

## **RISING MOISTURE, SALTS AND ELECTROKINETIC EFFECTS IN ANCIENT MASONRIES: FROM LABORATORY TESTING TO ON-SITE MONITORING**

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### **Abstract**

The investigation of capillary water rise mechanisms in old masonries is of great practical interest, as well as the investigation of the electrical effects accompanying such phenomenon. In fact, moisture presence facilitates all the decay processes in porous building materials and strongly threatens the preservation of materials in architectural heritage. Previous papers have shown that performing a correct and accurate measurement of spontaneous electric potential in masonries is very challenging due to several variables influencing these phenomena, such as materials microstructure, soluble salts nature and amount.

In this paper the influence of mortar joints on the capillary water rise and on the related electrokinetic effects was investigated on laboratory assemblies; then, the same measuring procedure was applied on site to a real XVI Cent. masonry building affected by rising damp.

### **1. Research aims**

Rising damp in masonries is a complex mechanism, influenced by a multitude of factors, therefore previous research carried out by the authors was performed on purposely designed laboratory models that allowed each variable to be studied independently. In a first study, laboratory models where a thin layer of brick powder was used between the bricks, instead of mortar joints, were used, so that capillary suction was dependent only on the brick microstructure [1-2]. In the cited studies, tap water was used to generate the rising flux, no additional salt being added intentionally. In a further study, salt-contaminated water was added, so that the effect of capillary rise on soluble salts distribution and spontaneous potentials could be determined [3].

In none of the previously cited studies mortar joints were used, in order not to complicate the evaluation of the above mentioned parameters. Indeed, it is known from literature [4] that in presence of mortar layers, capillary flux deviates from the classical capillary transport in a homogeneous material, this variation being influenced by the porosity of the mortar layer. For this reason, the first aim of this paper was to study the effect of mortars on spontaneous potentials and salt distribution. For this purpose, experimental fixtures were built, with fired clay bricks and three kinds of mortar joints.

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The **three different mortars** (respectively with cement, hydraulic lime and lime with powdered brick) were chosen to reproduce the most common to be used in real masonries, and for their differences in porosity.

After testing the proposed measurement method on laboratory scale masonry models complete with different kind of mortars, its applicability to real ancient walls was verified by means of a survey campaign in **a XVI Cent. masonry building** (Palazzo Isolani, Minerbio, Italy) **affected by rising damp**. This allowed to detect possible critical issues in the on-site application of the method, for further improvements. A future use of this method for the monitoring of dehumidification systems is expected.

## **2. Introduction**

**Rising damp is one of the most relevant phenomena leading to decay of ancient, as well as modern, porous building materials**, since it causes or speeds up all degradation processes (solubilisation, freeze-thaw cycles, biological attack, chemical attack, wind erosion) and it damages aesthetics, hygiene and statics of the building [5-6]. Moreover, while moisture migrates through material pores, soluble salts contained in it may be subject to crystallization cycles, leading to further severe decay [7].

Hence, **removing dampness is essential before any restoration work**, in order to make it effective. Unfortunately this aim is not easy to achieve, since all the existing techniques exhibit several limits: in some cases they are unsuccessful due to an indiscriminate application, i.e. they are applied without any knowledge of the actual characteristics of masonry, the rising flux and the environmental conditions; in other cases, the effectiveness of the techniques themselves is controversial [2]. Hence, **the development of effective procedures for the dehumidification of ancient brick and stone masonries has hardly been achieved** and for this purpose at least two aspects should be considered essential: i) a **correct measurement of moisture and salts** in the masonry before and after the intervention; ii) a **better knowledge of the actual dehumidification process** applied (mechanisms, effectiveness, limits, etc.).

Concerning the first issue, a correct measurement of moisture content in the materials is often the only way to test the effectiveness of a repair work. In particular, monitoring dampness levels for at least some months in the walls is essential. Since it's necessary to have comparable data during monitoring and since ancient building materials (especially bricks) are usually highly heterogeneous, **all the measurements need to be carried out always on the same bricks**, in order not to be influenced by the materials microstructure, which might affect the results [1]. At the same time, in order to be representative of the real conditions of the wall, the measurements must not alter the thermo-hygrometric conditions of the bricks. Thus, permanent sampling points method [1] can be used, which provides accurate and reliable data: **by drilling a hole in a brick, inserting fragments taken from the same brick in the cavity and sealing the hole, the fragments reach thermo-hygrometric equilibrium with the surrounding material and can be periodically used for moisture measurement by the gravimetric method [8], for an indefinite number of times.**

Concerning the knowledge of the dehumidification mechanisms, this is particularly important for the techniques based on the **exploitation of electrokinetic processes** in the masonry, such as electro-

osmosis, which are still scarcely investigated despite their large diffusion. As a matter of fact, when a capillary water flux is present in a masonry, spontaneous potentials (known as streaming potentials) occur due to the formation of an electrical double layer in the pores, at the material/water interface [9]; this layer originates from the existence of not saturated bonds on the solid surface which attract ions in the electrolytic solutions. These adsorbed ions create a polarization in the surrounding liquid that gives rise to charge separation and, consequently, to a diffused double layer [10], one fixed on the material surface and the other one in the flowing solution. The electric potential between these two layers is called Z-potential. In the electro-osmosis technique, used for clay and soil dessication and also proposed for masonry dehumidification, the mobile liquid phase (polarized) inside a porous material is made to flow by the application of an external electric field [2]. Dehumidification systems for old masonries based on electrostatic induction have been proposed as well [10]. They involve the insertion in the masonries of elements (bars, serpentines, etc.) polarizing in the opposite sign of the spontaneous streaming potential and contrasting capillary rise flow. Nevertheless, the above mentioned spontaneous potentials are not much investigated in masonries since they involve very low voltages and they are difficult to measure without altering the investigated system [2], especially on site. For this reason, the influence of the nature and microstructure of the masonry bricks on rising damp and related electrokinetic effects was investigated in laboratory [2], as well as the spontaneous potential occurring in masonry at the laboratory scale due to capillary rise of salt contaminated water [3].

