ISSN impreso 1996-6660 / ISSN online 2519-5719
DOI: https://doi.org/10.31381/perfilesingenieria.v20i21.6726

Evaluation of exposure to Wi-Fi radiofrequency fields in indoor and outdoor environments in the Ricardo Palma University campus, Lima, Peru, using a personal exposimeter

Evaluación de la exposición a campos de radiofrecuencia Wi-Fi en ambientes interiores y exteriores en el campus de la Universidad Ricardo Palma, Lima, Perú, utilizando un exposímetro personal

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RECIBIDO: 26 de abril de 2024.

ACEPTADO: 03 de junio de 2024.

Abstract

The objective of this study was to make an evaluation of Wi-Fi radiofrequency fields in campus of Ricardo Palma University in the Surco district, Lima, Perú using personal exposure meters. To carried it out a literature review was first made, then the location of the environments was defined. In total 96 outdoor and 10 indoor environments were selected. Subsequently, the exposure meter including the proprietary software for data processing was tested. The maximum contribution of Wi-Fi 2G and Wi-Fi 5G for outdoor environments by main frequency bands to average exposure were 1.83 x 10^{-6} and 3.39 x10^{-5} W/m^2 respectively and the maximum contribution of Wi-Fi 2G and Wi-Fi 5G for indoor environments by main frequency bands to average exposure were 1.33 x 10-6 and 2.96 x10-6 W/m2 respectively. Based on the ICNIRP 1998 limits, the exposure quotients were also obtained the maximum contribution of Wi-Fi 2G and Wi-Fi 5G for outdoor environments by main frequency bands to average exposure were 1.83 x 10-5 and 3.39 x10-4 % respectively and the maximum contribution of Wi-Fi 2G and Wi-Fi 5G for indoor environments by main frequency bands to average exposure were 1.33 x 10^{-5} and 2.96 x10^{-5} W/m^2 respectively. In conclusion, all measurements made were well below international limits, for outdoor and indoor environments the largest contributor to total exposure was broadcasting services, the second largest were mobile phone base stations, for outdoor environments the third largest was Wi-Fi 5G and mobile phone handsets exposure was well below that of mobile phone base stations and for indoor environments the third largest was mobile handsets and the last one was Wi-Fi.

Keywords: electromagnetic field, non-ionizing radiation, radiofrequency field, exposimeter, microenvironment.

Cómo citar

V. Cruz Ornetta, J. Ubillús Gonzales, J. González Prado, M. M. Peña Calero, y M. E. I. Pardo Rendon, «Evaluation of exposure to Wi-Fi radiofrequency fields in indoor and outdoor environments in the Ricardo Palma University campus, Lima, Peru, using a personal exposimeter», Perfiles_Ingenieria, vol. 20, n.º 21, n.º 21, pp. 111-135, jun. 2024.

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Resumen

El objetivo de este estudio fue realizar una evaluación de los campos de radiofrecuencia Wi-Fi en el campus de la Universidad Ricardo Palma en el distrito de Surco, Lima, Perú, utilizando exposímetros personales. Para esto, primero se realizó una revisión de la literatura, luego se definió la ubicación de los ambientes. En total, se seleccionaron 96 ambientes exteriores y 10 interiores. Posteriormente, se probó el exposímetro incluyendo el software propietario para el procesamiento de datos. La contribución máxima de Wi-Fi 2G y Wi-Fi 5G para ambientes exteriores por bandas de frecuencia principales a la exposición promedio fueron 1.83 x 10-6 y 3.39 x 10-5 W/m^2 respectivamente y la contribución máxima de Wi-Fi 2G y Wi-Fi 5G para ambientes interiores por bandas de frecuencia principales a la exposición promedio fueron 1.33 x 10-6 y 2.96 x 10-6 W/m^2 respectivamente. Con base en los límites ICNIRP 1998, también se obtuvieron los cocientes de exposición, la contribución máxima de Wi-Fi 2G y Wi-Fi 5G para entornos exteriores por bandas de frecuencia principales a la exposición promedio fueron 1.83 x 10-5 y 3.39 x 10-4 % respectivamente y la contribución máxima de Wi-Fi 2G y Wi-Fi 5G para entornos interiores por bandas de frecuencia principales a la exposición promedio fueron 1.33 x 10-5 y 2.96 x 10-5 W/m^2 respectivamente. En conclusión, todas las mediciones realizadas estuvieron muy por debajo de los límites internacionales, para entornos exteriores e interiores el mayor contribuyente a la exposición total fueron los servicios de radiodifusión, el segundo más grande fueron las estaciones base de telefonía móvil, para entornos exteriores el tercero más grande fue Wi-Fi 5G y la exposición de los teléfonos móviles fue muy inferior a la de las estaciones base de telefonía móvil y para entornos interiores el tercero más grande fueron los teléfonos móviles y el último fue Wi-Fi.

Palabras clave: campo electromagnético, radiación no ionizante, campo de radiofrecuencia, exposímetro, microambiente.

