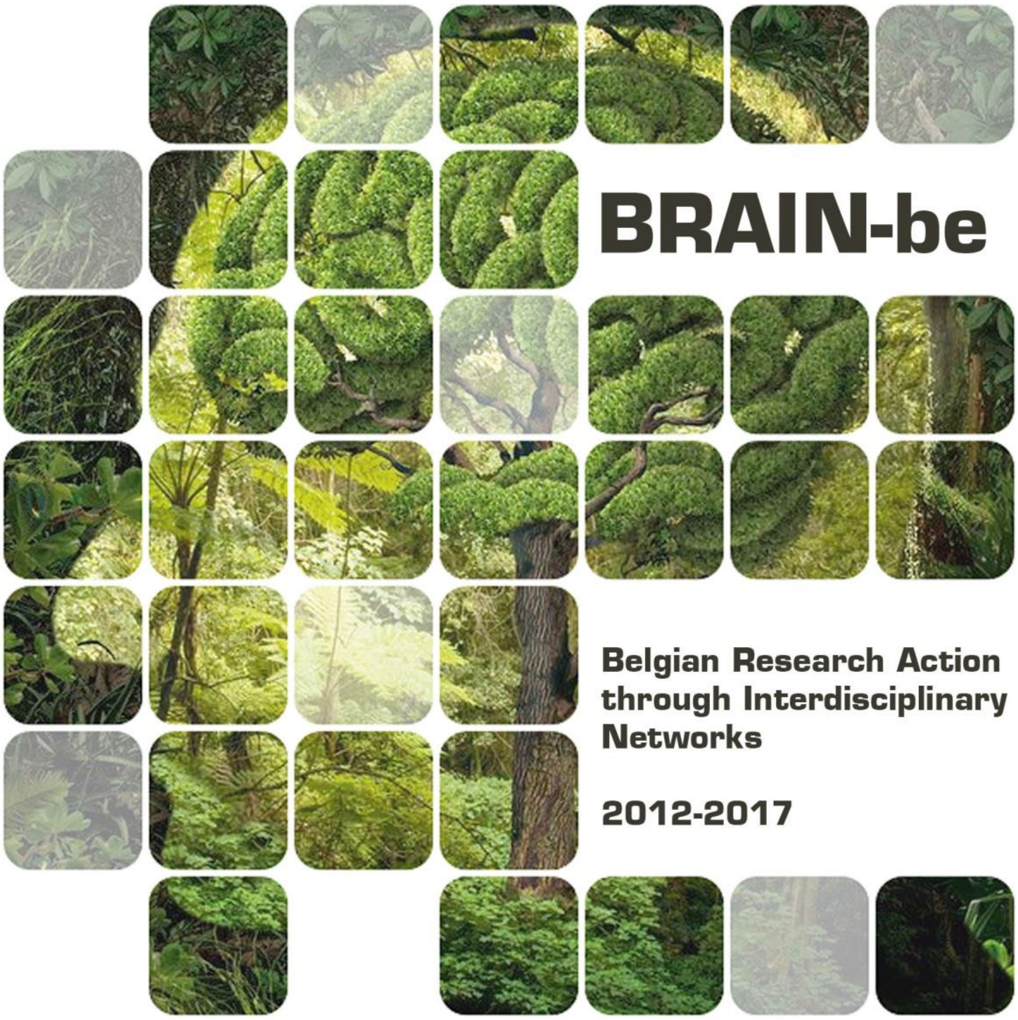

EMERISDA

Effectiveness of methods against rising damp in buildings:

European practice and perspective

Yves Vanhellemont (Belgian Building Research Institute (BBRI)

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EMERISDA

Effectiveness of methods against rising damp in buildings:

European practice and perspective

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0. ABSTRACT

0.1. English

Rising damp is a recurrent hazard to ancient buildings in Europe and its relevance is expected to increase in the future, due to climate changes. It is responsible for severe damage to numerous historic buildings, and its treatment is a necessity for the preservation of these buildings.

The aims of this project are to come to a scientifically based evaluation of the effectiveness of different methods against rising damp and to a define decision support tool for a conscious choice and successful use of these methods in the practice of conservation. To obtain this, case-studies and studies on scale models were executed, in order to quantify the efficiency of several intervention techniques.

