Effect of Plastering Mesh on Radio Signals: Modelling and Practical Measurements

Ari Asp
Faculty of Electrical Engineering, Information Technology and communication sciences, Tampere University
Tampere, Finland
Contact e-mail: ari.asp@tuni.fi

Jussa Pikkuvirta
Faculty of build Environment, Tampere University
Tampere, Finland

Arto Hujanen
VTT, Technical Research Centre of Finland Ltd

Ismo Huhtinen
VTT, Technical Research Centre of Finland Ltd

Mikko Valkama
Faculty of Electrical Engineering, Information Technology and communication sciences, Tampere University
Tampere, Finland

***Abstract*— The improvement of the energy efficiency of a building is often one of the reasons for the renovation of building facades. During such renovations, the energy efficiency is usually improved by increasing the thickness of insulation layer. The increased insulation layer increases the overall thickness of the wall, and to compensate for that, a new thin façade material is often sought. As a result, plastering has gained more and more popularity recently. However, especially in the case of thick plastering, a plaster mesh is often used to fix a layer of material, and this paper investigates the effect of the mesh on radio signal attenuation. This study shows that the plastering mesh significantly increases the overall wall attenuation, especially at lower frequencies used by mobile networks. The attenuation caused by the mesh is frequency dependent and decreases with increasing frequency. The attenuation behavior is entirely determined by the mesh size of the mesh.**

Keywords*— Radiowave propagation, energy-efficient buildings, plastering net, penetration loss, outdoor-to-indoor propagation, RF measurements.

I. Introduction

Today, there is an almost universal agreement about climate change and that the exceptionally rapid growth in global temperatures is mainly due to man-made greenhouse gases. As a result, the message of numerous climate conferences over the last decade is clear; energy efficiency must be improved rapidly in all areas of life, and carbon dioxide emissions must be reduced rapidly. [1]

Housing is one of the most energy-consuming fields in daily life and it is estimated that it accounts for 40-60% of total energy use. However, it is also an area that offers some of the best potential for improving energy efficiency. [2,3,4].

Heating accounts for the largest amount of energy consumed in housing, but the amount of energy required for heating can be reduced by improving the insulation of the building exterior cover. [5]. Due to this, when renovating the exterior walls of buildings, providing a better insulation level is often one of the targets, even if not the primary one. When an insulating layer is thickened, or the insulation material is changed, the old outmost portion of facade is usually removed and replaced with plastering.

This paper investigates the effect of a plastering mesh commonly used to support thick plastering layers on signal attenuation in mobile networks. As the results of this study are likely to be of interest to both radio network designers and construction engineering professionals, this paper aims to provide enough basic information for professionals in both fields to understand the problems caused by the plastering mesh.

The main problem is that material RF -attenuations on the exterior walls of buildings have a direct effect on the coverage and data transmission of the cellular networks. Because current cellular mobile phone systems are based on macrocells where base stations are located outside buildings, the signal path always passes through material layers of a building exterior cover. Based on measurements and simulations, this paper demonstrates that a plastering mesh can double the RF attenuation of the wall structure, especially at lower frequencies of cellular networks. The high attenuations of the lower frequencies are based on a frequency selective behavior of the mesh, which acts as a high pass filter. The problems are spreading because in many countries, especially those that experienced a construction boom some decades ago, the stock of apartment buildings is growing older, so the amount of exterior wall plastering work is constantly increasing.

Part II of this paper presents background information related to the tightening of energy efficiency requirements, the age distribution of the European regional building stock, and the use of plastering as a coating method. In addition, the frequencies used in current and near future mobile networks are briefly listed. Then, Part III covers reflections from plastering surfaces and theoretical modeling of mesh. Section IV describes the method used in the laboratory measurements, while Section IV presents the results of the mesh measurements and plastering mesh simulations. Finally, conclusions are drawn in Section V.

