Monitoring of Electromagnetic Radiation with an Impact on the Human Factor

Prof.PhD.Eng. **Mariana PANAITESCU**[1*], Prof.PhD. Eng. **Fănel-Viorel PANAITESCU**[1], Student Drd. **Marius-Valentin DUMITRESCU**[2]

[1] Constanta Maritime University

[2] Doctoral School of Energy, POLITEHNICA, Bucharest

* panaitescumariana1@gmail.com, mariana.panaitescu@cmu-edu.eu

Abstract: *The strong media coverage of the negative consequences of the polluting factors has created in the society a culturalization of the population in this direction. Real-time knowledge of indoor and outdoor air quality, water quality, noise pollution level, or electromagnetic radiation level are requirements of today's society. The demand for devices to monitor these pollutants has increased substantially in recent years. Electromagnetic radiation monitoring devices are also part of the increasingly demanded devices. The current market offers such devices, which have a high cost price, which can usually indicate only the presence of electromagnetic radiation but do not indicate the volume or area of radiation and do not even integrate their amount.*

Summarizing these inconveniences makes such equipment rare, monitoring the amount and sources of radiation being difficult or even impossible to achieve, the volume of data being small and inaccurate can not help achieve a correct picture of the phenomenon and adopt correct prevention policies or combat the phenomenon.

Thus, the need to develop a universal device for monitoring electromagnetic radiation called (EMR-MUD) has arisen. It complements the family of universal monitoring devices Indoor Air Quality Monitoring Universal Device (IAQ-MUD) and Outdoor Air Quality Monitoring Universal Device (OAQ-MUD) improving the image of pollutants.

It is able to monitor several areas of interest in the spectrum of electromagnetic radiation, built for indoor and outdoor spaces, to be reduced in volume, (possibly) portable, low price, maintenance close to zero, Internet connectivity for data acquisition and creation of databases for the elaboration of strategies for prevention and reduction of the monitored phenomena. With this device made in our own laboratory we can make:

- *Recording individual values for each monitored area;*
- *Local registration of monitored data and values;*
- *Issuing alarms when the limit values are exceeded;*
- *Online access to data for processing and analysis;*
- *IoT compatibility.*

Keywords: *IoT, IAQ, OAQ, 5G, Electromagnetic Radiation*

1. Introduction

The interaction of electrical or electronic equipment - electromagnetic environment is a dynamic reality and permanence. There is a continuous evolution of this interaction. New technologies create vulnerabilities in equipment that did not exist in the past and at the same time change the structure of the electromagnetic environment. The electromagnetic immunity of electrical and electronic equipment must constantly keep pace with technology, to cope with the dynamism and evolution of the equipment-environment interaction.

On the other hand, the requirements that electrical and electronic equipment must meet in terms of immunity and electromagnetic emission in order to be marketed have been regulated by national and international bodies. The regulations established the mandatory characteristics of the stands and test equipment in order to reproduce the reality as accurately as possible. But a closer look at immunity standards identifies their limits in mirroring a much more nuanced reality [1,2]. It also identifies inconsistencies and possibilities to unify the evaluation of similar phenomena. For accuracy and repeatability, current standardized testing methods and techniques must be used correctly [3]. At the same time, new ones need to be developed.