1. Introduction

Both in Peru and in the world, the growth of Internet access continues at an unstoppable pace, especially driven by mobile communications systems and wireless access via Wi-Fi systems. According to the Supervisory Body for Private Investment in Telecommunications (OSIPTEL) in Peru, in 2014-I there were 10.99 million mobile telephone lines with Internet access (mobile Internet) and in 2023-II there were 30.45 million mobile Internet lines. While the percentage of Internet access in homes due to fixed Internet is 39.4%, access due to mobile Internet is 48.7%[1] totaling almost 89% of homes with Internet access. In homes and corporate environments, as well as in free and paid public networks, Wi-Fi systems are used to connect to the Internet, whether fixed or mobile. According to the International Telecommunication Union (ITU) [2] (2024) global internet access via mobile networks in 2022 represented an average of 11 gigabytes per month but the broadband fixed network accounted for 257 gigabytes and these networks needs to be complemented by Wi-Fi networks. Despite of these facts and the very important role of Wi-Fi networks for internet access there is an increasing concern about these networks, Therefore, in recent years, numerous studies and reviews have been performed on the effects of electromagnetic waves from Wi-Fi on people's health, giving controversial results so the concern is still a problem to be solved. Some of these studies are summarized below. Ait-Aissa et al. (2010) [3] carried out research on gliosis and apoptosis in young rat brains exposed in utero to Wi-Fi radiation which concluded that there was no significant difference between the levels of persistent astroglia activation or induction of apoptosis in the brain of young rats. Ait-Aissa et al. (2012) [4] conducted a research to evaluate immunological biomarkers in the serum of rats exposed to Wi-Fi signal in utero and postnatally exposed in utero to a Wi-Fi signal, concluding that no significant differences were observed for any of the antigens or isotypes at any of the exposure levels, there were also no significant differences in birth and growth of young rats. Ait-Aissa et al. (2013) [5] evaluated the bioeffects on the developing nervous system of young rodents from exposure to Wi-Fi signals and there was no induction of 3-NT formation or increased of HSP expression in the cerebral cortex and hippocampus of young rats. Bektas et al. (2020)[6] performed a study on the effects of radiofrequency radiation emitted by mobile phones and Wi-Fi systems and on umbilical cord blood and placenta concluding that the results indicated that exposure to mobile phones during pregnancy could have significant potential to cause oxidative stress and DNA damage in umbilical cord blood and placenta, while no negative effects were evident for exposure to Wi-Fi.. In the case of combined exposure to mobile phones, the results of this study also indicated that combined effects of exposure to mobile phones + Wi-Fi show a contribution from Wi-Fi. Dasdag et al. (2015) [7] conducted a study to investigate the effects of long-term exposure to radiation from Wi-Fi systems on the testicles, concluding that 2.4 GHz Wi-Fi radiation affects testicular function and histology. Shokri et al. (2014) [8] carried out a research on the potential effects of short and long-term exposure to 2.45 GHz Wi-Fi radiation on the reproductive system of male rats, concluding that there was a decrease in sperm parameters in a time-dependent manner and the number of apoptosis-positive cells and caspase-3 activity increased in the seminiferous tubules of exposed rats.

The results of the research on health effects from Wi- Fi are controversial and the only established effects are the ones related to the increase in temperature caused by RF. The bulk of studies have been taken into account for the formulation of international recommendations on the maximum permissible limits of exposure to non-ionizing radiation, published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 limits [9] which replaced the ICNIRP 1998 limits [10] and the International Institute of Electrical and Electronics Engineers [11].

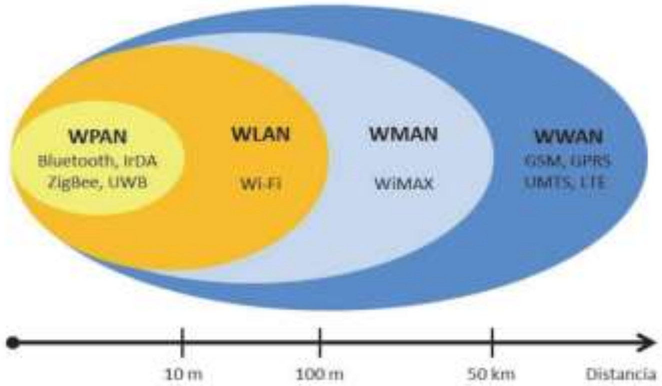
To know the level of exposure to electromagnetic fields generated by telecommunications services in general and by Wi-Fi systems in particular, measurement campaigns are constantly carried out. These campaigns are carried out using expensive equipment, applying protocols recommended by international organizations such as the International Telecommunications Union [12], the International Institute of Electrical and Electronic Engineers [12] or national organizations such as the Ministry of Transport and Communications of Peru [13]. Basically, there are two types of methods to measure RF electromagnetic fields. First there were developed the fixed-location measurements and after that they were conducted dynamic methods using equipment for fixed-location RF field evaluations but mounted on a car in order to perform measurements along a route. This latter one evolved to measurements with portable exposure meters (PEM) performed along a route. Based on these two concepts currently there are different methods used for exposure evaluation: spot measurements, monitoring measurements, dynamic measurements, and personal measurements. One of the methods broadly used are the spot measurement [14], [15], [16], [17], [18] which is carried out by conducting measurements at selected places and specific time periods with devices located in fixed places. On the one hand, this method allows strict compliance with the protocols and the use of very good meters (broadband meters or selective band analyzers, but also personal exposure meters), which facilitates an accurate measurement of the specific contribution of different sources to the total environmental exposure. of RF-EMF, but on the other hand it has limited spatial resolution and does not consider the specific characteristics of personal exposure [18], [19]. Understanding these restrictions, and to more quickly and accurately characterize the level of radiation that people are exposed to in certain areas of interest, it is best to use a personal RF-EMF exposure assessment that is performed using personal meters. The RF exposure meters are small enough that participants can wear them on the waist and thus capture exposure to RF fields from various sources and situations in their daily lives, but they can also be used for performing spot measurements. Although the use of personal exposure meters (PEMs) is limited by the uncertainty of the measurement readings due to the participant's body, it is a cheaper choice to conduct spot measurements so the objective of this study was to made an spot evaluation of Wi-Fi radiofrequency fields in the campus of the Ricardo Palma University, Lima, Peru located at the Surco district in Lima city which in the central western part of Peru. using PEMs.