In this paper the influence of mortar joints on the capillary water rise and on the related electrokinetic effects was investigated on laboratory assemblies. Afterwards, the same measuring procedure successfully tested on laboratory assemblies with different mortars was applied on site to a XVI Cent. masonry building affected by rising damp, highlighting some possible aspects to be improved in the method.

### 3. Laboratory tests

#### 3.1 Materials

For the laboratory tests three assemblies were built, piling up twelve commercial fired-clay bricks  $25 \times 12 \times 5.5 \text{ cm}^3$  (Stabila, Italy). Three different kinds of mortars were used for the joints, one for each assembly, changing only the nature of the binder, but keeping constant the mix proportions and the nature of the quartz sand:

- hydraulic lime based mortar (sand:lime:water 3:1:1/2 in volume), labelled HLM;
- cement based mortar (sand:cement:water 3:1:1/2 in volume), labelled CM;
- lime based mortar with powdered fired-clay bricks (sand:lime:brick powder:water 2:1:1:1/2 in volume), labelled LBM.

Mortars were prepared in a Hobart mixer (procedure, time and speed as in EN 196-1).

#### 3.2 Assemblies

The assemblies structure and size are shown in Fig. 1. After 3 months curing, the assemblies were subjected to continuous water rise by maintaining their bottom under 2 cm of water.

Permanent sampling points for the measurement of moisture and soluble salts had been set in the bricks number 2, 5, 8 and 11 (from the bottom), by drilling 1.5 cm diameter and a 20 cm depth holes (i.e.  $\frac{3}{4}$  of the length of the brick), according to [1]. Fragments taken from the same bricks were put inside the holes (the powder was already inside them after drilling and ensured a continuous path for the rising water) [1]. In order to make the fragments reach the thermo-hygrometric equilibrium with the host bricks, the holes were sealed with rubber stoppers and plasticine [1].

Electrodes for the measurement of the spontaneous electric potential were set in the same bricks and at the same height of the permanent sampling points (Fig. 1). Electrodes, consisting of 2.1 mm diameter stainless steel nails, were fixed, by hammer, into holes previously drilled into 2 mm holes previously drilled in the bricks. The holes diameters are expressly smaller than the nails in order to assure a better contact and fixing. A nickel-based conductive paste was used to further improve the electric contact between the nail and the brick [2].

### 3.3 Methods

The assemblies were kept at room conditions ( $T = 21\text{--}24\text{ }^{\circ}\text{C}$ ,  $RH = 30\text{--}50\%$ ), until capillary water rise reached a steady state. The first measurement was carried out six months after the construction of the assemblies: moisture was determined on the extracted fragments by the gravimetric procedure (at  $100\pm 5\text{ }^{\circ}\text{C}$ ) and then soluble salts were measured on the same fragments by extraction with deionised boiling water (electrical conductivity  $< 0.02\text{ }\mu\text{S}$ ), filtration by blue ribbon filter and ion chromatography (Dionex ICS- 1000, equipped with an Ion Pac AG14A guard column and an Ion Pac AS14A inorganic anion-exchange column kept at  $30\text{ }^{\circ}\text{C}$ ; measuring cell temperature  $35\text{ }^{\circ}\text{C}$ ).

The electrical potential, referred to earth, was measured by a portable high impedance ( $10^{14}\text{ }\Omega$ ) Keithley Electrometer 602 (accuracy  $\pm 10^{-5}\text{ V}$ ); water at the bottom of the fixtures was earthed by a stainless steel plate immersed in the tank [2].

## 4. On site testing

### 4.1 The building

The same measurement method described above was tested on the masonries of the Isolani Palace (Fig. 2), a XVI Cent. monumental building located in Minerbio, Bologna (BO) and designed by the architect Bartolomeo Triachini [11-12]. The building is presently affected by a significant presence of rising damp and consequent materials decay (Fig. 2) as well as by rain infiltration in the external monumental staircase only (Fig. 2a). The hygrometric conditions are made worse by the fact that the palace is presently waiting for restoration and hence it is not used: as a consequence, scarce ventilation is present inside the building.

## 4.2 Testing points

Three sampling areas were selected, in three different masonry walls affected by rising damp at the ground floor (A, B, C) (Fig. 3): two are inside (zones A and B) and one on the external façade (zone C). The three zones are different for orientation, exposure, decay, and estimated moisture presence, in order to represent different masonry conditions. Zone A (wall thickness 30 cm) appears damp and the original plaster is detached, with presence of salt efflorescence and biological growth on the wall surface; the zone is characterised by the presence of a manhole for water draining about 10 m far (Fig. 3) and by the presence of a thick and long crack (probably due to differential settlements) on the wall and ceiling about 50 cm from the sampling area. Zone B (wall thickness 75 cm) is on the internal side of the perimeter wall and plaster is present on the whole area. Zone C (wall thickness 75 cm) was chosen on the external side of the perimeter wall (north-west orientation), where evaporation was supposed to be maximum and in fact the area appeared less damp and less decayed than the internal sampling area. No plaster is present in the façade any more. Three permanent sampling points for each zone (marked as 1, 2 and 3) were set at different heights, in correspondence of single leaf bricks, in order to avoid multiple bricks (and hence mortar joints) drilling. The size of the hole and the whole measurement procedure (moisture and soluble salts periodical determination) were the same used in the laboratory testing. Electrodes were set at the same height of the sampling points, on the two adjacent bricks, since the external surface of most of the bricks was irregular, deteriorated and not flat; the purpose was also to collect an higher amount of electric potential data.

