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Protective Characteristics of Enclosing Structures Exposed to Electromagnetic Radiation

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Abstract. The intensity of electromagnetic radiation EMR in the urban environment is increasing every year. Over the past 50 years, the intensity of EMR has increased tens of times. These are communication systems, cable networks, equipment of industrial enterprises. EMR negatively affects the cardiovascular, nervous, immune and other human systems. Despite this in architectural and construction industry to date no systematic studies, especially regulations governing the assessment of protective characteristics when exposed walling external source of electromagnetic radiation. In the article methods and results of investigation of protective characteristics of enclosing structures are given.

1. Introduction

The power of electromagnetic radiation in the urban environment is constantly increasing. Over the past 50 years, the total power of EMR has increased tens of times. Aware of the growing risk of EMR exposure to humans, the World Health Organization (WHO) in 1995 officially introduced the concept of "global electromagnetic pollution" [1]. The relevance of the study of electromagnetic radiation is dictated by their negative impact on humans [2]. The cardiovascular, nervous endocrine, immune and reproductive systems are most affected. Sources EMR are located both in the urban environment and in buildings. In the urban environment, these are communication system antennas and electrical installations of industrial enterprises. In the premises of buildings - it is household appliances and cable networks. The "smarter the house", the more sources of EMR in it and the higher the EM field intensity [3]. The problem of protecting a person from external and internal sources of EMP is two separate tasks that can not be solved in one article. In this connection, in the present work, the protection of premises of residential buildings from an external source of EMP is considered. Of all the possible sources of radiation, the article considers the sources of EMP, the most common in the urban environment. This is cellular communication (0.45 - 2.1 GHz), Wi-Fi systems (2.45 - 5.2 GHz), satellite communications (1.5 - 12 GHz), telecommunications and radio communications. Thus, in studies, the frequency range was limited to frequencies of 2-7 GHz. The solution of the problem reduces to evaluating the energy flux density (PFD) of the building facade and establishing patterns of this energy attenuation when passing through the EM wave walling. Due to the fact that the electromagnetic waves from the external source acts on the entire facade of the building, research subject protection properties as the stone pieces fences and translucent structures skylights. The interaction of EMP with buildings and enclosing structures is determined by the frequency of the radiation and the wavelength. At low radiation frequencies, when the wavelength exceeds the size of the building, the EMR envelopes the obstacles. At high frequencies, when the wavelength is smaller than the size of the building, the EMR interacts with the enclosing structures of the buildings. For frequencies of communication selected in this study (1-7 GHz), the wavelengths are in the range of 1-100 cm, i.e. substantially smaller dimensions of the building and there EMI interaction with walling of the wave beam line (Figure 1).

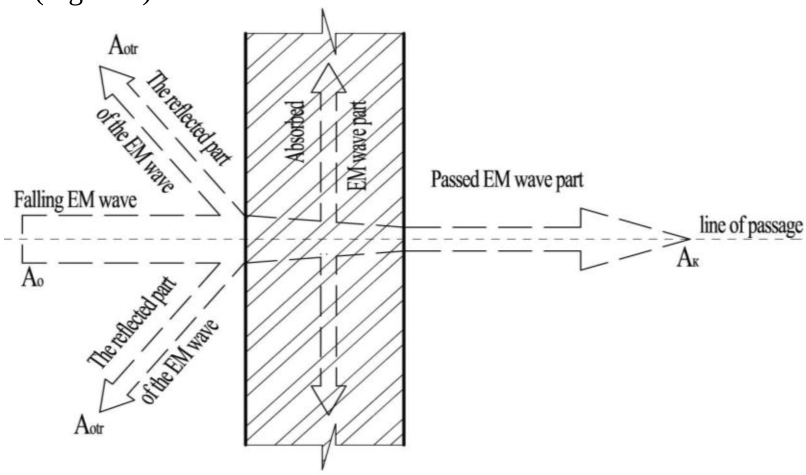

Figure 1. Scheme of interaction of EMW with enclosing structures

The quantitative measure of the protective characteristics of the enclosing structures is the "attenuation coefficient K", which is the logarithmic value of the ratio of the energy intensity of the wave transmitted through the shielding structure A_k (μW/cm^2) to the EM energy of the wave coming to the fence A_0 (μW/cm^2), measured in decibels, dB (1 dB = 0.1B) [4]:

$$K = 10\lg\left(\frac{A_\kappa}{A_o}\right) \text{ [dB] (1)}$$

Each value of K corresponds to a certain value of the relative attenuation of the energy of the EM wave transmitted through the enclosing structure (Table 1).