II. BACKGROUND

This section focuses on stricter energy efficiency requirements due to the (a) EU-level climate strategy, (b) age distribution of residential buildings in the EU, and (c) potential for energy efficiency improvements in the renovation of exterior walls of old residential buildings. This section also seeks to clarify why plastering is often chosen as a surface material in renovations. After that, we will briefly introduce the different plastering methods, especially the use of the plastering mesh. Finally, there is an overview of current and near-term frequencies that need to be considered when evaluating the impact of plastering mesh attenuation on the performance of different systems. To provide a clear picture of the causes and extent of changes in the RF attenuation of a residential building stock, this paper places emphasis on the background and causes of differing energy efficiency levels in general, and the effects of refurbishment of exterior walls. In addition, the paper outlines the surprising additional attenuation of the plastering mesh, and describes the transformation of the entire building stock to a more energy efficient direction and the potential problems that new building materials may cause.

A. *Energy Efficiency Strategies*

Improving the energy efficiency of housing and buildings is one of the most essential tools for achieving the objectives of the EU Energy Strategy [7,8]. The EU has set a binding target to reduce emissions by at least 40% below 1990 levels by 2030. In this way, the EU would fulfill its obligations under the Paris Agreement and move towards a climate-neutral economy. [6]. The potential of residential and commercial buildings energy efficiency improvement was identified in the 2006 action plan as one of the largest and most cost-effective measures to achieve the 2020 targets. The same document emphasizes the importance of improving the insulation layer of roofs and walls in residential buildings. [7,8].

B. *Age Distribution and Renovation Needs of Building Population*

The impact of directives requiring energy efficiency improvements is not only apparent in the choice of structures and materials used in new buildings, but are also in the renovation of an aging building stock. Statistically speaking, the stock of buildings in the EU -region is old, so there is a great need for repair [9].

When designing new houses, the life cycle of buildings is expected to be over 50 years, but at least in the Nordic countries, the need to repair exterior walls has often emerged within 30 years after the house was completed [12,13]. Exterior wall problems often appear as large cracks or other damage to the façade, and the entire façade is usually renewed to prevent further damage.

As façade renovation is one of the most expensive repairs for a housing association, it is usually the case that energy efficiency is also improved during the renovation by changing the insulation material or increasing the thickness of the insulation layer. In either case, the original facade is either removed or coated with new material. Usually the new surface layer is plastered as it does not significantly increase the overall original wall thickness [11,15,16].

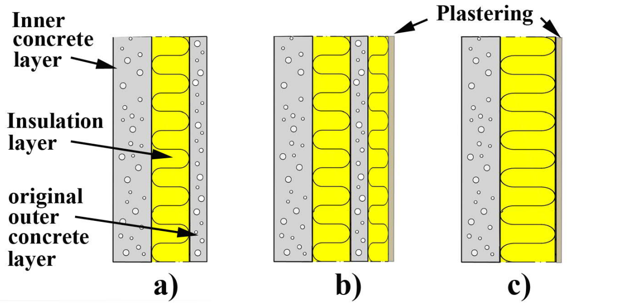

Figure 1. An exterior wall structure into which the insulation layers has been added during a renovation.

Figure 1 (a) shows the original situation before the facade renovation has been carried out. In Figure 1 (b), the old outer concrete layer is left in place within the structure, but a plastering-coated insulation layer is added on top of it. Finally, Figure 1 (c) shows a case where the both the old outer surface layer and the insulation have been removed and replaced with a completely new insulation layer that has been plastered on [11]. In most cases, an increase in the insulation layer is a justified coincidence of the exterior wall renovation, since, according to published studies focusing on suburban apartment blocks, additional insulation of the facades has achieved an energy saving of 9-10% [10].

C. *Renovation and Plastering*

The signal attenuation problem with radio signals from cellular networks is not the plastering material itself, but the metal plastering mesh used to support the plastering layer. Because there are two different plastering methods, this section introduces the differences between those methods and types of plastering meshes used with each of them. [18,19].

Plastering is used for both new building construction and for older house renovations, particularly because of its low cost and lightweight construction [11]. As mentioned, there are two basic techniques for plastering, a thin plastering and a thick plaster. The thin plastering can be done faster, in just one stage, whereas the thick plastering takes longer, so is primarily used when the surface beneath the plaster is uneven. The biggest difference that causes issues with radio signals, however, is that in the thin plastering layer the plaster mesh is made of fiberglass, but in the thick plastering the metal mesh is used.