In addition, some samples of mortar were withdrawn from the joints zone A, B and C, for characterisation purposes.

## 4.3 Methods

Measurements were carried out in six dates, from June 2011 to March 2012, in order to get a significant long-term monitoring. The first measurement was performed on the powders obtained from the hole drilling (very low drill speed was used not to dry the powder), while the other ones were performed on the fragments, according to the procedures in § 3.3. Of course, after extraction from the holes, fragments and powder were immediately sealed into air proof containers, in order to reach the laboratory in unaltered moisture conditions.

Electric potential were measured according to the procedure described in § 3.3. The measuring device was earthed by fixing a metallic nail in the external ground near the sampling zones.

To investigate the relationship between rising moisture and outdoor environmental conditions, environmental data provided by the meteorological survey stations of “ARPA Emilia-Romagna” (Agenzia Regionale per la Protezione Ambientale [Regional Agency for Environmental Protection]) were collected, according to a cheap and easy procedure outlined in [13] and to evaluate environmental conditions for a several years period [14]. Data were collected from the station of Mezzolara (Bologna, Italy), which was the closest to the building (about 12 km).

## 5. Results

## 5.1 Laboratory test

Moisture levels during the monitoring period are shown in fig. 4: HLM can be considered dry over the height of the 3<sup>rd</sup> brick, CM over the 2<sup>nd</sup>, while in LBM rising damp reaches almost the top of the assembly. At the height of the 1<sup>st</sup> sampling point dampness values are around 20% in HLM, 6-7% in CM and 22% in LBM.

Soluble salts amounts (expressed as anions) are shown in Fig. 4, and Table 1.

Sulphates are the most abundant and span from 0.2% to 0.8% for HLM, 0.1% to 0.7% for CM and 0.05% to 0.4% for LBM. Chlorides anions (about 0.002%) are almost constant with height and above the three assemblies.

Not negligible spontaneous potentials (voltage about 0,2 V) have been recorded in the damp areas (fig.4).

Bricks exhibit a higher porosity (34% Vol%) compared to lime with brick powder mortar (31%), hydraulic lime mortar (26%), and cement mortar (17%), as shown in Fig. 5.

## 5.2 On site test

Moisture levels during the monitoring period are reported in Fig. 6. In zone A dampness spans from 15-20% (point A1) to 12% (point A2) and 7% (point A3). In zone B it is about 15% for both B1 and B2, and 8% for B3. In zone C the values are lower: 10% in point C1, 2% in point C2, while point C3 can be considered dry.

Spontaneous dc potential data are shown in Fig. 7, absolute values up to about 0.65 V were recorded in the three zones.

In Tab. 2 the nature and amounts of the anions found in the sampling points are reported, while in Fig. 6 the same results are displayed in terms of total anions amount. Salts, and mostly sulphates, are very high in all of the zones (about 8%  $\text{SO}_4^{=}$  in zone A and C, 5%  $\text{SO}_4^{=}$  in zone B).

## 6. Discussion

### 6.1 Laboratory test

Moisture monitoring shows that the rising water reaches very different maximum rise heights in the three assemblies. The maximum water rise and corresponding efflorescence were visually assessed at the third brick from the bottom in HLM assembly, at the second brick in CM one and at the tenth brick in LBM one (Fig. 1). Moisture data in the sampling points (Fig. 4) confirm the different water amount and rise level in the three assemblies. Since the bricks used for the construction of the three assemblies come from the same batch and have identical characteristics, water rise level is controlled by the different pore size distribution of the mortars (Fig. 5). Brick exhibits, as expected, the higher total porosity (Fig. 5), while mortar with lime and powdered brick is only slightly less porous and this enhances the capillary rise in LBM assembly. Hydraulic lime mortar and cement mortar, besides being much less porous, are characterised by pores with significantly smaller radius (Fig. 5): this influences not only the quantity of the water absorbed by the mortars (coarse pores are known to contribute in more relevant way to moisture uptake leading to larger capillary absorption [15]), but also the velocity of the capillary transport through the mortar itself (smaller pore radius leads to slower capillary uptake); as a consequence, the overall rate of supply of water to upper



bricks is extremely lower.

In fact it is known from literature [15,16] that inflow rate decreases in presence of mortar layers since they increase the hydraulic resistance of the masonry slowing down the uptake process. This phenomenon can be ascribed to different factors: the presence of an interface resistance [15,17,18], the imperfect contact between brick and mortar due to micro-cracks originated by drying shrinkage and the mismatch between the pore systems of bricks and of mortar layers [15]. Correspondingly, the interface can exert a disturbance during drying, which generally leads to faster drying [17]. This leads to a jump in moisture content of the masonry [15].

The decline in the wetting process becomes more noticeable as the flow decreases [17] and is more visible in real masonries, characterized by multiple mortar layers: capillary suction follows the regular mechanisms till the height of the first mortar layer which determines a first reduction in the water uptake that reaches the second brick. As the water crosses several mortar layers the flux progressively decreases and **evaporation becomes more relevant than the rising flux.**

The fact that hydraulic lime mortar and cement mortar are so much less porous than the brick leads to similar heights of the rising damp front in the assemblies (Fig. 1), no matter of the difference in porosity between them.

