Transactions on the Built Environment vol 4, © 1993 WIT Press, www.witpress.com, ISSN 1743-3509

Development of a method for drying out the damp walls of buildings in Venice

V. Apih, M. Makarovič

Institute for Testing and Research in Materials and Structures (ZRMK), Ljubljana, Slovenia

ABSTRACT

Based on the results of several years of experimental work carried out on a typical building in Venice, the Palazzo Zorzi, a method, including both materials and equipment, has been developed for the reduction of dampness in the walls of such buildings. The effectiveness of this method has been proved by measurements of changes in moisture distribution over a four-year period. Using it, the penetration of sea-water into the walls was prevented, and the capillary transport of moisture up the walls was reduced, resulting in the drying out of the walls.

INTRODUCTION

All the World admires Venice, with its beautiful canal-side palaces, and its fascinating churches and art galleries. But behind the attractive fronts of the canal-side buildings are damp, decaying houses, unfit for habitation. Once abandoned by their inhabitants, they start to deteriorate even faster.

In Venice, as a result of efforts over past decades to improve the condition of the city's buildings, all known methods of damp-proofing can be seen. In most cases a mechanical procedure has been applied: cutting through the walls horizontally, and installing some kind of water barrier. This method does prevent damp rising from the foundations, but it is very radical and relatively expensive, and changes the appearance and structure of the walls. Thus, there is a constant search for new methods which would be as effective but cheaper and less destructive.

<u>The origin of dampness in walls</u>

Buildings become damp when water, and humidity from the surroundings, has free access to the walls.

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Water (ground water, precipitation, water from damaged pipes, flooding) reaches the walls of buildings due to faults in building construction and, exceptionally, during floods. At the surface of the wall it enters the capillary system of the wall material. Due to the adhesive forces between the molecules of the water and the molecules of the wall material it spreads from the damp to the dry material, counteracting gravity. In time, a state of equilibrium is attained between the water entering the wall, the capillary transport of water up the wall and outwards, and evaporation at the surface of the walls.

Atmospheric moisture condenses onto and into walls whose temperature is below the dew-point temperature of the surrounding air. Diffusion and capillary condensation take place, the hydrophilic surfaces of the pores attract water molecules, and soluble hygroscopic salts present in the walls can absorb considerable amounts of water from the air even at a relative humidity of well below 100%.

In order to carry out successful damp-proofing work in an actual building, it is therefore most important to first accurately define the actual reasons for dampness, i.e. the mechanism of the moistening of the walls. Only in this way can the most feasible treatment be implemented.

Damp-proofing treatments

In general, the aim of damp-proofing methods is:

1. to prevent water reaching and entering the walls,
2. to prevent the condensation and diffusion of moisture in the walls,
3. to block the capillary transport of water inside the walls, and
4. to accelerate the evaporation of moisture from the walls.

These basic treatments, which cure the causes of dampness, prevent or at least reduce the humidity of the treated walls. Complete renovation of a building has to include provisions to improve the building's appearance, too. Most frequently, the old plaster is replaced by a new hydrophobic plaster. If the buildings to be damp-proofed are not very damp, or if a high degree of drying-out is not required, then the application of hydrophobic plaster may be, in itself, a sufficient measure.

Buildings in Venice

In view of their specific structure, history and location, these buildings present a special problem:

- their walls are built on foundations which are constructed in a marshy lagoon, or, in the case of canal-side palaces, directly exposed to the sea, and constantly washed by waves caused by the wind, boats and tides,
- these buildings are exposed to frequent floods , rain often accompanied by strong winds, and a polluted atmosphere, with a relative humidity exceeding 70% for most of the year,

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- in the winter, due to low temperatures at night the walls of buildings become very cold; when the weather changes to warm southerly winds, heavy condensation of damp onto the cold walls takes place,
- the walls have been exposed, for centuries, to polluted sea water, so that the concentration of different salts in the wall material is very high.

Methods which have proved suitable for the damp-proofing of buildings in continental areas cannot be simply transferred to Venice. In order to develop a modified method, suitable for the damp-proofing of Venetian buildings, it was necessary to carry out preliminary research work. By agreement with the municipal authorities of Venice, the Palazo Zorzi was made available as a test building.

WALL DAMPNESS ANALYSIS IN A TYPICAL VENETIAN BUILDING

At the Palazo, with the kind assistance of experts from the municipal authorities, we learned about the specific structure of Venetian buildings. Most of the large palaces in Venice resulted from the joining together of several smaller, older buildings in such a way that the original buildings were enclosed with a new exterior wall. When flooding occurs, sea water can act not only on and through the outer surface of the walls but it also enters into the wall, making the inside wall and rubble a "moisture reservoir".