1.1. Characteristics of Wi-Fi networks

Wi-Fi is a wireless technology used to connect computers, tablets, smartphones, televisions, and other devices to the Internet. Consequently, a Wi-Fi network is a broadband radio local area network (RLAN) that allows the aforementioned devices to access the Internet through a router that acts as a hub to transmit the Internet signal to all its enabled devices. for Wi-Fi, connected directly to an Internet modem. This gives you the flexibility to stay connected to the Internet as long as you are within your network's coverage area. Personal Area Networks (PAN) cover a few meters, are for personal use and when developed with wireless networks, it is called Wireless Personal Area Network (WPAN). Wireless Local Area Networks (WLAN) are computer networks that allow communication and data exchange between different devices over short distances (typically in the order of 100 m), which is why they are used for home and corporate networks, and They are basically implemented using Wi-Fi technology. A metropolitan area network (WMAN) is a computer network that connects computers in a metropolitan area, which can be a large city, several cities and towns, or any large area with several buildings and can cover distances of the order of 50 km. Wireless Wide Area Networks (WWAN) are computer networks that can interconnect several WLAN or WMAN networks that could all be in different physical locations and can be corporate networks for private use or belong to Internet Service Providers (ISP) to provide connection. to its clients (public service). Figure 1 shows the location of the Wi-Fi network within wireless technologies. Figure 2 shows the basic diagram of a Wi-Fi network, showing the router, access points and terminals that connect to the network.

Figure 1.

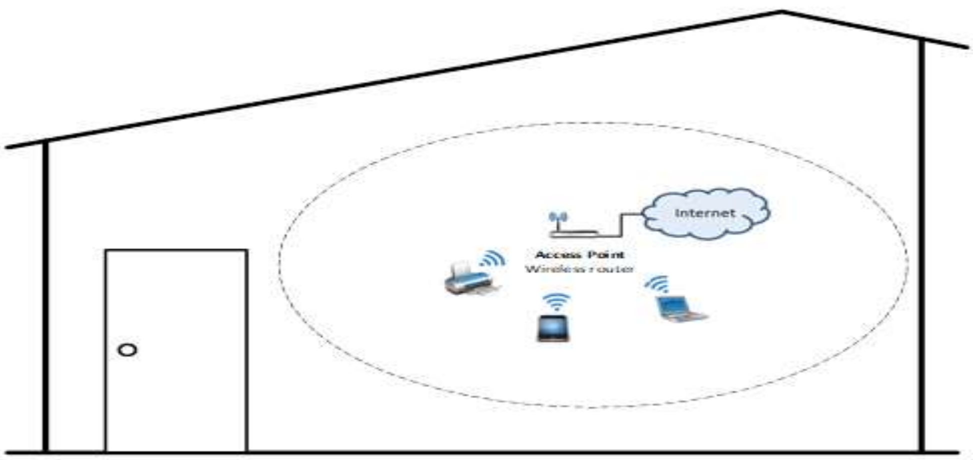
Classification of wireless networks by their range



Source: Techpedia [20]

Figure 2.

Scheme of Wi-Fi network at home



Source: Internetizado [21]

Recommendation ITU-R M.1450-5 [22] of the International Telecommunication Union (ITU) includes recommendations from the International Institute of Electrical and Electronics Engineers (IEEE), the European Telecommunications Standards Institute (ETSI) and the Association of Radio Industries and Businesses (ARIB) to standardize Wi-Fi systems with the aim of allowing cross-compatibility between various manufacturers and their compatibility with wired local area networks (LAN). Thus, current Wi-Fi systems work mainly in the unlicensed 2.4 and 5 GHz bands.

Due to this, Wi-Fi systems and their signals are present in almost all environments where the life of human beings takes place, at home, work, study centers, hospitals, buses, trains, ships, airplanes and many more; However, along with this great development and the tremendous utility associated with these systems, an important concern has arisen about the possible effects produced by electromagnetic waves from wireless communications systems, including Wi-Fi systems. In 2013, the International Agency for Research on Cancer (IARC) published volume 102 of the Monographs on the Evaluation of Carcinogenic Risks to Human Beings in Chapter 6, Section 6.3 Global Evaluation classifies Radiofrequency Fields as belonging to Group 2B " Possible Carcinogenic to Human" [23] which increases the concern of the public and institutions about the possible health effects of wireless technologies in general and Wi-Fi systems in particular.

This recurring concern about the possible effects of Wi-Fi networks has given rise to numerous specific studies on the possible effects on people's health and the levels of exposure to radio frequency produced by Wi-Fi networks [3], [4], [5], [6], [7], [8] . Furthermore, according to the standard health risk assessment model adopted by the World Health Organization [24] it includes four main components: hazard identification, hazard characterization, exposure assessment and risk characterization. In other words, assessing the health risks of Wi-Fi networks involves an important component of exposure assessment. Worldwide, there are several studies to assess the Wi-Fi; however, there are few studies for Peruvian and Latin American Wi-Fi systems. That is why the objective of this study was to carry out an evaluation of radiofrequency including Wi-Fi radiation on the campus of the Ricardo Palma University. The present study aims to answer questions such as: Does the radiation from the Wi-Fi systems on the URP campus comply with the exposure limits to non-ionizing radiation recommended by the WHO? What is the contribution of Wi-Fi radiation to the total radio frequency radiation? What are the comparative levels of total radiofrequency radiation between faculties?

2. Literature review

Ramirez-Vazquez et al. (2020) [17] has carried out measurements of Wi-Fi radiation on a university in Aman, Jordania and found a 34.38 and 28.82 $\mu W/m^2$ for spot and personal measurements (ICNIRP quotients for the general public of 3.45 $x10^{-4}$ and 2.88 $x10^{-4}$ % respectively). Ramirez-Vazquez et al. (2023) [25] has carried out measurements of Wi-Fi radiation on a university in Albacete, Spain and found a 6.36 and 30.5 $\mu W/m^2$ for 2G and 5G respectively (ICNIRP quotients for the general public of 6.36 $x10^{-5}$ and 3.05 $x10^{-4}$ % respectively). Aminzadeh et al. (2016) [26] conducted measurements in Belgium on 5G Wi-Fi indoor exposure and found an average power density of 165.8 $\mu W/m^2$ (an ICNIRP quotient for general public of 8.9 $x10^{-2}$ %). Bhatt et al., (2017)

