RISING DAMPNESS IN MASONRY: SOME EXPERIMENTAL RESULTS

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ABSTRACT

Within the Progetto Finalizzato Edilizia of the Italian National Research Council (CNR), in 1991 masonry walls were constructed in tanks that were subsequently filled with water. Once steady-state conditions were reached in 1992, some of these walls were subjected to chemical damp-proof course (dpc), a treatment performed by private companies. Today, as more than two years have elapsed since the end of the treatments, preliminary considerations can be made of the results obtained from measured dampness values, as well as from wall evaporation data.

INTRODUCTION

One of the most frequent causes of decay in masonry, especially in ancient, historical, and monumental buildings, is rising dampness related to phenomenon of capillary ascent in walls that are in contact with moist soils or water-bearing strata. When this phenomenon is observed in the building to be remedied and preserved, dampness must be eliminated or at least reduced because of its impact on the conditions inside the buildings that are bounded by damp walls.

The remedial treatment for masonry with rising dampness is all but simple. Over the past decades, various remedial techniques have been proposed, including the "chemical damp-proof course." This consists of drilling holes into the masonry wall (usually 20 to 30 cm above the floor with a distance between holes of 20 to 30 cm) in the external and/or internal side, and applying into the holes a liquid chemical compound that either seals the pores and the capillaries of the construction material or makes them water repellent. In any case, this chemical compound acts as a barrier that prevents the capillary ascent of dampness. If the liquid is applied without pressure, the treatment is named *impregnation dpc*; if it is applied with pressure, it is named *injection dpc*.

The effectiveness of such techniques has not been proved as yet. There are still many doubts about them (Van Hess 1991; Fiebrich 1991), but, chiefly, the differences in the large variety of chemical products being used are still unclear.

In 1989, within the framework of the "Progetto Finalizzato Edilizia," the CNR financed a research project,[1] the major objective of which was to propose a laboratory method to check the effectiveness of the chemical dpc treatments. The preliminary findings of a five-year investigation are presented here.

METHOD

In the laboratory of the CNR, 20 masonry walls were constructed, 12 using tufa blocks measuring 17 by 24 by 48 cm and 8 using clay-filled bricks measuring 5.5 by 12 by 25 cm (Table 1 shows some physical characteristics of the tufa blocks used). Walls are about 2.4 m high and 2.0 m wide. Two walls were 55 cm thick, two walls were 35 cm thick, and 16 were 25 cm thick. For the construction of masonry walls, type M3 spurious mortar was used (mean compressive strength 5 N/mm^2), pursuant to the Ministerial Decree of 20 November 1987: one part of cement, one part of hydraulic lime, five parts of inert material (2.5 limestone sand, 2.5 tufina[2]). The walls were dressed with 1.5-cm-thick plaster of civil-finished type; the lateral sides were waterproofed with bitumen sheathing to minimize the edge effects.

The walls were built in galvanized iron tanks measuring 60 to 77 cm wide, 230 cm long, and 25 cm high. A hole was made in each tank at a height of 20 cm on which a small copper pipe was welded horizontally.

[1]The investigation was conducted by a team consisting of research workers from three Italian universities and from a division of the CNR. The scientific coordinator of the research work is Professor Gaetano Alfano.

[2] Material resulting from the crushing of tufa.

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TABLE 1 **Some Characteristics of Tufa Blocks Used for Wall Construction**

	Tufa Blocks
apparent density	1.43 g/cm^3
density of the solid phase	2.63 g/cm^3
compressive strength (dry state)	2.41 N/mm^2
compressive strength (after soaking test)	2.10 N/mm^2
porosity	0.46
degree of saturation (in the soaking test)	24%

TABLE 2 **Some Characteristics of Groundwater Used to Fill the Tanks**

electrical conductivity at 25°C (μS/cm)	1600
pH	7.6
total hardness (ppm $CaCO_3$)	335
calcium hardness (ppm $CaCO_3$)	125
magnesium hardness (ppm $CaCO_3$)	210
chlorides (ppm NaCl)	702
total salts (ppm)	1000
ammonia (ppm NH_4)	absent
nitrites (ppm NO_2)	0.44
nitrates (ppm NO_3)	2.36
sulphates (ppm SO_4)	12

Between February and September 1991, after at least one year from their construction, plaster was removed from the bottom part of the walls for about 40 cm, and the tanks were filled with water. Subsequently, the tanks were sealed with polyethylene sheets.

