Electromagnetic Shielding Effectiveness of Historic Buildings: The Heritage Stone Town of Zanzibar

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Abstract: Owing to health and security hazards posed by concentration of EMR (electromagnetic radiations) from wireless transmission devices such as antennas and WiFi, it is time for building specialists to consider EMR shielding in general designs. Such a venture needs understanding of shielding behavior of various building materials in their isolated and combined forms. While shielding properties of several industrial materials are known, much remains to be understood from traditional materials. This article contributes to the knowledge of SE (shielding effectiveness) of the latter materials. It has tested the buildings of the 19th CE STZ (Stone Town of Zanzibar). The coral stones, mud, and mangrove pole buildings of this historic town were found to be effective in shielding the radiations, nearly the same as renowned buildings of the Roman Empire.

Key words: Buildings, electromagnetic radiations, environmental shielding, Zanzibar Stone Town.

1. Introduction

EMR (Electromagnetic radiations) present both opportunities and threats. Today's wireless telecommunication would have been impossible without it. However, they are pronounced as potentially hazardous to human health, animals and plants. Among the said detriments of EMR exposure to human include cancer, discomfort stress, and sexual impotency [1]. In India, EMR from mobile telecom antennas are linked to a huge loss of honeybees because the radiations interfere with bees' navigation system, which is magnetic in nature [2]. With the introduction of WiFi at homes and offices today, whose waves are more powerful, a much greater risk to health and live hood is posed [3]. Nonetheless, there are reports that deny a correlation between EMR and health hazards [4, 5], thus, creating opposing views on the issue. This difference in opinions makes the study of EMR and its effects controversial. A literature review of studies supporting presence of the effects and

those opposing indicate strong points on both sides. In any case, effects of EMR may not be seen in a shorter term. There is a general saying that, everything in this world has benefits and disbenefits. The matter of fact is whether the benefits outweigh the detriments. Therefore, it is convincing to believe in the EMR negative effects, or at least their potential existence. In doing so, we will be prepared for the effects.

Owing to the potential of EMR health hazards, research on how we can make living environment safer from the radiations is very important. Ogrutan et al. [6] support this idea. They further foresee its benefits to designing intelligent buildings, control over equipment interference, and prohibition of electronic spying. A look at previous researches revealed some activities on building materials. Lasiter [7] is probably among the first to measure attenuation of concrete, i.e. how much of energy radiation is absorbed by the material. Lee and Yen [3] studied the capacity of cement mortar to absorb EMR emitted by appliances in a confined living space. On the other hand, Cho et al. [8] researched on EMR shielding effect of "eco-friendly foamed concrete wall". These studies intended to enhance penetration of EMR contrary to the present study that advocates shielding

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but, their results also indicate the material's defense ability against EMR. Ahmadi-Shokouh [9] looked into properties of some floor finishes to the radiations. In their research, Micheli et al. [10] examined the EMR attenuation of historic buildings of the Roman Empire with concrete composite walls. Again, they focused on the shielding property of the walls, as to why they prevent use of electronic devices, similar to others.

Three aspects inspired the present article on EMR shielding. First is shielding property of historic buildings, which is under researched. Second is the fact that, most researches concentrated on metallic materials and modern building materials, concrete, aluminum sheets and glass in particular. Attenuation of traditional materials is hardly understood. The third is the environmental benefits of attenuation. Buildings are constructed to protect their occupants from undesirable external agents. Up to the present time, architects and building specialists mostly regard rain, heat, wind and light as key elements of environmental design in buildings [11]. EMR shielding in general building designs is uncommon [12]. At any rate, with increasing intensity of EMR environment, it might become necessary to control radiations' entering our buildings. Consequently, this article suggests consideration of EMR environment as another important dimension of environmental building design. To achieve envisaged control, SE (shielding effectiveness) of various building materials, both in composite and in isolation need to be understood. This article is interested with SE of traditional building materials of the heritage STZ (Stone Town of Zanzibar), Tanzania. Major building materials of the town structures are coral stones and lime-soil mortar, typical of historic buildings of East African Coast. The findings of this article would help building designers in controlling electromagnetic environment.

2. Methodology

Several procedures exist to measure SE. In this research, SE of the walls was determined according to

IEEE [13]. A survey was initially carried out to map EMR environment and frequency bands around the town. The town is the urban center of Zanzibar Islands and a tourism destination. Therefore, there is a huge concentration of transmission antennas from five (5) mobile operators, namely Vodacom, Tigo, Zantel, Airtel and Halotel. Zantel is the oldest provider with the widest coverage. She has positioned not only transmission towers but also low-level antennas to boost coverage as radio waves find it difficult to penetrate the town's stone buildings especially on ground floor. Zantel transmits the waves in 2G (frequency 900 MHz-1,800 MHz), 3G (frequency 2,100 MHz), and 4G (frequency 800 MHz) environments. This provider and the frequency bands were used in the measurement of SE. There are also WiFi transmissions in the area. However, WiFi bands are less controlled as the local transmitters can choose to put them on or off anytime, hence they were excluded in the measurements.

