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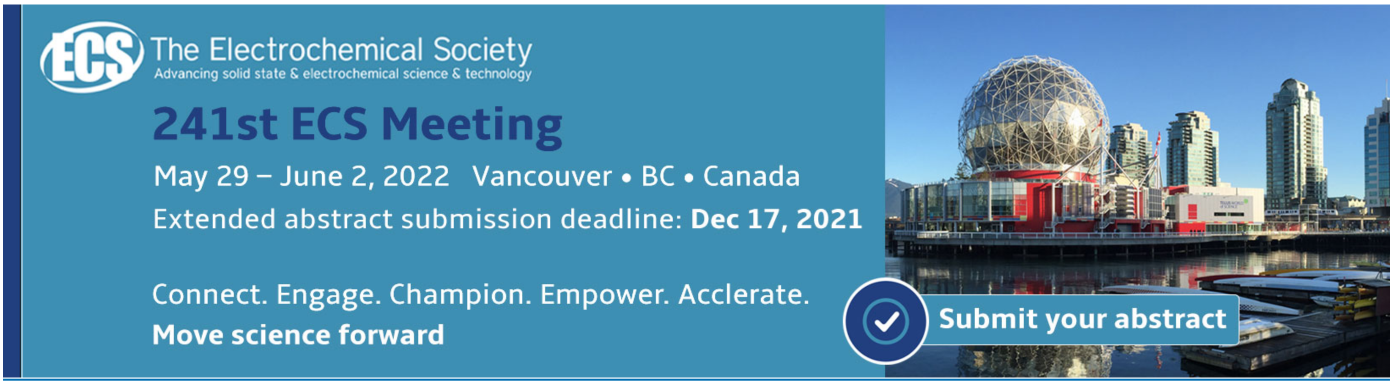


Capillary rising damp in Venetian context: state of the art and numerical simulation

E Guolo[1], P Romagnoni[1] and F Peron[1]
[1] Department of Architecture and Arts, University IUAV of Venezia, S. Croce 191, 30123 Venezia, Italy
Corresponding author: eguolo@iuav.it

Abstract. The fragility of Venice and its buildings are linked to the floods, observed since ancient times and emphasized in recent years: the periodic sea level rise, accompanied by rising damp, are the main causes of the alteration. In particular, the rising damp causes a series of complex diseases in the historic buildings, such as physical decay, chemical or biological, with loss of aesthetic and economic value. In addition, greater heat dispersion and reduced thermal comfort can also occur in interior spaces, with consequent risks for human health. This is a sign of “Sick Building Syndrome”. It is very important to develop models for assessing the vulnerability of assets and to manage sustainable plans related to maintenance processes and activities, satisfying the requirements of effectiveness and compatibility.Basing on numerical models performed with the WUFI 2D software, the paper analyses the different behavior of rising damp in relation to materials or masonry structures. In particular, the construction techniques and typical materials used in Venetian buildings were investigated, such as clay brick walls, lime plaster, Marmorino and Cocciopesto, adopted mainly to limit the capillary rise also caused by the phenomenon of “acqua alta”.

1. Introduction

The buildings in Venice are built with a masonry structure in clay brick and Cocciopesto mortar, and lie on a permeable soil rich in salts, border with salty water and exposed to a capillary saturation of over 70%. These factors allow the water to penetrate deeply into the porous material which, thanks to the rising damp, caused to aesthetic, structural and physical damages, by water-soluble salts that have crystallized. The water in the masonry reaches an average level of 2.5-3 m, with extreme cases up to 5 m, but the highest moisture content can be recorded in the lower part (25% of capillary saturation). Simultaneously the percentage of moisture decreases with increasing height, increasing the evaporation rate and leaving a high presence of soluble salts.

In general, rising damp depends on these factors: boundary conditions, salts, porosity of materials, wall thickness and nature of coating materials [1].

The historical systems adopted to hide damage from “acqua alta” as marble cladding, concrete bases, wooden panels or plasterboard, have aggravated the rising damp, because they blocked the natural transpiration of the brick and altered the priming-evaporation rate [2] [3].

This problem is particularly felt in Venice because it is linked to the interest in the conservation of the heritage peculiarity, improving sensitivity to restoration activity.

Since the experimental investigation in Venice are harmful to the heritage, we decided to build test walls in masonry in the laboratory and perform a comparison on numerical models to evaluate the behavior of moisture in the structure.

