SZENT ISTVÁN EGYETEM

SZENT ISTVÁN UNIVERSITY

# The effect of the building constructions on the electromagnetic fields

Thesis summary
of doctoral (PhD) dissertation
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# 1. INTRODUCTION, OBJECTIVES

In the first chapter I define the significance of the topic and present the objectives of my work.

## 1.1. Topicality and significance of chosen topic

Since the appearance of mankind, one of the most important issues in society has been to provide adequate shelter and comfort, since we spend one third of our lives there. With the development of building construction science and the requirements for buildings and building structures that are getting stricter and stricter, the increasingly varied building structures have more and more functions. In addition to natural impacts, it is increasingly important to protect ourselves against artificial impacts in the cities such as noise and light, which although can come from natural sources, we protect ourselves especially against the artificially produced variants. The aforementioned effects can be felt by our sensory organs, which is why we want to get rid of their disturbance, but it is also important to be protected against the unnoticeable, the not immediately-felt effects. Such effects are radon, electric, magnetic and electromagnetic radiation.

The latter cannot be perceived by human senses, but their effects may contribute to the development of a disease. There are sophisticated instruments to detect the presence and intensity of such radiation. We are exposed to electromagnetic field artificially triggered by wireless communication technology that emerged in the early 1990s and is constantly evolving. GSM, UMTS, and wireless internet are just a few of the most popular tools that have appeared in our daily lives, and consequently raised the radiation exposure artificial non-ionizing EM fields over the past 50 years in urban environments from $1.4 \cdot 10^{-9}$ μW / to about $5 \cdot 10^{-7}$ μW / $m^2$, namely to about a 350 times higher value. It is still debated whether this electromagnetic radiation adversely affects the precise biological balance of the human body. However, it is the ethical duty of those who work in the field of science to investigate the causes of the so-called civilization diseases. Most of the research and studies in the literature investigated the propagation of electromagnetic radiation used in telecommunications in urban environments, from the point of view of propagation losses with the goal of providing sufficient coverage. But the designers of the buildings did not get any guidance on how to design, and how the planned buildings will function, and what impact the construction will have on this electromagnetically saturated environment.

## 1.2. Objectives

The aim of my research is to provide a foundation for building construction and design methods in inner electromagnetic field levels that conforms to international health recommendations and are adapted to the future architectural trends in existing buildings and in those that are yet to be built. I examine the connection between modern architectural solutions and the rapidly increasing electromagnetic effects, and I present the arising problems and their solutions.

1. In my dissertation, I present and evaluate the current standards for outside sources affecting residential homes, I also examine and evaluate the electric and magnetic fields and radiation levels that can be measured in different dwelling types.

2. By a computer model and measurements, I examine what effect the variously distributed and sized architectural openings on vertical wall structures have on indoor electromagnetic fields.

3. In addition to the effects of the materials, I research the effect and consequence of architectural spatial formation, including the geometric fractures of the structures, the non-vertical construction of the structural walls, thus I intend to examine the effect of the light weighted roof structures and the reinforced concrete roof structures.

4. My research examines the shielding capability on high-frequency and the effect of residential panel buildings with conventional reinforced-concrete wall panels.

5. My aim is to optimize the layer sequence for building boundary structure, which has the capability to reduce the level of indoor electromagnetic radiation beyond international standards to the level of international recommendations.

# 2. MATERIAL AND METHOD

In this chapter, the experimental methods and tools are presented that have been used to accomplish my research goals. As a first step, I developed a process for interior measurements, then I made measurements through simulations using CAD software to which I added measurements in an anechoic chamber, where I examined brick walls covered with various grid density metallic net.

## 2.1. Measurements in real environment

I made low frequency measurements in different homes using a Gigahertz Solution NFA 1000 device, which is a 3D analyser between 5Hz and 1000kHz. I made the measurements on ELF-EF and ELF-MF in two steps. First, I measured the electric fields, then the magnetic fields starting from the entrance walking round in the room first by the walls, then in the middle. I paid attention to the beds, since this is the place where a person stays still for the longest time for relaxation.

The measured value of the field is continuously displayed on the device. I noted these values on a previously made floor plan at about 1-meter distances or at those places where the value was outstandingly low or high. I noted down the values exactly at the place where I measured it. Later, I recorded and evaluated these values in a spreadsheet in a computer. I examined the average value of ELF-EF and MF fields inside the apartment, compared the average values between different rooms, and I also evaluated the field distribution in the individual rooms.