Table №1. Deciphering the attenuation coefficient K

The attenuation coefficient K, dB	**The amount of energy of the electromagnetic wave:**	
	passed through the sample,m=$A_k/A_o=(10^{0,1K})*100\%$	**absorbed and reflected by a sample**
0	100 %	0 %
-5,0	31 %	69 %
-10,0	10 %	90 %
-20,0	1 %	99 %
-30,0	0,1%	99,9 %

It can be seen from the table that at K = 0, 100% of the wave energy passes through the fence, only 1% of energy for K = -20, and 99% of energy is reflected or absorbed by the enclosing structure. The electromagnetic situation in the building area from an external source of EMP is formed by the energies of the direct and reflected EM waves. For a certain configuration of the building, zones of exceeding the power density of the energy flux density (PES) may occur, for example, between houses 37 and 39 according to figure 2 [5].

Figure 2. Map of electromagnetic fields at a frequency of 2.45 GHz

(numbers around buildings - the energy flux density in μW/cm^2; the numbers circled show the total EM background in the building)

At present, there is no general theory that would allow estimating the distribution of PPE in the building by calculation, therefore the distribution of PPE in the microdistrict of buildings and at the facades of buildings can be obtained only by direct measurements.

2. Development of a method for assessing the protective characteristics of enclosing structures.

The method of assessing protective characteristics is based on the nature of the interaction of EMP with enclosing structures (Figure 1 and formula 1). For the experiments, the FSH8 electromagnetic field spectrum analyzer, operating in the frequency ranges from 0.3 to 8 GHz, from ROHDE & SCHWARZ, was used. The output power of the device is from 0 dBm to -50 dBm (error of measurement is <1.5 dB). The spectrum analyzer is equipped with antenna emitters of electromagnetic waves and receiving antennas, for selected frequencies. The FSH8 device provides generation and spectral analysis of electromagnetic waves. A photograph of the FSH8 spectrum analyzer and the experimental setup is shown in Figure 3.

The results of the measurement are recorded on the computer screen in the form of the dependence of the attenuation coefficient "K" on the frequency in a given frequency range. The minus sign before the attenuation coefficient K indicates a weakening of the signal as it passes through the sample. In the experimental setup, the angle between the wave beam and the sample is 90 degrees, but in real building conditions the angle between the wave beam and the facade of the building can take different values (Figure 2). To substantiate the value of this angle, a special experiment was performed in laboratory studies, the results of which are presented in Table 2.

Table 2. Change in the attenuation coefficient as a function of the angle of incidence of the EM wave on the sample surface.

№	Tested samples	The angle between the wave beam and the sample plane, degrees		
		90	67,5	45
1	Reinforced concrete block, thickness 150 mm	- 7,92	- 8,08	- 8,49
2	Masonry, 120 mm thick	- 5,6	- 6,35	- 6,75
3	Single-paned glass unit TR 3.13 - 22 - 8M1 (Silver 15)	- 22,87	- 25,3	- 29,62