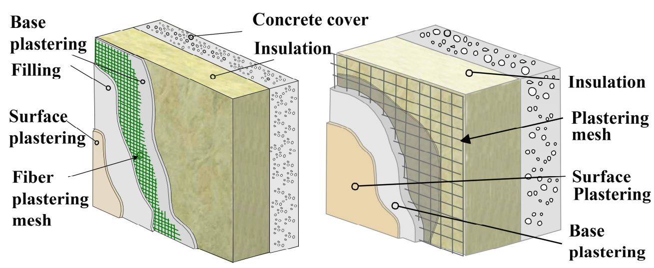

Figure 2. Thin and thick plastering approaches.

The thick plastering, which usually contains three overlapping mortar layers, is supported by a galvanized plastering mesh of about 19 mm eye-size installed between the plaster layers. The mesh is intended to be placed in the middle of the plastering surface, where it acts most effectively to prevent against cracking or breaking of the façade [13,20].

D. Frequencies of Existing and Emerging Mobile Communication Networks

Since the main focus of this study is to investigate the effect of the high-pass filter formed by the plastering mesh on the attenuation of RF signals, it is necessary to briefly look at the frequencies used in cellular networks. This is because, based on the listed frequencies, it is easy to assess the technical systems that are particularly affected by the additional attenuation caused by the plastering meshes.

It is well-known from previous publications that lower frequencies penetrate building materials better than higher frequencies. [21]. As a result, the development of cellular networks has been followed with some concern because the next generation of the cellular system will generally use higher frequencies than earlier ones. The continuous increase in frequencies is due to the fact that there are no longer unused areas in the lower frequency ranges.

However, in this study it is shown that the plastering mesh is causing radio signal attenuation, especially for the lower frequencies, which are used in current systems and generally considered a reliable choice for demanding connections.

The commercial cellular systems currently in use work in the 700 MHz to 2600 MHz frequency range, although the 380 MHz band used by officials, (such as police and firemen), networks should be kept in mind. [22]. The frequencies used by the 5G technology currently being introduced will initially be in the 3400-3800 MHz range, but the 3800-4200 MHz frequency band is also of interest [23]. A kind of threshold-value is considered to be the 6GHz frequency, below which the attenuation of the structures remains reasonable, and that is why connections can be made between outdoor and indoor. On the other hand, almost all of the free frequency bands are available above 6GHz.

In the context of the standardization of 5G system frequency bands, the following bands have been particularly considered; 24.25-27.5 GHz, 31.8-33.4 GHz, 37-43.5 GHz, 45.5-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81- 86 GHz. However, there will obviously be country-specific exceptions in these areas.
[24].

While the development of mobile technologies is inevitably moving towards higher frequencies, it must be remembered that frequencies below 1 GHz are essential for many important systems. Perhaps the most prominent of these is the 900 MHz GSM system, which provides mobile phone call service coverage in rural areas. In addition, the LTE network for data transmission also uses the 700-800 MHz frequency band, and the highly expanding Internet of Things (IoT) -based systems, such as Sigfox, LoRa, and IEEE 802.11ah, use frequencies of less than 1 GHz. Furthermore, the frequencies of NB-IoT cellular networks are usually in the 700-900 MHz range. In conclusion, while current discussions usually emphasize the importance of higher frequencies, the band below 1 GHz will remain very important for current and future systems.

III. THE EFFECT OF PLASTERING NET FROM RF PERSPECTIVE

This section examines how the plaster network affects propagation of RF waves. The focus is on plastering layer of the whole wall element, the reinforced concrete (inner layer in Fig 1) has its own attenuation. In general, there are several factors that need to be taken into account [25,26]:

1. Reflections at the air—plaster interfaces.
2. Attenuation due to the lossy plastering.
3. Iron mesh forms a structure that resembles that of waveguides. In particular, meshes have so-called cutoff frequency below which they cause exponential attenuation to waves that pass through the iron mesh.
4. Reflections and scattering due to the iron wires. This factor could be estimated via a truncated series of equation sets.

