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Summary report on existing methods against rising damp

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SUMMARY REPORT ON EXISTING METHODS AGAINST RISING DAMP

1. Relevance of the problem of rising damp in building

The presence of water in historic masonry structures is one of the most relevant problems affecting architectural heritage. The water can have different origins: accidental causes, condensation, wind driven rain, hygroscopic salts, flooding, and capillary rise from the ground (where water is supplied by aquifers under clay soils, underground water channels, agricultural irrigation and poor drainage or rainfalls [1]). In all these cases we are concerned with a single fundamental process, the movement of water through a permeable material whose water content is non-uniform and generally less then saturation [2].

The capillary rise of ground water in masonry walls is a well-known phenomenon in ancient buildings and one of the most recurrent hazards to monuments. The phenomenon of rising damp is more recurrent in old than new constructions, due to the fact that the old buildings have often masonry foundations and lack of a damp-proof course, i.e. of a layer hindering the water transport from the ground to the upper structure. Besides, old buildings can be affected by rising damp due to the kinetics of the rising damp process (old buildings could be more prone to rising damp since they were subjected for longer times to the presence of water on the foundations) and to the modification of environmental conditions during time (e.g. in Venice the occurrence of higher tides, or seismic movement or movement of phreatic aquifers).
The phenomenon of rising damp is quite slow; this means that damage to the building materials and structures may become visible only after several years from the construction or restoration intervention. Besides, changes in the ground water level may also affect the height to which the water rises in the wall. Also the presence of salt in the masonry may have a marked effect on the speed and height of the rising damp[3].

The presence of rising damp in walls does not only create an unpleasant climate in buildings due to the fact that a wall affected by rising damp is also a significant source of water vapour [4], but it also enhances damage processes as degradation of building materials (rotting of timber beams, detachment of plaster, moisture spots wall paper), poor thermal insulation efficiency of the external walls, decrease in mechanical performance of the masonry, frost action, salt crystallization and biological growth, with possible consequences on the health of the inhabitants [1, 5]. Furthermore, the presence of moisture can strongly affect the thermal performance of masonries, resulting in increased energy costs in heating or cooling of buildings [6]. Due to climate changes, as the increased frequency of events with long and intense rainy periods, the rise of sea level and the variations in the ground water table, the occurrence and the relevance of rising damp will probably increase in the coming decades [7-10].

The relevance of the problem of rising damp is reflected by the large variety of methods and products against rising damp on the market (figure 1). Existing methods include mechanical interruption, chemical interruption i.e. injection (with pressure) and impregnation (without pressure or with hydrostatic pressure only), methods based on evaporation increase and several electrokinetic methods (as electro-osmosis). Some of these methods (for example the injection with water repellent products) can be suitable to stop the ingress of capillary water, but are not effective in the case hydrostatic pressure is present.

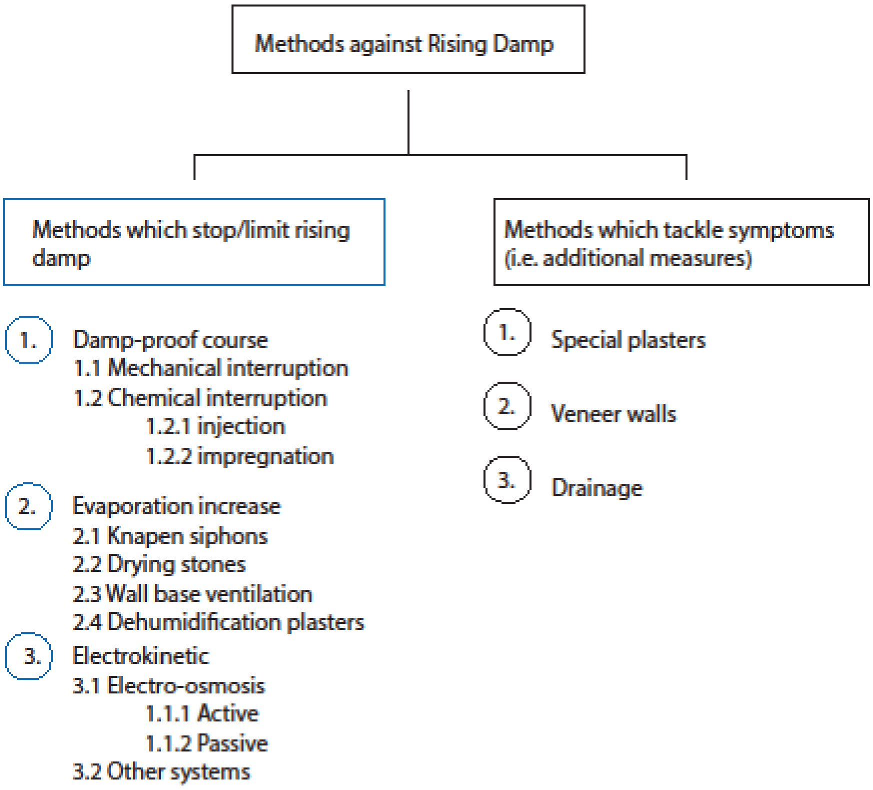


Figure 1 Overview of current methodes (Miedema, L.)

Next to methods aiming at stopping or reducing the moisture source, other solutions exist, which are mainly tackling the symptoms, such as the use of special macro porous and/or salt resistant plasters, or the use of veneer walls.

In this report the methods to stop or limit rising damp, defined as the capillary rise of water, are described. The methods which are only tackling the symptoms, which means they do not stop or limit the capillary rise of water, as veneer walls, are left out. Methods which increase evaporation, such as dehumidification plasters, are described as methods to limit rising damp. This is because these methods do not reduce or stop the ingress of water, but, by enhancing evaporation, lead to a reduction of the height reached by the rising damp in the walls, thus limiting the rising damp.

Because of the diffusion of the use of methods based on electrokinetic it is expected to increase, particular attention is given to these new systems. The diffusion of these methods and products in the participating countries will be discussed in conclusion of the project.

