in this field is limited today, it will expand over time. In addition, most of the materials available for use in buildings will have differences in component details of materials specific to the manufacturer. With the increasing awareness on this issue, a regulation requiring material manufacturers to test and publish these values for their own materials will make a complex dataset accessible.

Dielectric properties (permittivity, conductivity, and permeability) of materials found in the literature are listed in tables below. In these tables, the frequency column indicates the frequency range in which the material is tested. Other columns present relative permittivity (ε), permeability (μ), conductivity (σ), the real part of the relative permittivity (η'), the imaginary part of the relative permittivity (η''). A material that dissipates energy of electromagnetic or acoustic energy passing through it is defined as 'lossy' material.

Dielectric properties for concrete are presented in Table 4.2. It can be observed that different qualities such as the age of the concrete, gravel properties, reinforcement, etc. change the permittivity.

Table 4.2 Dielectric properties of concrete gathered from 8 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Concrete	0.58-3.68	5.6-5.5	0.25-0.09		μ:1	0.044- 0.016	CST MWS Library Data
Concrete	1-100	5.24		0.0462	0.7822		(ITU-R,2021)
Concrete	1-100	5.31		0.0326	0.8095		(ITU-R,2015)
Concrete (LW)	0.9-24	2-2.5	0.12-0.5				(Shah et.al., 1965)
Concrete (RF)	0.948/1.865	5		0.004			(Antonini et.al., 2003)
Concrete (one year)	5	5.5	0.18	5.01E-02		3.27E-02	(Pinhasi et.al, 2008)
Concrete (40 years)	5	4.6	0.24	6.68E-02		5.22E-02	(Pinhasi et.al, 2008)
Concrete (one year)	60	6.4954	0.4284	1.43E+00		6.60E-02	(Pinhasi et.al, 2008)
Concrete (wt small gravel)	1-100	4					(Zhekov et. al., 2020)
Concrete (wt large gravel)	1-100	3.4					(Zhekov et. al., 2020)
Concrete	1-100	5.31		0.023	0.8095		(Rude et.al., 2014)

Dielectric properties for some brick types are presented in Table 4.3. Considering the production process of the brick, differences in material quality in different samples can be expected.

Table 4.3 Dielectric properties of brick gathered from 9 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Brick	1-40	3.91		0.0238	0.16		(ITU-R,2021)
Brick	1-10	3.75		0.038			(ITU-R,2015)
Brick	1.7-18	3.7-4.11		0.0174	0.0364		(Landron et.al.,1996)
Brick	2-4	4					(Pisa et al., 2017)
Brick	6	4.3					(Pisa et al., 2017)
Brick (with holes)	5	4.12	0.16	4.45E-02		3.88E-02	(Pinhasi et.al, 2008)
Brick (without holes)	5	3.3	0.01	2.78E-02		3.03E-03	(Pinhasi et.al, 2008)
Brick wall	5	3.56	0.34	9.46E-02		9.55E-02	(Pinhasi et.al, 2008)
Brick (with holes)	60	3.95	0.073	2.44E-01		1.85E-02	(Pinhasi et.al, 2008)
Brick (without holes)	60	3.26	0	0.00E+00		0.00E+00	(Pinhasi et.al, 2008)
Brick (red)	1-100	3.2					(Zhekov et. al., 2020)
Brick (yellow)	1-100	2.96					(Zhekov et. al., 2020)
Brick wall	5.8	3.58		0.11			(Cuiñas & Sánchez, 2002)
Brick wall	2	4.44					(Cuiñas & Sánchez, 2002)
Brick (Red) Dry	2.35-5.25	5.86				1.16.e-01	(Wilson & Crawford, 2002)
Brick (Red) Wet	2.35-5.25	5.92				1.17E-01	(Wilson & Crawford, 2002)
Brick	1-10	3.75		0.038	0		(Rude et.al., 2014)
Brick	4	4.44		0.01	μ:0.99		(Landron et.al., 1996)

The dielectric properties of glass are presented in the Table 4.4. It has different values in different frequency ranges. In addition, it may be possible to associate the value differences from different sources with the content of the glass. It should be especially noted that film layers to be applied on the glass can be beneficial for shielding. Similarly, adding metal additives to the glass also affects shielding.

Table 4.4 Dielectric properties of glass gathered from 8 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Glass	0.1-100	6.31		0.0036	1.3394		(ITU-R,2021)
Glass	220-450	5.79		0.0004	1.658		(ITU-R,2021)
Glass	0.1-100	6.27		0.0047	1.0718		(ITU-R,2015)
Glass	0.003-300	4-9		0.000023		0.0005- 0.035	(Gustafsson et.al., 2006)
Glass	60	4.7	0.1551	0.518		0.033	(Pinhasi et.al, 2008)
Glass	60	6.13	0.50266	1.68		0.082	(Pinhasi et.al, 2008)
Glass	1-100	6.4				0.01 to 0.015	(Zhekov et. al., 2020)
Glass	5.8	6.06		0.35			(Cuiñas & Sánchez, 2002)
Glass	41.5	3.41		0.26			(Cuiñas & Sánchez, 2002)
Glass	2.35-5.25	6.38				2.60E-02	(Wilson & Crawford, 2002)
Glass	0.1-100	6.27		0.0043	1.1925		(Rude et.al., 2014)

Dielectric properties of Plexiglas are presented in Table 4.5. Although not very common, it is used as wall cladding material in some interiors.

Table 4.5 Dielectric properties of Plexiglas gathered from 4 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Pleksiglass	3-6	2.61	0.011				(Pisa et al., 2017)
Pleksiglass	60	2.76	0.018	0.0601		0.00652	(Pinhasi et.al, 2008)
Pleksiglass	1-100	~ 2.6				~ 0.010	(Zhekov et. al., 2020)
Pleksiglass (7.1mm)	2.35-5.25	2.74				3.20E-04	(Wilson & Crawford, 2002)
Pleksiglass (2.5mm)	2.35-5.25	2.5				9.37E-03	(Wilson & Crawford, 2002)

Commonly used insulation materials are presented in Table 4.6. The densities of these materials affect their dielectric properties. Since the number of resources for insulation materials is limited, more studies are needed on this subject. These data were used in the simulations and also compared with the results obtained from on-site wall measurements. These results are presented in the following sections.

Table 4.6 Dielectric properties of thermal insulation materials gathered from 5 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
EPS (16 density)	9	1.1					(Bandyopadhyay et. al., 1980)
EPS (450 density)	9	2					(Bandyopadhyay et. al., 1980)
Polystyrene	1-100	~ 2.5					(Zhekov et. al., 2020)
XPS	0.01-1	1.1					(Ellingson et.al, 2023)
Mineral Wool	2	4	-0.5		μ:0.4		(Xie et.al, 2016)
Mineral Wool	4	4.3	0		μ:0.65		(Xie et.al, 2016)
Mineral Wool	6	3.8	0.5		μ:1.2		(Xie et.al, 2016)
Mineral Wool	8	4	0.5		μ:1		(Xie et.al, 2016)
Mineral Wool	10	3.5	0.5		μ:1.1		(Xie et.al, 2016)
Mineral Wool	12	3.7	-0.4		μ:1		(Xie et.al, 2016)
Mineral Wool	14	3.9	0		μ:1.15		(Xie et.al, 2016)
Fiberglass	2.35-5.25	1.02				9.21E-04	(Wilson & Crawford, 2002)

Dielectric properties for gypsum ceiling board and rockwool ceiling board used as suspended ceiling material are given in Table 4.7. In addition to these two, plaster, wood and aluminum given in other tables can also be considered as finishing materials for ceilings.

Table 4.7 Dielectric properties of gypsum and rockwool ceiling boards gathered from 5 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Ceiling board (Gypsum)	1-100	1.48		0.0011	1.075		(ITU-R,2021)
Ceiling board (Gypsum)	220-450	1.52		0.0029	1.029		(ITU-R,2021)
Ceiling Board (Gypsum)	1-100	1.5		0.0005	1.1634		(ITU-R,2015)
Ceiling Tile	2.35-5.25	1.32				1.44E-02	(Wilson & Crawford, 2002)
Ceiling Board (Rockwool)	60	1.5876	0.0126	0.0421		0.00794	(Pinhasi et.al, 2008)
Ceiling Board (Rockwool)	1-100	1.5		0.0005	1.1634		(Rude et.al., 2014)

Dielectric properties for plaster board, which is a dry wall material, are given in Table 4.8 . In addition, dielectric properties for MDF, which can be used in dry wall construction and as roof and floor finishes, are given in Table 4.9.

Table 4.8 Dielectric properties of plasterboard gathered from 7 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Plasterboard	1-100	2.73		0.0085	0.9395		(ITU-R,2021)
Plasterboard	1-100	2.94		0.0116	0.7076		(ITU-R,2015)
Plasterboard	5	2.02	0.05328	5.01E-02		3.27E-02	(Pinhasi et.al, 2008)
Plasterboard	60	2.6	0.0364	0.121		0.014	(Pinhasi et.al, 2008)
Plasterboard	1-100	2.5 to 2.4				0.05 to 0.04	(Zhekov et. al., 2020)
Plasterboard	5.8	2.02		0			(Cuiñas & Sánchez, 2002)
Plasterboard	41.5	2.5		0.24			(Cuiñas & Sánchez, 2002)
Plasterboard (12,8mm)	2.35-5.25	2.19				1.11E-02	(Wilson & Crawford, 2002)
Plasterboard (9mm)	2.35-5.25	2.49				4.25E-03	(Wilson & Crawford, 2002)
Plasterboard + Tiles	2.35-5.25	3.08				5.88E-02	(Wilson & Crawford, 2002)
Plasterboard	1-100	2.94		0.0116	0.7076		(Rude et.al., 2014)

Dielectric properties for wood and wood derivatives are presented in the Table 4.9. The dielectric properties of wood may vary according to the types and the manufacturer. In the table, wood cement board is a composite material made from a mixture of wood wool (excelsior) and cement. Particleboard, also known as high density fiberboard (HDF), is made from small wood fibers and wood pulp. It is strongly pressed and then baked to increase its stability. Medium Density Fiberboard (MDF) is a wood product formed by wax and resin glue under high heat and pressure after shredding leftover hard or soft wood and turning them into wood fiber. Chipboard or particleboard is a material obtained by combining pieces of wood or lignified sawdust with glues and pressing at high temperature. Plywood is produced in sheets by gluing the fibre directions of the papels obtained by peeling the trees crosswise and pressing them under high temperature and pressure. It is used for different purposes in buildings due to its high strength, light weight, robust and water-resistant durability. Floorboard is a long plank making up part of a wooden floor in a building.

Table 4.9 Dielectric properties of wood, plywood, MDF, hardboard and floorboard gathered from 9 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Wood	0.2-4.84	2.5-1.6	0.36-0.25		μ:1	0.144- 0.156	CST MWS Library Data
Wood	0.001-100	1.99		0.0047	1.0718		(ITU-R,2021)
Wood	0.1-10	1.2-4.5		1E-10		0.007- 0.061	(Torgovnikov, 1993)
Wood	5	2.05	0.296	8.23E-02		1.44E-01	(Pinhasi et.al, 2008)
Wood	5	1.65	0.235	6.54E-02		1.42E-01	(Pinhasi et.al, 2008)
Wood	60	1.5	0.09	0.3		0.06	(Pinhasi et.al, 2008)
Wood	60	1.64	1.115	3.72		0.68	(Pinhasi et.al, 2008)
Pine	1-100	2.1 to 1.75				0.10 to 0.08	(Zhekov et. al., 2020)
Fir Lumber	2.35-5.25	2.58				2.00E-01	(Wilson & Crawford, 2002)
Wood	0.001-100	1.99		0.0047	1.0718		(Rude et.al., 2014)
Plainwood	5	2.0687	0.41388	1.38		0.201	(Pinhasi et.al, 2008)
Wood-Cement Board	1-100	6.3 to 5.5				0.08	(Zhekov et. al., 2020)
Hardboard	1-100	3.4 to 3				0.1 to 0.07	(Zhekov et. al., 2020)
MDF	1-100	3.2 to 2.8				~ 0.08 to 0.07	(Zhekov et. al., 2020)
MDF (wt Grey Veneer)	1-100	3.7 to 3.4				~ 0.09 to 0.08	(Zhekov et. al., 2020)
MDF (wt Brown Veneer)	1-100	3.8 to 3.4				~ 0.08 to 0.07	(Zhekov et. al., 2020)
Chipboard	1-100	2.58		0.0217	0.78		(ITU-R,2021)
Chipboard	5	2.88	0.4879	1.36E-01		1.70E-01	(Pinhasi et.al, 2008)
Chipboard	60	2.78	0.1362	0.455		0.049	(Pinhasi et.al, 2008)
Chipboard	1-100	3.2 to 2.8				0.075 to 0.06	(Zhekov et. al., 2020)
Chipboard (Veneer)	1-100	2.9 to 2.8				0.03 to 0.02	(Zhekov et. al., 2020)
Particle Board (19mm)	2.35-5.25	2.7				1.10E-01	(Wilson & Crawford, 2002)
Chipboard	1-100	2.58		0.0217	0.78		(Rude et.al., 2014)
Plywood	1-40	2.71		0.33	0		(ITU-R,2021)
Plywood	1-100	2.7 to 2.4				0.12 to 0.08	(Zhekov et. al., 2020)
Plywood	5.8	2.88		0.16			(Cuiñas & Sánchez, 2002)
Plywood	41.5	1.69		0.54			(Cuiñas & Sánchez, 2002)
Plywood	2.35-5.25	2.47				1.27E-01	(Wilson & Crawford, 2002)
Floorboard	50-100	3.66		0.0044	1.3515		(ITU-R,2021)
Floorboard	60	3.9135	0.32868	1.1		0.084	(Pinhasi et.al, 2008)
Floorboard	50-100	3.66		0.0044	1.3515		(Rude et.al., 2014)

The dielectric properties of air, earth and some metals are given in Table 4.10.

Table 4.10 Dielectric properties of air, ground, and metal gathered from 2 sources (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Vacuum (≈ air)	0.001-100	1		0	0		(ITU-R,2021)
Air	0.1-1	ε:1.00059			μ:1		CST MWS Library Data
Vacuum (≈ air)	0.1-1	ε:1			μ:1		CST MWS Library Data
Very dry ground	1-10 only	3		0.00015	2.52		(ITU-R,2021)
Medium dry ground	1-10 only	15	-0.1	0.035	1.63		(ITU-R,2021)
Wet ground	1-10 only	30	-0.4	0.15	1.3		(ITU-R,2021)
Metal	1-100	1		10,000,000	0		(ITU-R,2021)
Aluminium	lossy	lossy	lossy	3.56E+07	μ:1		CST MWS Library Data
Metal (iron)	lossy	lossy	lossy	1.04E+07	μ:1		CST MWS Library Data

Dielectric properties for aerated concrete, marble, limestone, and ceramic are presented in Table 4.11. Especially considering the production process, added additives can increase the shielding effect of the ceramic. There are also studies on this subject.

Table 4.11 Dielectric properties of aerated concrete, marble, limestone, ceramic gathered from 4 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η"	σ			
Aerated Concrete	0.9-24	5-7	0.1-0.7				(Shah et.al., 1965)
Aerated Concrete	60	2.26	0.1017	0.339		0.045	(Pinhasi et.al, 2008)
Thermalite Blocks	60	2.9396	0.2725	0.91		0.0927	(Pinhasi et.al, 2008)
Marble	1-60	7.074		0.0055	0.9262		(ITU-R,2021)
Marble	60	11.56	0.08092	0.27		0.007	(Pinhasi et.al, 2008)
Limestone	4	7.51		0.03	μ:0.95		(Landron et.al., 1996)
Ceramic Tiles	60	4.01	0.09223	0.308		0.023	(Pinhasi et.al, 2008)
Ceramic Tiles	60	8.58	0.7807	2.61		0.091	(Pinhasi et.al, 2008)

Dielectric properties for PVC, carpet, fabric, linoleum, paint with carbonyl iron, gypsum plaster, and stucco are given in the Table 4.12. PVC is used as wall cladding, suspended ceilings, and joinery, while plaster and stucco are used as wall and ceiling finishing material. The properties of blinds, carpet and fabric given in the table are based on a single study. On the other hand, the dielectric properties of these products can be affected by differences from the material used to the detail of the form.

Table 4.12 Dielectric properties of blinds, carpet, fabric, paint, plaster, and PVC gathered from 4 sources in literature (Compiled by the author).

Material class	Frequency range	Permittivity		Conductivity (S/m)		Tangent delta	References
	GHz	η'	η''	σ			
Blinds (closed)	2.35-5.25	3.49				5.96E-05	(Wilson & Crawford, 2002)
Blinds (open)	2.35-5.25	1.96				5.96E-05	(Wilson & Crawford, 2002)
Carpet (back)	2.35-5.25	1.31				6.69E-04	(Wilson & Crawford, 2002)
Carpet (weave)	2.35-5.25	1.32				5.96E-05	(Wilson & Crawford, 2002)
Fabric	2.35-5.25	1.49				5.96E-05	(Wilson & Crawford, 2002)
Linolium	2.35-5.25	3.08				6.31E-05	(Wilson & Crawford, 2002)
Paint wt carbonly iron	8-12	16	10	4	0		(Folgueras et. al, 2009)
Paint wt carbonly iron & polya	8-12	5.5	1.5	1.2	0.3		(Folgueras et. al, 2009)
Gypsum Plaster	1-100	2.75				0.005 to 0.01	(Zhekov et. al., 2020)
Stucco (25mm)	2.35-5.25	1.07				4.45E-01	(Wilson & Crawford, 2002)
PVC Black	3-6	2.87-2.94	0.1				(Pisa et al., 2017)
PVC White	3-6	2.65-2.70	0				(Pisa et al., 2017)

4.3 EMF Level Measurements

The first part of the assessment was on-site measurements. The results of these measurements are presented separately for outdoor and indoor spaces.

4.3.1 Outdoor In-Situ EMF Level Measurements

The results of outdoor measurements recorded at 4 different locations, which are considered as priority and sensitive locations, are presented in this subsection.

Table 4.13 Results for outdoor EMF level measurements.

Location		EF (V/m)			MF (mG)			RF Power (mW/m2)			Temp.	Hum.
Code	Description	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	C	%
N1	Nursery in Suburban (Source)	5.90	7.42	10.30	276.50	381.49	398.00	0.00	0.01	0.11	34.2	13
N2	Nursery in Suburban (Garden Wall)	3.50	4.84	5.60	3.90	4.14	7.10	0.01	0.05	0.22	34.4	14
N3	Nursery in Suburban (Building Wall)	0.90	6.09	29.40	0.00	3.60	4.40	0.00	0.04	0.65	35.8	14
N4	Nursery in City Center (Garden Wall)	1.10	3.02	6.10	4.70	8.63	15.90	0.00	0.03	1.12	29.7	21
S1	Preliminary School in Suburban (Garden Wall)	4.90	6.44	10.30	172.40	227.63	238.80	0.00	0.00	0.01	34.9	13
R1	Residential in City Center (Garden Wall)	1.80	3.61	4.40	0.20	1.09	2.10	0.05	0.15	0.69	32.1	30
R2	Residential in City Center (Building Wall)	1.50	3.13	4.70	0.20	1.24	1.70	0.08	0.54	2.92	31.8	30

The results of measurements made for 6 minutes at selected points outdoors are presented in Table 4.13. The transformer base station measurement, which itself is considered as a source, is excluded from the evaluation. The average EF strength is above 1V/m and 3V/m in all measurements recorded in suburban and city center buildings. At points N3 and S1, it is above 6V/m. These values are considered excessive for sensitive places where children spend long periods of time. 3V/m is the limit value for schools and hospitals in Turkey. In the literature, 1 - 1.5V/m is the recommended value considering health and applicability.

If we evaluate the MF strength averages considering the Bio-Initiative's 1mG recommendation, all measurements are above this value. When we evaluate the 4mG value, which is associated with childhood leukemia by the World Health Organization, as a limit, we see that the measurements recorded at 3 points are also above this limit. The reason why 2 points in the suburb are above 4mG is the surrounding sources.

Within the scope of this study, the determination of outdoor EMR levels was carried out at a limited number of locations. The measurement results show that improvements are needed. This idea is also supported by various studies in the literature. Beyond this, with the production of an estimation system for cities as Sakacı & Çerezci (2019) suggested, it may be possible to reach an application like BEP-tr, the energy performance application for buildings used in Turkey.

4.3.2 Indoor In-Situ EMF Level Measurements

In the flat selected as a case study, measurements were recorded at sample points shown in Figure 4.1 to determine the current situation. The average results of these measurements are presented on the plan drawing as seen in Figure 4.1 and Table 4.14 Results for indoor EMF level measurements.

In the first 24 measurements, the house electricity was switched off from the fuse box. The electricity was already switched off in the neighboring flat downstairs during the measurements. In the neighboring flat at the eastside in the plan, the electricity is on but there is no user during the measurement period. The minimum, maximum and mean values of the measurements as well as the temperature and humidity values at the time of the measurement can be seen in Table 4.14.

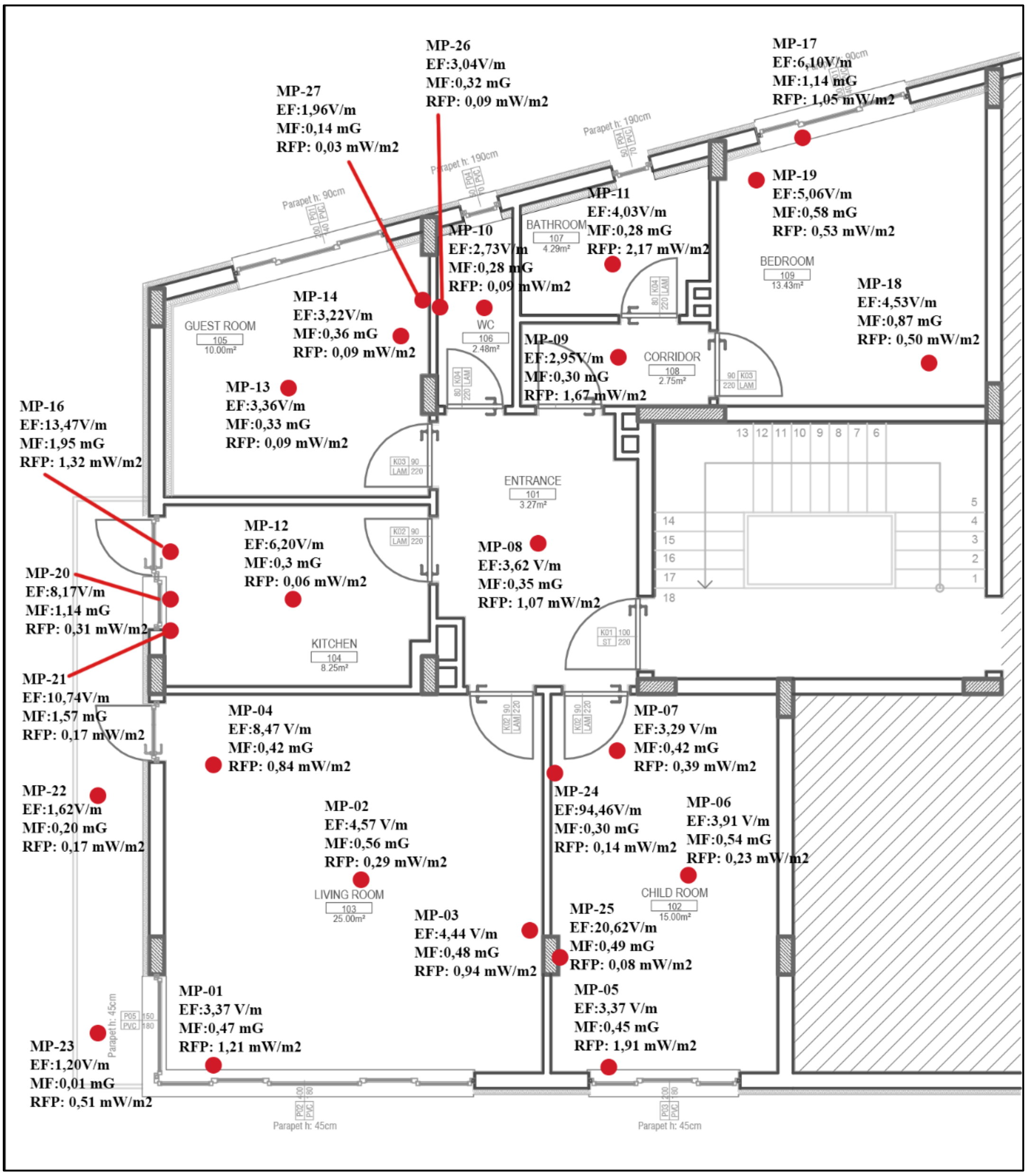


Figure 4.1. Indoor In-situ EMF level measurement points.

EF strength is above 1V/m at all points in the interior of the flat. In addition, 22 out of 25 points have EF strength values above 3V/m. Excluding the wall edges, the highest average value recorded in the occupied area is 8.47V/m and the lowest value is 2.73V/m. Highest value is recorded 20.62 V/m near a wall. If values of 1V/m, 3V/m and 6V/m are used gradually for evaluation, some improvements are also required in this flat.

Again, excluding the wall edges, the highest average value recorded in MF strength measurements is 0.87mG and the lowest average value is 0.28mG. These values are below the bio-initiative recommendation of 1mG. It should also be remembered that no devices were working at home during the measurement. Measurements at the wall edges show average values above 1mG.

Table 4.14 Results for indoor EMF level measurements.