I have used a Gigahertz Solution HF59B High frequency analyser with a triangular antenna for 800MHz-2,5GHz. With this tool I walked slowly around the room turning around many times to observe what the direction of the highest irradiation is. I marked the directions with red arrows on the floorplan and noted down the value next to it. Since my main interest focused on the effect of outside or uncontrollable sources, I always asked the owner of the dwelling place to turn off the Wi-Fi router if there was one. In most cases, the radiation came from the direction of the façade wall, and in some cases from a neighbouring Wi-Fi router.

## 2.2. Simulations on buildings

Since it is not reasonable to build a building according to the various possible scenarios, I used the CST Microwave Studio software, a full wave electromagnetic solver. It performs the analysis by making use of powerful numerical techniques, in this case, the Finite Integration Technique which in time domain approaches the FDTD method.

In a virtual building which was created in the CST program through series of simulations, I examined the effect of the size of the room, the placement and size of the windows, and the size of the wall between windows on the inner electromagnetic radiation.

The selected virtual building is actually a room with outer dimensions 5.0 m x 3.6 m x 3.3 m. The walls, the roof, and the floor consist of concrete slabs of 30 cm thick. The characteristics used for this material in the simulations are selected from the material library in the electromagnetic simulation software used: CST's "one-year old concrete". The real part of the permittivity is 5.608 and the imaginary part is 0.217, which is in agreement with the values described in the literature. Later, I placed a door and windows in this reference building. For boundary conditions, open boundary was chosen. The minimal distance between the structure and the simulation surface is 1/8 wave length.

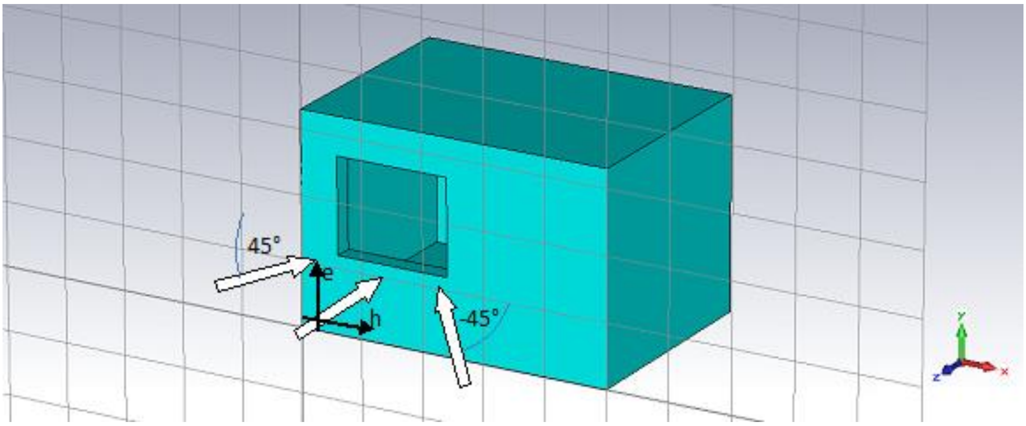


Fig. 1. The chosen reference building, and irradiation scenarios used. The window depicted is just an example.

The directions-of-arrival chosen are all horizontal, which is very common in real situations, and the angles are 90°, 45°, and -45°. The considered frequency is 1 GHz. This is very close to the 900 MHz GSM band. The amplitude chosen is 1 V/m. However, since the problem considered is a linear one, the other amplitudes are easily accommodated for by just using proportionality. The polarization considered is vertical. The reason for this is that this type of polarization is used the most often, since it propagates the easiest above the conducting earth.

Two horizontal planes were selected. They conform to two situations: sleeping height at 0.5 m, and sitting height at 1.40 m. According to Le Corbusier's modular system this is where people's heads remain still for longer periods of time.

### 2.3. Measurements in anechoic chamber

Besides the simulations, I made measurements in the anechoic chamber of the Telecommunications and Microwaves Department at KU Leuven, in Leuven, Belgium where I tested metallic nets with different grid density to determine their shielding ability. The chosen frequency was between 900MHz and 3 GHz, the amplitude chosen was 1 V/m. The measurement was done on a 1m x 0,75m, 30 cm thick porotherm brick wall, first in front of which, on the second measurement series behind, I placed a 1,25x 1,25 cm, 2,5 x 2,5 cm grid with a 0,65 mm diameter aluminium and a 5 x 5 cm grid with a 1,4 mm diameter coper net. The net was mounted on a cardboard, so it was easy to place in front of or behind the brick wall.