1.1 Definition of rising damp

Rising damp is defined as the capillary rise of water from the ground to the walls of a building. There are different possible sources of rising damp:

- by vertical transport of moisture from the ground under the foundations (figure 2, arrow A)
- by horizontal transport of moisture from the ground adjacent to the wall (figure 2, arrow B)
- by surface water (rain water that accumulates in the ground) (figure 2, arrow C)

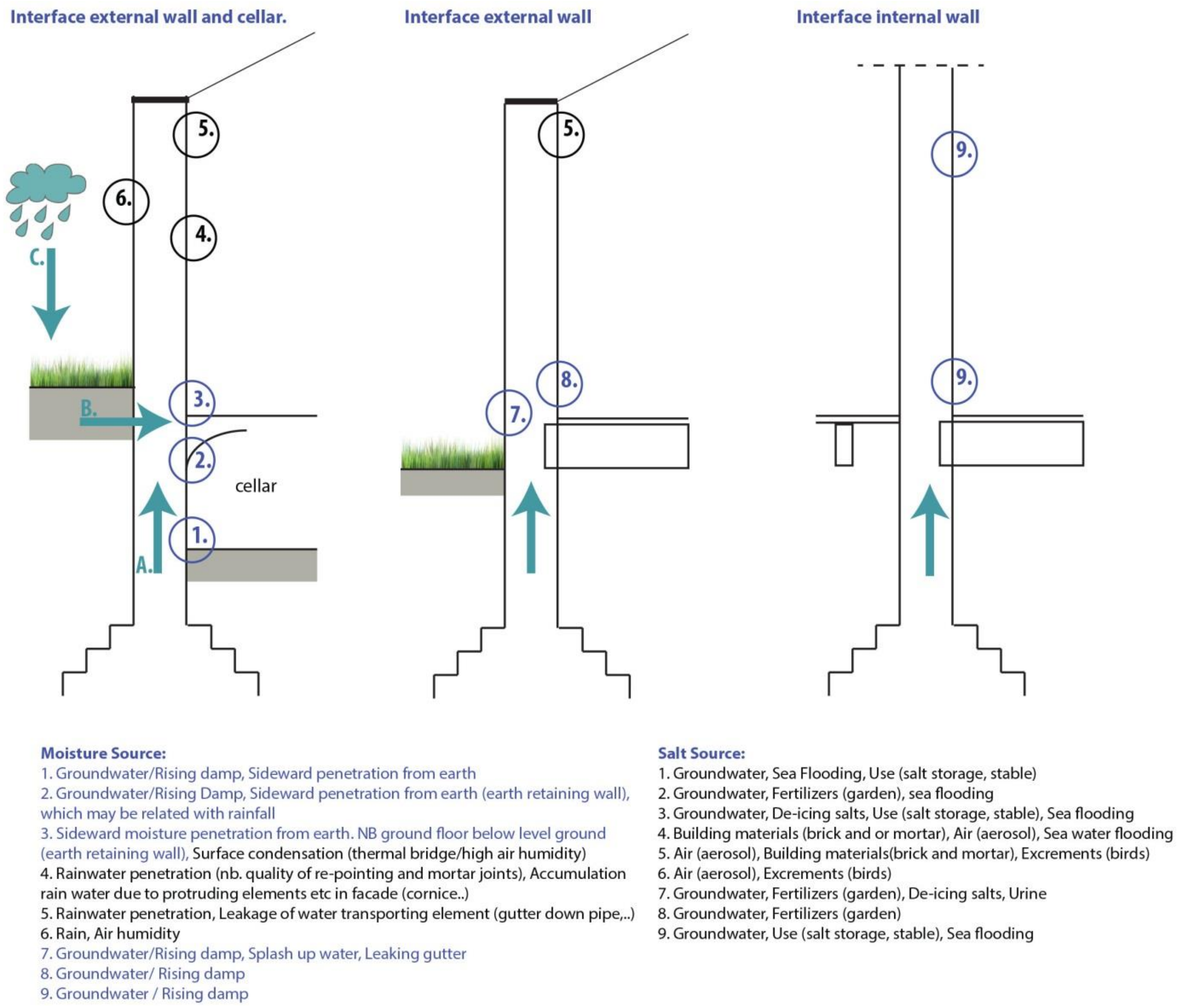


Figure 2 Moisture and salt sources (Miedema, L. /based on MDDS)

Rising damp may occur even when the foundations are not in direct contact with the groundwater of surface water. In fact, above the groundwater level, the ground can still contain a large amount of water, which has migrated from the groundwater zone to the upper zone by capillarity. When the foundations are in the capillary zone, rising damp may still occur in the wall. The presence and thickness of this capillary zone in the soil depends from the type of soil and its moisture transport properties.

A wet wall may also be the result of rain water (surface water) that, not properly collected, accumulates in the ground and rises up by capillarity into the wall. It is important to distinguish between rising damp from ground water and rising damp due to insufficient drainage, since the solutions for tackling the problem are different.

1.2 Principle of capillarity

Capillarity is the mechanism governing rising damp in a wall [4, 11]. Capillary forces can transport water from the ground into the wall, against the gravity forces. Capillary is a consequence of surface tension and capillary forces take place in the pores of the material [11]. Because of the attraction between water and the pore walls of the building materials, water rises in the capillary and a meniscus is formed. The capillary rise is due to the prevalence of the adhesion forces between water and capillary surfaces compared with the cohesion forces of the water itself [1]. For most cases capillary forces are dominant and the effects of gravity can be neglected. The total inflow of absorbed water is controlled by transport properties of the wall and the total evaporative loss. Therefore applying a low-permeability render coat to damp-effected walls is a poor solution because of reducing the water evaporation and increasing the height of the water rise in the wall [11]. Similarly, very strong drying conditions may reduce the water content resulting from capillary rise, whereas poor drying conditions may exacerbate the problem [4].