2. Materials and methods

In the masonry structure, a heterogeneous system composed of several materials, different decays can be observed on brick and mortar, due to the main agents of alteration, such as salts and atmospheric pollutant.

Hygroscopic salts, such as sulphates, nitrates, nitrites, chlorides and carbonates, are the real problem in manufactured products, because they occur when water evaporates and dry the material. A wall can be contaminated when the internal salts are between 0.3% and 3% by weight (heavily contaminated) [4]. The solid-state salts settle down into pores, with consequent saturation which determines of stress states, such as swelling, detachment and a various superficial damage, even with discoloration or white deposits. The most dangerous process is crystallization, because it involves a high pressure with a dimensional order higher than tensile strength of the materials [5].

2.1. Materials

The raw material of the brick is clay, which must perform a series of works to achieve a certain degree of plasticity for its transformation into elements to be glazed in the furnace, at temperatures between 900-1000°C. Thanks to these processes it is possible to reach different percentage of porosity, between 15% and 45%, and a pore diameter ranging between 0.1 μm and 1 μm [6].

The mortar used in Venice is a mixture of cement or lime, water, fine aggregates (sand, ground marble, glass from the Murano furnaces) and other additives, in such proportions as to guarantee the workability of the wet mix and good mechanical resistance when dry. These mortars can be aerated or hydraulic, the latter with reduced porosity and therefore little water permeability and resistance to mechanical actions, suitable for humid environments. Until the early XX century, lime-based mortars were used, and to add the “hydraulic” properties, Cocciopesto plaster was added using volcanic ash or crushed bricks and lime-based tiles.

Another type of plaster used is the Marmorino, deriving from the mixture of lime and marble powder, which allows to obtain a smooth and precious finish. The difference between ordinary plaster and Marmorino is the application technique, which is to apply several layers (about three), which create effects of transparency and reflection.

2.2. Laboratory test

The first step of the test concerns the construction of a masonry structure, six prismatic systems of 100 x 120 x 25 cm positioned in an epoxy tank of 120 x 80 x 19 cm, with the aim of assessing the behavior of the masonry directly exposed to the action of water, as in the symbolic case of Venice. This wall is made of clay bricks (UNI 12.5 x 25 x 5.5 cm) and lime mortar NHL 5.

These walls were positioned in indoor environment with controlled conditions (temperature 20 ± 3°C and capillary saturation 45 ± 5%) and fresh water without salts in the tanks. This choice was made to limit the variables that can influence the model.

During the six months of experimentation, rising damp was monitored with non-destructive methods: thermography (Figure 1), capacitive monitoring of electrical resistance at different heigh (20 cm, 40 cm, 80 cm) and surface humidity with a contact thermo-hygrometer (Figure 2). All systems demonstrate a rapid imbibition rate in the first 10 days, then a slow reduction in the height of water on the surface.