[27] conducted Wi-Fi measurements in Melbourne, Australia and Ghent, Belgium finding an average electric field of 0.02 V/m (an ICNIRP quotient for the general public of 8 x10^{-2} %) for 2G Wi-Fi and the same value for 5G Wi-Fi. Bhatt et al., (2022) [28] performed Wi-Fi measurements in Melbourne, Australia and found a median electric field of 0.01 V/m (an ICNIRP quotient for the general public of 2 x10^{-5} %) for 2G Wi-Fi personal exposure and a median electric field of 0.016 V/m (an ICNIRP quotient for the general public of 5.12 x10^{-5} %) for 2G Wi-Fi environmental exposure. Birks L.E. et al. (2018) [29] conducted a study on personal exposure to Wi-Fi in Denmark, Slovenia, Spain, The Netherlands and Switzerland and found a median electric field of 1.8 µW/m^2 (an ICNIRP quotient for the general public of 1.8 x10^{-5} %). Ramirez-Vasquez et al., 2020 [16] conducted a study of personal exposure to radiofrequency electromagnetic fields in outdoor and indoor school buildings, in Albacete, Spain and found the average exposure levels of 33.1 and 121 µW/m^2 (ICNIRP quotients for the general public of 3.31 x10^{-4} and 1.21 x10^{-4}% respectively).

3. Materials and Methods

In order to perform this study, they were conducted the following steps:

3.1. Definition of environments and data collection

Measurements were made in indoor environments such as classrooms and the main library and outdoor environments inside faculties for not less than 6 minutes per area.

4. Study instruments

For practical reasons, a calibrated personal exposimeter EME Spy Evolution, MVG was used for the measurements. This small-sized equipment with an isotropic probe allows the evaluation of the individual contribution to the total level of non-ionizing radiation of the 20 services shown in table 1.

Table 1.

Telecommunication Services of Eme Spy Evolution [30]

	Telecommunication Service	Minimum Frequency (MHz)	Maximum Frequency (MHz)
1	FM	88	108
2	TV-VHF	174	216
3	TV-UHF	470	644
4	LTE Band 12 UL	698	716
5	LTE Band 12 DL	728	746
6	LTE Band 13 DL	746	756
7	LTE Band 13 UL	777	787
8	LTE Band 26 UL	814	849
9	LTE Band 26 DL	859	894
10	ISM/Intelligent Meters	902	928
11	LTE Band 4 UL	1710	1755
12	LTE Band 25 UL	1850	1915
13	DECT 6.0	1920	1930
14	LTE Band 25 DL	1930	1995
15	LTE Band 4 DL	2110	2155
16	LTE Band 40	2300	2400
17	Wi-Fi 2G	2400	2483
18	LTE Banda 7 UL	2500	2570
19	LTE Banda 7 DL	2620	2690
20	Wi-Fi___33 5G	5150	5850

5. Limits Used to Evaluate evaluate the Exposure to NIR

On July 6, 2003, the Ministry of Transports and Communications of Peru issued "The Maximum Permissible Limits of Non-Ionizing Radiation in Telecommunications" [13] by means of Supreme Decree No. 038-2003-MTC, which are based on the ICNIRP reference levels 1998[9] and considers not only general public exposure but also occupational exposure in the frequency range 9 kHz to 300 GHz. In the frequency range used to carry out this study, the new ICNIRP reference levels 2020 are the same as those of ICNIRP 1998 (see table 2), so the ICNIRP 2020 compliance criteria [10] are the same used for the ICNIRP 1998 guidelines.

Table 2.

Peruvian Maximum Permissible Limits FOR Non-Ionizing Radiation (rms values)

	Frequency Range	E (V/m)	H (A/m)	Seq (W/m2)
Occupational Exposure	9 – 65 kHz	610	24.4	-
	0.065 – 1MHz	610	$1.6/f$	-
	1 – 10 MHz	$610/f$	$1.6/f$	-
	10 – 400 MHz	61	0.16	10
	400 – 2000 MHz	$3f^{0.5}$	$0.008 \times f^{0.5}$	$f/40$
	2 – 300 GHz	137	0.36	50
Population Exposure	9– 150 kHz	87	5	-
	0.15 – 1MHz	87	$0.73/f$	-
	1 – 10 MHz	$87/f^{0.5}$	$0.73/f$	-
	10 – 400 MHz	28	0.073	2
	400 – 2000 MHz	$1.375f^{0.5}$	$0.0037 \times f^{0.5}$	$f/200$
	2 – 300 GHz	61	0.16	10

Table 3 shows the values of the Maximum Permissible Limits of Non-Ionizing Radiations of Telecommunications Services that can be evaluated by EME SPY Evolution.

6. Exposure to Multiple Frequencies

The level of exposure to NIR emitted on a single frequency could be expressed through a parameter called "exposure quotient". As it can be seen in equation (1) its value is given by the quotient of the measured power density ($S_{measured}$) and the power density limit (S_{limit}) (ICNIRP, 1998).

$$Exp\ quotient = \frac{S_{measured}}{S_{límit}} \quad (1)$$

As it can be seen in the equations (2) and (3) the exposure quotient can be expressed in terms of the measured.

7. Exposure Quotient

The level of exposure to NIR emitted on a single frequency could be expressed through a parameter called "exposure quotient". As it can be seen in equation (1) its value is given by the quotient of the measured power density ($S_{measured}$) and the power density limit (S_{limit}) (ICNIRP, 1998).

$$Exp\ quotient = \frac{S_{measured}}{S_{límit}} \quad (1)$$

Table 3.