In the following section, we review the theoretical background for items 1-3. We aim at a qualitative study, i.e., we aim not to establish quantitative analytical estimates. We assume that the plaster consists of “plates” and iron wire grids, whose normal are in the z-direction, which is also the direction of the signal propagation. Due to these assumptions, we study wave propagation in the z-direction, and the xy -plane forms the so-called transverse plane. Consequently, the main factor to be studied is the exponent term $e^{-\gamma z}$ where $\gamma = \alpha + j\beta \in \mathbb{C}$ is so called the propagation constant, and in which α, β are so called the attenuation constant and phase constant, respectively.

A. Reflections and Impedances

The reflection at the air-plaster interface can be estimated via reflection and transmission coefficients at each interface. Since three different interfaces exist in the plastering structure, multiple reflections are formed in the composition as shown in Figure 3. The image shows a principle image of a plastering surface on the wall with a plastering mesh in the center. For the sake of simplicity, the transmitted signal is assumed to propagate from the base station to the indoor user’s mobile phone. The first of the interfaces is the outer plaster surface from the direction of the base station signal and its reflection and transmission coefficients are ρ_1 and τ_1 respectively. The corresponding coefficients for the inner plastering surface are ρ_3 and τ_3. The ε_r value of the plastering material is about 4 when the mortar is completely dry. In the general case, complex permittivity $\varepsilon = \varepsilon_0 \varepsilon_r = \varepsilon_0(\varepsilon_r' - j\varepsilon_r'')$, and $j\varepsilon_r'' \neq 0$ is used [25]. The simulations were made with the ε_r -value 5.54 –j 0.7, which corresponds to the case where the mortar is not completely dry, and thus better represents the real-life situation. The centermost reflection surface is the surface of the plastering mesh, and its ε_{r2} value changes as a function of the frequency. Generally, for the plastering mesh, the $\rho 2 + \tau 2 \approx 1$, which means that the total energy of incoming RF –signal either reflected or is transmitted through the iron mesh, thus the internal losses of the mesh itself are negligible. The losses caused by the mesh itself are mainly eddy current losses and those are so small that they usually do not need to be taken into account.

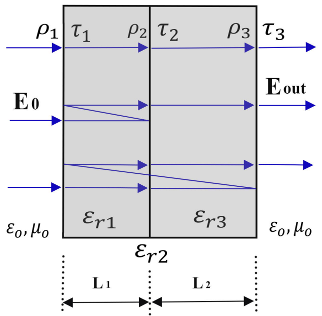

Fig 3. The layers of plastering structure into which the iron plastering net has installed

Figure 3 shows the principle of reflection surface analysis for a plastering structure that includes an iron plastering mesh submerged into the plastering material. The basic theory shown in figure is limited to first-order reflections, but naturally, in accurate calculations multiple reflections must be taken into account. In figure 3, the upper arrows represent the portion of the signal that propagates directly through the entire plastering without reflections. The second level of arrows represent a situation in which a part of the signal is reflected back from the plastering mesh but is reflected a second time from the front surface of the plastering back to its original direction. The situation can be mathematically represented by the following formulas [25]

$$E_{out} = E_o\tau_1\tau_2\tau_3 e^{-jk(L_1+L_2)} - E_o\tau_1\rho_2\rho_1\tau_2\tau_{3e^{-jk(3L_1+L_2)}} + E_o\tau_1\tau_2\rho_3\tau_2\rho_1\tau_2\tau_{3e^{-jk3(L_1+L_2)}} + \ldots \quad (1)$$

The reflection and transmission coefficients in the above formula depend directly on the impedance ratios on both sides of the interface. The impedances of different substances, in turn, are usually determined directly by the εr values, and for example, for the first interface they are obtained from the following formulas

$$\rho_1 = \frac{\frac{1}{\sqrt{\varepsilon r}}-1}{\frac{1}{\sqrt{\varepsilon r}}+1} \text{ and } \tau_1 = \sqrt{1-\rho_1^2} \quad (2,3)$$

A more general expression of the intrinsic impedances η exploits the propagation constant γ following way

$$\eta = \frac{j\omega\mu}{\gamma} \quad (4)$$

That allows calculation of η separately for each material of the structure. For the material interfaces, the reflection and transmission coefficients are obtained as

$$\rho = \frac{\eta_2-\eta_1}{\eta_2+\eta_1} \text{ and } \tau = \frac{2\,\eta_2}{\eta_2+\eta_1} \quad (5,6)$$

In above formulas, it is assumed that the signal is coming perpendicular to the surfaces.