2.3. Simulation

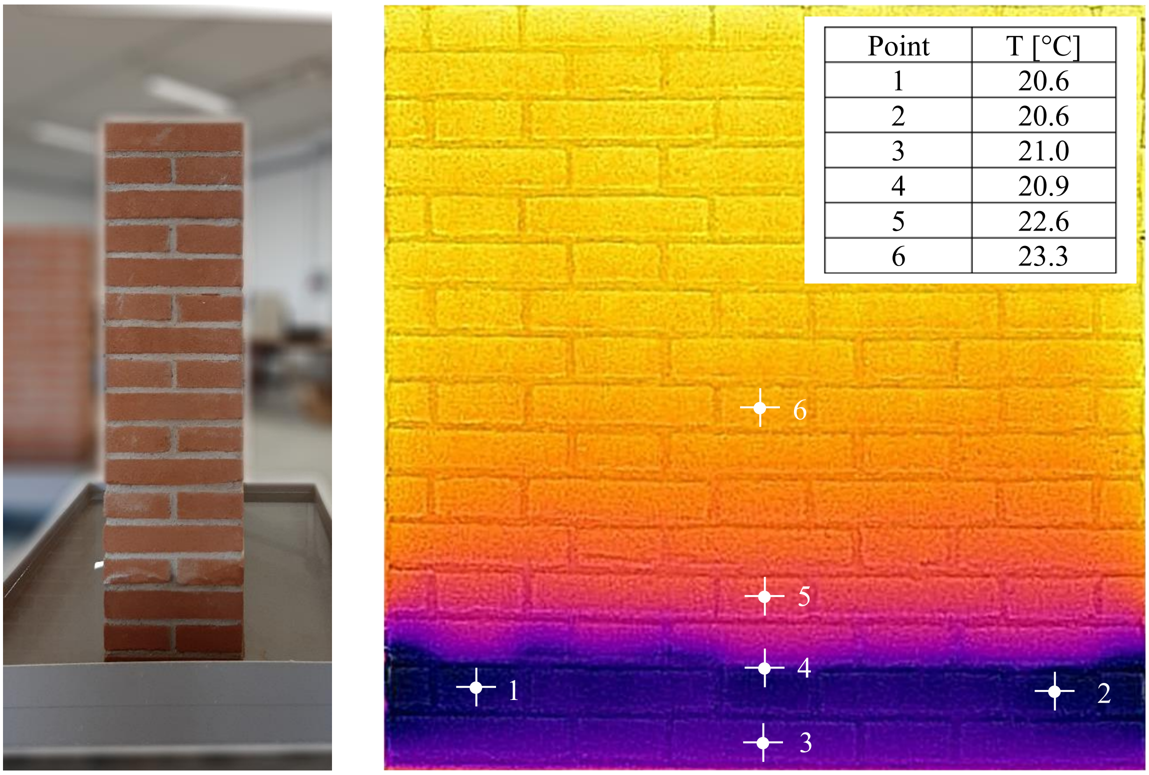
In architectural or civil engineering, dynamic simulation is used for the conservation of the building stock and assume the long-term conditions of the envelope components. The WUFI 2D simulation software – developed at the Fraunhofer Institute for Building Physics – allows a two-dimensional analysis of the heat and moisture transport in building components, defining the material’s characteristics and environmental conditions. The reference standard EN 15026 [7] make it possible to analyze interstitial condensation, the influence of solar irradiation, rains, vapor migration, construction moisture into materials, absorption due to rising damp, condensation summer, thermal inertia and the effect of water content on thermal conductivity, all phenomena also related to the drying phase [8] [9].

In the WUFI software, the laws governing hygrothermal transport are:

Moisture balance
$$\frac{\partial w}{\partial \emptyset}\cdot\frac{\partial \emptyset}{\partial t} = \nabla[D_{\emptyset}\nabla\emptyset + \delta_p \nabla(\emptyset p_{sat})] \tag{1}$$

Energy balance
$$\frac{\partial H}{\partial T}\cdot\frac{\partial T}{\partial t} = \nabla(\lambda\nabla \mathrm{T}) + h_v \nabla[\delta_p \nabla(\emptyset p_{sat})] \tag{2}$$

Where ϕ is the relative humidity [-], t time [s], T temperature [K], w water content [kg/m^3], p_{sat} saturation vapor pressure [Pa], λ thermal conductivity [W/(m K)], H enthalpy [J/m^3], D_ϕ liquid conduction coefficient [m^2/s], δ_p vapor permeability [kg/(m s Pa)], h_v latent heat of phase change [J/kg].
In porous materials [10] the pores system accumulates water molecules until it reaches a specific equilibrium moisture content, corresponding to the air humidity in the environment. This derives from ratio to capillary saturation of the interstitial air and the temperature. A capillary material in contact with liquid water, will absorb the water until it reaches free saturation, i.e. a capillary saturation of about 100%.



Point	T [°C]
1	20.6
2	20.6
3	21.0
4	20.9
5	22.6
6	23.3

Figure 1. Masonry wall built in laboratory and an example of thermography after 10 days of imbibition.

The moisture content is highly dependent on boundary conditions and, it is correlated to condensation and evaporation of water: condensation increase the water content. The moisture storage function is:

$$w\ (\varphi) = w_f \frac{(b-1)\varphi}{b-\varphi} \tag{3}$$

Where $w(\varphi)$ is moisture content [kg/m^3] corresponding to relative humidity φ, w_f moisture content at free saturation [kg/m^3], φ relative humidity [-], b approximation factor [-] [11].

In porous building materials the predominant moisture transport mechanism is the capillary liquid transport, described by the diffusion formula. The liquid transport coefficient for suction D_{ws} describes the capillary absorption of water when the imbibing surface is completely wetted. The liquid transport coefficient for redistribution D_{ww} describes when the water redistributes in the material and new water is not absorbed.