Fig 2. The arrangement of the measurement in the anechoic chamber with two Hyperlog antennas

I did measurements with two Horn antennas and with two Hyperlog antennas as well. The distance between the two antennas at first was 150 cm with one antenna being 15 cm behind the wall. I also made two control measurements. First, I changed the distance from 150 cm to 140 cm. At the second measurement, the antenna behind the wall was placed into an aluminium box in order to exclude any possible reflective radiation. The signal strength values which was recorded by a computer was compared to a reference signal strength without the bricks and was evaluated with the MATLAB program.

I had several aims with the measurements performed in the anechoic chamber. On the one hand, I examined at which grid density can I measure effective shielding and I also examined whether the shielding net was more effective when it was in front of or behind the brick wall. I have verified the validity of the general principle whether shielding was more effective if placed on the side where the source is located.

Examining the grid density is important because we can get an answer to the question whether reinforcements in the reinforced concrete provide any shielding or not. In other words, do buildings constructed from reinforced concrete panels or with sliding formwork have a shielding effect similar to Faraday's cage?

At the same time, the aim of architectural procedures is not to completely exclude the radiation used for high-frequency telecommunications, thus it is necessary to determine the range from which the shielding is already effective, but only to a desired level.

# 3. RESULTS

In this chapter, I present the new scientific results of my research work, which contributes to understanding the effect of building constructions on the electromagnetic fields and provides help to reduce the inner electromagnetic levels.

## 3.1. General Conclusions on the Electromagnetic Aspects of Housing

I have ascertained through measurements near high-voltage power lines as external sources, that even though the prescribed 13 m clearance was kept I measured twice the amount determined by WHO and building biologists, and a 20 times higher value than the average of what I have measured in buildings that are not near to high-voltage power lines.

### *3.1.1. Electromagnetic characteristics of dwelling types*

I made measurements in 46 flats, where I observed, that within specific building types, for example block of flats, downtown apartment houses, lately built multi-storey residential houses, the measurement results are similar among those flats that belong to the similar type of building, but significantly differ if those flats are compared that belong to different types of buildings. I have presented that the values measured in low frequency are at least twice as high in the downtown apartment buildings as in the panel residential buildings, yet in high frequency I got the opposite result. The measured power density in the downtown apartment houses is one tenth of the power density measured in the panel residential buildings. As I explained, this is due to the constructional difference in the elevation wall, to the difference in the proportion of the openings on the elevation wall, and to urban planning methods. Various types of dwellings therefore require differentiated treatment. We need to differentiate between the apartment buildings made of brick built before 1920 (the so-called tenement houses), panel residential buildings and detached houses.

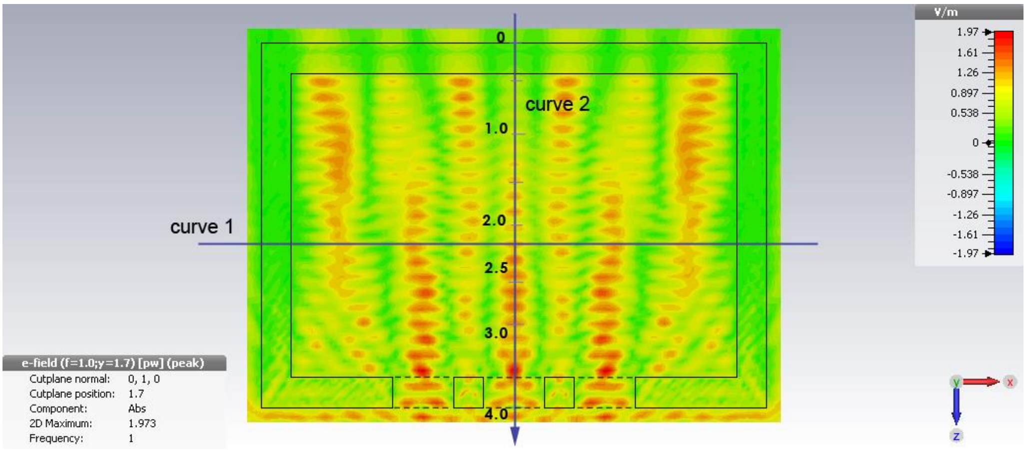
### *3.1.2. The role of grounding in the value of electric and magnetic field*