Restrictions and regulations on exposure to electromagnetic fields are based on information accumulated in recent decades and reflect the current state of understanding of the levels of these fields to be considered safe.
The EMF (electromagnetic fields) effect evaluation sequence begins with the evaluation of electric and / or magnetic field sources. The source is not in itself a problem, being generally known along with its technical characteristics [4].
Our field of analysis is exposure. Exposure only exists when one or more people work or live in the fields produced by these sources, one can talk about EMF exposure. Exposure is "complicated" by factors such as the movement of the exposed person in the field, its spatial variations, and many possible combinations of exposure parameters [5]. In case of exposure to electromagnetic radiation, it is necessary to take into account the resulting internal fields. The internal magnetic fields are almost identical to the external ones, because the magnetic permeability of the body is close to unity. On the contrary, the electric fields inside the body differ considerably from the external ones, being reduced by about six orders of magnitude. At the same time, the alternating magnetic fields induce by Faraday effect electric fields with important values [6].
In addition, there are endogenous electric fields that can be comparable in amplitude. By combining all these factors and taking into account the extremely complex electrical properties of body tissues, the resulting problem is particularly complex. This leads to the difficult problem of understanding internal exposure: the cells and tissues of the body are affected by the fields created inside and not by the external ones, which can be measured.
The research of electromagnetic fields from the point of view of health effects brings to the fore, for the engineer and physicist, a problem of the first magnitude, that of the exposure dose and, consequently, of its effect.
Laboratory research can isolate a single parameter for investigation. In reality there are a multitude of parameters that need to be investigated. It is therefore necessary to take an approach close to the real world.
However, the human body is suitable for types of experiments that can be much more relevant, namely the way in which electromagnetic radiation influences / interferes with human electrical and magnetic activity [7, 8].
According to ICNIRP [2], exposure to electromagnetic fields of radio frequency below 100 kHz has the effect of negligible energy absorption. In contrast, exposure to electromagnetic fields with frequencies higher than 100 kHz can lead to significant energy absorption and temperature increases. In general, exposure to uniform electromagnetic fields (flat wave) has the effect of a very uneven distribution of them in the body and, implicitly, of energy absorption. Taking into account the physical-chemical properties of the human body, unevenly distributed (in relation to the area of the body and age) it results that energy absorption must be evaluated by dosimetric measurements and calculation.
From the point of view of energy absorption by the human body, uniform electromagnetic fields can be classified / 3 / into four categories, taking into account their frequency range:

- 100 kHz - 20 MHz; energy absorption decreases rapidly with frequency, but significant absorption may occur in the neck and limbs;
- 20 MHz - 300 MHz; there is a relatively pronounced absorption throughout the body, higher values may occur in certain areas due to resonances;
- 300 MHz - 10 GHz; significant local absorption occurs;
- over 10 GHz; energy absorption is manifested mainly on the body surface.

Experimental results and theoretical studies conducted so far internationally have shown that the adverse biological effects of exposure to microwave fields are thermal in nature [7]; they occur if the power absorption in the tissues is greater than 4 W / kg, mediated for the whole body. Against this threshold, the maximum level of occupational exposure is set by international standards or regulations at 0.4 W / kg, for the whole body [8].
Given the fact that the population may be permanently exposed and implicitly accepting a cumulative effect of microwave exposure, also taking into account other environmental factors or the increased sensitivity of some population groups, the exposure limit of the population has been reduced of international standards in the ratio 1/5 to the occupational exposure limit, i.e. it is 0.08 W / kg, for the whole body. Local exposure limits (for body parts) are also deduced based on

thermal criteria. According to the European legislations, the specific energy absorption rate (SAR) limit for localized exposure is ≤ 8 W / kg for occupational exposure and ≤ 1.6 W / kg for population exposure [4, 6].

2. Methods and researches

2.1 The notion of the specific energy absorption rate SAR

The concept of a normalized mass ratio of the rate of absorption of energy produced by a microwave source was strongly introduced in the late 1960s and early 1970s. In 1981 the National Council for Radiation Protection and Measurements officially introduced the term specific absorption rate (SAR). The American National Institute of Standards, ANSI was the first organization to consider SAR as a key parameter in dosimetry, within a standard for radiation exposure protection. SAR is formally defined as the time derivative of incremental energy (dW) absorbed (and dissipated) in an incremental mass (dm) contained in a volume (dV) of known density (ρ).

SAR is expressed in units of Watts / kg and is given by the expression [9, 10]:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right), \qquad \text{[W/kg]} \qquad (1)$$

SAR is a function of the electric field induced in the tissue, being expressed by the relation [11, 12]:

$$SAR = \frac{\sigma}{\rho} E^2, \qquad \text{[W/kg]} \qquad (2)$$

where: E represents the mean square root value of the induced electric field strength [V / m] in the tissue, ρ is the tissue density, expressed in [kg / m^2], σ is the dielectric conductivity of the tissue [Siemens / m] [7].
SAR is highly dependent on both frequency and distance as well as the H field and the strength of the equipment under test. It is also dependent on tissue composition as well as other factors. The relationships that are established in the case of mobile equipment are complex, being generally non-linear.
The limits set for SAR legislation (Table 1) (Figure 1) are:

Table 1: The limits set for SAR

Professional / Controlled Exposure 100kHz-6GHz	**General / Uncontrolled Exposure 100kHz-6GHz**
<0.4W/kg-whole body	<0.08W/kg-whole body
< 8W/kg-body parts	< 1.6W/kg-body parts

