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Preliminary small-scaled thermal resistance testing of a masonry wall with enhanced electromagnetic shielding effectiveness

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Abstract:
This study presents the preliminary results of a small-scale masonry wall thermal resistance (R-value) measurement. Two small-scale masonry walls were constructed using regular and antimony tin oxide (ATO)-containing bricks. ATO has shown potential for improving the protection against electromagnetic radiation penetration. R-values of the walls were measured using a FluxDAQ device equipped with a heat flux sensor and two temperature sensors for obtaining the heat flux and inside and outside temperatures during the measurement. Furthermore, the thermal conductivity (λ) of the bricks was measured by using the Fox200 Heat Flow Meter. Both results can be used for determining a walls' thermal transmittance (U-value), which is often used for describing the energy losses and as a measure of a wall's energy efficiency. This research sought to investigate whether there is a correlation between the results obtained by the small-scale masonry wall and Fox200 device. Ultimately, this experiment aims to verify whether the small-scale masonry wall non-standard method described herein can provide approximately similar results to the standardised method.

Keywords:
small-scale testing; thermal resistance; thermal properties; EM shielding material

1 Introduction

Electromagnetic (EM) radiation is everywhere around us and has been present from the beginning of the universe. People are constantly exposed to low levels of natural EM radiation such as radioactive gases leaking from the earth (radon), ultraviolet light, and cosmic rays from outer space entering the Earth's atmosphere through the ionosphere [1]. In the 19th Century, scientists discovered that people could enhance their lifestyles by producing artificial sources of EM radiation. Today, two centuries later, life without artificial EM fields is unimaginable. With the rapid advancement of technology, EM radiation is emitted by many electronic devices, including smartphones, laptops, televisions, and Wi-Fi routers. The EM spectrum includes a wide range of frequencies from very low-frequency radiation emitted by power lines to high-frequency (RF) radiation emitted by cell phones and other wireless devices. According to Bandara and Carpenter [2], the level of radiation to which people are exposed has increased by 10^{18} times from 1950 to 2010. Because of this increased exposure to EM radiation, there has been growing concern with regards to potential health issues. A previous study [3] suggested that long-term exposure to high levels of EM radiation may be associated with an increased risk of certain health problems, including cancer and neurological disorders. These growing concerns related to health issues due to long-term exposure have led scientists to seek ways to reduce exposure. One method is to use conductive shielding barriers, such as masonry or concrete walls, with improved EM shielding properties [4, 5]. Vrdoljak et al. [6] studied several conductive additives; among these, antimony tin oxide (ATO) showed the highest potential as an additive in small clay samples for enhancing EM shielding.

The novelty of this study lies in the investigation of the thermal resistance of a masonry wall constructed with ATO-containing bricks and comparing it to a masonry wall constructed with regular bricks. This study also sought to determine whether a cost acceptable, non-standard method, such as the application of closed boxes, could provide results similar to the more specialised and expensive Fox200 instrument for measuring the thermal properties of bricks and walls. The aim of this study was to conduct preliminary small-scale thermal resistance testing of a masonry wall that included either ATO-containing or regular bricks and comparing the results. The objective was to determine whether there were any significant differences between the thermal resistance properties of the two walls. If differences were detected, the masonry wall would be subjected to further testing according to the prescribed standards and norms for thermal resistance to more comprehensively evaluate the impact of ATO on wall performance.