The water level in the tanks was kept constant using the above hole as overflow. Every two weeks, water was added until it leaked out of the copper pipe. The difference between the amount of water added and that collected from the copper pipe is a good measure of the amount of water added to restore the level and, under steady-state conditions, also provides a measure of water evaporated from the sides of the wall.

The water used to fill the tanks is pumped from a water tank periodically supplied by a well (located near the laboratory) that collects groundwater. This is done to use water with salt characteristics that are as similar as possible to those observed in the soil. The authors' findings (see Table 2) indicate that the tanks are filled with brackish water, with characteristics that are between those of drinkable water and seawater; in addition, the salt identified is chiefly sodium chloride, as one would expect since the well is located a few kilometers from the sea.

Water salinity has produced a marked phenomenon of blooming on the walls, especially in the areas where clear signs of surface dampness are detectable with the naked eye, at the maximal height of capillary ascent. Figures 1 and 2 show the walls studied in the experiment.

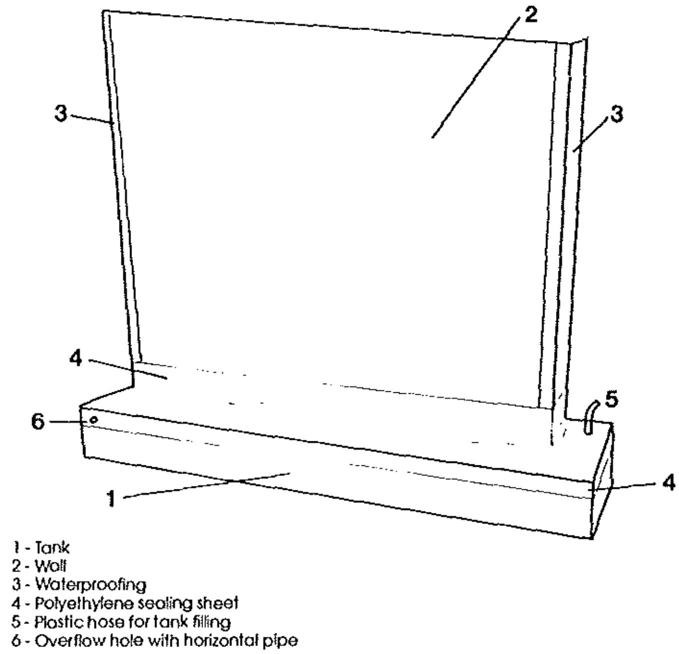

Figure 1 *A representation of the walls in the laboratory of the Institute CNR IRIS in Bari.*

Figure 2 *A photograph of the wall T5.*

TABLE 3 **Summary Picture of the Walls Constructed in the Laboratory**

Wall Code	Thickness (m)	Reference Wall	Treatment Code	Wall Code	Thickness (m)	Reference Wall	Treatment Code
T1	0.55	T2	CI2	B11	0.25	B4	CI1
T2	0.55	—	—	T12	0.25	T5	CI1
T3	0.35	—	—	T13	0.25	T5	CI3
B4	0.25	—	—	B14	0.25	B4	CM2
T5	0.25	—	—	T15	0.25	T5	CM2
T6	0.25	T5	CM3	T16	0.25	T5	TGM
T7	0.25	T5	CM4	B17	0.25	B4	CM3(*)
T8	0.35	T3	CI2	T18	0.25	T5	CI2
B9	0.25	B4	CI3(*)	B19	0.25	B4	CI2(*)
B10	0.25	B4	CM1(*)	B20	0.25	B4	CM4(*)

Note: The walls in tufa blocks are denoted by T followed by one or two digits, while those in clay-filled bricks are denoted by B followed by one or two digits. (The reference wall is made of the same material and has the same thickness but has undergone no remedial treatment; codes denoting the type of treatment will be explained in Table 4; (*) denotes treatments not performed yet.

Between June 1992 and September 1993, 10 of the 20 walls were subjected to chemical dpc performed by primary private companies. To have reference walls against which to evaluate the effectiveness of chemical dpc treatments, four walls were left untreated; three, in tufa, were 55 cm, 35 cm, and 25 cm thick; one, in clay-filled bricks, was 25 cm thick. One of the 25-cm-thick tufa walls (T16 in Table 3) was subjected to mechanical dpc to make a quantitative evaluation of the sealing effect in tanks (the mechanical dpc consists of creating a horizontal incision in the wall and inserting a watertight layer made of several possible materials—e.g., metal, polyester—in it as a shield against the rising damp).