ELVs for the 0-1 Hz frequency range are defined in terms of magnetic induction external (Table A1 of Annex II to the EMC Directive). ELV for sensory effects are set to prevent vertigo and other perceptions. These are determined in mainly by the electric fields induced in the tissues when the body moves in a strong static magnetic field, although there is currently some evidence that they can appear in the absence of movement. Therefore, for a controlled work environment in which movement in the field is limited and workers are informed, overtaking may be allowed temporary ELV for sensory effects, provided that this is justified by the practice or process in question. In this case, the exposures shall not exceed ELV for health effects.
ELVs for the 1 Hz-10 MHz frequency range are defined in terms of electric fields body-induced (Table A2 and Table A3 of Annex II to the EMC Directive).
For frequencies up to 400 Hz, there is both ELV for sensory effects and ELV for health effects. ELV for sensory effects aims to prevent retinal phosphenes and minor transient changes in brain

function. Thus, they apply only to the tissues of the central nervous system (CNS) at the level of the head of an exposed worker.
ELV for health effects applies to all frequencies between 1 Hz and 10 MHz and are intended to prevent stimulation of peripheral and central nerves. Thus, these ELVs apply to all tissues in the body of an exposed worker.

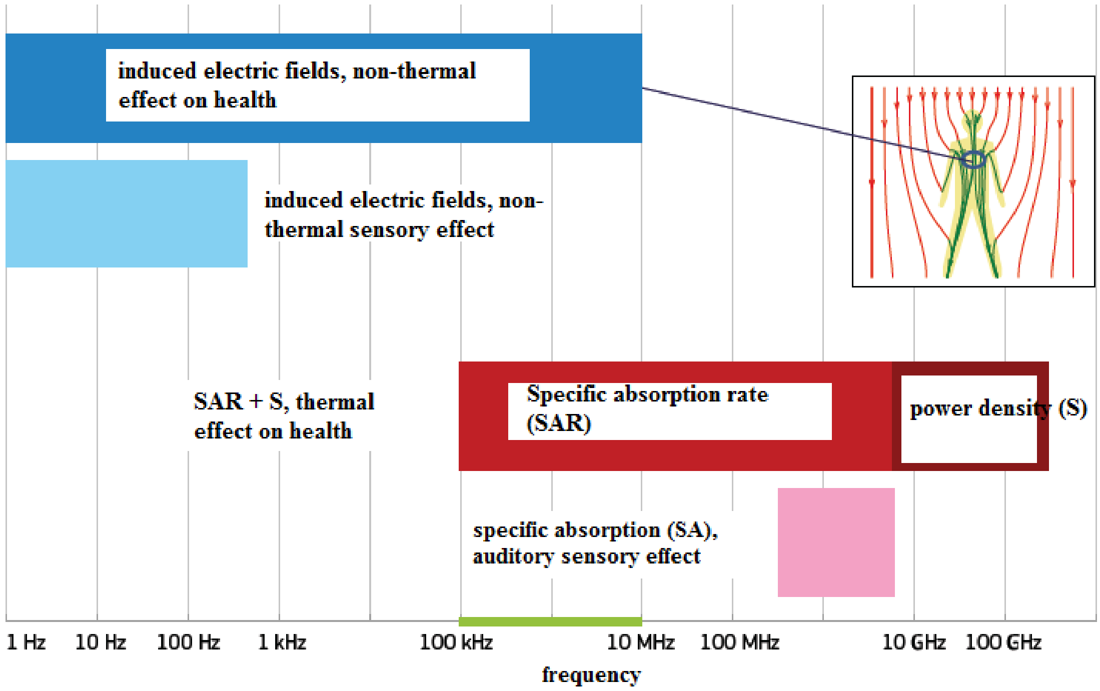

Fig. 1. The range of frequencies in which different ELVs are used

Note: Blue bars indicate non-thermal effects, and red bars indicate thermal effects.