Measuring instruments involved were simply smart phones. To minimize instrumental errors, two (2) phones of the same brand, Samsung Galaxy A8 were used. This phone brand is among the strongest in catching up with the network. SIM cards were fitted in the phones and G-Net Track Lite v6.2 software was installed in the phones. The software can display transmitters' ID, type, frequency in terms of generation whether 2G, 3G, or 4G, signal strength and their intensity with time. It can also print data reports from the measurements. One phone was placed outside the external wall (enclosure) to read the outdoor received frequency values and another inside the wall at 300 mm to record the indoor values (Fig. 1). Measurements were performed to buildings randomly selected at different areas of the town. Results of the measurements are presented in Table 1. The SE was computed by taking the difference between the outdoor and the indoor values as follows:

$$SE \text{ (dB)} = E_1 - E_2 \quad ([13], \text{ p. 31})$$

where,

Fig. 1 Set up for measurement of SE.

E_1 is the frequency in the absence of the enclosure;

E_2 is the frequency within the enclosure.

Results of the SE were analyzed and discussed in the Results and Discussion section of this article.

3. Buildings of the Historic Stone Town of Zanzibar

The STZ started as a fishing village and developed into a mercantile metropolis of East Africa in the 19th century [14]. Its oldest surviving traditional stone and mud building dates back to 1830. Arab and Indian merchants constructed 2-3 storey buildings with coral stone walls bonded in mud and lime mortar. The stones' configuration within the walls was largely rubble. The buildings' floors were also from the same materials but supported by mangrove poles at 30cm centers (Fig. 2a). This construction resulted into massive load bearing structures with oblong windows punching external walls (Fig. 2b).

Builders opted for large story heights to allow breeze easily penetrate the interior from surrounding narrow,

organic streets (Fig. 2c). For strength and stability reasons, the buildings have massive walls at ground and at least first floors. Although the Arab and Indian buildings share the same material and construction techniques, they differ significantly in typology. Arab buildings are huge rectangular mansions with open yards at the center. The Indian's on the other hand are smaller and narrow, typically constructed as adjoining row houses.

The combination of the buildings' design and the town's plan of narrow, organic and winding streets appear to have dramatic effect on the penetration of EMR into the buildings. Residents' complaints of weak mobile phone signal reception are indications of restricted penetration. This has made some cellular phone providers to install additional low-level antennas to boost transmission and penetration. However, in Arab structures, courtyards receive better signals than Indians' packed row houses and residents in Arab buildings are used to keeping their mobile phones around courtyard areas. This stimulates the need to study

Table 1 Records of indoor, outdoor readings and computation of SE.

Stone Town area	House No.	Wall thickness (cm)	Signal type	Receiving cell ID	External reading (dBm)	Internal reading (dBm)	SE (dBm)
Shangani	77	60	4G	30842	89	91	2
Vuga	323	60	4G	30883	93	95	2
Darajani	B1-73	60	4G	25593	93	95	2
Malindi	1206	65	2G	34006	95	99	4
Darajani	265	70	2G	25596	83	89	6
Kiponda	1250	62	3G	34006	83	91	8
Malindi	154	70	4G	20861	79	87	8
Vuga	500	60	2G	20881	95	103	8
Mkunazini	697	60	3G	14003	95	105	10
Hamamni	Bath	62	3G	20861	79	91	12
Hurumzi	Marumaru	60	3G	30863	85	97	12
Forodhani	Old Fort	120	4G	50863	65	79	14
Malindi	912	75	3G	14003	77	91	14
Mkunazini	487 Masjid	60	3G	50865	81	97	16
Kajificheni	465	60	4G	30862	79	95	16
Forodhani	Old Fort	80	3G	50866	75	91	16
Hurumzi	711	75	2G	14003	89	105	16
Hurumzi	631	65	3G	14003	89	105	16
Darajani	1195	70	3G	14003	87	103	16
Shangani	544	90	3G	10843	57	75	18
Vuga	327	70	3G	30844	85	103	18
Darajani	1200	65	3G	14003	87	105	18
Forodhani	PBZ	60	3G	30863	81	101	20
Hamamni	1950	135	2G	30861	85	105	20
Malindi	1966	55	3G	30861	83	103	20
Vuga	2199	75	3G	30861	87	107	20
Malindi	656	60	3G	34006	85	105	20
Mkunazini	293	75	3G	30836	71	91	20
Darajani	980	70	3G	14003	81	101	20
Kajificheni	95A	75	3G	30862	83	105	22
Shangani	155	46	2G	30863	83	105	22
Shangani	Masjid	60	3G	30843	71	93	22
Malindi	216	55	3G	30861	89	111	22
Vuga	501	70	3G	30863	91	113	22
Mkunazini	622	75	3G	14003	91	113	22
Hurumzi	292	65	3G	30832	79	101	22
Malindi	662	70	2G	34006	79	103	24
Mkunazini	712	60	3G	30831	87	111	24
Darajani	685	60	3G	14003	67	91	24
Shangani	158	65	3G	30863	81	107	26
Malindi	391	60	2G	30863	81	107	26
Vuga	496	70	3G	30844	81	107	26
Hamamni	1999	65	2G	20862	57	85	28
Kajificheni	School	69	3G	30862	51	79	28
Hamamni	1999	65	3G	20862	75	105	30
Hurumzi	194	57	3G	30863	79	109	30
Hamamni	1762	65	3G	20861	79	111	32
Kiponda	1275	60	3G	34006	79	111	32
Mkunazini	760	70	3G	30835	63	103	40