B. Attenuations Due to the Lossy Plastering

Generally, in lossy materials the wave propagation is characterized by the complex propagation constant γ, which has the following definition [25]

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\varepsilon}\sqrt{1-j\frac{\sigma}{\omega\varepsilon}} \quad (7)$$

C. Plastering Mesh Description Using a Circuit Theory

The attenuation of the plaster mesh can be assessed by many methods. For example, the waveguide theory-based method has the advantage of the simplicity of estimation, but the accuracy remains modest. The reason for this is the very small depth of the mesh-like structure where the waveforms modes of the waveguide cannot generate. Examples of a much more accurate equations for iron mesh attenuation are the following circuit model based admittance approximation formulas [27]

$$Y_{ind} \approx (-j)\left(\beta-\frac{1}{\beta}\right)\frac{\left[\left(\frac{a}{c}\right)+\frac{1}{2}\left(\frac{a}{\lambda}\right)^2\right]}{\ln\csc\left(\frac{\pi}{2}\frac{\delta}{a}\right)} \quad (8)$$

where $\csc(x) = \frac{1}{\sin(x)}$ (9)

$$\text{and}\beta = \left(1-0.41\,\frac{((a-c)/2)}{a}\right)/\left(\frac{a}{\lambda}\right) \quad (10)$$

The dimensions of a grid are represented in figure 4

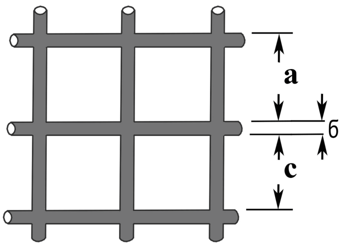

Figure 4. The dimensions in inductive mesh.

From where the transmission coefficient can be calculated by the following formula

$$T = \frac{1}{1+Y_{ind}} \quad (11)$$

Where the admittance Y is admittance of inductive mesh.

The admittance calculation seems to be working well at a general level for the structure where there is an insulating material in the middle that is surrounded by conductive material. When assessing the precision, it should be noted that the above-described wire mesh is in a practical situation as part of the outer wall surface with a 10-20 mm plaster layer on each side, a more detailed analysis of the overall attenuation of the structure would require separate reflection and transmission coefficients of each interface of the total structure. However, this was not done in this study because it requires a careful analysis of the electrical properties of the plaster, especially for the determination of the (complex) ε parameter for mortar and reinforced concrete.

IV. Measurement Methods

The measurements of the plastering mesh were carried out on the ground floor of University of Tampere, where all the walls are 300 mm thick reinforced concrete. The concrete wall has a 600 x 600 mm opening where the mesh to be measured was placed. To minimize interfering multi-path components, the walls of the measurement room were coated with a thin layer of aluminum. Measurements were based on far-field method with a horn antenna (A-INFO JXTXLB-880-NF) on each side of the plastering mesh under measurement. Both antennas had a distance of 1.6 m from the mesh, which avoided problems of the near field. The first of the antennas was a transmission antenna controlled by a Rohde & Schwarz SMJ series signal generator. On the other side of the mesh to be measured was a Rohde & Schwarz FSG series spectrum analyzer connected to the receiving antenna. The measuring range was limited to 6 GHz due to the measuring equipment. The measurement was based on a comparative measurement in which the signal level passed through the mesh was compared with a signal received by the same arrangement without the mesh. The principle of the measuring arrangement is illustrated in Figure 5.