For the 100 kHz-6 GHz frequency range, the degree of heating due to exposure depends on the rate at which energy is absorbed into the tissues. This is defined by the specific energy absorption rate (SAR), which is used to specify the ELV for health effects, with separate values for whole body exposure and those located (Table A1 in Annex III to the EMC Directive). Values for the whole body protect from heat stress and heat shock and are applied to the calculated SAR value as an average for the whole body. Localized values protect against the thermal damage of some specific tissues and apply to the SAR value averaged over any mass of 10 g of contiguous (or connected) tissue. Both whole-body SAR and localized SAR are averaged over a six-minute time frame.
For the 300 MHz-6 GHz frequency range there is also an ELV for effects that are designed to prevent "microwave" phenomena caused by exposure to pulsating fields (Table A2 in Annex III to the Directive on EMF). These are specified in terms of calculated specific absorption (HS) as an average for a mass of 10 g of tissue at the head.
The penetration of the electromagnetic field (EMC) into the body decreases with frequency in the radio frequency range, so that, for frequencies above 6 GHz, the field is mainly absorbed on body surface. This means that there is a lot for those frequencies more relevant to limit the power density incident on the body surface than the rate at which energy is absorbed into a mass of tissue. The power density is calculated as an average for 20 cm^2, within the maximum limit calculated as an average for any surface of 1 cm^2. For the 6-10 GHz frequency range, the power density is calculated as an average for any period of six minutes. Beyond this value, the average calculation time decreases with increasing frequency, reflecting the decrease depth of penetration (Table A3 in Annex III to the EMC Directive).
Warming the body by more than 1^{o} C can have health-altering effects (e.g. decreased psycho-motor performance). The effects of local heating depend on the sensitivity of the exposed area; for example, temporary warming of the limbs has no effect on health, but warming of the testicles by more than one degree can lead to infertility, and heating of the eyeball area by 1-2 ^{o} C favors the

production of cataracts [7], [8]. In determining the maximum permissible values for SAR as a basic restriction, safety factors were taken into account (compared to the 4 W / kg limit mentioned above): a factor of 10 for occupational exposure (limited and controlled), above which applied another factor of 5 for the uncontrolled exposure of the population (taking into account the existence of more sensitive categories: children, the elderly, sick people or with a delicate physical condition) [8].
Thus, the ICNIRP norm recommends the maximum allowable SAR level for the population, at the exposure of the whole body, at the value of 0.08 W / kg. Higher values are allowed for partial exposure: max. 2 W / kg in the head and torso area and max. 4 W / kg in the limb area. In the case of power density S (for frequencies> 10 GHz) the maximum permissible value is 10 W / m^2. All values corresponding to controlled exposure in occupational environments are 5 times higher (SAR values of 0.4 W / kg for the whole body, 10 W / kg for the head and torso, 20 W / kg for the limbs, respectively S of 50 W / m^2) [9]. It should also be noted that all SAR specific strength values are considered to be mediated over an exposure time interval of 6 minutes, and the values required for partial exposure are considered to be mediated over a volume corresponding to 10 g of tissue around the maximum local value. The power density S is considered to be spatially mediated on a surface of 20 cm^2 of the exposed body (around the local maximum value) and temporally over an interval of 68 / f1.05 minutes (where the frequency f is introduced in GHz). [14]

2.2 The experimental research

Electromagnetic radiation is the energy radiated in the form of a wave, which occurs as a result of the interaction between the electric field and the magnetic field, and occurs due to the acceleration of electric charges.
The electromagnetic field has two complementary components, namely the electric field and the magnetic field, whose values are directly proportional to the distance from the source that causes the electromagnetic disturbance.
The operation of electrical equipment can be characterized by useful electrical signals and disturbing electrical signals (disturbances). The disturbing electrical signal causes some unwanted effects, with minor consequences, or with damage / destruction of equipment.
Depending on the geometry of the circuit and its dimensions relative to the wavelength, either only the electric field, or only the magnetic field, or both fields are predominant. Depending on the characteristics of the circuit generating the field, the field energy is mainly found in the electrical component or the magnetic component, or in equal proportions in both components.
Real-time knowledge of indoor and outdoor air quality, water quality, noise pollution level, or electromagnetic radiation level are requirements of today's society. The demand for devices to monitor these pollutants has increased substantially in recent years. Electromagnetic radiation monitoring devices are also part of the increasingly demanded devices. The current market offers such devices, which have a high cost price, which can usually indicate only the presence of electromagnetic radiation but do not indicate the volume or area of radiation and do not even integrate their amount.
Summarizing these inconveniences makes such equipment rare, monitoring the amount and sources of radiation being difficult or even impossible to achieve, the volume of data being small and inaccurate can not help achieve a correct picture of the phenomenon and adopt correct prevention policies or combat the phenomenon.
Thus, the need to develop a universal device for monitoring electromagnetic radiation called (EMR-MUD) (Figure 2, Figure 3) has arisen. It complements the family of universal monitoring devices Indoor Air Quality Monitoring Universal Device (IAQ-MUD) [11] and Outdoor Air Quality Monitoring Universal Device (OAQ-MUD) by improving the image of pollutants [12].
It is able to monitor several areas of interest in the spectrum of electromagnetic radiation, built for indoor and outdoor spaces, to be reduced in volume, (possibly) portable, low price, maintenance close to zero, Internet connectivity for data acquisition and creation of databases for the elaboration of strategies for prevention and reduction of the monitored phenomena.
Monitored radiation areas:
• zone 1 100 kHz - 7 Ghz
• zone 2 925 Mhz - 960 Mhz