ROOM	EF (V/m)			MF (mG)			RF Power (mW/m2)			Temprature	Humidity	Electricity
point	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	C	%	
MP01	2.70	3.37	4.60	0.30	0.47	0.60	0.67	1.21	2.67	29.5	31	off
MP02	2.70	4.57	7.20	0.40	0.56	0.70	0.04	0.29	2.10	28.5	31	off
MP03	2.70	4.44	6.40	0.40	0.48	0.60	0.03	0.94	2.25	28.2	31	off
MP04	3.10	8.47	12.10	0.30	0.42	0.60	0.01	0.84	1.82	28.3	30	off
MP05	2.30	3.37	4.80	0.30	0.45	0.60	0.64	1.91	22.53	29	30	off
MP06	2.70	3.91	5.10	0.40	0.54	0.60	0.03	0.23	3.21	28.8	30	off
MP07	2.70	3.29	4.00	0.30	0.42	0.60	0.02	0.39	2.95	28.6	30	off
MP08	2.30	3.62	5.60	0.30	0.35	0.60	0.03	1.07	11.35	28	30	off
MP09	1.90	2.95	3.70	0.30	0.30	0.40	0.05	1.67	16.95	27.2	31	off
MP10	2.10	2.73	3.30	0.20	0.28	0.30	0.03	0.09	2.13	27.3	31	off
MP11	1.90	4.03	36.80	0.20	0.28	0.30	0.04	2.17	21.27	26.7	33	off
MP12	3.30	6.20	9.60	0.20	0.30	0.40	0.02	0.06	0.24	27.9	31	off
MP13	2.30	3.36	4.80	0.30	0.33	0.50	0.03	0.09	1.16	28.1	31	off
MP14	2.50	3.22	4.60	0.30	0.36	0.50	0.03	0.09	1.37	28.1	31	off
MP15	2.70	3.26	4.00	0.30	0.41	0.60	1.26	1.73	2.48	28.1	31	off
MP16	8.50	13.47	19.20	1.70	1.95	2.40	0.44	1.32	2.63	27.9	31	off
MP17	4.90	6.10	7.80	1.00	1.14	1.30	0.58	1.05	15.57	28.1	31	off
MP18	3.60	4.53	5.30	0.70	0.87	1.00	0.03	0.50	12.74	28.1	31	off
MP19	3.10	5.06	7.20	0.50	0.58	0.80	0.08	0.53	2.99	28.1	31	off
MP20	4.30	8.17	11.80	0.70	1.14	1.40	0.03	0.31	2.53	28	31	off
MP21	8.30	10.74	13.20	1.50	1.57	1.70	0.04	0.33	1.30	28	31	off
MP22	0.80	1.62	2.40	0.00	0.09	0.20	0.06	0.17	0.65	32	30	off
MP23	0.50	1.20	1.80	0.00	0.01	0.10	0.06	0.51	2.95	32	30	off
MP24	80.10	94.46	110.90	0.20	0.30	0.40	0.02	0.14	2.50	34.7	36	on
MP25	13.30	20.62	30.40	0.40	0.49	0.80	0.01	0.08	1.03	32.9	36	on
MP26	2.50	3.04	3.60	0.30	0.32	0.40	0.01	0.09	9.04	36	38	on
MP27	1.10	1.96	3.00	0.00	0.14	0.20	0.01	0.03	0.09	36.1	36	on

It can be seen that the EF is significantly higher in the MP-24 and MP-25 measurements recorded close to the wall when the power is on. On the contrary, at MP-26 and MP-27 which are 80cm away from exterior wall, the EF value was close to the other measurements in the room. This is due to the electrical wiring passing through the wall where MP-24 and MP25 were measured. Taking this result into account, it is also advisable not to plan electrical wiring at the bedside, even if it is not actively used during sleep.

4.3.3 Indoor EMF Sources

To compare the EMR emission potential of everyday household appliances, measurements were recorded for some devices. The results can be seen from Table 4.15. Among these appliances, dishwasher, TV, microwave oven, washing machine and refrigerator have similar results with the table in the literature (Table 2.3). The values of the computer were measured higher. In addition, combi boiler, Wi-Fi router, printer and hood are presented. Looking at the EF intensity, respectively washing machine, refrigerator, printer, dishwasher, combi boiler, screen, MW oven can be defined as high EF source compared to others. In terms of MF values, combi boiler, computer, MW oven, washing machine, dishwasher and hood can be defined as high MF sources respectively compared to others.

Table 4.15 Results for electrical device measurements.

Source		EF (V/m)			MF (mG)			RF Power (mW/m2)		
Device	**Code**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Printer (Wi-Fi)	**s1**	966.00	1406.95	1953.60	0.70	1.08	1.90	14.64	17.00	20.23
Dishwasher	**s2**	429.30	1368.49	2122.00	7.30	116.13	220.60	0.01	1.35	67.27
Laptop	**s3**	2.70	3.91	36.00	260.70	326.54	351.50	1.25	9.05	19.39
Screen	**s4**	233.80	287.99	359.60	1.00	5.26	14.10	31.99	85.31	567.87
TV	**s5**	3.10	3.60	4.60	1.20	1.83	5.90	1.55	49.43	104.75
Wi-Fi Router	**s6**	2.70	3.51	4.80	0.80	3.38	7.60	79.69	998.04	1148.84
Combi	**s7**	903.30	1267.91	1758.80	312.70	331.08	346.50	0.04	0.31	4.26
MW Owen	**s8**	55.90	172.76	776.30	0.40	295.66	370.20	0.02	211.34	760.91
Refrigerator	**s9**	30.90	1563.26	2122.00	0.50	11.18	13.70	0.00	0.49	42.70
Hood	**s10**	5.50	8.84	29.10	20.10	98.60	121.10	0.13	1.33	2.38
Washing Machine	**s11**	1185.70	1738.95	2181.20	24.80	149.46	283.00	0.02	0.13	2.01

Considering the fact that EF and MF intensity decrease with distance from the source, it would be a reasonable approach not to plan these devices on common walls with children's rooms, which can be defined as sensitive spaces. Similarly, devices for tracking children such as Wi-Fi cameras and baby monitors, which were not measured here, should also be considered as sources of EF and MF. Although children are prioritized due to their sensitivity, a similar principle should be adopted for all bedrooms. In addition to keeping unnecessary electronic devices away from the space during sleep, measures can also be taken against radiation from devices in other rooms and from outside.

4.3.4 Measurements on wall types

The results for measurements on wall types, that performed in real time conditions in an uncontrolled environment inside the house selected as a case study, are presented in this section.

The EMF levels emitted by the microwave oven were measured 3 times in different days at a distance of 3cm. MF strength values were found to be approximately the same each time. It was also observed that the MF strength values emitted by the microwave oven were in a time-dependent cycle. It switches between high and low trend approximately every 15 seconds. Since simultaneous measurements could not be made at the source and probe point, only high trend data were taken into account in order to reduce the margin of error in the evaluation. The same procedure was applied for both source and wall transmittance measurements.

Since the measurements were made in an uncontrolled environment, the shielding effectiveness calculation could have led to misleading results. For this reason, the evaluation was based on the transmission percentage calculation in order to compare the measured wall types among themselves. Since the wall types here are also present in parametric SE simulations, it is also possible to compare the values defined in the simulation with real-life materials.

Table 4.16 Results for measurements on wall types.

Measurement Point Code		Mean MF (mG)	Mean MF (mG) without source	Wall Thickness (cm)	Distance Btw. Source and Probe (cm)	Calculated TC %	Temperature (°C)	Humidity (%)
W07	**PpBw1Pp**	329.24	0.70	15	18	95.90%	32.5	26
W08	**PpBw1Cr**	335.22	0.70	15	18	97.64%	30.1	31
W09	**CrBw1Pp**	335.87	0.55	15	18	97.83%	30.8	28
W10	**AsEsAsPpBw1Pp**	306.77	0.70	20	23	89.35%	31.7	28
W11	**PpEcPpBw1Pp**	313.68	0.70	18	21	91.37%	31.9	29
W12	**PpXsPpBw1Pp**	306.33	0.70	18	21	89.23%	32.5	26
W13	**PpEsPpBw1Pp**	319.99	0.70	20	23	93.21%	31.8	28
W14	**PpEcPpBw2Pp**	136.75	0.53	31	34	39.83%	26.7	29
W15	**PpBw2PpEcPp**	136.10	0.59	31	34	39.64%	31.1	26
W21	**PpCw2Pp**	170.16	1.19	25	28	49.56%	31.8	28
Free Space 3cm		343.31	0.4	no wall	3cm	NA	29.6	28

MF strength and transmission percentage values can be seen from Table 4.16 where the temperature and humidity values at the measurement points are presented.

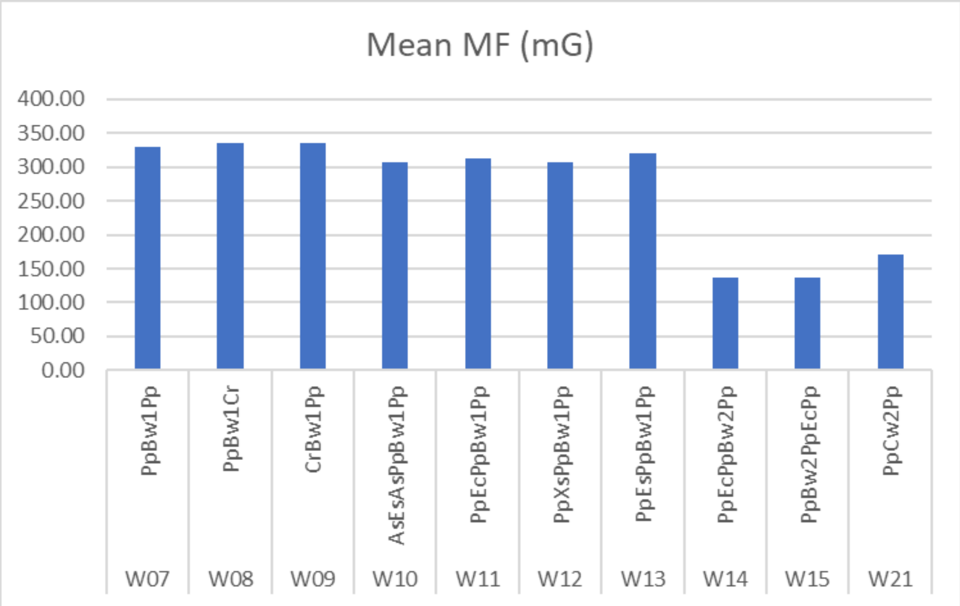


Figure 4.2. Comparison of the results for measurements on wall types.

A comparison between cases W8-W9 and W14-W15 shows that the order of the wall layers with respect to the source direction does not affect the transmission percentage. Approximately the same values were measured in these pairs.

When W07 and W08 are compared, it can be interpreted that plaster wall cladding provides more shielding than ceramic wall cladding as seen in Figure 4.2.

Looking at W11, W12 and W13, although they have similar values, XPS offers more shielding than carbon EPS and white EPS. Carbon EPS is seen to have more shielding capability than white EPS, although its thickness is less than that.

A comparison of the W14 with the W12 shows that the increase in wall thickness makes a significant contribution to shielding capability.

The plastered and painted reinforced concrete wall examined in W21 is not exactly a comparable case. Since reinforcements are not added in the simulations, it is not possible to compare it with simulation cases, but the difference in effect between it and the unreinforced concrete wall in the simulation will be observed.

4.4 Validation for simulations

Before starting the comparisons on the simulations, the model of the room selected as a case study was prepared in the CST-MWS environment. Since EF data for base stations has been provided by BTK, EMF Meter has been validated by comparing the EF strength data. Similarly, the validation of simulation results and on-site measurement values were also done based on EF strength values.

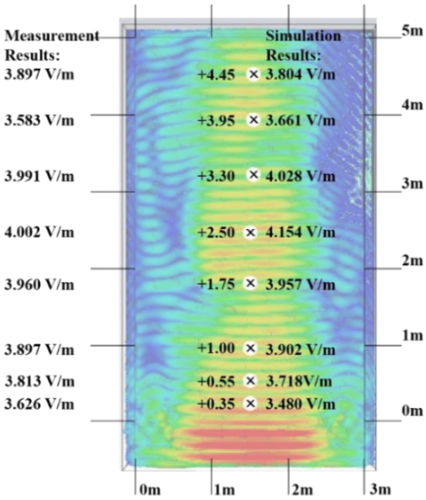


Figure 4.3. Sample points for EF level measurements and simulation comparison.

Simulation results were obtained at the same points with measurements made at 8 different depths inside the room as seen from Figure 4.3. When the results were compared, the margin of error was found to be between 0.09% to 4.02% as shown in Table 4.17.

Table 4.17 Comparison of indoor EF strength measurements and simulation results.

Sample Points Depth	Measurement Results	Simulation Results	Error Percentage
Meters	V/m	V/m	%
0.35	3.62594	3.48035	4.02%
0.55	3.81255	3.71842	2.47%
1.00	3.89708	3.90231	0.13%
1.75	3.96042	3.95667	0.09%
2.50	4.00209	4.15363	3.79%
3.30	3.99125	4.02758	0.91%
3.95	3.58286	3.66109	2.18%
4.45	3.89749	3.80409	2.40%

4.5 Simulation results

Simulation studies, the second part of the EMR Level assessment, were run both to calculate the parametric shielding effectiveness results for wall types and to measure the effect of architectural design parameters in space, by simulating a model of the room selected as case study.

4.5.1 Parametric simulations on wall samples

The results of parametric simulations on wall samples under controlled conditions in the simulation environment are presented in this subsection. In addition, the results of all cases can be seen in Appendix D as a color map in plan, section, and point cloud. The shielding efficiency of materials is frequency dependent. So, it is possible to observe the shielding effectiveness of wall types (Table 3.1) at frequencies between 750 Mhz and 10GHz by these parametric simulations on wall samples. In the Space simulations, results could only be presented at 1GHz because more advanced computers are required to calculate higher frequencies. By the help of results presented in this subsection, it will be possible to comment on frequencies higher than 1GHz for wall types when evaluating the space simulations.

In the first 3 cases, 10 cm thick aerated concrete, brick and concrete walls were evaluated as exposed. The concrete wall is not defined as reinforced in the software and this is a point that should be considered during the evaluation.

As seen in Figure 4.4, aerated concrete presents a SE value close to zero, while concrete presents an SE value of about 2 dB and brick presents an SE value of about 3dB at 1GHz frequency. This is important to understand the results of space simulations.

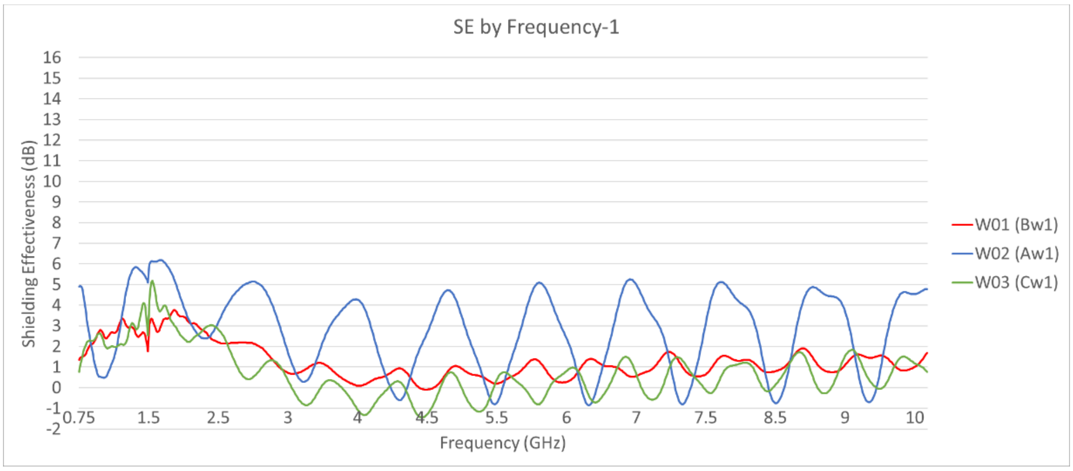


Figure 4.4. Results for parametric simulations on wall sections – group 1.

On the other hand, in the overall frequency spectrum, the wavy graph of aerated concrete wall (W02) presents values up to 6dB and its trend is higher than that of brick. At a frequency of 1.9GHz, the brick wall (W01) offers an SE value reaching approximately 4dB. After 2.5GHz, the SE value is variable in the range of 0-2dB. Concrete wall (W03) presents maximum SE value at 1.5GHz frequency, while its general trend is weak compared to other materials. Although a concrete wall will present higher SE when it is reinforced in real life conditions.

W04, W05 and W06 are 20cm thick versions of the walls in the first 3 cases. As can be seen from Figure 4.5, increasing the wall thickness for all materials increased the shielding effectiveness in all frequency ranges. When 20cm walls are considered, the slopes of the materials with respect to frequencies are relatively similar to the slopes in 10cm walls. Although the high values of the aerated concrete wall are higher than the brick wall, the trend of the wavy graph is below the brick wall at 20cm. The concrete wall offered the least SE compared to the other two.

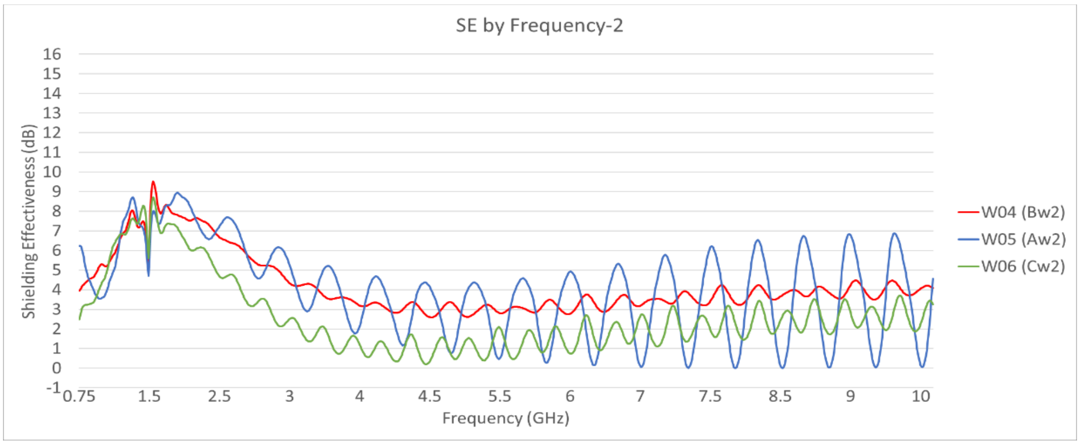


Figure 4.5. Results for parametric simulations on wall samples – group 2.

In the case where both sides of the brick wall are covered with plaster and paint (W07), there is generally a minimal contribution to SE compared to the exposed brick wall (W01) as seen in Figure 4.6. In some frequency ranges, such as in the 6GHz-7.5GHz range, there is a decrease in SE. At 1GHz, the SE of W07 is 2dB while that of W01 is 2.8dB. This should be considered when evaluating space simulations. Instead of this frequency specific negative effect, plaster and paint cladding will provide a positive effect in most of the other frequencies for SE.

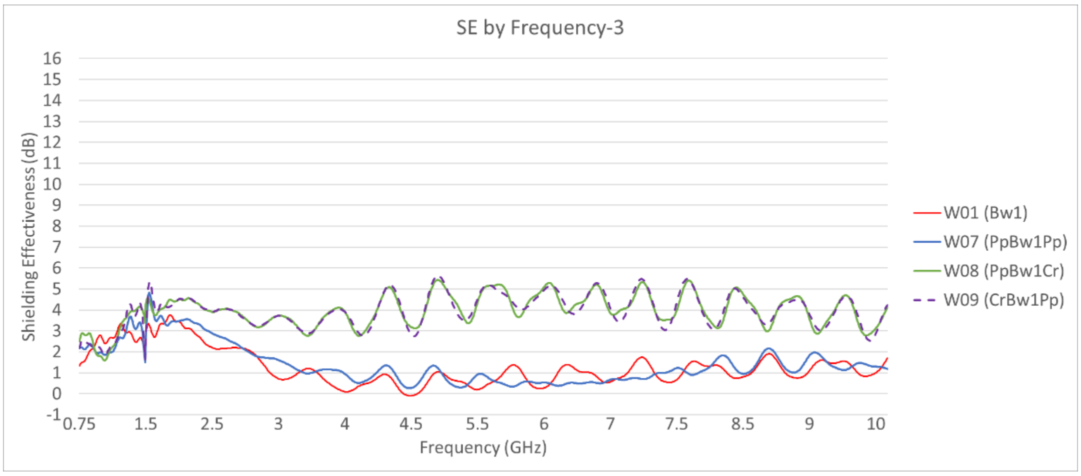


Figure 4.6. Results for parametric simulations on wall samples – group 3.

As can be seen from Figure 4.7, the ceramic wall cladding has a positive effect on the SE. The highest SE (5.5dB) was reached at 5GHz for the wall (W08/W09) covered with ceramic on one side and plaster and paint on the other side.

It is seen that the results of the case where the ceramic coating is in the direction of the radiation source (W08) and the case where it is in the opposite direction (W09) present similar values in most of the frequencies. As mentioned in the previous subsection, the results of the on-site wall measurements support this conclusion.

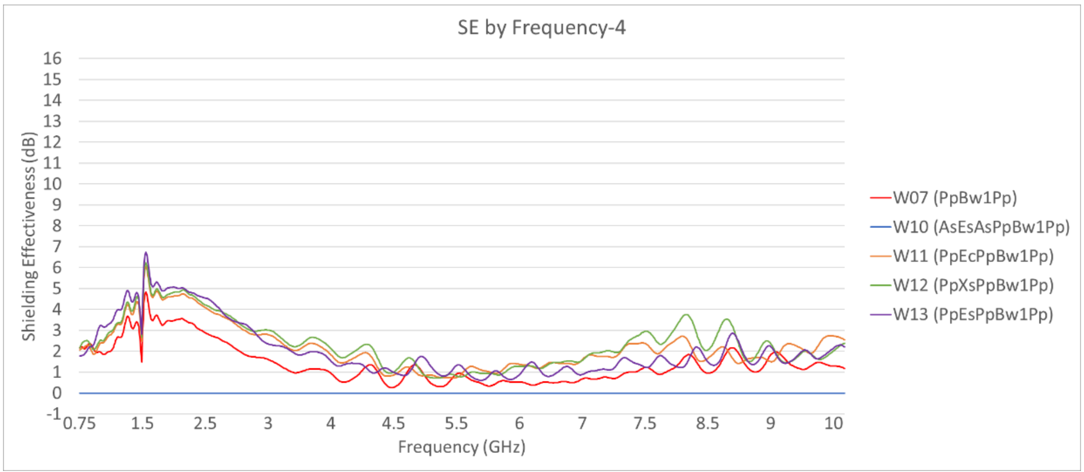


Figure 4.7. Results for parametric simulations on wall samples – group 4.

The ceramic-coated wall in C8 and C9 seems to offer higher SE than the plaster-painted wall in C7. The opposite was the case in the on-site measurements. This difference can be explained by the dielectric properties of the ceramic defined in the simulation. The ceramics in the literature and the ceramics subject to on-site measurements may not have the same dielectric properties. It should be noted that the ceramics used in the simulation have flat surfaces while the ceramics on the wall used in the on-site measurement have wavy surface.

For the 1GHz frequency, there is a difference of 0.4dB between them (W09>W08). This should be considered when evaluating the space simulations.

In the case (W10) where the aluminum sandwich panel placed on a brick wall plastered on both sides, the receiver (probe) measured a zero value. So, SE cannot be calculated for this case, but it is much higher than the other cases. A similar result could not be obtained in the on-site measurements, but it is possible that an accurate assessment could not be made because the aluminum sandwich panel sample used in the measurement did not completely cover the front of the MW oven. Up to 2.8GHz frequency, the SE of the wall with 5cm EPS insulation (W13) is higher than the wall with 3cm carbon EPS insulation (W11) and the wall with 3cm XPS insulation (W12). The results of the on-site measurements were different. XPS offered the best shielding, followed by W11 and W13. This difference may be due to the difference between the dielectric values obtained from limited sources in the literature and the dielectric values of the materials used in the measurement. Looking at the overall frequency spectrum from Figure 4.7, all three cases (W11, W12, W13) present higher SE than the uninsulated wall. Beyond 3GHz, W12 offers the highest SE, followed by W11. W13 offers a lower value than them. All three insulation offer the highest SE at 1.5GHz (approximately 6.5-7dB). At 1 GHz, W11 and W12 have similar SE value (2.5dB). W13 is higher than them (3.2dB).

The case where 6cm thick carbon EPS was added to a 20cm thick brick wall covered with plaster and paint on both sides was examined when the EPS was both in the direction of the radiation source (W14) and in the opposite direction (W15). These cases give similar results for all frequencies in between 0.75GHz-10GHz as seen from Figure 4.8. The direction of the insulation did not significantly change the shielding effectiveness.

The SE values obtained when PVC (W18), Timber (W17) and marble (W16) finishing are used instead of plaster and paint coating on the face of the same insulated wall in the direction of the radiation source are higher than plaster and paint finishing.

Comparing this trio at 1GHz, W16 offers the highest SE (14dB), while the other two offer lower and similar SE (8dB). At frequencies beyond 3GHz, on the other hand, W18 offers higher SE than the other two. The SE of W16 and W17 varies with frequencies. So, when running space simulations at 1GHz, a marble-clad wall is expected to give better results, but it is important to remember the situation at other frequencies when evaluating.

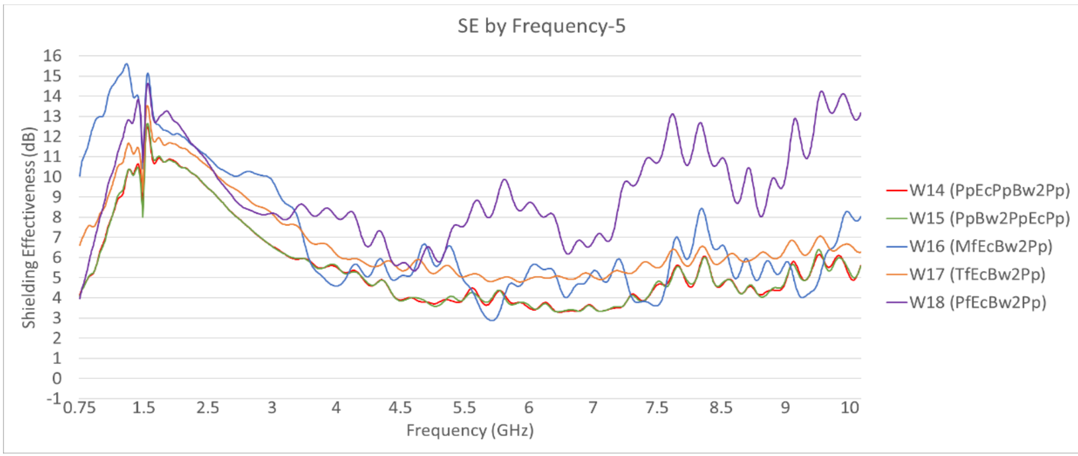


Figure 4.8. Results for parametric simulations on wall samples – group 5.

When the 20cm brick wall of W14 examined above is replaced with 20cm thick aerated concrete (W19) or concrete (W20), it is examined how it performs with insulation wall layers. In terms of insulation layers, concrete wall shares the highest SE values in the group with brick wall up to 3GHz, while it presents the highest values after 3GHz as seen in Figure 4.9. This is a notable result considering the comparison between exposed walls. Brick wall with insulation layers also shows better results than aerated concrete wall. Evaluating the materials individually and evaluating the layers as a whole, as they are used in buildings, presented different results.

When looking at the concrete wall (W21), which is covered with only plaster and paint on both sides without EPS insulation layer, the effect of carbon EPS insulation board can be clearly seen. There is an average difference of 4dB at all frequencies between the case with and without EPS insulation while it was 2dB in between 20cm exposed concrete wall (W6) and 20cm exposed brick wall (W4). On-site measurements showed that W21 offered better results than W7 and W13. The same situation is observed in the simulation results. In the measured results, the shielding capability of the reinforced concrete wall seems to be higher. This can be explained by the fact that reinforcement is defined in the simulation.