Finally, the diffusion water resistance factor μ represent the ratio between the diffusion coefficient of water vapor in air and the water vapor in the building material, since in pore spaces, the water vapor diffusion is impeded by the reduction of cross-section accessible, by the adsorption effects and by the tortuosity of the structure.

2.4. Methods

Parallel to the laboratory test, a dynamic simulation is performed for a comparison with the real model, with the need to investigate the building composition and its exposure. Most of the materials properties were determined from technical data or found in literature. The characteristics of the materials required by the software are showed in Table 1. Instead, the required boundary conditions are (i) indoor/outdoor air temperature, (ii) indoor/outdoor air humidity, (iii) global and diffuse solar radiation, (iv) thermal radiation from the sky, (v) precipitation and (vi) wind speed/direction [12].

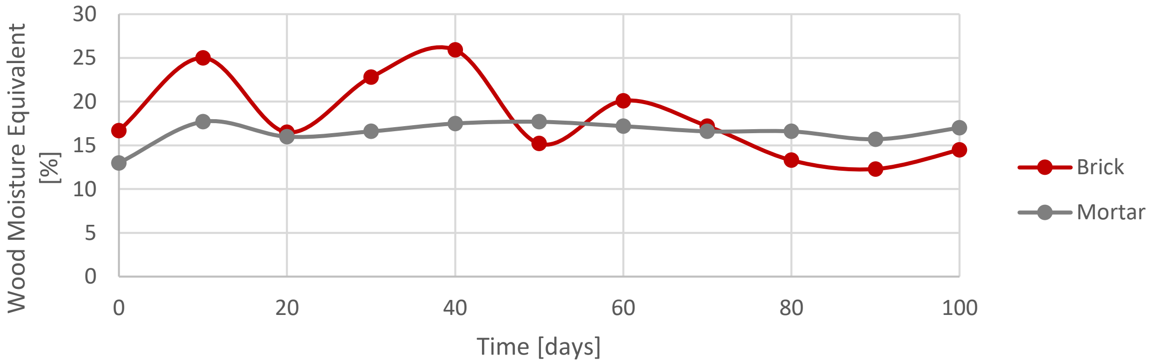


Figure 2. Laboratory monitoring of superficial moisture in the central elements of masonry walls.

The climate of Venice according to the "reference year" [13] was used as outdoor conditions. The variable of heat gains due to solar radiation and precipitation have been excluded, because they could accelerate the drying processes and the moisture visible on the surface.

Table 1. Hygrothermal parameters of the used materials.

	Brick	Lime mortar	Cocciopesto plaster	Marmorino plaster
Bulk density [kg/m^3]	1560	1550	1450	1650
Porosity [vol. -%]	40	40	40	32
Heat capacity [kJ/kg]	850	850	850	850
Thermal conductivity [W/(m K)]	0.369	0.92	0.93	0.80
Diffusion resistance factor [-]	9.5	15	10.5	0.14

The ascent height depends on the thickness of wall, so we simulated two types of Venetian construction commonly used in residential building. For further checks, the one-wythe construction types were also considered.

3. Results

Through the data collected in the laboratory on the masonry test walls it is possible to notice similarities with the simulation performed for Venetian masonry. In all situations there is an imbibition deriving from capillary rise in the first 10-20 days of direct contact to the liquid water, and a subsequent stabilization or slowing down of the water content.

Figure 3(a) and Figure 4(a) show the total average water content 10 days after imbibition for the same structure (clay bricks and lime mortar), but in different types of construction. It is possible to highlight the different values of water content in bricks and mortar, and how the water content varies with wall's height. In particular, the water content is much higher in mortar than in bricks.

The images in Figure 3(b) and Figure 4(b) show the water content for a two-wythes masonry wall with Cocciopesto and Marmorino plaster. In these cases, we can observe how the trend of water content in the structure is very similar to the previous cases without plaster in the first 10 days, with a rapid rise.