Fig. 2 (a) Partially collapsed building revealing its massive walls and mangrove supported floors; (b) oblong windows on external wall; and (c) a narrow street measuring 1.6 m wide.

EMR penetration both outdoors to indoor and indoor transmission in the different building types. The massive walls in particular, are worth an in depth study on the way stonewalls prevent penetration of EMR.

4. Analysis and Discussion

At the outset, pilot measurements were conducted to check reliability of the instruments used. Signals are assigned 5-digit numbers by service transmitters known as cell ID's. There were several transmitting cells from a single antenna. Using the ID's, one can track indoor signal coming from outdoor. To further check the signal identity, the cell ID digits were confirmed to Zantel and found to correspond with the range of 2G, 3G and 4G frequency bands assigned to this company and recorded by the phones.

In this research, measurements of SE were performed in 49 buildings. Some of these buildings include monuments constructed of very thick walls up to 135 cm. But, most walls measured 60 cm thick in majority of residential structures. The walls' mass constitutes rubble stones bonded with lime-soil mortar. Thickness of bonding mortar is not uniform in this traditional construction and varies between walls of different buildings. Internal and external plasters are

made from the same mortar and their thickness range between 50-75 mm. The plaster is applied in two layers; one inner layer called "*mtomo*" is a combination of mortar and pebbles, followed by the top layer of mortar only (Fig. 3). Therefore, it was difficult to determine accurately the impact of the plaster in the walls' SE and so the SE reported in this case is taken as composite for the whole wall. Originally, lime wash was used to paint the buildings. Nowadays some apply water based modern paints but can be considered to have negligible effect in the overall attenuation of EMR compared to those with lime wash.

The strongest signal recorded outside the buildings was -51 dBm with an indoor value of -79 dBm for a 90 cm thick wall. This gives an attenuation of 28 dBm. According to the transmitter (Zantel), attenuation values <15 dBm allow a good penetration of the EMR and users can make and receive phone calls relatively well. For attenuation ≥ 20 dB, greater shielding of EMR results and users can hardly operate their phones [10]. With regards to outdoor values, a signal of $-75 \text{ dB} \pm 15 \text{ dB}$ (i.e. -60 dB to -85 dB) is considered adequate for potential indoor penetration regardless of the obstacle. The values recorded during field measurements presented in Fig. 4 a indicate largely good strength of

Fig. 3 A wall displaying the structural stones and layers of plasterwork.

Fig. 4 (a) Outdoor signal measurements and (b) computed SE from outdoor and indoor values.

outdoor signals (≤ 60 –84 dB). However, a significant part of it can be regarded as relatively weak (85–104 dB).

Outdoor signal weakness may be attributed to the denseness of the STZ fabric. The town's plan developed in an organic way. There is no conceived formal plan for space between houses, no for the streets and their directions. The paths are generally narrow and winding, allowing only pedestrians, carts, and motorbike to move around. A typical narrow street is about 1.5–2 meters wide. There is even less than a meter street, known as “suicide street” (Fig. 5a). Further, the buildings have thick walls as shown in

Table 1. This situation restricts both outdoor transmissions between streets and building blocks and indoor penetrations. Notwithstanding buildings' SE under this study, the shielding effect of the STZ environment is therefore of interest and could be taken as area for further study.