The maximum height of rising damp can theoretically, in homogeneous materials, reach many meters; however, in practice, due to the presence of boundaries between materials with different pore sizes (e.g. example mortar or brick with different microstructure) and due to evaporation, the maximum level reached by rising damp in brick and stone masonry is generally limited to 1-2 meters. Rising damp causes a characteristic distribution of water content inside the affected wall, with an high moisture content at the base of the wall (up to saturation of the material) which slowly declines up to the wall. Ground water often contains small amounts of soluble salts (mostly chlorides, nitrates and sulphates) that are transported with the water up in the wall and are left behind when the water evaporates; at the upper fringe of rising damp, salt efflorescence are visible. The soluble salt are deposited at different heights in the wall depending on their solubility (fractionation): the less soluble salts (e.g. sulphates) generally precipitating in the lower part and the more soluble (chlorides and nitrates) in the higher part of the wall [12].Besides, it should be mentioned that the practice situations is very complex, as next to the presence of salt mixtures, condensation, hygroscopic moisture upatke etc contribute in transporting soluble salts in a wall.

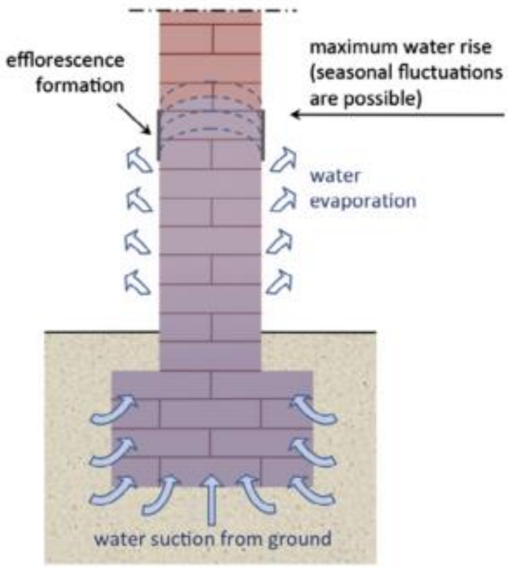


Figure 3 Schematic representation of water capillary rise in masonry [1]

2. Intervention methods against rising damp

There are different types of intervention possible to stop or limit rising damp from ground water. In this report the methods are grouped according to figure 1, and shortly described. For each method advantages and limits, as resulting from the literature, are mentioned. Besides the expected compatibility of each method with historic buildings is considered. An intervention can be defined compatible if it does not cause or enhance any damage (technical or aesthetical) to the historic building on which it is applied.

2.1 Systems based on the creation of a damp-proof course

First the systems based on the creation of a damp-proof course are discussed. With this technique an low absorbing or impermeable barrier at the base of the wall is created, just above ground level [13]. These systems can be further subdivided in mechanical interruption and chemical interruption methods.

2.1.1. Mechanical interruption

Mechanical interruption consists in the insertion, after removal of a joint or of a course of masonry, of an impermeable layer or a layer with a low water absorption in the wall.
As earlier mentioned, rising damp is strongly related to the use of brick foundation and the lacking of dense layers at the bottom of the walls. The possibility of using a low absorption materials as a barrier in the wall in order to stop rising damp was already known in the old times. In locations affected by rising damp, brick masonry was often built inserting special layers of natural stone just above the floor level. The low porosity of the stone was expected to hinder the water capillary rise [14]. For example, in Venice traditional construction method use Istria stone curb or base with a low porosity (figure 4). In other cases, layers of masonry with specific brick and mortar, with a low porosity, were used; in Dutch this is known as “trasraam”[5].

Figure 4 Alberaria Tower (Venice) and Salt emporium (Venice): horizontal courses of Istria stone blocks were used at the base of the walls to limit the capillary rise of water.

In 1827 Cavalieri San-Bertolo [15] suggested the insertion of lead slabs in the wall during construction or the insertion of stone impregnated with a glue composed of boiled linseed oil and litharge [1] to reduce rising damp.

Different techniques exists for creating a mechanical interruption of a wall [5]. The so called wedge-method consist in removing, meter by meter a brick/stone course, inserting a pvc foil and replacing the brick by concrete wedges set one upon the other. The joints are then filled up with a mortar containing a resin. The Massari method [16], developed in Italy by Massari, consists in drilling two overlapping series of holes in the wall. Before drilling the second series, the first is filled up with synthetic, water repellent mortar (figure 5).

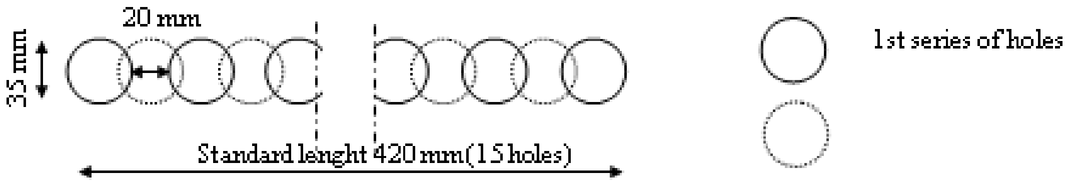


Figure 5 The Massari method: two series of overlapping holes are cored and filled with water repellent mortar [5, 16]

Another method has been developed, based upon stainless steel slabs which are inserted by hammering into the mortar joint and can even go through soft bricks. The advantage of this method consists in the fact that no mortar joint or brick course needs to be removed first. However, the use of this method is restricted to walls consisting of relatively soft materials.

A wide range of materials can be used for the sheets, such as steel or lead plates, plastic, glass, bitumenbased membranes, polyethylene or polyester-based, PVC membranes (e.g. gallerie dell'Accademia (Convento della Carita) [1]. In Venice the use of lead plates and bitumen paper are common. Because of the water often exceeding the level of the original mechanical cut, in some cases a second layer, at a higher level in the wall, is added (figure 6) [17, 18].