Soluble salts amounts in the assemblies (Fig. 4 and Tab. 1) are essentially constituted by **sulphates, already present in the original bricks.** Their amount in LBM and CM assemblies decreases in the bottom part due to the washout effect of rising damp, while **they accumulate in the top part of the assemblies due to evaporation.** In HLM assembly, salts slightly increase almost everywhere, which might be ascribed to some salts presence in the original mortar.

Electric potential trend with height can be qualitatively related to the trend in anions amount (Fig. 4), as found elsewhere [2-3]: in LBM assembly, where the capillary rise is high, the relevant curves exhibit peaks at the same height, confirming that streaming potential variations follow the variations in anions content, although a quantitative proportionality can be assessed. The lack of a proportionality was expected in fact, as found in literature, the relationship between spontaneous potential and anions amount is complex; high concentrations of ions may even make the potential change sign by reducing the double layer thickness [3,19].

Anyway the variation of dc potential, again, corresponds to a variation in anions amount.

## **6.2 On site test**

Moisture levels (Fig. 6) show that dampness values are high in all of the three zones, and mostly in the internal ones, where it reaches also the higher areas of the wall. The amount of moisture decreases with height, as expected, in zones A and C, while the trend is quite different in zone B, probably due to the difference in porosity among the bricks of the three sampling points (in particular, high porosity of the brick B2, at a height of about 1 m from the ground floor). In zone C the higher testing point can be considered dry, as expected due to the higher water evaporation rate on the external façades.

**Despite the obvious variations in the outdoor climate parameters during the monitoring period (RH, temperature and precipitation data are not reported here for brevity sake), moisture amount in the investigated walls does not exhibit wide seasonal differences.** The only zone B exhibits some

variability, but this was due to an occasional storage of furniture adjacent to the wall, causing a temporary hindrance to surface evaporation.

Fairly good matching can be observed in spontaneous dc potential data between the left and right electrodes (Fig. 7). In zones A and B, electric potential is quite uniform with height in all the dates, while the values in zone C trend are much less uniform. This seems due to the fact that, in zones A and B the equilibrium line is above the investigated area and the **three sampling points are all moist**; conversely, in zone C the water rise front falls between the second and third sampling point (and in fact C3 is almost dry). Some seasonal variation of electric potential can be noticed in Fig. 7, partly to be ascribed to difference in temperature, influencing both zeta potential [9] and conductivity of the investigated materials.

Salts, and mostly sulphates, are very high in all of the zones, as shown in fig. 9 and tab. 2. In order to investigate the possible presence of gypsum in the mortar joints, acting as sulphate source, some samples withdrawn from the mortar layer of each area were analysed by X-ray diffraction: all the samples resulted common lime mortar, hence **the presence of sulphates is related to the water rising from ground**. In zones A and C the presence of chlorides and nitrates is significant as well.

During the investigated period, soluble salts content in the walls does not show any clearly identifiable trend and different anions amount could be simply due to the different salts content of the original brick fragments inserted in the sealed holes. In fact, due to extremely high salts amount, some heterogeneity in salts distribution even within the same brick could be envisaged.

For the same reason, unlike what observed in laboratory experience, the correspondence between the soluble salts and spontaneous potential curves (comparing Figs. 6 and 7) is less defined: since electrodes are not on the same bricks where samples were taken, differences in the salt content among the different bricks might be more relevant than the influence of rising damp in determining the streaming potential so that the correspondence cannot be noticed.

## **7. Conclusions**

A method for monitoring rising damp, soluble salts and spontaneous potentials was investigated in laboratory models, made by using different kinds of mortar for the joints, in order to study their effect as a weir for moisture stream and soluble salts diffusion. The method proposed:

- provides accurate and reliable data
- provides comparable data during periodical measurements, as it involves the use of permanent sampling points and fixed electrodes
- does not alter the thermo-hygrometric conditions of the masonry
- is scarcely destructive
- provides moisture data measured deep into the wall, where influence of environmental conditions is negligible [5].

The same procedure was applied for the first time on site (Palazzo Isolani) and it allowed to successfully **measure moisture, salts and spontaneous dc potential**, showing that the **method proposed can be used for real buildings**. Non negligible dc potential (up to about 0.6 V) were measured thanks to stainless steel nails fixed in the wall with the aid of conductive paste. These potentials have the same order of magnitude of the ones measured in laboratory models. However,



on site, it was not possible to clearly relate the height of peaks in the anion content and in the dc potential curves, due to different reasons:

- the equilibrium line of rising moisture seems to be higher than the highest sampling points in zones A and B: moisture content decreases with height from ground, but it is still relevant in the highest sampling points (~ 5-7% in A3 and B3, see figure 6) which means that upper points are still below equilibrium line, where the main salt crystallization (and highest salt content) can be expected. Maybe if there was an higher sampling point (above equilibrium line) we would have measured a correspondent clear potential variation.
- the extremely high salt concentration in the bricks causes a heterogeneous distribution of the salts themselves and the electrodes should be rather fixed exactly in the same bricks in which the sampling points are located.

Further improvements of the measuring procedure are presently under testing in other historic masonry buildings.

