Journal of Computer and Communications, 2024, 12, 1-10
https://www.scirp.org/journal/jcc
ISSN Online: 2327-5227
ISSN Print: 2327-5219

Experimental Assessment of the Effects of Building Materials on Wi-Fi Signal 2.4 GHz and 5 GHz

Sylhane Bytyqi, Besfort Jashari

Department of Telecommunication, Faculty of Electrical and Computer Engineering, University of Pristina, Pristina, Kosovo
Email: sylhanebytyqi@gmail.com

How to cite this paper: Bytyqi, S. and Jashari, B. (2024) Experimental Assessment of the Effects of Building Materials on Wi-Fi Signal 2.4 GHz and 5 GHz. *Journal of Computer and Communications*, **12**, 1-10.
https://doi.org/10.4236/jcc.2024.125001

Received: February 4, 2024
Accepted: May 12, 2024
Published: May 15, 2024

Abstract

We are all witnesses to the widespread use of wireless LANs (WLAN) and their easy implementation in indoor environments. Wi-Fi is the most popular technology for the WLAN. However, interference caused by building materials is a common, yet often overlooked, contributor to poor Wi-Fi performance. This interference occurs due to the nature of radio wave propagation and the characteristics of the wireless communication system. Therefore, during the implementation of these networks, one must consider the quasi-static nature of the Wi-Fi signal and its dependence on the influence of various building materials on the propagation of these waves. This paper presents the effects of building materials and structures on indoor environments for Wi-Fi 2.4 GHz and 5 GHz. To establish the interdependencies between factors influencing electric field levels, measurements were conducted in an experimental Wi-Fi network at different distances from the access point (AP). The results obtained show that the electric field strength of the Wi-Fi signal decreases depending on the distance, the building materials, and the transmitted frequency. Concrete material had the most significant impact on the strength of the electric field in Wi-Fi, while glass had a relatively minor effect on reducing it. Wi-Fi operates within the radio frequency spectrum, typically utilizing frequencies in the 2.4 GHz and 5 GHz bands. Additionally, measurements revealed that Wi-Fi signal penetration is more pronounced at lower frequencies (2.4 GHz) as opposed to the Wi-Fi signal 5 GHz. The findings can be used to address the impact of building materials and structures on indoor radio wave propagation, ultimately ensuring seamless Wi-Fi signal coverage within buildings.

Keywords

WLAN, Electric Field, AP, Building Materials, Frequency, Wi-Fi

1. Introduction

In the past decade, the utilization of Wi-Fi technology has experienced a substantial surge across a multitude of environments, spanning healthcare facilities, workplaces, universities, and homes. The popularity of Wi-Fi technology has come because of the ease with which it is implemented and used in everyday life. To ensure a smooth and reliable Wi-Fi experience, it's essential that the signal maintains its strength throughout its journey from the sender to the receiver. In an ideal scenario, radio waves would seamlessly travel from the transmitting antenna to the receiving device without any loss in strength. However, the reality is quite different. As soon as the Wi-Fi signal is emitted from the transmitting antenna, it begins to encounter various obstacles and factors that cause it to weaken. Most problems with wireless networks are caused by physical obstacles such as walls, windows, etc.

Therefore, before designing a WLAN, it is necessary to consider all the factors that affect Wi-Fi signals, such as interference, frequency, and characteristics of the indoor environment. The signal strength received by end users is influenced by the penetration rate resulting from various construction materials used in households. Also factor that influences the signal penetration rate is frequency. For instance, the penetration rate of the 2.4 GHz Wi-Fi signal is higher than that of the 5 GHz Wi-Fi signal [1]. In environments where range and penetration are critical, such as in residential homes with thick walls, 2.4 GHz Wi-Fi may be preferred. In environments where high-speed connections and reliability are paramount, such as in offices or public spaces with many users, 5 GHz Wi-Fi may be more suitable.

Radio waves can pass through different materials, but some materials can absorb or reflect these signals by contributing to signal attenuation.

The International Telecommunication Union of Radiocommunication (ITU-R) emphasizes the significant impact of the electrical properties of materials and their structures on the propagation of radio waves. They emphasized the importance of comprehending the losses incurred due to building materials and structures, aiming to provide guidance to engineers on preventing interference in indoor radio wave propagation [2] and [3]. Hence, it's crucial to distinguish between materials like concrete, glass, and wood when exposed to wireless signals.

