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Innovative and easy-to-implement moisture monitoring system for brick units

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HIGHLIGHTS

- Graphite sensor can effectively monitor moisture in masonry due to rain penetration.
- Graphite-resin mix gives electrode electrical conductivity, viscosity and strength.
- The proposed system detects different moisture regimes and transport mechanisms.
- Calibration procedure converts electrical resistance into moisture content values.
- System fosters non-destructive, repeatable measurement with adequate resolution.

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ABSTRACT

The system measures the change in electrical resistance due to the presence of water. It is composed of an electronic board and brick (P20) instrumented with graphite electrode-couple sensors. It is mainly designed for the laboratory evaluation of rain penetration in masonry components. The system successfully monitors the change in moisture content correctly detecting storage and transport mechanisms. Compared to similar systems it is cost-effective with easy fabrication and installation, fostering non-destructive, repeatable measurements with adequate space and time resolution, identifying transient conditions at different depths into building components. Application to real structures is proposed as future work.

1. Introduction

Moisture penetration in porous building materials represents a serious threat to the serviceability of constructions as well as, in the long term, to their structural performance. In-situ monitoring of moisture profiles constitutes an essential task for the assessment of the actual building conditions (e.g. residual load bearing capacity), for the understanding of the hygric performance of the building envelopes (i.e. for the diagnosis and design of interventions) and for the evaluation of retrofit and renovation strategies.

The moisture monitoring method here presented is based on the change in the electrical properties of bricks due to the presence of water. Electrical methods [1–3] exhibit several advantages over others as they are mostly non-invasive, non-destructive, repeatable and do not necessitate water removal from samples prior to testing [4]. For DC circuits, Ohm's law relates the electrical current I passing through a conductive sample to the voltage V applied to the sample's ends, i.e. $R = \frac{V}{I}$ where R is electrical resistance (referred to as electrical impedance Z, for AC circuits) which is a function of material properties, geometry and dimensions of the sample [5]. The resistivity ρ of a material defines its opposition to the flow of electricity and it can be determined by measuring the electrical resistance R and multiplying the measured value by a factor k, known as the geometry factor, representing the influence of the dimensions and geometry of the test setup, that is $\rho = R \cdot k$.

From the extensive studies focusing on measurement techniques of moisture in building materials [6–12], it is also known that the electrical resistance is, in a simplified description, primarily governed by the following: the amount of water present in the pores, the electrical conductance of the pore fluid, the porosity and pore connection, the presence of salts and finally temperature. The general trend observed is that the resistance of a material sample decreases with increasing moisture and salt content. Additionally an increase in a solution's temperature will cause an increase in

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the mobility of the ions in solution as well as in the number of ions in solution due to dissociation of molecules. As the conductivity of a solution is dependent on these factors then an increase in the solution's temperature will lead to an increase in its conductivity [13–17].

Among the available moisture measurement methods the two-electrode one is here used. This is the simplest technique for measuring electrical resistance in which the voltage drop V and the current I passing through a sample are measured. The two-electrode method is particularly useful when, as in the case of bricks, the material has large electrical resistance [18]. The proposed system envisages a voltage applied across the brick by means of pairs of electrodes located at different points which allow recording the moisture movements as well as estimating its magnitude.

The moisture monitoring system presented in this paper is composed of an electronic board for data measurement connected to a PC for data logging and power supply and an instrumented brick in which a number of measuring points are installed, made of pairs of electrodes drilled directly into the building material. This system is mainly designed for laboratory applications and particularly for the evaluation of the hygric performance of masonry building elements subjected to wind-driven rain. Its main aim is to endorse repeatable and non-destructive measurements spatially and temporally distributed so that the effects on the moisture transport properties and the hydraulic continuity of the porous material are minimised [19]. It should be underlined that a number of assumptions are considered for the determination of the location of the measurement in the brick. These can be found in Section 4. The paper presents the following structure: the first section provides a description of the electronic circuit, including the electronic board and the software application used for data collection; the sensor design and fabrication, along with an outline of the materials and procedure employed, is presented in Section 3; Section 4 discusses the instrumentation of the brick which can be embedded into masonry components for moisture monitoring; the calibration of the system, in particular that of the electronic board and sensors, is provided in Section 5. The last part of the paper (Sections 6 and 7) outlines the validation process of the system and briefly describes the main steps involved in the conversion of electrical resistance measurements into moisture content values.

