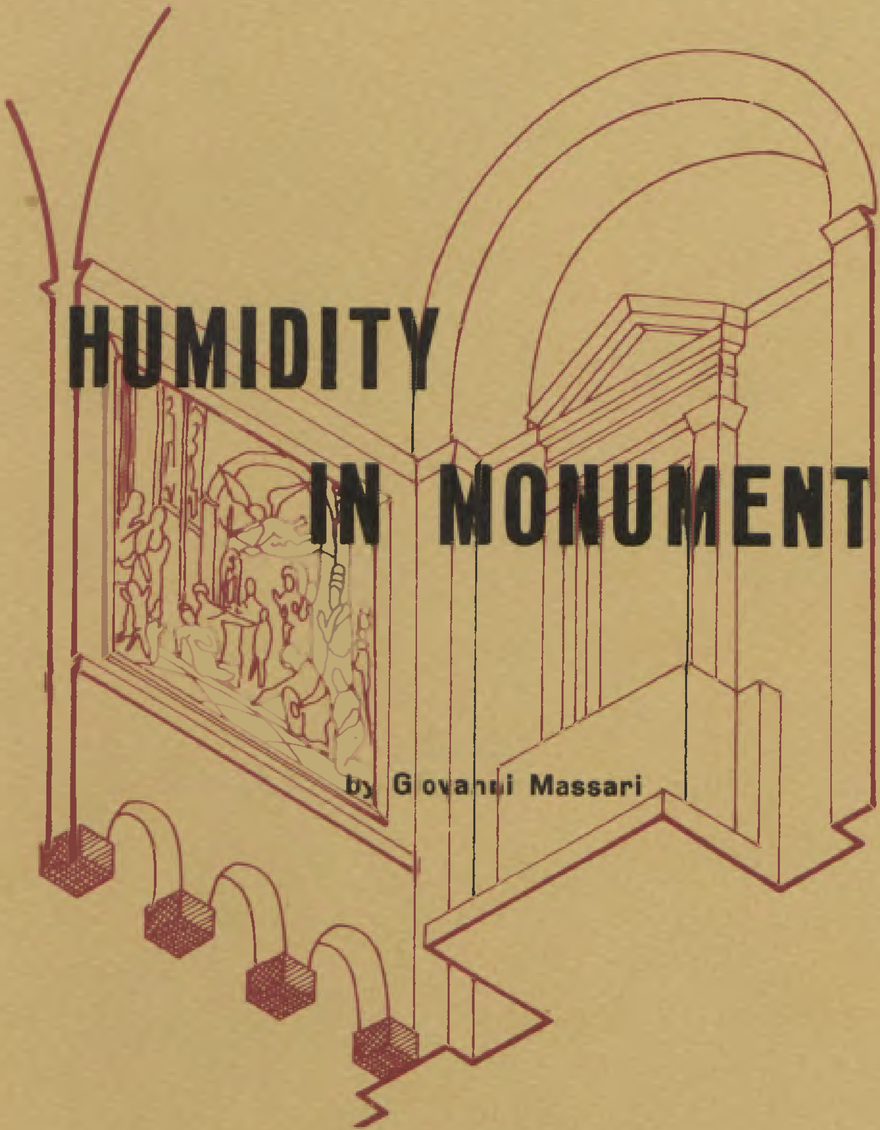
FACULTY OF ARCHITECTURE - UNIVERSITY OF ROME

INTERNATIONAL CENTRE FOR THE STUDY OF THE PRESERVATION
AND THE RESTORATION OF CULTURAL PROPERTY

HUMIDITY IN MONUMENTS



by Giovanni Massari

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CHAPTER I.

Some harmful results of exposure to damp: destruction of frescos, distortion and flaking of marble, ruination of stucco and of decoration to say nothing of menace to human health and comfort.

A precise investigation of the origin of the humidity is a prerequisite to satisfactory treatment. Just like fever, dampness is a symptom of illness. The doctor must first diagnose the illness producing the fever. Dampness is the consequence of an unbalance of certain physical forces in a building, a monument or in a single piece of masonry. Architects and engineers should act, in the case of dampness, like doctors, making all the tests necessary to determine the nature of the illness. It is dangerous to rely on "common sense" as was done in the past. On the contrary, the phenomenon should be put into figures, after careful collection of the essential data.

We start from the principle that dampness comes from water either in the liquid or in the vapour phase. The first thing to do is to find and regulate the water and this can only be done by means of instruments. Suitable instruments can record whether there is water in the wall, say, under a green spot of mould; they can record its percentage as compared with the mass of the wall, its distribution and its tendency to increase in concentration in the direction from the plaster to the core or vice versa. The plaster can be dry and the core damp and each condition has a logical meaning. Sometimes, as for example in the condensation phenomena, we may never find the water because it appears only at intervals. A thin layer of water appearing for a few minutes every morning at dawn, when the peasants go to church, is sufficient to produce a large quantity of mould over an old tempera painting executed in a glue medium. As soon as the sun rises, the water disappears, but the mould has received its daily ration of water, just as the old women receive from God their daily bread.

We must find and measure the water. If it cannot be found, or its quantity is not sufficient for an explanation of the damage, thermal investigation should be added to the studies on humidity. Thermal investigation is performed by measuring the surface temperature of all the walls surrounding the damp room, as well as the air temperature. In fact, the condensation dampness comes exclusively from the air and depends on the excessive gap between warm air and cold walls. For the same reason, in winter time, we often see the windows of a well heated bedroom covered with dew: the cause of this phenomenon is the excessive difference between the temperature of the external and internal air on the two faces of the glass. In summer time, the same difference frosts a glass of cold beer on a crowded bar table. As soon as we renew the air in the room, the dew disappears and the damp on the glass of beer disappears as well, provided we leave it on the table for ten minutes, so that the difference between liquid and air temperature decreases.

The diagnosis of the mechanism by which water penetrates into the wall is a fundamental one. Fig. 1 shows schematically the four possible means of entry. The dampness may rise from the ground, or it can come from the air, through condensation on a uniformly cold wall, or else it can gather in spots that appear and disappear according to the climate of the day. This happens because the wall structure is not homogeneous: the wall is colder where the stones are heavy and warmer in those points built with light materials. Sometimes dampness arises from several causes acting together and the damage to the object is then the result of this complicated system as happened with Leonardo's Cenacolo (Fig. 2).

Oblique rain passes rarely through the wall, but it often cools it, causing condensation on the inner face. as happens in dance halls, in churches and in crowded dwellings, where the breath of many inhabitants raises the relative humidity of the air excessively.

The main characteristic of capillary rising dampness is its unalterability. The water quantity inside the wall is constant, regardless of the season and of the time of day. Besides, it can only be found at the ground floor and in the lower part of the building, and it never exceeds 4 metres above road level. A water quantity up to 3% in weight is tolerable in brickworks. An amount up to 5% in weight is tolerated by the structures consisting of soft absorbent materials, such as tufa, light limestone and light sandstone. The humidity is estimated by taking samples from 15-20 cm. beneath the plaster, that is from inside the wall-core: the samples are weighed when still wet; they are then dried and re-weighed. The reason we take samples from 15-20 cm. beneath the surface is that here the water content is constant throughout the year, regardless of daily and seasonal alterations. The weight difference between wet and dry samples shows the amount of water contained. Within the above mentioned limits (3% in bricks - 5% in tufa and light sandstone) the water within the wall affects neither monuments or people, provided the rooms have good ventilation. Above these limits, mould and erosion appears and those who are compelled to live or work in such damp closed areas soon feel uncomfortable. The effective cure for rising dampness consists in cutting the capillary fillets in the wall or in intercepting the water before it reaches the wall itself.

Condensation has the characteristic of being a discontinuous phenomenon, always caused by low temperature. Water, when present, is abundant in the plaster and scarce in the core; the plaster affected is always the area exposed to the warm air, that is on the inner surface of the wall. But water can be completely absent at the time of measurement.

When there is doubt as to whether condensation is likely to be taking place, it is necessary to ascertain, by means of a thermometer, which is the coldest surface inside the wet room. Treatment of condensation should always be based on the supply of heat, that is, the coldest wall surface should be slightly heated and in the meantime the room should be ventilated, so that the relative humidity of the air does not rise excessively.

The optimum range of air humidity is between 50% and 70%. If the air is still, in closed areas, at 75%, moulds start to develop, especially when there is an organic nutrient present, as for example animal glue, paper, leather or parchment. The "merulius lacrimans" the worst house-fungus, can live without any water in complete absence of ventilation provided it has a wooden support and the temperature remains below 27°. The most effective remedy against moulds and fungi is good ventilation.

Good ventilation, on the other hand, may be dangerous for frescoes painted on damp masonry. They become spoiled rapidly when submitted to dry and wet alternative phases. A fresco painted in an underground room in which there is constant dampness, far from the action of sun, can remain in a perfect condition of conservation for centuries. This is often seen in Italy. But a few years after having been opened to the public, frescoed Etruscan tombs have been ruined because of the irregular ventilation and alterations in the humidity of the air caused by the presence of visitors. When the diagnosis is established, that is, once it has been ascertained whether dampness is purely a matter of capillary rise, or of condensation, or else a combination of both, the remedies are dictated by reason. To fight rising dampness, we should place a barrier across the path followed by the water, or prevent it from entering the wall foundations. To fight condensation dampness, the difference of temperature between warm — wet air and cold wall should be eliminated: this can be obtained by protecting the wall, so that heat is not dispersed towards the outside, or by heating slightly the inner surface, or else by reducing the relative humidity of the air. If the two kinds of dampness are simultaneously present, it is necessary to assess which of them is prevailing and start by fighting this one. In any case, beware of the miraculous commercial products and try to judge any remedy critically and with your own brain, without believing the salesmens' miraculous specialities. Beware of technical over-simplifications as, for example, bituminous vertical linings or cement plasters: the dampness, instead of coming from the air, may come from the inside of the wall itself !

Introduction and explanation of the instruments used for the study of wall dampness.

Three groups are shown separately:

(a) Instruments for measuring the relative humidity of the air: hair hygrometer, traditional psychometer, instantaneous electric psychometer.

(b) Instruments for determining the moisture content of walls: electric pin measurer for plaster, electric pressure measurers for plaster, scale unit and traditional oven to determine the water-content in the samples taken from the framework, new dielectric heat oven for air extra-rapid drying of the samples (Massari method).

(c) Instantaneous electric thermometer with a thermoelectric torque for the measurement of temperature of the air and on the surface of walls, "Siemens" optical infra-red thermometer, for the distant measurement of surface temperature in large rooms (churches, halls etc.).

For studying the distribution of damp air in large halls Kettenacher's principle regarding the degree of saturation of still air in close vicinity to a damp wall. Kettenacher demonstrated that serious phenomena of dampness may arise on the walls of closed rooms, even if the amount of water contained within the wall is relatively low, that is, equal or just above 3%, which has been stated to be the maximum tolerated in brick walls.

For example, with a quantity of 3.5% of water in the brick wall let us say that adjacent to the wall becomes saturated with water vapour (90% - 100%) but only for a distance of 5-6 cm. from the wall, while in the centre of the room the relative humidity of the air remains normal, i.e. 65-70%. Then, large quantities of mould may grow behind paintings, or shelves, or may be found in cupboards and this all seems out of proportion to the general dry conditions in the centre of the room. It is often wrongly believed that the fault lies in the wall and expensive work is planned for its rehabilitation. In fact, no rehabilitation is necessary. Two single measures are sufficient: daily ventilation and the removal from the wall of all paintings, shelves and cupboards, so as to leave 9-10 cm. space for free air to circulate, for in such circumstances it can never reach saturation.

CHAPTER II.

As we do not want these studies to be too theoretical, we now propose to illustrate them by 5 examples of damp monuments, churches, palaces and villas which we have studied.
We give descriptions below of the shape of the building and the apparent form of dampness to which it was subject; we explain the diagnosis, the treatment applied and the work leading to rehabilitation.

I.

The first example is that of S. Maria della Rotonda, Albano, *in which dampness was not damaging frescoes and works of art but the health of the public and of the priest himself: in fact, the religious authorities had to close the church.*

The Building

By request of the Amministrazione delle Antichità e Belle Arti the study of the church was initiated in the winter of 1960. The circular plan building, with a diameter of about 16 metres, covered by a dome, with 4 large niches on the diagonals, resembles a small Pantheon. Originally it was a Roman thermal bath, but from time immemorial, through many events and modifications, it was adapted to the Christian cult. When entering the church, which contained an old painting of the "Black Madonna," very popular among the Albanese, the visitors felt an unpleasant cold dampness that caused the gradual desertion of believers with the consequent decrease in religious functions.

There is logic based on appearance and logic based on substance. If we try to find the cause of dampness according to the spots, moulds, erosions etc., we follow logic based on appearance, that is, we apply what we call "common sense," marvellous synthesis of intuition and rationality, valid in conservation among men, but fallacious when used in the field of physical phenomena, as for example, dampness in a church. To understand the phenomenon, we must first of all, translate it into figures and never judge it according to our common sense.