Studies have shown that physical barriers significantly weaken the Wi-Fi signal. According to research, materials commonly used in construction such as wood, gypsum, and metal have a distinct impact on the propagation of Wi-Fi signals.

Furthermore, numerous research works have acknowledged this phenomenon and undertaken comprehensive investigations to assess the influence of diverse building materials on the rate of Wi-Fi signal propagation and other electromagnetic waves.

A study conducted a comparison of the radio signal strength when it passed through the wall or floor of a building [4].

Another study determines the impact of certain building materials on Wi-Fi signal propagation by comparing the strength captured without anything blocking with the strength captured after being given a barrier in the form of a building [5]. According to this research, plastic is identified as the material that most significantly reduces Wi-Fi signal strength when employed as a barrier. Conversely, a hollow plywood wall is found to have the least impact on reducing Wi-Fi signal strength when used as a barrier.

There are various methods available to enhance the potency of the Wi-Fi signal, and one of these approaches involves employing a directional aluminum reflector, as suggested by [6]. According to another study conducted an ornament-attached reflector or a small hole in the wall structure within the wall can improve Wi-Fi signal [7].

As referenced in [8], there is a universally accepted method for assessing Wi-Fi signal strength, leaving room for further exploration and advancements. Over the past five years, various research teams have made notable progress in this area, as evidenced by several publications [8] [9] [10].

This research aims to assess how certain construction materials affect the way Wi-Fi signals propagates, and to understand if and how materials commonly used in building construction can either block or weaken Wi-Fi signals. This evaluation involves comparing signal strength in unobstructed conditions to signal strength when a barrier composed of these building materials is introduced. Additionally, in this study, the Wi-Fi signal was evaluated in both frequency bands (2.4 GHz and 5 GHz) for comparison.

This research aims to test materials such as concrete and glass under new environmental conditions in addition to those that have already been tested. This study can be used to design buildings with good propagation Wi-Fi signals.

2. Materials and Methodology

This work investigates the 2.4 GHz and 5 GHz bands of the Wi-Fi signal. This is due to the high usage of these frequency bands, primarily in indoor environments.

The experimental evaluation of Wi-Fi signals was carried out within the laboratory facilities of the Faculty of Electrical and Computer Engineering at the University of Pristina. This controlled laboratory environment provided an ideal setting for conducting precise measurements and observations of Wi-Fi signal propagation under controlled conditions.

The laboratory room under examination measures 12 meters in length, 7 meters in width, and 4 meters in height, featuring concrete walls with a thickness of 30 centimeters. In this lab, a Wi-Fi experimental network architecture was built by combining one Access Point (AP) and one laptop (workstation). Moreover, this area was not covered by any Wi-Fi APs nearby, which would contribute to the overall electric field values in our measurements. There was no other Wi-Fi identified in environments under the study using Acrylic Wi-Fi Home Software.

The differences in distance between the Wi-Fi transmitter (router or access point) and the receiver (device being tested) can significantly affect the strength and reliability of the Wi-Fi signal. This variation in distance introduces a potential source of interference that may impact the accuracy of the study's results.

The measurement positions were selected to ensure that the distance between the workstation and the access point (AP) does not affect the electric field level when building material obstructions are present. Measurements were conducted at four different scenarios for both frequency bands (2.4 GHz and 5 GHz).

Initially, measurements were taken at two meters distance (d = 2 m) from the AP in the Line of Sight (LOS) position. Then the workstation was moved behind the wall where the electric field level was measured near the workstation, as shown in Figure 1.