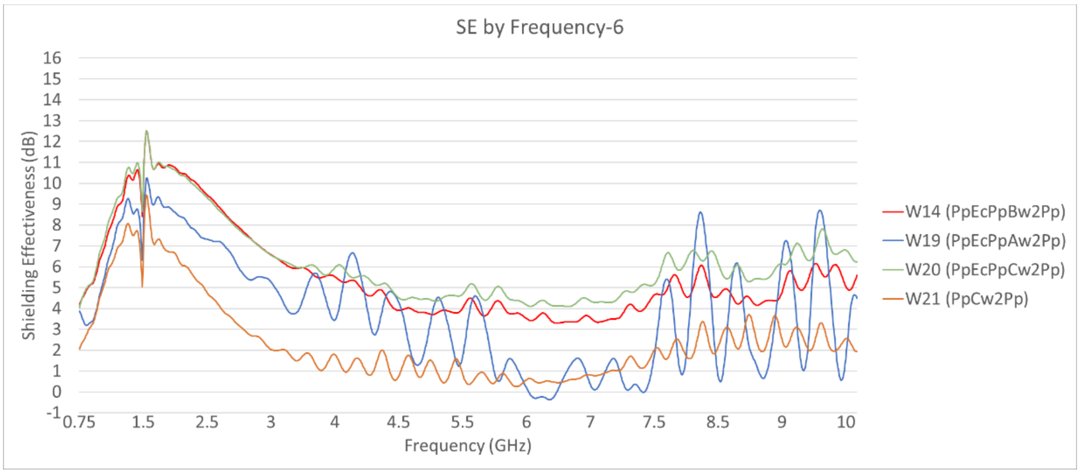


Figure 4.9. Results for parametric simulations on wall samples – group 6.

In case W22, representing the dry wall, plasterboard was used, while in case W23 MDF was used. In these two cases, which present a completely different wall system from the other cases, the thickest layer is 10cm mineral wool. Although these two cases present similar results, the SE is lower at all frequencies compared to the insulated brick wall (W14) as seen from Figure 4.10. The SE obtained is also low compared to the exposed brick wall. It can be said that the dry wall system is weak in terms of shielding effectiveness. It is also important to remember here that the water content in the materials contributes positively to shielding.

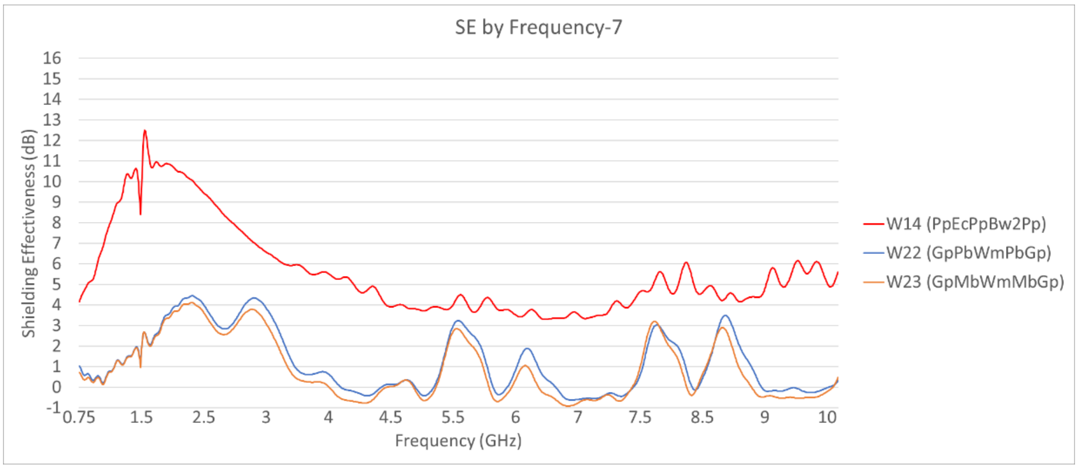


Figure 4.10. Results for parametric simulations on wall samples – group 7.

Looking at W24, W25 and W26, which examine the slab layers, frequency sensitive changes are observed. At the 1GHz frequency at which the space simulations were performed, the case with the marble floor finishes (W26) presents about 5dB SE, while the cases with the floorboard (W25) and ceramic coating (W24) present lower SE than the exposed concrete floor (W03) as seen from Figure 4.11. Looking at the frequencies as a whole, it can be seen that the case with ceramic coatAluing generally offers better SE than the others.

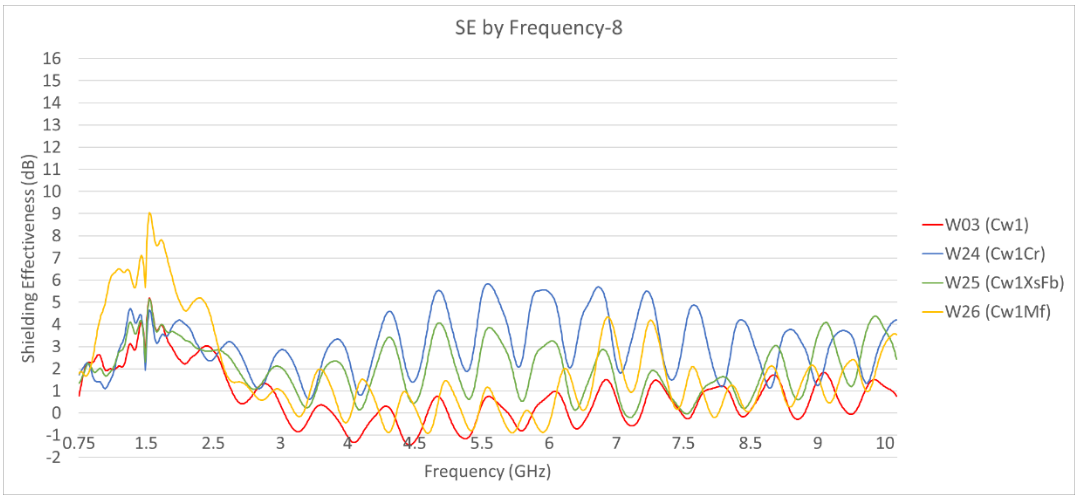


Figure 4.11. Results for parametric simulations on wall samples – group 8.

It can be seen that all suspended ceiling finishes offer better SE results compared to exposed concrete slab (W03). In the simulation with aluminum suspended ceiling (W28) before all cases, SE could not be calculated because the probe measured zero, but it is much higher than all other cases. Aluminum, as a metal, offers a strong shielding incomparable to other building materials due to its electromagnetic reflectivity.

Then, PVC, timber and plasterboard suspended ceilings offer the highest SE values respectively as seen from Figure 4.12. This ranking applies to almost all frequencies. The SE of the case with PVC suspended ceiling reaches 12.1dB at 1.5GHz and 14.4dB at 9.6GHz.

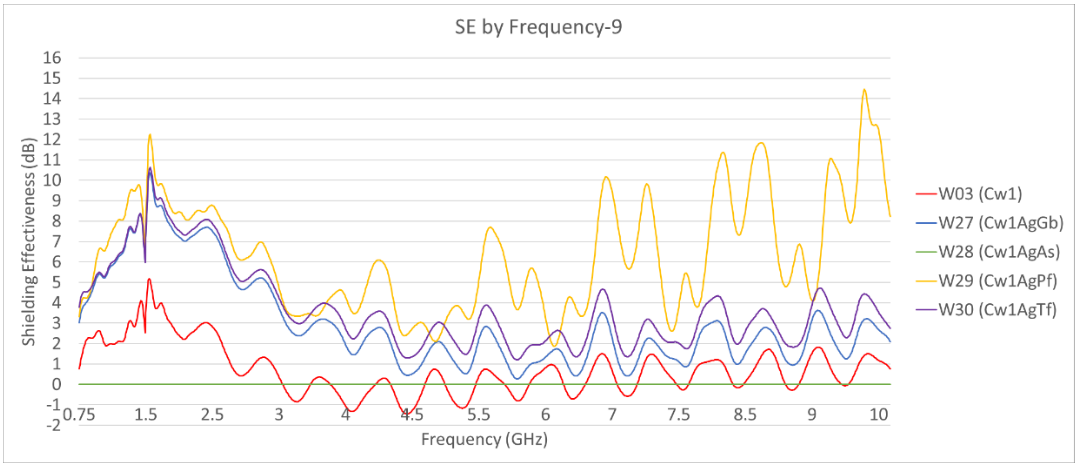


Figure 4.12. Results for parametric simulations on wall samples – group 9.

4.5.2 Simulations for architectural design parameters

Simulations were run for 50 different cases to observe the effects of architectural design parameters on indoor EMR levels. The comparative results of these cases are presented in this subsection.

As defined before, EMR is EM waves composed of electric and magnetic fields which transport energy and momentum at the speed of light through space or material medium. As Prof. Feynman (2011) points out there are EF and MF at every point in space and we associate the EF strength (E) and MF flux density (B) vectors with each singular point in space. Since E and B values vary depending on the time for the selected point (Feynman, 2011) , we measure the vector value at time t at a point of our choice. Considering this complexity, the evaluation of architectural spaces needs to be simplified. In other words, it is impractical to control each point in space independently considering the density of points in space in architectural design. Adverse health effects due to excessive EMR exposure depend on the intensity, frequency, and duration of exposure. From an architectural point of view, the volume of interest should be spaces that can be accessed and occupied by users during a long period of time. For this reason, this study focuses on sleep activity and studies were conducted for a plane 70cm above the ground. In general, it may even be possible to classify architectural spaces according to their function based on the definitions of 6 minutes and 30 minutes of exposure time mentioned in the literature. Such a classification also requires a detailed study of user behavior, which is difficult to predict.

4.5.2.1 Changing wall thicknesses:

As seen from Figure 4.13, the EM power density strength in the interior decreases as the wall thickness in the source direction increases. This decrease is seen both at the maximum value and as a decrease in the area above 0.1 W/m2. In C3, while the wall is 10cm, almost all occupied areas inside are above 0.1W/m2. In C1, when the wall is 20cm, the red zone has decreased, and in C2, when the wall is 30cm, almost the entire occupied area is below 0.1W/m2.

On the other hand, C4 and C5 examined the results if the thickness of the walls of the chamber other than the source direction is also increased. If we compare C4, where the thickness of all walls is increased to 20cm, with C1, we see that the maximum value decreases from 0.177W/m2 to 0.162W/m2. Similarly, the area covered by values above 0.1W/m2 is also diluted. We can see a similar relationship when we compare C5 and C2 where all walls are increased to 30 cm. In these examples there is no cladding on the brick walls. In cases where reflectivity is more effective than absorption, increasing the thickness of the walls behind may also have a negative effect.

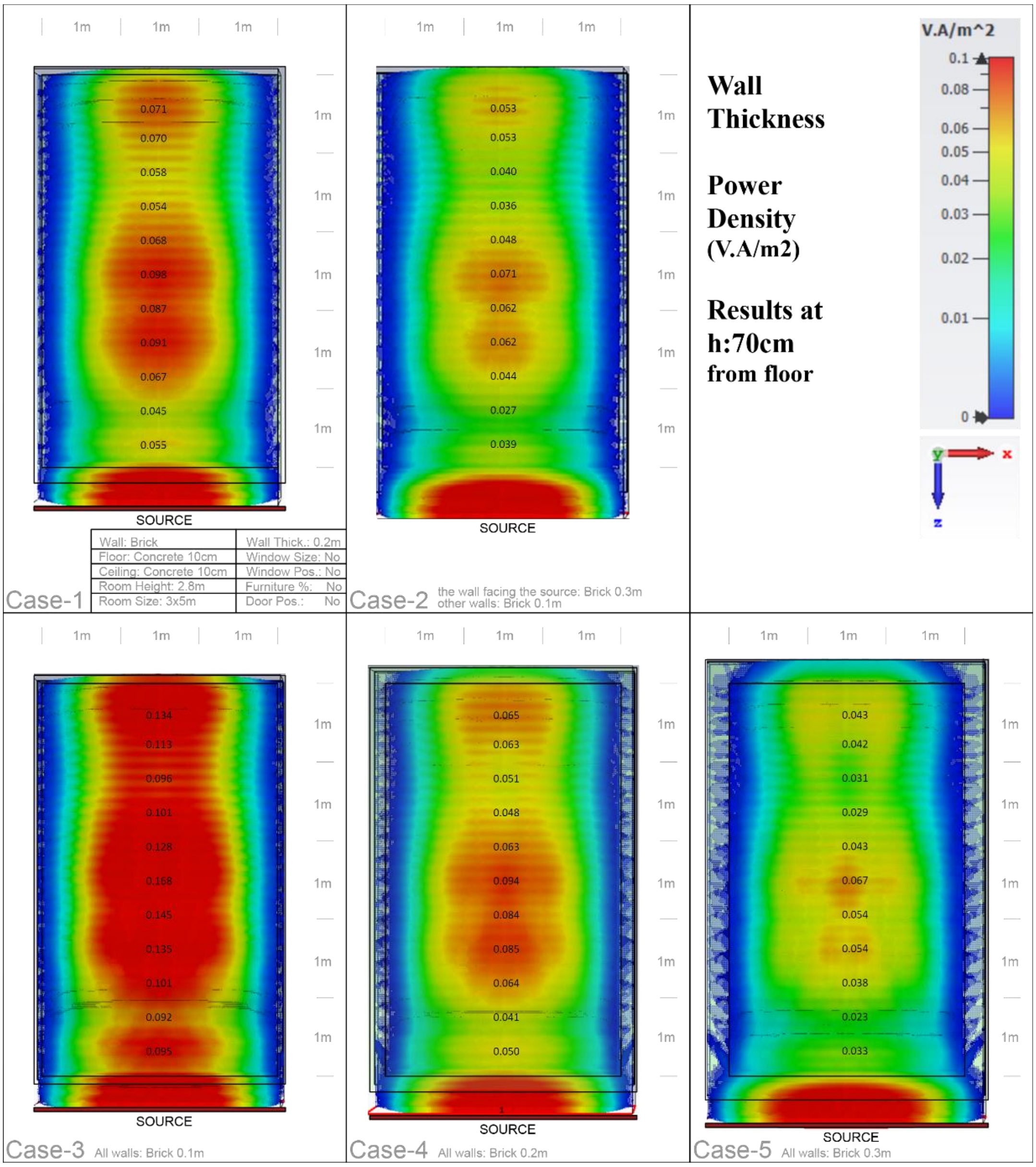


Figure 4.13. EM Power density results for wall thicknesses.

As can be seen from Figure 4.14, the highest shielding efficiencies were achieved within the first 1m and between 3-4.5m. In C5, where all walls are 30cm thick, 6dB is reached, while in C2, where only the wall in the direction of the radiation source is 30cm, the highest value is 5.4dB. The average difference between these two is 1 dB.

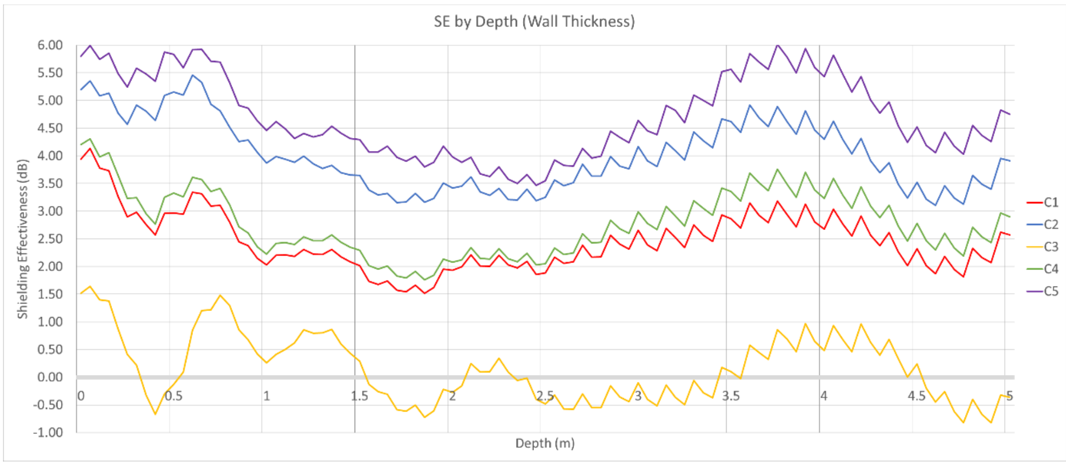


Figure 4.14. SE results by depth for wall thickness.

The difference between C4 where all walls are 20cm and C1 where only the wall in the direction of the radiation source is 20cm is 0.5dB on average. The average difference between the 20cm thick wall and the 30cm thick walls is around 3dB. Considering these differences, it is clear that the thickness of the wall in the source direction has a greater effect than the thickness of the back walls. In C3, where all walls are 10cm thick, the SE becomes negative at some depths.

In summary, when this group, where wall thickness is considered as a variable, is examined, it is possible to say that increasing the wall thickness offers a healthier space indoors in terms of EM power density strength.

4.5.2.2 Changing wall materials:

In C6 with plaster and paint applied over brick on the wall in the direction of the source, a negative result is observed compared to C1 with only brick as seen in Table 4.14. This is an unexpected result considering that the core material and its thickness are the same. As mentioned in previous section presents parametric results for wall types, in the range 0.9-1.4GHz, the plastered wall offers less shielding effectiveness compared to the exposed wall. At C6, the highest SE is 3dB as seen from Figure 4.16. At other frequencies, such as 2.4GHz, it shows better shielding effectiveness. Therefore, it should be noted that this result is specific to the 1GHz frequency.

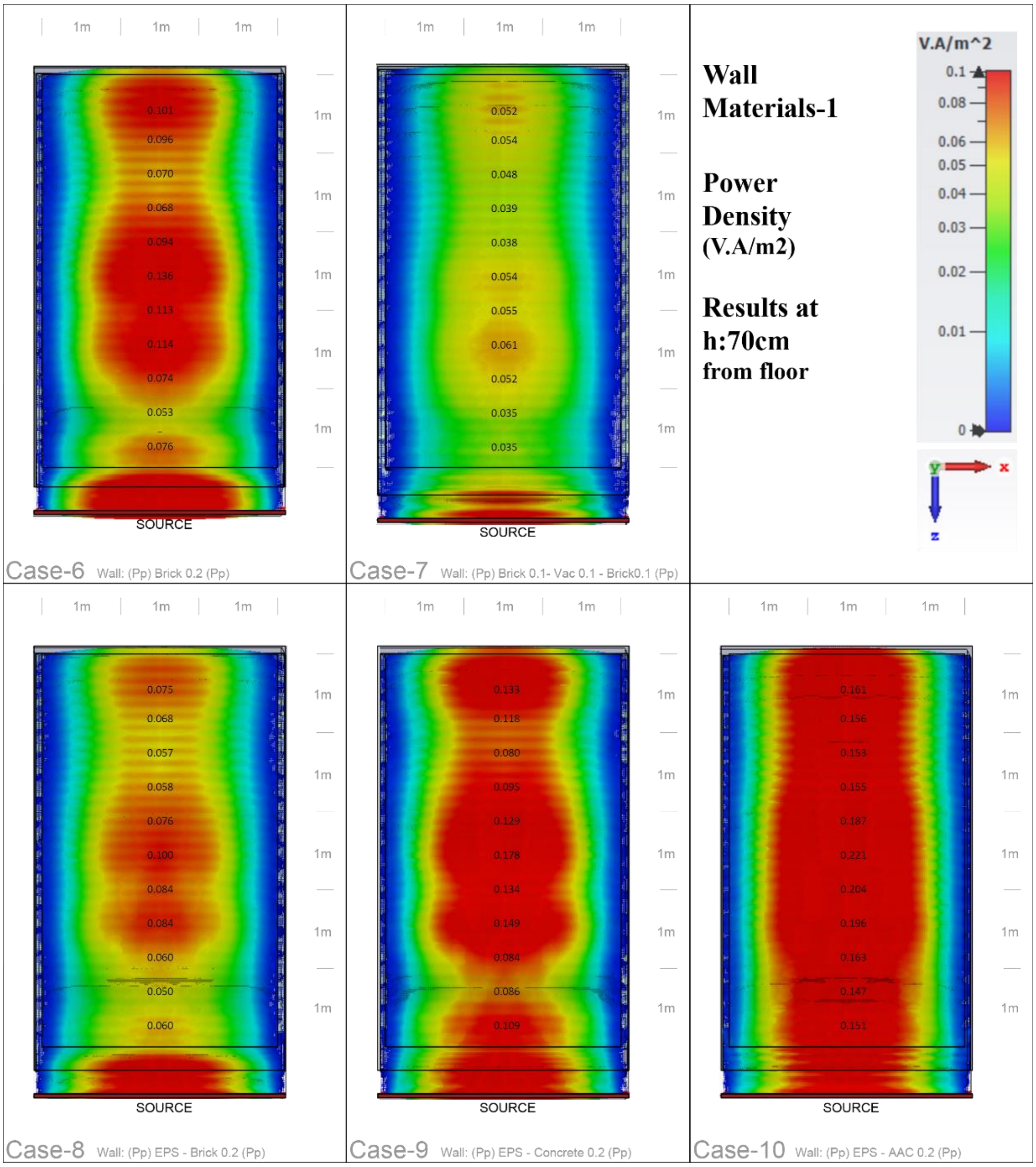


Figure 4.15. EM Power density results for various wall materials (C6-C10).

In C7, which is obtained by leaving a 10cm air gap between two 10cm brick walls and finishing the 30cm core with plaster and paint, a more positive result is observed compared to C2, which is a 30cm exposed brick wall. There was a decrease in EM power density strength values especially in the center of the room. In this case, SE reached 5.5dB as seen from Figure 4.16. Therefore, it can be said that it is useful to design a system detail by leaving a 10cm air gap between 10cm brick walls instead of 30cm brick walls.

When we compare C8, which is plastered and painted on 20cm brick and 6cm EPS, with both C6 and C1, it is observed that EPS makes a positive contribution to the EM power density strength distribution in the interior. At C8, the highest SE is 3.3dB.

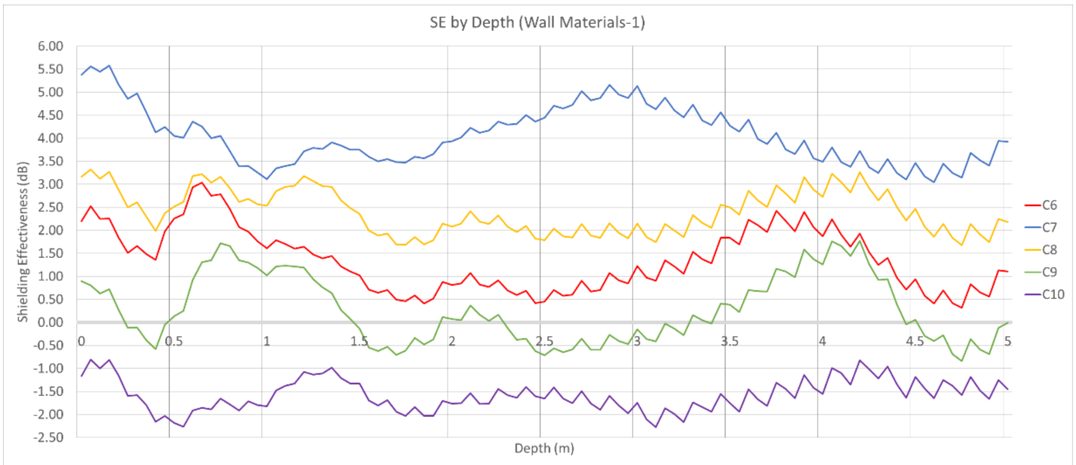


Figure 4.16. SE results by depth for wall materials – 1.

Compared to C8, concrete was used instead of brick core in C9 and AAC was used in C10. At C9 the highest SE is 1.75dB and at a depth of 1.5-3.5 m the SE decreased to negative. When we compare C9 with C8, we see that the area above 1W/m2 increases significantly as seen from Figure 4.15. This is an expected result between 1-10GHz due to the dielectric properties of brick and concrete. On the other hand, it should be remembered that reinforcements could not be added to the concrete wall within the scope of this study. In the literature, it is stated that the SE of the reinforced concrete wall increases depending on the mesh density of the reinforcement.

At C10, it is seen that the entire occupied area exceeds 1W/m2 almost as if there is no wall. This result is specific to the 1GHz frequency. The shielding effectiveness of the AAC wall fluctuates in the range of 1-10GHz. At some frequencies it offers higher SE than a brick wall, while at others it offers lower SE. When we look at the trends, it is below the brick wall. It is noteworthy that while the aerated concrete wall provides around 4dB SE at 1GHz in the simulation with the wall piece, the results in the space simulations are negative. In the simulations with the wall piece, the back of the wall is open, while in the space simulations, the back of the wall is closed with 10cm thick brick walls. It can be interpreted that these walls prevent the exit of the radiation entering the interior.

Looking at the cases where mineral wool (C11) and XPS (C12) were preferred instead of EPS insulation board compared to C8, it was seen that XPS offers on average 0.2dB better SE compared to EPS as seen from Figure 4.17. The values for these two cases are quite close to each other, with XPS reaching a maximum of 3.5dB. Mineral wool, on the other hand, offers SE above 4dB in the first 1 meter and 2-4m range.

Looking at the cases where marble (C13) and timber (C14) facade cladding were preferred over plaster and paint cladding compared to C8, it was seen that timber offers 0.8dB better SE on average compared to plaster and paint. Marble offered higher SE at 1GHz frequency with results reaching 6dB. Also, power density strength values are decreased in the plane as seen from Figure 4.18 At this point, it is necessary to remember the parametric simulations performed on the wall piece. Depending on the frequency of focus, marble may also offer lower shielding effectiveness.

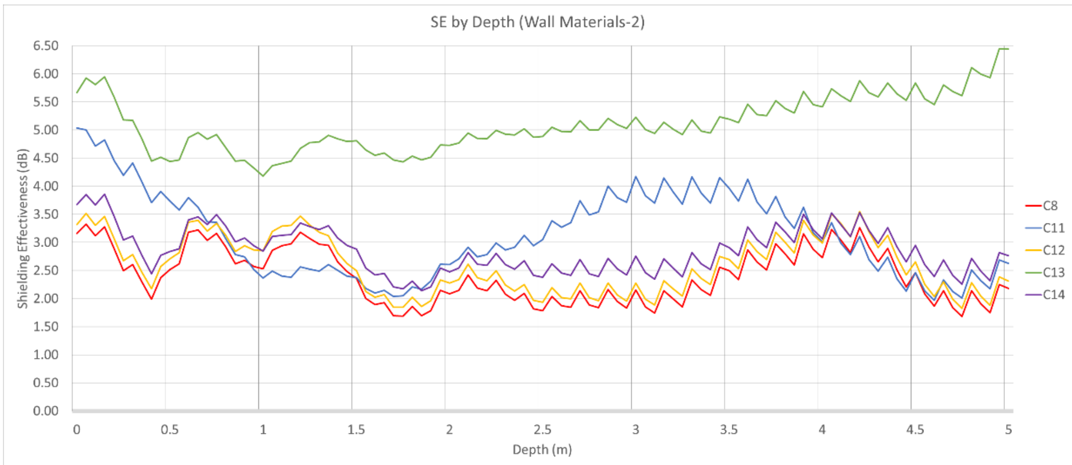


Figure 4.17. SE results by depth for wall materials – 2.