In the process of performing measurements in low frequency, it became clear that the presence or absence of grounding of electric systems affects the magnitude of the low-frequency indoor electrical and magnetic fields. In electric field, I measured a difference that was 3- to 10, in magnetic field 2 to 4 times the magnitude in earthed and not earthed dwellings. I have also stated that, with certain household appliances, the position of the plug in the socket makes a difference, because I measured between a 1.5 to 3 times difference in the resulting electric field. After the renewal of the electrical system, which was investigated in two buildings, electric fields decreased on average by 50%, the magnetic field in one case decreased negligible in average and in the other case it decreased to 83%.

## 3.2. The effect of architectural openings on indoor electromagnetic fields

Using international research that also apply computer simulations in high-frequency and the experience of my own measurements, I examined how a building or part of a building affects electromagnetic fields. My observations on the size of the room and the location and division of the windows revealed that they have a negligible effect on indoor electromagnetic radiation (Fig. 3).

When examining the wall sections between windows, however, I found that the lowest level of electrical and magnetic fields were formed at the 50 cm wall section, and the largest at the 20-30 cm range which is commonly used in architecture.



e-field (f=1.0;y=1.7) [pw] (peak)
Cutplane normal: 0, 1, 0
Cutplane position: 1.7
Component: Abs
2D Maximum: 1.973
Frequency: 1

Fig. 3.On curve 2 the value of E-field is indicated, in case there are three equally sized windows with 30 cm distance on the elevation.

In addition, I examined the shielding possibilities of the interior in a series of simulations and examined how much radiation attenuation can be achieved by shielding the different structures. I have shown that shielding the walls alone results in a higher radiation value than the unshielded state since the shielding layer on the back wall reflects the waves entering through the window, which additively interfere with the incoming waves, thus result in higher maximum values. By shielding only the windows, however, this reflective effect can be reduced, but due to the poor shielding ability of the walls, a significant decrease in indoor radiation cannot be measured. Thus, I found that window shielding is important, what is more, shielding the window is a more effective method than just shielding the wall.

It is recommended to have a smaller window-facade wall ratio, of course, keeping the required lighting ratio (1:6 illumination: floor space). From an electromagnetic point of view, it is preferable to use more windows with 50 cm wall between them than a single large window, unless the window is protected from electromagnetic radiation, in which case it is more appropriate to have fewer and bigger windows than smaller ones.

## 3.3. Effect of delimiting structures on electromagnetic fields

### *3.3.1. The effect of architectural shaping on indoor electromagnetic fields*

In electromagnetics it is well known that the rounding of corners can alter the diffraction of waves in a given corner. To examine this effect, I rounded the corners of a room with the same radius as the thickness of the wall. The study showed that the pattern remains similar, and the maximum values measured at the same point are reduced only to a negligible extent. Tests of window openings did not show much difference either in cases of squared or rounded corners or window bezels.

Taking the rounding method further, in the next simulation series, I changed the form of the reference building keeping the same floor space area. I investigated how electromagnetic radiation behaves in circular and octagonal areas, and in both cases I measured concentrated additive interference by the center axis of the irradiation direction, especially in the windowed room. In the case of a windowless room, the waves interfered additively in points (Fig. 4).