General public limits for services measured by Eme Spy Evolution

	Service	Frequency band (MHz)	Mid Band Frequency (MHz)	Seq (W/m^2)
1	FM	88-108	98	2.000
2	TV-VHF	174-216	195	2.000
3	TV-UHF	470-644	557	2.785
4	LTE Band 12 UL	698-716	707	3.535
5	LTE Band 12 DL	728-746	737	3.685
6	LTE Band 13 DL	746-756	751	3.755
7	LTE Band 13 UL	777-787	782	3.910
8	LTE Band 26 UL	814	849	4.158
9	LTE Band 26 DL	859	894	4.383
10	ISM/Intelligent Meters	902-928	915	4.575
11	LTE Band 4 UL	1710-1755	1732.5	8.663
12	LTE Band 25 UL	1850	1915	9.413
13	DECT 6.0	1920	1930	9.625
14	LTE Band 25 DL	1930	1995	9.813
15	LTE Band 4 DL	2110-2155	2132.5	10.000
16	LTE Band 40	2300-2400	2350	10.000
17	Wi-Fi 2G	2400-2483	2441.5	10.000
18	LTE Band 7 UL	2500-2570	2535	10.000
19	LTE Band 7 DL	2620-2690	2655	10.000
20	Wi-Fi 5G	5150-5850	5500	10.000

As it can be seen in the equations (2) and (3) the exposure quotient can be expressed in terms of the measured electric field strength ($E_{measured}$) and the field strength limit (E_{limit}). If the magnetic field were measured, the same expression would be used,

$$Exp\ quotient = \left(\frac{E_{measured}}{E_{límit}}\right)^2 \qquad (2)$$

$$Exp\ quotient = \left(\frac{H_{measured}}{H_{límit}}\right)^2 \qquad (3)$$

8. Exposure Quotient to Multiple Frequencies

The multi-frequency exposure ratio can be expressed in terms of the measured electric field strength for each frequency ($E_{i\text{-}measured}$) and the electric field strength limit ($E_{i\text{-}limit}$) or in terms of the measured magnetic field strength for each frequency ($H_{i\text{-}measured}$) and the magnetic field strength limit ($H_{i\text{-}limit}$) (Equations (4) and (5)).

$$Exp\ quotient = \sum_{i>1MHz}^{300\ GHz} \left(\frac{E_{i-measured}}{E_{i-limit}}\right)^2 \qquad (4)$$

$$Exp\ quotient = \sum_{i>1MHz}^{300\ GHz} \left(\frac{H_{i-measured}}{H_{i-limit}}\right)^2 \qquad (5)$$

9. Preparation of the equipment

Before starting the evaluation, the equipment was configured to record the measurements values: electric field strength (V/m), power density (mW/cm^2, W/m^2), exposure quotient (general public and occupational) values every 5 seconds. This allows simultaneous evaluation of the services shown in Table 1. The equipment was placed on the tripod, and it was then activated. Simultaneously, the whole measurements values were recorded, as well as the position using a GPS. Each measurement lasted 6 minutes.

10. Selection of locations

The places where the measurements would be carried out in the different faculties were identified and selected. The criteria considered for this purpose was to choose the points below the access points.

Table 4 shows the number of points evaluated in each faculty, classified according to the type of environment. In total were evaluated 106 points: 96 outdoor and 10 indoor.

Table 4.

Number of locations Evaluated

Faculty/Type of measurement	Indoor	Outdoor
Architecture and Urban Planning	2	15
Biological Sciences	-	15
Economics and Business	1	13
Engineering	4	14
Human Medicine	3	9
Humanities and Modern Languages /Psychology	-	17
Pavilion G	-	13
TOTAL	10	96

11. Results and Discussion

11.1. Results

These measurements included different telecommunications services and systems such as broadcasting, mobile telephony and Wi-Fi.

Figure 3 shows the mean of the power density (W/m2) for outdoor environments by main frequency bands. The contribution of Wi-Fi 2G and Wi-Fi 5G were 1.83 x 10-6 and 3.39 x10-5 W/m2 respectively.

Figure 3.

Average exposure by main frequency bands for outdoor environments (W/m2)

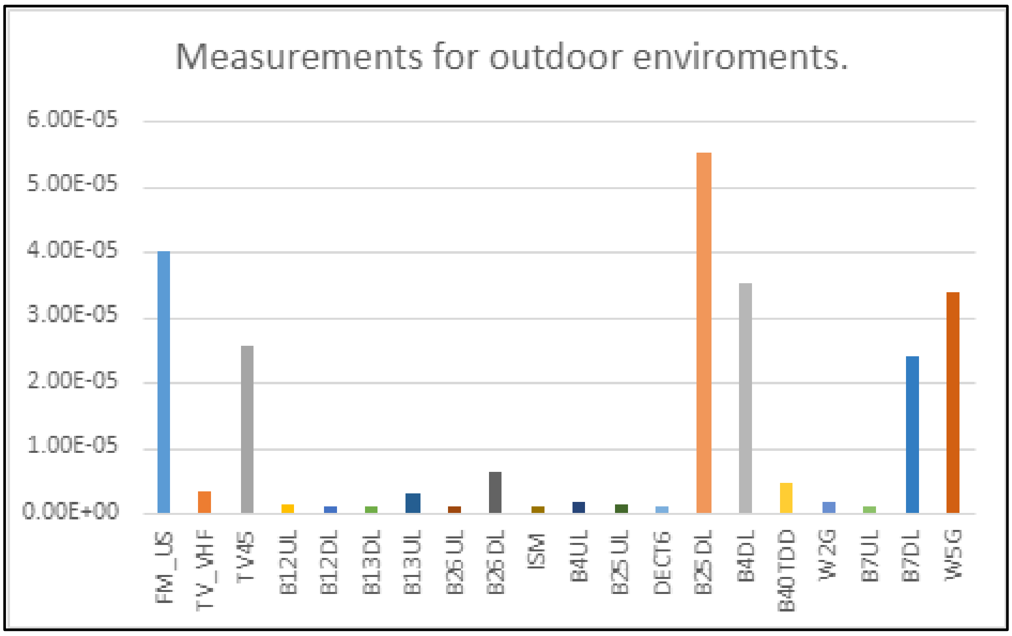


Figure 4 shows the mean of the power density (W/m2) for indoor environments by main frequency bands. The contribution of Wi-Fi 2G and Wi-Fi 5G were 1.33 x 10-6 and 2.96 x10-6 W/m2 respectively.

Figure 4.