In the case of S. Maria della Rotonda, the common sense diagnosis was evident, but wrong: it had always been thought that the damage was caused by the evaporation of the old brickwork (just exceeding 1 metre in height) of the annular wall, visibly humid (Fig. 4 - entry to the church).

The Diagnosis

The exact diagnosis was based on careful instrumental measures. It was ascertained that two originally distinct causes cooperated in creating such a high dampness level in the air (87% - 95%): this was the evaporation of the damp perimeter wall and the condensation of water and air vapour, due to the low temperature of the floor. As we can see in Fig. 5, the floor temperature (compact and waterproof, to allow the flowing of thermal water to the still existing central drain) was in winter 4°C lower, in comparison to the average temperature of the perimeter wall: the floor constitutes then what physicists call "the cold wall." With the help of an optic infra-red thermometer, it was possible to collect rapidly the surface temperature measurements, which allowed us to separate quantitatively the two types of damage (rising dampness and condensation) and to realize with astonishment that the most worrying phenomenon was that of condensation, due to the floor: in fact, this is dry and cold, while the perimeter ring masonry was humid, but warm and not very harmful.

The Bath Floor, as the main problem

If we consider that the two entrances of the church both have high elevations, and that the floor is about 4 metres below the level of the surrounding streets, we can easily see how the low floor temperature, cooling the layer of air above it, can determine stagnation of heavy and damp air which can in no way flow downwards. The phenomenon is shown in Fig. 6: it is a condition resembling that of the last Girone of Dante's Inferno! Just like the damned souls, the believers immerged in saturated air. This is the main point of the problem. Even if, with appropriate work, we had been able to drain the damp perimeter wall of the brickwork, we would not have eliminated the main cause of the unhealthiness of the place, coming from the ice-cold floor (you can see, on the upper part of Fig. 7, its characteristic structure of a perfect bath base).

The Rehabilitation (drying) Work

This work had the purpose of modifying the floor structure, by decreasing its thermal inertia and by inserting a heated coil which would gradually raise the temperature (lower part of Fig. 7). Note that we did not build a heating system in the church, because the present heat output, through the floor, is only 10 calories/h/m^3, of the air in the room, while for real heating, 30 calories would be required. Now the dampness has disappeared (1965) and the church is again comfortable and welcoming. Such work can be taken as an example for similar cases of churches or large damp rooms on the ground floor.

II.

The second example of rehabilitation concerns the "inexplicable dampness" of a fresco on the first floor of the Town Hall of Siena, *dealt with in 1960.*

The Affected Fresco

The fresco in question was by Spinello Aretino and it illustrated the arrival in Rome of Pope Alexander III Chigi, from Siena. This fresco is in the Balia Hall on the first floor of the Town Hall, Siena, on a wall of the apparent thickness of 2,20 metres. The dampness was shown by the colour darkening in irregular and scattered stains. Those who were interested in the progressive deterioration of the fresco were convinced, according to their "common sense," that the dampness was coming from the bottom: capillary rising dampness. According to some scientists it was due to a salt deposit: in fact, the Republic of Siena had for some centuries, employed the space below the ground floor as a store-room for salt (Fig. 8) and they thought that the whole area had become saturated with salt; on the other hand, the technicians attributed the origin of the presently active rising dampness to the large drain that receives the rainwater from the opposite square (Il Campo). In fact, this drain passes under the building along the very thick wall on which, at first floor level, the fresco is painted. Each hypothesis seemed quite logical; the measurement (never before taken) of the water contained in the wall in the room beneath, would decide the issue.

Water Measurements in the Plaster

But, surprisingly, the measurement was completely negative (Fig. 9) as far as concerns both the lower and upper brickwork. So, it was possible to reject not only the hypothesis of capillary humidity rising from the bottom, but even the other hypothesis of dampness descending from the ceiling and due to roof leakages.

The problem became harder when further measurements in the back of the wall, corresponding to the fresco, showed that it was absolutely dry. The water was only on the fresco and in very high quantity: 12% to 18% in weight.

A Working Hypothesis

The case was becoming irritating. To orientate further research, though the hypothesis had no basis, we supposed that water flooding of unknown derivation was stored in the inner space of the framework, inside the enormous wall thickness (1.70 to 2.20 metres). And, also, still as a working hypothesis, we supposed that irregularity of the inner construction of the framework allowed this water to flow slowly, because of gravity, through certain outlets and only through those, towards pre-determined points of the frescoed surface where it might justify the dampness.

In order to check this hypothetical presence of water in the wall, it was decided, in the second phase of research, to perform careful deep drilling, of course not in the area covered by the fresco, but in the basement area, an area covered with the back of a large wooden bench of the period, to a height of more than 2 metres.

Discovery of the Supporting Wall

Once the hole had been lightly started with an electric drill it was found, with surprise, that the structure was not thick, but it consisted of a supporting wall in layers of heavy Siena-bricks, 6 cm. thick, close-grained and plaster walled; behind these bricks we found an irregular air-space: the fresco was painted on this heavy supporting wall. Beyond this was the real main wall, with an average thickness of about 1.65 metres. Further measurements about the water distribution revealed:

— that the main wall was perfectly dry;

— that the back of the frescoed supporting wall contained about 4%-5% water, while the frescoed side contained 12%-18%.

This evidence (Fig. 10) was of definite importance, as it demonstrated that the water came from the fresco surface and spread towards the interior, diminishing in concentration in the narrow thickness of the supporting wall. But, if we consider the enormous thermal inertia of the wall masses and the fact that the fresco is painted on the supporting wall, the condensation diagnosis, while it was rejected when the fresco was thought to be painted on the main wall with equal surface temperature on both sides becomes at once of significance for we are now considering the supporting wall which is operating as a diaphragm.

Hollow Space Microclimate

Condensation is due to the difference of the air temperature on both supporting wall surfaces and it is a seasonal phenomenon. The temperature of the large amount of air contained in the Balia hall varies according to the season and metereological variations. The air in the hollow space is not affected by such changes and keeps an almost constant temperature.

The volumes of the two masses are unbalanced: the hall, about 500 mc, the hollow-space about 7 mc: ratio = 71.1. The two walls encircling the hollow space are also unbalanced, the main wall has an average thickness of 1.65 metres; the supporting wall, plaster included, is 7-8 cm. thick: the ratio between the two masses is = 22 : 1 approximately. The thermal inertia of the thin supporting wall is therefore minimum if compared to that of the main wall. While the hall air coming through the windows immediately affects the painted surface, heating it rapidly in summer and cooling it in winter, the little amount of air included in the hollow space is very slow in following the seasonal variation. This is due to the fact that its temperature is connected to that of the enormous thermal mass of the main wall. For example, in June-July, the supporting wall surface on the frescoed side may have a temperature of 23°-24°C; while its inner surface, towards the hollow space may be still at 15°-16°C. In these conditions, when also the air dampness in the Balia Hall oscillates around 60% (this possibility is frequent in summer) the 8 degrees of thermal change between the two supporting walls bring condensation water on the warmest side, that is the frescoed side. Condensation is abundant when compared with the enormous air volume of the Balia Hall.

Recommended Measures for Rehabilitation

Our purpose is that of equalling the temperature on the two supporting wall surfaces. The hollow space should be put into communication (in the largest possible manner) with the hall air, in order to retain the small air quantity in the hollow space at the same temperature in summer and winter. This was done, very cheaply in 1960, when a canal was opened in the main wall and in the supporting wall slots, as shown in Fig. 11: water contained in the fresco-plaster decreased from 12%-18%, as it originally was in 1960, to 4% in 1964. A rapid and economic restoration.

III.

Another serious example of dampness: every year, in Spring, water filled the floor of the crypt of Saint Columbau (Columbauus) in Bobbio Abbey, *where rest the mortal remains of the Saint who spread the Christian religion in Ireland.*

Local Climate and Temple Structure

The climate is good except for snow and some winter harshness, but the air is generally very dry. The Abbey is on a hillside, in a position facilitating drainage of rainwater.

The load-bearing wall structure is composed of stone blocks, mainly cobblestone from the Trebbia bed, put together with excellent lime mortar. This is the so-called "cold" brickwork, i.e. the heat inner transmission coefficient is over 2 cal/h/m³. The crypt perimetrical wall, the thickness of which is 1,20 m., was recently protected from dampness with a flat brick coating. This addition proved to be detrimental, because brick is an excellent water absorber, when it comes from the ground, while a close stone brickwork, as the Bobbio one, can only absorb the small quantity of water rising through the mortar. When the walled material does not cooperate in transmitting water the capillarity of the mortar is not in itself sufficient to produce a serious dampness invasion. In this case, the Trebbia pebbles do not cooperate at all.

Measurements Undertaken

Instrumental measurements showed that the crypt air was very damp (91%) in respect to the external air (41%). On the contrary, the water content of the wall was low and never rose above 2 m. from the floor. In relation to the total wall thickness (1,30 m.) and the underground position of the crypt, this rising capillary dampness is not worrying, because it is a function of the brick coating. If, instead of being made with stones and pebbles, the wall had been of brick construction, for its whole thickness (1,20 m.) the dampness would have risen beyond the upper church floor.

The water content of the floor is very low too, nearly normal. The floor consists of excellent grit-stone and marble squares on a solid, waterproof, anticapillary cement-gravel concrete foundation; the water does not exceed 2,9%. This kind of floor, without an intervening air-space is in close contact with the cold ground below and is therefore submitted to the condensation of water vapour contained in the air of the room.

Diagnosis

Expensive projects had been undertaken in the past to eliminate dampness, but they were performed randomly, without having measured the water quantity and distribution in the wall structures. This lack of diagnosis resulted in three constructions, that, in this particular case, were all wrong (Fig. 12) as they were intended to counteract the ground dampness:

(a) laying a heavy floor, applied on the damp ground without an intervening air space and therefore "cold" or condensing;

(b) application on the wall inner surface, made of anticapillary stones, of an adherent flat lining of bricks, absorbing the water coming from underground;

(c) application, on the outer surface, of a thick waterproof concrete dam, in case the water comes from the outer ground.

Each of these three operations was carefully performed, with excellent materials and ability, but the corresponding expenses were a waste; they had made the situation worse. The measurements undertaken show that the rising dampness is not so important owing to the wall anticapillary building material (stones); and that the real cause of dampness is the condensation coming from the air. This assertion is supported by a Rector's observations, according to which the most serious damage is felt in the transition period, from winter to spring, when the crypt floor is covered by water. In fact, when the tepid, vapour-rich air of Spring enters the crypt, its temperature decreases on contact with those surfaces that, for thermal inertia, retain the winter cold for a long time. On the grit and marble floor the water stagnates, not because it rises from the ground below, but because it is deposited there by condensation of water vapour of the air; on the contrary, the wall condensation is absorbed by the plaster, which subsequently swells and falls off.

From the thermal point of view the most detrimental work was that of the large concrete dam built externally against the crypt wall, on the basis of the wrong belief that fluid water penetrated from outside. This 90 cm. thick heavy structure doubled the thermal inertia of the original wall, extending the seasonal interval of time favourable for internal condensation. Instead, a simple hollow space, or better still, a totally open hollow space would leave the restored monumental outer perimeter of the crypt in contact with free air.

Restoration Measures

These arise from the condensation diagnosis and aim at giving back to the crypt the minimum of heat it needs. The object of the work must be the complete elimination of "cold" surfaces and their replacement with structures such that intervening voids have an apparent specific weight less than a half of that of the previous heavy structure. So, as shown in Fig. 13 we should:

1. Supply the crypt with a modest electric heating system, delivering a small heat charge highly distributed. For example, resistors in a silicone sheath, immerged in the mortar bed of the floor, just below the squares or strips of brick. Such resistors can be found in electric heaters. Their installation is very simple and should be performed during the reconstruction of the floor mentioned in (2), by increasing the number of resistors along the perimeter and mostly on the North side. On the whole, a power of 5 Kw., corresponding to a delivery per hour of about 4300 calories that is 4,3 calories per cubic metre of air, should be installed. The heating is minimum (as compared to 1000 cubic metres of air of the crypt), and should be kept on from the end of February to the end of May, starting every day at dawn, with an automatic lighting device and at least for 10 hours per day or more. The windows should always stay partially open, in order to facilitate the exchange of air produced by heat. It should be stressed that this is not a heating system for people, but a restoration system for brickwork.

2. The second measure was the demolition of the grit and marble floor and rebuilding with simple old-fashioned limestone squares or strips of bricks of normal specific weight, that is without grit. The structure below was lightened with an air space, as shown in Fig. 13, and then with an anticondensation flooring 10 cm. thick finished in the rough and made from pumice, or blast furnace slag, or expanded clay grain (Leca type) or cellular cement, or any inexpensive and suitable material; in any case, the thickness should not be less than 10 cm. and the specific weight should not exceed 800 Kg. per cubic metre.