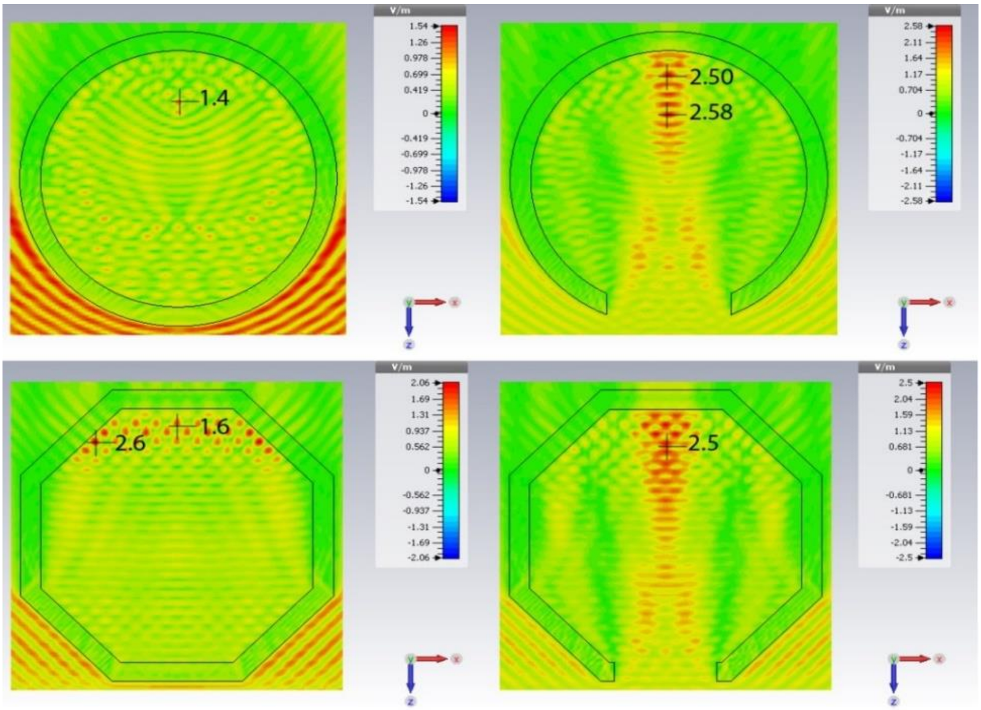


Fig. 4. The electric field of regular circular and octagonal ground floor-plan rooms

To approximate the irregular spaces typical of modern architecture, the reference building was truncated with different planes and I examined the changes in the indoor radiation. In the case of truncation, I observed that on the side where the corner was truncated it was lower, on the opposite side higher maximum values were generated than in the untruncated reference building (Fig. 5).

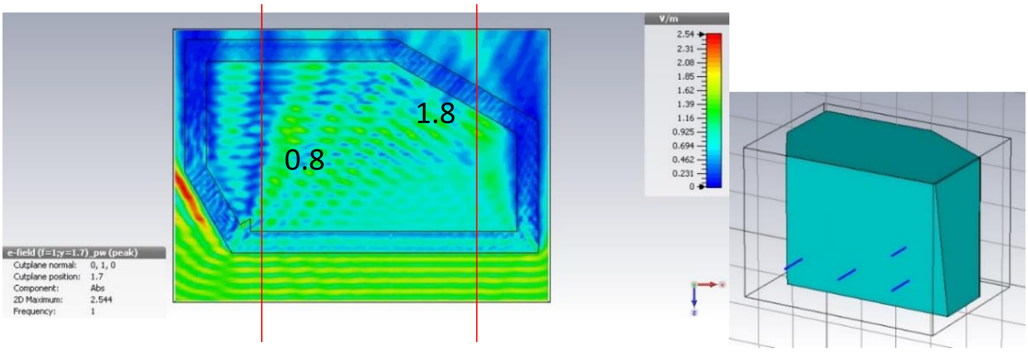
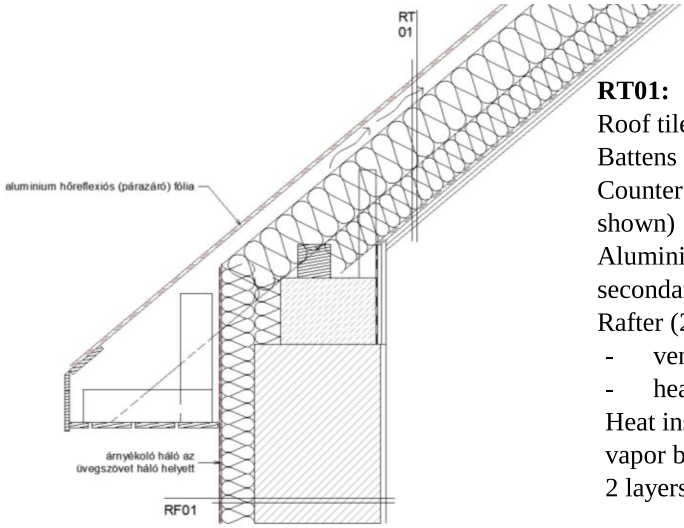


Fig. 5. Field distribution of a building which is truncated on three sides with the maximum value measured along the two line (left) and the shape (right)

### 3.3.2. *The effect of attic structures on the electromagnetic field*

The attic design test proved that effective shielding can be achieved if the outer vapor permeable foil in the layer sequence is an aluminium coated heat-reflecting foil, because it reflects electromagnetic radiation (Fig. 6). Otherwise, due to the additive interference of the waves reflecting from the built walls of the interior, points of greater value are generated than radiation from the outside.