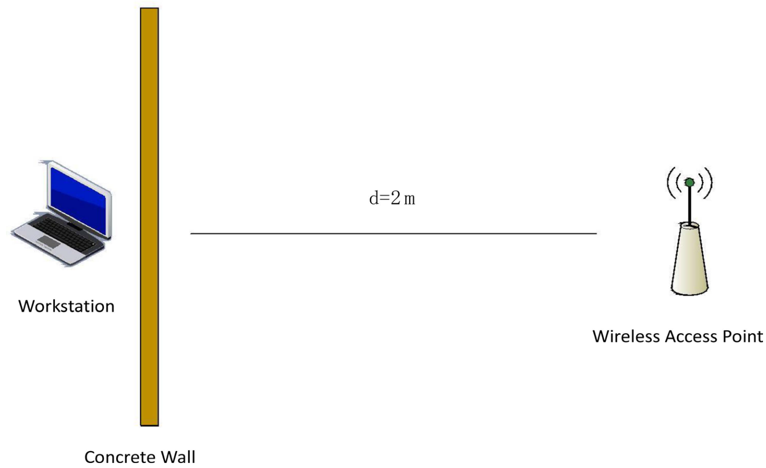

Figure 1. Concrete wall obstacle.

Additionally, measurements were conducted at six meters distance (d = 6 m) from AP in the LOS position. Afterward workstation was located behind glass window in NLOS position with AP, maintaining the same distance of six meters (d = 6 m) from the AP, as shown in Figure 2.

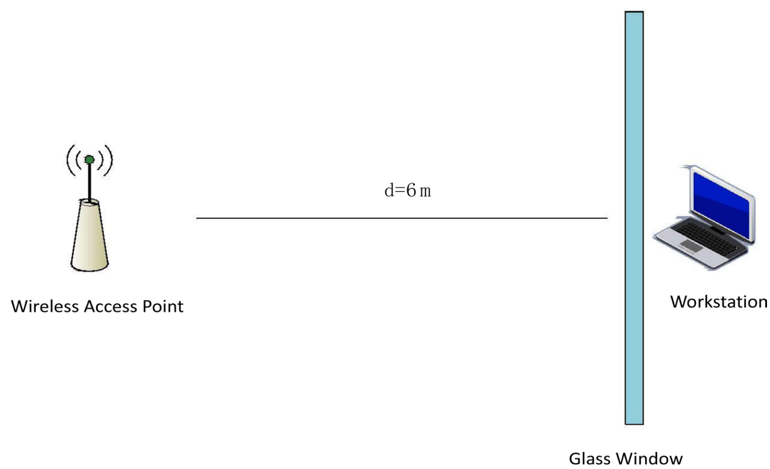

Figure 2. Glass window obstacle.

This method is employed because the materials under examination cannot be readily relocated by the author and must be tested directly at their original placement location.

Hence, the authors will conduct repeat measurements at consistent distances for each Wi-Fi frequency, ensuring the control of the distance variable and the accuracy of the Wi-Fi signal strength assessment, which is solely influenced by frequency. **Figure 3** shows the laboratory environment where the measurements were conducted.

Figure 3. Laboratory environment.

The Access Point (AP) model utilized for this study was the Aruba Networks model APIN0225. This AP was configured to operate in accordance with the IEEE 802.11 n/ac standard, which represents advanced Wi-Fi technology designed to deliver high-speed wireless connectivity, with a maximum speed of 135 Mbps.

While measurements were conducted on Wi-Fi 2.4 GHz, the AP was set to work only on 2.4 GHz, disabling 5 GHz, on Channel 1, with a central frequency of 2.412 GHz and a channel bandwidth of 22 MHz. On the other hand, while measurements were conducted on Wi-Fi 5 GHz, the AP was set to work only on 5 GHz, disabling 2.4 GHz, Channel 100, with a central frequency of 5.500 GHz and a channel bandwidth of 40 MHz.

The communication between the workstation and the Access Point (AP) was facilitated by an internal Wireless Local Area Network (WLAN) utilizing radio frequency (RF) waves.

The measurements were conducted using the NARDA SRM 3006, a meticulously calibrated spectrum analyzer renowned for its precision and reliability in capturing and analyzing radio frequency (RF) signals, which is shown on **Figure 4**. This device is a frequency-selective measurement system designed for safety analysis and environmental measurements in high-frequency electromagnetic fields, covering a frequency range from 9 kHz to 6 GHz.

Figure 4. Narda SRM 3006.

The technical specifications of the measurement instrumentation can be found in [11]. The device was configured to record every 6 seconds a value of the electric field and then these values were averaged. All measurements were recorded for a duration of 6 minutes, as this is the thermal constant for the human body [12].