Average exposure by main frequency bands for indoor environments (W/m2)

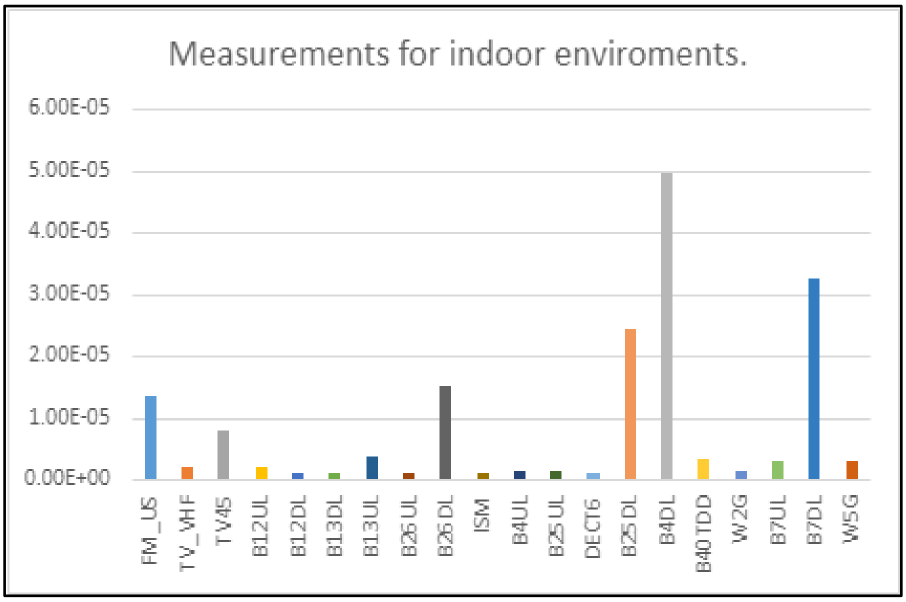
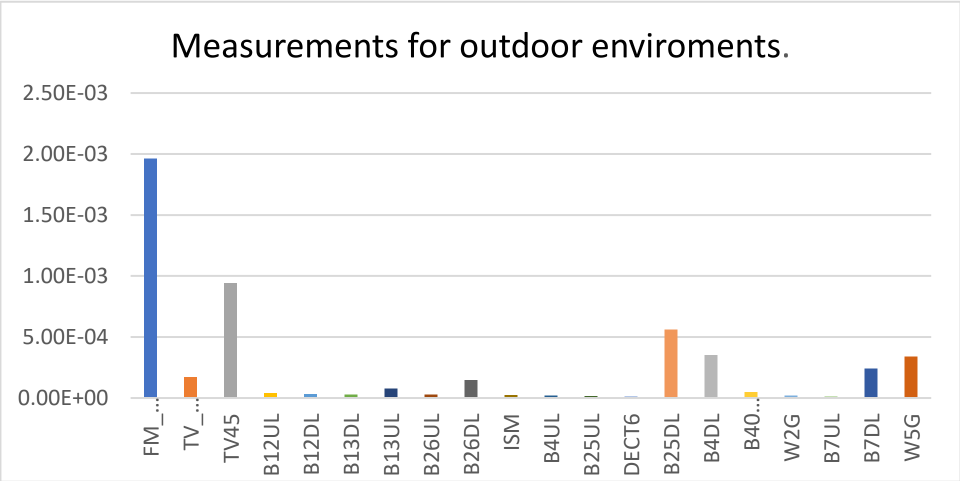


Figure 5 shows the mean General Public Exposure (%) for outdoor environments by main frequency bands. The contribution of Wi-Fi 2G and Wi-Fi 5G were 1.83 x 10-5 % and 3.39 x10-4 % respectively.

Figure 5.

Average exposure by main frequency bands for outdoor environments (%)*

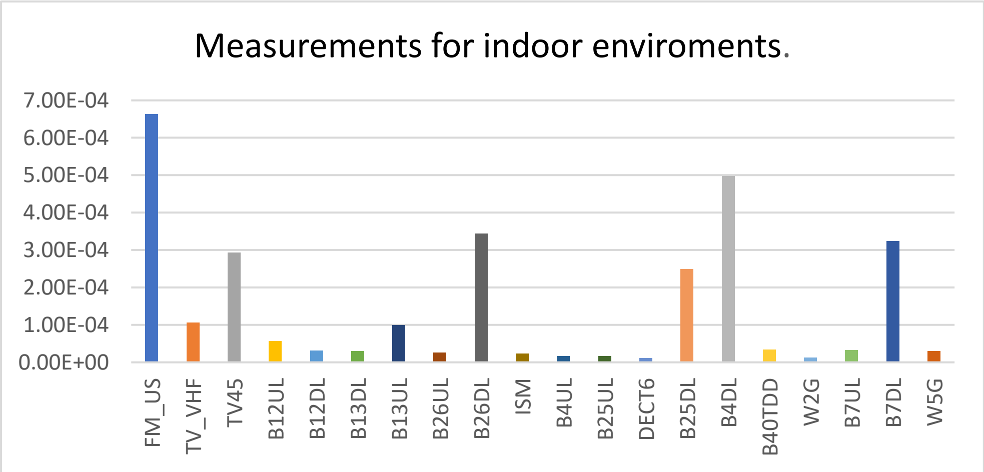


*The percentage is about the ICNIRP population reference levels

Figure 6 shows the mean General Public Exposure (%*) for indoor environments by main frequency bands. The contribution of Wi-Fi 2G and Wi-Fi 5G were 1.33 x 10-5 % and 2.96 x10-5 % respectively.

Figure 6.