TABLE 4 **Table 3 Codes Matched by Type of Treatment and Product Used**

Treatment Code	Type of Treatment	Product Used
CM1	injection dpc	silicon-silicates
CM2	injection dpc	silanes
CM3	injection dpc	siloxanes
CM4	injection dpc	silicates
CI1	impregnation dpc	silicon-silicates
CI2	impregnation dpc	silanes
CI3	impregnation dpc	siloxanes
TGM	mechanical dpc	plates in galvanized steel

Table 3 shows a summary picture of the walls constructed and of the remedial treatments made or planned. They are denoted by codes that are explained in Table 4.

RESULTS

Since 1992 the environmental conditions of the laboratory in which tests were made have been continuously monitored. As no environmental control was exerted, the microclimatic conditions in the laboratory varied as a function of the outdoor climatic conditions. In the laboratory the air is always still near walls.

Air temperature and relative humidity (measured every two minutes by means of a data-acquisition system) were stored in a computer for subsequent processing. To evaluate the effect of local environmental conditions on surface evaporation, the surface temperature of

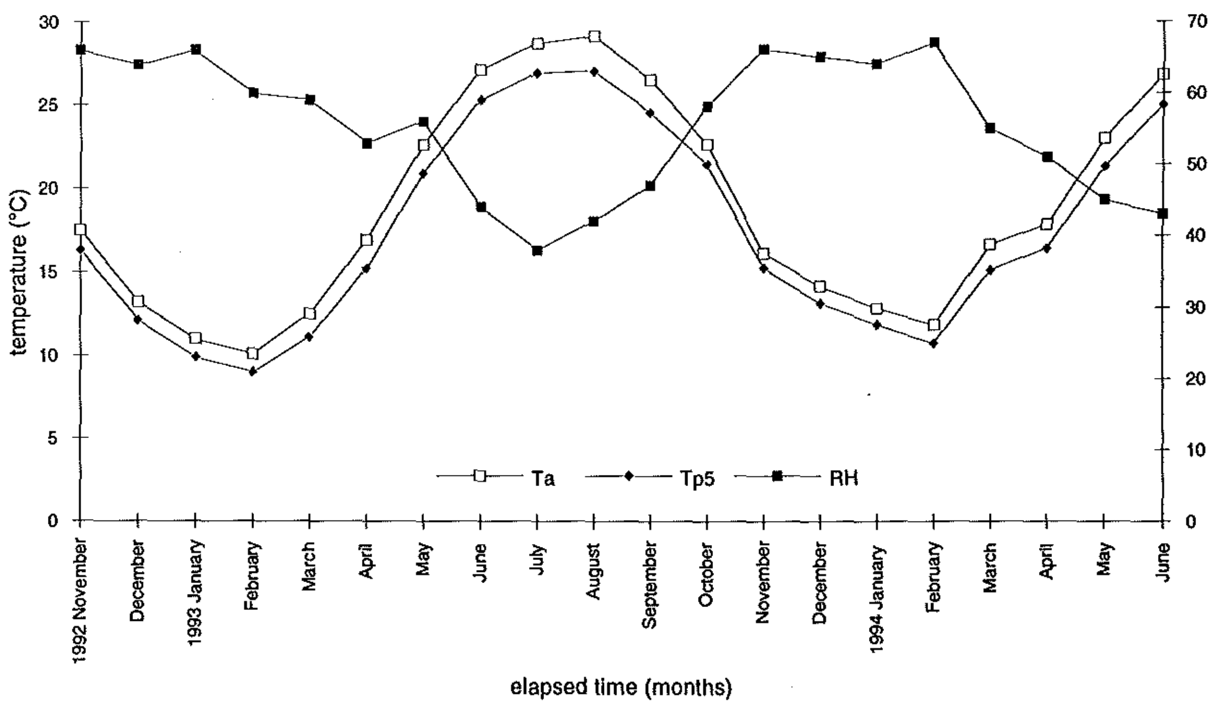

Figure 3 *Average Monthly Values of air Temperature, T_a, and air relative humidity, RH, measured in the laboratory from November 1992 to June 1994; average surface temperature, T_{p5}, of the damp area in wall T5.*