a *b*

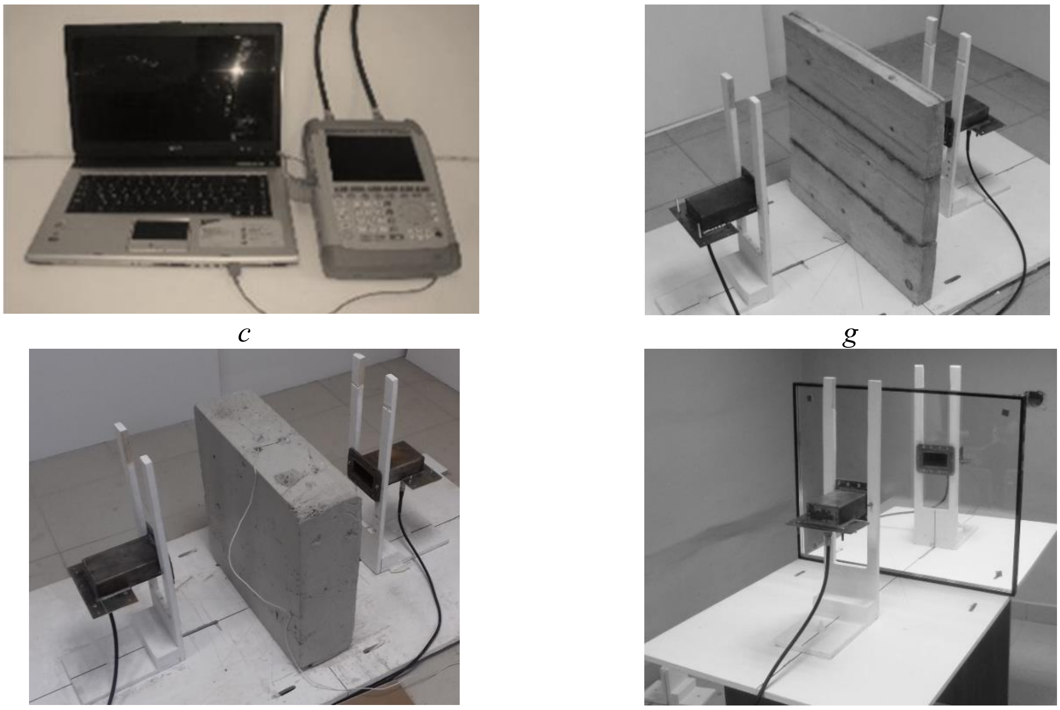

Figure 3. Photograph of the FSH8 device (a) and a photo of the experimental installation with test samples of wood (b), reinforced concrete (c) and double-glazed windows (g)

From Table 2 it can be seen that at an angle of 90 degrees, the greatest amount of EM wave energy passes through the sample (the attenuation coefficient is minimal), therefore, in order to increase the reliability of the protection of the enclosing structures from EMR, further investigations were carried out at an angle of 90 degrees. According to the developed technique, the protective characteristics of the main functional layers and enclosing structures in general have been investigated. The results of the evaluation of the protective characteristics of the main functional layers of the enclosing structures are given:

- facing layers (Table 3) [6];
- heat-insulating and structural layers (Figures 4 and 5) [7];
- glass (table 4) and double-glazed windows (table 5) [8].

Table 3. Protective characteristics of the facing layers

№	Facing layers	Thickness δ, mm	The attenuation coefficient K, dB	The amount of energy passed through the sample,%
1	Ceramic granite slab of ventilated facade	8	-2,1	61
2	Cement-sand plaster	16	- 2,27	59
3	Gypsum fiber boards	10	- 3,55	44
4	Gypsum fiber boards with 30% schungite content	10	- 6,92	20
5	Metal siding	0,8	-20,43	0,9

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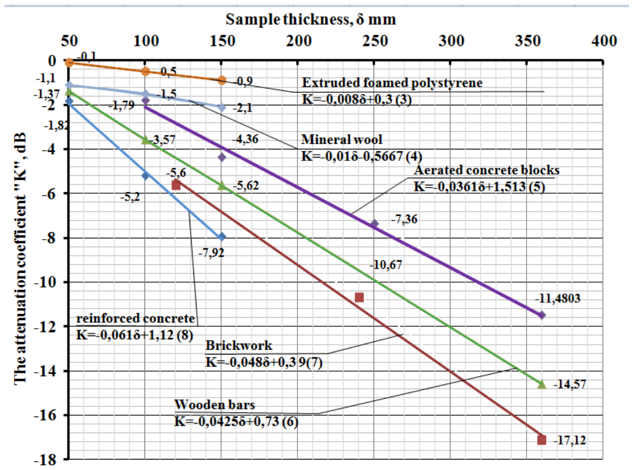


Figure 4. Coefficients of attenuation of energy of electromagnetic waves during their passage through heat-insulating and structural functional layers.