When carrying out building or reconstruction work, the masons of Venice never threw away any older material, but they used it again. Thus, in any wall, bricks not only from different regions and different brickworks, but also from different centuries can be found. For example, when three neighbouring bricks were removed from the same level, 0.5 m above the ground, they were found to differ according to appearance, structure and composition, as well as moisture content and hygroscopicity (resulting from different salt content) - see Table 1.

Table 1. Moisture and hygroscopic moisture content of three neighbouring bricks in a wall of the Palazzo Zorzi

colour of the brick	moisture (mass %)	hygroscopic moisture (mass %)
red	26.9	3.9
yellow-to-red	18.1	2.3
yellow	35.7	3.6

The variations in moisture and salt content in four basement walls of Palazzo Zorzi can be clearly seen in Figure 1, where the average measured moisture and the hygroscopic moisture in individual 0.5 m high layers of the walls, as well as the minimum and maximum values, are given.

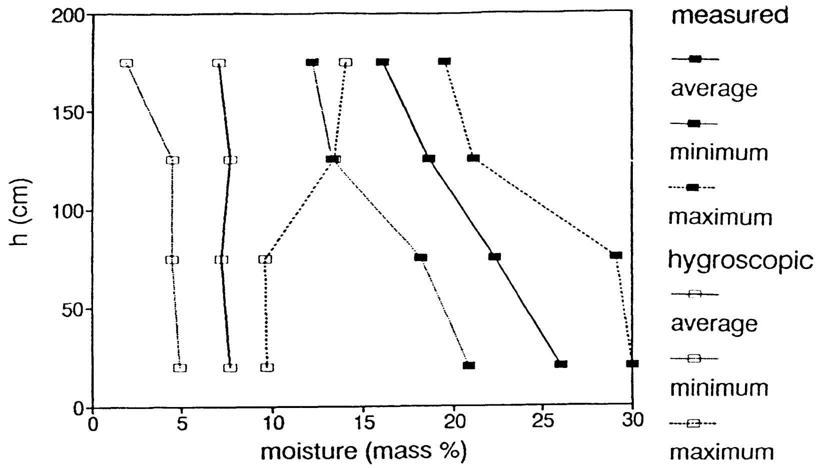

Figure 1: Moisture and hygroscopic moisture distribution

The only way to estimate accurately whether or not a treatment applied to encounter moistening of a wall has been successful is to examine the changes in the distribution of moisture related to wall height. If, as is the case in the buildings of Venice, the walls have a high salt content, then their moistening due to water absorbed by hygroscopic salts certainly cannot be neglected.

Measurements of humidity distribution

Moisture content was measured gravimetrically on specimens drilled out of the walls as fine dust. Since the pre-diagnostic study of the walls had pointed out the great heterogeneity of the walls and bricks, it was necessary to take each time at least 50 samples, in order to get an accurate picture of humidity distribution at different times. The humidity presented in the diagrams is the average moisture content of samples taken in an individual layer of the wall, at heights of 0.0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 metres.

Measurements of hygroscopic behaviour

After the moisture content had been analysed, the dry samples were placed in a test chamber at a relative humidity of 86%. Percentage weight increase of the samples was determined over a period of 10 days. The hygroscopic moisture in the diagrams is, like the humidity, given as the average increase in weight of the samples taken in the same 0.5 m layer of the wall.

Reasons for dampness of the walls

Based on the results of this preliminary study of the construction of buildings in Venice, the climate of Venice and the results of a detailed analysis of the walls of the Palazzo Zorzi, it has been concluded that the reasons for the dampening of the ground-floor walls of the buildings in Venice are the following: (1) unrestricted access and ingress of sea water during flooding, (2) capillary transport of sea water from the foundations upwards, (3) a high concentration of hygroscopic salts in the wall material, and (4) capillary and surface water condensation due to unfavourable effect of significant differences between air temperature and wall temperature.

It should be possible to achieve drying out of the walls if the influence of all four of the above causes for high water presence in the walls can be reduced or eliminated altogether. Based on this conclusion, a method for dampness reduction, described in the following section, was designed, developed, applied and verified through periodic measurements of humidity distribution in the treated walls.

BASIC CONCEPT OF DAMPNESS-REDUCTION TREATMENT

1. In order to prevent sea water entering the walls during flooding and high tides, and to make possible the second step of the treatment, it is necessary to fill the cavities in the wall, up to the maximum expected flood level, with a hydrophobic grout. It has to be able to fill all the cavities in the wall, the empty places between the leaves of the wall, as well as the fine cracks in the bricks and mortar, and at the joints. The hydrophobic body thus formed will also hinder capillary water transport.