• zone 3 1805 Mhz - 1880 Mhz
• zone 4 2110 Mhz - 2170 Mhz.
Functions:
• Records individual values for each monitored area
• Local recording of monitored data and values
• Issuing alarms when the limit values are exceeded
• Online access to data for processing and analysis
• IoT compatible.

The novelty is that a modular equipment has been made, an option not found in other equipment, composed of the basic unit with the role of interpretation, storage, display, online retransmission of information, received from one or more sensory modules, with a narrow spectrum, specialized for the area of interest to be monitored. These sensor modules are connected to the base unit via the I_2C communication line via the quick sockets, which allow them to be changed in a few seconds.

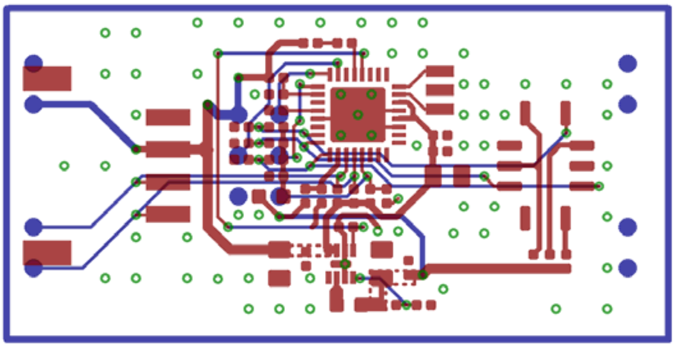

Fig. 2. PCB prototype for Atmega 328 8-Bit microcontroller adapter

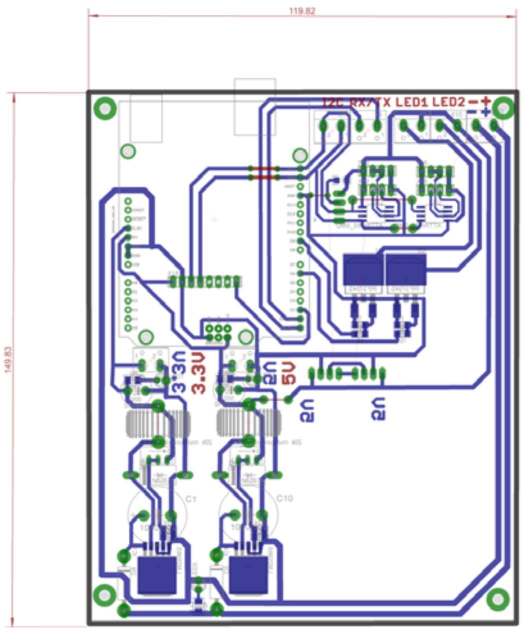

Fig. 3. Prototype PCB EMR-MUD equipment

The storage capacity of the 4MB ESP8266 microcontroller as well as its Internet connectivity facilities allow the creation of an HTML page and its loading in the processor's memory. Thus, the data obtained can be accessed in real time. The wiring of the prototype was made in our own laboratory.

Thus, one or more sensors can be attached depending on the area or areas to be monitored, thus achieving an exact identification of the area and the source generating electromagnetic radiation. Interconnectability and compatibility with the two devices in the same family of environmental quality monitoring equipment is also a novelty that we have not found in any other device. This equipment basically wants to replace a spectral analyzer, expensive equipment with relatively large dimensions, impossible to mount in several locations simultaneously due to the huge investment. The equipment that is closest to what we wanted to achieve in this work is the Narda SRM-3006 Selective Radiation Meter (Figure 4).