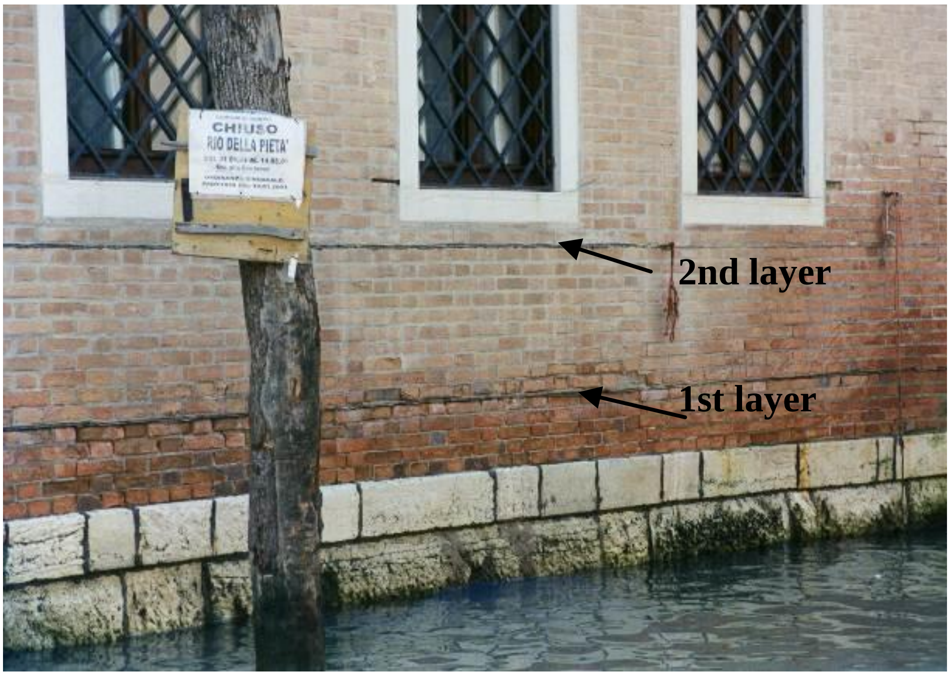


Figure 6 Presence of mechanical interruption (2 layers) in a building in Venice

The method of mechanical interruption is considered the most reliable and effective among the interventions against rising damp. When carried out correctly, the moisture transport above the impermeable layer is completely stopped [13]. Besides, the intervention is in theory reversible. However, the method has some important limits:

- The mechanical cut of the wall may lead to cracks and compromise the stability of the structure of ancient buildings. This may increase the seismic vulnerability of the structure, acting as a plane of sliding during earthquake. In Italy law requires a specific structural evaluation in case of intervention that modifies the strength and deformation ability of the structures and many Conservation Authorities have explicitly banned wall cutting [1,17-18] .

- In some cases, as for example in thick or irregular stone masonry, the method is not applicable [5].

- The costs of this type of intervention are high.

- The wall cutting implies as result in an almost complete water saturation of the masonry below the barrier [1]. The use of plasters or other finishing layers below the level of the mechanical cut should be discouraged since it can work as a bridge for water to reach the parts above the cut.

- The mechanical interruption leaves a visible layer in the masonry (figure 8), fact which may alter the aesthetic value of a cultural heritage building.

Figure 7 Mechanical interruption Italy (Universita Ca'Foscari Venezia) Figure 8 Mechanical Interruption in Belgium (BBRI)

2.1.2. Chemical interruption

Chemical interruption is also known as chemical damp-proofing, chemical barriers, chemical injections or damp-proof courses. The chemical interruption is created by drilling holes at the base of the wall along a horizontal profile. The distance and depth of these holes are depending on the type of product and on the material of the masonry. Normally intervals at a distance of 10-15 cm from each other are used, up to a depth of approximately ¾ of the wall thickness [5]. Generally holes for treatment with liquid products are drilled in an angle (30 - 45 °), while for more viscous products horizontal holes are used. The aim is to create a horizontal barrier through and through the horizontal section of the wall. Depending on the thickness and on the accessibility of the wall, the holes can be drilled from one side or from two sides of the masonry. The holes are filled with the chemical product either with pressure (injection), or without pressure (impregnation).

Figure 9 Treatment of a wall using pressure (injection))(on the left) and using only hydrostatic forces (impregnation) (on the right)[4]

The chemical product, depending on their chemical composition, work by filling the pores and/or by making them water repellent. Products exist combining these two working principles. In the case of products filling the pores, the pores are obstructed and consequently preventing water from rising. In the case of water repellent products, the interfacial tension between the pore surface and the water is modified, making the contact angle greater than 90 degrees, so that the resulting tension determines a downward pressure which prevents the rise of water [13].

A further classification of products can be done according to their solvent: water or organic solvent. The products in water are more or less miscible with water present in the pore system of the material, facilitating transport by diffusion in saturated substrates. Products in organic solvent are not miscible with water, therefore the application of pressure is needed to ensure penetration in water filled pores. Products can also be differentiated depending on their viscosity. Liquid products have a viscosity similar to that of water. Next to liquid products, products in the form of cream exists.

Figure 10 Chemical interruption Belgium (BBRI)

Figure 11 Chemical interruption Italy (Universita Ca'Foscari Venezia)

Chemical injections against rising damp were introduced in the 1960's [16]. In the last years a development towards products in water instead of in organic solvent is observed, mainly because of they are more environmental friendly and less toxic for the operator. Also the use of products in the form of cream is becoming more usual, most probably because of the easiness of application: the product does not require complicate injection or impregnation systems, it does flow out and the holes can be closed directly after application, with considerable savings in terms of time and costs. Recently, a tendency towards the use of water repellent products or combinations of water repellent and pore filling principles (e.g. silicate/siliconate products) has been observed, while products based only on pore filling are rarely used.

Table 1. Class of products classified according to their working principle

Working principle	Product
Pore filling	Silicates (water-glass based products) Acryl-amide gel Paraffin
Pore filling & water repellent	Silane-based gel Silicate/siliconate mixtures
Water repellent	Silicone Silane Siloxane Siliconate Stearate

In spite of the extensive research carried out on the effectiveness of different chemical products in teh last decades, no definitive answer can be given yet about the effectiveness of this method in different practice situations [1] [19] [20] [21]. In spite of the large diffusion of methods and products to stop rising damp, scientific literature on their effectiveness, in laboratory and in the field, is scarce and not conclusive, as confirmed by a recent review on the subject [1]. Literature on laboratory research includes the study of fundamental aspects, as e.g. the transport of immiscible and miscible fluids (water and injection product in organic solvent) in pores [21, 22] as well as the study of the effectiveness of specific methods and products against rising damp. This second line of research largely focuses on the study of chemical injection products [23-25]. However, results from different literature sources are hardly comparable, as they are strongly dependent on the test procedure. For example, the existing laboratory procedures for the evaluation of chemical injections [25-28] (e.g. BBA differ in size of the specimens, specimens' material(s), initial water saturation degree, use of salt solution or water for saturating the specimens and methods, techniques and criteria used for the evaluation of the effectiveness.