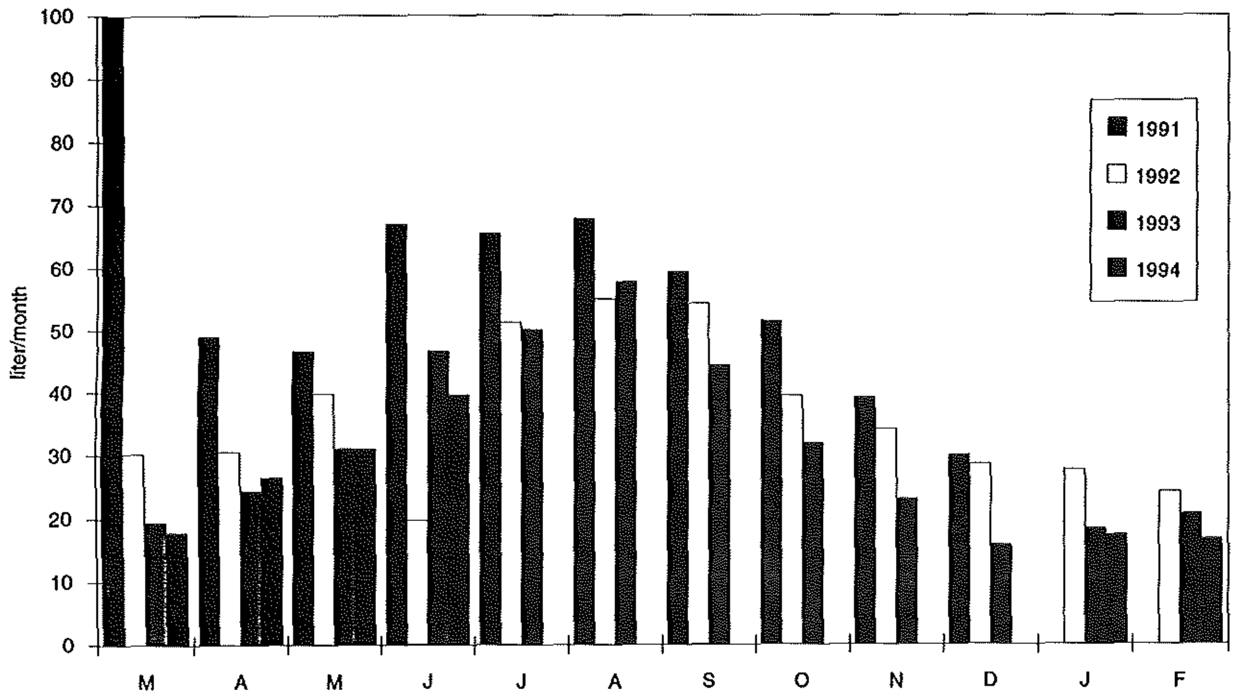

Figure 4 Monthly addition of water M, in l/month, for wall T1 over the period March 1991-February 1994.