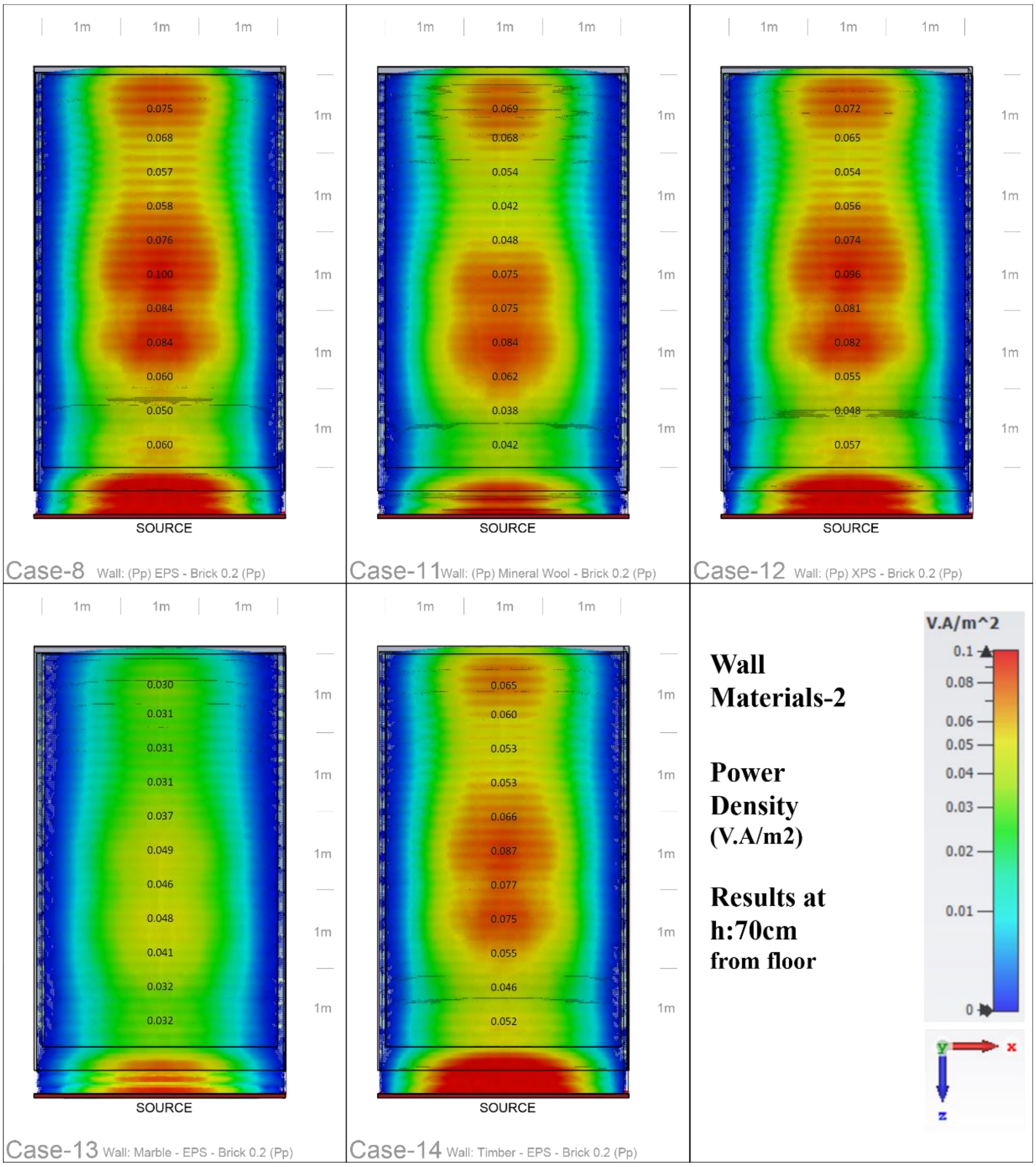


Figure 4.18. EM Power density results for various wall materials (c11-c14).

Looking at the cases where ceramic wall cladding is preferred in the direction opposite to the radiation source (C15) and in the direction of the ceramic wall cladding radiation source (C16) instead of plaster and paint finish compared to C8,; C15 offers poorer SE than plaster and paint finish, while C16 offers on average 2dB better SE.

At this point it is worth recalling that the simulation on the wall piece. Although this is the case for the 1GHz frequency, across all frequencies between 1-10GHz, the ceramic coated wall presents a similar graph regardless of the direction the ceramic is applied on, which on average shows a 4dB higher SE compared to the brick wall. Space simulations for higher frequencies can be performed using more advanced computers or with greater facilities in the laboratory. The results presented here are for the 1GHz frequency and further work is needed for other frequencies.

The highest SE is 3.3dB in C17, where PVC coating is preferred instead of plaster and paint coating on the exterior. In the Figure 4.19, the C17 façade also shows lower shielding effectiveness after 1m compared to the C8 with plaster and paint coating. This is again specific to the 1GHz frequency.

As seen in the simulation with the wall piece, it shows better SE performance compared to other cladding materials (except aluminum), especially at frequencies above 3GHz. C18, which represents a dry wall system made of plasterboard and mineral wool, has a negative impact (-3dB) on the space and increases the values over 0.01W/m2 in the whole space as seen from Figure 4.20. It can be concluded that the dry wall system is not a reasonable choice for EM shielding.

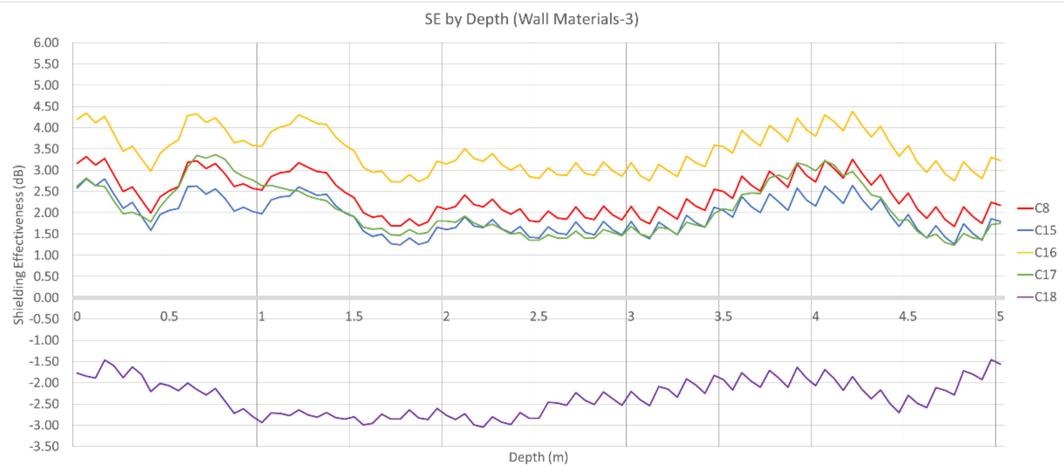


Figure 4.19. SE results by depth for wall materials – 3.

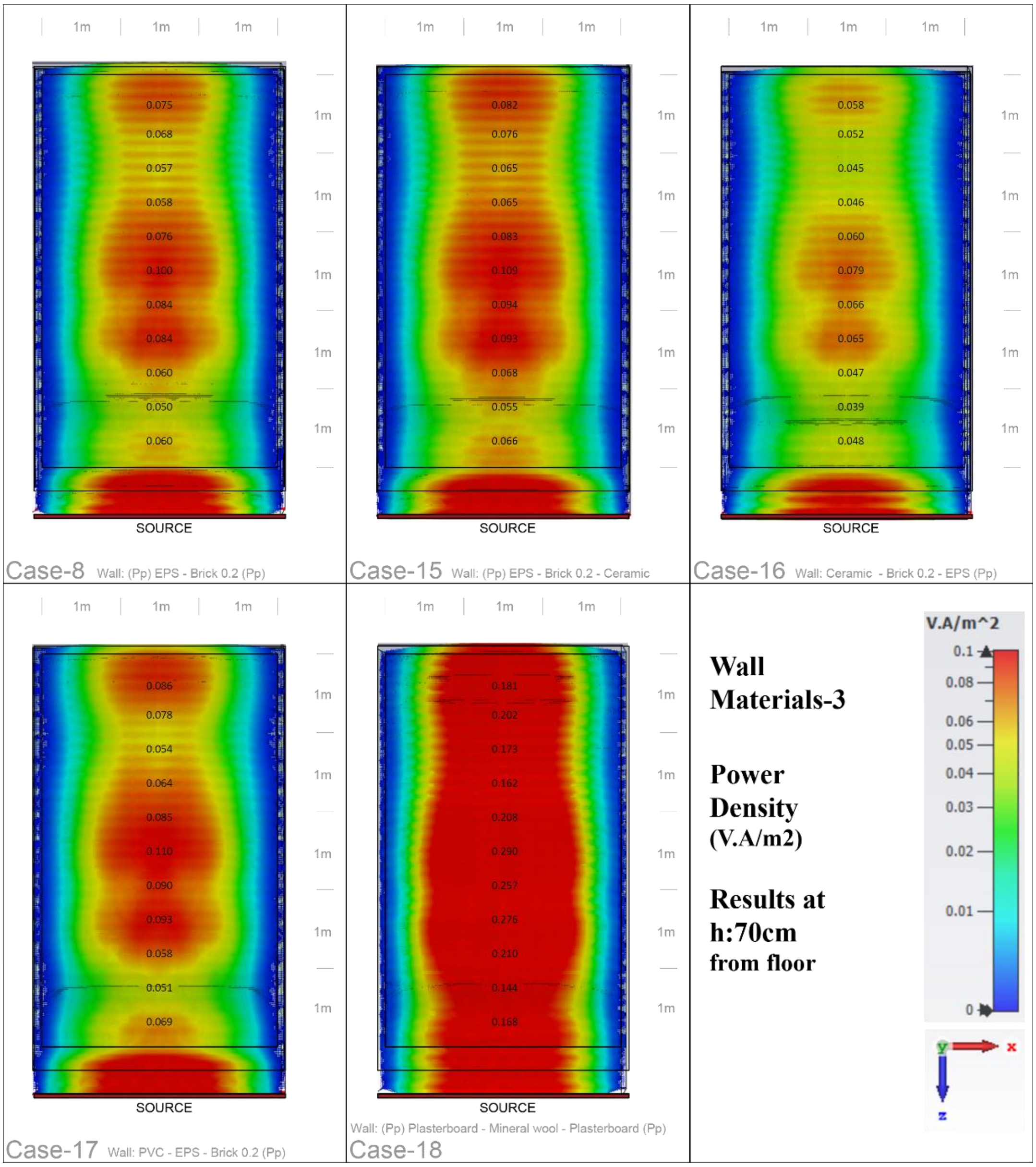


Figure 4.20. EM Power density results for various wall materials (C15-C18).

4.5.2.3 Changing floor finishing materials:

When analyzing the change in floor finishing, it is important to remember that the floor finishing are not directly facing the radiation source in the simulation environment. Only the effect of EM reflectivity or absorptivity of the materials as an internal surface is observed in the simulations. In real life situations, the radiation affecting a room will not be coming from one direction but from different directions. From this point of view, the shielding effectiveness of the flooring layers can be examined from the simulations on the wall piece presented in the previous section. When the cases with carpet (C19), wood floorboard (C20) and ceramic (C21) floor finishings are compared to exposed concrete flooring, all these cases show similar results as presented in Figure 4.21. C22, which represents the case with marble floor finish, shows a lower SE in the first 2m depth and a higher SE in the last 2m depth as seen from Figure 4.22.

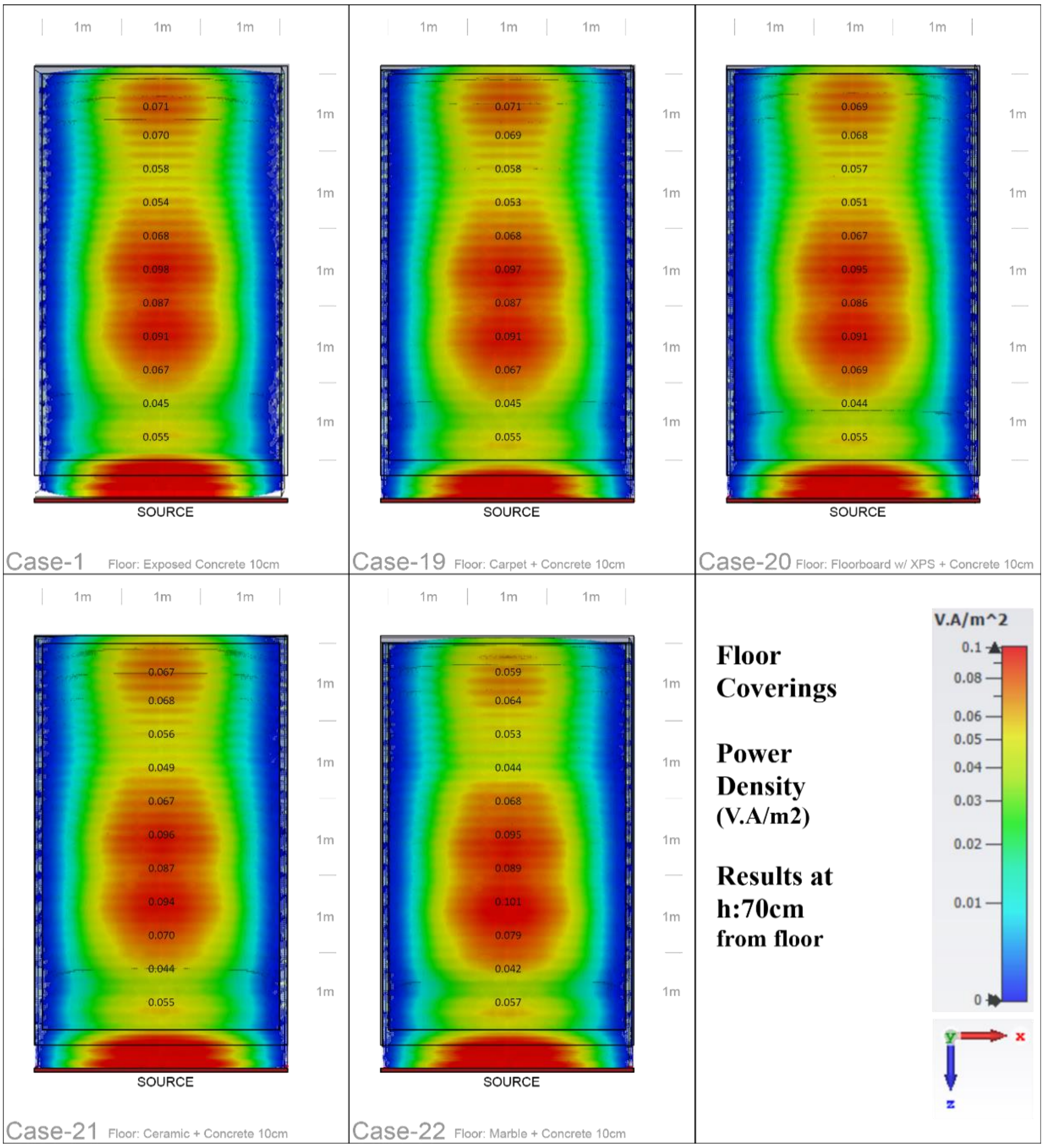


Figure 4.21. EM Power density results for floor finishing materials.

It should be noted that these results are presented for a height of 70cm above the ground. The modifications may produce different results at different heights in the cross section.

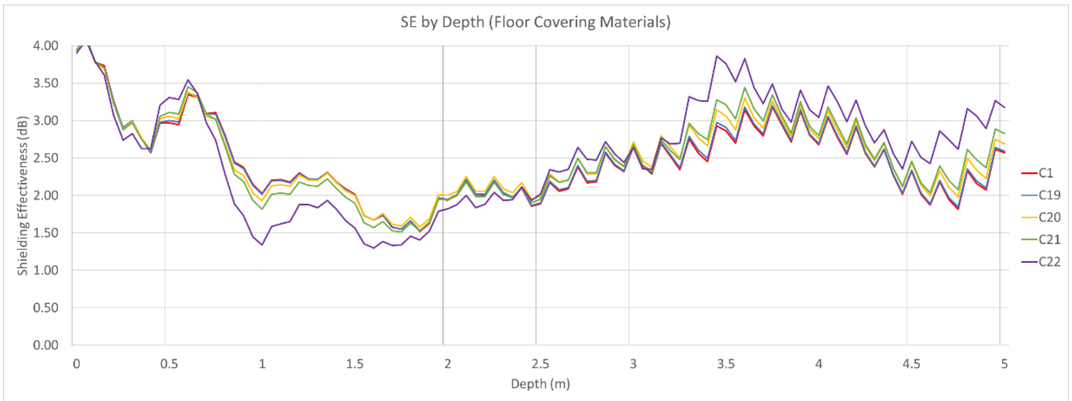


Figure 4.22. SE results by depth for floor finishing materials.

4.5.2.4 Changing ceiling materials:

The case where aluminum (C23), gypsum board (C24), PVC (C25) and wood (C26) suspended ceiling finishes were preferred instead of exposed concrete slab ceiling (C3) was evaluated. It was found that the wooden suspended ceiling (C26) offered similar results to exposed concrete.

The other cases, especially C23 and C24, were found to offer SE values up to 2dB better in some areas of the room as seen in Figure 4.24. Although the pattern of distribution within the room is similar in all cases; slight dilutions parallel to the SE graph are observed in C23, C24 and C25 as seen in Figure 4.23.

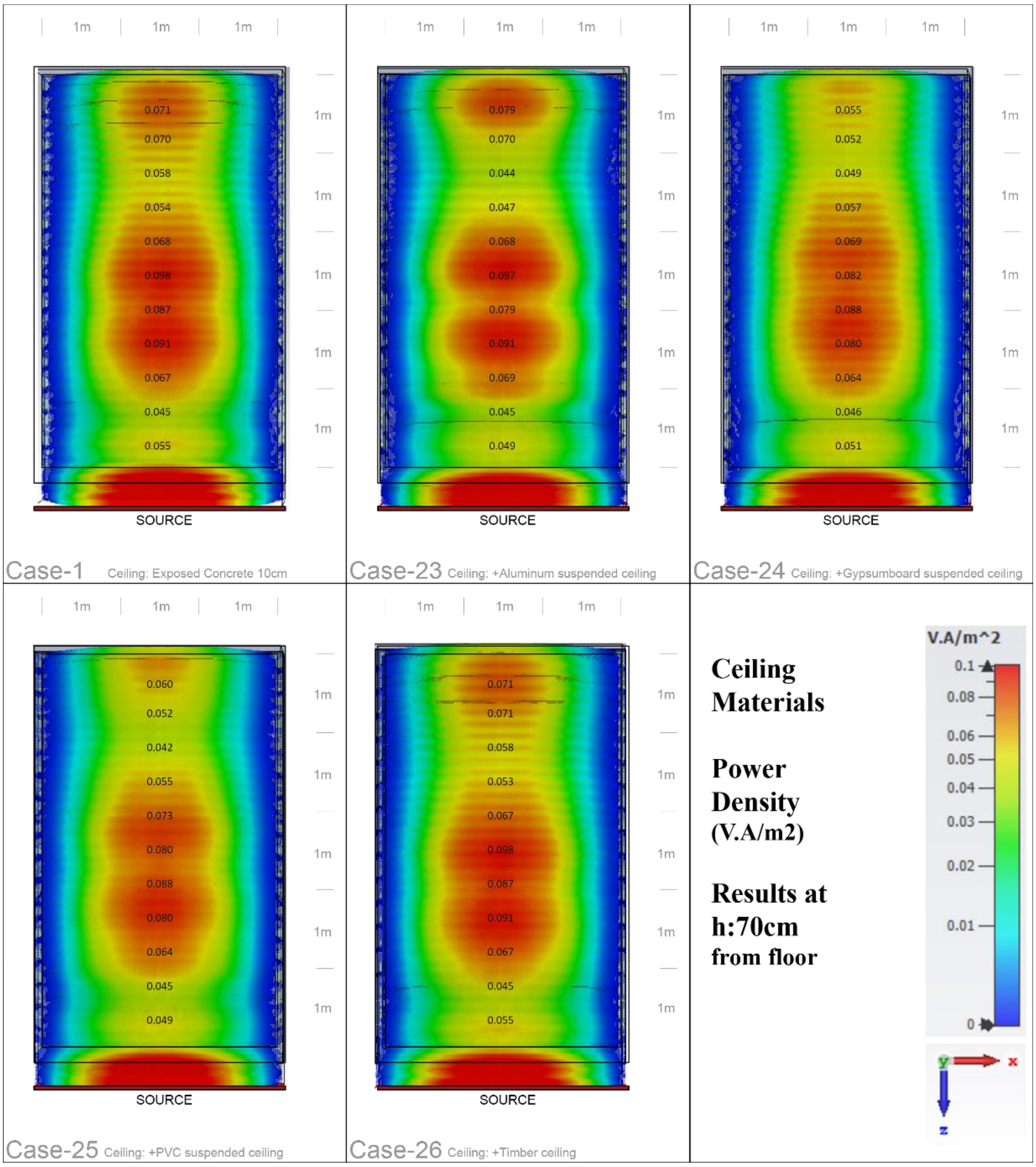


Figure 4.23. EM Power density results for ceiling materials.

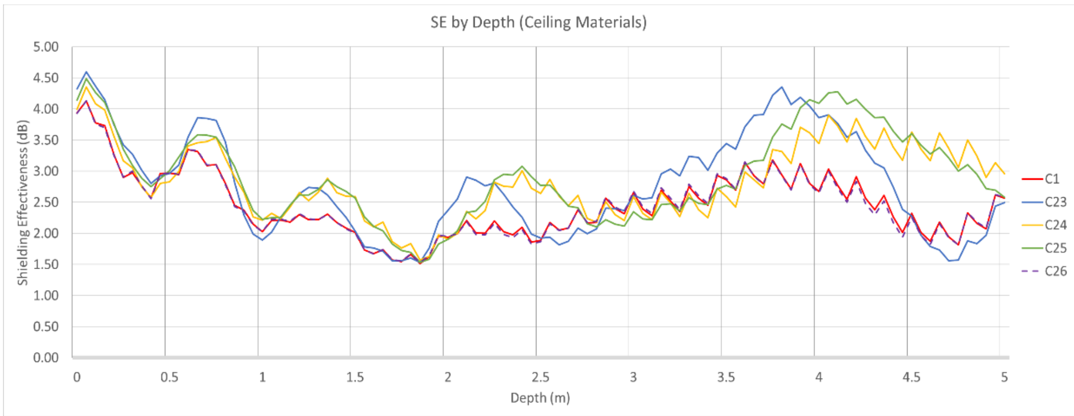


Figure 4.24. SE results by depth for ceiling materials.

4.5.2.5 Changing room depth and width:

When the cases where the depth and width of the room were modified, it was seen that the case (C32) where the width of the room was increased to 5m (5x5m) offered the highest shielding effectiveness compared to the other cases. In this case, the SE reaches a maximum of 6.5dB and is in the range of 4.5-5dB after 2m as seen in Figure 4.26.

The case where the depth was reduced to 3m, but the width was increased to 5m (5x3m) (C30) is in 2nd place. In C30, the highest SE is 5.5dB. These are followed by C31 with 4x4m dimensions and C29 with 4x3m dimensions.

C27 with 3x4m and C28 with 3x3m are at the bottom, respectively in the group as seen in Figure 4.26. Furthermore, C27 and C28 present lower SE values compared to C1 in 3x5m size. As can be seen from Figure 4.25, the increase in depth has a positive effect on both SE values, relieving the parts of the space where high EM power density is focused. On the other hand, it was observed that an increase in width had a more positive effect than depth. The details of this relationship will be interpreted again in the regression analysis.

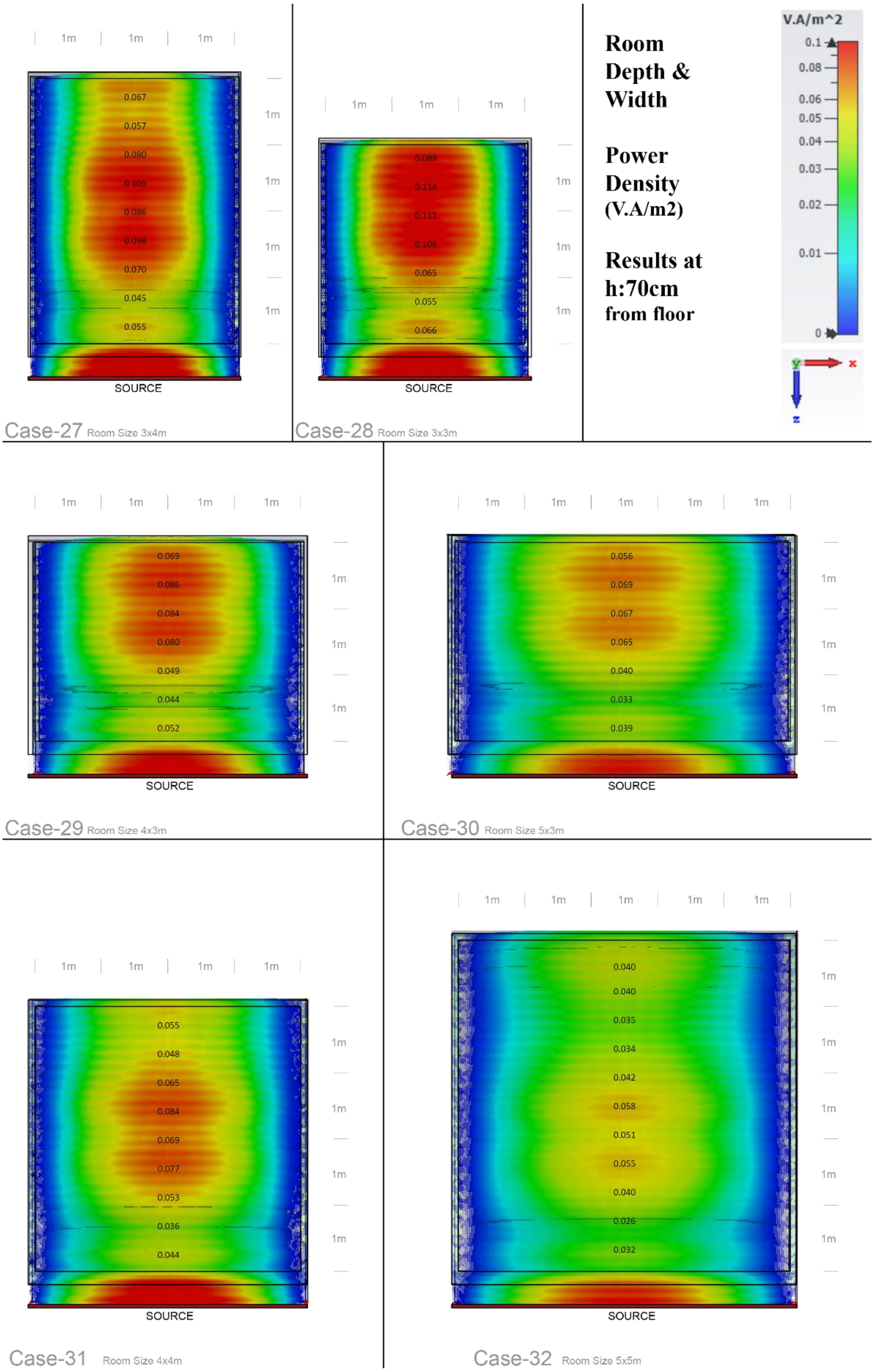


Figure 4.25. EM Power density results for room depth and width.

