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Electrical Effects during the Wetting-Drying Cycle of Porous Brickwork: Electrical Aspects of Rising Damp

Sandor Levai, Valentin Juhasz, Miklos Gasz

Abstract**—**Rising damp is an extremely complex phenomenon that is of great practical interest to the field of building conservation due to the irreversible damages it can make to old and historic structures. The electrical effects occurring in damp masonry have been scarcely researched and are a largely unknown aspect of rising damp. Present paper describes the typical electrical patterns occurring in porous brickwork during a wetting and drying cycle. It has been found that in contrast with dry masonry, where electrical phenomena are virtually non-existent, damp masonry exhibits a wide array of electrical effects. Long-term real-time measurements performed in the lab on small-scale brick structures, using an array of embedded micro-sensors, revealed significant voltage, current, capacitance and resistance variations which can be linked to the movement of moisture inside porous materials. The same measurements performed on actual old buildings revealed a similar behaviour, the electrical effects being more significant in areas of the brickwork affected by rising damp. Understanding these electrical phenomena contributes to a better understanding of the driving mechanisms of rising damp, potentially opening new avenues of dealing with it in a less invasive manner.

Keywords**—**Brick masonry, electrical phenomena in damp brickwork, porous building materials, rising damp, spontaneous electrical potential, wetting-drying cycle.

I. Introduction

ELECTRICAL phenomena accompanying chemical effects in old masonry walls due to the presence of moisture and salts are an important yet unexplored area of building physics. The high concentration of ground salts, a prime characteristic of rising damp, makes electrical effects more significant, which play an important role in the capillary movement of moisture.

Rising damp describes the movement of moisture from the ground into porous building structures [1]. Although it is commonly known to be caused by liquid capillary action, the phenomenon is much more complex, being a mix of several vapor and moisture transport mechanisms [2] that occur simultaneously inside the capillaries.

Due to the fabric decay and damages rising damp can cause in old buildings [3], [4], especially in very old structures with thick solid walls, a better understanding of its mechanics and drivers is of primary importance to the field of building conservation.

Various aspects of rising damp, such as the effects of humidity, temperature, soluble salts and salt crystallization [5], [6], have been studied in detail, however due to the complexity of the subject, many technical aspects are still not fully clarified. Electrical phenomena – also referred to as spontaneous electrical effects – accompanying the movement of moisture in porous building materials are one of these unexplored areas, with relatively few scientific publications [7], [8] discussing the subject.

Electrical phenomena accompanying the movement of fluids in micro- and nano-channels, however, have been extensively studied in other fields of science such as microbiology, electrochemistry or medicine due to the development and explosive growth of "lab-on-a-chip" (LOC) devices [9] during the past few years. These millimetre or centimetre size miniaturized devices integrate several laboratory testing functions on a single circuit, commonly called the "chip", for the large-scale automated analysis of blood, DNA or protein samples. Being very small in size, LOC devices manipulate very small amounts of liquids, in the microlitre or nanolitre range, using chemical, thermal or electrical gradients. External fields are used to induce motion or to control flows directly. Various subcomponents such as valves, pumps, dispensers, separators, mixers etc. can be created without any moving parts [10], just by shaping the form of capillary channels in which the fluid moves, based on electrokinetic transport (electrically driven fluid flow) principles.

The principles employed in LOC devices parallel very closely the environment of old porous walls where charged liquid (saline water) moves in micro- or nano-capillaries under chemical, pressure, temperature (temperature and humidity changes), or electrical gradients (external electric and magnetic fields). As the effect of electric and magnetic fields in electrokinetic transport is important, we can assume that they also play a significant role in the movement of moisture in old wall capillaries.

Current research paper aims to deeper explore the various electrical phenomena in porous masonry based on both laboratory and in-situ measurements on real buildings.

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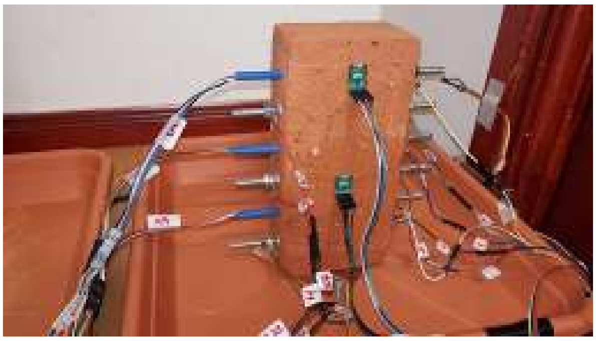

Fig. 1 Sample brick in the lab

II. Laboratory Tests

As the scientific literature detailing electrical phenomena in porous masonry is so scarce, very little information being available, we started with simpler small-scale experiments aimed to understand the basics. We have taken one old-style porous brick in which we embedded a variety of micro-sensors, monitoring every key aspect of moisture movement (Fig. 1).