Average exposure by main frequency bands for indoor environments (%)*

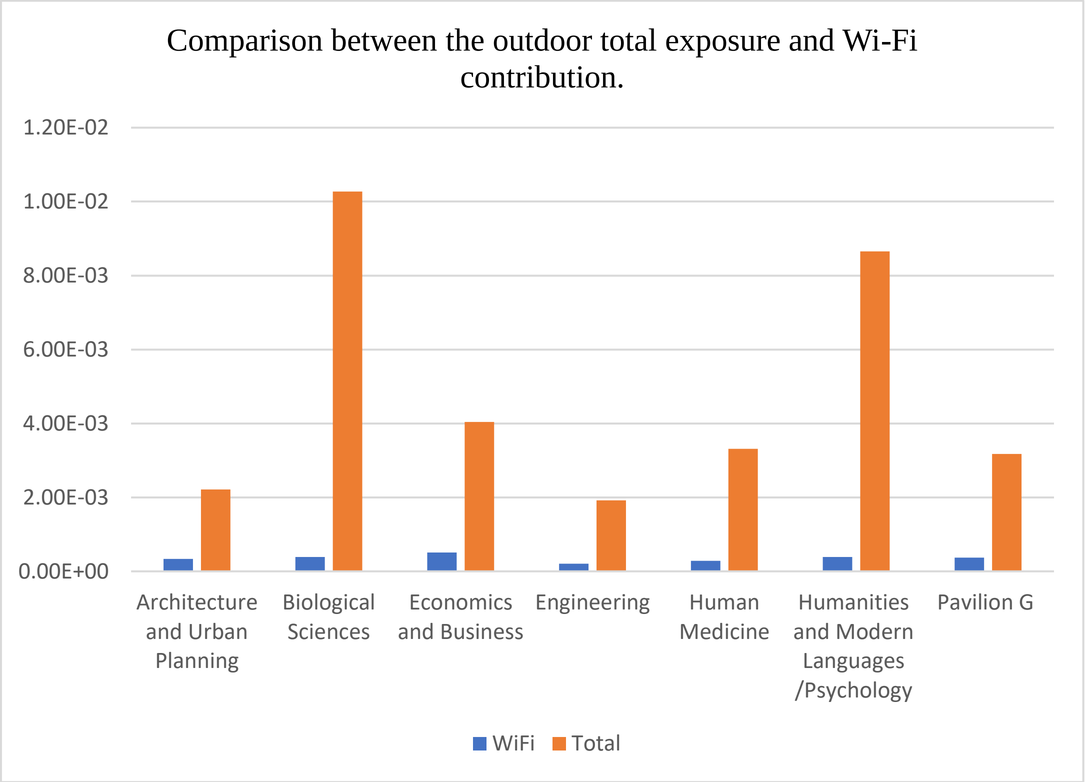


*The percentage is about the ICNIRP population reference levels

Figure 7 shows a comparative graph of total exposure and Wi-Fi contribution to General Public Exposure (%) in outdoor environments by faculties The maximum value of the total exposure was 1.03 x 10-2 % for the Faculty of Biological Sciences and of the Wi-Fi contribution was 5.08 x10-4 % for the Faculty of Economics and Business.

Figure 7.

Comparative of the total and Wi-Fi contribution average exposure by faculties for outdoor environments (%)*

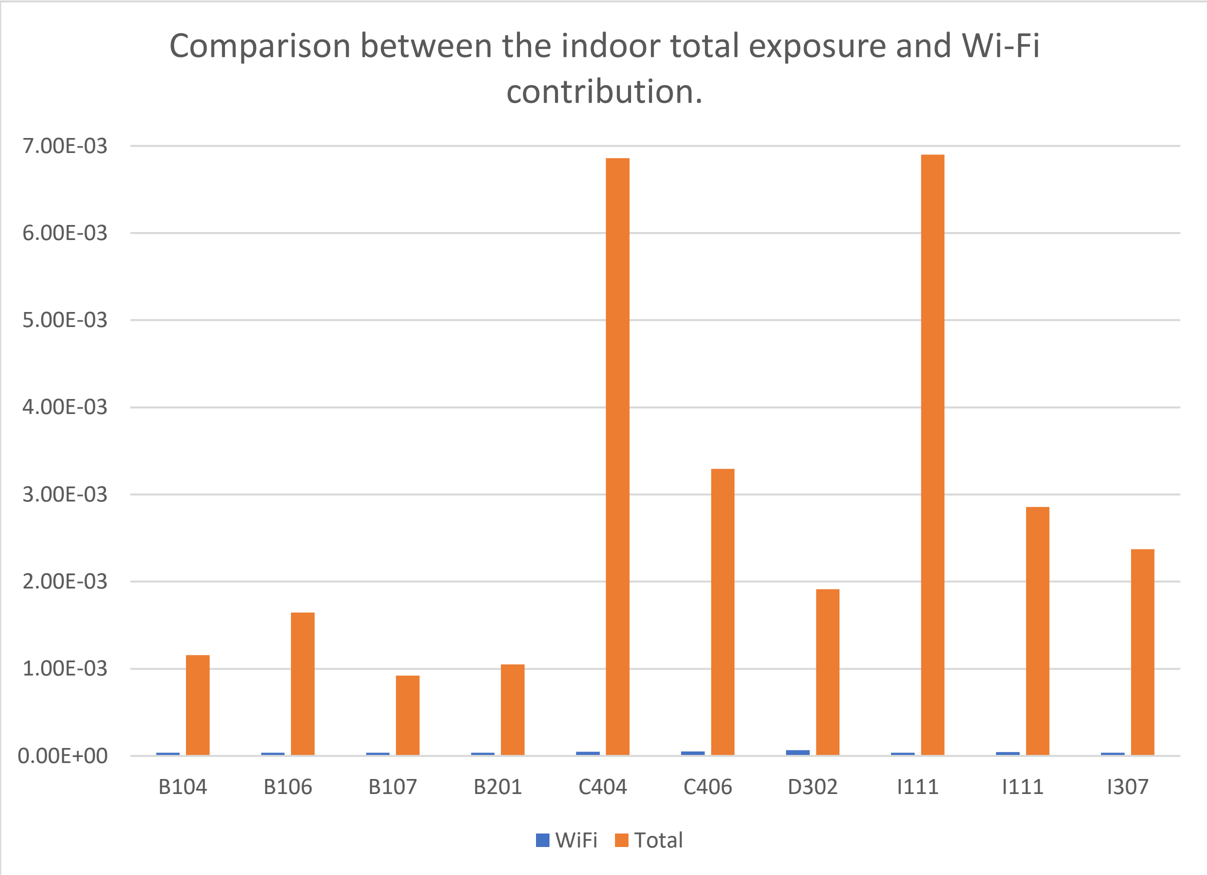


*The percentage is about the ICNIRP population reference levels

Figure 8 shows a comparative graph of the total exposure and the Wi-Fi contribution to General Public Exposure (%) in outdoor environments by faculties The maximum value of the total exposure was 1.03 x 10-2 % for the Faculty of Biological Sciences and of the Wi-Fi contribution was 5.08 x10-4 % for the Faculty of Economics and Business.