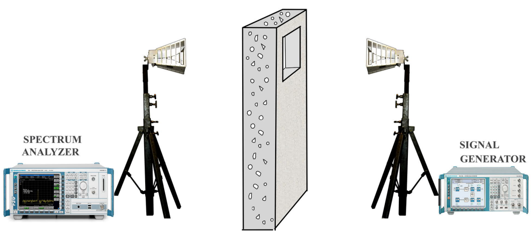

Figure 5. Measurement setup.

In order to compare measurement results and theory, a matlab code was formulated to simulate the mesh attenuation in a computational manner. With the code, it is possible to simulate structures in which several materials are joined together in a overlapping construct. The calculation is based on a transmission line model in which the original structure is modeled using series connected components. The properties of the components are the complex propagation constant, characteristic impedance, *Zi*, and the length of the line component, *li*.

The characteristic impedance, *Zi*, is described based on permittivity and permeability of the material that have been measured separately.

$$Z_i = \sqrt{\frac{\mu_i}{\varepsilon_i}}, \; k_i = 2\pi f\sqrt{\mu_i \varepsilon_i} \qquad (12,13)$$

V. Obtained Results and Analysis

In the propagation measurements, two types of commonly utilized plastering meshes were adopted, of which the 19 mm mesh represents the most common plastering mesh type and, for comparison, a mesh size of 25 mm mesh was measured mainly to help assessment of the impact of the mesh size. For simulations of the total attenuation of the mesh and plastering, a sample of plastering was also prepared, the ε_r -value of which was measured by the Reflection-Transmission method using a circuit analyzer and focusing antennas [28].

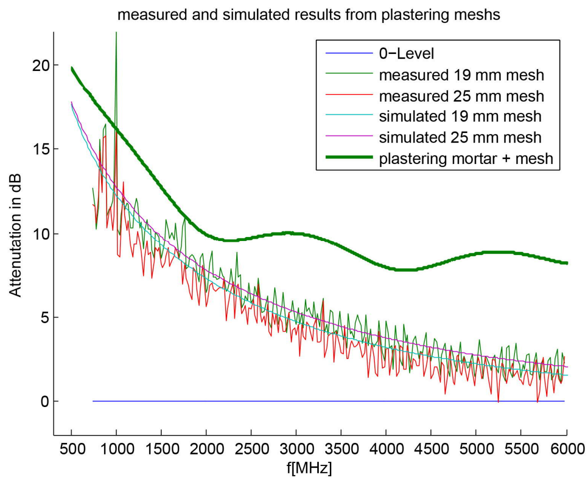

Figure 6. Simulated and measured RF attenuations of a plastering net.

Figure 6 shows the results of laboratory measurements and simulations of two different plastering meshes in the 500 MHz to 6 GHz frequency range. The thicker green curve shows the combined attenuation of the 19 mm plastering mesh and slightly damp 30 mm thick plastering mortar layer. The plastering mortar attenuation was calculated by using the ε_r -value 5.5 –j 0.7. As can be seen, the results of the reference simulations match very accurately with the actual RF measurement results. It is also observed that meshes with different sizes do not differ substantially from each other from the RF attenuation perspective. In general, based on the obtained measurement and simulation results, the plastering mesh causes significant RF attenuation, especially at low frequencies, which up until now have been commonly considered suitable for wireless systems due to lower material RF attenuation. Thus, this is a new finding that has not been observed earlier in the literature and may have substantial impact on, for example, the indoor coverage of the IoT networks operating commonly at 700-900 MHz range.

Typically, the composition of plastering mortar and mesh are combined with a 150 - 180 mm thick reinforced inner concrete layer of sandwich element whose additional attenuation has to be taken into account. The attenuation of inner concrete layer varies via concrete type and the thickness.