3. Results and Discussion

Figure 5 shows the electric field strength dependent on distance from AP for good propagation. The transferred file was video streaming from YouTube. The measurements were done in the proximity of the workstation at a 20 cm distance. It has been seen that the maximum field strength E_{max} = 0.413 [V/m] is for good propagation (LOS, d = 2 m) but then the workstation is located at a distance six meters (d = 6 m) far from the AP, E-field strength value start to decrease E_{max} = 0.222 [V/m].

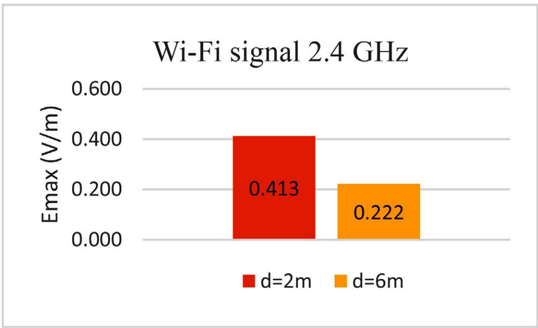

Figure 5. E-field strength dependence on distance to the access point for good propagation condition—LOS.

Figure 6 shows the electric field strength dependencies on building material (concrete) in poor propagation conditions, where the workstation was placed behind a concrete wall.

When the workstation is on LOS with AP the electric field strength was E_{max} = 0.413 [V/m], whereas it was E_{max} = 0.156 [V/m] when workstation was behind a concrete wall for the approximate same distance with AP.

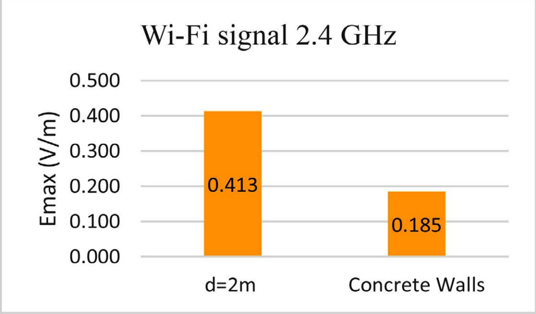

Figure 6. E-field strength dependence on building material when a workstation is placed behind a concrete wall.

There is a reduction of 55.22% in E-filed strength when a concrete wall separates the workstation from the AP.

In the measurements conducted to assess the influence of building materials, the effect of glass on the Wi-Fi signal level has been analyzed.

The highest value of the electric field strength was once again recorded when the workstation was in line-of-sight (LOS) position at a distance of d = 6 m, with E_{max} = 0.222 [V/m]. In contrast, the E-field was E_{max} = 0.156 [V/m] when the workstation was situated behind a glass window.

As seen in Figure 7, when the access point is located behind the glass at six meters distance (d = 6 m) from the access point (AP), the electric field strength has a slight decrease compared to the same distance when the access point was in conditions of good propagation (LOS). This implies that the glass material has a relatively low impact on the attenuation of the Wi-Fi signal.

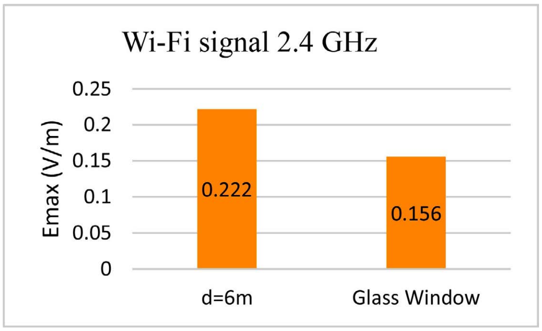

Figure 7. E-field strength dependence on building material when a workstation is placed behind a glass window.

Figure 8 characterizes the variation of the electric field strength in two meters distance from AP at Wi-Fi 5 GHz was E_{max} = 0.482 [V/m] whereas when the workstation is located at six meters (d = 6m) from AP the E-field was E_{max} = 0.160 [V/m].

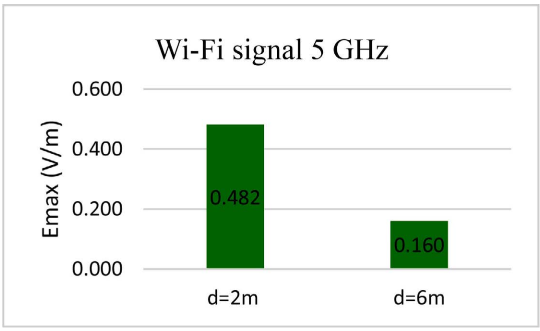

Figure 8. E-field strength dependence on distance for Wi-Fi 5 GHz.