3. The third objective was the demolition of the whole supporting wall and its rebuilding with new and dry hollow-flat tiles, without any weakening of the back wall. The air space was replaced with a continuous layer of polystyrene slabs, 4 cm. thick, of heavy closed cell type (20 Kg/ cubic metre) and good quality.

IV.

The fourth example for the study of a building attacked by rising damp, is that of a villa constructed from an ancient monumental farm in the Roman countryside.

Location and Ground-water Bearing Stratum

The building, which is original in that it has preserved the dignity and the setting of its imposing predecessor, dominates the surroundings from the summit of a hill. The old-fashioned thick walls are entirely composed of tufa. The ground is mainly clay, the rainwater deflection conditions are excellent. Owing to the voids just against the building, the water-bearing stratum is lower than the foundation plan level.

Water Measurement in Brickwork

Percentage of water in brickwork about 20%; very high in all ground floor brickwork, including the main inside wall, with normal rise, up to 1,50 m. from floor level and even more in the points having a waterproof lining. It is a typical case of dampness rising from the ground. A propitious condition is the demonstrable lack of water in the foundation of floors built some years ago with an intervening air space. The upper floor is safe, with no dampness at all, in perfect hygienic condition.

Proposed Criteria for Restoration

The clayey ground retains water and the fact that the inside main wall is as humid as the perimetrical walls means that the whole earth mass, under and inside the building, is saturated with water. As the diagnosis is: "rising dampness from dispersed underground water," restoration should follow two objectives:

(a) to drive away from the building all surface rainwater;

(b) to cut off underground water penetrating the foundations.

Specific Works: In order to reach objective (a) we should advise:

— to connect all the downspouts very carefully and divert the excess water with a culvert, the same should be done for black waters.

— to remove the gravel from the square around the building, because it retains rainwater thus obstructing its deflection and to replace it with waterproof paving as, for example, Roman stones built on a lime and pozzolana foundation. The removal surface gradient should not be under 2%; the paving should cover the drainage mentioned in (b), exceeding it by at least 1 metre. In order to reach objective (b) we should advise:

— to build an open drainage system, all around the construction (Fig. 14) at a distance of about 3 metres, filled with washed gravel, tamped without sand one sector after the other about 1 metre deep below foundation level; floor gradient, 2% downstream. Slanting side walls 1/20 protected by flat filled brick edge course. Waterproof cement layers covering a Roman stone floor, as shown in Fig. 15. A double deflection downstream from the drainage should be allowed.

The lowering of the water level in the ground floor walls will start from the second year. Before starting the work, present levels and water percentages should be marked on the walls, so that they can be checked after the second year.

Drying can be accelerated if, soon after drainage, a perimetrical hollow space is built against the whole foundation (Fig. 15).

The hollow space will be of the usual type: about 1,30 m. deep, that is, the floor is slightly higher than the foundation level of the house (1,70). The ground supporting wall is in thin reinforced concrete; the floor is cemented and slanting in the point of deflection. Water may eventually penetrate in any sector of the hollow space; a slanting exit culvert connector should be installed thus connecting it with the drainage system, as outlined in Fig. 15.

V.

The fifth example is that of the Palazzo dell'Accademia di S. Luca, Rome, *which is interesting for the complete failure of the Knapen dehumidifier syphon.*

The Dehumidifier Syphon Discovery

Since the beginning of this century, they tried to use the beautiful vaulted groundfloor halls of the "Palazzo dell'Accademia" with the purpose of preparing design, project and work of art exhibitions. Even the radiator heating system could eliminate moulds and erosions on the wet plaster.

It was about 1935, when the academician Gustavo Giovannoni, famous Professor at the Faculty of Architecture who trained generations of engineers and architects, pierced carefully the travertine of the Palazzo external socle and applied, inside the wall, the so-called "Knapen dehumidifier syphons," a messianic finding that was very popular at that time, because it was supported by apparently rational though pseudo-scientific propaganda. With the syphon installment, the workers demolished, on the internal wall, the spoilt and stained plaster, repairing it with abundant applications of waterproof cement. The halls, once so disfigured and unpleasant, suddenly appeared clean without any mark of the old dampness and extremely agreeable with the freshness of the new paint. We learned afterwards that the effect lasted about 3 or 4 years; then stains and erosion reappeared and everything started again. It had been a simple "make-up." In fact, of the two works that had been performed, the external one (dehumidification pipes) had not dehumidified anything and the internal one (plaster renewal) had been a temporary damage disguise, with, moreover, the malice of attributing to the pipes the first apparent improvement.

Thirty Years later

The problem was still unsolved, when some academic architects posed again the question about a possible and effective restoration, after a study based on instrumental diagnosis and without any faith in miracles. For the first time, the "common sense" was left aside and they started measuring the water contained in the walls of the unhealthy rooms. The study revealed that, of the two parallel walls, surrounding the damp rooms (see plan in Fig. 16) one, internal to the arcade, was dry, while the other, in Vicolo Scavolino, contained a heavy charge of water, up to 20% in weight (that is, 30-32% in volume) distributed in a very irregular way.

Deduction

The water supply could not come from the water bearing stratum or from diffused and homogeneous water, dispersed in the subsoil at foundation level; in such case, both the parallel walls would be homogeneously saturated. Certainly, there was a specific and local cause, acting only on the external wall.

The True Cause of Dampness

When the communal Technical Services, satisfying the request of the Accademia, excavated the Vicolo Scavolino in order to inspect the subsoil, they noticed that the old brick culvert, both a drain and a sewer, was deeply depressed, like a slack cord, all along the Palazzo damp wall, but the roadway remained intact. The culvert kept working, no more freely, but full for many metres, sprinkling the Palazzo foundations with the periodic charges of water remaining in the bent sector. The trouble had probably been in existence for about 50 years, but the culvert (full though in a desultory way) had kept working with regularity and the communal Technical Services had not noticed anything wrong. Once the depression was eliminated (Fig. 17) and the culvert as rebuilt with rectilinear gradient, the Palazzo wall slowly started drying. Three years later (1965) the upper damp level had lowered from 2,00 m. to 0,30 m. and the wall rehabilitation was then certain.

The Knapen pipes are still there. Perhaps within 20-30 years someone will say that thanks to them the wall has been restored!

• • •

Nowadays the Knapen original syphon is out of fashion. But it is still considered a novelty of technical progress, when it appears in various editions, created by many imitators in Switzerland, France, Hungary and Germany more often than in Italy. None of these new imitators mentions Knapen. Fig. 18 shows some recent imitations of the old Knapen syphon: in group (A) it is possible to see how the original section of triangular tile was replaced with cylindrical or semi-cylindrical sections; in group (B) there are other types of syphons. not tile made but plastic made, which are cheap and unbreakable, extendable for further segments; type (C) is a rather expensive French model, in stainless steel, that is a nickel-steel alloy, which is supposed to attract water miraculously by electro-osmosis; group (D) concerns some tile syphons made in Italy, on the basis of the Knapen prototype but with the addition of copper pieces or wires; these are believed to have an electric effect in making water descend from the wall to the ground by electro-osmosis. All these are pseudo-scientific claims and no faith should be given to them. In my view all these measures are perfectly uselss against rising dampness.

The Knapen pipe uselessness was confirmed by A. Watson, the British creator of a new system for measuring the dampness variation in a wall, through micro-wave absorption. In a two year study he found no reduction of the initial water content in the wall treated with Knapen pipes. This negative result was made officially known at the Helsinki Symposium of the European tile makers, in August 1965. But the German Gunter Mall had already demonstrated, in "Bautscheden" (Bauverlag editions, GmbH, Wiesbaden, Berlin 1963) that not only are the Knapen pipes useless, but they often are detrimental, as they make the water level rise on the wall, being subject to internal condensation. Many technical offices and administrative departments all over the world, dealing with monument preservation, have a "routine life," without keeping abreast of scientific discoveries. At present they fight wall dampness with Knapen pipes, which now are probably plastic or stainless steel made and therefore very modern.

Other wall dampness interception systems as liquid silicone or ethyl polysilicate diffusion inside the wall appear theoretically useful against rising dampness, but in practice it is never possible to obtain a really waterproof horizontal layer. There is no way of controlling from outside how these isolated liquids are spread inside.

As it is very difficult for architects dealing with restoration, to distinguish true from false science, at the International Congress of Restoration Experts, held in Venice in 1964, Massari presented the following procedure for new devices and commercial products for the restoration of walls affected by rising dampness: "Before accepting the new specialities and devices on the market, we should officially define the dampness conditions of the structure to be restored; we should therefore draw, at a depth of 15-20 cm. inside the wall, at least 5 samples, at different heights from the floor, for example, 0,40 - 0,80 - 1,20 - 1,60 - 2,00 m. The samples shut into perfectly sealed glass vessels, will be sent to a hygiene or chemistry qualified laboratory, belonging to a public organisation or to the University, with the request of determining the water content of the sample in percentage by weight. Once the device, or commercial speciality, is applied, the sample drawing should be repeated in the same quantity and at the same levels as the previous drawings and they should be sent to the same laboratory for water proportioning. The second sample should be drawn a reasonable length of time afterwards, in order to be able to evaluate the device effectiveness (for example, after at least one year). The device will be presumably effective if the water contained in the samples has clearly decreased. The checking should be performed by the administrative centre responsible for the monument's preservation and not by the person who has applied the device.

Lastly, one should beware of rehabilitation works in which the old, spoiled plaster is demolished and re-made with waterproof materials. Such work will only result in an external "make-up." After a couple of years the new plaster becomes stained and spoiled as the old one was, or else, if it is in cement, it swells and falls off, since the true cause of dampness, that is the water load in the framework, has not been eliminated.

CHAPTER III.

We have seen the failure of the different systems (Knapen syphons and their imitations, passive electro-osmosis etc.) with which we had tried to replace the old traditional and really efficient technique against rising dampness: that of the breach cut (Fig. 10).

This failure caused a scientific team devoted to the "study of the wellbeing of brickwork," belonging to CNR, to re-examine the traditional methods of cutting with the use of new and modern mechanical instruments and new waterproof materials. In fact, the traditional handmade cutting had many limits, as it destroyed the brickwork, was very slow and tiring and moreover it could not be performed when the thickness of the wall to be cut exceeded 75 cm.

The two innovations were: a small American device perforating the stone by a series of cylindrical holes that we employ to cut the wall horizontally in a rapid and gentle way (Fig. 20); and a new plastic material, polyester resin, to introduce in the cut the waterproof barrier interrupting the capillary threads. During the experimental phase, as shown on slides, the cut was opened on brickworks up to 1,60 m. thick. The base thickness of most monumental churches and houses does not exceed this limit. It is, therefore, possible to rehabilitate, by means of a new technique applied to the traditional procedure, nearly all old damp buildings, even those statistically unsafe or bearing delicate frescoes and decorations and that could not survive the handmade cutting, with chisel blows, as once happened.

Polyester resin (as waterproofing layer) is introduced in the cut in the fluid state and solidifies in three hours, bearing a weight of 900 kg. per square cm., three times as much as concrete can support. The whole process is demonstrated on the slides accompanying these lessons.

The cost of the rehabilitation work using rapid mechanical cut was in 1966 about 160.000 Lire per square metre of the horizontal surface of the cut wall. About a third of such cost is devoted to the use of cutting pipes, with the edge surrounded by a crown of small diamonds. A medium size church or house, with a damp wall perimeter of 50-100 linear m. would cost approximately, 6-13 million Lire. The work requires a period of three months.

The small 18th century church of St. Maria della Neve, next to the Colosseum in Rome was restored with this technique. When the aim is that of protecting an isolated fresco from dampness, it is not necessary to cut the whole perimetrical wall (as in the mentioned church); a U-shaped cut will be sufficient, that is a cut consisting of a horizontal section under the fresco and two vertical sections, one at each side of it, as shown in Fig. 21, representing the restoration of a beautiful fresco by Perugino, in Florence, that was attacked at the bottom by rising dampness. With the U-shaped cut the restoration cost is reduced to a minimum, and every fresco can be saved, avoiding the so-called "strappo" too often wrongly employed.

Since the traditional technique of the breach cut has been improved the problem of rising dampness can be considered as solved for in the case of monuments the real obstacle was not represented by the cost so much as by the lack of a truly valid operative technique. On the other hand it should be considered that the horizontal mechanical cut is effective when applied to brickwork above ground but of no use for the crypts, hypogeums or semi-buried churches, where condensation dampness is prevailing. And the cut could not do anything against condensation: this would be the same as putting medicaments on a wooden leg!