It follows from Fig. 4 that the protective characteristics of the tested materials (attenuation coefficient K) increase both with an increase in the thickness (δ) of the samples and with an increase in the material density (ρ). Moreover, the increase in K from δ is linear (formulas 3-8, in Fig. 4), and the increase in K from ρ is non-linear (Figure 5). An analysis of the entire volume of experimental data made it possible to establish that an increase in K from δ (in the range 50-350 mm) and an increase in K from ρ (in the range 45-2000 kg/m^3) is of the same order. This made it possible to obtain a generalized graphical dependence K = f (ρ, δ) suitable for practical calculations of the attenuation coefficients of individual layers of K_i of a large number of wall materials in the specified ranges of δ and ρ (Fig. 5). It can be seen from Fig. 5 that the most protective characteristics of materials (attenuation coefficient K) increase in the density range up to 1000 kg/m^3, and in the range 1000-2000 kg / m^3, the growth of K is 1-2 dB. In Figure 7, the arrows show an estimate of the value of K for a material with ρ = 1000 kg/m^3 for a layer thickness of 100 and 350 mm.

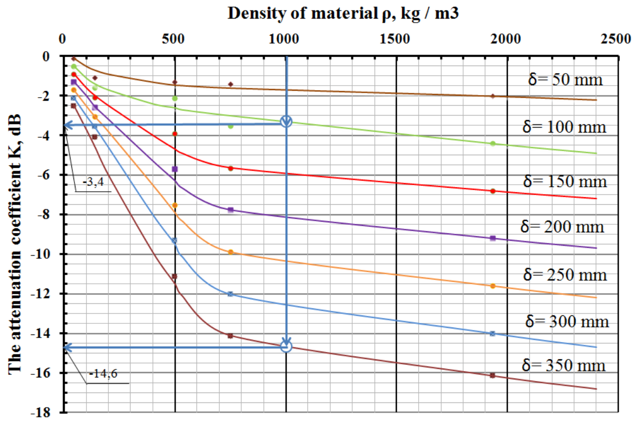


Figure 5. Generalized graphical dependence K = f (ρ, δ) for heat-insulating and structural layers of enclosing structures

Glass testing (Table 4) showed that glasses with special coatings (metal and oxide metal sputtering) possess the greatest protective properties (K> -27.5 dB), these are energy-saving and multifunctional glasses (lines 1, 2 of Table 4). These types of glasses retard more than 99% of the EM energy incident on them. For ordinary silicate glasses with the "M" mark, as well as frosted and enameled silicate glasses, the value of the attenuation coefficients K is much lower and ranges from 0 to -5 dB. These glasses let in 31 to 89% of the energy of the EM wave incident on them. Investigation of double-glazed windows (Table 5) showed that their protective properties are determined by the type of glass with the maximum attenuation coefficient. Thus, if there are energy-saving or multifunctional glasses in the insulating glass unit, the protective properties of the insulating glass units are determined by these types of glasses, as seen in lines 1 and 2 of Table 5. These double-glazed windows absorb and reflect more than 99% of the EM energy incident on them.

Table 4. Protective characteristics of the glasses studied

№	Glass grade	Characteristics of glass	Coefficient of attenuation, dB	The amount of energy passed through the sample,%
1	**4TopN+**	Energy-saving	-35,5	0,02
2	**8StoprayVision-60T**	Multi-functional	-27,5	0,17
3	**6M1Em**	Silicate enameled	-5,0	31,62
4	**8M1MateluxClearT**	Silicate frosted	-4,5	35,48
5	**6M1**	Silicate	-0,5	89,12

Note: The figure before the glass mark means its thickness in mm.