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## TABLES

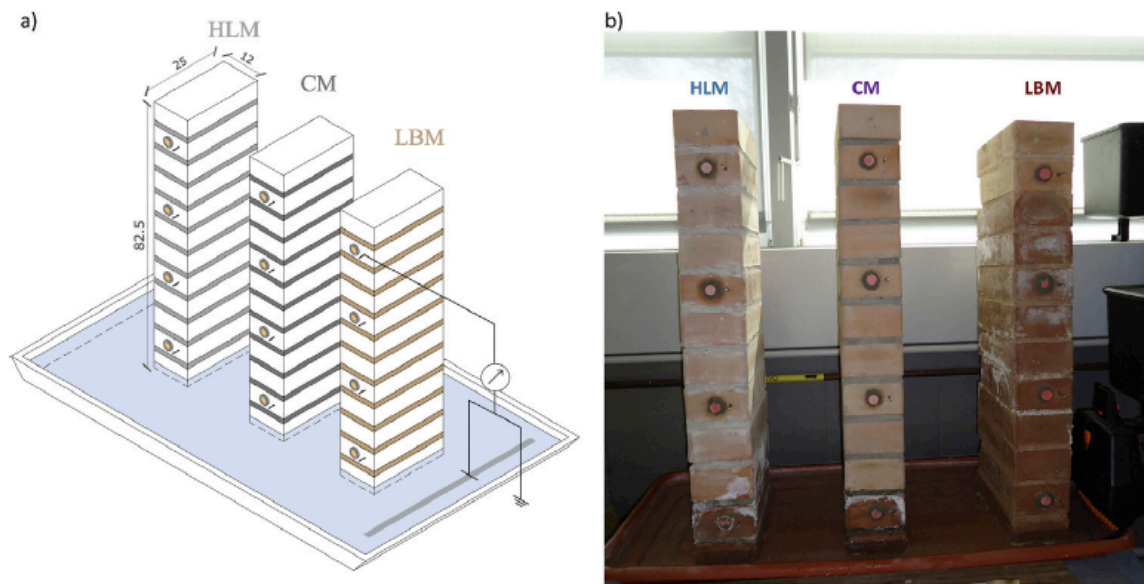
	sampling point	height [m]	sampling date	Cl <sup>-</sup> (wt%)	SO <sub>4</sub> <sup>=</sup> (wt%)
HLM	HLM 2	8.5	180 days	0.059	0.227
			240 days	0.089	0.236
			originally present	0.008	0.048
	HLM 5	26.5	180 days	0.010	0.486
			240 days	0.039	0.681
			originally present	0.007	0.410
CM	CM 2	8.5	180 days	0.020	0.594
			240 days	0.017	0.073
			originally present	0.017	0.530
	CM 5	26.5	180 days	0.007	0.527
			240 days	0.021	0.553
			originally present	0.024	0.428
LBM	LBM 2	8.5	180 days	0.012	0.175
			240 days	0.017	0.130
			originally present	0.018	0.869
	LBM 5	26.5	180 days	0.011	0.079
			240 days	0.018	0.043
			originally present	0.014	0.117
	LBM 8	45.5	180 days	0.016	0.350
			240 days	0.022	0.203
			originally present	0.013	0.253
	LBM 11	62.5	180 days	0.019	0.413
			240 days	0.012	0.398
			originally present	0.012	0.334

Table 1: Chlorides and Sulphates amounts in the models

	sampling point	height [m]	sampling date	Cl <sup>-</sup> (wt%)	NO <sub>3</sub> <sup>-</sup> (wt%)	SO <sub>4</sub> <sup>=</sup> (wt%)
zone A	A1	0.35	first measurement	0.006	0.007	0.346
			30 days	0.072	0.027	0.080
			90 days	0.046	0.017	0.067
			150 days	0.009	0.011	0.040
	A2	1.15	first measurement	0.016	0.064	0.188
			30 days	0.027	0.031	7.065
			90 days	0.023	0.036	4.855
			150 days	0.013	0.024	2.943
	A3	2.15	first measurement	0.704	1.690	0.058
			30 days	0.371	1.036	2.066
			90 days	0.375	0.986	4.387
			150 days	0.502	1.333	4.870
zone B	B1	0.15	first measurement	0.003	0.008	0.028
			30 days	0.007	0.013	0.035
			90 days	0.006	0.008	0.040
			150 days	0.008	0.006	0.034
	B2	1.2	first measurement	0.007	0.024	0.154
			30 days	0.010	0.010	1.562
			90 days	0.010	0.009	0.383
			150 days	0.014	0.013	1.425
	B3	1.98	first measurement	0.018	0.099	0.070
			30 days	0.039	0.066	3.298
			90 days	0.017	0.030	0.882
			150 days	0.012	0.032	1.359
zone C	C1	0.4	first measurement	0.007	0.040	0.021
			30 days	0.009	0.014	18.340
			90 days	0.010	0.013	7.828
			150 days	0.006	0.017	6.868
	C2	1.35	first measurement	0.342	1.506	0.125
			30 days	0.112	0.681	0.720
			90 days	0.109	0.659	0.473
			150 days	0.129	0.747	0.935
	C3	2.2	first measurement	0.007	0.029	0.014
			30 days	0.007	0.012	0.050
			90 days	0.006	0.019	0.107
			150 days	0.006	0.020	0.100

Table 2: Chlorides, Nitrates and Sulphates amounts in zones A, B and C

## FIGURES



Figure

1: Laboratory models (a) permanent sampling points and permanent electrodes and (b) level of moisture rise 6 months after the construction.