2. To prevent capillary water rise, a chemical barrier should be installed, with penetration just above the grouted section (at maximum flood level).

3. To reduce surface and capillary moisture condensation and moistening of the walls, it would be necessary to reduce the air humidity and increase the temperature of the walls by suitable heating and ventilation.

4. To achieve good final results the salts should be removed from the walls. However, at the present time no appropriate method is known.

THE MATERIALS AND EQUIPMENT NEEDED

In order to carry out the so conceived damp reduction treatment, it was first necessary to develop suitable materials and equipment. The properties of the materials had to fulfil the aims of the proposed damp-reduction method, but they also had to be acceptable to the conservationists of Venice.

The hydrophobic injection grout was formulated on the basis of the results of previous research on "masonry-friendly" injection grouts. Although it is prepared with a low water content, it can be injected through thin injection tubes, has good ingress into fine cracks, and low shrinkage during the hardening process. The incorporated hydrophobic additive makes the grout water-repellent from the very beginning of the hardening process: the capillary water absorption of 40x40x160 mm specimens at an age of 24 hours, standing in water 10 mm deep, is slower than the rate of drying. The capillary water rise of the hardened grout after 28 days is less than 3 mm. Using the right proportions of cement, natural puccolana and fine-grained mineral filler, it was possible to make the colour of the grout similar to that of Venetian bricks, and, likewise, its compressive strength of 16.5 N/mm^2 was compatible with that of Venetian bricks.

The penetrating equipment for the installation of chemical barriers into walls, which is usually used when damp-proofing brick walls of buildings in Slovenia, was found to be unsuitable, due to the specific nature of Venetian masonry. The newly developed equipment allowed the penetrating agent to be introduced into the wall continuously and uniformly at a rate adjusted to the absorption capacity of the wall. Drill-holes, with a small diameter of only 15 mm, were sufficient for the placing of infusion tubes.

EXECUTION OF THE DAMP REDUCTION TREATMENT, AND THE RESULTS

Due to organisational difficulties, the damp reduction work at the Palazzo Zorzi was actually carried out in a period of relatively unfavourable weather, from September to December 1987. These months are characterised by frequent rain, fog and high tides. Nevertheless, after the damp-proofing works had been carried out (hydrophobic grouting of the walls up to a height of 1.0 m above the foundations, and the establishment of a chemical barrier at this height), the newly installed grout-penetration barrier began to take effect. It prevented the ingress of water into the walls, as well as the capillary transport of water from the wet parts to the drier parts of the walls. As a result, the walls began to dry out (see Figure 2).

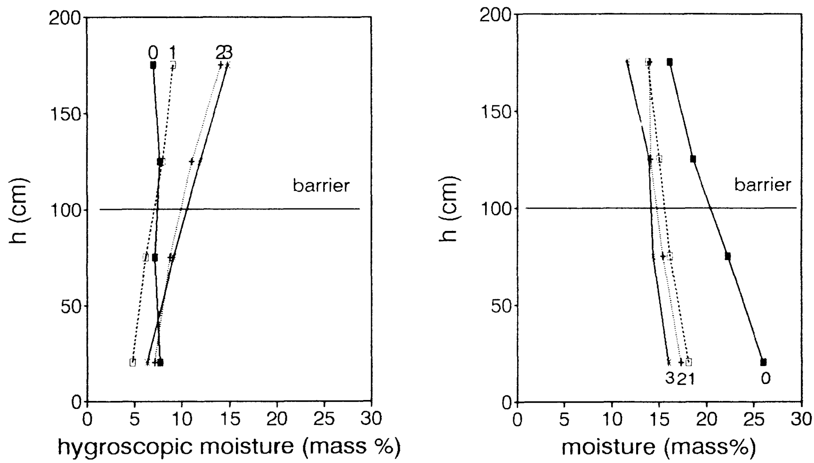

Figure 2: Hygroscopic moisture and total moisture distribution before treatment ("0"), and one ("1"), two ("2") and three and a half years ("3") after application of the damp-reduction treatment

The drying out process was a slow one. On average, the walls dried out by 24 % in the first year after the damp-proofing works were carried out. Over the following years the moisture content of the walls diminished slowly but steadily, confirming the effectiveness of the proposed treatment. The drying rate was strongly negatively influenced by the hygroscopicity of the salts depositing out of the water that evaporated at the surface of the treated walls.

It is evident that the negative side effect - the condensation and absorption of atmospheric humidity by the hygroscopic salts - can provide a fairer evaluation of the newly developed method of treatment. The effectiveness of the applied injection-penetration treatment can therefore be better judged through the comparisons presented in of Figure 3.