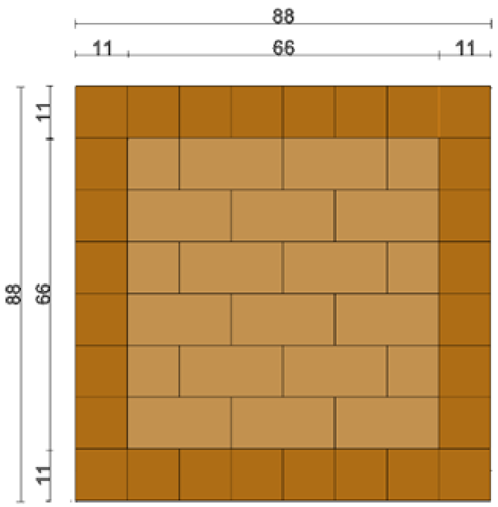

Figure 1. Composite clay box dimensions

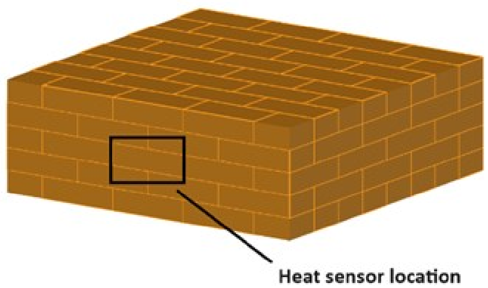

Figure 2. Inner and outer heat sensor location

In this study, ATO (10 % mass) was incorporated into a regular-sized fired brick to create a closed box for which the R-value was tested. The λ values of the bricks were measured by using standardised methods. The bricks were fired at 850 °C. To measure EM shielding efficiency, a closed box was initially constructed using the shielded box method [7]. After obtaining EM radiation measurements, the influence of ATO on the thermal properties of the bricks was examined. Before testing the thermal properties according to the official and prescribed standards, a preliminary test was conducted in a closed box. Figure 1 shows the dimensions of the small-scale closed box; the inner area was 66 × 66 cm. Figure 2 shows the location of the heat flux sensor used to test the thermal properties of the walls made of two different types of bricks.

2 Methodology

For the heat flux measurements, the experimental set-up consisted of a closed box, two heat sensors, an infrared lamp, and FluxDAQ, which is a signal measurement system that can be used to accurately measure and record precise analogue voltage signals from its heat flux/thermocouple thermal sensors. The FluxTeq R-value Measurement System is a low-cost data acquisition system designed to accurately and directly collect the R-value data of building materials through its heat flux and temperature sensors [8]. The system was accompanied by a heat flux sensor and an extra temperature sensor to enable the simultaneous collection of heat flux and inside and outside temperature measurements. This device is usually used for the *in situ* measurement of the R-values of walls and windows. A lamp was mounted on the opposite side of the test area, as shown in Figure 3.
The infrared lamp was turned off after the temperature of the inner box surface reached 65 °C, and the temperature drop was recorded until the upper surface reached the starting (ambient) temperature. An infrared lamp was placed inside the box as a heating source to measure the R-value and obtain the temperature gradient. The gradual increase in temperature was also monitored using a thermographic camera.
Figure 2 shows the location of the heat sensor. Heat flux and temperature sensors were placed on the inner face of the wall, whereas the other temperature sensor was placed on the outer face of the wall. The data collection frequency was 43 s (the default value for FluxDAQ). Figures 3 and 4 show the experimental set-up.

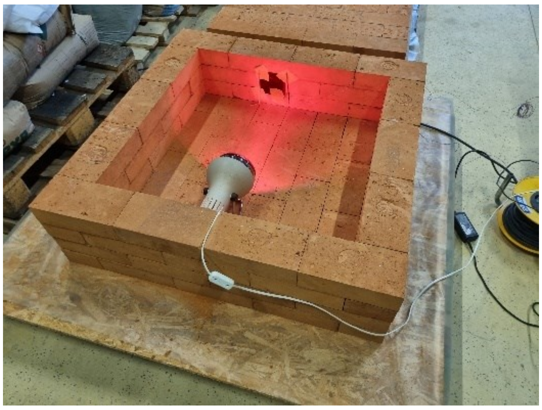

Figure 3. Composite clay box with installed infrared lamp

Figure 4. Experimental setup of box during the measurement

The λ value (W/mK) measures how easily heat flows through a material, regardless of the thickness of the material. The lower the λ value of a material, the better the thermal performance. The R-value (m^2K/W) measures the resistance to heat flow through the thickness of the material. A higher R-value indicates a higher thermal resistance of the material and, therefore, better insulating properties. The R-value was calculated as the ratio of the material thickness to the thermal conductivity. The U-value of a building element is the inverse of its total thermal resistance. The U-value (W/m^2K) measures the amount of heat lost through the thickness of a specific material and includes all three ways in which heat loss occurs – conduction, convection, and radiation. The lower the U-value, the better the material functions as a heat insulator. The U-value was calculated by taking the reciprocal of the R-value and then adding the convection and radiation heat losses. When dealing with the abovementioned values, the following should be kept considered [9]:

- Higher numbers are advantageous when comparing the R-values of materials.
- Lower values are better when comparing U-values.