FIGURES

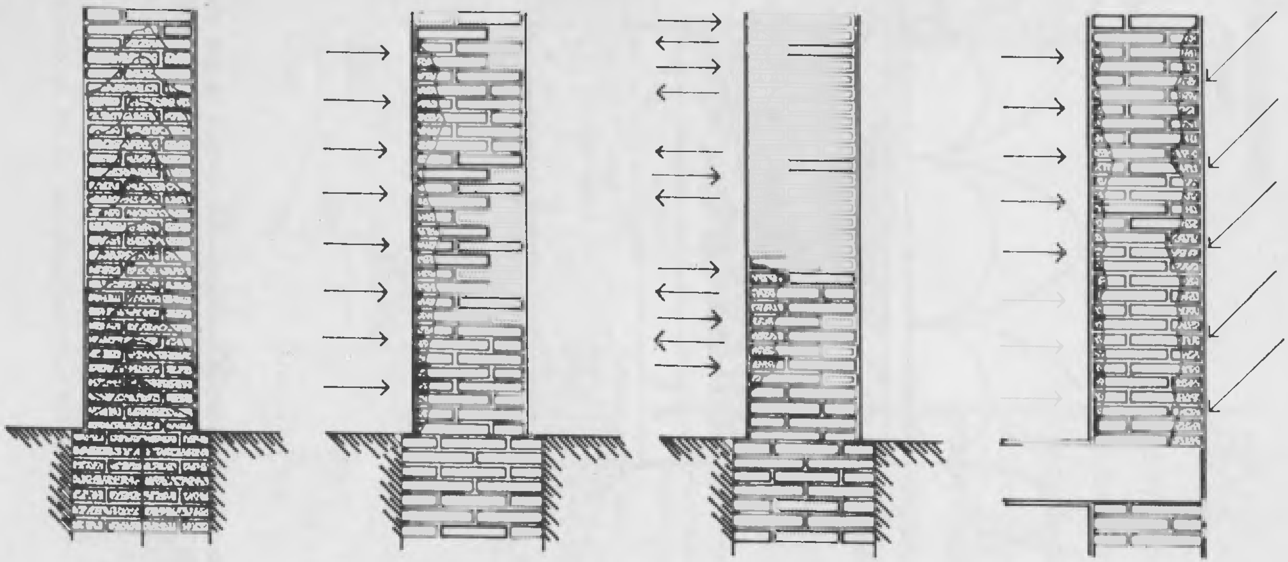


Fig. 1 - Four means of access of water into a wall: water rising from the ground, deposited by air all over the wall, entry in isolated areas, the result of driving rain.

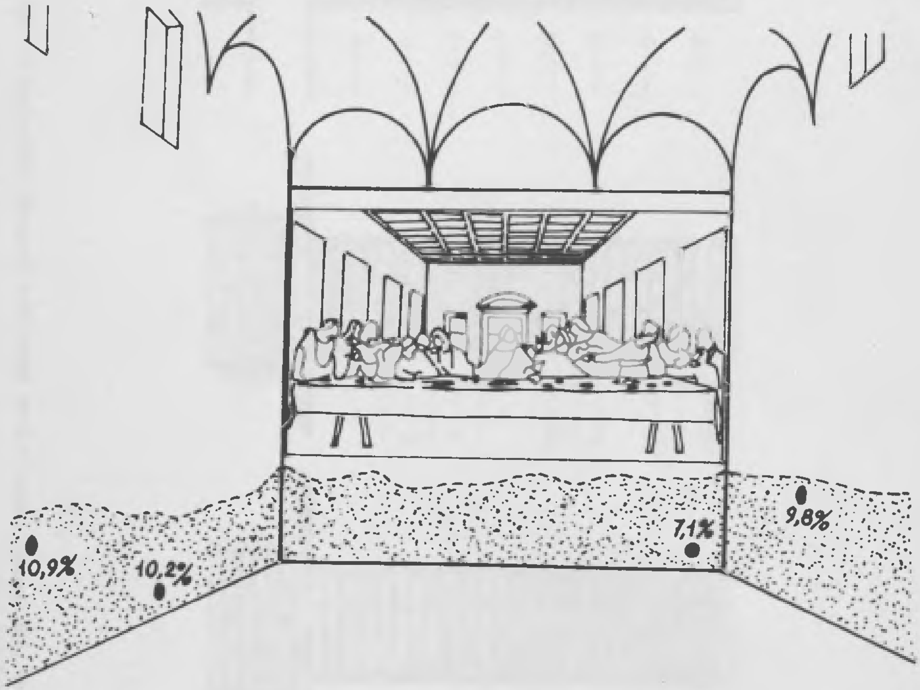
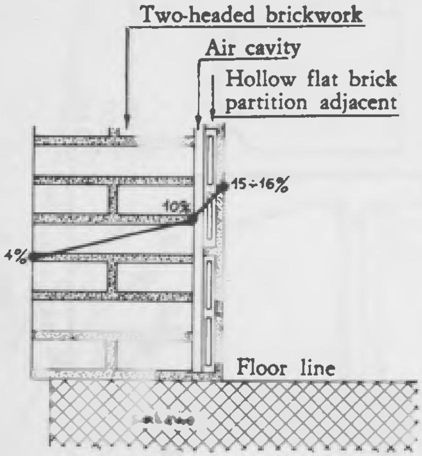
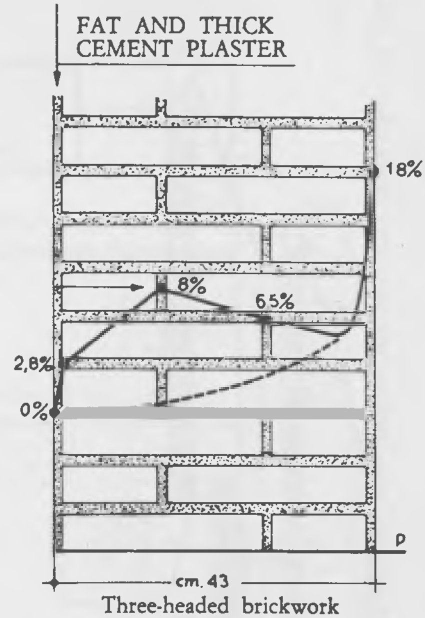


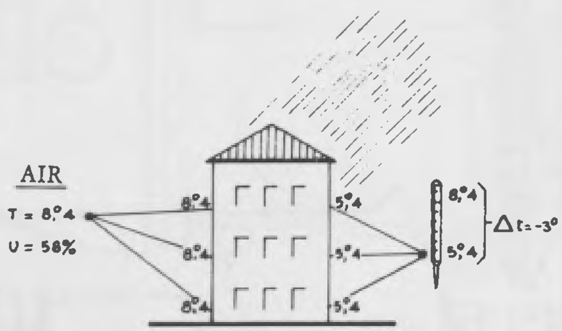
Fig. 2. - Leonardo's "Cenacolo" - Milan. The fresco is not reached by ascending dampness; nevertheless it is damaged by condensation of water vapour from the air.



Rainwater never passes through a wall; curve of the percentage of water in a damp wall of a tenement house in Mestre. The maximum (15%-16%) shows in this case that the water starting-point is on the inner wall. The absorption occurs through capillarity from damp to dry, that is from the inside to the outside, where the brick facing — immediately after drying — favours again the capillary migration.



Measurements taken in a tenement house wall (Chiadino in Monte, Trieste), exposed to the effects of strong wind and rain.



Among Italian towns, Genoa has the driest air in winter, and yet it is one of the most exposed towns to wind/rain dampness; this sort of dampness comes from the quick evaporation of damp walls, as the air is on an average very dry. On the rain beaten side, it is as if the external temperature of the air had decreased from 8.4° to 5.4°C.

Fig. 3 - Generally, driving rain cannot pass through a thick wall; however, it cools it strongly causing condensation on the inner surface, notably in churches and in crowded houses.

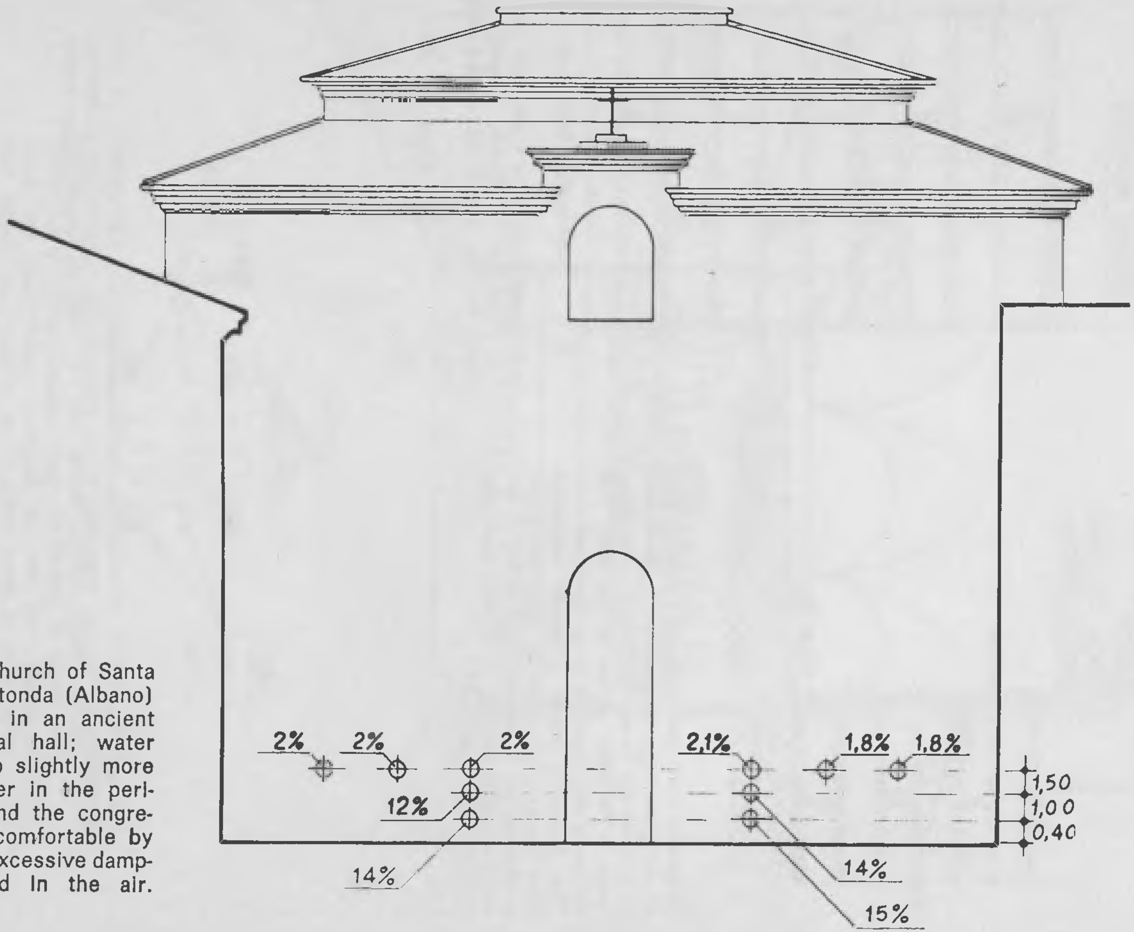


Fig. 4 - The Church of Santa Maria della Rotonda (Albano) had its origin in an ancient Roman thermal hall; water mounted up to slightly more than one meter in the perimetral wall, and the congregation felt uncomfortable by reason of the excessive dampness contained in the air.

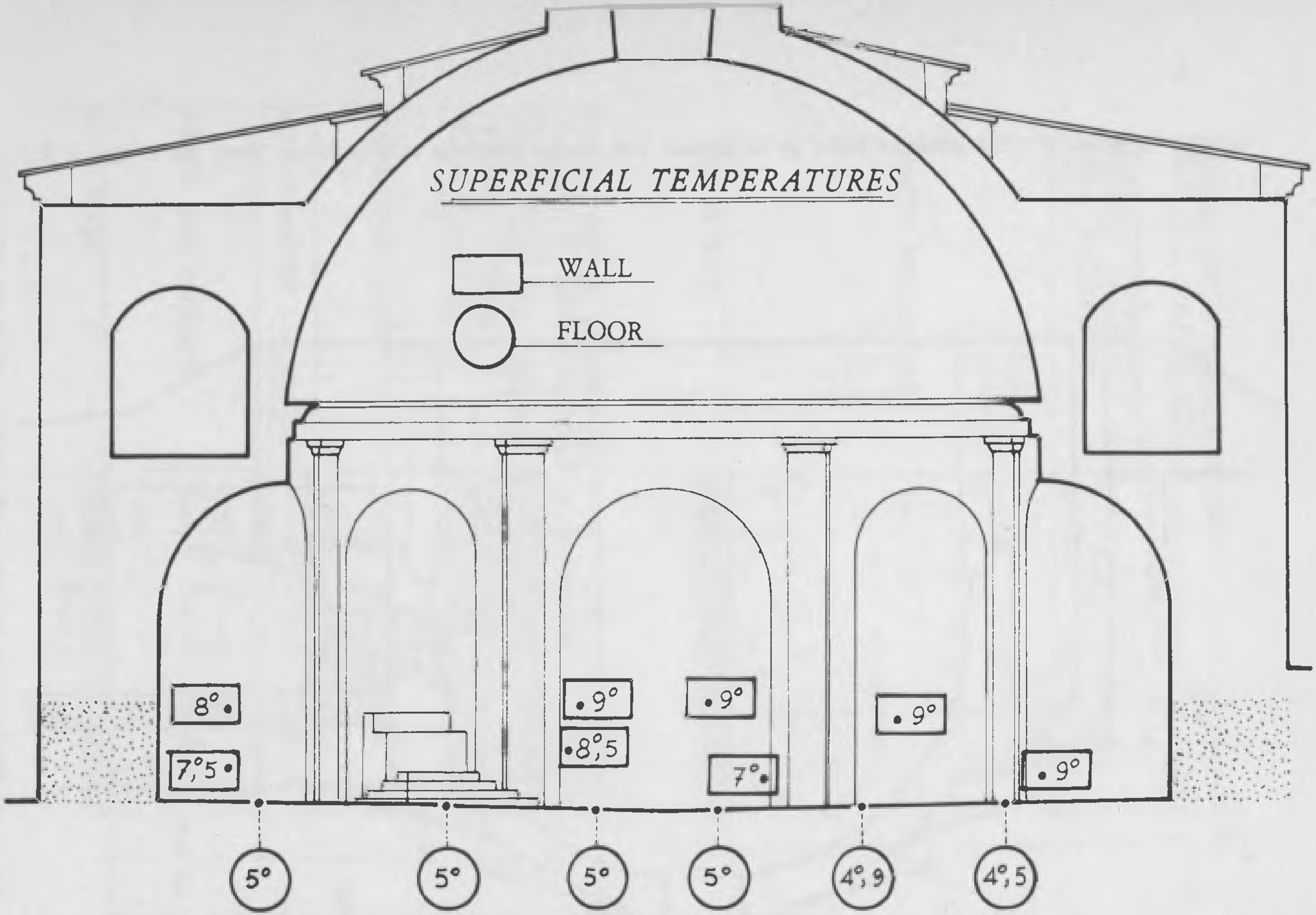


Fig. 5 - Study of the superficial temperatures demonstrated that the floor was excessively cold, compared with the wall, thus producing condensation.