On the basis of the literature and of the experience of the authors, the following factors can be identified as relevant for the effectiveness of the intervention of chemical interruption:

- *Regularity of the masonry:* flowing of the products in cracks, cavities etc. present in the masonry compromise the spreading of the product through the cross section and thus the effectiveness of the intervention. To overcome this problem, producers suggests to inject the masonry with a grout or a cement slurry to occlude large voids and cavities, prior to injection. It should be taken into account that the presence of fresh cement creates a high alkaline environment which may limit the effectiveness of certain chemical products. The use of chemical products with a high viscosity (creams) may avoid the flowing of the products in large cracks and voids: cream products, once inserted in the wall, slowly turn to liquid and are transported in the pore system exclusively by capillarity.

- *Saturation degree of the wall to be injected*: this seems to be a crucial factor determining the spreading (mostly in the case of products in organic solvent) and even more the reaction and thus effectiveness of the products [29]. In some cases pre-drying of the masonry prior to application is attempted using heat or difference in pressure; however, there are no scientific data about the effectiveness of this pre-conditioning methods.

- *Type of material constituting the masonry*: the porosity and pore size distribution of the material (combination) constiting the masonry is important in determining the effectiveness of the intervention. Generally, the effectiveness of chemical products in the mortar is lower than in the brick; however, for a good performace of an intervention, a sufficient effectiveness of the treatment in the mortar is required.

- *Type of active component*: silane and siloxane seems to be more effective than other types of products. A long-term laboratory experiment [13] showed that silane-based treatments were the most effective both in terms of reduction in water absorption and in the transient duration required to reach the stationary conditions. Similarly, recent TNO laboratory research, showed the better behaviour of silane and siloxane porducts with respect to stearate and silicate/siliconate [19].

- *The type of solvent*: products miscible in water (as emulsion or micro-emulsion) can diffuse in water filled pores and can therefore spread also saturated pore system; differently, products in organic solvent may require the use of moderate pressure to be successfully injected in walls with a high saturation degree [19]. On the other hand, products in organic solvent are believed to have, once sufficiently spread through the pore system, a better effectiveness [19].

- *Use of pressure*: pressure injection is quicker and thus generally preferred in the practice; As mentioned above the use of a moderate pressure might be necessary for products in organic solvent, but not required for produt in water. The use of high injection pressures should be avoided when not necessary, since it may damage soft materials, as lime mortars.

When considering the compatibility of chemical injections, it should be mentioned that chemical injection products, once they have polymerized and become active, are not reversible. Besides, chemical damp-proofing causes some damage to a historical wall because of the drilling of holes for inserting the products.

2.2 Systems based on evaporation increase

Other systems against rising damp are based on evaporation increase. These methods do not reduce or stop the ingress of water, but, by enhancing evaporation, lead to a reduction of the height reached by the rising damp in the walls. A common limit of these methods consists in the fact that, in the case salts are present in the rising water, these will keep accumulating even at a higher speed in the wall. In this chapter Knapen tubes, drying stones and wall based ventilation are discussed.

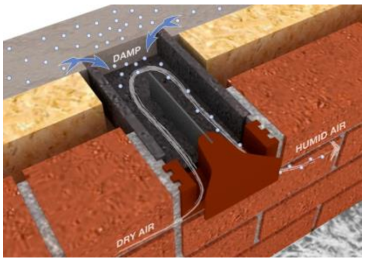
2.2.1 Knapen siphons

Since the early 20th century the so-called ‘Knapen siphons’ or ‘Knapen tubes’ or ‘Atmospheric siphons’ i.e. fired clay or perforated plastic or metal tubes were inserted in the masonry. Originally they were made of ceramic tubes placed in a hole drilled in the wall. The principle of these methods is to enhance the drying process by accelerating the evaporation [30]. The principle behind this atmospheric drainage siphons is that damp air is heavier than dry air [31]. Knapen believed that inserting oblique drainage tubes into walls, would release damp air coming from inside the wall, thereby facilitating the wall-drying (process). However, the Knapen-siphons were proven to be barely successful in moisture removal in laboratory testing, where the bare holes proved to be more effective [32]. As a matter of fact, some conditions were found to unfavourably influence the effectiveness of Knapen tubes, such as unheated rooms, absence of direct solar radiation, and dense building materials, to an extent that the tubes might sometimes even cause the wall to become damper [63]. This reverse action might also be possible in case of high outdoor air relative humidity (supply of moisture to the wall) [1].

Figure 2, Different types of Knapen Siphons in a wall (Lubelli, B.)

2.2.2 Drying stones

Several other variations have been developed based on the same principle. The “drying stones” are another example: these stones, looking like bricks, contain aero-dynamically shapes holes. The shape of the holes should cause a forced ventilation and by that the drying of the wall. The stones are placed at a distance of about 30cm at the base of the wet wall. In the Netherlands a system that works on these principles is the ‘Schrijver system’ (www.schrijver.nl). The drying principle is described by the producer as follows: “the airflow cools the chambers inside, and damp collects and condensates inside the air chambers. As a result damp is drawn from the surrounding wall or cavity and transferred to the cavity within the element. The same airflow causing the cooling effect transports the condensed moisture to the outside” (www.schrijver.nl). In the past the Schrijver elements were made of brick, nowadays a plastic material is used which can be finished with different colours.



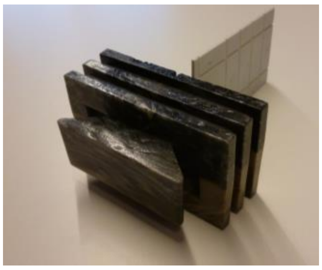



Figure 13 Schrijver System principle (www.schrijversysteem.nl)
Figure 14 Schrijver system in the past (Van Hunen, M.)
Figure 15 Current Schrijver system (Lubelli, B.)

Scientific literature is not positive about this system. TNO measured the moisture content of treated and non-treated walls in the same building every three months over a period of one year. The result obtained after one year time was not satisfactory; in both treated and not treated areas, the situation became worse than at the beginning [33]. As for the Knapen syphon, the temperature, the Relative Humidity and the air speed play an important in affecting the working of this system.