**RT01:**
Roof tiles (not shown)
Battens (not shown)
Counter battens (ventilated air gap) (not shown)
Aluminium heat reflexive (vapor barrier) secondary waterproof layer
Rafter (20/12) between:
- ventilated airgap 5 cm
- heat insulation 15 cm

Heat ins and frame 10 cm
vapor barrier foil
2 layers gypsum boards

Fig. 6. The placement of the aluminium secondary waterproofing foil for attenuation in the layer sequence

When examining the cross section of a “coffin-shaped” reinforced concrete roof slab, I found that the power density is concentrated on the opposite side of the irradiation, and when the height of the jamb wall is increased, the concentrated area does not rise but moves slightly downward.

## 3.4. Attenuation of regular reinforced concrete walls in high frequency

I ran simulations on reinforced concrete walls with the usual structural reinforcement densities. Computer simulation of the reinforced concrete wall was made from 1 cm diameter rods in concrete walls with steel grid inserts with different grid densities. Through this examination, I found that the traditionally applied 20 or 10 cm steel mesh provides very low shielding capability, therefore the residential buildings built from reinforced concrete panels do not work as Faraday cages. When examining material properties, I also found that a 50 cm thick solid brick wall has better shielding capacity (7.74 dB) than a reinforced concrete wall with 5x5 cm steel reinforcement (6,10 dB).

Table 1. Attenuation of walls from different materials based on simulation results

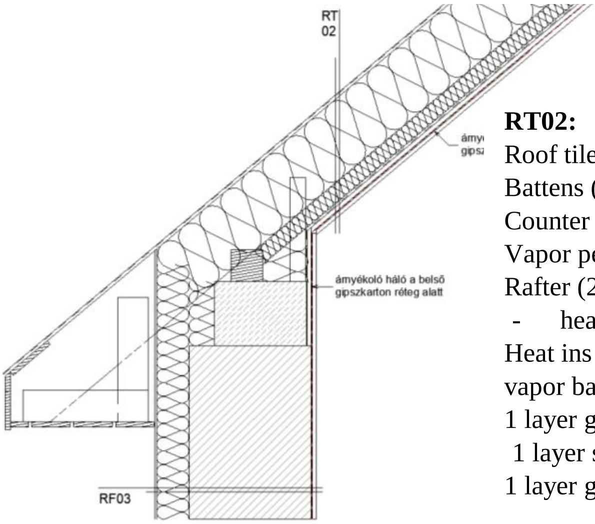
| Material | thickness | In reference building | |
|---|---|---|---|
| | | E- field | SE |
| Brick | 50 cm | 0.41 | **7.744 dB** |
| Concrete | 30 cm | 0.903 | 0.886 dB |
| RF concrete 20x20 | 30 cm | 0.86 | 1.310 dB |
| RF concrete 10x10 | 30 cm | 0.84 | 1.154 dB |
| RF concrete 5x5 | 30 cm | 0.495 | **6.107 dB** |

## 3.5. Grid density and location of the built-in electromagnetic attenuation layer

To comply with the standards, electromagnetic radiation can be reduced to the level of international recommendations using a metal shielding layer or mesh. The shielding calculated by the simulations and measured in the anechoic chamber becomes effective at 1 GHz from 5x5 cm, at 2.4 GHz from 2.5 x 2.5cm grid density (5-9 dB). My studies were conducted by halving the grid density. At 1 GHz frequency with a 2.5x 2.5 cm grid, depending on material and diameter from 8 to 14 dB, with a 1.25 x 1.25 cm grid 20 dB, with a 0.625 x 0.625 cm grid 25 dB shielding value was achieved. At 2,4 GHz frequency I received a shielding attenuation value of 15 dB in the case of a grid of 1,25x1,25 cm and 20 dB with a 0,625x0,625 cm grid. 6 dB attenuation means that the penetrated radiation is half of the irradiation value, 12 dB means it is one-fourth, 20 dB means it is one-tenth.