Based on the total R-values measured with the FluxDAQ and material thickness, the λ values can be easily calculated.
The second experiment was conducted by using a FOX200 Heat Flow Meter to measure the λ values of the materials – regular and ATO-containing bricks. Samples were conditioned to a constant mass for 24 h in a ventilated oven at 105 °C before testing. Thereafter, the specimens were cooled and stored in sealed polyethylene bags. The specimens were removed, weighed, and placed in the apparatus immediately before testing. The samples were placed between two plates in the test stack, and a temperature gradient was established over the thickness of the material. The measurements were obtained in compliance with [10]. Figures 5 and 6 show the experimental set-up for the Fox200 and experimental specimen, respectively.

Figure 5. Experimental specimen for the Fox 200

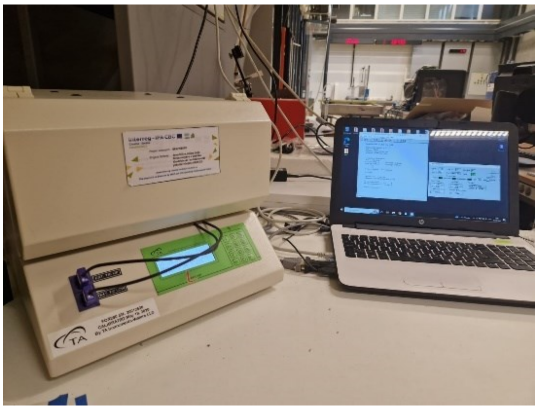

Figure 6. Fox200 measurement process

3 Results

The presented results are based on measurements of the thermal properties of the closed clay box walls. Data were measured until the inner heat sensor measured 65 °C. The differences in the recorded temperatures at the beginning and end of the experiment using a thermographic camera are shown in Figures 7 - 9. Figure 10 shows the temperature measured by the heat sensor located inside the box. The results show that the reference model reaches the desired temperature noticeably earlier than the box with ATO bricks. The reference box reaches 65 °C in 2 h 20 min, whereas the ATO box reaches the desired temperatures at approximately 3 h 30 min. The difference in the time required to heat the box to 65 °C between the reference and ATO boxes can be partially attributed to ventilation losses because the ATO-containing brick had slightly greater damage that contributed to greater ventilation heat loss compared to the reference brick. Figure 11 shows the temperature measured by the heat sensor placed on the outer face of the box.

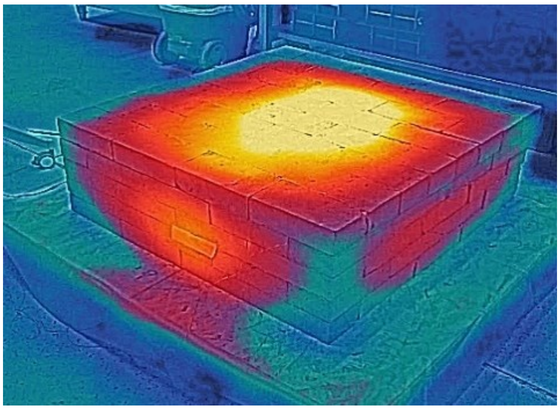

Figure 7. Thermographic image of the sample box while measuring the R-value at the beginning of the experiment (ATO box)