Regarding the compatibility of these systems, both the Knapen siphons and drying stones have impact on the historical value of the building, because parts of the wall are taken out. This is much more relevant in the case of the Schrijver system. Considering the aesthetic aspect, both systems are clearly visible in the façade, as can be seen in figure 16.

Figure 16 Before and after application Schrijver Systeem, Raamsingel 42, Haarlem (Google Maps september 2009 - Miedema, L. 2014)

2.2.3 Wall based ventilation

In the recent years research on a new technique on wall base ventilation system has been carried out. The technique consists of ventilating the base of walls through the installation of a hygro-regulable mechanical ventilation device (figure 17)[31]. This method increases evaporation, which leads to reduction of the level achieved by the damp front. Experimental results show that wall base ventilation on both sides of the wall reduces the level reached by the damp front [31, 34].

However, next to the limits common to all methods based on increased ventilation (these methods do not solve the problem but only reduces the height of rising damp and may lead to increased salt accumulation at the upper fringe) wall based ventilation can be difficult to apply when there is the presence of adjacent buildings. This method is only applicable when the groundwater is lower than the base of the wall.
The lack of extensive scientific data on the application of this method and on its consequences for the state of conservation of the building do not allow to draw definitive conclusions on the effectiveness and compatibility of this method.

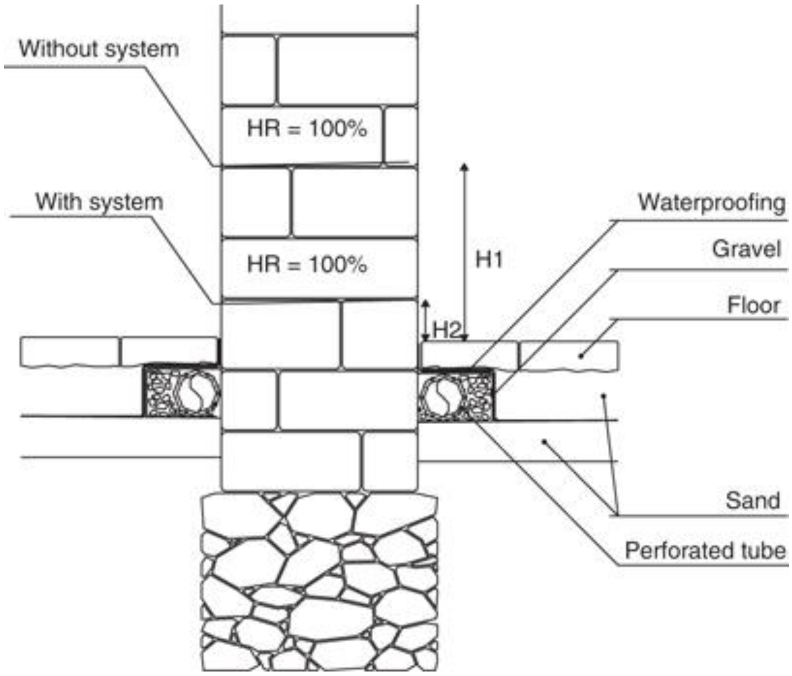


Figure 17 Principle of the wall base ventilation system [25]

2.2.4 Dehumidification plasters

Dehumidification plasters might be also included among those methods which aim to reduce the effect and severity of rising damp by enhancing evaporation of the wall. Dehumidifying plasters have a very high porosity (up to 45 vol%) distributed in a wide range of pore sizes (0.01 – 100 µm) and with a large volume of coarse pores. These macro pores are meant to enhance evaporation and to act as crystallizing and expanding chambers for salts, which should accumulate inside these pores without damaging the plaster [35].

Dehumidifying renders are supposed to work as sacrificial layers by protecting the masonry from the external agents and by favouring the crystallization of salts in the pores of the render, instead of in the masonry. They should be usually substituted every 10-15 years.

Several mortar producers offer nowadays a line of dehumidifying/restoration mortars and these products have a large diffusion in the practice of conservation. However, further research is needed to definitely assess the actual effectiveness of these plasters in enhancing evaporation and thus reducing the moisture content and the decay in walls affected by rising damp.

2.3 Systems based on electrokinetic phenomena

In the recent years the market of conservation has developed towards the use of products and methods which claim to be less invasive and more sustainable than traditional systems [36]. Next to the better known system based on active and passive electro-osmosis, several other methods, defined by the producers themselves as electro-cybernetic methods, are flourishing on the European market. If the principle of active electro-osmosis is scientifically proven and successfully applied in laboratory , the other method do not have, to the author best knowledge, a scientifically based proof of their working principles [37, 38].
The occurrence of electrical effects in moist masonry walls is due to the electrical double layer arising at the water/solid surface in moist porous building materials: when capillary water flux is present, a spontaneous potential takes place [14]. In this chapter the systems based on electro-osmosis phenomena are discussed. First the principle of electro-osmosis is explained; then the systems based on this principle are discussed.

2.3.1 Electro-osmosis

Another class of dehumidification systems is based on the electrokinetic effects affecting water migration in porous materials. Electrokinetic effects are caused by the formation of an electrical double layer at any aqueous electrolyte/solid interface, and thus also at surface of pores in damp porous materials, as schematically shown in figure 18. The application of an external electric field can therefore lead to a motion of water in pores in porous solid, i.e. electro-osmosis [1]. This principle governs dehumidification methods based on active electro-osmosis; differently, the so-called passive electro-osmosis is improperly named electro-osmosis, since no application of electrical field is foreseen.

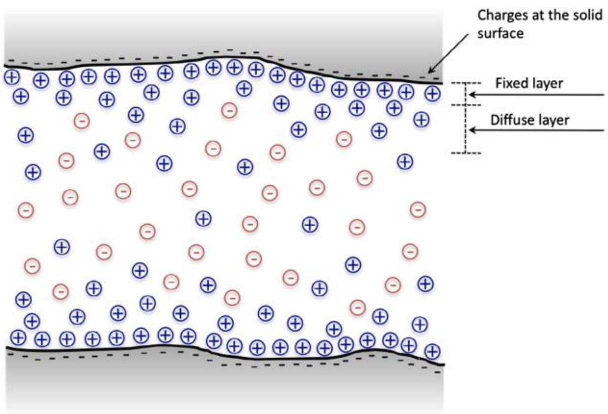


Figure 18. Schematic representation of the double layer at the pore surface [1]

Active electro-osmosis

The use of active electro-osmosis for tackling the rising damp problem, involves placing electrodes in the wall (anode) and in the soil (cathode) and applying an electric field which causes a current circulation between the anode and cathode, leading to water migration towards the cathode and thus drying at the anode.