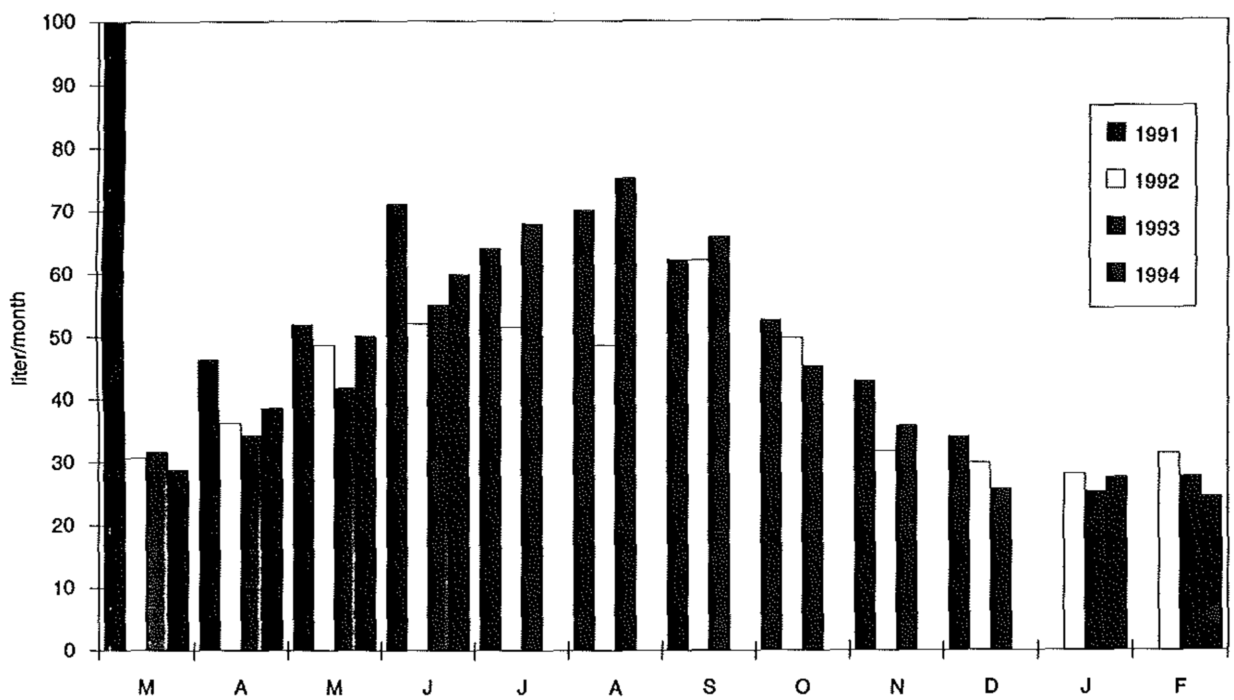

Figure 5 Monthly addition of water M, in l/month, for wall T2 over the period March 1991-February 1994.

Sensors consisting of copper-constantan thermocouples were placed in the superficial layer of plaster to measure the damp area's surface temperature in each wall.

Figure 3 shows the average monthly values of air temperature and relative humidity measured in the laboratory from November 1992 to June 1994, as well as the damp-area surface temperature of T5, a 25-cm-thick tufa wall. Looking at Figure 3, we can observe that T_a and T_p have the same trend, with an average yearly deviation of 1.5°C.

As indicated earlier, every two weeks water is added in the tanks to restore the initial level. Since the sealing of tanks, added water has been assumed equal to the water evaporated from the wall. Figures 4 and 5 show the