Field measurements generally showed no strong correlation between wall thickness and SE as portrayed in Fig. 5b, though the shielding capacity of the individual walls is high. For exceptionally very thick walls, of 90, 120 and 135 mm thick observed, the SE was recorded as 18, 14 and 20 dB respectively, while in average a 60 mm thick wall showed an SE of 20 dB and

Fig. 5 (a) “Suicide street” at Darajani market area allows only one person to pass at a time and (b) scatter diagram of wall thickness and their SE.

above with exception of few walls. Thick stonewalls of this town appear to be more porous than thinner walls. This is because to construct thick walls requires more stones and additional bonded mortar joints therefore, the probability that amount of voids in the overall wall mass is high. However, this is not only for thick walls, the use of coral stones in the construction of buildings in STZ has generally introduced voids and so reduced the ability of the walls to restrict electromagnetic waves. If completely solid stones were used, their effectiveness against the radiations would have improved.

From Table 1, the highest value of SE recorded was 40 dBm while the lowest was 2 dBm. Although there is a wide discrepancy between the walls' SE, about 73% of the walls significantly attenuated EMR to a restrictive level of mobile phone penetration mentioned by the above transmitter, and this affirms the complaints for restricted phone use by STZ residents. Therefore, the buildings of the historic STZ are potential to shield its occupants from EMR. The construction technology and materials of these buildings worth attention of building designers.

In general, walls of 60-70 cm thick provide adequate barrier to EMR of at least 20 dB. The highest shielding of 40 dB was recorded for a 70 cm wall. However, walls thinner than 60 cm performed better in some occasions. Again, this difference could be due to masons' construction skills, types of stones used, stones' configuration, and thickness of lime mortar employed. Moisture content within the wall mass could also affect the SE nonetheless, this could not be ascertained.

SE of objects cannot be attributed to their geometry (i.e. size, shape, volume, weight, etc.) alone, it has to be looked upon the type of signal falling on them. Signal types relate to their strength of transmission. EMR are transmitted at different wavelengths each of which defines their embedded energy. A correlation between SE and signal type was observed in this research. 4G

waves have high frequency so they penetrated more into the walls than low frequency waves such as 3G. In such a case the walls recorded lower SE. The lower SE at high frequency confirms the presence of voids in the stonewalls as pointed out by Micheli et al. [10] who noted the same when determined SE of ancient Roman buildings of 700 and 1500 CE. In addition to the voids there are possibly cracks formation within the STZ building walls that weakens the walls' ability to shielding. The buildings of the historic town take too long to be repaired. A survey in 1992 established that only 14% of the town's buildings are in good condition, the rest are either deteriorating, poor, in ruins or have collapsed [14]. The situation has not changed much over the past years. Different attenuation of various signals can be taken as another check for reliability of instruments used to collect the data reported in Table 1.

Data collected in this research were compared to similar studies to understand the relative strength of the STZ buildings' walls in attenuating EMR. Some of these studies tested SE of building materials in their original form, others in modified form. One comparable study was that of Micheli et al. [10] who examined attenuation of buildings in Rome. He measured historic buildings of the Roman Empire (700-1500 CE) and found to have SE range of 25-35 dB. The historic buildings of the STZ compare pretty well to the Roman buildings with average SE range 20-32 dB. However, the former were constructed with bricks and concrete while the latter employ stone and lime-soil mortar. Bricks and concrete is a regular construction and the amount of pore spaces can be controlled more than in the stone structures. That is to say, the SE of STZ buildings is significant even under unregulated construction circumstances.

5. Conclusion

This research joins hands to advocate the control of electromagnetic radiations entering our buildings. It has tested the efficiency of historic buildings from the heritage Stone Town of Zanzibar to shield from

electromagnetic radiations. The research was motivated by the fact that measurement of shielding effectiveness has concentrated much on modern materials and so forgot the role that traditional materials such as stone and mud can play in this task. The town's buildings were found to have considerable shielding from the radiations nearly the same as that of famous Roman Empire of the 700-1500 CE. Although the highest value of shielding recorded was 40 dB, in average the walls achieved a threshold of 22 dB adequate to restrict operation of wireless telecommunication devices. This indicates that, historic towns are not only eco-friendly and sustainable from their material point of view but also they are potential protectors of hazardous radiations.

Researches on electromagnetic radiation shielding of buildings and their materials have been of great interest to electronics, and telecommunication engineers because they are keen to ensure the radiations penetrate building environments for better operation of wireless electronic devices. Professionals from construction industry have overlooked this area, in particular the potential hazards posed by the radiations. The professional's role to design and construct buildings that shield occupants from the effects of the surrounding environment has fallen short of this consideration. This is an important area to the industry since electromagnetic radiations may not only affect human health but can interfere with occupants' normal equipment operation. It is the duty of building designers to ensure we live in a healthy environment yet perform our activities in a conducive internal environment.

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