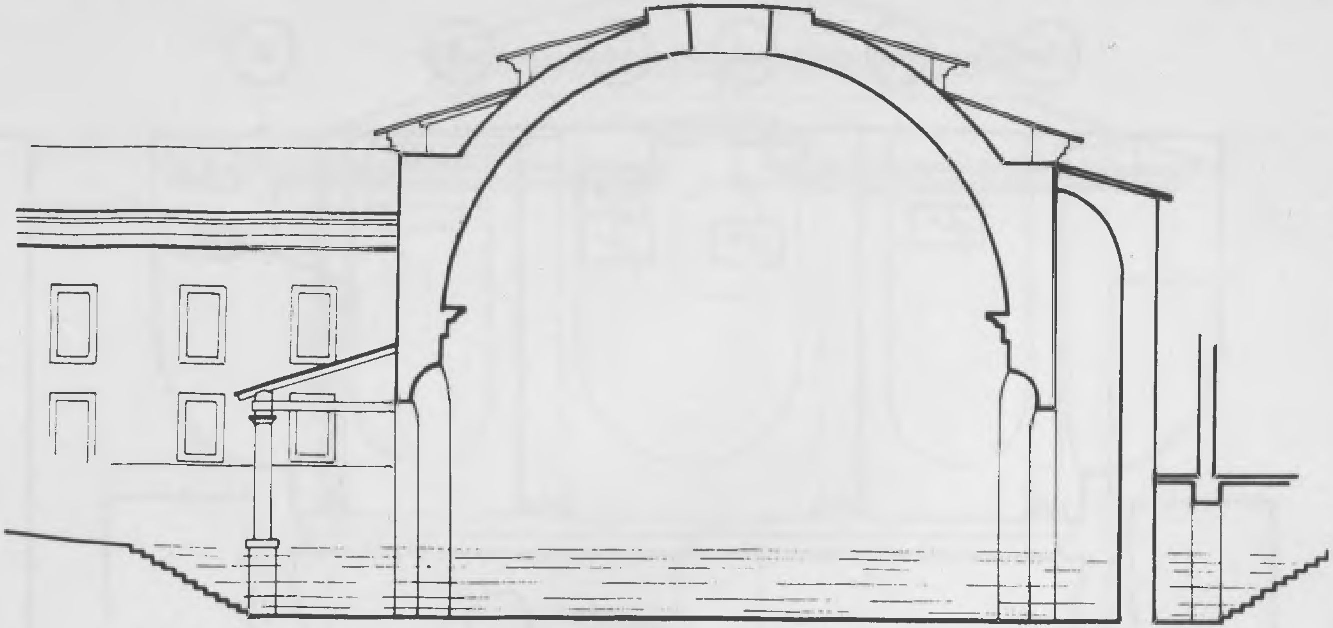


Fig. 6 - The cold, damp, heavy air was stagnant without any possibility of being changed as if it were in a basin.

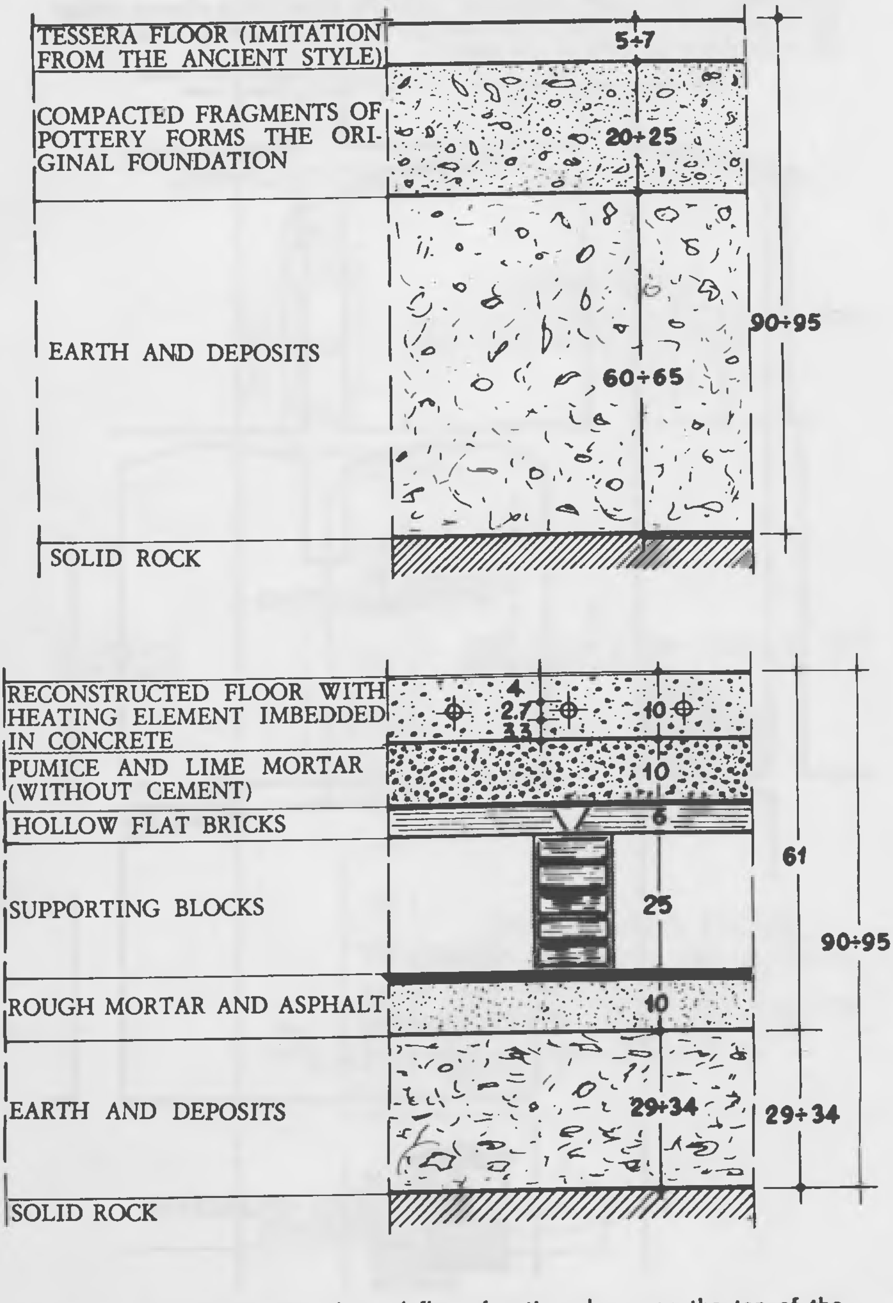


Fig. 7 - The old massive thermal floor (section shown on the top of the page) was taken away and a new floor was built having an air cavity and pumice structure (section shown above).

Vertical section of the wall supporting the damaged fresco. The previous conventional diagnosis was "capillary dampness mounting from the floor," either due to impregnation of the wall under the fresco (from adjacent ancient salt storehouse) or to absorption from the rain water channel collecting in the large square in front of the palace.

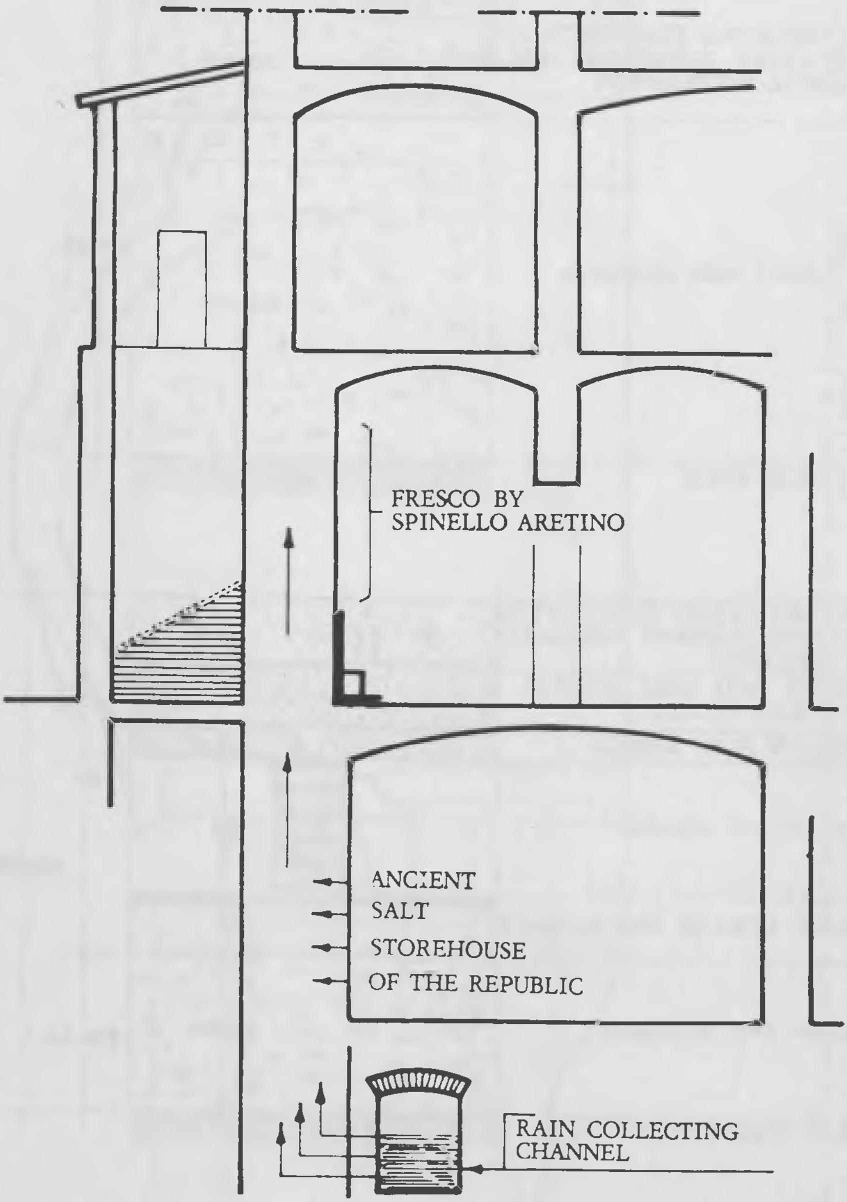


Fig. 8 - The ununsual case of a damp fresco, among other dry frescoes on the first floor of the Siena Townhall.

The instrumental diagnosis (October 1960), based on the measurement of the water in the wall, demonstrated that the wall was perfectly sound and dry, both above and underneath the floor.