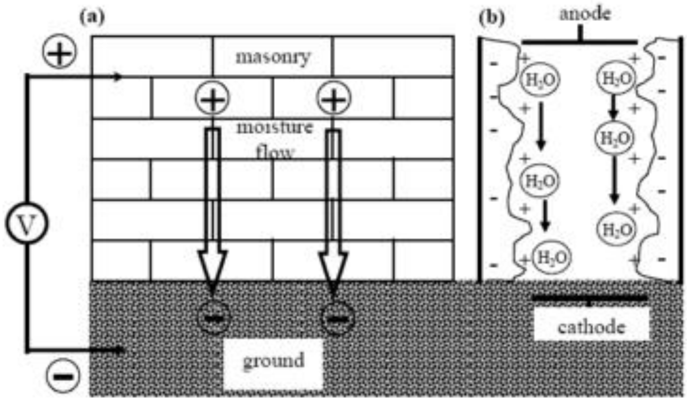


Figure 19. Schematic of an electro osmosis setup used on a masonry wall [16]

The principle of electro-osmosis is used for treatment of soils with satisfactory results [39, 40]. However, the application of active electro-osmosis for de-humification of masonry seems to pose more problems for its actual application. These difficulties are mainly related to:

1. The chemical nature of the building materials and its pH which are strongly affecting the results [38, 41]
2. The much higher moisture content in clay soil (up to 70-90%) than in masonry material (generally lower than 30%). In clay and peat, a 25% reduction in water is more than adequate and represents great success; in a brick wall, one could speak of drying and success if for example the original 30% (very high porous material) could be reduced to 5% - by volume [16].
3. the rigidity of building materials which, differently than clay soils, do not significantly shrink and with decreasing moisture content; in building materials the decrease in moisture content may lead to loss of electrical continuity and thus stopping of the dehumidification process [38]

Next to the above mentioned crucial problems, other issues complicate the application of electro-osmosis for dehumidification of masonries in the practice of conservation. These include:

- the corrosion of the electrodes: this problem has been solved in laboratory by the use of special clays[42] however, considered electro-osmosis need to work continuously for long time, corrosion of the electrodes might still be a problem.
- loss of electrical contact between electrode and masonry surface;
- salt migration: the electro-osmotic flow is proportional to the thickness of the electrical double layer, i.e. a charge separation which occurs at the interface between solid surface and

solution. A higher ion concentration in the pore solution reduces the double layer thickness, resulting in a decrease of the electro-osmotic flow [6].

In spite of these unsolved issues, active electro-osmosis has already been applied in the practice of conservation since the 1960s [1]. The literature on the effectiveness of the method is controversial. Many authors are skeptical : Massari writes : "Experimental results have not yet clarified whether electro-osmosis can force the drying of walls as far as necessary, but there are doubts as to whether it can overcome the rapidly increasing electrical resistance that the wall mass puts up as drying proceeds" [16] Also other authors seems to be of similar opinion [43]. Also experimental results are controversial, with some authors reporting positive results [37, 44] and some others assessing the ineffectiveness of this method when applied in the practice[38].

Passive electro-osmosis

Systems based on passive electro-osmosis claim to return the capillary wall water to the ground, by making it follow a capillary path in reverse, without applying electric current. More specifically, the claimed mechanism can be explained as it follows: due to the presence of the electrical double layer at the pore surface, when water flows through a porous material (e.g. due to capillary forces) a spontaneous polarisation arises (streaming potential) at the ends of a porous material. The magnitude of the streaming potential depends on the potential difference arising across the double layer at the brick/water interface which in turn depends on the specific conductance of the aqueous solution (nature and concentration of the dissolved ions)[36]. In damp masonry, spontaneous potentials up to about half a volt have been measured between the base of the wall and the damp zone[45, 46].

Massari reports that, actually, this discrepancy in potential diminished a few days after the method has been applied, and then disappears. The claim of the supporters of the passive electro-osmosis system is that the short circuit established between the base and the summit has annulled the current that was producing the capillarity. In truth, the difference in potential is always there. The difference in potential between the old electrodes left more than 24 hours in the wall disappears because the electrodes have been polarized [16].

Many authors [16, 43] agree on the absolute inefficacy of this method in the field. Experimental results confirms the inefficacy of this method as well [32, 47].

A positive aspect of electro-osmosis (active and passive) in the case the methods would work, is its relatively good compatibility with monumental buildings, as it is a reversible intervention. However, the bars or the strips or the electrodes are visible and rust, due to corrosion of the electrodes, might stain the walls. The relatively good compatibility might be, next to the easiness of installation, one of the reason why these methods are adopted in monumental buildings.

2.3.2 Other systems

In this chapter methods based which claim to be based on the use of electromagnetic waves, earth radiation and potentials are discussed. It should be stressed that, at the author's best knowledge, no scientific literature or results on the principles and effectiveness of these methods are available.

Most of the time the producers of these systems point at the positive experiences in practice, which up to now have not been reproducible by independent scientists. Sometimes, unfairly, the theory of electro-osmosis is referred to [www.dinantvochtbestrijding.nl / www.muurvochtverwijdering.nl]. Most wireless devises claim to be based on electromagnetics (figure 20).