Figure 4.26. SE results by depth for room depth and room width.

4.5.2.6 Changing room height:

Increasing the ceiling height of the room has a significant positive effect on SE as seen in Figure 4.27. In C33, where the height was increased to 3m, the lowest SE was 6dB and the highest SE was 15dB as seen in Figure 4.28.

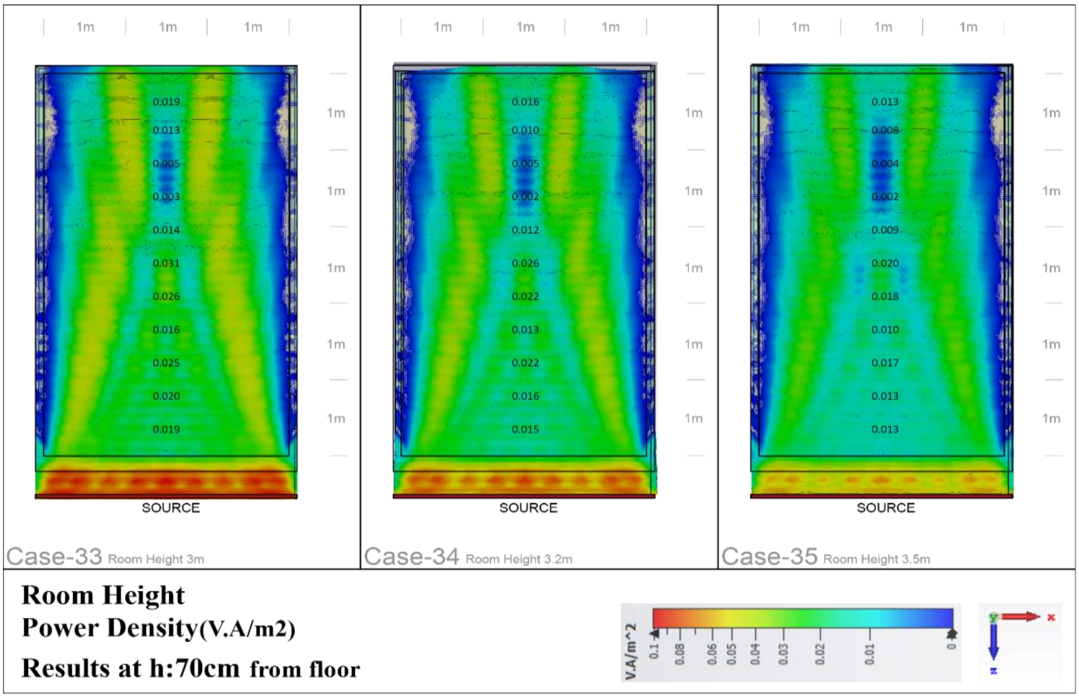


Figure 4.27. EM Power density results for room height.

When the height was increased to 3.2m (C34) the lowest SE was 6.8dB and the highest SE was 16.2dB. When the height was increased to 3.5m, the lowest SE was 7.8dB and the highest SE was 17.2dB. Increasing the net height of the room to more than 2.8m resulted in a significant SE increase at 70cm from the floor.

Figure 4.28. SE results by depth for room height.

Although it is said in the literature that the height of the room does not add to the indoor EM power level, the benefit in the height of the plane used during the sleep period can be defined as successful. Looking at the overall volume, the same maximum EM power density values is seen at different heights. The distribution of EMR in the interior has changed. Above 0.1W/m2 the intensity shifted from the center to the edges and started to appear 100cm above the floor due to the cases. From an architectural point of view, when we look at the focus on human health, reducing the intensity in the occupied volume can be considered successful. In summary, not only preventing EMR from entering the room, but also changing the part of the room that it affects can be useful in determining the layout of the room. More studies can be done on the effect of room height on SE.

4.5.2.7 Changing window wall ratio:

When the case (C36) with a 1.3x1.3m window in the center of the wall in the direction of the plane wave is examined, it is seen that the EM Power density values in the plane 70cm above the floor decrease compared to the case without window (C1) as seen from Figure 4.29.

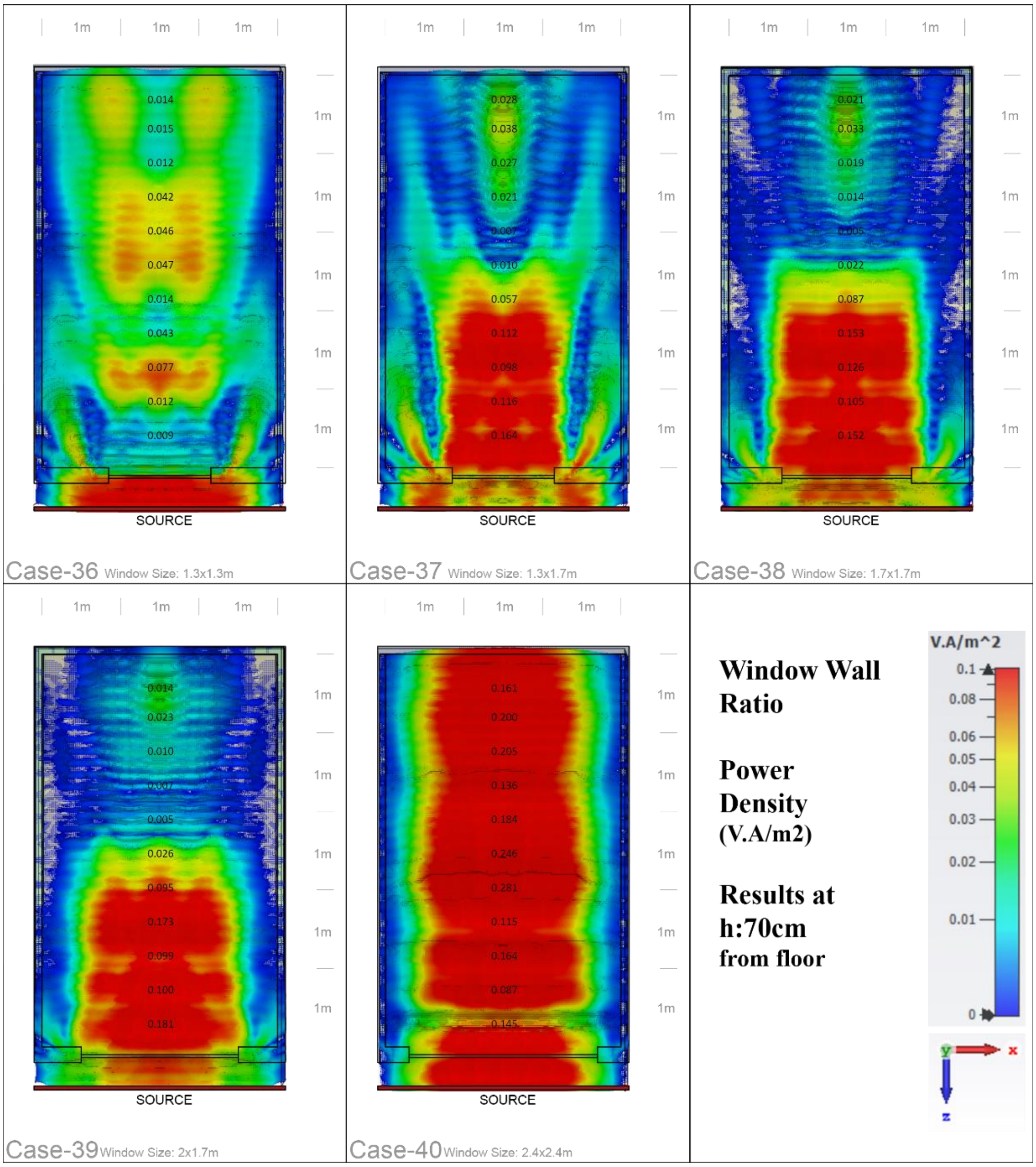


Figure 4.29. EM Power density results for window wall ratio.

Although this seems to be a positive result, when we look at the room in cross-section beyond the horizontal plane, it is seen that the decrease in power density values occurs in the 60c-90m height range and increases significantly at other heights in sections as seen from Figure 4.31. In fact, when looking at the room in general, the power density strength has increased significantly. While the maximum PD strength was 0.22W/m2 in C1, it was 0.67W/m2 in C36.

In summary, opening a window in the center of the wall increased the EM PD strength throughout the room and had a positive effect on the height used during sleep.

The same is true in cases C37 (1.3x1.7 window), C38 (1.7x1.7m window), C39 (2x1.7m window) where the size of the window was increased. The maximum PD value in the volume increased to 0.71W/m2 in C37, 0.77W/m2 in C38 and 0.70W/m2 in C39.

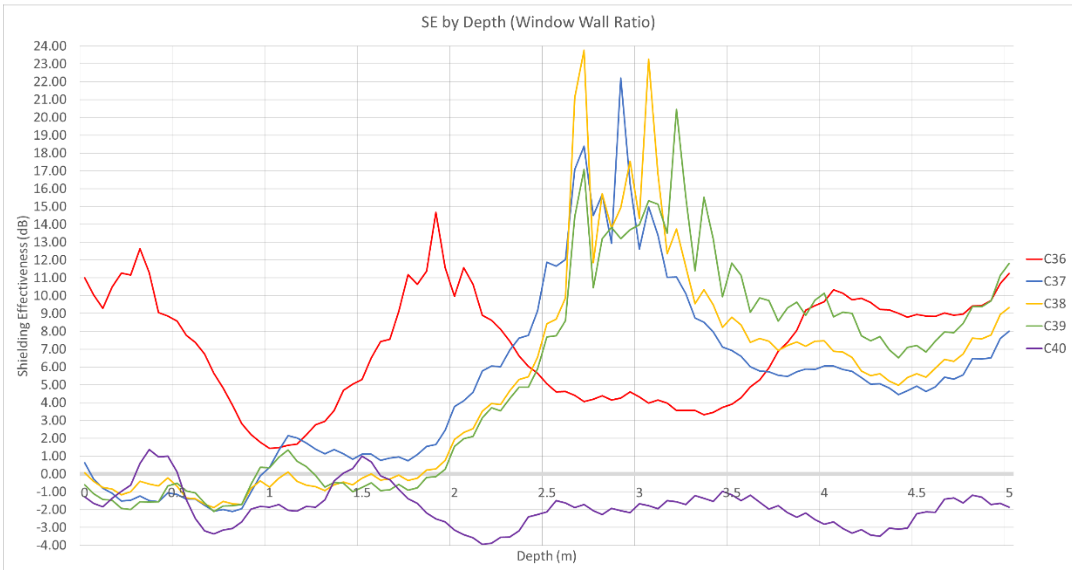


Figure 4.30. SE results by depth for window wall ratio.

When analyzed in cross-section as seen from Figure 4.31, it was observed that the PD intensity increased as the window size increased throughout the room. On the other hand, in these cases, there is a decrease in values after a depth of 2m at a height of 70cm above the floor. In other words, window sizes do not actually decrease the values inside the room but play a role in changing the regions where the radiation is focused. This may also be due to the changing opening position with the window size. The shielding activities seen from Figure 4.30 only present the situation at a height of 70 cm above the ground. It does not reflect the situation of these cases in cross-section.

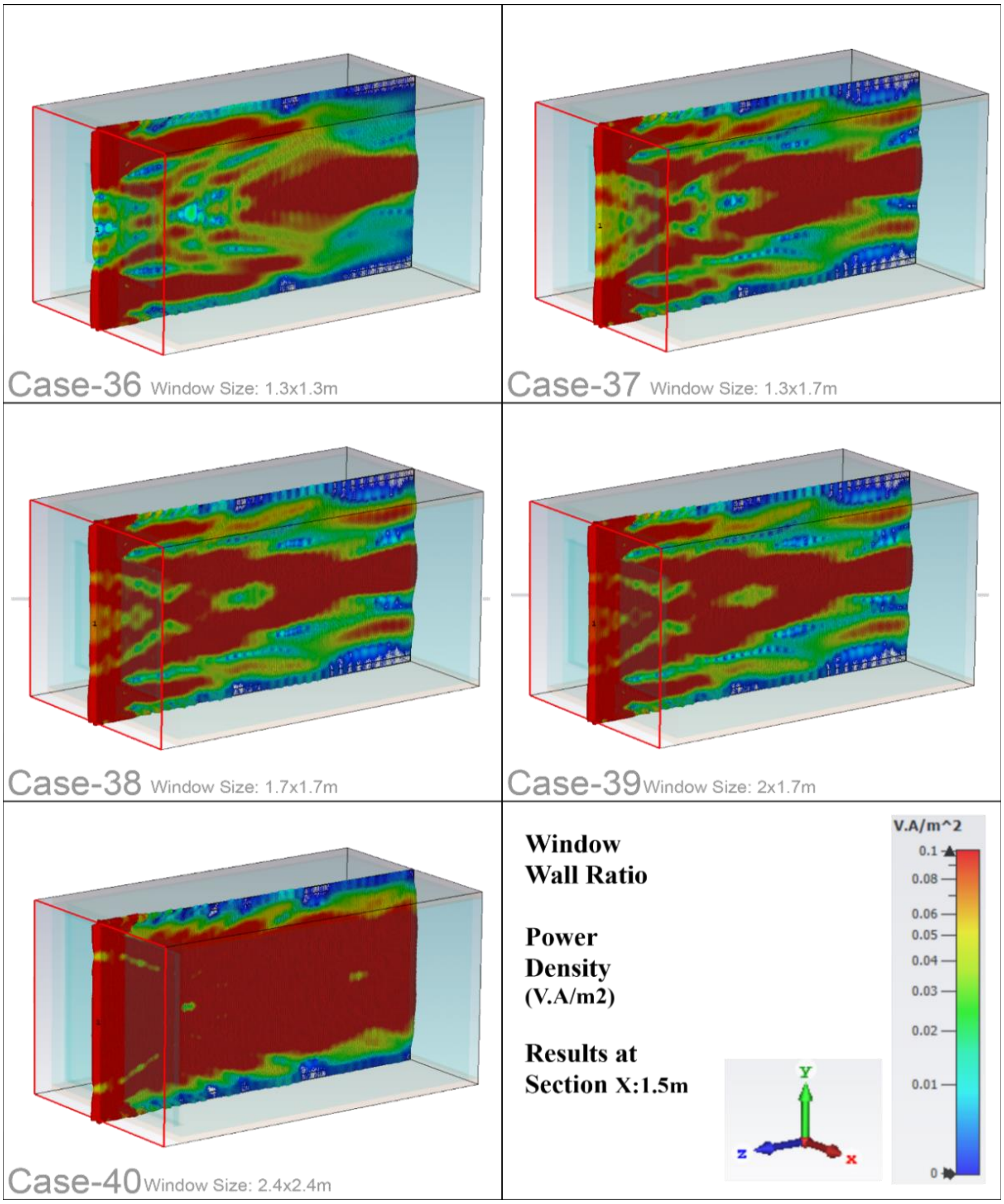


Figure 4.31. EM Power density results in vertical section plane (x:1,5m) for window wall ratio.

In C40 (2.4x2.4m), which represents a situation where the entire area of the facade (except the columns and beam areas) is glass, the highest PD value was 0.47W/m2. Although the peak value decreased compared to the other cases, the increase in C40 was spread over the entire room in both plan and cross-section, rather than being focused in one region. It is also seen Figure 4.30 that the shielding effectiveness in C40 has dropped to negative.

4.5.2.8 Changing window position:

In cases where the 1.3x1.3m window was on the back wall (C41) and on the side wall (C42), similar results were obtained as seen in Figure 4.32. This similarity is also observed in SE graphs as seen in Figure 4.33. These results are similar to the case without window (C1).

On the other hand, these results presented lower SE values on average compared to case C36, where the same size window was positioned on the wall in the direction of the radiation source. This does not mean that opening a window in the incident wave direction (C36) is beneficial to reduce the EM power density in the room. It just creates a less harmful plane at 70cm above the floor.

In the case where the window is moved to the side on the wall in the direction of the radiation source (C43), the EM power density strength shifts from the center of the room in the opposite direction. In the SE calculation of C43, unlike the other cases, the values in the region with this power density strength were used. For this reason, the SE values on the other side of the room will be higher in fact.

The case where the 1.3x1.3m window is in the center of the wall in the direction of the radiation source (C36) compared to the case where the window is shifted upwards (C44) shows a negative effect in the evaluation plane. Almost the entire plane is above 1W/m2. In the case where the window is shifted downwards (C45), the power density is concentrated and increased in value at the center line, while it is diluted at the edges. As seen in Figure 4.33, shielding activities form different trends. SE plots for this group are insufficient to interpret the spatial distribution. As seen in the cross-sections in Figure 4.34, EM power density does not actually decrease in volume, only its spatial distribution changes. Different distributions are also seen in different sections of the same case.

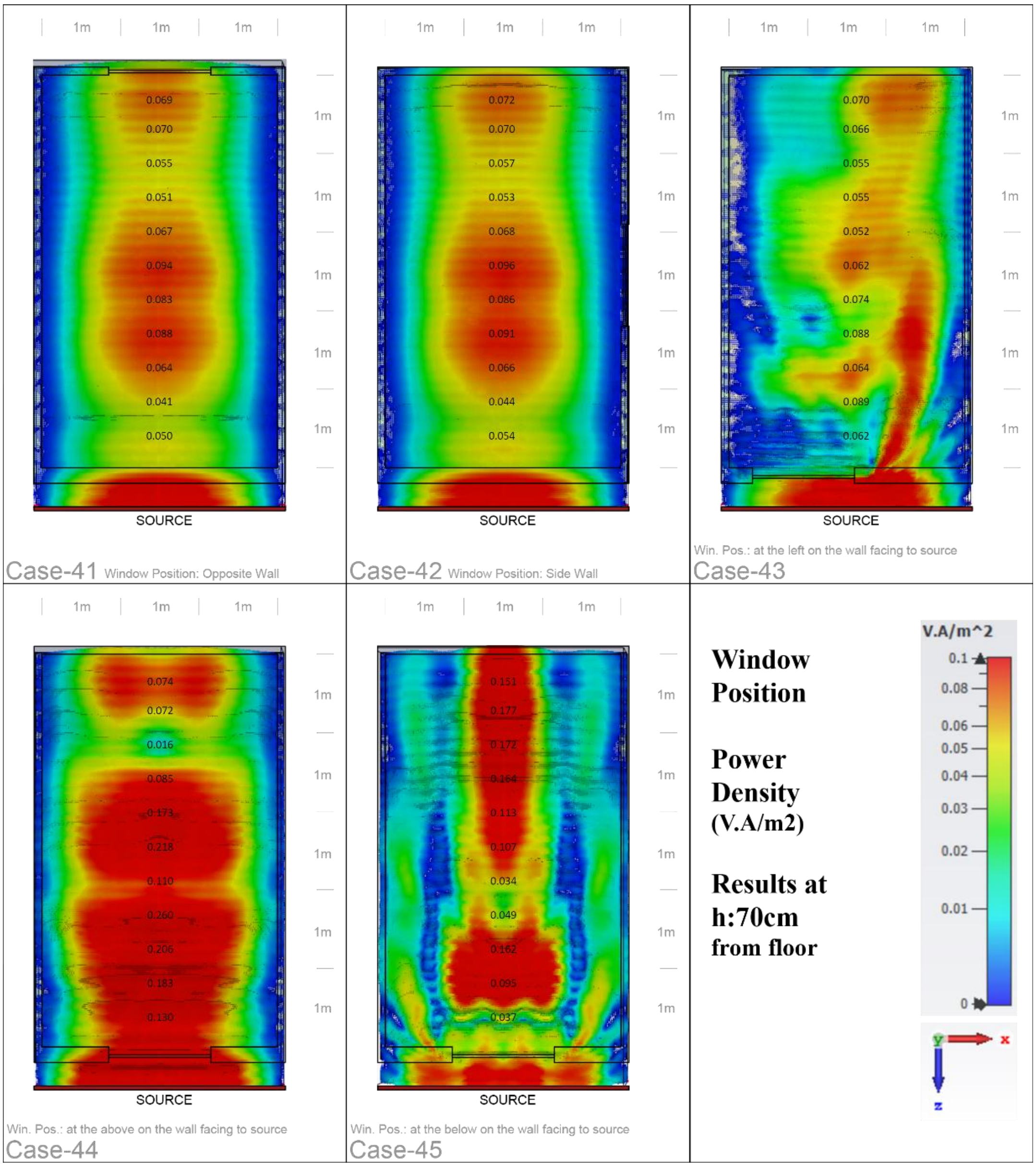


Figure 4.32. EM Power density results for window position.

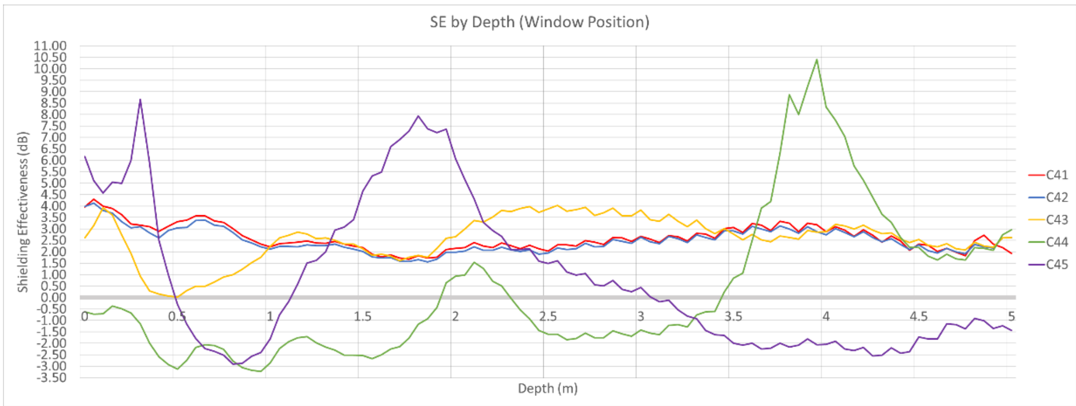


Figure 4.33. SE results by depth for window position.

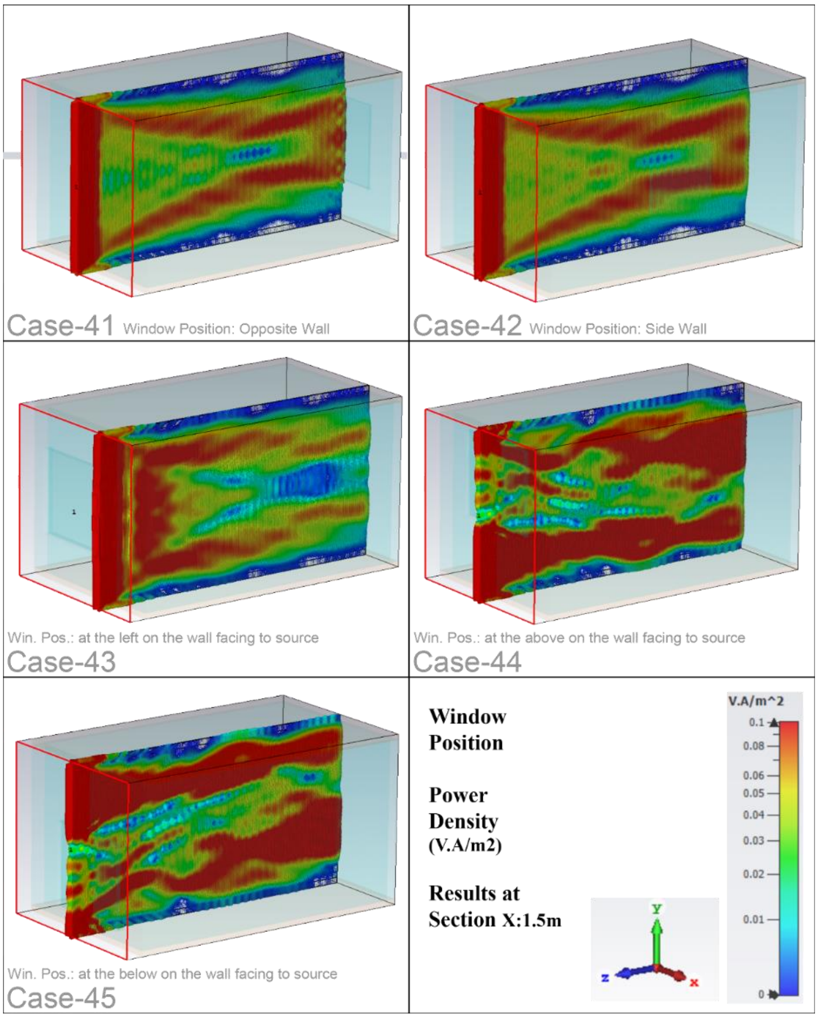


Figure 4.34. EM Power density results in section (x:1,5m) for window position.

4.5.2.9 Changing furniture density & material and door position:

When a metal baby bed, dresser and wardrobe are added to the room (C46), the highest PD strength in the volume increases from 0.21W/m^2 to 0.59W/m^2 compared to the empty room (C1). In the plane 70cm above the floor, the highest value increases from 0.17W/m^2 to 0.35W/m^2. Also, it increases from 0.21 W/m^2 to 0.59W/m^2 in the volume, especially near furniture as seen in Figure 4.35.