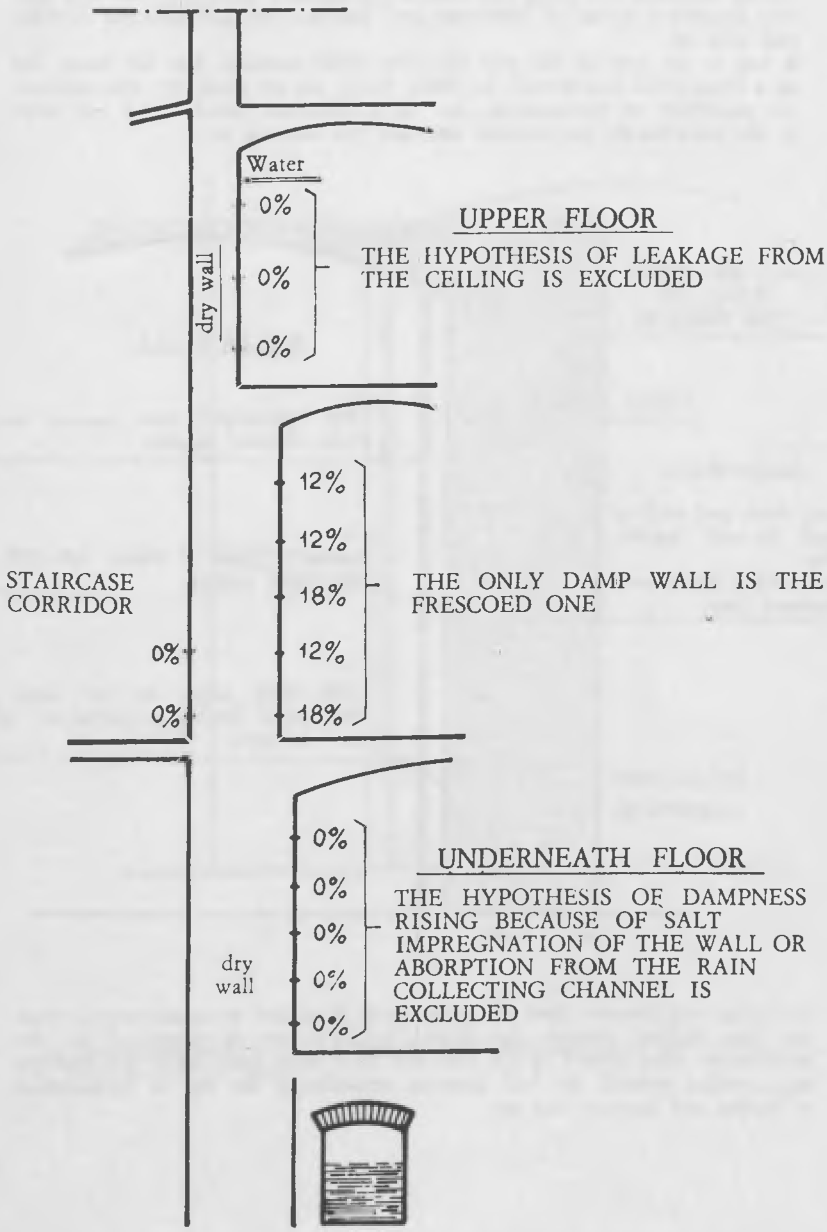
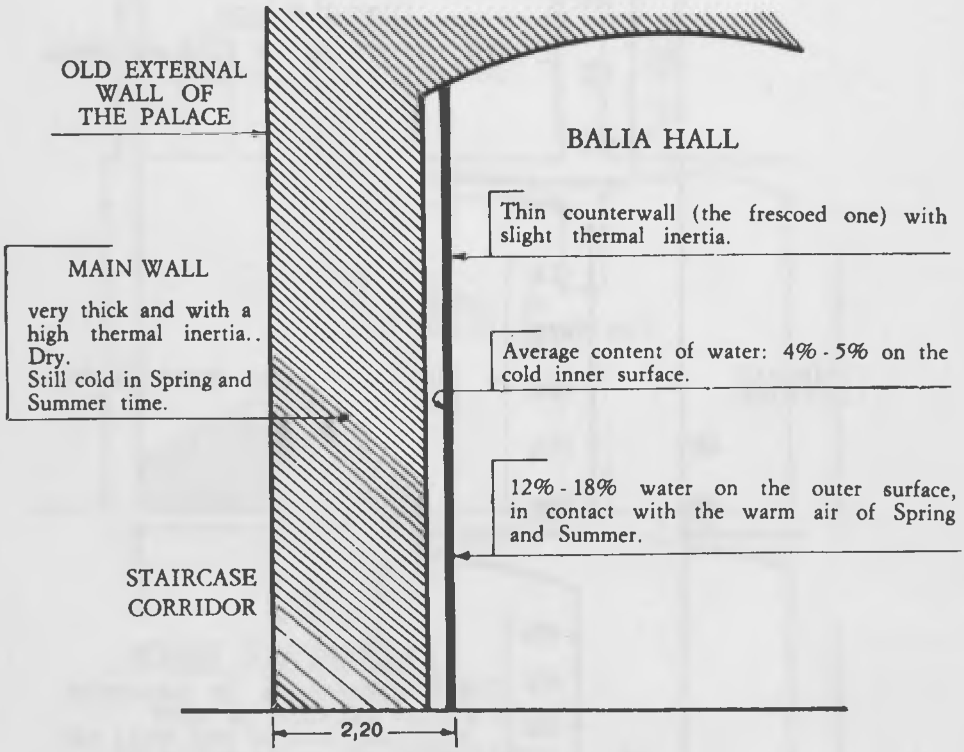


Fig. 9 - Measurement of water contained in the frescoed wall.

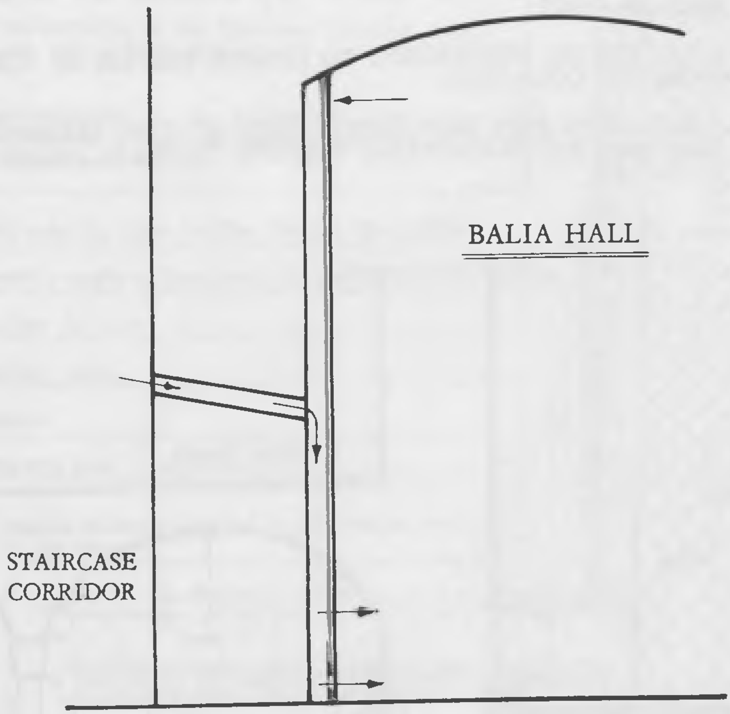
Having excluded the rising and descending capillary dampness, the only possible hypothesis is that of "condensation," due to a thermal difference between wall and air.
A test at the base of the wall (October 1960) revealed that the fresco lies on a Siena brick counterwall, in which bricks are set vertically; this confirms the possibility of condensation due to a difference between the two sides of the counterwall, the internal one and the external one.



In Spring and Summer time the counterwall is subject to condensation, since the side looking towards the closed hollow space is submitted to the temperature delay caused by the cold and thick main wall; while the frescoes side, looking towards the hall, receives immediately the rise of temperature of Spring and Summer free air.

Fig. 10 - The double structure of the wall previously considered single.

The remedy employed to eliminate condensation consisted in ventilating the hollow space, in order to obtain the same temperature on the two sides of the counterwall.



The water contained in the frescoed wall gradually decreased from 12% - 18% in 1960 to 4% in 1964.

Fig. 11 - In a few years dampness was eliminated at small cost by establishing the same air temperature in front and behind the fresco.

STRUCTURES PRODUCING CONDENSATION OF WATER VAPOUR BY THERMAL INERTIA:

(a) FLOOR WITH A HIGH SPECIFIC GRAVITY WITH A CEMENT-CONCRETE FOUNDATION LYING ON DAMP SOIL WITHOUT AN INTERPOSED HOLLOW SPACE.

(b) COUNTERWALL INSUFFICIENT TO ISOLATE THE AIR OF THE CRYPT FROM THE COLD WALL.

(c) A SOLID CONCRETE DAM ADDED EXTERNALLY TO PREVENT DAMPNESS BUT UNDESIRABLE FOR THE THERMAL INERTIA THAT IT CAUSES.

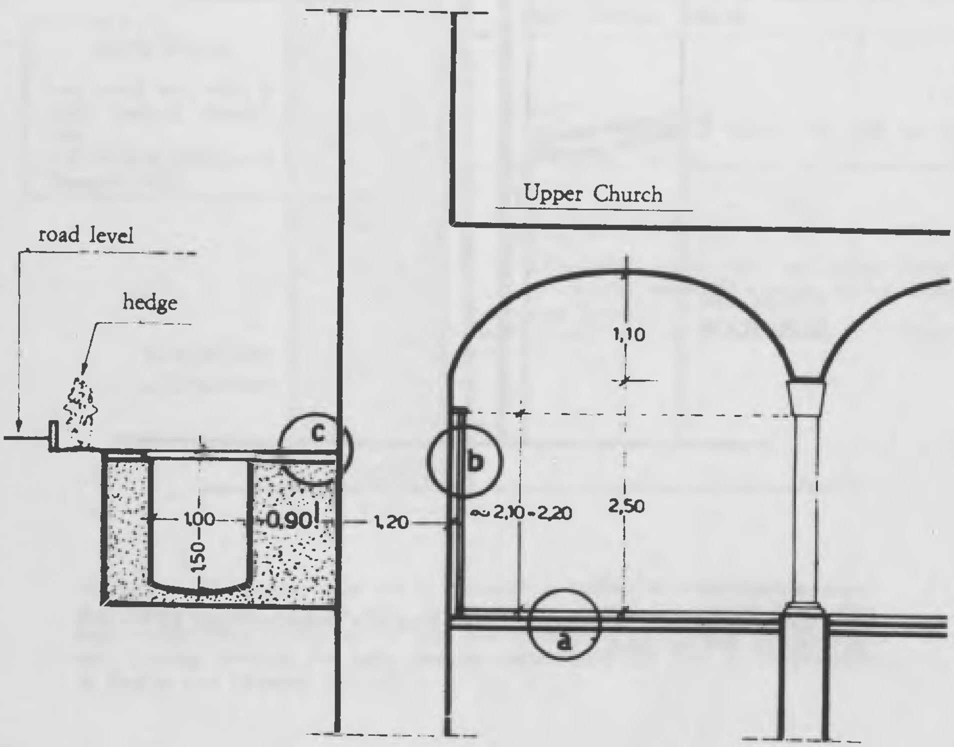


Fig. 12 - Crypt of S. Colombano (Bobbio).

VERTICAL SECTION

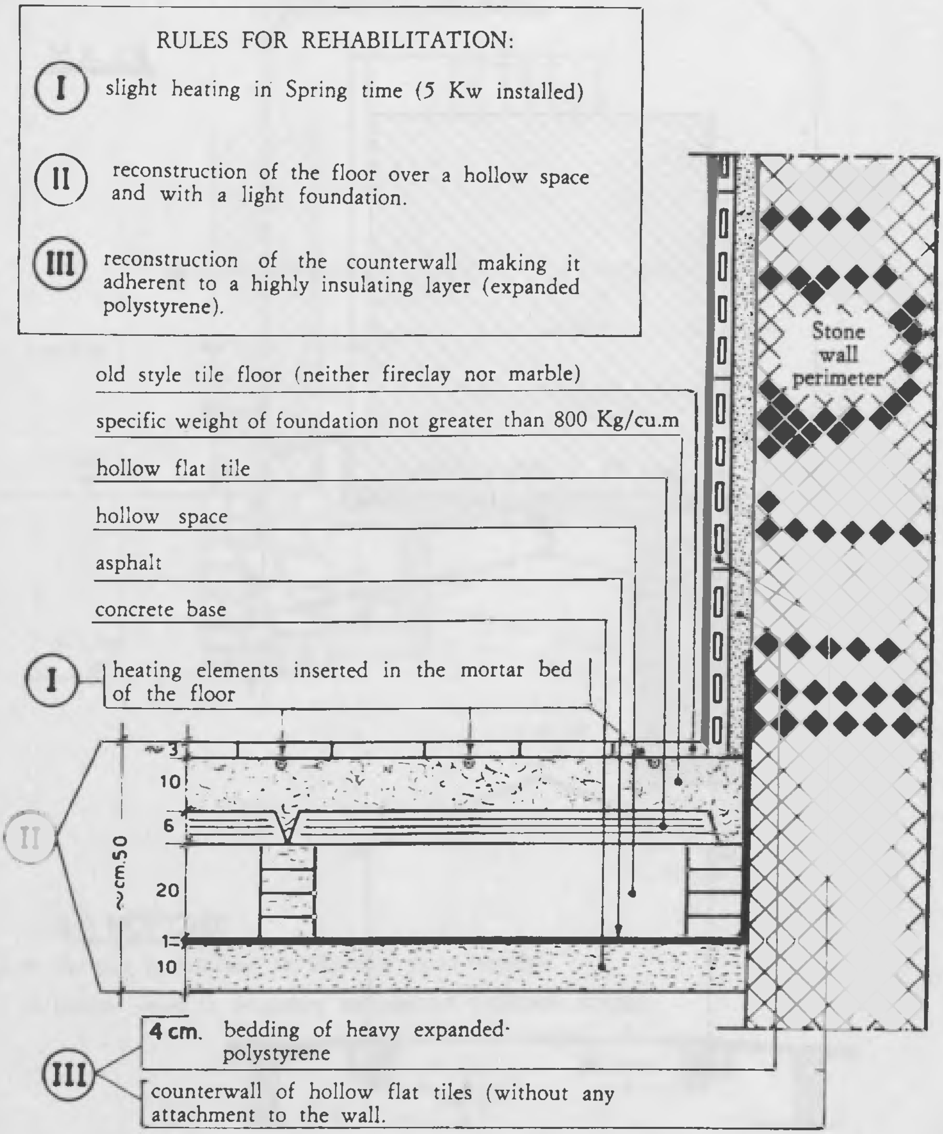


Fig. 13 - Crypt of S. Colombano (Bobbio).