The measured average density of 10 μW/m$^2$ in the dwellings, which is categorized as a 'strong anomaly' by building biology assessment, can be reduced to one tenth with the 0.625x0.625 cm grid mesh according to my results. The values below the power density of 5 μW/m$^2$ are classified as 'weak anomaly' but it still provides the possibility of telecommunication. The aimed and achieved power density with this shielding is 1 μW/m$^2$.

The metal mesh should be placed on the inside to avoid condensation. Installation suggestions are shown in the following figure 7.and 8.



**RT02:**
Roof tiles (not shown)
Battens (not shown)
Counter battens (ventilated air gap) (not shown)
Vapor permeable secondary waterproof layer
Rafter (20/12) between:
- heat ins 20 cm

Heat ins and frame 5 cm
vapor barrier foil
1 layer gypsum boards
1 layer shielding metallic net
1 layer gypsum boards

Fig. 7. The proposed location of attenuating metal mesh is in the layer sequence

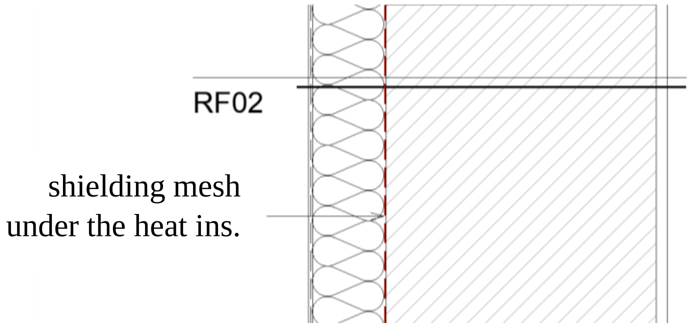


Fig. 8. The recommended location for a metal fabric mesh for facade insulation.

# 4. NEW SCIENTIFIC RESULTS

To Sum up the results of the measurements and calculations conducted, I have demonstrated the effect of building structures on high-frequency electromagnetic radiation, furthermore I gave a solution to reduce the electromagnetic load within the building. My new scientific results can be found in points listed below:

1. *Possibility of grouping flats based on electromagnetic fields by residential building types*

I have found that electric field, magnetic field and electromagnetic radiation of a similar magnitude can be measured per building type, therefore flats in different types of residential buildings can be differentiated by inner electromagnetic values. The reason for this is that in low frequency the electric and magnetic field is higher (20-187 V/m, 31-82 nT) in the brick residential buildings built before 1946, compared to residential buildings built from block bricks or reinforced concrete panels (1,6-54 V/m, 21-41 nT). Meanwhile, on high frequency the electromagnetic radiation is higher in residential buildings built with RF panels (12-94 $\mu W/m^2$) compared to the ones with brick walls (3-7 $\mu W/m^2$).

With regards to the electric and magnetic fields I have found that in old brick buildings, often the non-grounded electrical networks cause greater electric and magnetic fields in low-frequency than the newly constructed networks. I have presented that by renewing the electrical network of flats, an average 50% reduction in electric fields can be achieved.

2. *The effect of architectural openings, and their shielding on the inner electromagnetic fields*

In regards to the openings on the building, I proved that the distribution of electromagnetic radiation changes in the interior spaces without shielding, but the maximum value remains the same regardless the placement of the same sized openings on the facade. I proved that shielding only the wall - without shielding the window - greatly increases the internal electromagnetic field load (from 1 V/m to 3,13 V/m). If one can choose between shielding the windows or shielding the walls, shielding the windows can achieve significant results (from 1 V/m it rises only to 1,25 V/m).

3. *Effect of delimiting structures on electromagnetic fields*

I have proved that the maximum value of electromagnetic radiation in indoor spaces with an unshielded wall structure is greater in certain points than the irradiation value outside the building. With regard to the high-frequency electromagnetic radiation behavior of building structures, I have shown that electromagnetic waves are distorted due to the geometric change caused by the corners and wall sections, generating hot spots in the electromagnetic interior, which are only negligibly attenuated with rounding. Similar amplification bands are created horizontally by the reinforced concrete “coffin-shaped” roof structures. At a 45-degree roof inclination, the wave concentration is approximately at 1 meter height and moves slightly downward by increasing the height of the jamb wall.

### *4. Shielding of traditional reinforced concrete wall structures in high-frequency*

I proved that buildings with reinforced concrete walls and with regular reinforcement (grid 20 cm) do not behave as a Faraday cage and do not attenuate the electromagnetic radiation on the examined 900 MHz high-frequency and above.