The distance from the AP is a factor that significantly influences the electric field strength. For closure distance to the AP electric field strength was higher while with increasing the distance from AP the E-field was decreased.

Figure 9 shows the electric field strength at Wi-Fi 5 GHz, dependencies on building material (concrete) in poor propagation conditions, where the workstation was placed behind the concrete wall.

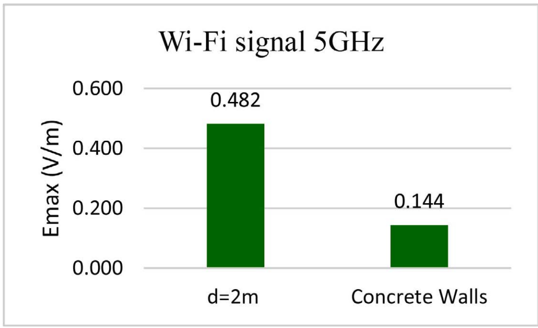

Figure 9. E-field strength dependence on building material (concrete wall) for Wi-Fi 5 GHz.

When the workstation is on LOS with AP the electric field strength was E_{max} = 0.482 [V/m], whereas it was E_{max} = 0.144 [V/m] when the workstation was behind a concrete wall for the approximate same distance with AP. There is a 70.12% decrease in E-field strength when a concrete wall is located between the workstation and AP.

Figure 10 presents the measured values, when the workstation was moved behind the glass window. As it can be seen from the figure below, a higher value E_{max} = 0.160 [V/m] was gained when the workstation was in LOS with AP (d = 6 m) whereas when the workstation was behind the glass window the E-field was E_{max} = 0.144 [V/m].

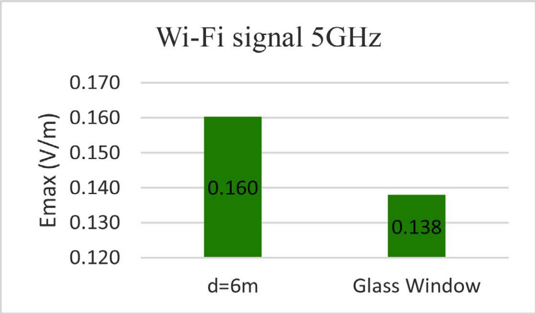

Figure 10. E-field strength dependence on building material (glass window) at Wi-Fi 5 GHz.

Figure 11 shows a comparative analysis of electrical field measurements conducted on Wi-Fi signals operating at both 2.4 GHz and 5 GHz frequencies.

By comparing the results at Wi-Fi 5 GHz with those at Wi-Fi 2.4 GHz, increased electric field strength is observed for Wi-Fi 2.4 GHz. This is explained by the fact that the Wi-Fi signal at 5 GHz is less able to penetrate obstacles compared to signals at lower frequencies (e.g., 2.4 GHz).

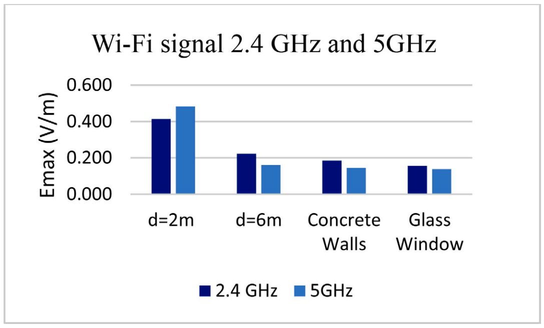

Figure 11. E-field strength depending on frequency.

4. Conclusions

This paper presents the results of the impact of different building materials on Wi-Fi signals 2.4 GHz and 5 GHz.

The objective of the study was to assess how Wi-Fi signal strength varies within different building structures by analyzing the electric field strength.

The results obtained in this paper showed that electric field strength depends on the distance, building materials, structural properties, and frequency of transmission.