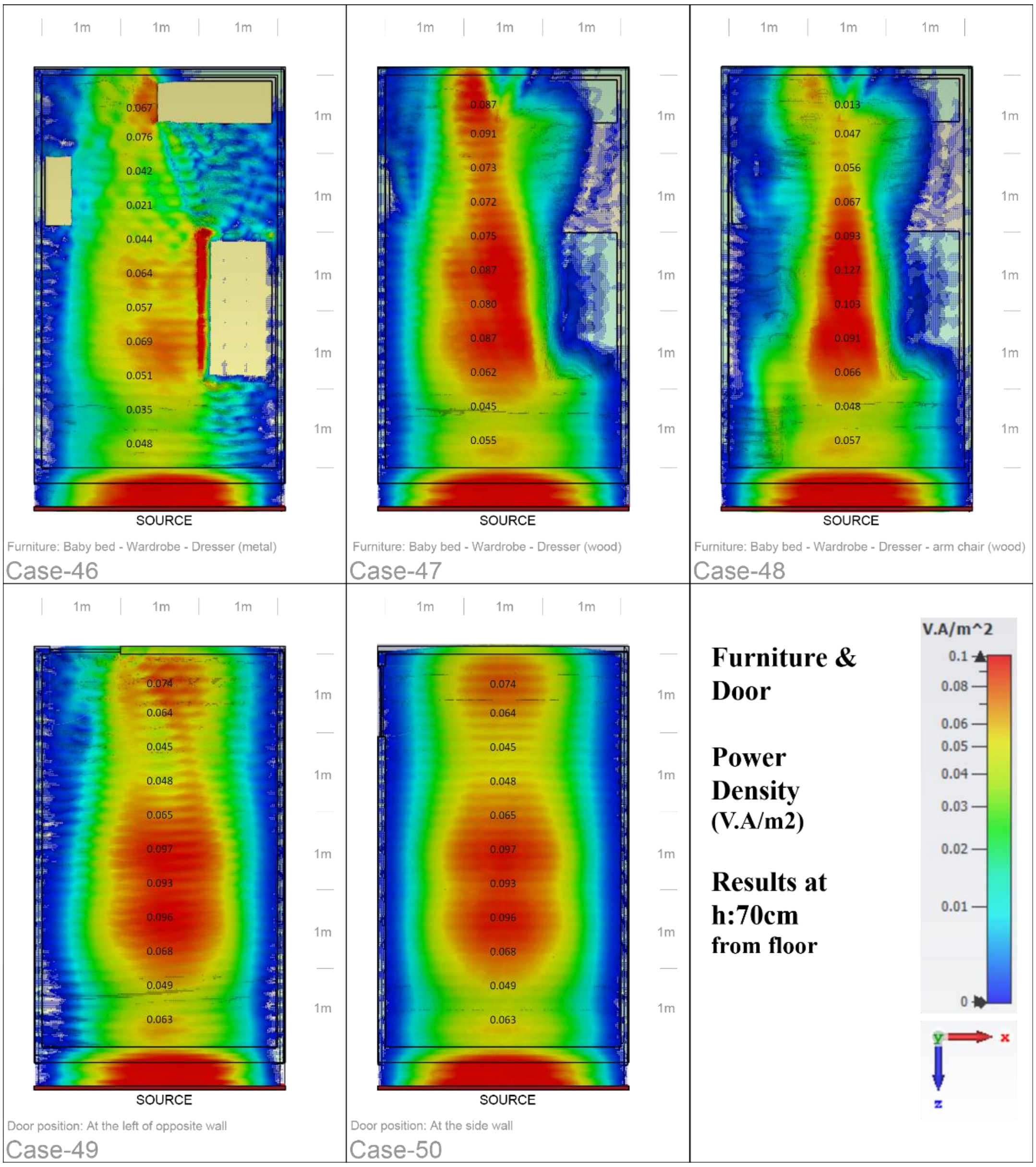


Figure 4.35. EM Power density results for furniture and door.

When we look at this plane in general, we see more usable space with lower values in C46 compared to C1. In other words, metal furniture significantly increases the power density indoors due to reflectivity. As this increase is distributed at different heights, it is observed as a decrease in the overall plane at 70cm above the floor as seen in Figure 4.35.

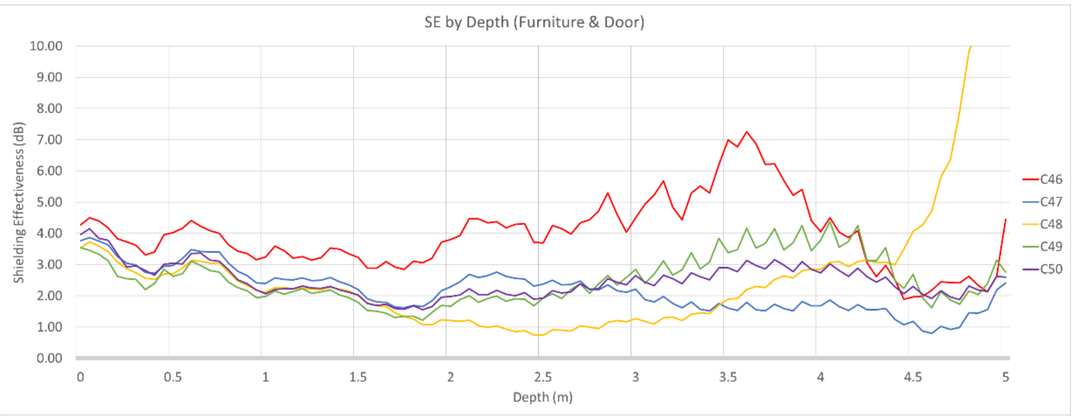


Figure 4.36. SE results by depth for furniture density & door position.

For both C47 and C48 which have wooden furniture, the highest PD value in the volume is 0.2W/m^2.

When a wooden baby bed, dresser and wardrobe are added to the room (C47), we see that the highest PD strength value in the volume remains unchanged compared to the empty room (C1). In other words, wooden furniture does not increase the PD strength in the interior because it does not cause reflected waves like metal furniture. This result confirms the theoretical suggestions in the literature. C47 shows that the position of the furniture affects the distribution of PD strength in the horizontal plane. The intensity shifts towards the gaps where there is no furniture. It should be noted that in this case the wardrobe and dresser are already closed boxes and the bars of the baby bed are modeled as a monolithic plane.

In the case where a wooden baby bed, a chest of drawers and a wardrobe plus a three-seater armchair were added to the room (C48), we see that the highest PD strength value in the volume remains unchanged compared to the empty room (C1).

In C48, the PD density is concentrated on the central axis due to the placement of the furniture on opposite walls.

The highest values were unchanged in the case where a door was added to the back wall (C49) and in the case where a door was added to the side wall at the point of the room closest to the back wall (C50) compared to the case without a door (C1) across the room. The door added to the side wall (C50) did not cause any significant change in the plane at a height of 70cm. The door added to the back wall caused a decrease in PD values in the section close to this door. Since the permeability of the glazed door is high, it can be interpreted that some of the radiation moves out of the room in that section.

As seen in Figure 4.37, furniture materials and door position affect the movement in the plan, not the movement in the section.

It should be noted that although plane wave is applied from one direction in the simulation, there will be sources acting from different directions in real life. For this reason, the small benefit of the door in the opposite direction of the source may also appear as a negative effect when radiation sources in different directions are considered.

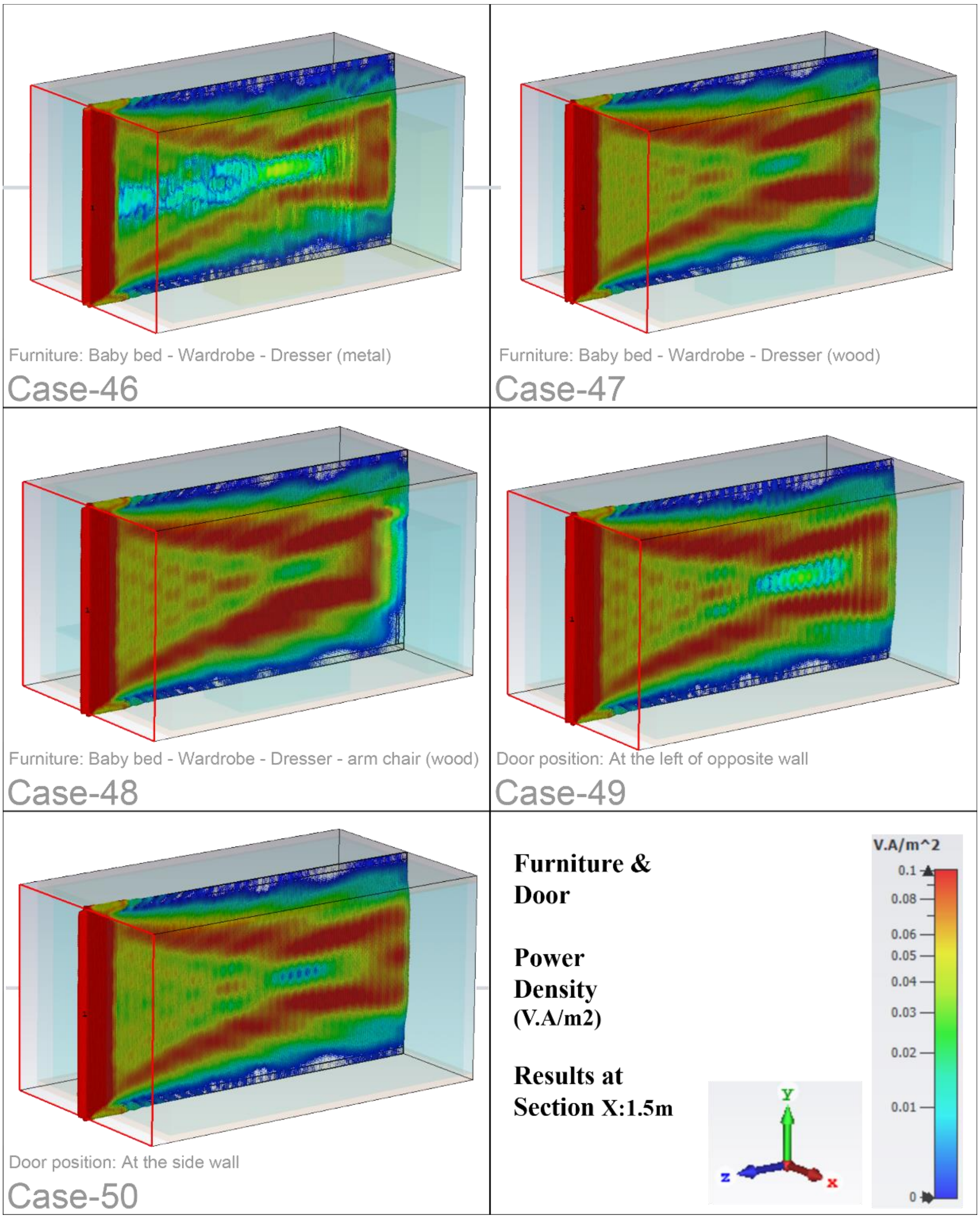


Figure 4.37. EM Power density results in section (x:1,5m) for furniture and door.

4.5.3 Regression analysis on simulation results

The power density strength values evaluated for the cases and the variables that the cases focused on were subjected to correlation and regression analysis together. Stepwise regression method is used to obtain a prediction model by significant values. Data on the spatial distribution of EMR were included in the regression analysis. Big data and artificial intelligence (AI) support may be necessary to analyze this.

Variables in the wall thickness group were defined by the numerical value of their thickness in meters. Similarly, variables in the room depth, room width and room height groups were defined with numerical values in meters. In addition, the space aspect ratio, which is a component of the width and depth variables, was also numerically included in the analysis. Variables in the window-wall ratio group were included in the analysis as both opening area and window to wall ratio.

On the other hand, the variables in the opening position group were assigned numerical values from 0 to 6. This hierarchical definition was made in the light of the evaluations in the previous subsection. Similarly, the variables in the door position group were defined with the values 0, 1 and 2. No door was defined as 0, 1 if the door was on the side wall and 2 if the door was in the direction of radiation flow.

Finally, wall materials, floor materials and ceiling materials groups were defined numerically with capacitance values. The materials on the walls of the buildings are considered as series connected capacitors and calculated as follows:

$$C_{\text{Envelope}} = \varepsilon_o A/[(d_1/K_1)+(d_2/K_2)\ldots+(dn/Kn)]$$

Where C is capacitance in Farads or c/V,

ε_o is permittivity of air, K is relative permittivity of material,

A is area, and d is thickness of wall.

For the cases windows, separate calculations were made for glass and wall areas and combined with their percentages.

In summary, as can be seen from the equation, this value is directly related to the thickness of the materials in the wall layers, dielectric properties, and wall area. At the same time, the wall area calculation is related to the height and width of the room. In cases with windows, the area of the window and its ratio with the wall affect this value, in other words, the shielding ability of the wall.

The last step of the stepwise regression analysis, which is the twelfth, can be seen in Table 4.18.

Table 4.18 Results for stepwise regression analysis.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.701571609
R Square	0.492202723
Adjusted R Square	0.470594328
Standard Error	0.046664316
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.099202201	0.049601101	22.77831036	1.21262E-07
Residual	47	0.102345244	0.002177558		
Total	49	0.201547445			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.540596719	0.163347176	3.309495337	0.001799837	0.211984586	0.869208851	0.211984586	0.869208851
Capacitance of Wall C1	10061004	1670780.308	6.021739634	2.49529E-07	6699827.563	13422180.43	6699827.563	13422180.43
Space height Sh	-0.15887445	0.057673036	-2.754744	0.008328917	-0.274897633	-0.042851267	-0.274897633	-0.042851267

The prediction model produced by using the coefficient obtained from the regression analysis for PD at a height of 70cm above the ground is as follows:

$$\text{Max PD} = 0.54 + (10{,}061{,}004 \text{ x } C_{\text{Envelope}}) - (0.16 \text{ x Room Height})$$

Where PD is power density, $C_{Envelope}$ is capacitance of envelope.

Since this is a statistical model, the units on both sides of the equation do not necessarily correspond to each other. The numerical relationship presented by this model is obtained by taking capacitance ($C_{Envelope}$) in farads, room height in meters and power density (PD) in V.A/m^2. This prediction model was tested on 3 different rooms including the room selected as case study. The mean error was 5.55%.

CHAPTER 5

CONCLUSION

This study focused on electro-smog mitigation for achieving healthy buildings by investigating the relationship between architectural design parameters and EMR levels. The research also aimed to provide a decision support model for the early design stage. This chapter gives the basic conclusion according to results and implementation strategy of decision support model for architects and occupants. At the end of this study further investigations are proposed.

5.1 Architectural design parameters and EMR levels for healthy buildings

The aim of this study is answering the question: “is architectural design effective for mitigating radiation exposure in indoor spaces?” This study focused on a series of design variables including wall thicknesses, wall materials, floor finishings, ceiling materials, room depth, room width, room height, window size, window position, furniture density, furniture material and door position. When the results obtained in the study are evaluated from different perspectives, it is observed that architectural design has an effect on EMF levels in the interior and this effect is not only on the strength but also on the distribution of it in the interior. Considering the widely used current building materials and other building design variables that are the subject of this study, it is not expected that any parameter will give a result that will compete with the Faraday cage made of copper. When approached with the As Low as Reasonably Achievable (ALARA) principle promoted by the European Union, reducing electro-smog, especially in sensitive places, is an important step. In particular, the duration of exposure plays an important role in the adverse health effects resulting from EMR exposure. For this reason, this study focused on sleep activity, which takes up about one third of a day and human life. When the results were analyzed in the plane at a height of 70cm from the floor, which was determined by considering the standard bed level, it was seen that architectural variables can be effective in reducing the levels that may be harmful to health in the space below the limit. This result is of course also related to the intensity of radiation emitted by sources outside the room (incident wave). Nevertheless, it has been seen that this benefit can be achieved in a room selected as a case study in Ankara, in the city center, taking into account the current levels.

Having recognized that architectural variables have an impact on indoor EMF levels, a secondary aim of this study was to provide a decision support model at the early design stage for architects to design healthy spaces by reducing electro-smog. This aim was achieved by regression analysis of the data obtained by simulations.

The contributions to the literature in this study are as follows:

- Since the adverse health effects from EMR are related to the duration of exposure, it is proposed to develop a solution by focusing on the parts of the interior where long-term activities take place. In parallel, this study focuses on sleeping activity. Focusing on the used part of the volume, not the whole volume, the evaluation was made on a plane 70cm above the floor.
- The various wall types presented in the study were tested for the first time in a simulation environment.
- It is proposed to focus on the total shielding capability of wall types consisting of layers as used in buildings, rather than the individual shielding effectiveness of the materials. Wall types were evaluated with this approach in this study.
- The effect of floor and ceiling materials, which has not been studied before, was calculated in a simulation environment in this study.
- The effect of the depth and width of the room as well as the effect of the space aspect ratio on indoor EMF levels are presented.
- Although the effect of room height has been previously studied in the literature, this study presents a different result with a different approach

focusing on the duration of exposure. Although it is reported in the literature that the height of the room has no effect on the EMF level indoors, this study shows that the change in height affects the EMF distribution indoors. In this way, it is shown that it is possible to apply different heights according to the function of the space.

- The impact of door position on EMF distribution and level in the interior is presented.
- The architectural literature in this field has been compiled.
- Dielectric properties of building materials have been compiled.
- A model is presented to estimate the maximum EMR level indoors based on the capacitance of the building envelope and the room height.
- The shielding effectiveness calculation used for materials in the literature has been used to compare the effect of different variables on the occupied space.

In this study, whose essential aim is to raise awareness about the design of a safe and healthy building in terms of EMR, some objectives were reached respectively.

In the first stage, international regulations, recommendations in the literature and building rating systems were reviewed and EMF limits recommended for human health were compared. There is no consensus on this issue. The limits in force vary from country to country. In addition, some of the studies in the literature argue that these limits should be lowered for human health. There are also different limits for different frequency ranges and exposure times. The discussion on limits is beyond the field of architecture. For this reason, different limits are gradually taken into consideration in this study. For power density, the value of 0.1W/m^2 applied in Chile, Bulgaria and Italy, which has special limits for sensitive places, is taken as a basis. Power density limit is applied as 0.27W/m2 for 900MHz and 0.54W/m^2 for 1800MHz in Türkiye. On the other hand, EUROPAEM recommends 0.01mW/m^2 for the sleep period and 0.001mW/m^2 for sensitive areas. Similarly, TQB has set levels below 0.01mW/m^2 as a target which is equal to 0.00001W/m^2. For EF strength, evaluation was made gradually with 1V/m, 3V/m and 6V/m value applied in Italy. The 1mG recommendation of Bio-Initiative was taken as a basis for MF strength assessment.

In the second stage, outdoor and indoor EMF levels were evaluated with on-site measurements. Within the scope of this study, outdoor measurements were made for 4 different buildings and indoor measurements were made for a residential unit. When the measured values were analyzed, it was seen that additional measures are needed to reduce the EMR level in these kindergarten, primary school, and residential samples. This finding is supported by different studies in the literature. In addition, the EMR levels emitted by some household appliances were also determined by measurements and compared with data in the literature.

In the third phase, data and recommendations from the architectural literature on EMR were compiled. Studies on this topic in the field of architecture are quite limited. The majority of these studies draw attention to the issue and offer theoretical suggestions. Some of them provide data based on measurements, but these are insufficient to support the improvement of a space or the design of a new building. Two simulation-based studies, on the other hand, provide a hint that architectural form can influence EMF levels in interior spaces through individual parameters. In addition, a review of existing buildings shows that EMR shielding measures are either to protect sensitive data for counter-intelligence or to protect devices from EMI problems. In addition, in recent years, a fabric tent has been proposed for exhibitions, and a prototype structure has been presented that optionally allows or prevents EMR from entering the interior. In addition to the architectural literature, it has been learned that the roughness or smoothness of the surfaces affects the permeability in studies conducted to enhance the propagation of electromagnetic waves. In similar studies, it was noted that humidity and trees affect the propagation of radiation.

In the fourth phase, wall thicknesses, wall materials, floor finishings, ceiling materials, room depth, room width, room height, window size, window position, furniture density, furniture material and door position are defined as the variable groups. The sub-variables of these groups were determined by the author considering the common characteristics of existing buildings and new constructions.

In the fifth stage, to determine the effect of materials, their dielectric properties must be included in the calculations. For this reason, the dielectric properties of all common building materials available in the literature were compiled. These compiled tables can be useful for different studies. However, for materials other than brick, glass, concrete, wood and aluminum, limited data is available from a limited number of sources in the literature. For some materials, no information was found. For this reason, more studies on the dielectric properties of building materials may be needed. Providing these data by material manufacturers can provide more accurate data, especially for materials with different components such as ceramics. Because different component ratios depending on the manufacturers may change the dielectric properties.

In the sixth stage, the effect of different variables in the simulation environment was calculated. Before these calculations, validation for the simulations was performed by comparing the measurements made in the room selected as a case study with the data calculated in the model of this room in the simulation environment. Space simulations were performed only at 1GHz frequency due to personal computer limitations.

In addition, parametric shielding effectiveness calculation was performed on the wall sample for various wall types in the range of 750MHz-10GHz in the simulation environment. These data supported the evaluation of the space simulations. For example, it was seen that some materials offer weak shielding effectiveness at 1GHz frequency, while offering high shielding effectiveness at higher frequencies.

Also, since the validation was performed on the materials in the room selected as a case study, in-situ measurements were made on some wall types to compare the calculation data resulting from the dielectric properties of different materials from the literature. In this comparison, it was observed in both simulations and in-situ measurements that the order of the wall layers relative to the radiation source was not effective. On the other hand, when in-situ measurement and simulation results are compared, it is observed that there are some differences in the ranking of the materials according to their shielding capabilities. This is observed for materials whose dielectric properties are obtained from a limited number of sources in the literature. There may be qualitative differences between the materials whose data are shared in the literature and the materials used in in-situ measurements.

Space simulations tested 50 different cases and simulations on wall types tested 30 different cases, 10 of which were compared with in-situ measurements. As a result of these processes, evaluations were made on maximum PD (V.A/m^2), SE (dB) values to determine which variables were more effective. So, a data set is generated. The results were not only quantified but also the distribution of radiation inside the room was analyzed and noted in different cases.

In the seventh step, the generated data set was subjected to stepwise regression analysis and the effective parameters to mitigate EMR levels at 70cm height were identified. Furthermore, a prediction model was developed.

While the results are presented in the previous chapter, some key findings are as follows:

- Measurements in a limited number of cases have shown that improvements or additional measures are needed for some buildings.
- Zoning of functions is reasonable, considering radiation emitted by household appliances as well as external radiation.
- The shielding effectiveness of parameters, properties and materials is frequency dependent.
- Wall thickness increases SE in all frequencies for all materials.
- The evaluation of the wall layers as a whole instead of individual materials yields different results and rankings.
- The order of the wall layers does not have an effect on transmission percentage.

- The change on surfaces that are not in the direction of the radiation source causes a negligibly small effect. Even if radiation was given from only one direction in simulations within the scope of this study, it comes from different directions in real life.
- The increase in both room width and depth benefits electro-smog mitigation when the radiation comes from one direction. This is useful result for designing by considering the direction from which high intensity radiation is coming. Otherwise, it should be reassessed for multidirectional exposure.
- The increase in height significantly benefits electro-smog mitigation for the level studied here.
- Although room height does not change the maximum PD in the interior, it does affect the distribution within the space. Therefore, its effect varies according to the activity focused on.
- Opening a window in the direction of the radiation source increases indoor PD. The position of the window affects the indoor radiation distribution. The effect of openings such as windows and doors in other walls not in the direction of the radiation source is negligible.
- The metal materials used in the furniture have increased the maximum PD in the interior. The position of the furniture affected the radiation distribution. PD decreased in areas behind wooden furniture.
- As a summary, wall thickness, room height, depth and width decrease PD for the studied level (at 70cm high from the floor). Different wall materials have different effects, but some wall types also decrease PD. On the other hand, window wall ratio increases PD.
- Room height, furniture density, furniture materials, window position and door position change the radiation distribution in the volume.

5.2 Validation of results

To validate the simulation results, the simulation was run for the model of the room selected as a case study. In addition, measurements of the room in real life were recorded with the electricity off, i.e. only exposed to radiation from the external environment. These results were validated by comparing them with each other. Spatial evaluations were made based on this validation.

On the other hand, the simulation results for the study on the wall types were compared with the measurements made with the simple setup on the wall types in-situ. In this way, compatible and incompatible results were identified.

Finally, the spatial simulation results are subjected to stepped regression analysis. The statistical model equation obtained as a result of stepped regression analysis was validated by applying it to rooms with different characteristics.

5.3 Implementing decision support model

The decision support model developed with the results obtained in the study was tested on the case study room. The percentage of error is 5.55%.

Remembering that EMR levels are based on different variables such as frequency, the number of sources in the environment, the intensity of the sources and so on, it is clear that we need a much larger data set is needed for a tool. The model currently presented represents a first step for a tool in future. Although it can give reasonable results within the architectural design parameters and frequency range that the study focuses on, the database should be expanded to evaluate different cases that vary with variables.

The system proposed by Yener and Çerezci (2022) on estimating EMF levels for cities and the model presented here may be included together in a decision support tool or benchmarking framework in the future. For the development of such tools, the dataset needs to be further developed and tested.

5.4 Research limitations and further studies

As mentioned at the beginning of the study, the effect of EMR levels on human health in architectural spaces and the use of architectural design parameters to find solutions to this problem is still a new topic. The data in the literature that can give idea on the relationship between architectural design and EMR levels are compiled and presented. There is limited knowledge. In the study, data were generated by making assessments for 1Ghz and 2.4Ghz frequencies. There is a long way to go to expand the database and to provide more effective solutions for healthy spaces through architectural design. Some of these can be listed as follows:

- In the additional experiment conducted on wall types within the scope of this study, a MW oven, one of the household appliances that cause indoor radiation, was used as a source. In this way, the effectiveness of the walls of the house against the radiation emitted by a device used in daily life was observed. In addition, the results obtained from this additional experiment were used for comparison. On the other hand, transmission coefficient and shielding effectiveness measurements in a controlled environment with specialized devices should be made for wall types. Due to the lack of necessary facilities, measurements could not be made in a laboratory using anechoic chamber and specialized radiation sources; but maybe undertaken for future studies in this field.
- In this study, we focused on the height plane (h:70cm) where the brain and heart are located during sleep. In future studies, the study can be extended by considering activities such as working at a desk, sitting, working at a kitchen counter.
- In this study, spatial evaluations were performed at 1GHz frequency and simulations for transmission coefficient and shielding effectiveness were performed parametrically in the frequency range of 500MHz to 10GHz. In the future, spatial evaluations can be extended to frequencies where 5G or other next generation technologies operate by using more advanced computer

systems. Although the software is capable of calculating higher frequencies or larger buildings, this requires sophisticated devices such as supercomputers and longer computation times. The same is true for measurements. Measurements on wall types should also be extended to different frequencies. This extension should not only address super (SHF) and extremely high frequencies (EHF), which will become common with 5G, but also extremely low frequencies (ELF). For example, the electrical installations used in buildings operate at 50Hz, i.e. ELF. The term Electro-smog covers all frequencies.