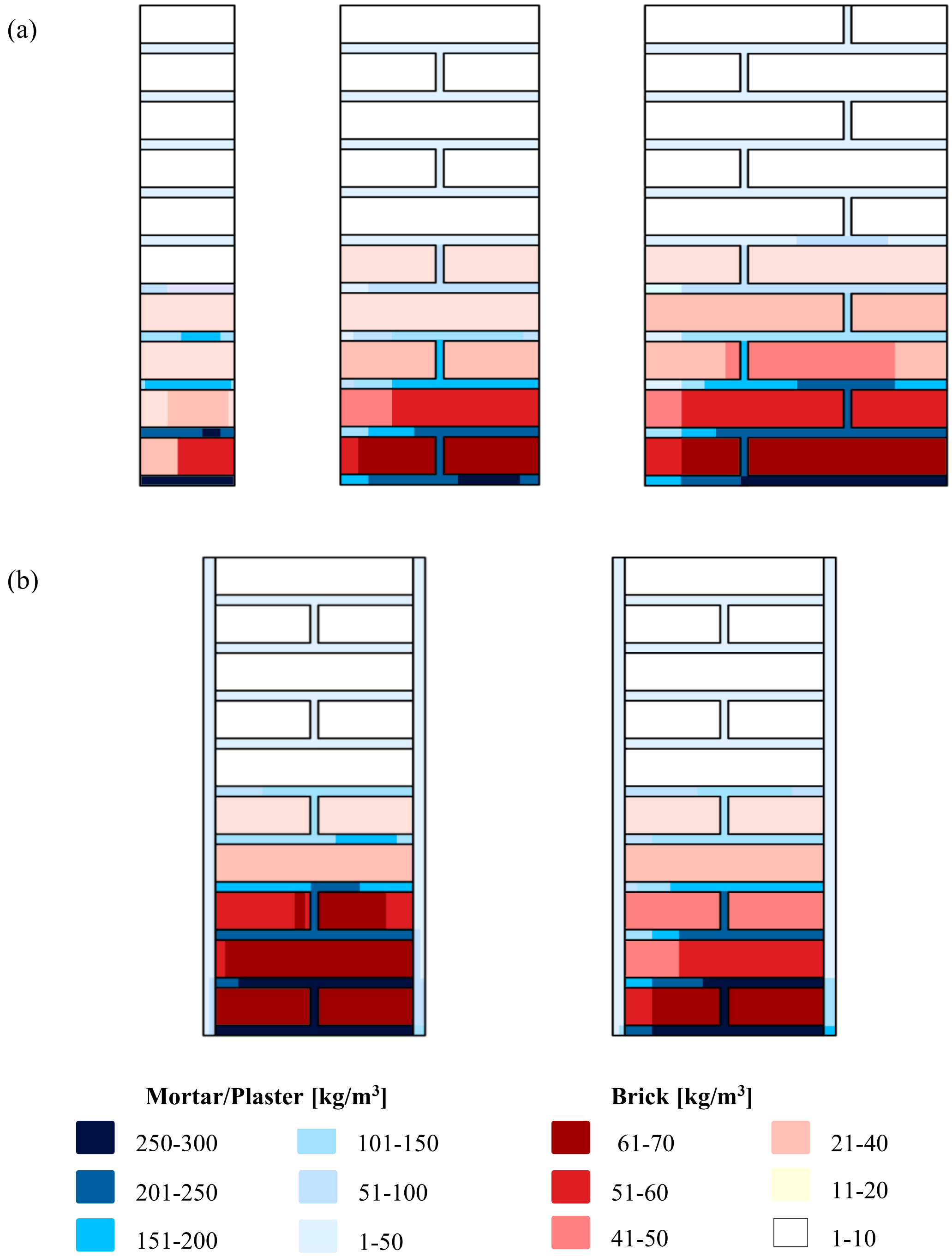


Figure 3. Distribution of water content [kg/m^3] in the masonry wall simulated, after 10 days of imbibition.

In the following days, the water content decreases much more slowly, when retained inside the masonry, especially in the case of the Cocciopesto plaster.