One of the key requirements of these experiments was the ability to capture data in real time along multiple channels with high accuracy, low noise and – for the capturing of any transient signals – with fast sampling rates. For data logging we have selected a Tektronix-Keithley DAQ6510 80-channel professional data acquisition system. Featuring 6½ digit resolution with 0.0025% basic accuracy, it is particularly suitable for the measurement of small signals, offering 100 nV (0.1 μV) resolution for voltage, 10 pA for current and 1 μOhm for resistance measurements. For additional accuracy, the data sampling can by synchronized with the 50/60 Hz mains frequency, further minimizing any noises. The unit features a large 7 million readings internal memory, so once configured, it can operate without user input or interruption for extended periods of time (Fig. 2).

The following data have been collected:

- Voltage, current and resistance measurements: Various electrical parameters have been collected from the masonry using embedded 6 mm stainless steel masonry wedge anchors, used as electrical contacts. The masonry has been pre-drilled with a masonry drill then the wedge anchors have been embedded into the brick at 40 mm depth.
- Depth temperature and relative humidity (RH): Temperature and RH data have been collected from 50 mm depth from the centre of the brick using embedded AD22100 temperature and Honeywell 4000 series humidity sensors.
- Surface temperature and relative humidity: Temperature and RH readings have been collected from the surface of the brick using SHT31A dual temperature-RH sensors.
- Ambient temperature and relative humidity: Ambient readings have been collected using the same SHT31A dual sensors.
- Magnetic field readings: To monitor the effect of magnetic field changes from the environment, high-sensitivity low-noise Sensys FGM3D 3-axis magnetic sensors have been used with a 150 pT resolution, capable of detecting tiny variations in Earth's geo-magnetic field.

To make high resolution measurements, the sampling rate has been chosen 2 sec, the DAQ6510 datalogger takes automatic readings on all channels every 2 seconds.

The brick has been wetted from the base with 500 ml of tap water to simulate rising damp, then let it dry naturally.

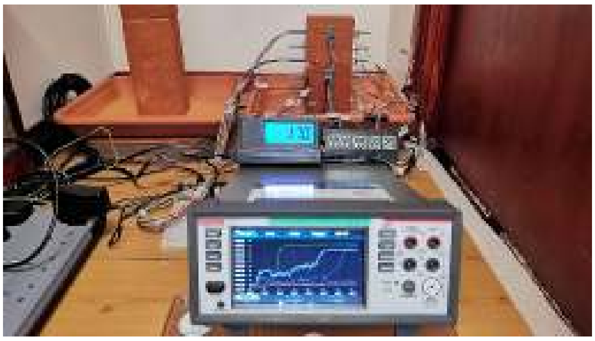

Fig. 2 Experimental setup

III. The Wetting–Drying Cycle and Associated Electrical Phenomena

Here are the voltage variations from our test brick showing the variation of electrical voltages during a 7-day wetting-drying cycle. As shown on Fig. 3, voltages varied in the -120 mV to 300 mV range, taking both positive and negative values.

Looking at the voltage variation more closely, we can differentiate the following wetting-drying stages:

1. Dry masonry: In a perfectly dry brick there are no electrical phenomena present. A dry brick is a very good insulator with very high resistance (above 120 Mohms, the upper limit of our datalogger). The voltages and currents in it are virtually zero (or very close to zero). Under normal room temperature and humidity conditions (e.g. at 20 °C, 50% RH), the brick already contains a tiny amount of moisture from the air, as a result a small voltage (typically less than 5 mV) and a very small current (typically less than 1 nA) can be measured in an air-dry brick. However, we can call this a zero-baseline condition.
2. Initial wetting: Once the brick is wetted at its base with tap water and the moisture starts absorbing into the fabric, voltages and current appear instantly in it. After a quick transient phenomenon – lasting only a few seconds, most likely because water vapors condense on capillary surfaces during which the voltage briefly drops to negative values – the voltages start sharply and steadily rising (Fig. 4). The speed of voltage increase is proportionate with the speed of wetting (rate of water absorption): the more abundant the wetting, the faster the voltage rise.