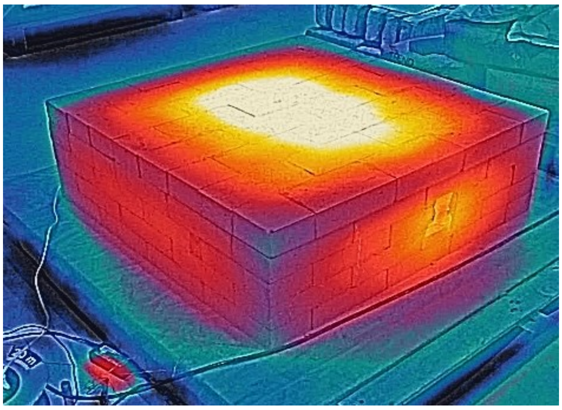

Figure 8. Thermographic image of the sample box while measuring the R-value at the end of the experiment (ATO box)

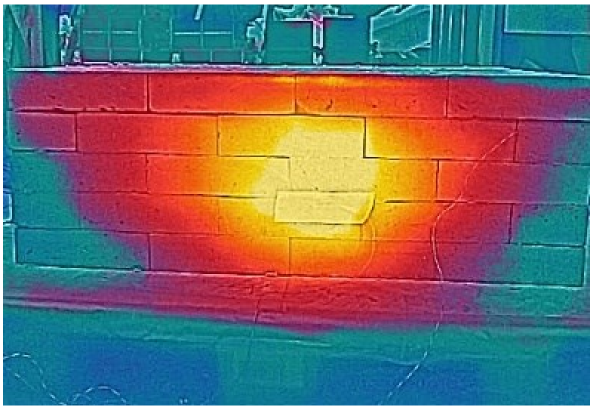

Figure 9. Thermographic image of the sample box while measuring the R-value at the beginning of the experiment – sensor close up (ATO box)

According to the results, even though the two experiments (reference box and ATO box) were performed on two different days, the outer temperatures were almost the same. Based on these results, the external temperature was determined to not affect the results of the experiment.