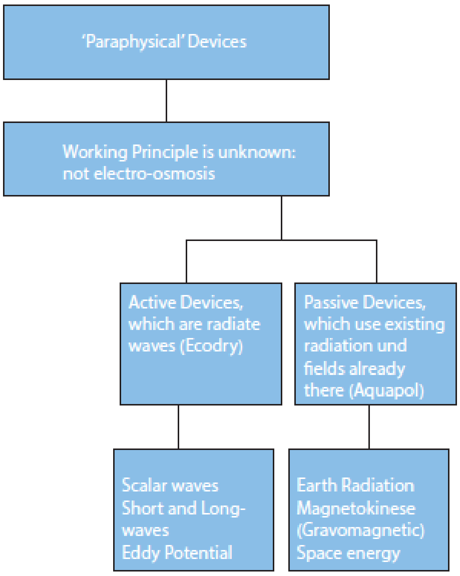
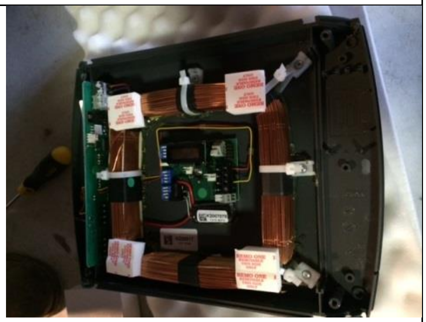
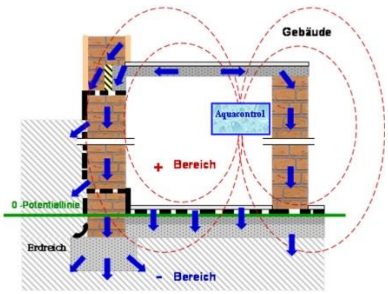
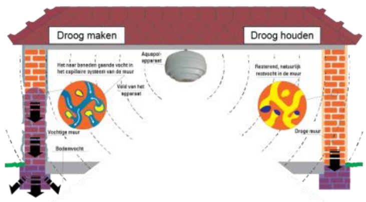
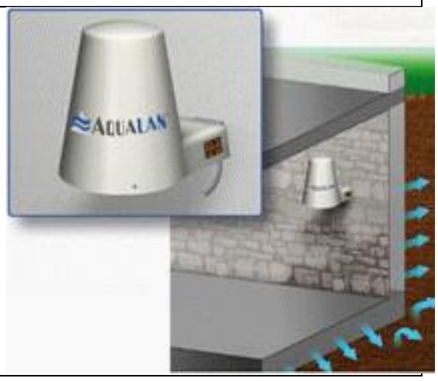


Figure 20 Classification of methods (Miedema, L. based on [48])

The information reported on the website of the producers is often unclear and insufficient to even classify the system according to their working principle. Therefore, only an overview of dehumidification systems based on not better specified electric principles is given in the figure below, as could be obtained from an internet research. The description of the working principle is derived from information reported on the website of the producers.

Product/system	Principle according to producer	Picture
Ecodry (The Netherlands, Italy, Germany, Czech Republic, Austria, Greece, Denmark, Slovenia, France, Spain)	"Ecodry works with integrated Impulse-Resonance Techonology which disturbs the process of rising damp. The effect is that the water returns to the soil. Ecodry also causes an increase in the evaporation at the surface. There are different systems which have a reach of 12,5-14m (www.ecodry.de)	  Ecodry system at Paardenmarkt, Delft (Miedema, L.)
De muurontvochtiger (The Netherlands, Germany)	"The system is an active process on an electrophysical base. Its principle is based on the existing potential of an opposite electrical field. This potential is reduced to ground level. The moisture and the soluble salts in it follow the polarity and migrate within a few weeks back to the soil. The difference in potential is reversed. By a right application of the product, after 4-6 weeks measurable results be determined. An improvement of the indoor climate can be seen. After 3-5 months one can usually start the renovation." [www.demuurontvochtiger.nl]	 
Dinant vochtbestrijding (Hydrosecco) (The Netherlands, Belgium)	"Wireless electro-osmosis" [www.dinantvochtbestrijding.nl]	

Aquapol (The Netherlands, Germany, Austria, Switzerland, Hungary United Kingdom, Italy, Norway, Greece, France, Lituania, Poland, Czech Republic, Slovakia, Slovenia, Romania)	“Magneto-Kinetic”. “A unit is installed in a certain area in the building and sends the damp back into the capillary system of the walls where it came from. The drying out is achieved by certain in nature existing oscillations. The AQUAPOL unit consists of a receiver part and a transmitter part. The receiver part receives a natural geo-energetic field. This aspirated ground energy is specially transformed and sent back into the sphere of activity of the unit. In addition to this process space energy enters from above and amplifies the device in its effort by increasing the force in the sphere of activity. The Aquapol system works with the mauerpotential. After 1-2 hours a difference can be measured. The system has a reach of 12,5 meter.” [www.aquapol.co.uk]	 
Muurvochtverwijdering: Delta unit (The Netherlands)	“Wireless electro-osmosis” [www.muurvochtverwijdering.nl]	
Domodry (Italy)	The system acts by means of a small unit (28x17x6cm) mounted inside the building and plugged into a domestic power socket. Domodry neutralizes the electric charge of the water present in the ground in contact with the masonry, thus interrupting the rise of new water through the capillaries of the wall. The excess moisture will then be gradually expelled through spontaneous evaporation [http://www.domodry.it/eng/].	

In spite of the unclarified scientific basis on which these systems claim to work, the market for these products has increased in the last decade. In The Netherlands and in Italy these systems are often applied in monumental buildings [www.ecodry.de], mainly because of their reversibility, non-invasiveness and easiness of installation. The actual effectiveness of the system on rising damp is generally left to measurements performed by the producer.

3. Conclusions

On the basis of the above reported short overview, the following consideration can be made:

- A method does not exist which can be applied with success in any situation. The most suitable method should be chosen depending on a series of parameters, as masonry type, degree of water saturation, presence of hydrostatic pressure, monumental value of the building etc. The application method can be determinant as well for the success of the intervention. This underlines the need of operative guidelines able to assist actors involved in conservation in a conscious choice and application of these methods in practice.

- Some of the methods are based on principles which are not fully clarified. Moreover, information on the actual effectiveness of the methods in the practice is scarce. A scientific and independent evaluation of the effectiveness and compatibility of existing methods against rising damp, including also the identification of gaps in the knowledge on which further (fundamental) research is urgently needed. This is particularly true in the case of electro based method. Since the diffusion of these methods is increasing, and they are applied in monumental buildings, it is important to verify their effectiveness by independent scientific research.

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