Figure 2: Isolani Palace at Minerbio: (a) North façade; (b) decay phenomenon occurring in Isolani Palace due to rising moisture and salts near zone C; (c) zone A; (d) zone B; (e) zone C.



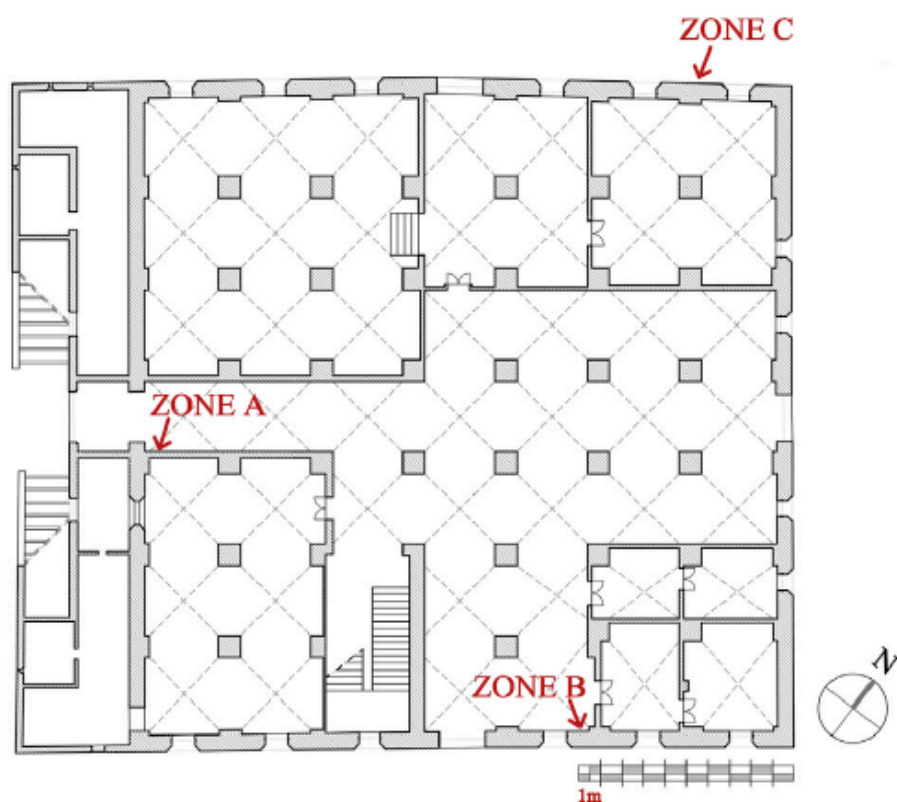


Figure 3: Ground floor plan, with the localisation of the sampling zones A, B and C

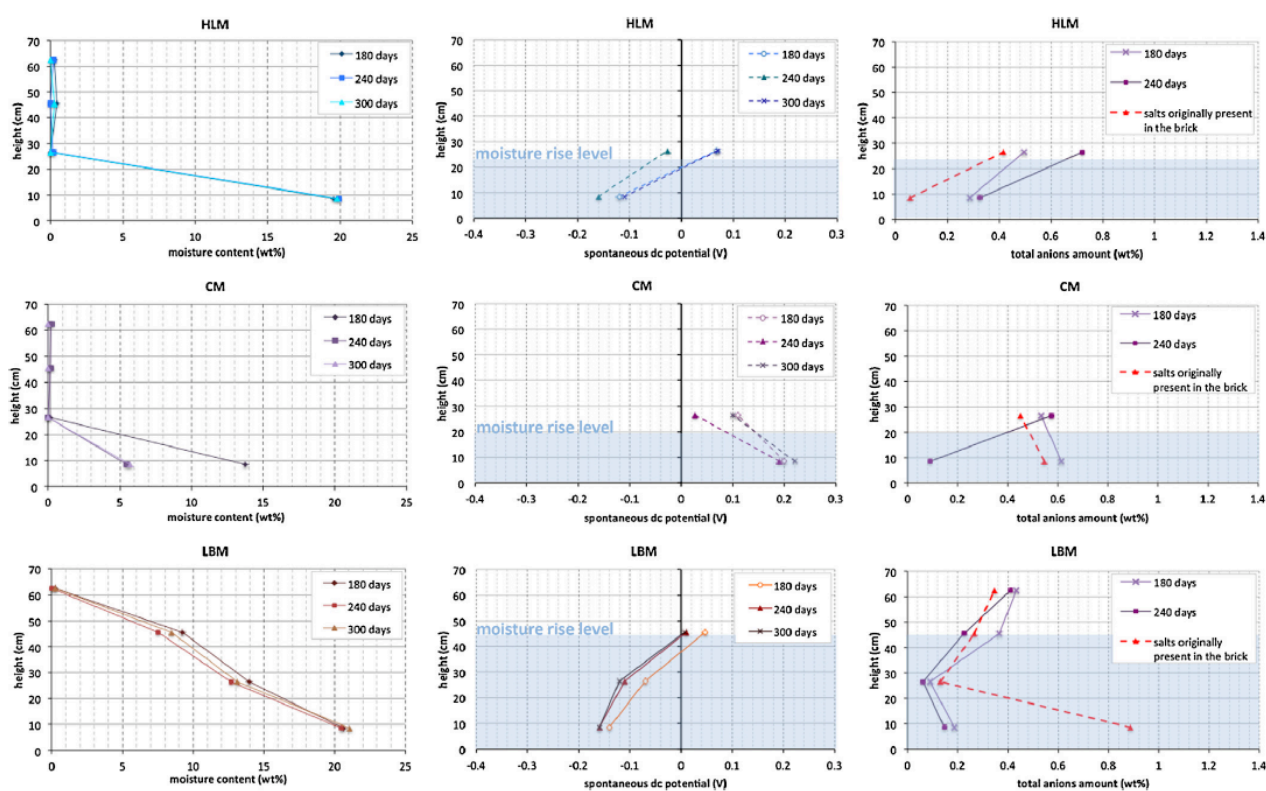


Figure 4: Comparison between moisture, spontaneous dc potentials and soluble salts