Figure 8.

Comparative of the total and Wi-Fi contribution average exposure by classrooms for indoor environments (%)*

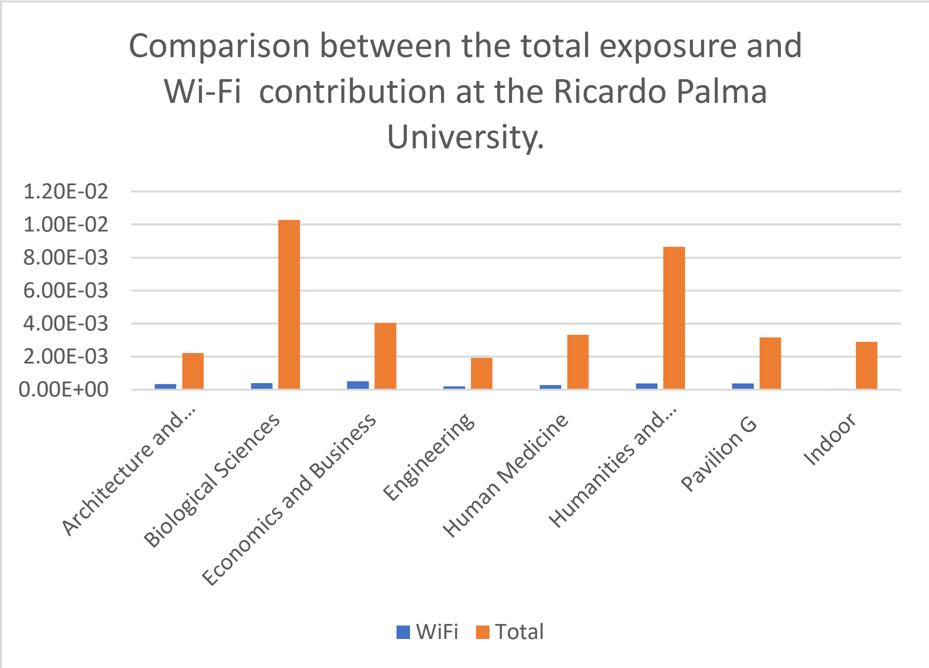


*The percentage is about the ICNIRP population reference levels

Figure 9 presents a comparative of the total and Wi-Fi contribution to average exposure by faculties and indoor measurements (%[*]).

Figure 9.

Comparative of the total and Wi-Fi contribution average exposure by faculties and indoor measurements (%)*



*The percentage is with reg to the ICNIRP population reference levels

11.2. Discussion

In this study, a personal exposure meter (PEM) was used to perform the measurements and a 5-s interval was used to simultaneously measure more frequency bands (20). It was the same interval used by Ramirez-Vasquez at the University of Castilla-La Mancha in Albacete, Spain [25], different from the studies by Ramirez-Vasquez at the German Jordanian University, Amman, Jordan, Sagar et al. [19] in Switzerland, and Aminzadeh et al. (2016) [26] in Belgium that used a 4-second interval between two measurements. It was also different from Bhatt et al., (2017) [27] in Melbourne, Australia and Ghent, Belgium, which used a 3-second interval.

In the Ricardo Palma University research, the maximum of the average exposure by faculties of Wi-Fi 2G and Wi-Fi 5G contributions were 1.83 x 10^{-5} and 3.39 x10^{-4} % respectively, which are of the same order of the values found by the study of Ramirez-Vazquez et al., (2020) [17] at a university in Aman, Jordania (Wi-Fi contribution to average exposure of 3.45 x10^{-4} % for spot measurements). Ramirez-Vazquez et al., (2023) [25] found at a university in Albacete, Spain a 2G and 5G contribution of 6.36 x10^{-5} and 3.05 x10^{-4} % respectively which are nearly the same values found in the URP study.

12. Conclusion

Spot measurements made with personal exposure meters have proven to be very useful for making measurements in larger areas than spot measurements with an interesting trade-off between technical and economic factors.

All the measurements made were well below the international limits, as in other studies worldwide.

As in most studies in Peru the largest contributor to total exposure was broadcasting services. The second largest were mobile phone base stations.

Exposure from mobile phone handsets was well below the exposure of mobile phone base stations as it was in several studies performed worldwide.

The contribution of Wi-Fi radiation to total RF exposure is typically one of the smallest. For outdoor environments, the third highest was 5G Wi-Fi, and for indoor environments, the lowest was Wi-Fi.

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Conflicto de intereses

Los autores expresan que no existen conflicto de intereses en el desarrollo de la presente investigación.

Responsabilidad ética y legal

El desarrollo de la investigación se realizó bajo la conformidad de los principios éticos del conocimiento, respetando la originalidad de la información y su autenticidad.

Declaración sobre el uso de LLM (Large Language Model)

Este artículo no ha utilizado para el desarrollo de la investigación textos provenientes de LLM (ChatGPT u otros).

Financiamiento

La presente investigación ha sido financiada por el Vicerrectorado de Investigación de la Universidad Ricardo Palma.

Agradecimiento

Al Vicerrectorado de Investigación de la Universidad Ricardo Palma por financiamiento del Proyecto.

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