Table 5. Protective characteristics of the insulated glass units

№	Double-glazed windows (brand)	Number of chambers and thickness	Composition	Coefficient of attenuation "K", dB	The amount of energy passed through the sample,%
1	**6SPhCl /16AL/4TopN**	single-compartment double-glazed window, thickness 26 mm	**6Stopsol Phoenix Clear** (sun protection glass 6 mm thick) **16AL** (aluminum frame with a thickness of 16 mm) **4TopN+**(energy-saving glass 4 mm thick)	-35,5	0,02
2	**(4SrNeo / 16AL / 4M1)**	single-compartment double-glazed window, thickness 24 mm	**4StoprayNeo** (Multifunctional glass 4 mm thick) **16AL** (aluminum frame with a thickness of 16 mm) **4M1** (ordinary glass 4 mm thick)	-20,5	0,89
3	**(8MatClearT / 18Chrul 704 / 6M1Em)**	single-chamber double-glazed window, thickness 32 mm	**8M1MateluxClearT** (Silicate frosted thickness 8 mm) **18ChromotekUltra** (aluminum-plastic frame with a thickness of 18 mm) **6M1Em** (glass with enamel coating 6 mm thick)	-1,0	79,43
4	**(4M1/10al/4M1/10al/4M1)**	double-glazed windows, thickness 32 mm	**4M1** (silicate glass 4 mm thick) **10al** (aluminum frame with a thickness of 10 mm) **4M1** (silicate glass 4 mm thick) **10al** (aluminum frame with a thickness of 10 mm) **4M1**(silicate glass 4 mm thick)	-0,5	89,12

Double-glazed windows consisting of "M" glasses and their varieties (K = -1 dB) pass through themselves 79% or 100% of the incident energy, that is they are ineffective for protection against electromagnetic radiation (line 3, table 5).

Determination of the protective characteristics of the main functional layers makes it possible to evaluate the protective characteristics of the enclosing structures as a whole.

Two methods for assessing the protective characteristics of enclosing structures in general are proposed: calculated and experimental.

The calculation method uses the results of estimating the coefficients of attenuation of functional layers (Figures 4 and 5, Tables 4, 5). The initial data for the calculation is the structural solutions of the enclosing structure designed from the thermal protection conditions, for which the materials of the functional layers, their density ρ and thickness δ have been determined.

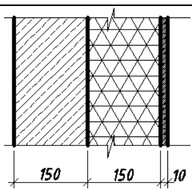
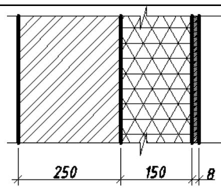
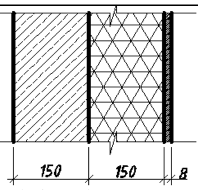
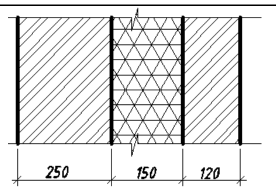
Because of the linearity of the dependence of K on δ (Figure 6), the fading attenuation coefficient as a whole is determined by the sum of the coefficients of the individual layers K_i:

$$K_{ogr} = \sum_{1}^{n} K_i, \text{dB} \qquad (3)$$

The design of the building also defines the types of double-glazed windows, hence, according to table 5, its attenuation coefficient $K_{st.p.}$

An experimental evaluation of the protective characteristics of enclosing structures is generally carried out in the same experimental setup by testing the fence fragment with real functional layers. Table 6 shows the comparative data for the four structural solutions of the external walls.

Table 6. Comparison of the calculated and experimental methods of determining the K_{ogr}.