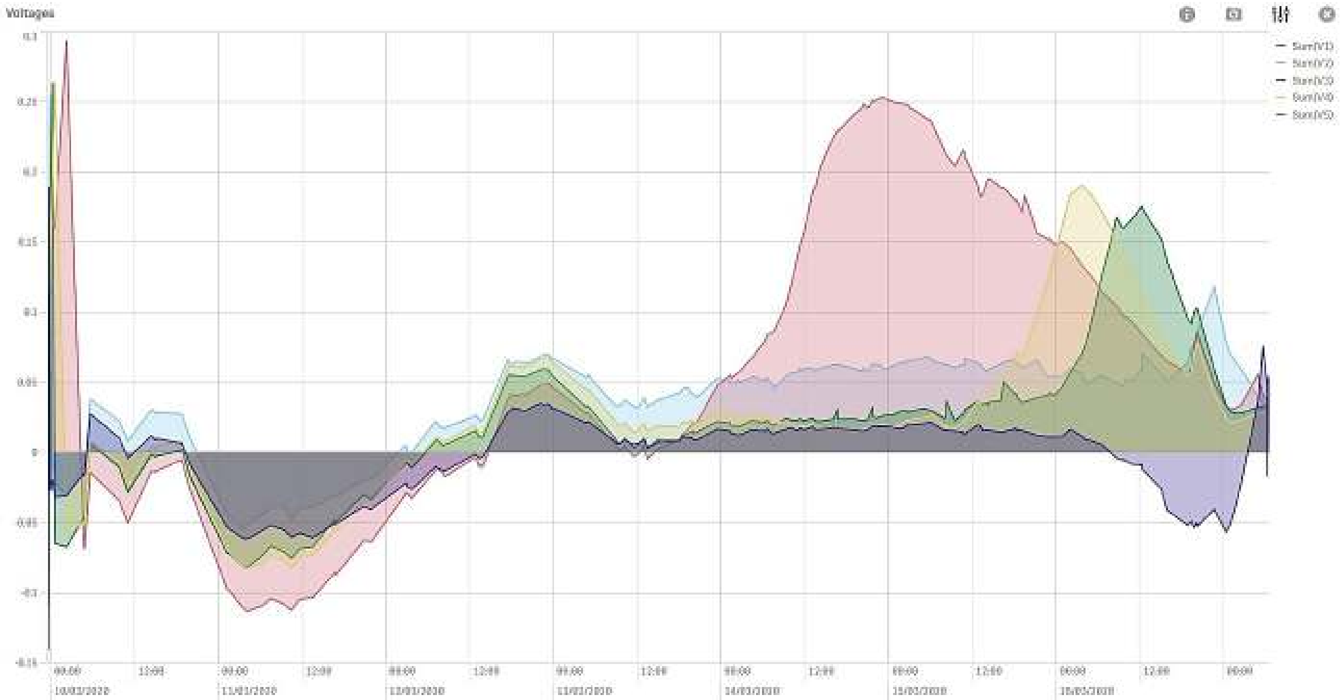

Fig. 3 A typical wetting-drying cycle

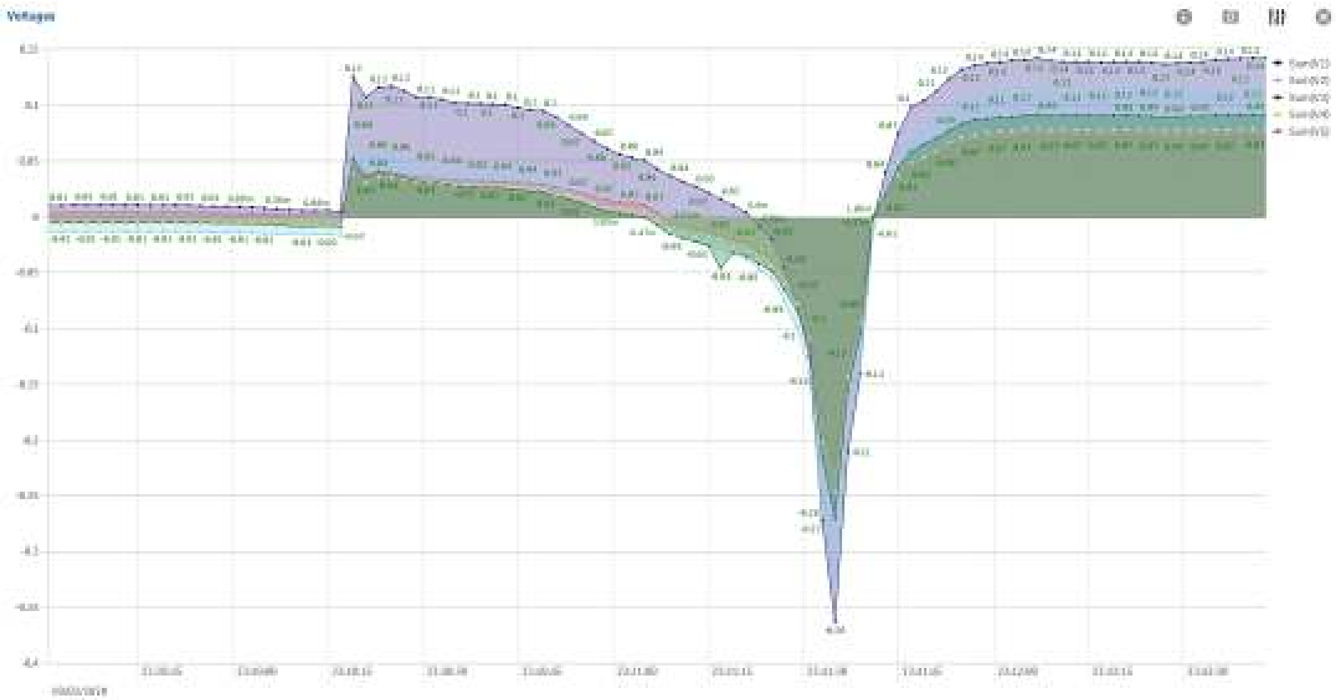

Fig. 4 The start of wetting

The temperature of the brick also drops significantly as evaporation draws away heat from the wet brick.