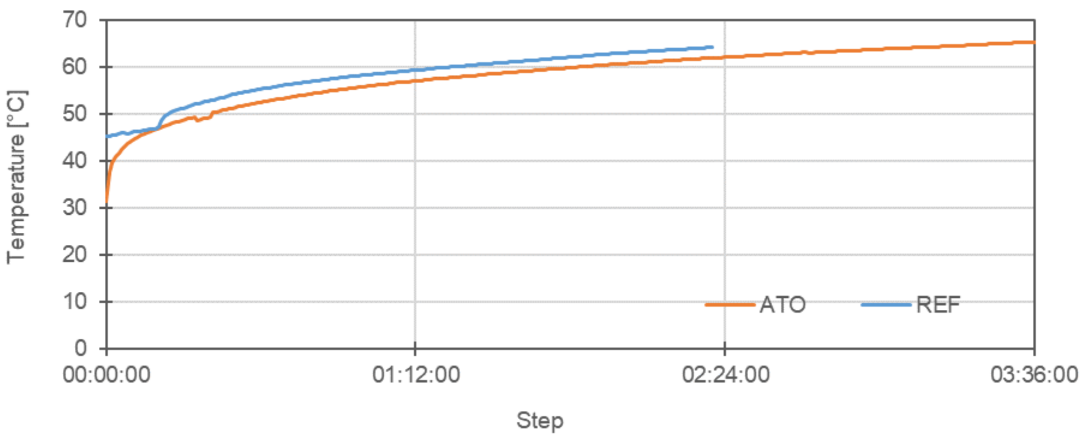

Figure 10. Inner temperature of a closed clay box

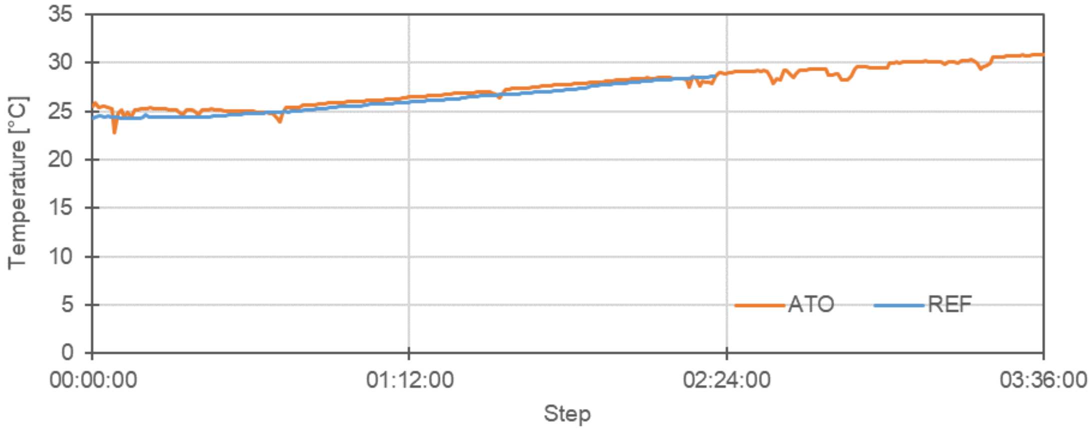

Figure 11. Outer temperature of a closed clay box

Figures 12 and 13 show the R-values measured with the FluxTeq measurements system and calculated λ values, respectively. According to the results, the R-value of the ATO wall (box) is noticeably higher than that of the regular wall (box). The average R-value of the ATO box was 0,6569 m^2K/W, whereas that of the reference box was 0,5214 m^2K/W. According to the literature, the standard R-value for fired bricks of this thickness typically ranges from 0.18 to 0.71 m^2K/W, which can indicate that the experiment was valid. However, there is no standard R-value that is universally applicable to all fired bricks. The thermal insulation properties of fired bricks can vary significantly based on factors such as composition, density, moisture content, and manufacturing process.
Based on the R-value and wall thickness (12 cm), the λ values were calculated, as shown in Figure 13 The average λ value for the ATO box is 0,1827 W/mK, whereas that for the reference box is 0,2301 W/mK.

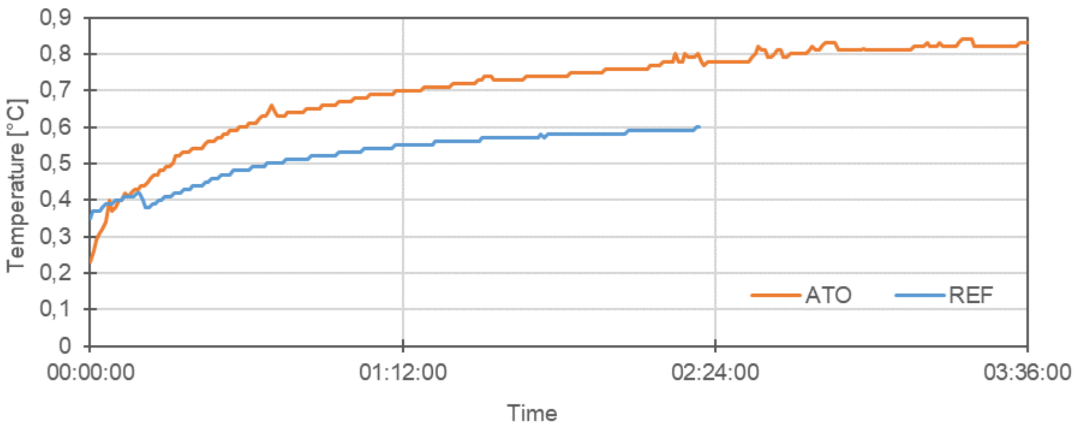

Figure 12. Thermal resistance (total R-value) of samples measured with the FluxTeq measurements system

A Fox200 instrument was used to verify whether the non-standard, small-scale closed box method could provide approximately realistic results.
Table 1 presents a comparison between the thermal properties results obtained by the small-scale closed box experiment and FluxDAQ setup (R-values were measured) and the standardised Fox200 setup (λ values were measured).