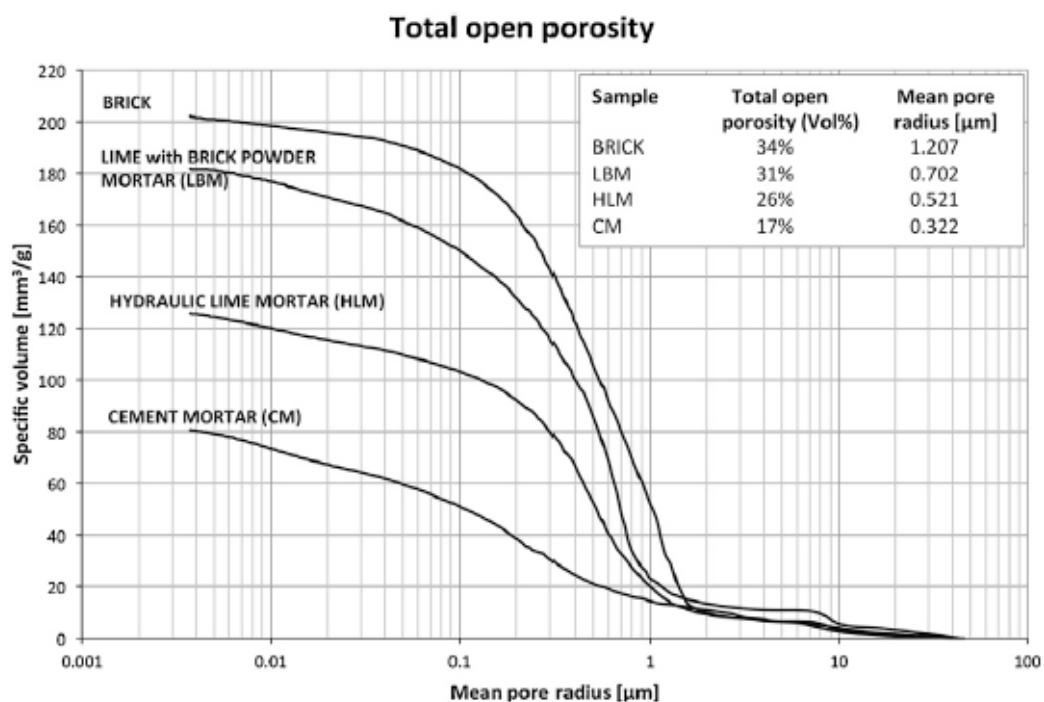


Figure 5: Pore size distribution of the mortar and brick samples

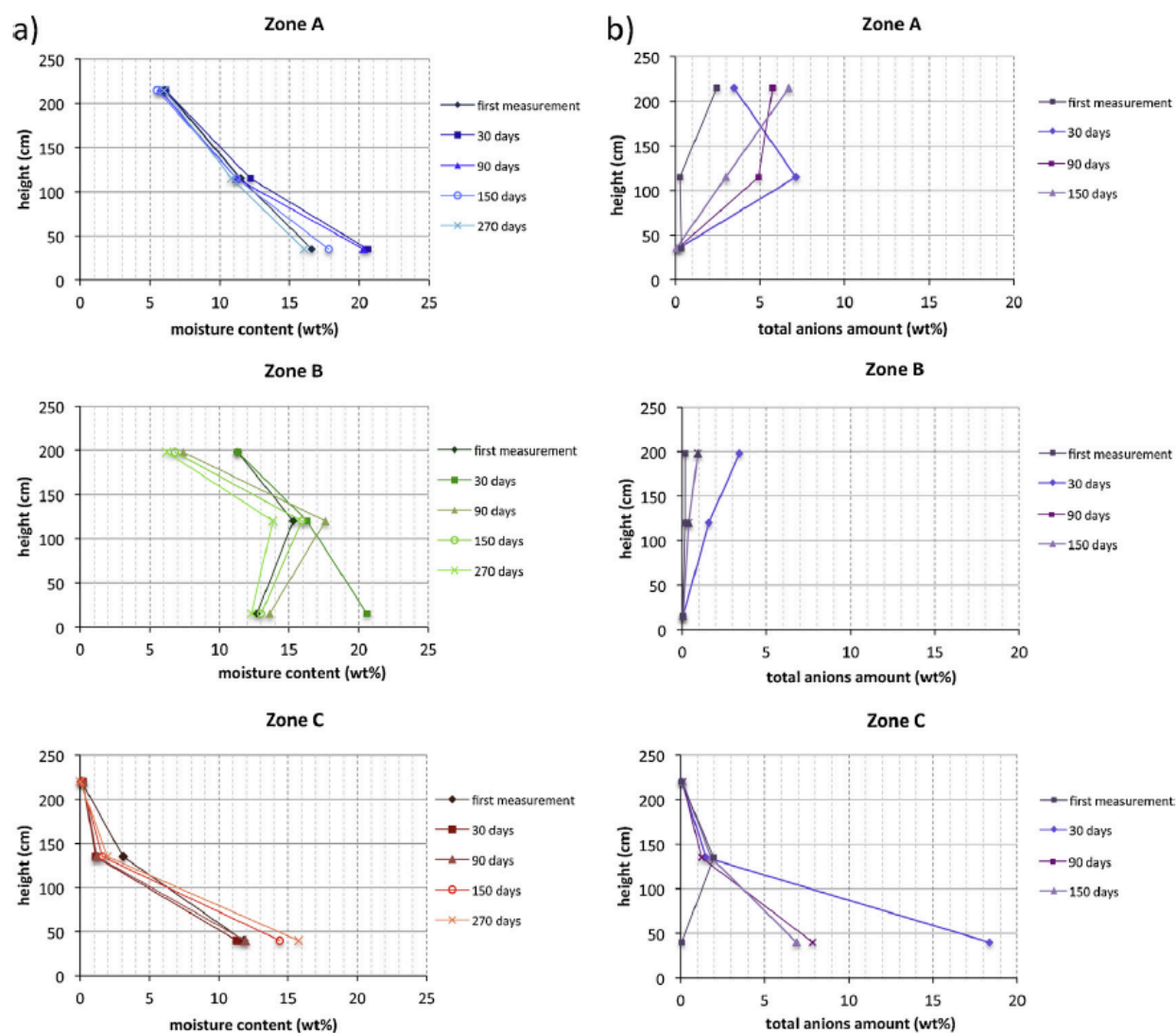