3. Moisture saturation: The rising moisture in the brickwork evaporates, forming a vapor cloud that is pushed ahead of the liquid water front. This vapor cloud consists of mobile protons with positive charges [11], producing a positive voltage in the brick ahead of the rising front. When the liquid front reaches the sensor, it saturates the nearby area resulting in an instant condensation. This manifests as a sharp voltage drop, the voltage sharply “reversing” from positive to slightly negative (Fig. 5).

During condensation the opposite of evaporation occurs: A high number of protons move back from the vapor into the bulk water, charging the water positively and the vapor negatively [11], resulting in a negative voltage. As the water column climbs higher and higher in the brick, it reaches each of the embedded sensors one after the other, reversing all voltages. As the speed of the water column decreases with height, the voltage reversal interval will slow down in time.

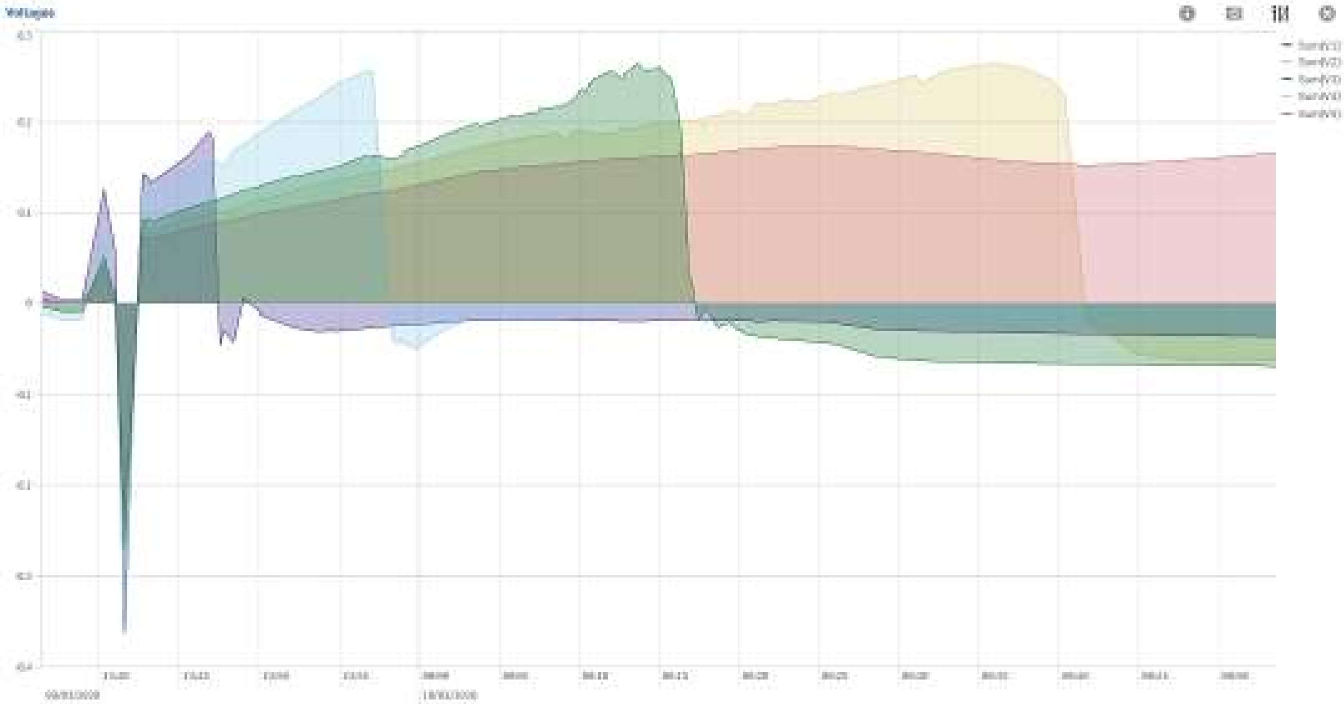

Fig. 5 Moisture saturation and voltage reversal

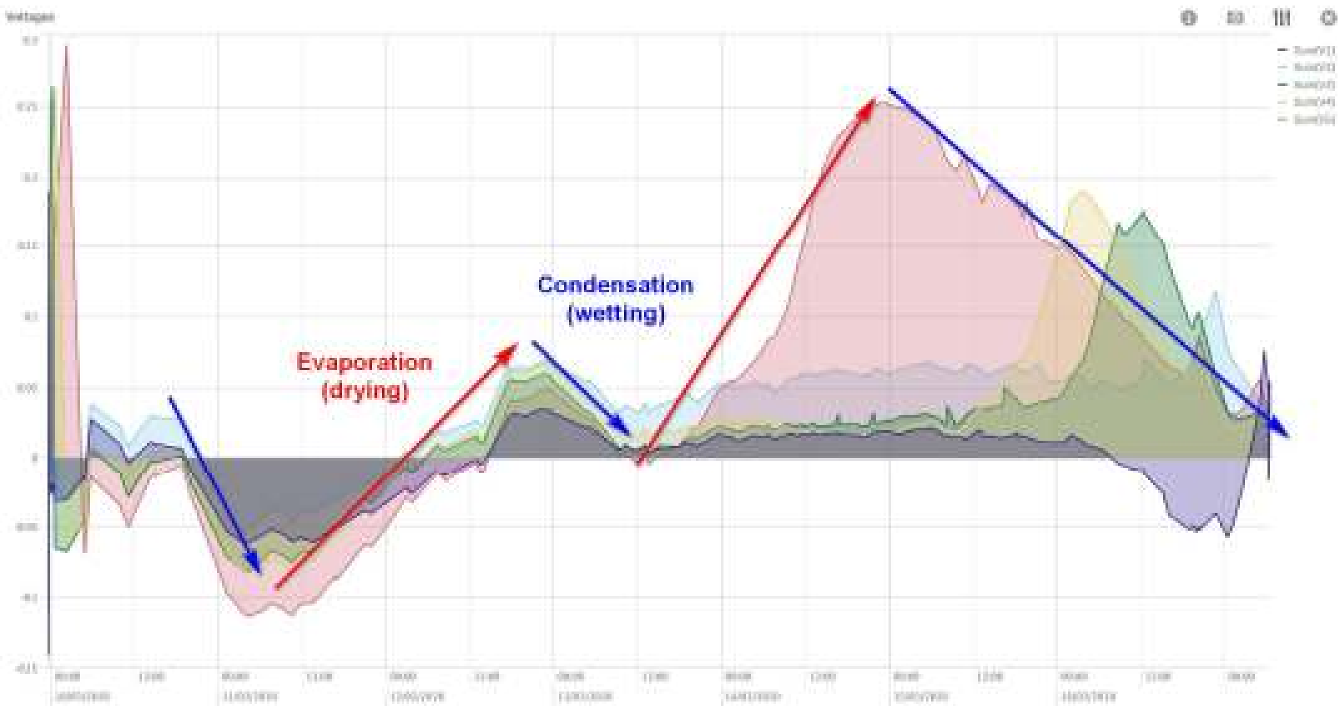

Fig. 6 Subsequent evaporation and condensation cycles

4. Damp state: Consisting of subsequent evaporation and condensation cycles; this stage is most older buildings in real life are found. Depending on environmental conditions (e.g. the amount of rain, sunshine, temperature changes, day-night, summer-winter cycles etc.) the wall fabric goes through shorter or longer condensation

(wetting) and evaporation (drying) cycles, being in constant change (Fig 6). These ongoing changes are shown by up-down variations of the voltage, which accurately displays minute variations in the moisture content of the masonry.

5. Final drying: If no moisture is applied at the base of the brick, it will eventually dry out. In comparison to the initial fast wetting, the dehydration cycle is lengthy and slow. As the final moisture evaporates from the brick, the voltages gradually drop to zero and all electrical activity ceases.

IV. On–Site Testing

Once the basic electrical aspects of the wetting and drying cycle have been understood, and the fundamental relationships between moisture movement and electrical variations have been clarified, we moved to the next stage of our research project, measuring electrical potential variations in real walls.

Our test building was a 150-year-old stone cottage in the middle of a forest. The cottage had a Victorian slate damp proof course, however on some walls early signs of rising damp could already be discovered – the mortar along the mortar bed was crumbling and the paint was flaking.

Fig. 7 On-site testing

We have taken the same measurements as in the lab – voltage, current, resistance, temperature, magnetic field and RH (from the surface, depth and ambient) readings – using the same sensors. However, readings have been taken from both bricks and mortar beds (lime), to better understand the movement of moisture in different materials (Fig. 7).

V. Findings & Discussion

In real buildings, similar to the lab, the presence of moisture is always accompanied by electrical effects. We found that the source of moisture is irrelevant – whether it is rising damp, rain water ingress or else – once moisture finds its way into to the masonry, it always triggers electrical phenomena in the form of voltage and current changes. Based on our measurements, here are the most important findings:

- Order of magnitude: The value of wall voltages and currents depends on the moisture and salt content of the masonry. Voltages were typically in the ± 500 mV DC range, while currents in the ± 20 µA DC range.
- Tap water vs sea water: The presence of salts in masonry (regardless whether from the ground or otherwise) seems to significantly increase the value of voltages and currents. In our lab experiments, bricks wetted with plain tap water resulted in wall currents of about 500 nA, with occasional peaks reaching 1 µA. Wetting the same bricks with sea water resulted in typical currents of about 15 µA, with occasional peaks of over 30 µA – a 30x increase between tap water and sea water. Salt ions seem to significantly increase to the conductivity of the masonry, creating much higher currents. Voltages have also increased in the presence of salts, reaching over 2V DC occasionally.
- Electrical resistance: the electrical resistance of masonry also shows significant variations during the wetting-drying cycle (Fig. 8). Dry bricks measured in the lab show very high resistance, well over 120 Mohm (the upper limit of our measurement instrument), possibly being in the order of gigaohms. Bricks wetted with tap water show resistance as low as 500 Kohms, which in the presence of sea water drops further to around 20 Kohms. Measurements on real buildings have shown similar values: 15 Kohm resistance in the lower area of walls, subject to dampness and salts from rising damp. Once the masonry starts drying out, the resistance of the fabric starts increasing.
- Transient phenomena: Measurements on real buildings uncovered some interesting phenomena that need further analysis. We spotted the presence of transient pulses with very sharp fronts, affecting both wall currents and voltages (Fig. 9). These seem to originate from the ground as their amplitude was highest near the ground, decreasing with height. The pulses had higher amplitude in the saline, more conductive mortar than in the less conductive bricks. These transient pulses can play an important role in the mechanism of rising damp. By injecting energy into the building fabric, they can potentially interfere with electrical phenomena in the electrical double layer (EDL) of the capillaries. External pulsating electric fields have been reported to affect the wetting characteristics and filling dynamics of capillaries or to influence liquid flows [12]. Recent advancements in electrokinetics (electrically driven fluid flow and particle motion), especially in the field of electro-osmosis, lead to the discovery of many new phenomena such as induced-charge electro-osmosis (ICEO) or nonlinear electro-osmotic slip, where an applied electric field around a polarizable surface (such as the surface of a capillary) creates fluid movement [13], [14]. The detection of these pulses can only be done with fast data sampling (typically 2 seconds or less between subsequent readings). At low sampling rates, such as several minutes between readings – a common practice during long-term building monitoring – these pulses become "invisible", which explains why they have not been reported to date.