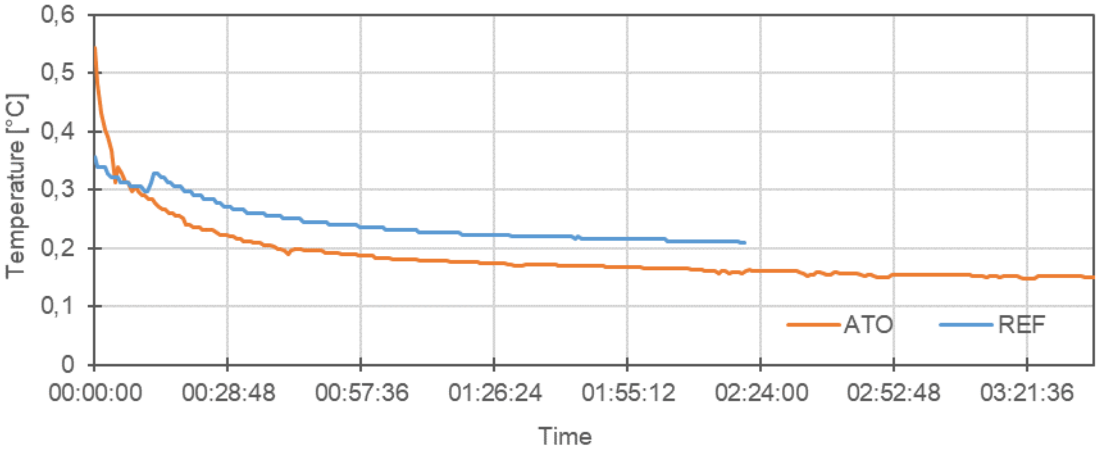

Figure 13. Thermal conductivity (λ) of the samples calculated from the measured R-values in the closed box experiment

Table 1. Summarised experimental results

FluxDAQ setup for measuring R values		
Thermal property / Type of the material	Reference bricks	ATO bricks
R values – measured [m^2K/W]	0,5214	0,6569
λ values – calculated [W/mK]	0,2301	0,1827
Fox200 setup for measuring λ values		
Thermal property / Type of the material	Reference bricks	ATO bricks
R values – calculated [m^2K/W]	0,9753	1,3208
λ values – measured [W/mK]	0,2026	0,3781

4 Discussion

The results reveal that the obtained values do not match. In particular, those for the ATO-containing bricks. For several reasons, the Fox200 was determined to provide more accurate results, which was expected because the Fox200 setup is a standardised device for measuring thermal properties, whereas the closed box is an improvised small-scale method.

The thermal conductivity of 0,20 W/mK matched the literature results. By adding ATO to the clay, an increase in the λ value was expected because ATO contains metals; thus, the decrease in thermal conductivities indicated by the experiment with the closed box is contradictory.

The discrepancy between the results obtained using the closed box and Fox200 instrument could be due to ventilation losses through the box. The closed box method does not account for ventilation losses that occur during measurement, which can significantly affect the results. In contrast, the Fox200 instrument is designed to minimise ventilation losses and provide accurate measurements of λ values. Therefore, the closed box method is not a reliable method for measuring thermal properties. In addition to ventilation losses through the box, the discrepancy between the results obtained using the closed box and Fox200 instrument could have been caused by other factors such as the size and shape of the box, type of material used to construct the box, and accuracy of the temperature sensors.

The closed box method is a non-standardised method for measuring thermal properties and is not recommended for accurate measurements. The Fox200 instrument is a specialised and expensive instrument designed for the accurate measurement of thermal conductivity.

5 Conclusions

The study utilised ATO in the production of standard-sized fired bricks which were then used to construct a closed box for testing the thermal resistance (R-value), and Fox200 was used to measure their thermal conductivities (λ). The study investigated whether a non-standard method, such as that using closed clay boxes, could provide results similar to that of Fox200 for measuring thermal properties. The purpose of this investigation was to determine whether the closed box method could be a viable alternative to the more specialised and expensive Fox200 instrument by producing approximately similar results to those of Fox200. The comparison of the results obtained from both methods revealed a significant discrepancy between them, indicating that the closed box method is not applicable for measuring thermal properties.

Acknowledgment

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