- The outdoor radiation level and frequency affecting the building were determined individually and in accordance with the case study selected in this study. Focusing on the shielding of the effective frequency by performing both spectrum analysis for different cases in different locations may be one way to extend this.
- In this study, indoor measurements were made in a flat on the top floor of an residential building. Considering that antennas and base stations are located on the roofs of the surrounding buildings, future studies may investigate whether there is a difference in radiation exposure according to the floors of the apartments.
- EMR shielding wall paints, wallpapers and fabric products are not covered in this study, but these materials are also becoming widespread. In addition, studies on frequency selective surfaces (FSS) could be evaluated for buildings in the future.
- Studies in the field of architecture are also related to studies in the field of materials. For this reason, the database can be expanded by conducting studies on the electrical and magnetic properties of building materials, which are missing in the literature.

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APPENDICES

A. Definitions of terms

Adverse health effect: An effect detrimental to a person's physical well-being due to exposure to an electric, magnetic, or electromagnetic field or to induced or contact currents or voltages.

Adverse health effect threshold: the lowest exposure level known to cause the health effect.

Anechoic chamber: A room or enclosure with inside surfaces that absorb electromagnetic fields to attenuate reflections.

Assessment: The process of making determinations and recommendations about an exposure situation, including determining the objectives of the process, determining the characteristics of the situation under consideration, identifying appropriate metrics and limits, performing the necessary evaluations, and making determinations and recommendations based on the results.

Attenuation: A general term, expressed as a ratio, used to denote a decrease in magnitude of a field quantity from one point to another.

Averaging area: The area over which a physical quantity is averaged for assessing compliance.

Averaging time: The time period over which exposure is averaged for purposes of comparison with the exposure reference level or dosimetric reference limit.

Combined standard uncertainty: The result of combining individual standard uncertainties affecting a measurement or prediction. See also: expanded uncertainty; standard uncertainty; coverage factor.

Conductivity: A property of materials that determines the magnitude of the electric current density when an electric field is impressed on the material.

NOTE—The SI unit of conductivity is siemens per meter (S/m), the inverse of resistivity.

Controlled environment: Deprecated. See: exposure environment (restricted). coverage factor: A multiplier that is applied to the combined standard uncertainty to obtain the expanded uncertainty. See also: combined standard uncertainty; expanded uncertainty; standard uncertainty.

Coverage factor: A multiplier that is applied to the combined standard uncertainty to obtain the expanded uncertainty. See also: combined standard uncertainty; expanded uncertainty; standard uncertainty.

Dielectric constant: See: Relative permittivity.

Electric field: A fundamental component of electromagnetic (EM) waves that exists when there is a difference in potential between two points in space.

Electric field strength: Force exerted by an electric field on an electric point charge divided by the electric charge. NOTE: The SI unit for electric field strength is newton per coulomb or volt per meter (N/C = V/m).

Electric field vector: The magnitude and direction of the force on a stationary positive unit charge. See also: electric field strength.

Electromagnetic field: Any field consisting of electric and/or magnetic components, regardless of whether it is propagating (radiating) or not.

EM Interference: Any electromagnetic disturbance, whether intentional or not, which interrupts, obstructs, or otherwise degrades or limits the effective performance or safe operation of an electronic or electrical device or system.

EMF Evaluation: The process of quantifying human exposure to electromagnetic field (EMF) by employing exposure metrics using measurement and/or computation, including consideration of uncertainty, and making necessary adjustments to normalize the result.

Expanded uncertainty: An interval expected to encompass a large fraction (usually 95%), of the distribution of values that could reasonably be attributed to the true value of a measurement or computation. See also: combined standard uncertainty; coverage factor; standard uncertainty.

Exposure: The state of being in the presence of electric, magnetic, or electromagnetic fields, or in contact with a current or voltage source.

Exposure environment: A defined area that is characterized by the maximum potential exposure that could occur within it.

A) restricted environment: An environment in which exposure can result in exceeding the unrestricted environment dosimetric reference limit.

NOTE 1—Implementation of an effective safety program (such as per IEEE Std C95.7-2014 for the radio frequency range) is to help prevent persons being exposed above the DRL or ERL for the restricted environment.

NOTE 2—In some documents, exposure in restricted environments is referred to as “upper tier” or “controlled environment” or “occupational exposure.”

NOTE 3—Members of the general public are not permitted in restricted environments unless they become subject to the applicable safety program, at which time they are no longer considered members of the “general public.”

B) unrestricted environment: An environment in which exposure does not result in exceeding the dosimetric reference limit that marks the safety program initiation level, and which serves as an exposure limit for the general public. See also: general public.

NOTE 1—The exposures can occur in living quarters or workplaces where there are no expectations that the DRL or ERL for unrestricted environments would be exceeded and where the induced currents or contact currents do not exceed the limits for unrestricted environments.

NOTE 2—In some documents, the unrestricted environment is referred to as a "lower tier" or an "uncontrolled environment" or a "general public exposure."

Exposure limit: A threshold such as a dosimetric reference limit (DRL) or exposure reference limit (ERL) including, when applicable, frequency dependency and spatial and temporal aspects (*e.g.*, averaging).

NOTE—ELf is the numerical value of the exposure limit at frequency f.

Exposure value: The result of a measurement or computation of the electromagnetic energy reported in the SI units relevant to the exposure metric being implemented and scaled to represent the applicable reference conditions.

Far-field (region): The region where the angular field distribution is essentially independent of distance from the source.

NOTE—In the far-field region, the field has a predominantly plane-wave character (*i.e.*, locally very uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation). For large antennas especially, the far-field region is also referred to as the "Fraunhofer region."

Finite difference time domain (FDTD) method: A numerical algorithm for solving Maxwell's differential equations of electromagnetic field interactions in the time domain by discretizing the problem space into unit cells where the space and time derivatives of the electric and magnetic fields are directly approximated by simple, second-order-accurate central-difference equations.

Finite element method (FEM): A class of numerical algorithms for solving Maxwell's differential equations of electromagnetic field interactions.

General public: All members of the human population who have no knowledge or control of their exposure and are, consequently, not permitted in a restricted environment. The unrestricted environment exposure limit applies to the general public. See also: exposure environment (unrestricted).

NOTE 1— The general public includes, but is not limited to, children, pregnant women, people with impaired thermoregulatory systems, and persons using medications that can result in poor thermoregulatory system performance.

NOTE 2— Some documents and regulations use the similar term "general population."

Incident energy density: The quantity of energy per unit area that impinges on the body surface.

NOTE—The SI unit for incident energy density is joule per square meter (J/m2).

Incident power density: The quantity of power per unit area that impinges on the body surface. See also: power density.

NOTE 1— The SI unit for incident power density is watt per square meter (W/m2).
NOTE 2— In this recommended practice, the incident power density just outside the body surface is employed to define local exposure reference levels at frequencies greater than 6 GHz.

Induced current: Electric current flowing in the body of a person in a freestanding condition due to an electromagnetic field.

Local exposure: An exposure condition in which a limited portion of the body is subject to most of the incident energy and is usually the result of 1) the source being located very close to the body or 2) a highly concentrated region of energy associated with contact with an energized conductor exposed to environmental fields.

Low-level fields: Electromagnetic fields in the frequency range 0 Hz to 300 GHz that produce induced internal electric fields, specific absorption rate, or epithelial power density at or below the corresponding dosimetric reference limits.

Magnetic field: A fundamental component of electromagnetic waves produced by a moving electric charge.

Magnetic field strength: The magnitude of the magnetic field vector.

NOTE 1— The SI unit of magnetic field strength is ampere per meter (A/m).
NOTE 2— In air and simple (nonmagnetic) media, the magnetic field strength H is related to the magnetic flux density B by: B = H μ, where μ is the permeability of the medium.

Magnetic field vector: A field vector that is equal to the ratio of the magnetic flux density to the permeability.

NOTE—The SI unit of magnetic field vector is ampere per meter (A/m). magnetic flux density: A vector quantity that determines the force on a moving charge or charges (electric current).

NOTE 1— The SI unit of magnetic flux density is tesla (T).

NOTE 2—In air and simple (nonmagnetic) media, the magnetic flux density B is related to the magnetic field strength H by B = H μ, where μ is the permeability of the medium. NOTE 3—One gauss (deprecated unit) equals 10–4 T. Similarly, 1 mG = 0.1 μT.

Mean: The arithmetic average of a series of numerical values.

Median: The value within a statistical distribution at which 50% of values are greater than and 50% are less than.

Median threshold: The threshold value within a statistical distribution at which 50% of subjects have greater thresholds and 50% have lesser thresholds.

Microwave: An informal term that signifies radio frequencies in the range from about 300 MHz to 300 GHz.

Near-field (region): A region, generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character and vary considerably from point to point.

Partial-body exposure: See: local exposure.

Peak field: The instantaneous value of a time-varying electric or magnetic field when at its maximum value.

Peak power density: The maximum spatial and/or temporal power density in a propagating wave.

Permittivity (complex): The ratio of the electric flux density in a medium to the electric field strength at a point.

NOTE—Complex permittivity (ε′) is expressed as

$$\varepsilon^* = \varepsilon_0\left(\varepsilon' - j\varepsilon''\right) = \varepsilon_0\left(\varepsilon' - j\frac{\sigma}{\omega\varepsilon_0}\right)$$

Where;

- ε_0 is the permittivity of vacuum (8.854 × 10-12 farads per meter)
- ε′ is the dielectric constant, or real part of the complex relative permittivity
- ε′′ is the imaginary part of the relative complex permittivity
- σ is the conductivity of the medium
- ω is the angular frequency in radians per second

Plane wave: An electromagnetic wave characterized by mutually orthogonal electric and magnetic fields that are related by the free-space wave impedance η0.

NOTE—For plane waves, power density (S), the electric field strength (E), and the magnetic field strength (H) exhibit the following relationship: S = E2/η0 or S = η0 H 2, where S is in W/m2, E is in V/m, and H is in A/m.

Plane-wave-equivalent power density: The calculated power density of an electromagnetic wave that is equal in magnitude to the power density of a plane wave having the same electric field strength or magnetic field strength. Syn: equivalent-plane-wave power density.

NOTE 1— The SI unit of plane-wave-equivalent power density is watt per square meter (W/m2).

NOTE 2— Plane-wave-equivalent power density is computed as follows:

$$S_E = \frac{|E|^2}{\eta_0} \text{ W/m}^2 \quad \text{or} \quad S_H = \eta_0 |H|^2 \text{ W/m}^2$$

where |E| and |H| are the root-mean-square values of the electric- and magnetic field strengths, respectively, and η0 is the wave impedance of a plane wave in a vacuum.

Polarization (electromagnetic): The locus of the tip of the electric or magnetic field vector observed over time at a fixed point.

Power: A physical quantity describing the rate of delivery or transmission of energy. The SI unit of power is watt (W).

Power density: Electromagnetic power per unit area crossing a surface of interest. See also: plane-wave equivalent power density.

NOTE 1— The SI unit of power density is watt per square meter (W/m2).

NOTE 2— The surface of interest is frequently chosen to be orthogonal to the electromagnetic wave direction of propagation.

Power level: At any point in a system, the ratio of the power at that point to some arbitrary amount of power chosen as a reference. Power level is often expressed as decibels referred to 1 mW (dBm) or decibels referred to 1 W (dBW).

Probe: A measurement device that minimally perturbs the measurand while providing an output signal that is suitable for display or recording and has a defined relationship to the measured physical quantity.

Radio frequency (RF): A frequency between approximately 3 kHz and 300 GHz.

Reference condition: Established factors, including decision rules, reference state and applicable exposure reference level (ERL) and dosimetric reference limit (DRL), that, when applied, obtain an assessment that fulfills its purpose and is repeatable.

Reference state: The characteristics of the electromagnetic field (EMF) source(s) and the exposure environment that are being compared with the applicable exposure limits. NOTE—The reference state is established by normalizing the actual conditions observed to the conditions intended for comparison.

Reflected wave: A wave in a medium produced by reflections from objects or discontinuities in the medium or from a boundary of a different medium.

Reradiated field: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting object by electromagnetic waves incident on that object from one or more primary radiating sources.

NOTE—Reradiated fields are sometimes called “reflected” or more correctly “scattered fields.” The scattering object, sometimes called a “reradiator,” “secondary radiator,” or “parasitic radiator,” can be a source of contact currents.

Scattering: The process that causes waves incident on discontinuities or boundaries of media to be changed in direction, amplitude, frequency, phase, or polarization.

Short-term exposure: Exposure for a duration less than the corresponding averaging time.

Spatial average: A method for averaging field strength, field strength squared, or power density over a specified line, area or volume.

Spatial maximum: The maximum point value of a spatially distributed parameter.

Specific absorption: The quotient (SA) of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given mass density (ρ). The SI unit of specific absorption is joule per kilogram (J/kg).

Specific absorption rate (SAR): The time derivative (SAR) of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ). The SI unit of specific absorption rate is watt per kilogram (W/kg).

Standard uncertainty: The standard deviation associated with the result of a measurement or computation that characterizes the expected dispersion of values around that result.

Standing wave: A spatially periodic or repeating series of amplitude maxima and minima that is generated by two propagating waves of equal wavelength traveling in opposite directions. For any component of the field, the ratio of the amplitude at one point to that at any other point does not vary with time.

Static field (electric or magnetic): A non-time-varying field created by a fixed difference in potential (or flow of direct current) between two points (or a magnetic pole).

Thermal effects: Changes associated with heating of the whole body or an affected region sufficient to induce a biological effect.

Total exposure ratio: The sum of a set of exposure ratios employed to characterize a total (potential) electromagnetic field (EMF) exposure in relation to a corresponding exposure limit considering that the total exposure ratio incorporates all relevant frequency, temporal and spatial components necessary to maintain consistency with the corresponding exposure metric. NOTE—If the total exposure ratio exceeds unity, then the evaluated exposure condition exceeds the corresponding exposure limit.

Wave impedance (of plane wave in a vacuum): The ratio of the electric field strength to the magnetic field strength of a propagating electromagnetic wave.

All definitions in this Appendix are given with reference to (IEEE, 2021).

B. **Definitions and formulas related with shielding effectiveness**

(ii) **Attenuation** is the gradual decrease in the intensity of a signal propagating along a medium. It is expressed in decibels per unit distance (dB/m) and calculated using the following formula (Rosencrance, 2023).

$$A_p = 10 \log_{10}(P_s/P_d) \text{ ……….. Eq.5}$$

where Ap is Attenuation of Power, Ps is Signal Power at transmitter end, Pd is Signal Power at receiver end (Rosencrance, 2023).

When Attenuation is expressed in terms of voltage, the formula is:

$$A_v = 20 \log_{10}(V_s/V_d) \text{ ……….. Eq.6}$$

where Av is the voltage attenuation in decibels, Vs is the source signal voltage, and Vd is the destination signal voltage (Rosencrance, 2023).

(iii) **Transmission coefficient** or transmission percentage is "*the ratio of the amplitude of the transmitted wave to the incident wave at a discontinuity",* and it is calculated using the following formula (FSC, 1991).

$$\Gamma = E_{trans}/E_{inc} \text{ ……….. Eq.7}$$

(iv) **Reflection Loss** (RL), also known as return loss, is a measure of the fraction of power that is not delivered by a source to a load (Steer, 2023).

$$RL_{dB} = 10\log P_i/P_r \text{ ……….. Eq.8}$$

Where P_i is the power incident on a load, P_r is the power reflected by the load and RL_{dB} is the return loss in decibels.

(v) **Reflection coefficient** is "*the ratio of the amplitude of the reflected wave to the incident wave"* and it is calculated using the following formula (FSC, 1991).

$$\Gamma = E_{refl}/E_{inc} \text{ ………… Eq.9}$$

(vi) **Absorption** is the process by which a material converts EM energy into its internal energy such as thermal energy (Baird, 2019). The EM absorption depends on material's relative permittivity and permeability (Wahba et al., 2021) thickness and density of materials, and the frequency of the EM waves (Kuma, 2016).

(vii) **Conductivity** (σ, S/m) quantifies "*the effect of matter in determining the flow of current in response to an electric field*" (Ellingson, 2023). In other words, material's ability to conduct electric current (ICNIRP, 2010). Its unit is siemens per meter (S/m). Higher conductivity value is a sign of better conductor; and calculated using the following formula.

$$\sigma = J/E \text{ ………… Eq.10}$$

where the conductivity (σ) is the ratio of the current density (J) to the electric field strength (E).

(viii) **Permittivity** (ϵ, F/m) quantifies "*the effect of matter in determining the electric field in response to electric charge*" (Ellingson, 2023). Permittivity measures the ability of a material to store energy within it. So, it is the ability of a material to polarise in response to an external electric field. Its unit is farads per metre (F/m) (ICNIRP, 2010).

(ix) **Relative Permittivity** (ϵ_r) (also known as dielectric constant) is a common way to describe the permittivity of materials relative to the permittivity of free space (ϵ_0) which is 8.854 x 10^{-12} F/m (ICNIRP, 2010); and it is calculated using the following formula:

$$\epsilon_r = \epsilon / \epsilon_0 \text{ ………… Eq.11}$$

(x) **Permeability** (μ, H/m) quantifies "*the effect of matter in determining the magnetic field in response to current*" (Ellingson, 2023). "*The scalar or* *tensor quantity whose product by the magnetic field strength is the magnetic flux density"* (ICNIRP, 2010). Its unit is henries per meter (H/m), or equivalently in newtons per ampere squared (N/A^2). The permeability (μ) is the ratio of the magnetic flux density (B) to the magnetic field strength (H):

$$\mu = B/H \quad \text{……….. Eq.12}$$

(xi) **Relative Permeability** (μ_r) is *"the ratio of the permeability of a given medium to the permeability of free space (μ_0) which is $4\pi\ 10^{-7}$ H/m"* (ICNIRP, 2010). and it is calculated using the following formula:

$$\mu_r = \mu / \mu_0 \quad \text{……….. Eq.13}$$

C. TQB Criteria for EMF

		1000
A	LOCATION AND FACILITIES ▲	200
A.2.3	Alternating magnetic fields in low frequency range ▲	10

In the planning phase

☐ Recommended distances to high frequency landlines (depending on the voltage) are respected for the planned buildings OR if the distances are not as recommended, an overview measurement on the property is required (the magnetic flux density results in a value B < 0.1 μT at representative positions). [click for more information]	3
☐ There are no buried high frequency cables at or close to the property or the recommended distances from the planned buildings to buried high frequency cables are complied with (20 m to the left and right of the route of the buried cable). If the recommendation for the distances are not complied with, an overview measurement is necessary (the magnetic flux density results in a value B < 0.1 μT at representative positions).	3
☐ There is no transformer station at this or an adjoining property or at the adjoining public ground OR if there is a transformer station, an overview measurement is necessary at representative positions of the property (the magnetic flux density results in a value B < 0.1 μT).	4
☐ Distance recommendations to the previously mentioned electrical plants are not complied with or an overview measurement of the magnetic flux density (at the property) results in a value B ≥ 1,0 μT.	0

After completion / with existing buildings

The measurement of the magnetic flux density B in exposed rooms results in a:

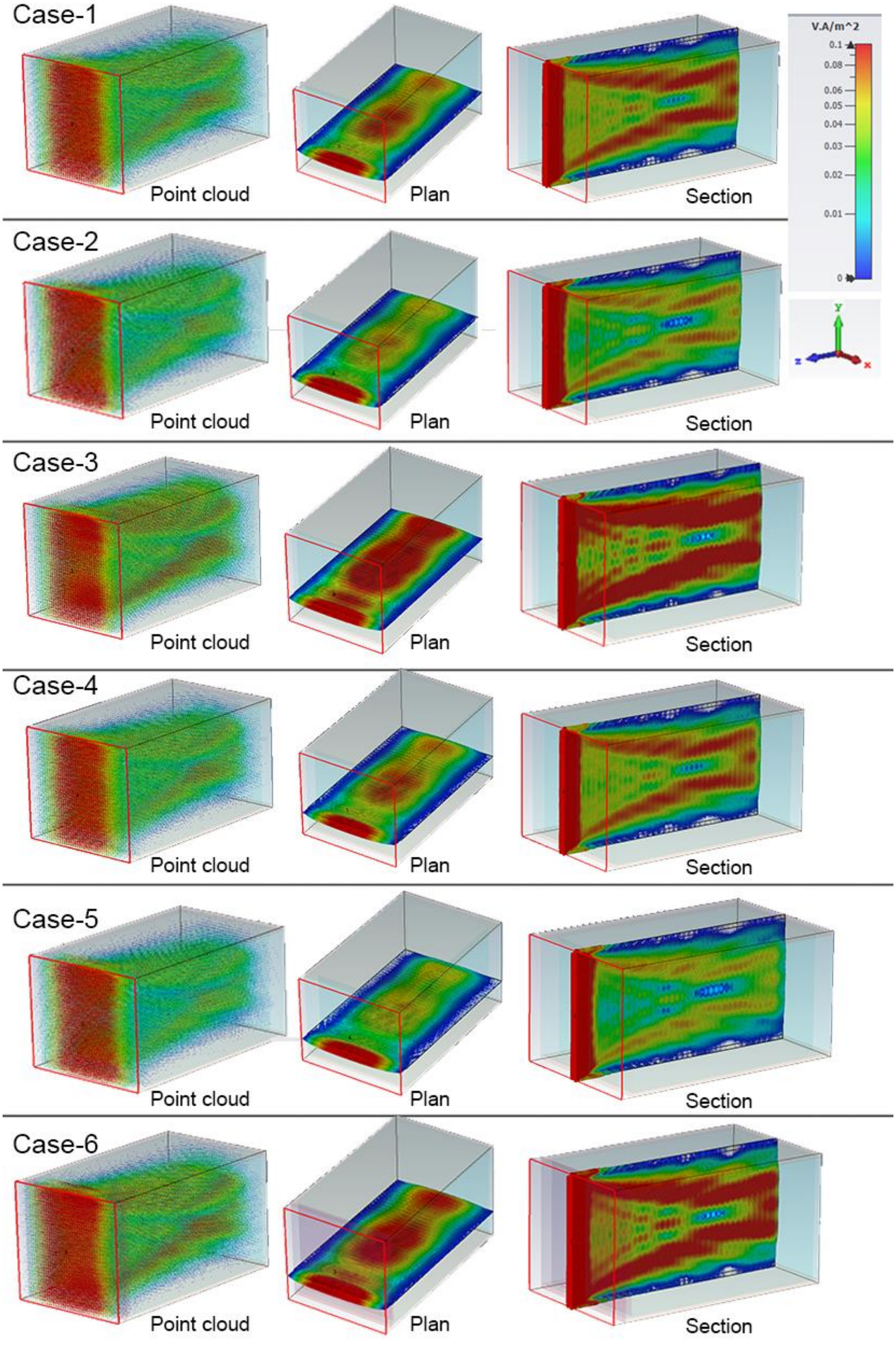
○ $B \leq 0.1$ μT	10
○ $0.1 < B \leq 0.2$ μT	8
○ $0.2 < B \leq 0.4$ μT	6
○ $0.4 < B \leq 1$ μT	4
○ $B > 1$ μT	0

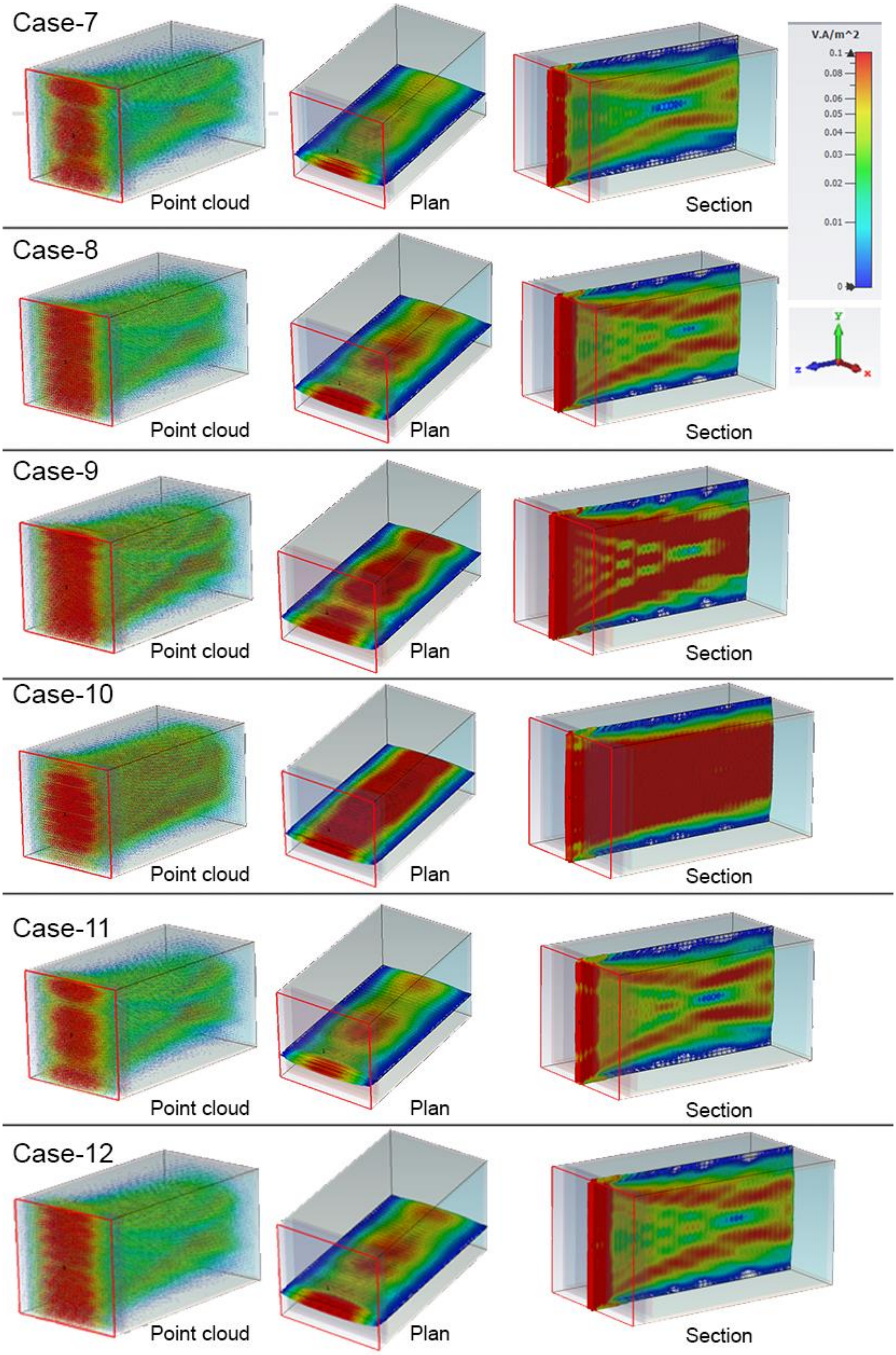
		1000
A	LOCATION AND FACILITIES ▲	200
A.2.3	Alternating magnetic fields in low frequency range ▶	10
A.2.4	Low frequency-pulsed high frequency fields ▲	10
	In the planning phase	
	○ The power flux density of low frequency-pulsed high frequency fields at all measurement positions selected to be representative is ≤ 1 mW/m². Overview measurements at the construction site are not necessary if there are no transmitters of such fields within a radius of 100 m from the property border.	10
	○ The power flux density of low frequency-pulsed high frequency fields at all measurement positions selected to be representative is ≤ 3 mW/m². Overview measurements at the construction site are not necessary if there are no transmitters of such fields within a radius of 100 m from the property border.	5
	○ The power flux density of low frequency-pulsed high frequency fields at all measurement positions selected to be representative is higher than 3 mW/m².	0
	After completion (new buildings) / with renovations and existing buildings The measurement of the power flux density S in exposed interior spaces with the windows closed results ...	
	○ S ≤ 0.01 mW/m²	10
	○ 0.01 mW/m² < S ≤ 0.1 mW/m²	8
	○ 0.1 mW/m² < S ≤ 1 mW/m²	6
	○ 1 mW/m² < S ≤ 3 mW/m²	4
	○ S > 3 mW/m²	0