VI. Conclusions

This article investigated the attenuation caused by a plastering method commonly used in building renovation, and in particular the effect the plastering mesh has at frequencies used by cellular networks. The first theoretical part of the study describes the background to the growing popularity of plastering as a facade material for various residential buildings. The report also evaluates wireless systems that are most affected by plastering mesh attenuation. The main result, however, is the strong attenuation of the plaster mesh, especially at low frequencies, which is generally assumed to penetrate the exterior walls of buildings with relatively little attenuation. On the basis of our measurements, it was shown that the thick plastering layer has an attenuation of about 10 dB at all frequencies, even though the plastering attenuation has so far been assumed to be in the order of 2-3 dB. Thus, the thick plastering layer almost doubles the RF attenuation of the entire wall structure. The additional attenuation caused by the plastering mesh is so great that problems it may cause should start to be considered by companies when planning renovations and evaluating the performance and capacity of wireless networks, especially with GSM, Lora, Sigfox and NB-Iot networks.

References

[1] EU comission and its priorities, "Energy Strategy and Energy Union , Secure, competitive, and sustainable energy" Available: EU commission release, https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union [Accessed: May 22, 2018]

[2] European Commission, "Towards a smart, efficient and sustainable heating and cooling sector", Available: EU commission Press Release Database, Brussels, 16 February 2016: http://europa.eu/rapid/press-release_MEMO-16-311_en.htm [Accessed: May 22, 2018]

[3] EAE, European Energy Saving Guide 2016 , of the European Association for External Thermal Insulation Composite Systems (EAE), Available: https://www.ea-etics.eu/files/dokumente-eae/5_Publications/Energy-Saving-Guide/Energy_Saving_Guide_2016.pdf [Accessed: May 22, 2018]

[4] Deloitte, "Energy Efficiency in Europe The levers to deliver the potential.", Available: Deloitte Conseil release 2016, https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/energy-efficiency-in-europe.pdf [Accessed: Jan 15, 2020]

[5] P. L. Simona, P. Spiru, I. V. Ion ; "Increasing the energy efficiency of buildings by thermal insulation" , International Scientific Conference "Environmental and Climate Technologies", CONECT 2017, 10–12. May 2017, Riga, Latvia Available: doi.org/10.1016/j.egypro.2017.09.044 [Accessed: Jan 15, 2020]

[6] EU's Climate action, 2030 climate & energy framework, Available: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed: May 1, 2020]

[7] S. Lechtenböhmer, A. Schüring; "The potential for large scale savings from insulating residential buildings in the EU", Wuppertal Institute for Climate, Environment and Energy GmbH, Germany, DOI: 10.1007/s12053-010-9090-6

[8] P. Bertoldi, B. Atanasiu, "Electricity Consumption and Efficiency Trends in European Union –Status Report 2009"; JRC 53919, ISBN 978-92-79-13614-6, European Communities, 2009 , DOI: 10.2788/39332

[9] BPIE, "EUROPE'S BUILDINGS UNDER THE MICROSCOPEA - country-by-country review of the energy performance of buildings", ISBN:9789491143014, Published in October 2011 by Buildings Performance Institute Europe (BPIE), http://bpie.eu/publication/europes-buildings-under-the-microscope/ [Accessed: Jan 15, 2020]

[10] A. Uihlein, P. Eder; " Policy options towards an energy efficient residential building stock in the EU-27", European Commission, Joint Research Centre, Institute for Prospective Technological Studies, C/Inca Garcilaso 3, 41092 Seville, Spain, Available: Energy and Buildings, Volume 42, Issue 6, June 2010, Pages 791-798 https://doi.org/10.1016/j.enbuild.2009.11.016 [Accessed: Jan 15, 2020]

[11] M. Hirsimäki, Kerrostaloyhtiön julkisivukorjaus ja ulkoseinien lisäeristäminen, Available: http://urn.fi/URN:NBN:fi:amk-201301291832 [Accessed: Jan 15, 2020]

[12] M. Méquignon , H. Ait Haddou, F. Bonneaud; "From lifespan of building walls to environmental indicators" Proceedings of the 14th IFAC Symposium on Information Control Problems in Manufacturing Bucharest, doi.org/10.3182/20120523-3-RO-2023.00127May [Accessed: Jan 15, 2020]

[13] J. Lahdensivu: "Durability Properties and Actual Deorientation of Finnish Concrete Fasades and Balconies", Tampere University of Technology, Publication 1028, Available: https://tutcris.tut.fi /portal/files/2041944/lahdensivu.pdf [Accessed: May 22, 2018]