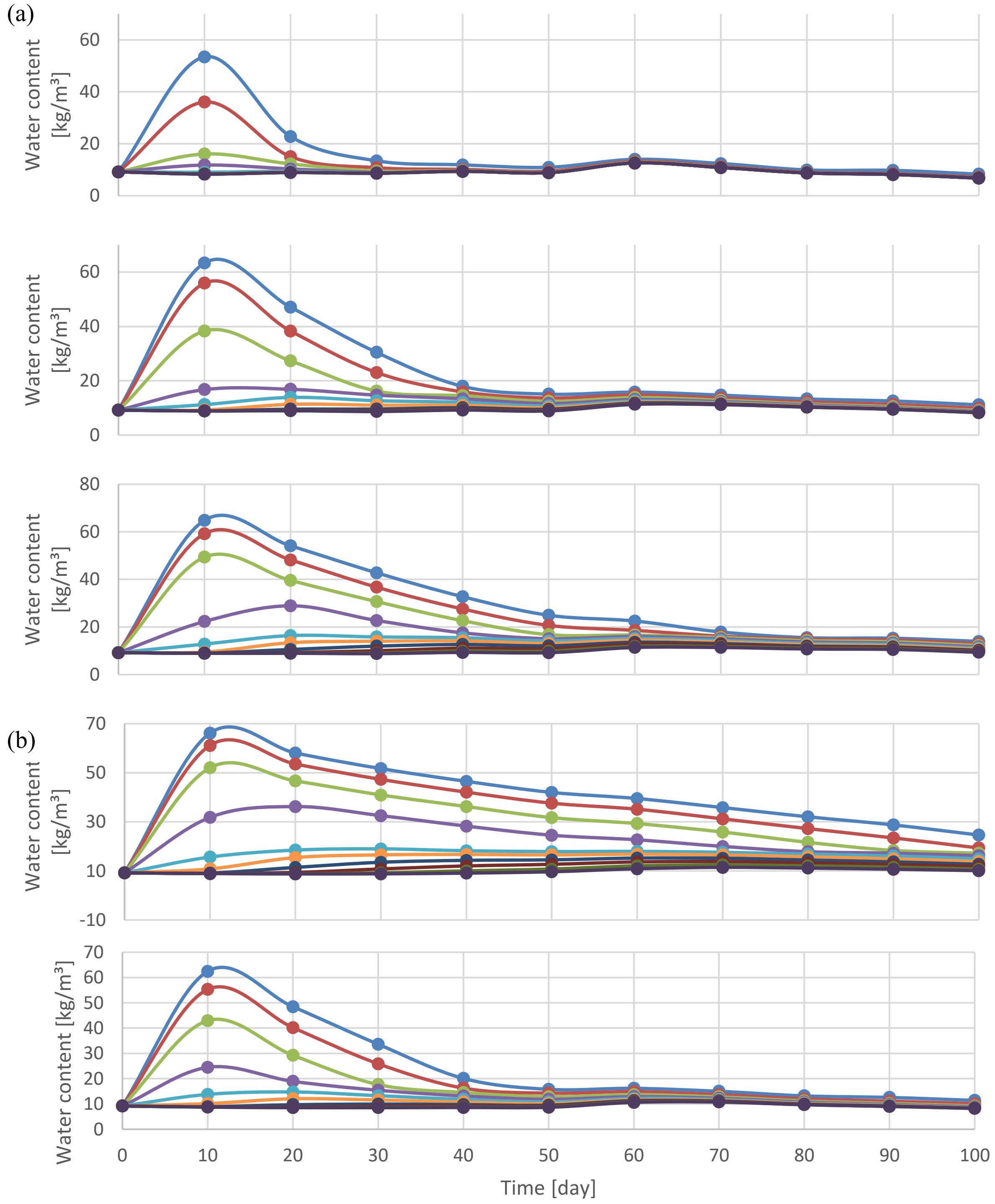


Figure 4. Course in time of water content [kg/m^3] in the first 10 brick of masonry wall simulated. From the top: one-wythe masonry wall, two wythes, three wythes, two wythes with Cocciopesto plaster, two wythes with Marmorino plaster.

For all structures, the average water content in the bricks is approx. 27 kg/m^3, with a maximum of approx. 70 kg/m^3 in the lower brick and a minimum of 10 kg/m^3 in the upper brick. Therefore, the first brick courses are already completely saturated after a short time. As a result, the total moisture content increases by about 4.5-4.7% of the volume in the firsts 10 brick courses.

4. Conclusions

These analyses have shown that the phenomenon of rising damp which have been simulated with the WUFI software are in accordance with practical observation in laboratory on the test wall, with a rapid ascent in the first days of direct exposure to water and subsequently a stabilization and decrease of the water content.

For this experiment it was considered an "ideal case" to limit the variables that influence the capillary rise, but in the real case, the humidity level is higher, because there are a series of boundary conditions (i.e. hygroscopic salts or poor protection from rain) which cause a significant increase in water content, as well as a prolonged exposure over time. This corresponds to numerous observations in the Venetian case.

The real causes affecting rising damp and moisture content in the building structure should be analyzed with additional investigation, as current tests do not demonstrate a high capillary force.

Acknowledgments

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