Recommended distances:

- 20 kV....at least 80m
- 110kV....at least 95m
  - 220 kV....at least 120m
- 380 kV....at least 160m

D. Results for space simulations (color maps in plan, section, and 3D)

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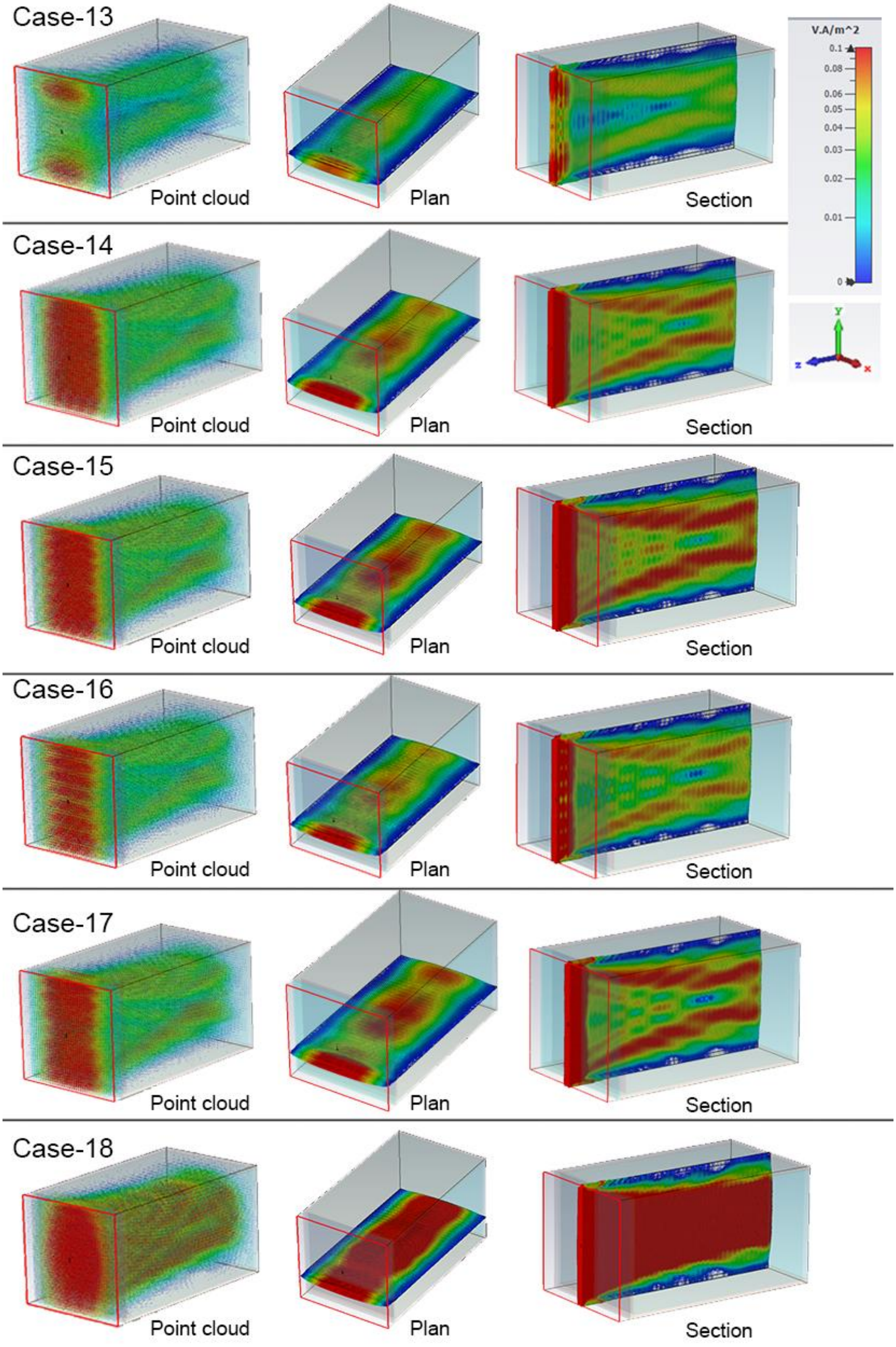
Section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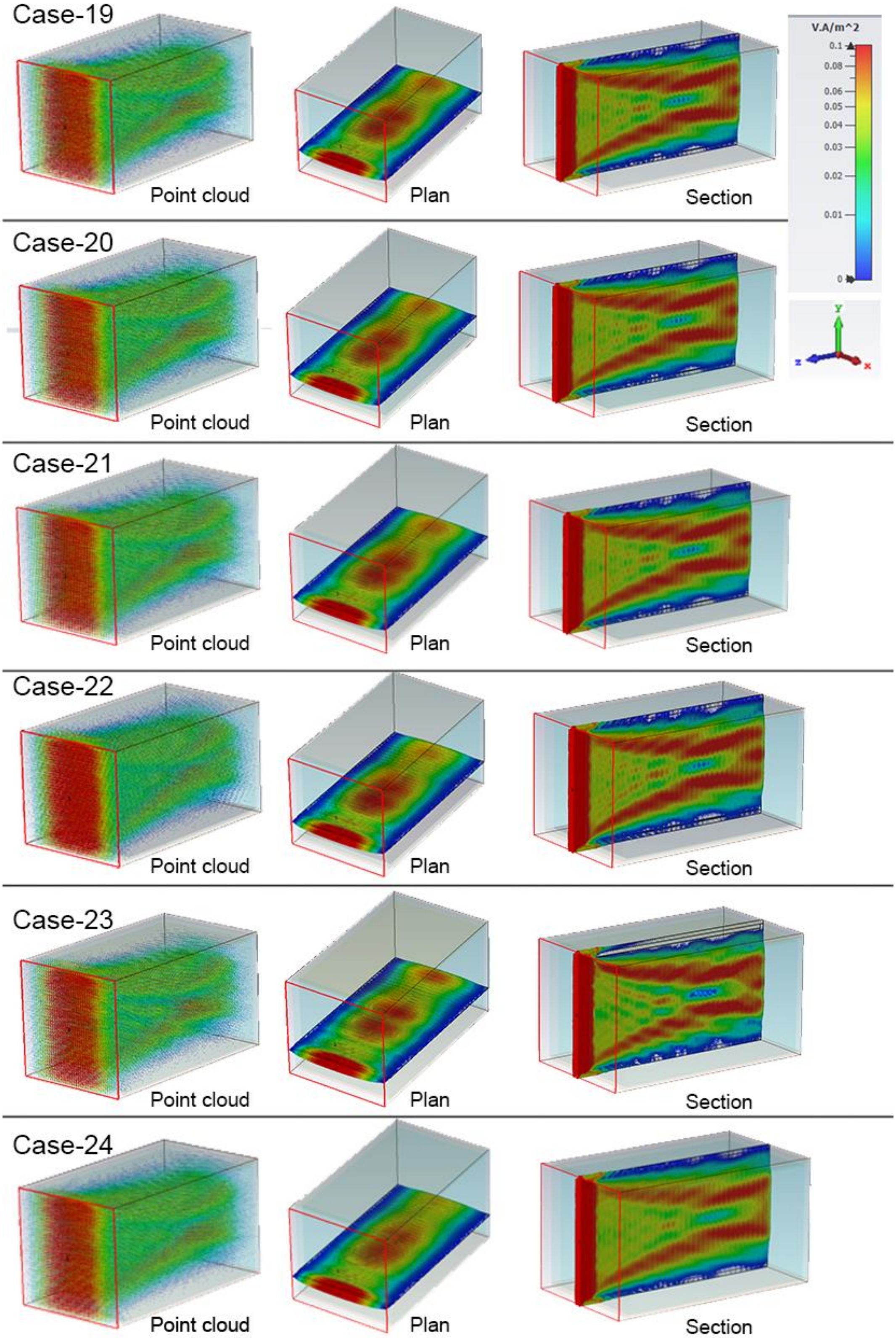
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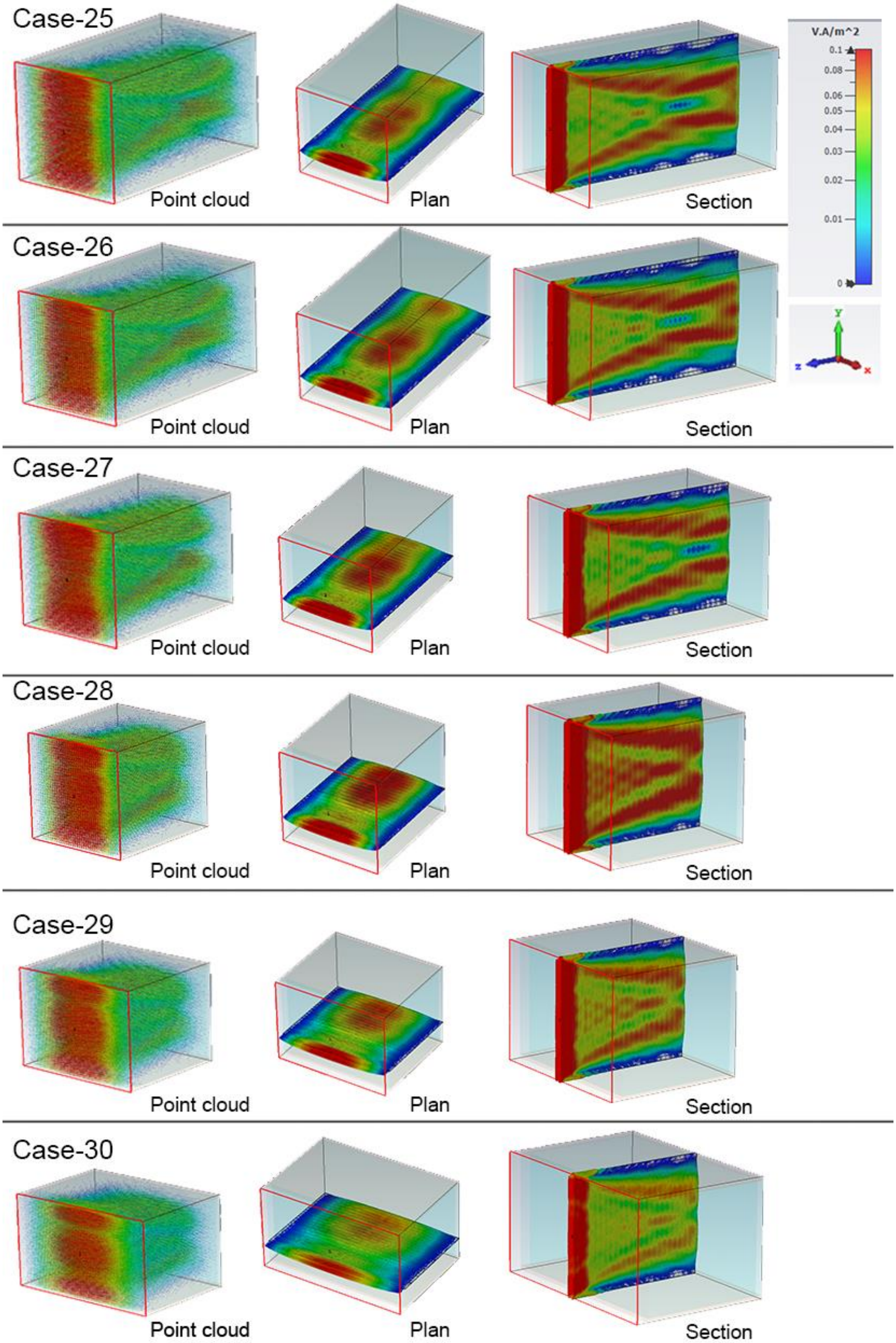
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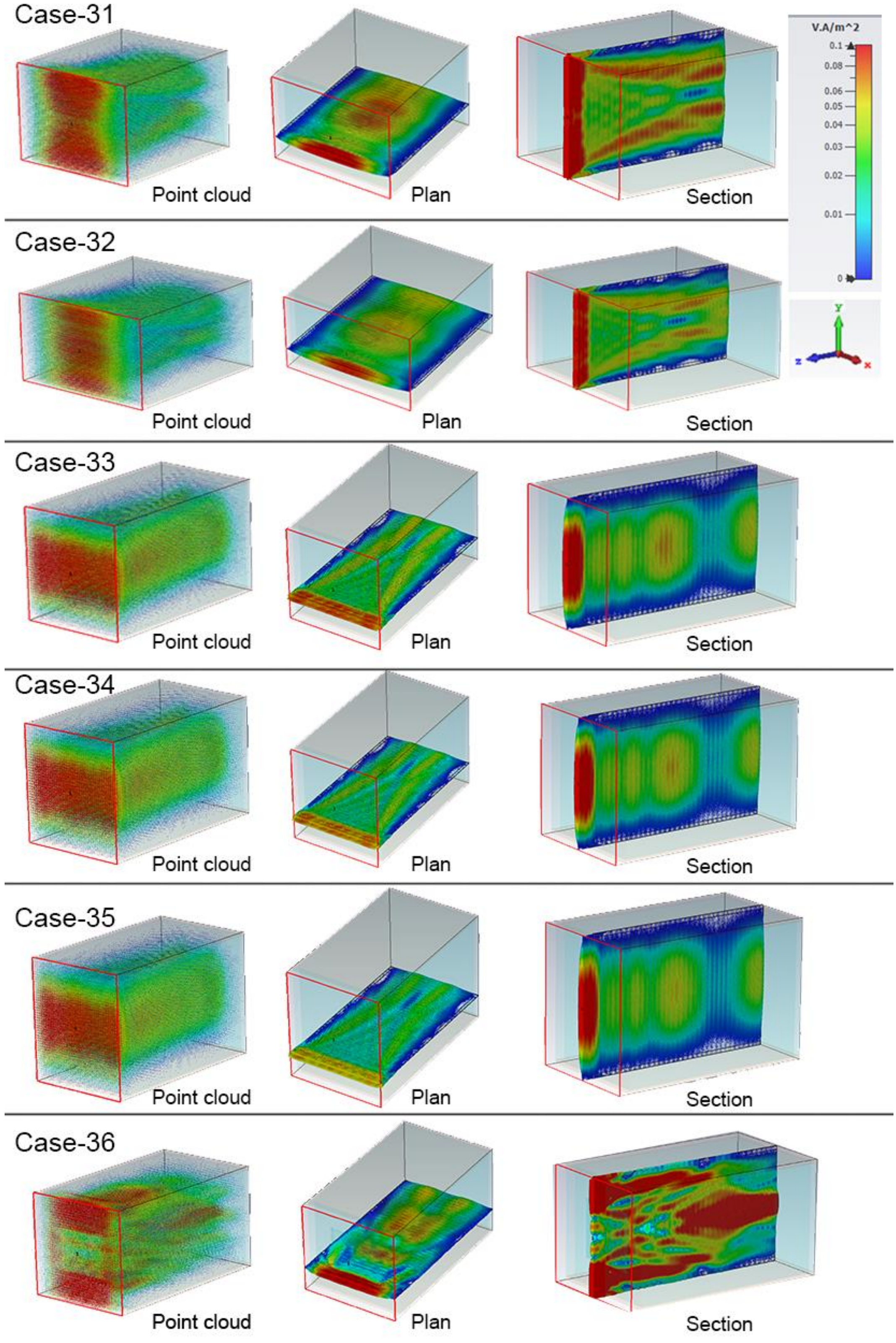
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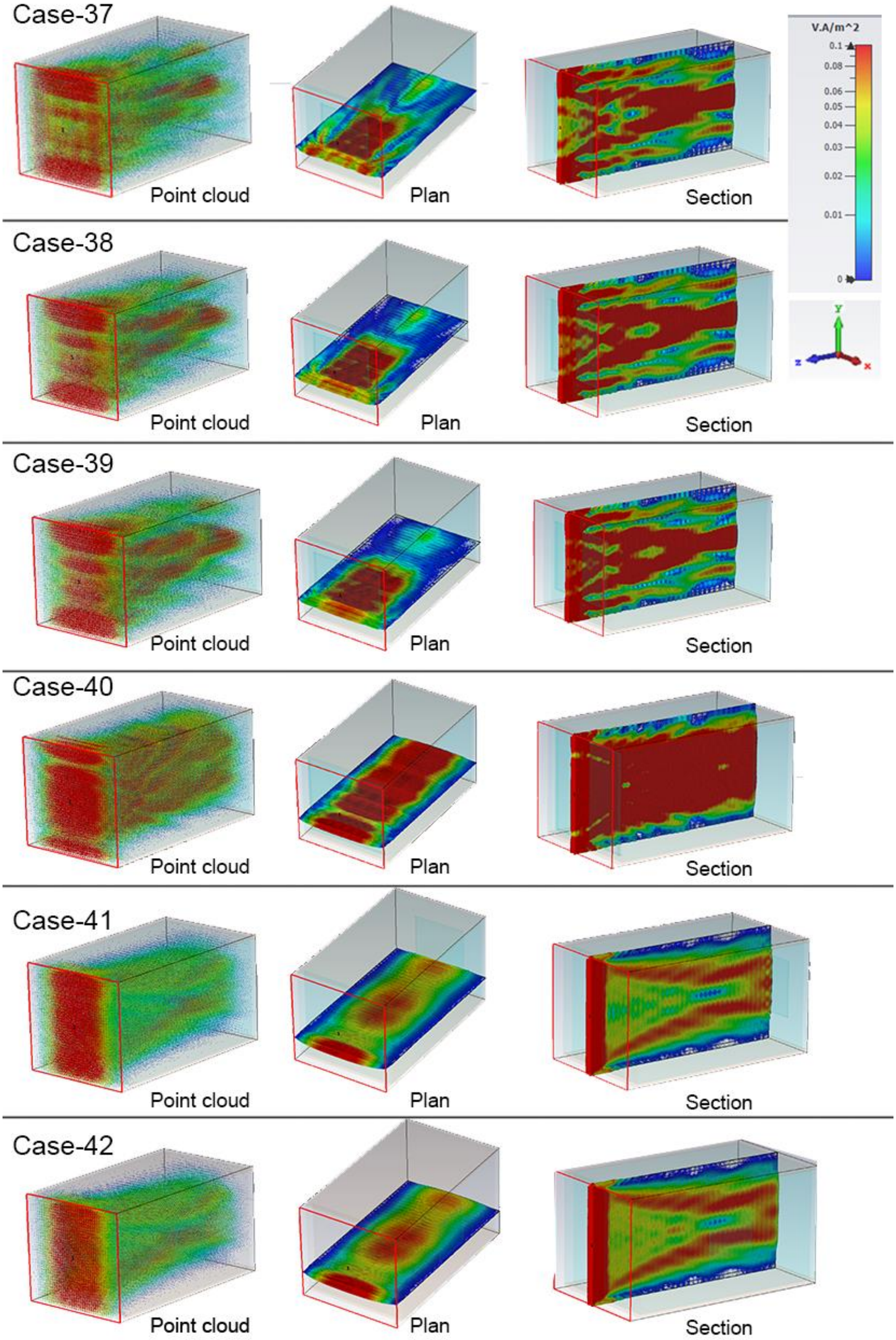
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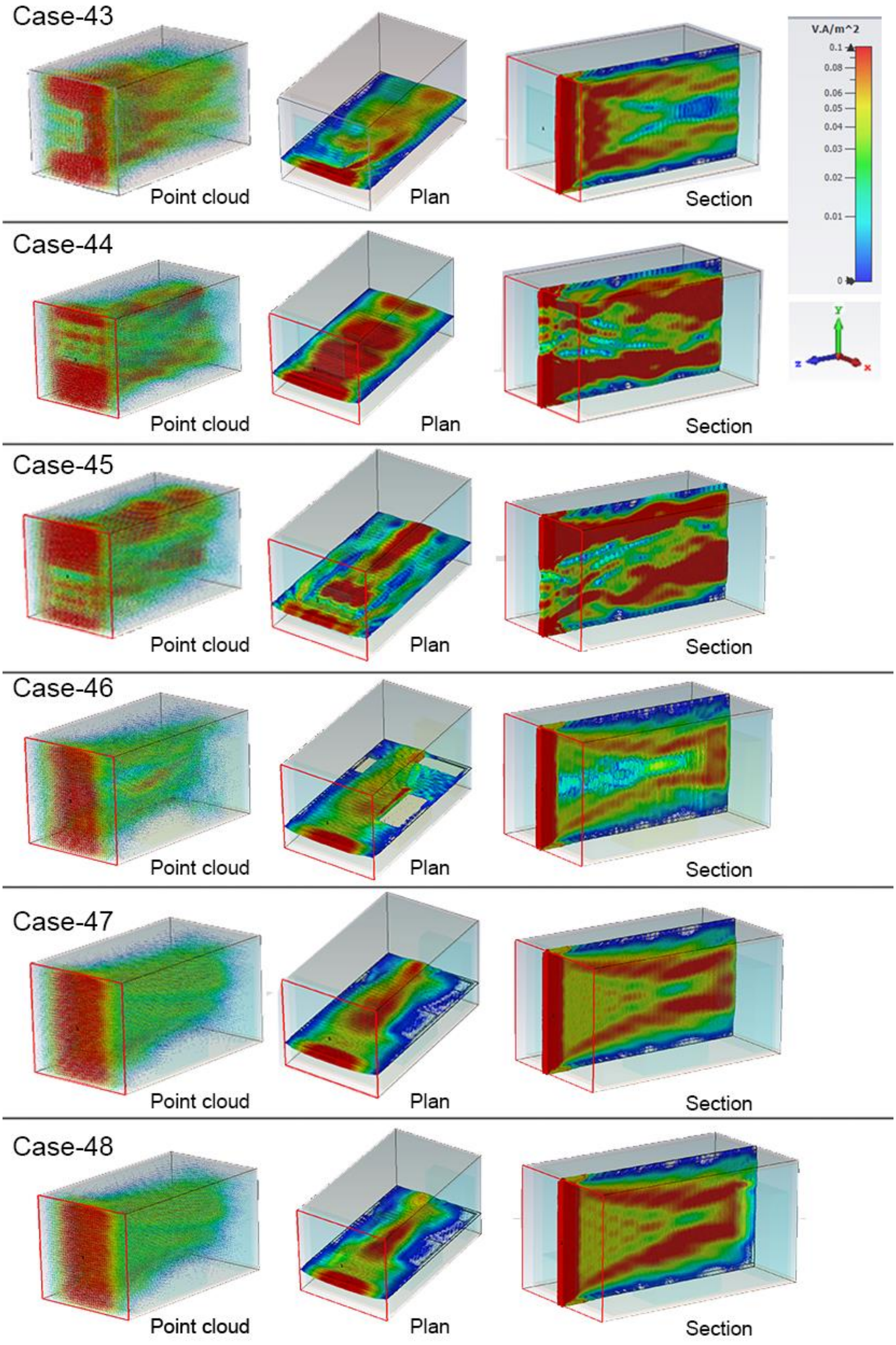
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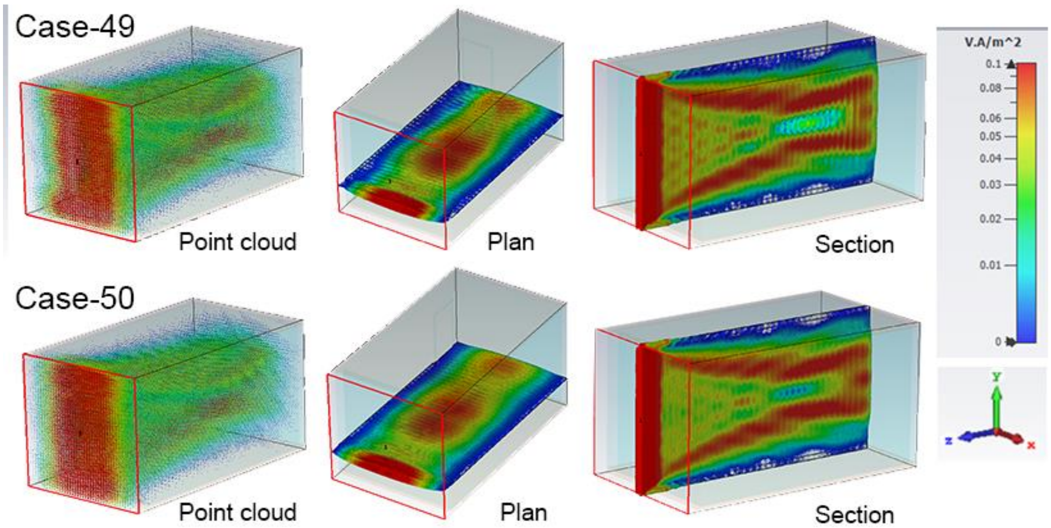
Plan
Section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BS	METU Architecture	2010

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PUBLICATIONS

1. Yöntem, S. T., Yöntem, E., Ayaroğlu, M., Kayaçetin, N. C., Çakırlar, Y. B., Tetik, B. (2012). GreenAge Symposium. In GREEN AGE 2 - 2nd INTERNATIONAL SYMPOSIUM PROCEEDING. Istanbul, Türkiye; Mimar Sinan Fine Arts University Press.

Tennis, Photography.