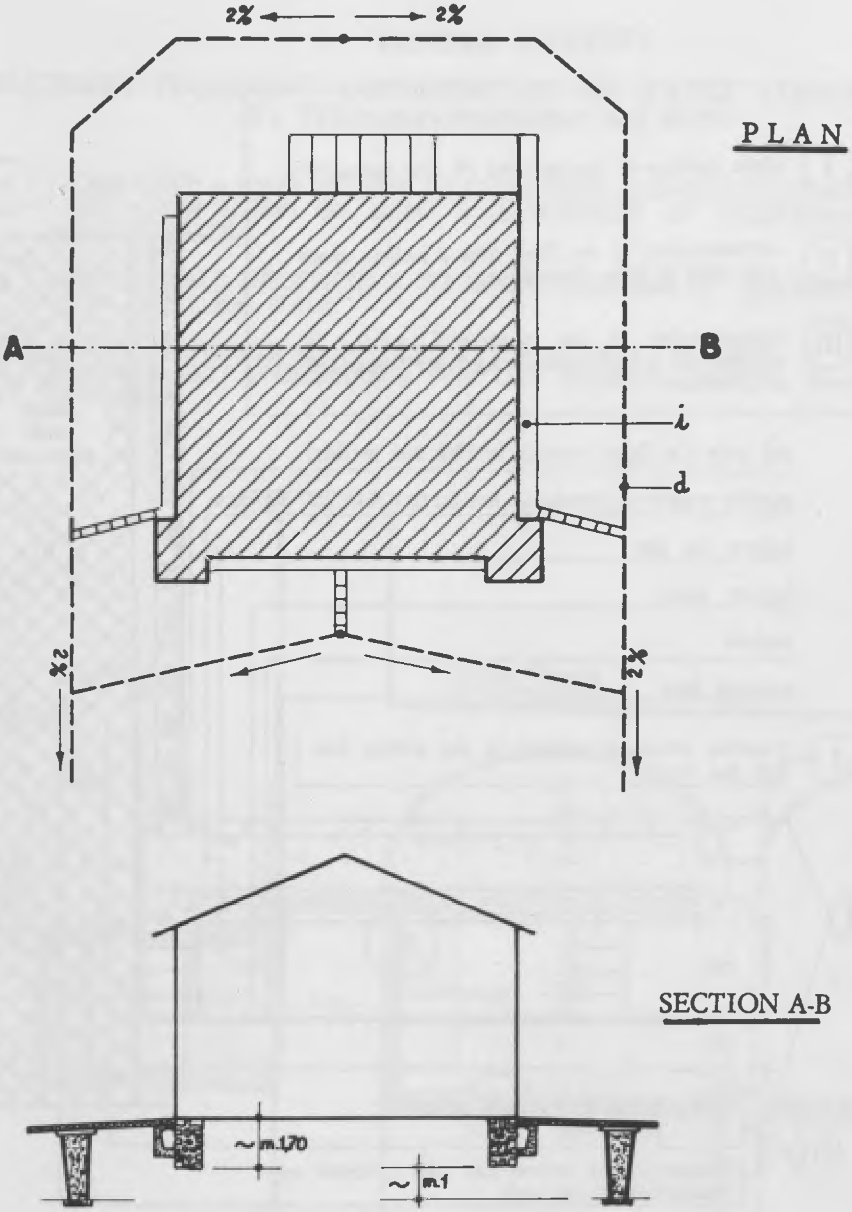
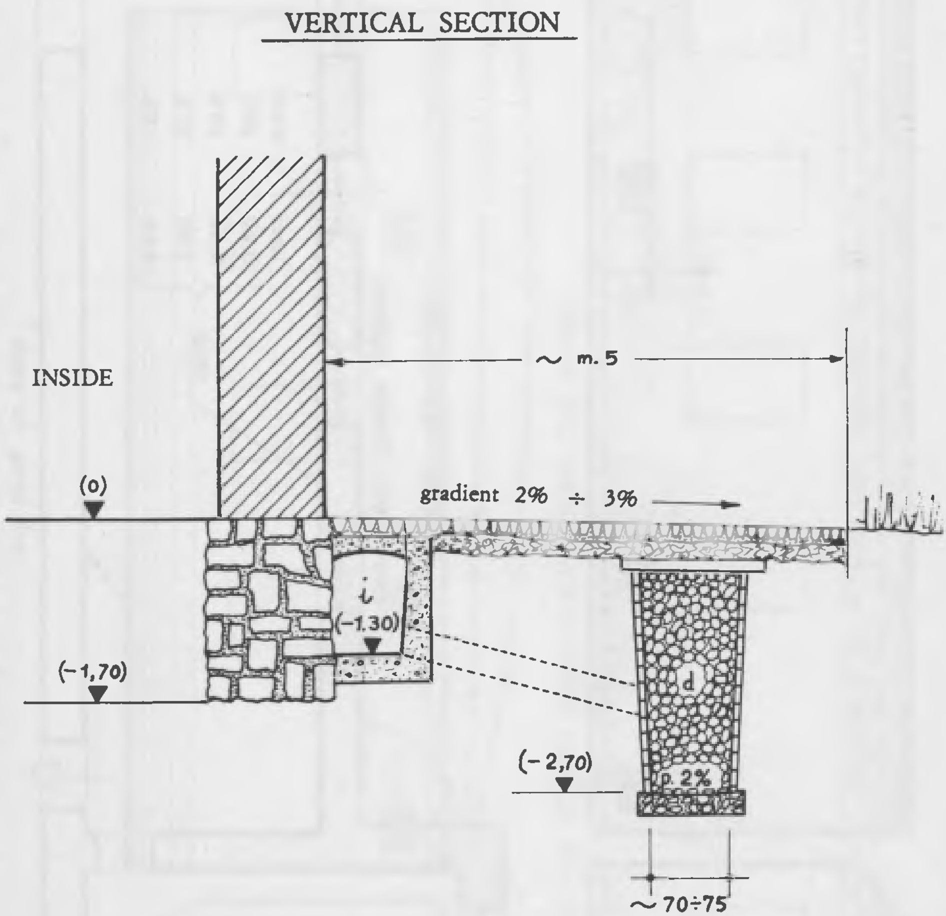


Fig. 14 - Scheme for floor drainage surrounding an old villa in the country near Rome to prevent damp ascending in the walls.



d = drainage (specifically to eliminate water supply).

i = hollow space (a secondary measure to accelerate drying)

Fig. 15 - Detail of the operation in a clayey ground.

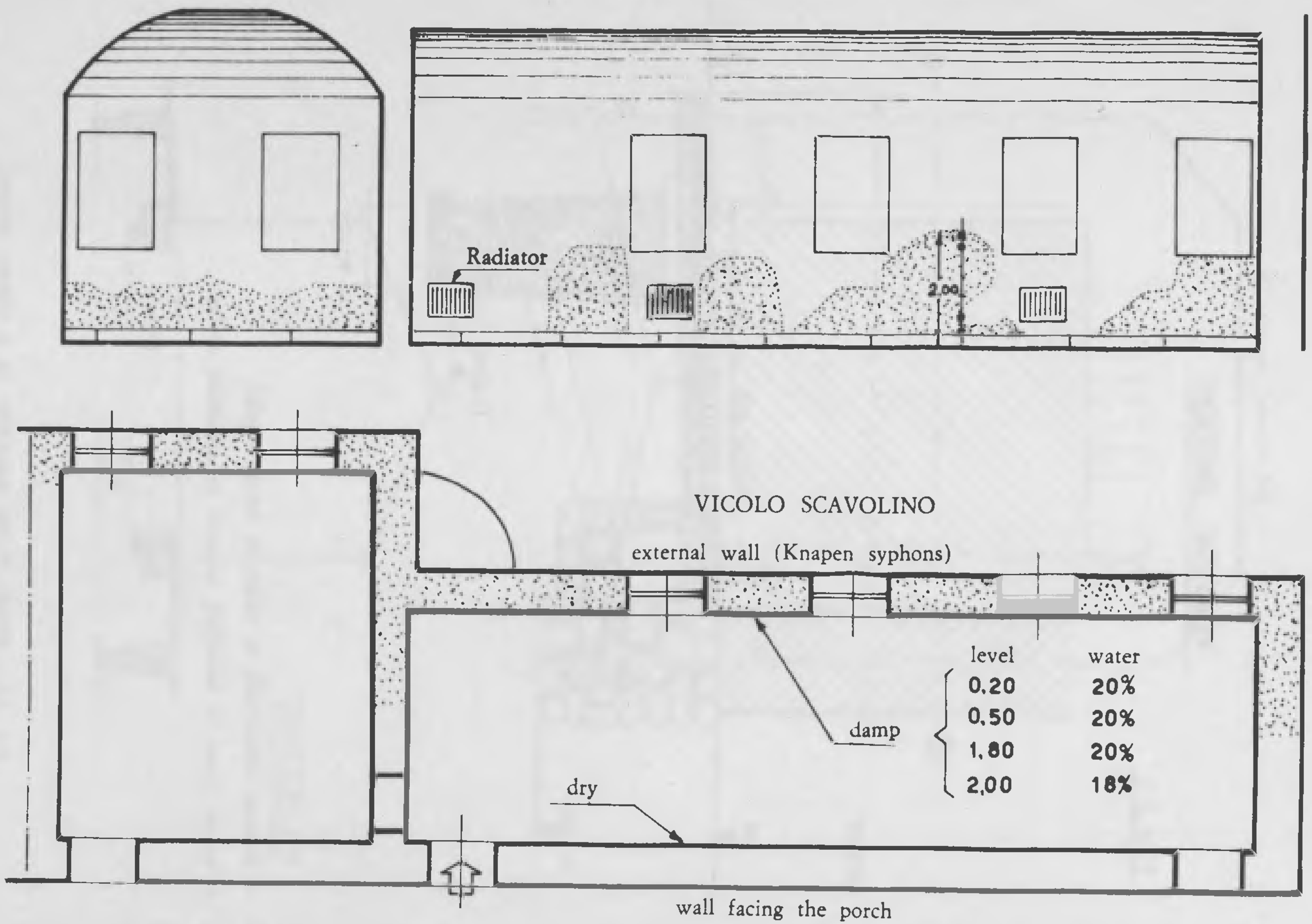


Fig. 16 - The Knapen syphons were employed about 30 years ago in the Palazzo dell'Accademia di San Luca without any effect at all against dampness, wrongly diagnosed as coming from a water bearing stream.

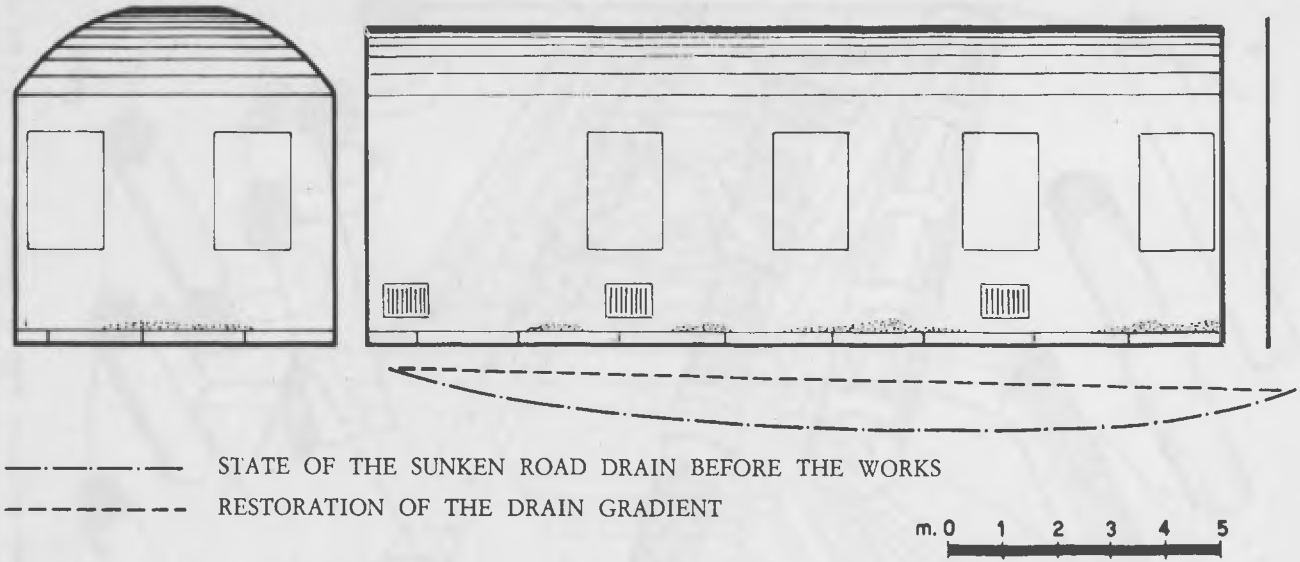


Fig. 17 - The measurements of water contained in the different walls show that the cause of the damage was simple and limited. It was sufficient to restore the road drain and in 3 years time the wall became dry again.