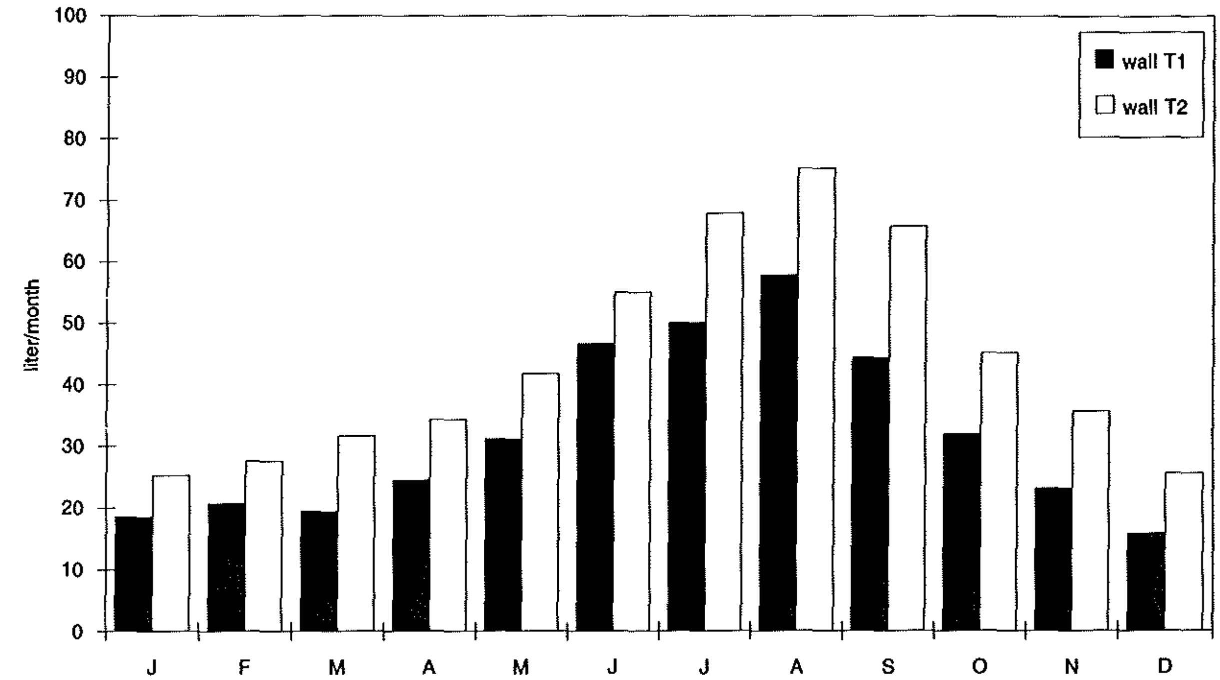

Figure 6 *1993 Monthly values of water addition, in l/month, for walls T1 e T2.*

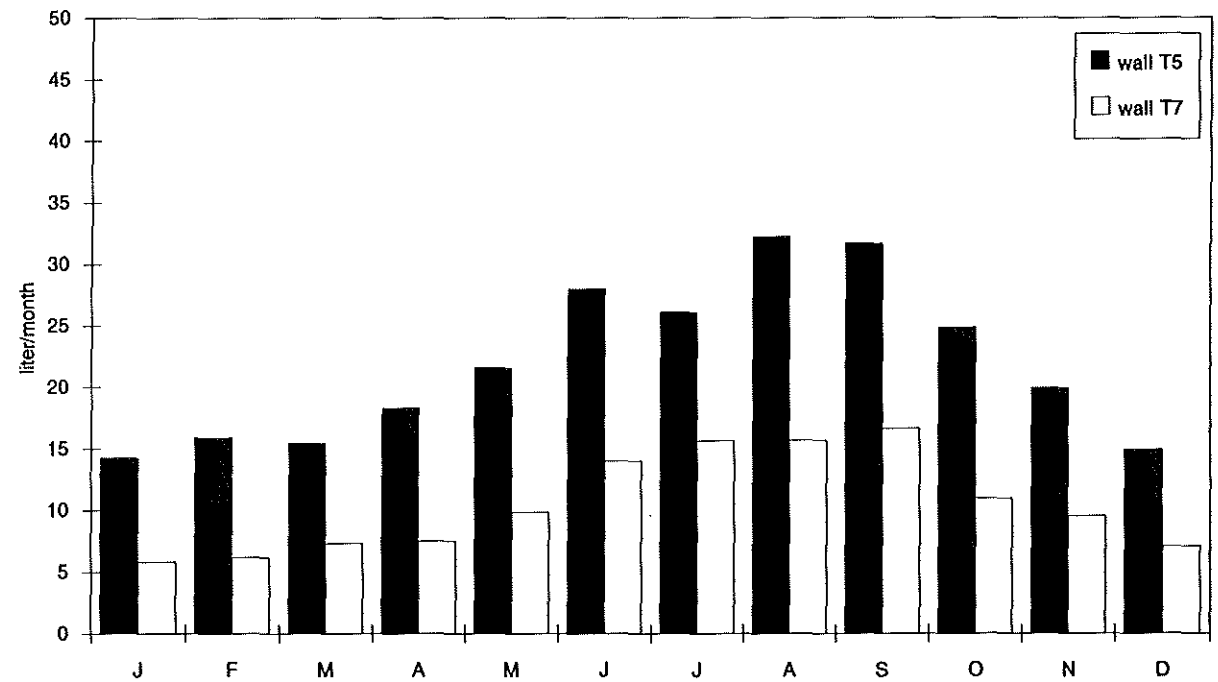

Figure 7 *1993 monthly values of water additions in l/month, for walls T5 and T7.*

amount of water that was added monthly to walls T1 and T2, respectively, in the period from March 1991 to February 1994. The 12 months of the year are plotted on the abscissas. At each month, the values of the monthly addition of water are plotted. The time span is, from left to right, 1991, 1992, 1993, and 1994. It should be noted that additions of water are larger in the summer, when higher temperatures cause more intense evaporation.

In Figure 6 the monthly additions of water are plotted for walls T1 and T2 over the period from January 1 to December 31, 1993, with the value of wall T2 on the right side. As previously mentioned, walls T1 and T2 are identical, but only on wall T1 was chemical dpc treatment applied in June 1992. Therefore, wall T2 is the reference for wall T1.

Figure 7 shows, for 1993, the monthly water additions, in liters per month, for walls T5 and T7. T5 is the reference for T7.