2. Measurement electronics

2.1. Circuit

The moisture monitoring system relies on an ammeter-voltmeter method [20]. The circuit enables to assess the voltage drop due to the changing electrical resistance of the brick (Fig. 1, left). An alternating voltage $V_{exc} = \pm 5$ V is applied with a frequency of 0.5 kHz. As underlined in other studies, AC is preferred over DC measurement as it prevents polarization effects [21]. The decision to use 5 V on one hand relates to the need to produce a low cost device and therefore employ cost effective electronic components, on the other end it also intends to avoid an over electrification of the brick which would be more susceptible to external noise during measurements. The selection of a 0.5 kHz frequency is further discussed in Section 5.1. Voltages V_1 and V_2 are measured by means of voltmeters across two resistors R_1 and R_2 of known resistance 47 kΩ. Depending on the direction of the current one of these measurements indicate the voltage drop due to the effect of crossing the brick. The electric current flowing through the circuit I_{circ} equals to the sum of the voltages V_1 and V_2 over the sum of the resistances R_1 and R_2. This allows ruling out potential leakages along the circuit. The voltage at the brick V_b equals to the applied voltage V_{exc} minus V_1 and V_2. From this it is possible to compute the resistance of the brick R_b as the ratio between the voltage V_b and the current I_{circ}. The electrodes resistances are denoted by R_s. These are nullified in the measurement by employing the geometry factors for each electrode-couple sensor position in the brick. In order to allow simultaneous measurements at multiple points on the brick, a multiplexer is used so that several signals share the same device. The multiplexer prevents the crisscrossing of current flow among different pairs of electrodes installed on the same brick while forcing the measurement to take place between an exact pair.

2.2. Electronic board

The electronic board and software for the moisture monitoring system has been designed and developed by Benjamin Wolf at the Institute of Theoretical and Applied Mechanics in Prague, Czech Republic. The board has dimensions 75 mm × 30 mm (Fig. 1, right). It is composed of two rows of input slots (7 for each row) for connecting the electrodes to the board. Each electrode composing a pair, namely the exciting and receiving ones, is fastened to the same position on the two rows (e.g. the exciting electrode connected to 1st slot from the top on the left row and the receiving electrode fixed to the 1st slot from top on the right row etc.). The board is provided with a USB plug for connection to a data logging device such as a laptop which also functions as the board power supply. The two black electronic components at the top side of the board in Fig. 1 are the multiplexers; the other two black square components in the middle are the signal amplifiers; the single black component adjacent to the red led is the ADC; the black

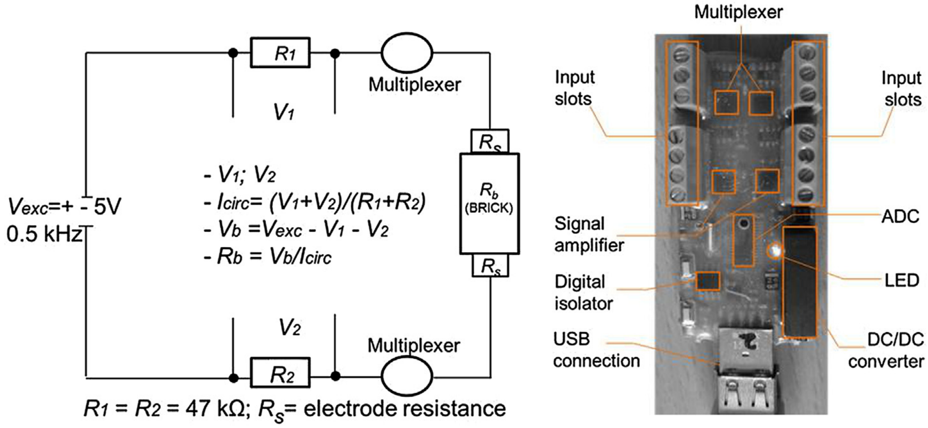

Fig. 1. Left: schematic representation of the circuit; right: electronic board.