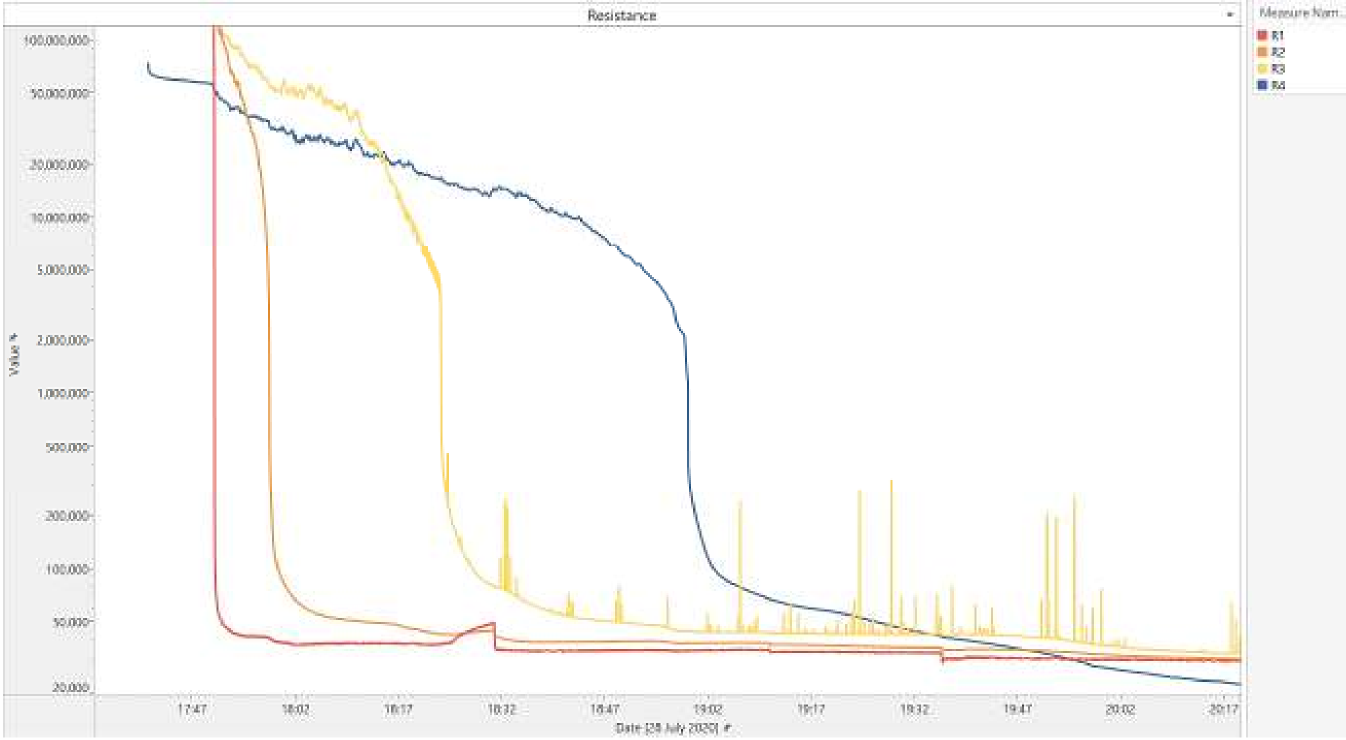

Fig. 8 Resistance of masonry decreases during wetting

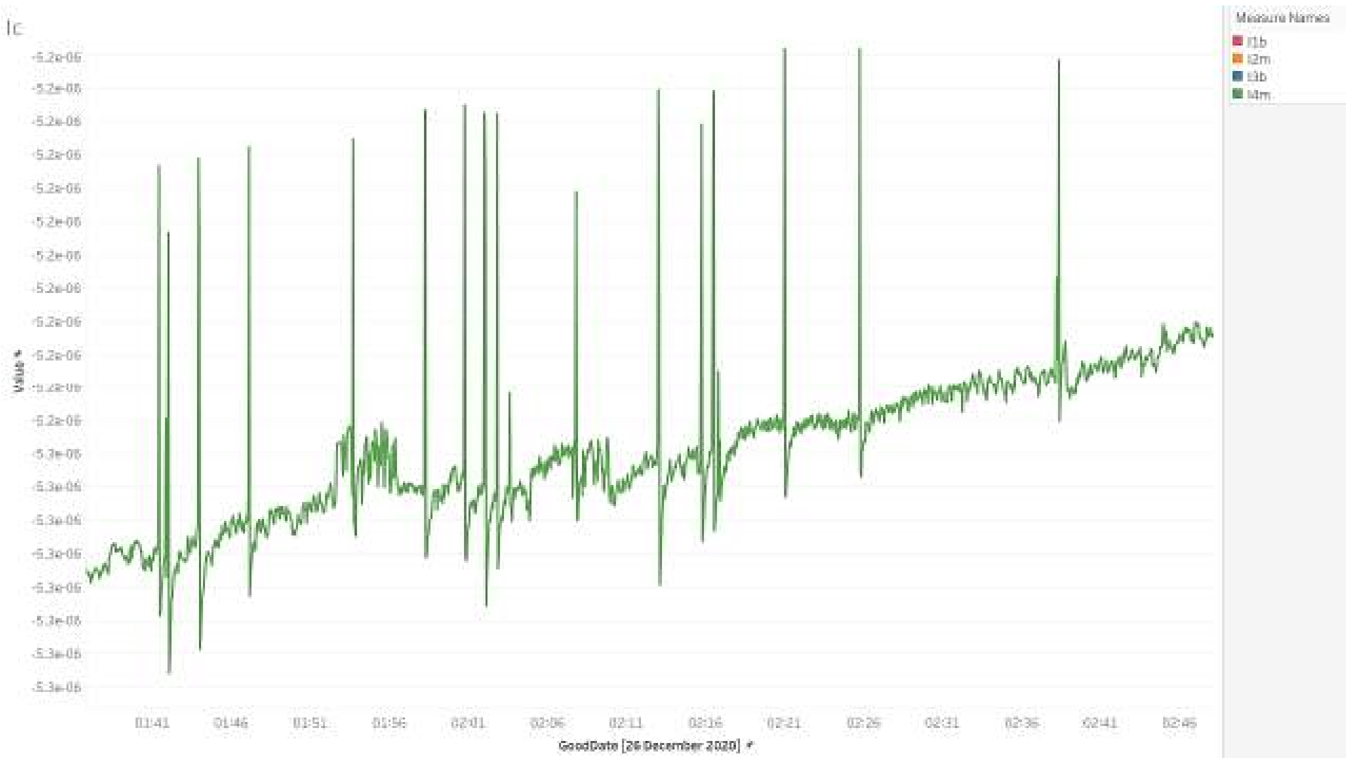

Fig. 9 Transient pulses in masonry

- Mortar vs bricks: Overall, electrical effects seem to be more pronounced in mortar than in bricks. Due to their higher salt content, mortar is more conductive, channelling electrical phenomena better.
- Humidity vs voltage changes: The variation of voltages in damp masonry seems to match humidity changes very closely both on the surface and in depth. On Fig. 10 we can see the voltage changes (blue line) on an internal wall

in our 150-year-old test cottage during a 7-day period, voltages varying between 25 mV to 310 mV. Humidity changes on the surface (thin red line, 56%-76% RH) and in depth (thick red line, 80.0%-82.8% RH) virtually reversely mirrored the voltage changes in the wall. A decrease in RH values, indicating evaporation, resulted in an increase of the wall voltages. Indeed, evaporation leads to the presence of more positively charged protons in the vapor cloud, resulting in an increased positive voltage during evaporation. Conversely, an increase in RH, indicating condensation or wetting, results in less positively charged protons in the vapour cloud, leading to a decrease of wall voltages. Monitoring wall voltages with embedded wall electrodes can be a simple way of monitoring moisture changes in a damp masonry, giving us instant indication whether the fabric is getting drier or wetter.