Just to evaluate the leakages from the tank-wall system caused by imperfect sealing, on the wall T16, as mentioned, a mechanical dpc treatment was performed. For this wall we can assume that the water addition is equal to the leakage. The mean value of the water addition for wall T16 was 2.0 liters per month, so this value has been assumed as the leakage of each wall.

With the environment microclimatic data and the surface temperatures of the four reference walls at hand, it was possible to gain an insight into the phenomenon of surface evaporation. This research, in a way parallel to the main investigation (efficiency of remedial treatment of rising dampness), was urged by the system's engineer's need to have reliable values of the surface evaporation of damp walls to design air-conditioning systems appropriate to the specific environmental conditions. Because the literature provides little information and data on damp walls' surface evaporation, the results of this work are a good contribution to quantify the phenomenon.

More specifically, it can be observed that based on the data of air ambient temperature, t_a (°C); relative humidity, RH (—); surface temperature of the areas affected by the capillary ascent, t_p (°C); average daily water evaporation, m (l/d); and Δp_v (kPa), the difference between the vapor pressure at surface temperature (t_p) and the partial vapor pressure in the air, the evaporative coefficient (C_{ev}) can be calculated. It refers to the total front linear development of the evaporating surface, L (in the cases considered L = 4 m), and is defined by the relation:

$$C_{ev} = m/L \cdot \Delta p_v \tag{1}$$

in l/dmPa.

For the four reference walls, T55, T35, and T25 in tufa blocks and B25 in clay-filled bricks, the data were processed on a monthly basis and then averaged on a yearly basis. The results are shown in Table 5.

The results shown in Table 5 identify different behaviors of tufa and brick walls. With respect to this, the value of C_{ev} for wall T3 must not be surprising. In fact, although this was constructed in tufa as the other two walls, T2 and T5, it differs from these in terms of thickness and in the arrangement of tufa blocks. For wall T3, tufa blocks are arrayed longitudinally, thereby allowing an easier rise of water because, for the most part, capillaries are oriented vertically.

The authors recently started making moisture content measurements relying on direct (gravimetric and calcium carbide) methods, which, to date, provide the most reliable and absolute results (Aghemo et al. 1991; de Wit 1991; Troatman 1991). However, because they involve the destruction of masonry, they cannot be used frequently.

TABLE 5 **Average Reference Evaporative Coefficients C_{ev} for the Four Reference Walls**

Wall	$C_{ev} \cdot 10^4$ (l/dmPa)
T2	4.3
T3	6.1
B4	0.5
T5	2.2

TABLE 6 **Moisture Content Values, U_a, as a Percentage (%) Relative to the Sample Dried Mass**

h (m)	s (m)	U_a (%) Wall T5	U_a (%) Wall T7
0.40	0.05	6.8	0.7
0.40	0.13	7.1	1.1
0.80	0.05	5.5	0.0
0.80	0.13	4.4	0.5

Note: Measurements made in February 1994 for walls T5 and T7 at four spots on the median vertical plane perpendicular to the wall. h: height from sealing; s: depth. The equilibrium moisture content, measured at 20°C and 75% relative humidity, was found to range from 0.1 and 0.3%.

Table 6 shows the values measured at four different spots on walls T5 and T7 in February 1994. All such spots were located on the median vertical plane perpendicular to the wall, at two different heights (40 cm and 80 cm from the sealing of the polyethylene sheet on the wall) and at depths of 0.05 and 0.13 m, i.e., at $t/2$ and $t/5$, with t denoting the wall thickness. The hygroscopic (or physiologic or equilibrium) moisture content of the samples obtained was found to be low, ranging from 0.1% and 0.3%. The low values can be accounted for by the fact that the tufa blocks used were taken directly from a quarry.

To assess the efficiency of the remedial treatment, three indices are suggested.

1. Evaporation performance index (%), E, is defined by the relation

$$E = [(M^r - M)/(M^r - M^{16})] \cdot 100 \tag{2}$$

where

M = average monthly addition of water to the wall under examination and for a given period, after the remedial treatment (l/month);

M^r = average monthly addition of water to the reference wall for the same period as that of M (l/month); and

M^{16} = average monthly addition of water to wall T16 for the same period as that of M (l/month).

Note that E allows one to assess the efficiency of the remedial treatment in that, if this has been totally successful, over time E tends to 100 as M tends to 0.