[14] A. Köliö, P. J. Niemelä, Jukka Lahdensivu, "Evaluation of a carbonation model for existing concrete facades and balconies by consecutive field measurements", Cement and Concrete Composites 65 (2016) p.29-40 Available: https://doi.org/10.1016/j.cemconcomp.2015.10.013

[15] Onlinelibrary.wiley.com, appendix A, Available: "weights of building materials", https://onlinelibrary.wiley.com/doi/pdf/10.1002/9780470259795.app1 [Accessed: Jan 15, 2020]

[16] British Standard BS 648:1964 Incorporating Amendment Nos. 1 and 2, "Schedule of Weights of building materials", UDC 691:624.045 Available: https://www.slideshare.net/LuanTruongVan/bs648-1964-weights-of-building-materials [Accessed: Jan 15, 2020]

[17] N. Hall, Ph.D., P.E., A.I.A "Exterior Insulation and Finish Systems (And Other Problems with Building Envelopes)" Available: http://www.largelossdrying.com/pdf/Exterior%20Insulation%20and%20Finish%20Systems%20(EIFS).pdf [Accessed: Jan 15, 2020]

[18] A. N. Dancygier, D. A. Yankelevsky, and H. Baum. "Behavior of Reinforced Concrete Walls with Interior Plaster Coating under Exterior Hard Projectile Impact", Materials Journal, 1999 - concrete.org

[19] J. M. Proença, A. S. Gago, A. V. Costa, A. M. André - Proceedings of the 15WCEE Lisboa 2012 "Strengthening of masonry wall load bearing structures with reinforced plastering mortar solution", Available: http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_1830.pdf [Accessed: Jan 15, 2020]

[20] R. Dylewski, J. Adamczyk "The comparison of thermal insulation types of plaster with cement plaster", Journal of Cleaner Production 83 (2014) 256-262, doi.org/10.1016/j.jclepro.2014.07.042 [Accessed: Jan 15, 2020]

[21] W. C. Stone, "Electromagnetic signal attenuation in construction materials," NIST Construction Automation Program Report No.3, NISTIR 6055, Available: http://fire.nist.gov/bfrlpubs/build97/PDF/b97123.pdf.

[22] Frequencies –List of Mobile Frequencies by country (GSM, CDMA,LTE) Available: http://www.spectrummonitoring.com/frequencies/ [Accessed: May 22, 2018]

[23] Hu Wang, 5G Spectrum and Policy Forum, 29 June 2017, GSMA MWC Shanghai, "The Use of 3300 – 3800 MHz For 5G Early Rollout: Opportunities and Challenges": Available: https://www.gsma.com/spectrum/wp-content/uploads/2017/07/Hu-Wang-GSA-The-USE-of-3300-3800-MHZ-For-5G-Early-Rollout.pdf [Accessed: May 22, 2018]

[24] A.Kühn (CPG-19 Chairman), "5G and IMT identification –Views from CEPT-", Available: https://www.itu.int/en/ITU-R/seminars/rrs/2017-Africa/Forum/CEPT-ECC.pdf [Accessed: May 22, 2018]

[25] D.M.Pozar,"Microwave engineering", John Wiley & Sons Inc. , fourth edition, ISBN-978-0-470-63155-3

[26] C.A. Balanis," Advanced engineering electromagnetics", John Wiley & Sons Inc. , second edition, ISBN-978-0-470-58948-9

[27] S-W. Lee, G. Zarrillo, C-L Lae, "Simple Formulas for Transmission Through Periodic Metal Grids or Plates", DOI: 10.1109/TAP.1982.1142923 [Accessed: May 22, 2019]

[28] A.Asp, T.Hentilä, J.Pikkuvirta, A.Hujanen, I.Huhtinen, M.Valkama, " Impact of Different Concrete Types on Radio Propagation: Fundamentals and Practical RF Measurements" SpliTech 2019, DOI: 10.23919/ SpliTech.2019.8783022