Figure 6: Zones A, B and C: (a) moisture content and (b) soluble salts amount

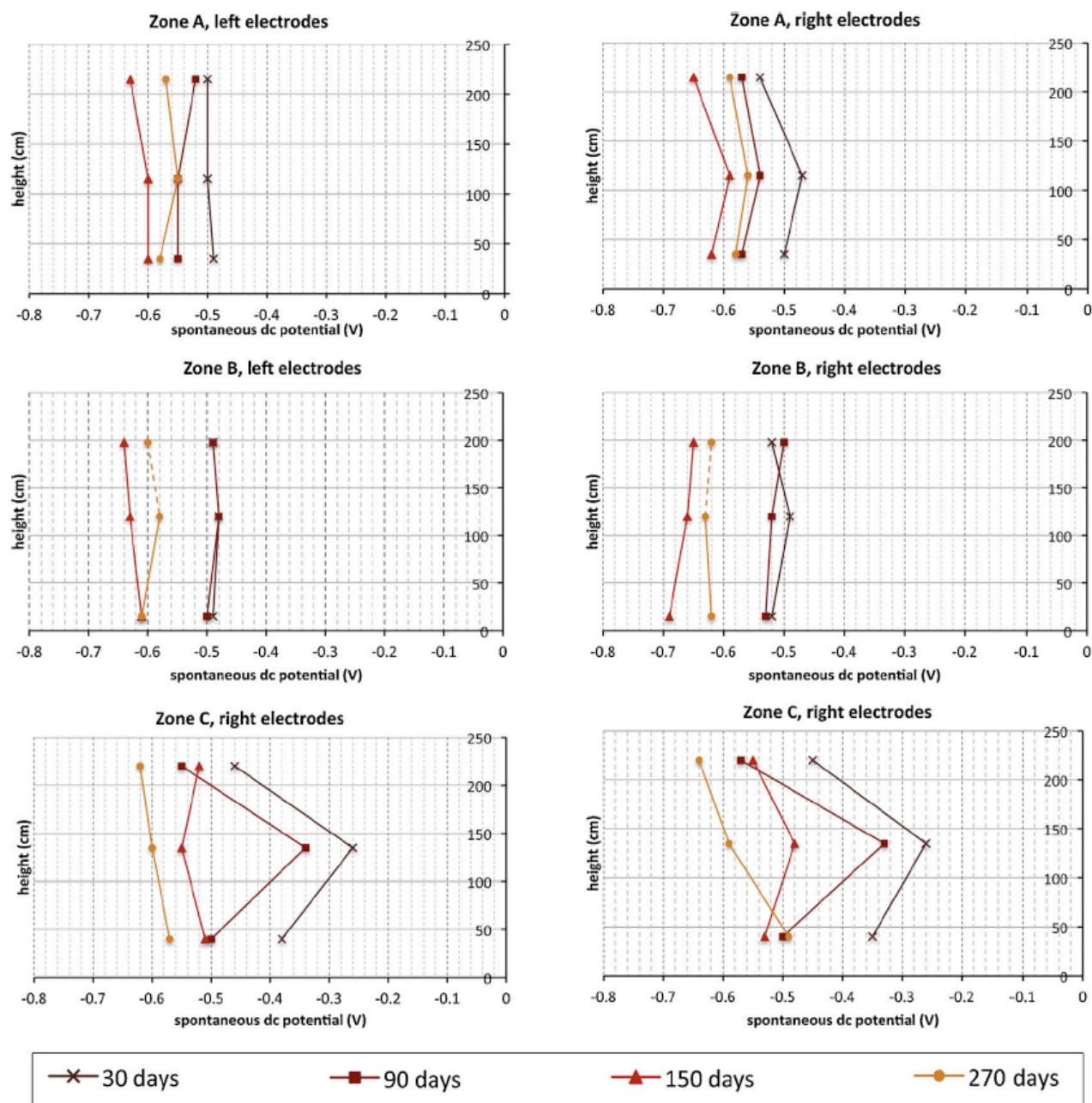


Figure 7: Spontaneous dc potentials in zones A, B and C