External wall constructions	 Reinforced concrete (150 mm) Mineral wool (150 mm) Plaster (10 mm)	 Ceramic brick (50 mm) Mineral wool 150 mm) Porcelain tiles (8 mm)	 Reinforced concrete (150 mm) Mineral wool (150 mm) Porcelain tiles (8 mm)	 Ceramic brick (250 mm) Styrofoam (150 mm) Ceramic brick (120 mm)
Calculation using the formula using figures 8 and 9	12,29 dB	15,7 dB	12,12 dB	18,0 dB
Experiment by the developed technique	13,75 dB	14,49 dB	14,08 dB	16,38 dB
The discrepancy between the results in the estimation of K,%	10,6 %	7,7 %	13,9 %	9,0 %

It can be seen that the discrepancy between the calculated and experimental method does not exceed 15%, which can be considered satisfactory. The results of the study of the protective characteristics of functional layers and enclosing structures as a whole are obtained in relative units, dB or %, which does not allow to directly assess the ability of the fence to not exceed the permissible level of PPE in the building premises, which is represented in absolute units, $\mu W/cm^2$. To solve this problem, it is required to disclose the notion "the required level of protection of enclosing structures". The term "required level of protection" implies the determination of such a value of the attenuation coefficient K, at which the normalized values of PPE in the building premises will not be exceeded for any values of the PES in the microdistrict near the facades of buildings. In accordance with this, the required coefficient of attenuation of CR is determined by comparing the PPE norm in the room - A_n (μW/ cm^2) and the value of the PPE at the facade of the building - A_f (μW/cm^2):

$$K_{tr} = 10\lg\left(\frac{A_n}{A_f}\right) \quad [\text{dB}] \qquad (4)$$

The enclosing structures will perform protection against EMP if their coefficients of attenuation are K_{ogr} and $K_{st.p.}$ will exceed the required coefficient of attenuation K_{tr}, that is:

$$K_{ogr} \geq K_{tr} \qquad K_{st.p.} \geq K_{tr} \qquad (5)$$

If inequality (5) does not hold, then the protective properties of individual layers should be increased or the double-glazed unit replaced.

Example. Initial data: To determine the correspondence of the enclosing structures of a residential house to the intensity of electromagnetic influences in a microdistrict of development. The energy flux density (PPE) at the facade of the building is A_f = 25 μW/cm^2. The normative value of PPE in a residential building is A_n = 10 μW/cm^2. The design of the "dull" part of the outer wall, formed from the thermal protection conditions and the characteristics of the materials, is summarized in Table 7. In the window structure, the double-glazed 4M1/10AL/4M1/10AL/4M1 glass is used (line 4 of Table 5).
Solution: Determination of the required coefficient of attenuation K_{tr} according to the formula (4):

$$K_{\text{tr}} = 10 \cdot \lg\frac{10}{25} = -3{,}97dB$$

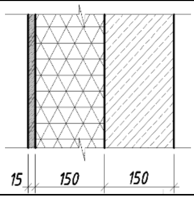
Determination of the attenuation coefficients of individual layers of the fence K_i according to Figure 4. The results of the calculation are shown in Table 7. Determination of the coefficient of attenuation of the fence as a whole K_{ogr} by formula (3):

$$K_{ogr} = (-2{,}27) + (-2{,}1) + (-7{,}92) = -12{,}29dB$$

Verification of the suitability of the "deaf" part of the wall and the window structure with the selected intensity of EM radiation:

- "deaf" part of the fences K_{ogr} = -12.29 dB <K_{tr} = -3.97 dB;
- Window construction $K_{st.p.}$ = 0 dB> K_{tr} = -3.97 dB.

Table 7. Characteristics of enclosing structures

Design outer wall	**Layer characteristics**				
	№	**Type of material**	**ρ, kg/m³**	**δ, mm**	**Coefficient of attenuation K_i, dB**
	1 2 3	Cement plaster Mineral wool Reinforced concrete	1500 140 2500	15 150 150	-2,27 -2,1 -7,92

The stone part of the enclosure corresponds to the inequality (5), and the translucent part does not correspond. It is required to increase the protective characteristics of the insulating glass unit. If you replace this double-glazed window with the 4SrNeo / 16AL / 4M1 (lines 2 of Table 4) with K = -20.5 dB, then we get: K = -20.5 dB <K_{tr} = -3.97 dB

3. Conclusion

After adjusting the protective characteristics of the translucent structure, the enclosure as a whole will meet the requirements for protecting the premises of an apartment building from an external source of electromagnetic radiation.

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