Fig. 4. SRM-3006 Selective Radiation Meter

In the testing phase of the equipment, it was installed in the electronics laboratory where it was created and where the radiation emitted by the electrical and electronic equipment in this space was monitored. The identified radiation generating sources are: power supplies for printers (4) and computers (2), wireless routers (1), frequency converters for electric motors (1), mobile phones (4), microwave oven (1) (Figure 5).

Fig. 5. The electronics laboratory with equipments

2.3 The experimental results and interpretations

The daily average of the readings from a week is shown in Table 2 & Fig. 6-daily average of SAR; Table 3 & Figure 7-Power Density (W / m^2) daily average of readings in a week.

Table 2: The daily average of SAR

Day	Zone 1 SAR (V/m)	Zone 2 SAR (V/m)	Zone 3 SAR (V/m)	Zone 4 SAR (V/m)
Monday	1.83	0.67	1.13	1.08
Tuesday	3.51	4.32	0.64	1.9
Wednesday	2.23	3.12	1.24	1.07
Thursday	1.32	2.43	1.01	0.86
Friday	0.95	0.47	0.35	0.25
Saturday	0.14	0.51	0.11	0.28
Sunday	0.13	0.52	0.12	0.27

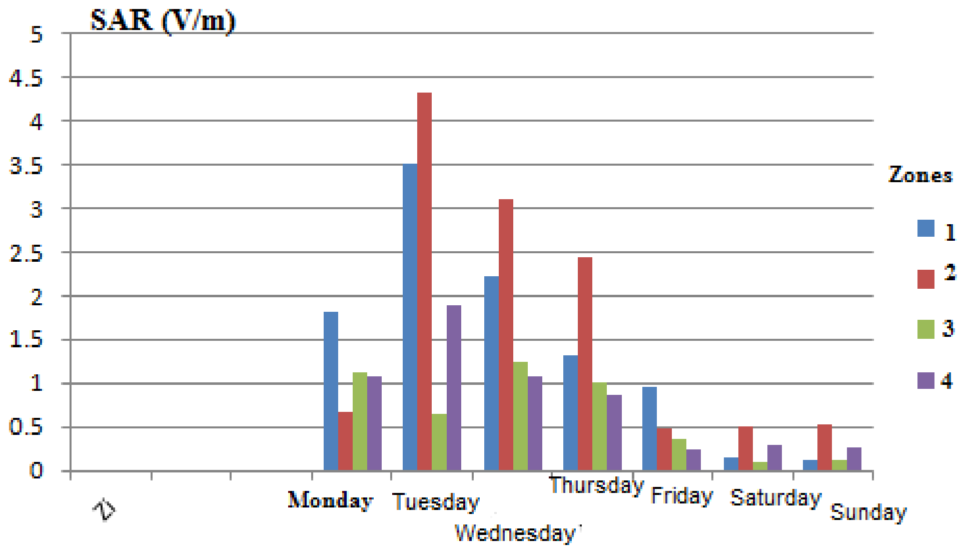

Fig. 6. The daily variations of SAR in lab

Table 3: The daily average of power density

Day	Zone 1 PD (W / m^2)	Zone 2 PD (W / m^2)	Zone 3 PD (W / m^2)	Zone 4 PD (W / m^2)
Monday	0.053953	0.049502	0.001086	0.009576
Tuesday	0.049502	0.058477	0.001376	0.009981
Wednesday	0.039802	0.050011	0.001244	0.008213
Thursday	0.038491	0.051201	0.001388	0.007214
Friday	0.004641	0.048971	0.001032	0.007009
Saturday	0.002414	0.000621	0.000351	0.000186
Sunday	0.002394	0.000586	0.000325	0.000166