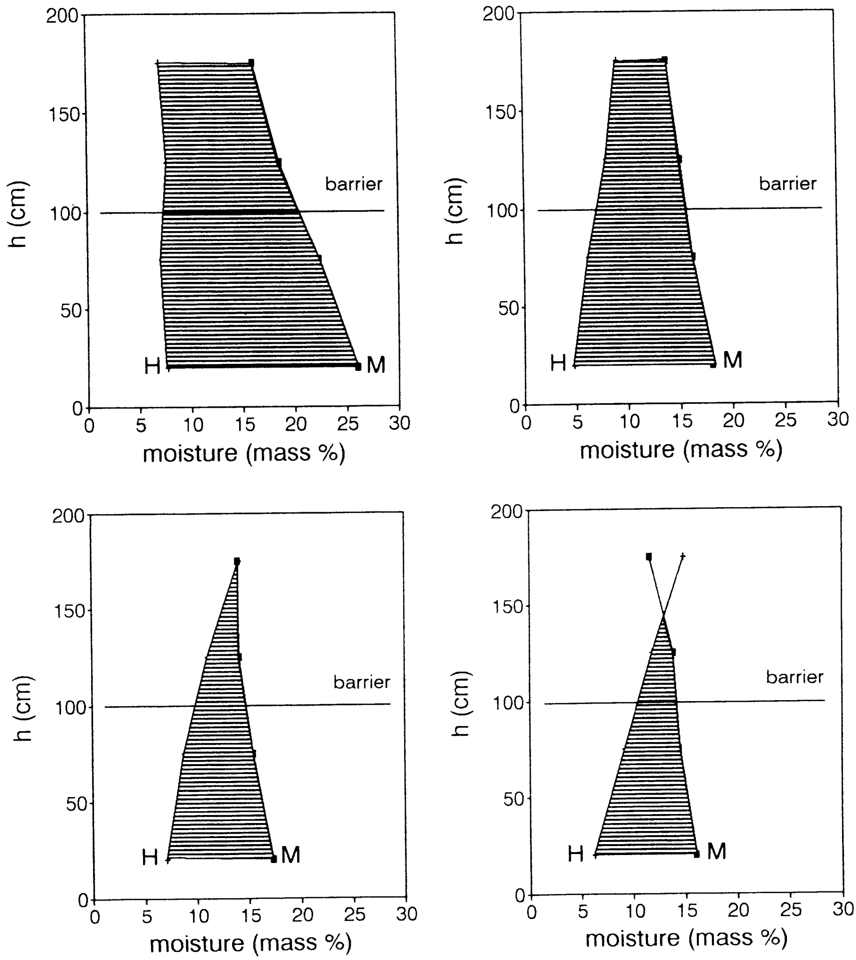

Figure 3: Changes in the measured ("M"), hygroscopic("H") and capillary ("C") moisture in the treated walls over a period of 3.5 years

In Figure 3 the lines marked "M" represent the moisture distribution (the total average humidity, measured as described in the previous section) before treatment, and one year, two years, and three and a half years later. Total measured humidity is the sum of the humidity absorbed from the air due to the hygroscopic behaviour of the wall material (marked by the lines "H"), and of the capillary water ("C"), shown hatched. Reduction of this hatched area over the course of time is a realistic indicator of the effectiveness of the applied damp-proofing method. As follows from the results of long-term observation of the treated walls (Figures 2 and 3), a great proportion of the moisture in the walls is due to the presence of salts. Therefore treatment by means of which it might be possible to reduce the content of salts in walls would be needed, but, as mentioned before, no appropriate procedure is yet known.

CONCLUSIONS

By a combined process of grouting walls with hydrophobic grout and then penetrating them with water-repellent agents, water ingress and capillary transport can be successfully reduced (Table 2).

Table 2: The distribution of capillary water (total humidity less hygroscopic humidity) before and 3.5 years after treatment

wall layer (height in cm)	capillary water before treatment	(mass %) 3.5 years later	treatment effectiveness reduction of capillary water
0 - 50	18.3	9.7	47 %
50 - 100	15.3	5.2	66 %
barrier			
100 - 150	10.9	2.0	82%
150 - 200	9.1	0.0	100%

Based on the results of the research presented, it follows that, applying a properly designed treatment, it is possible, with reasonable success, to reduce the moisture content of walls even in the extreme conditions of the water-city Venice. Because of the special conditions there, more time is needed for drying out of the walls. The degree to which the walls of treated buildings can be dried out is limited by the presence of salts, and by the extent to which buildings are properly heated and ventilated.

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