The distance from the access point (AP) is a crucial factor that significantly affects Wi-Fi signal strength. When positioned closer to the AP, Wi-Fi signal strength tends to be higher, but as the distance from the AP increases, Wi-Fi signal strength decreases.

Among the materials assessed in the testing, the results indicate a substantial decrease in the electric field strength when a concrete wall separates the access point (AP) from the workstation, as opposed to the scenario where a glass window is an obstructing element. Results show that Wi-Fi signal penetration is more pronounced at lower frequencies (2.4 GHz) as opposed to the Wi-Fi signal 5 GHz.

In the future, additional research work can be conducted using other building materials, to obtain more results in determining which material can best maintain Wi-Fi signal strength. Looking ahead, there might be shifts in construction practices and materials, primarily driven by the goal of improving signal transmission within them.

These results can be used by construction engineers to reduce Wi-Fi signal losses caused by construction materials. During the design of interior spaces, thick concrete walls should not be used, while the concept of open offices should be applied in workplaces.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Own, C.M., Hou, J. and Tao, W. (2019) Signal Fuse Learning Method with Dual Bands

Wi-Fi Signal Measurements in Indoor Positioning. *IEEE Access*, **7**, 131805-131817. https://doi.org/10.1109/ACCESS.2019.2940054

[2] Recommendation ITU-R (2013) "Propagation by Diffraction" P Series Radio Wave Propagation. Electronic Publication Geneva P.526 vol.13. https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.526-13-201311-S%21%21PDF-E.pdf

[3] Recommendation ITU-R (2015) "Effects of Building Materials and Structures on Radio Wave Propagation above 100 MHz" P Series Radio Wave Propagation P.2040 Vol.1. https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2040-1-201507-S!!PDF-E.pdf

[4] Din, Z.U. and Bernold, L.E. (2017) Experimental Study of Signal Behavior for Wireless Communication in Construction. *Construction Innovation*, **17**, 475-491. https://doi.org/10.1108/CI-11-2016-0061

[5] Aileen, Suwardi, A.D. and Prawiranata, F. (2021) Wi-Fi Signal Strength Degradation over Different Building Materials. *EMACS* (*Engineering, Mathematics and Computer Science*), **3**, 109-113. https://doi.org/10.21512/emacsjournal.v3i3.7455

[6] Gorade, S., VattI, R., Kaurwad, V., Bhakre, S. and Kadam, R. (2018) Enhancement of Signal Strength of Single Antenna Wi-Fi Routers. *Proceeding of* 2018 *IEEE International Conference on Current Trends toward Converging Technologies*, Coimbatore, India, 1-3 March 2018. https://doi.org/10.1109/ICCTCT.2018.8551077

[7] Suherman, S. (2018) WiFi-Friendly Building to Enable WiFi Signal Indoor. *Bulletin of Electrical Engineering and Informatics*, **7**, 264-271. https://doi.org/10.11591/eei.v7i2.871

[8] Bechet, P., Miclaus, S. and Bechet, A.C. (2012) Improving the Accuracy of Exposure Assessment to Stochastic-Like radiofrequency Signals. *IEEE Transactions on Electromagnetic Compatibility*, **54**, 1169-1177. https://doi.org/10.1109/TEMC.2012.2191290

[9] Bechet, P., Miclaus, S. and Bechet, A.C. (2015) An Analysis of the Dependence of the Electromagnetic Exposure Level in Indoor Environment on traffic Direction, Instantaneous Data Rate and Position of the Devices in a WLAN Network. *Measurement*, **67**, 34-41. https://doi.org/10.1016/j.measurement.2015.02.035

[10] Joseph, W., Verloock, L., Goeminne, F., Vermeeren, G. and Martens, L. (2012) Assessment of RF Exposures from Emerging Wireless Communication Technologies in Different Environments. *Health Physics*, **102**, 161-172. https://doi.org/10.1097/HP.0b013e31822f8e39

[11] Solutions, N.S.T. (2010) Selective Radiation Meter SRM-3006. https://www.narda-sts.com/index.php?eID=dumpFile&t=f&f=1474&dl=1&token=724573573771fe00e45c3e2a48f652174de7d844

[12] Safety Code 6 (2015) Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz. https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/consult/_2014/safety_code_6-code_securite_6/final-finale-eng.pdf