2. The degree of drainage (%), P, is defined by the relation

$$P = [(U_a^r - U_a)/(U_a^r - U_{a,f})] \cdot 100 \tag{3}$$

where

U_a = moisture content measured on a sample of material drawn from the neighborhood of a point on the wall being examined (%);

U_a^r = moisture content measured on a sample of material drawn from the reference wall at the same point as that selected for the wall being examined (%); and

$U_{a,f}$ = equilibrium moisture content of the sample of material used for measuring U_a (%).

If the remedial treatment has been totally successful, the degree of drainage also tends to 100 over time, as U_a tends to $U_{a,f}$.

3. Residual dampness, R (as a percentage), is defined by the relation

$$R = U_a - U_{a,f}. \tag{4}$$

For a totally successful treatment, index R tends to zero as U_a tends to $U_{a,f}$ over time.

We have calculated the three indices for the eight tufa walls on which a remedial treatment has been applied. The values are shown in Table 7. The same calculation was not performed for clay-filled bricks because the capillary ascent observed there is still negligible and does not allow any evaluation.

On the basis of the definitions of the three indices, only one value for the whole wall is obtained for E, while the values for P and R refer to the individual spots at which they were measured.

In Table 7, E and P are less than zero in seven cases, i.e., the addition of water for E or the moisture content for P appears to be greater in the wall being examined than in the reference wall.

From Table 7 we infer that, in general, there is a good agreement between index E and index P: a high value in E (> 50) is matched by a high value in P, at least at 80-cm height. For reasons that are still unclear, there is no agreement for walls T8 and T15.

Overall, a positive judgment undoubtedly can be expressed for the treatment of wall T7, where all three indices show more than satisfactory values. The judgment is negative for wall T1 and particularly for wall T18, for which the chemical dpc caused an increase in dampness. For walls T6, T12, T13, and T15, dampness has strongly diminished at 80-cm height; however, it remains fairly high above the treated area.

Last, even if several months have elapsed since the treatments were made, we are not yet certain that the system is in a steady-state condition because moisture content values and the yearly additions of water in the reference walls are still slowly diminishing.

TABLE 7 **Values of the Three Indices E, P, and R Measured on the Masonry Treated in the Laboratory with Chemical *dpc***

		P		R	
Wall n.	E	h = 40 cm	h = 80 cm	h = 40 cm	h = 80 cm
T1	33.1	<0	<0	7-8	6-7
T6	50.3	20-30	100	4-5	0
T7	57.0	80-90	90-100	0-1	0-0.5
T8	67.9	<0	40-50	8-9	1-2
T12	35.2	40-50	100	3-4	0-0.5
T13	13.0	<0	90-100	8-12	0
T15	29.5	70-80	100	1-2	0
T18	<0	<0	<0	16-18	8-9

Note: The values of E refer to the period 1 July 1993-30 June 1994. The values of P and R were evalutated in May 1994.

CONCLUSIONS

The research results seem to confirm the validity of the proposed laboratory method to check the effectiveness of chemical dpc treatments.

Although we are not yet certain that the system is under steady-state conditions, the results obtained ultimately confirm the doubts that are commonly expressed for chemical dpc treatments; to date, successful results have been obtained for only one out of the eight treatments made on the walls built in the laboratory.

The experiment also has provided interesting data for evaporative coefficients.

NOMENCLATURE

C_{ev} = average daily linear evaporation coefficient, l/dmkPa;

E = evaporation performance index (defined by Equation 2), %;

L = total front linear development of the evaporating surface, m;

m = average daily water evaporation, l/d;

M = average monthly addition of water to the wall under examination and for a given period after the remedial treatment, l/month;

M^r = average monthly addition of water to the reference wall and for the same period as that of M, l/month;

M^{16} = average monthly addition of water to wall T16 for the same period as that of M, l/month;

P = degree of drainage, defined by Equation 3, %;

R = residual dampness, defined by Equation 4, %;

t = wall thickness, m;

t_a = air ambient temperature, °C;

t_p = surface temperature of the areas affected by the capillary ascent, °C;

U_a = moisture content measured on a sample of material drawn from the neighborhood of a point on the wall being examined, %;

U_a^r = moisture content measured on a sample of material drawn from the reference wall in the same point as that selected for the wall being examined, %;

$U_{a,f}$ = equilibrium moisture content of the sample of material used for measuring U_a, %;

RH = relative humidity, %;

Δp_v = difference between the vapor pressure at surface temperature t_p and the partial vapor pressure in the air, Pa.

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