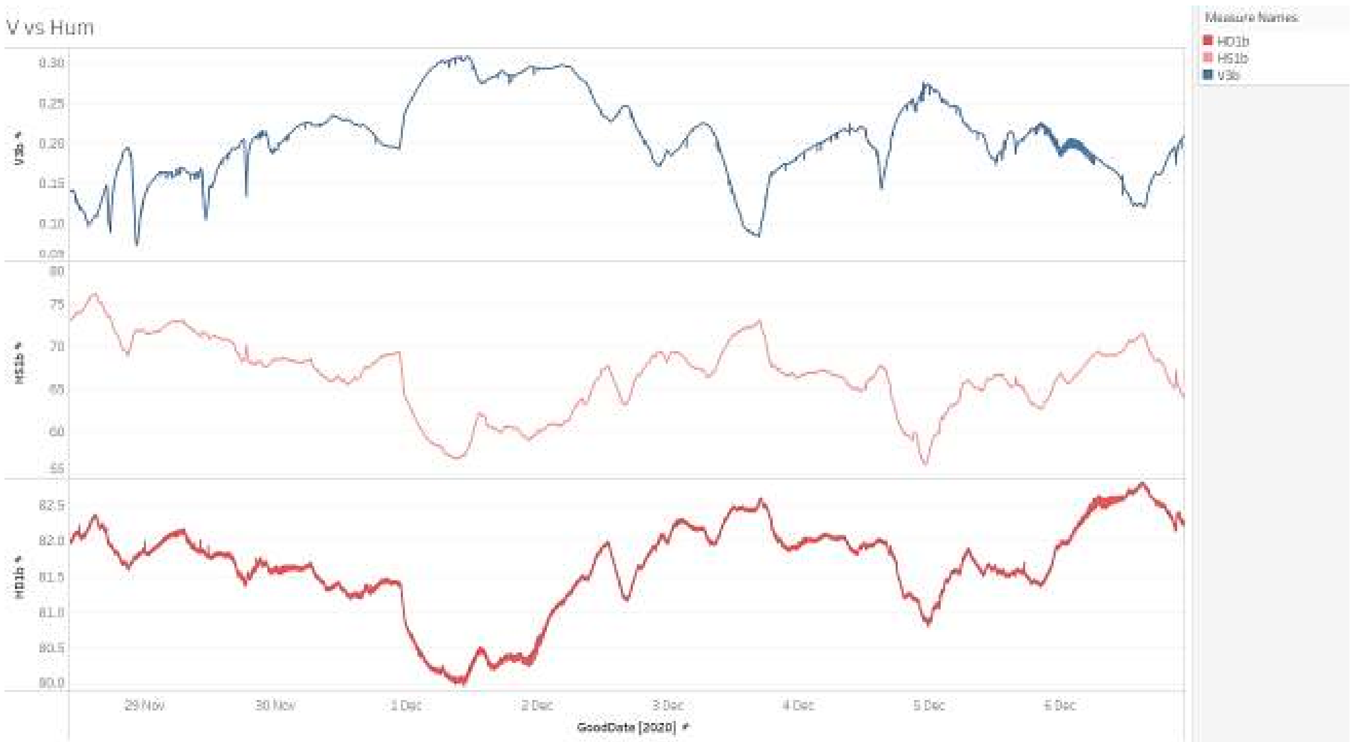

Fig. 10 Voltage changes (blue) in a damp wall follow humidity changes (red) very closely

VI. Conclusions and Suggestions for Further Research

Various electrical aspects accompanying the presence of moisture in porous building materials have been investigated. From experiments performed both in the lab and on real buildings the following conclusions can be drawn:

1. While there are no electrical effects in a completely dry masonry, the presence of moisture in any porous masonry is always accompanied by electric charges, which show up in the wall fabric as small electrical voltages and currents.
2. Salts in damp masonry are an important catalyst of electrical phenomena, significantly increasing the order of magnitude of both voltages and currents.
3. Sharp transient pulses have been observed near the ground in real buildings, which might play an important role in the mechanism of capillary moisture transport. This is currently under investigation.
4. Voltage changes in damp walls closely mirror humidity changes. An increase in the wall potential indicates evaporation (drying), a decrease of it indicates condensation (wetting). This does not apply during the initial wetting stage of a dry masonry or during the final dehydration stage of a damp masonry.
5. Variation of electrical voltages and currents can potentially be used to monitor the wetting or drying condition of masonry.
6. Electrical phenomena in damp masonry are very important phenomena that needs more research.

Electrical phenomena accompanying the movement of moisture in porous masonry are a virtually unknown and unexplored area of building physics. They are most likely to affect old buildings, especially several hundred-year-old heritage buildings with thick solid walls, due to the amount of moisture and salts present in them.

As buildings are located at the soil-air interface – in solid contact with the soil but extending up into the air – they are subject to electrical influences from both the ground and the air. Many natural and man-made phenomena [15] originating from the air (lightning, storm charging, electromagnetic fields etc.); from the soil (geomagnetically induced currents, piezoelectric charging, thermoelectric effects etc.); electric charges created by water movement (electrochemical effects, electrokinetic effects, oceanic charging etc.) or even space weather effects (geomagnetic storms, substorms and pulsations) [16], just to name a few, are all known to generate electric charges in the soil and in the air [17]. These electrical effects from the environment, by interacting with the electrical double layers of the wall capillaries, can interfere with or influence the dynamics of both liquid [18] and vapor [19] capillary moisture transport.

From building conservation viewpoint, the impact of the electrical environment on old buildings, and its significance on the mechanics of capillary moisture movement are virtually unknown as this subject area has been barely researched. Factoring in the ever-increasing abundance of man-made electromagnetic fields, with the advent of 5G we also seem to undergo an "electromagnetic climate change" which is likely to impact – positively or negatively – many old buildings we care about to preserve for future generations, making any research in this field timely and highly relevant.

A better understanding of how electrical effects from the environment impact old buildings and various moisture transport mechanisms could open the door to newer, smarter and less-invasive technologies, allowing us to deal with moisture in heritage buildings more effectively.

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