### *5. Grid density of the shielding against EM waves placed in the structure*

I concluded, that the building materials used in the building constructions are in themselves not suitable for effective shielding, also to avoid too thick walls. At the same time, the necessary level of exclusion of external radiation from the building, and the reduction of electromagnetic radiation of interiors to the level of international recommendation ($<5\ \mu W/m^2$) can be achieved by the correct selection of the layer system that includes the installation of an electrically conductive mesh with a density corresponding to the target shielding purposes. For this, effective shielding at 1GHz was obtained with 1.25x1.25 cm, at 2.4GHz with a 0.625x0.625 cm grid density, causing the penetrated radiation to fall to 1 / 10th of the irradiation value.

# 5. CONCLUSION AND PROPOSALS

On the basis of the reasons described above, it can be said that in the 21st century electromagnetism from an architectural point of view raises a problem that has not been considered in architecture, which must be taken into account by architects today and in the future, and if necessary technical solutions should be applied. For this, it is necessary to provide guidance and a set of criteria for the architect. Due to the behaviour of waves, the electromagnetic phenomena of the interiors should not be treated merely with instinct. With the help of measurements and simulations it is necessary to make appropriate design proposals.

From the results, the following recommendation can be formulated as a proposal:

If necessary, protection can be achieved against radiation emitted by internal sources by control, conscious usage, and appropriate design. It is recommended not to place aWiFi router which is a high-frequency radio source in a bedroom. For the wall of the bedroom, the proposed shielding requirement is a 12dB, which can be achieved by embedding a metallic grid layer of 0.625 x 0.625 cm into the plaster. With this, the power density level remains suitable for use (-77dBm).

Different types of apartments require different treatment. We have to differentiate between apartment buildings made of brick built before 1920 (so-called tenement houses), residential panel buildings made of RF concrete panels, and detached family houses. It is recommended to check the grounding of the electrical networks, or to renew the whole network, mainly in the case of the older apartment buildings made of brick. It is recommended, that the wiring is placed under the ceiling at aprox. 50 cm and not approx. 50 cm from the floor at the height of the bed and the seating furniture mainly in the bedroom. In addition to the soundproofing requirement, the separating walls of the apartment houses must be built with a minimum 20dB electromagnetic radiation reduction requirement. For this, the 30 cm thick flat separating bricks (on 2,4 GHz: 9 dB) in itself is not suitable. If necessary, protection against radiation from external sources can be achieved by shielding, conscious design of the shielding in the structure of the building with particular attention to the shielding of architectural openings.

As a suggestion, I recommend, however, that when designing the offices, the layout of the workstations is the same as the placement of beds in the apartments, since the worker sits in the same place with a little movement for about eight hours a day.

Finally, I would like to draw attention to the effects of different personal usage, although examining this is not part of my task. An example for this is mobile phone use, as the radiation emitted by the phone increases during use, which is a feature of normal operation. Effects of devices brought into the room, may it be one’s own or belonging to others, and if necessary, the possible methods of personal protection against such sources can be the subject of further research.

# 6. SELECTED PUBLICATIONS RELATED TO THE THEME OF THE DISSERTATION

*Proofread articles in an international language:*

1. **Gergely Vizi**, Guy A. E. Vandenbosch, (2015): Building materials and electromagnetic radiation: The role of material and shape, Journal of Building Engineering pp. 96-103
2. **Vizi G.** (2015) Comparing examination of electromagnetic field levels in downtown apartment houses with flats in housing estates, Hungarian Agricultural Engineering No. 28/2015, pp. 34-38, HU ISSN 0864-7410, DOI: 10.17676/HAE.2015.28.34

*Proofread articles in Hungarian:*

3. **Vizi G.,** Szász A. (2012): Lakások elektromágneses mértéke és ezek csökkentési lehetőségei. Víz, gáz, fűtéstechnika, Épületgépészeti szaklap XIII. évfolyam 6. szám, 74-79. o., ISSN 1786-8238

4. **Vizi G**., Szendrő P., Szász A. (2013): Elektromágneses tér kibocsátás különböző környezetben. Mezőgazdasági Technika, LIII. évf. május, 5-7. o.

5. **Vizi G.,** Vandenbosch G. A. E. (2015) Beltéri elektroszmog - Az építészeti nyílások hatása, Magyar Építőipar 5 szám, 2015. nov, 193-200.o.