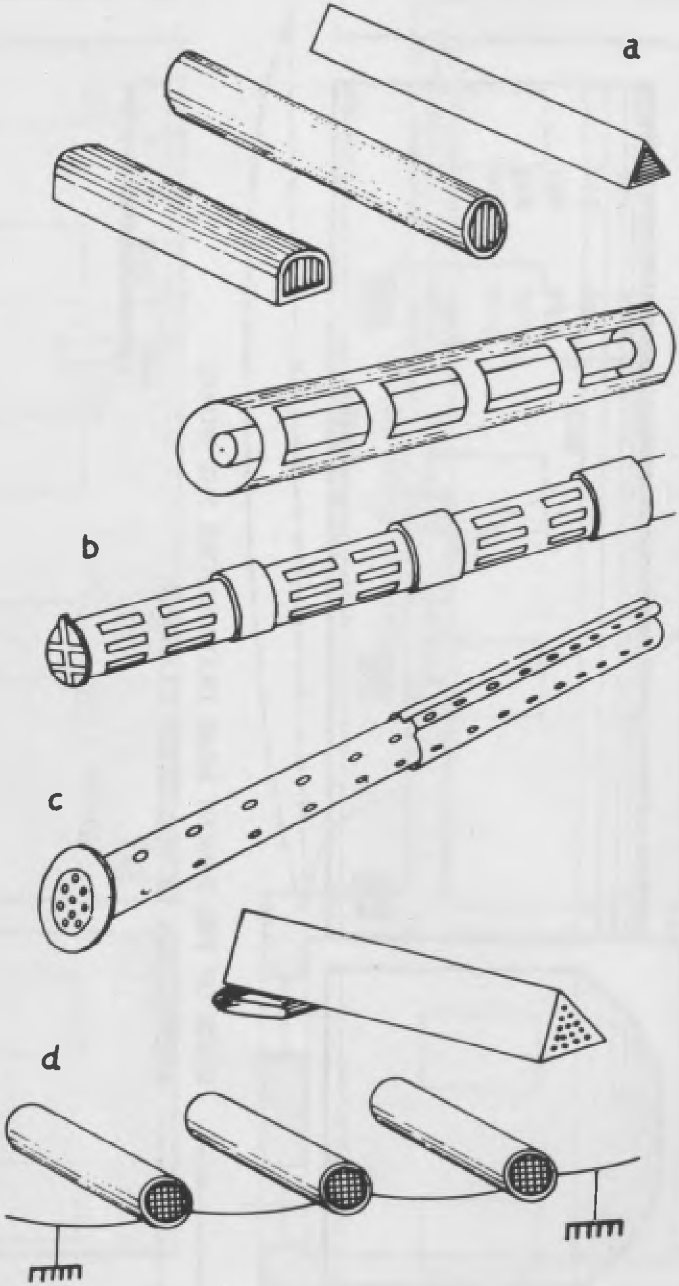


Fig. 18 - Recent imitations of Knapen syphons; they have all proved to be useless against ascending dampness.

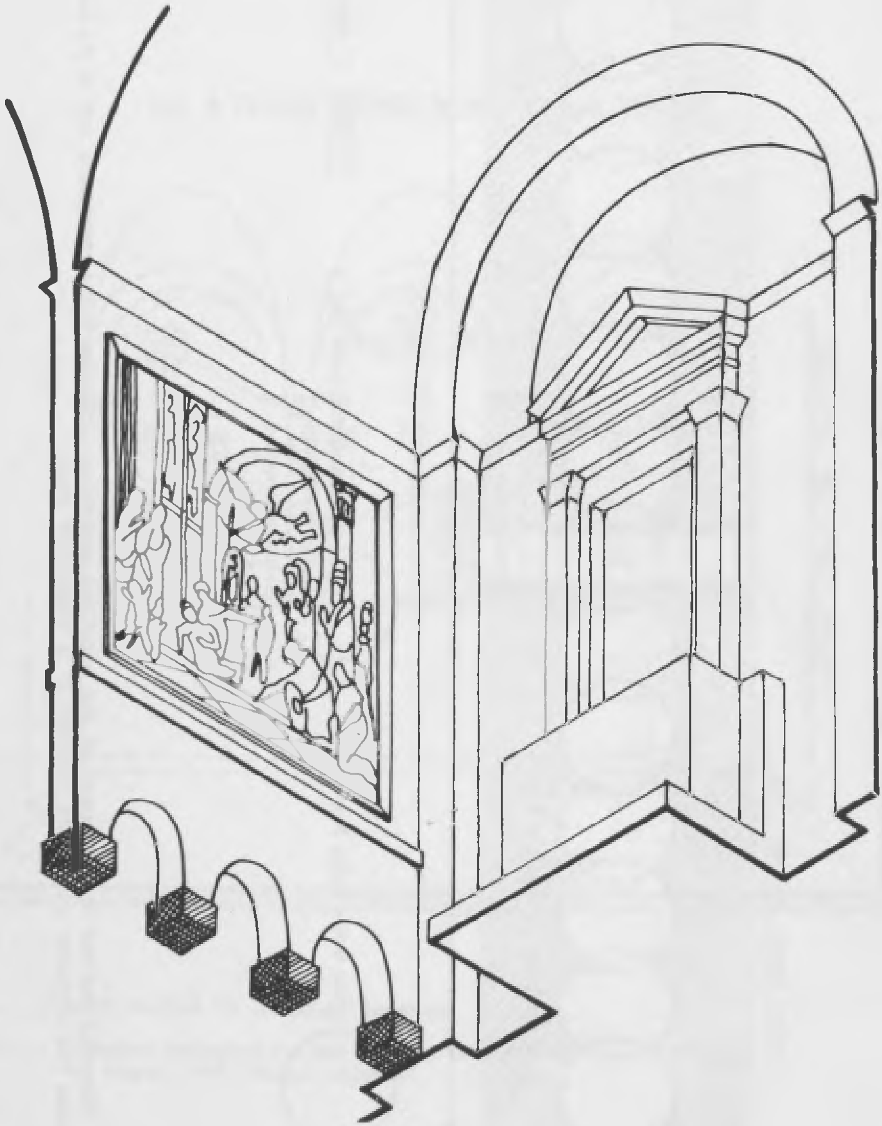


Fig. 19 - The best technique to fight ascending dampness is the traditional cut in the wall with the insertion of an isolating layer. This is the fresco by Domenichino, in the Church of S. Luigi de' Francesi (Rome), saved by Arch. Koch with small arches placed on waterproof basalt plinths.

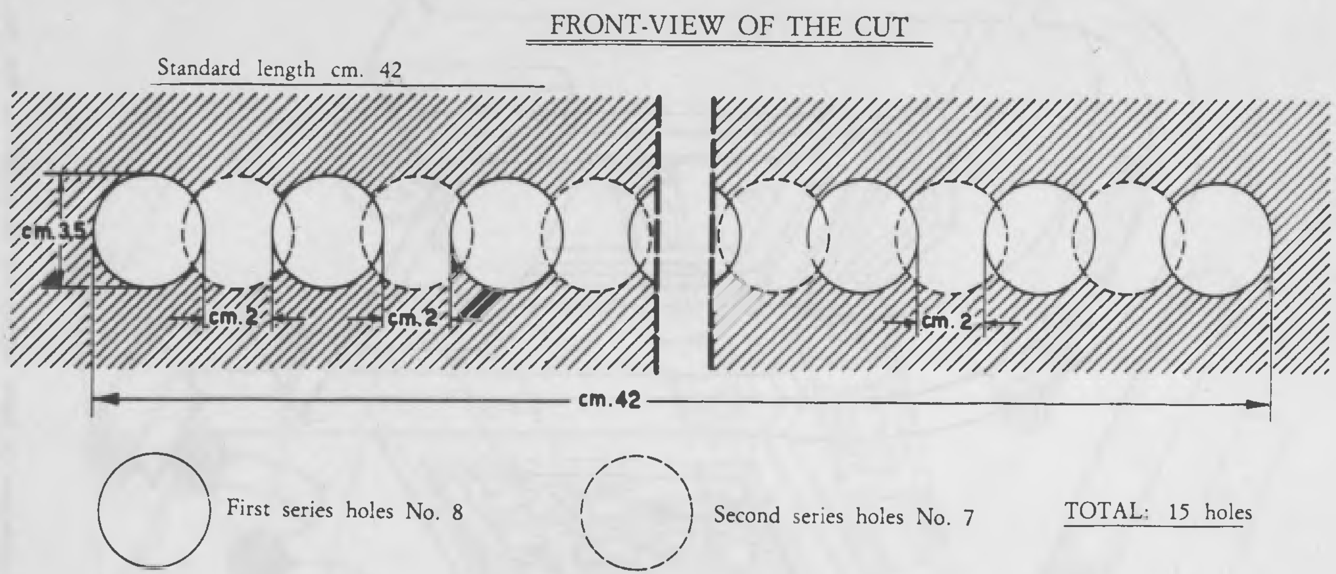
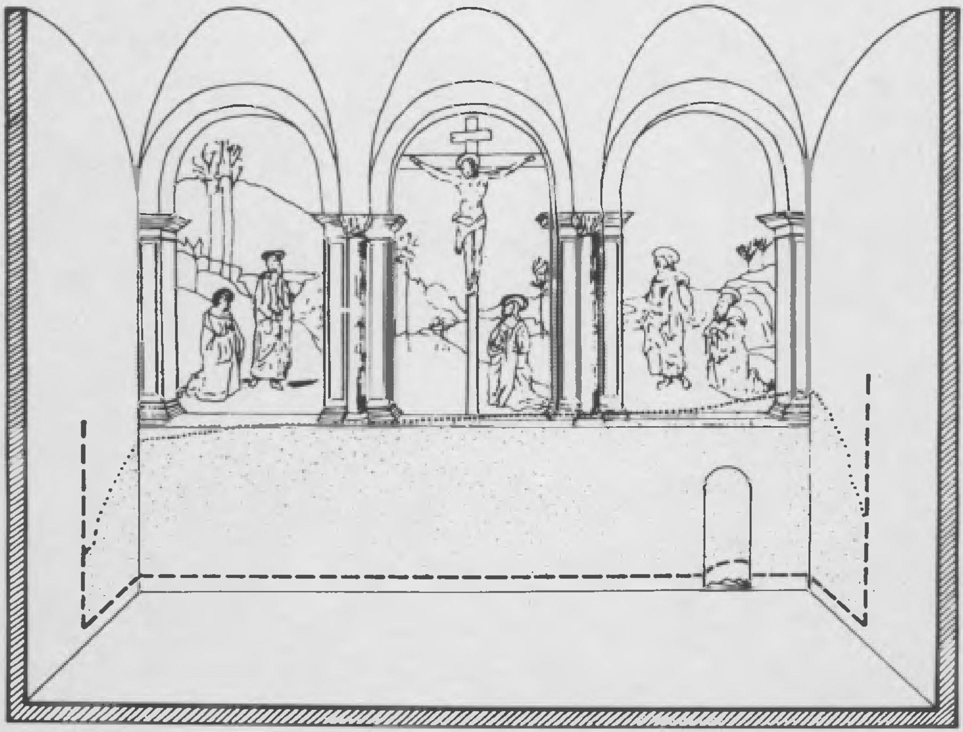


Fig. 20 - Massari's method is a renewal of the traditional technique, consisting in the mechanical cut of the wall with a continuous row of holes, and in the insertion of a waterproof resin.

ON A HARD STONE WALL 80 cm. THICK



.... Level reached by ascending dampness.

–––––– U-shaped brickwork cut and isolation with polyester resin, performed in August 1968 (Massari method).

Fig. 21 - Fresco by Perugino, in the convent of Santa Maria Maddalena de' Pazzi (Florence).

RISTAMPATO MARZO 1977