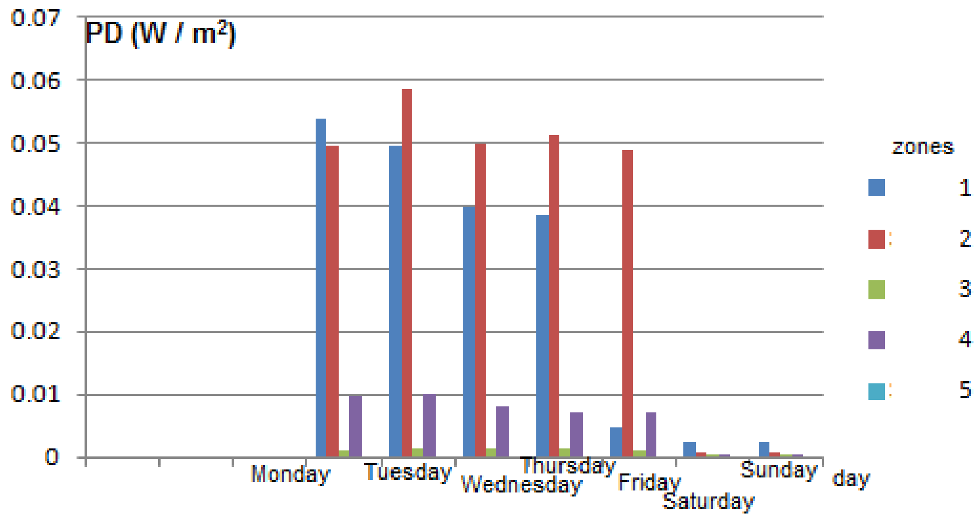

Fig. 7. The Power Density - daily average of readings in a week

The data acquisition was made through the "Tera Term" program, which offers the possibility of accessing data both on a local serial communication and accessing data via the Internet (over IP).

The obtained data can be synchronized with the local time (LT) or with the Coordinated Universal Time (UTC) and can be imported in tabular programs for further analysis.

3. Conclusions

The need to monitor electromagnetic emissions on areas of interest has led to the design and implementation of this versatile, adaptable, easy-to-use and maintenance equipment that can be used in different environments to be monitored. The energy consumption is low; the supply can be done both from the electricity grid and from batteries. The small physical dimensions allow for easy installation and low production costs, making it the ideal device for multiplication. After checking the sensor readings (calibration with certified equipment) we can say that the equipment successfully fulfils the main objectives, i.e. the readings performed by the sensors fall within the fields specified by their manufacturer.
In the future we want to increase the monitoring areas by adapting new I2C compatible sensors, e.g. Geiger counter, sound level meter.

References

[1] *** "European Digital Cellular Telecommunications System (Phase 2+) (GSM); Mobile Station (MS) Conformance Specification; Part 1: Conformance Specification", ETSI TS 151 010-1.
[2] ICNIRP. "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)." *Health Physics* J. 74, no. 4 (1998): 494-522.
[3] MacLean, Kathy. "Introduction to specific absorbtion rate standards." *Interference Technology, Annual EMC Guide* (2004).
[4] ***. "Country reports on EMF and Health: Sources, Regulation and Risk. Comunication Approaches." (2005).
[5] ***. "Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)" (1999/519/EC).
[6] ***. "Possible effects of Electromagnetic Fields (EMF) on Human Health", Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), European Commission, Health & Consumer Protection Directorate General, (21 March 2007).
[7] Leszczynski, D., S. Joenv, J. Reivinen, and R. Kuokka. "Non-thermal activation of the hsp27/p38MAPK stress pathway by mobile phone radiation in human endothelial cells: Molecular mechanism for cancer and blood-brain barrier-related effects." *Differentiation* 70 (2002): 120-129.
[8] Marinescu, Andrei. "Electromagnetic Compatibility in motion - New EMC Directive". *Buletinul ACER* 12 (April 2005).
[9] Panaitescu, Mariana, Marius Valentin Dumitrescu, and Fanel-Viorel Panaitescu. "Indoor air quality monitoring universal device." Paper presented at the The 8th International Conference on Modern Manufacturing Technologies in Industrial Engineer ISSN 2286-4369, online edition, Iasi, Romania, June 23-27, 2020.
[10] Viegi, Giulio. "Indoor air pollution and airway disease." *Int.J.Tuberc.Lung Disease* 8 (2004): 1401.
[11] Dumitrescu, Marius-Valentin. *Studies on techniques and technologies for monitoring and control e\of environmental factors-Applications of Doctoral Thesis*. Bucharest, Romania 2-86, 2019.
[12] Panaitescu, Mariana, Fanel-Viorel Panaitescu, Marius-Valentin Dumitrescu, and Valeriu Nicolae Panaitescu. "The Impact of Quality Air in The Engine Room on the Crew." *Int.J.of Marine Navigation and Safety of Sea Transportation* 13, no. 2 (2019): 409-414.
[13] Bahrin, Vasile. "The electromagnetic field of radiation generated by electrical equipment / Câmpul electromagnetic de radiație generat de echipamentele electrice." *Electrician J.* 06 (2014): 6-12.
[14] ***. Espressif System ESP32. *Technical Reference Manual* V4.1 (2019): 285-286.