An important result of these studies is that of the four main intervention types (i.e. mechanical interruptions, physico-chemical injections, electro-osmosis and electrokybernetic methods methods), only the first two show a distinct efficiency, even though there is no intervention technique that is universally applicable. The choice for an intervention technique should not only be guided by its efficiency, but also by several other parameters, such as the stability of the building, its location (seismic regions), its material composition, its heritage value, … The influence of these parameters is represented in a decision support tool.

Keywords

Rising damp, mechanical interruption, physico-chemical injection, electro-osmose, elektrokybernetic methods

0.2. Nederlands

Opstijgend grondvocht is een vaak voorkomend probleem bij oude gebouwen in Europa. Naar verwachting zal het belang ervan nog toenemen, ten gevolge van klimaatveranderingen. Het is verantwoordelijk voor ernstige schade aan talloze oude gebouwen, en de behandeling ervan is dan ook noodzakelijk voor de conservering van deze gebouwen.

De doelstelling van dit project is om een op wetenschappelijk onderzoek gebaseerde evaluatie van dergelijke interventiemethodes tegen opstijgend grondvocht te komen. Tevens wordt een beslissingsondersteuningshulpmiddel opgesteld, dat voor elk specifiek geval een verantwoorde keuze van interventietechniek moet voorstellen. Hiertoe zullen een aantal praktijkgevallen en schaalmodellen bestudeerd worden, om aldus de efficiëntie van de technieken te bestuderen.

Een belangrijk resultaat van deze studies is dat van de vier belangrijkste groepen van interventies (mechanische onderbreking van de muurvoet, fysico-chemische injecties, electro-osmose en electrokybernetische methodes), enkel de eerste twee een beduidende efficiëntie vertonen, alhoewel ook vermeld moet worden dat geen enkele techniek universeel toepasbaar is. De keuze voor een bepaalde techniek dient niet enkel gemaakt te worden op basis van efficiëntie, maar tevens op basis van gegevens als stabiliteit, de locatie (aardbevingen), bouwmaterialen, erfgoedwaarde, … De invloed van deze parameters zit vervat in het beslissingsondersteuningshulpmiddel.

Sleutelwoorden

Opstijgend grondvocht, mechanische onderbreking, fysico-chemische injectie, electro-osmose, elektrokybernetische methode.

0.3. Français

L'humidité ascensionnelle dans les murs est un danger récurrent pour les bâtiments anciens en Europe et sa pertinence devrait augmenter à l'avenir, en raison des changements climatiques. Il est responsable de graves dommages à de nombreux bâtiments historiques et son traitement est une nécessité pour la préservation de ces bâtiments.

Les objectifs de ce projet sont d'arriver à une évaluation scientifiquement de l'efficacité des différentes méthodes contre l'humidité ascensionnelle et de définir un outil d'aide à la décision pour un choix conscient et une utilisation correcte de ces méthodes dans la pratique de la conservation. Pour y parvenir, des études de cas et des études sur des modèles réduits ont été réalisées, afin de quantifier l'efficacité de plusieurs techniques d'intervention.

Un résultat important de ces études est que, des quatre principaux types d'intervention (c.-à-d. interruptions mécaniques, injections, d'électro-osmose et méthodes électro-cybernétiques), seules les deux premières montrent une efficacité distincte, même s'il n'existe pas de technique d'intervention universellement applicable. Le choix d'une technique d'intervention ne doit pas seulement être guidé par son efficacité, mais aussi par plusieurs autres paramètres, tels que la stabilité du bâtiment, sa localisation (régions sismiques), matériaux, valeur patrimoniale, … L'influence de ces derniers paramètres sont représentés dans l'outil d'aide à la décision.

Mots clés

Humidité ascensionnelle, barrière mécanique, injection physico-chimique, électro-osmose, méthodes électro-cybernétiques

1. INTRODUCTION

1.1. English

Rising damp is a recurrent hazard to ancient buildings in Europe and its relevance is expected to increase in the future, due to climate changes. The presence of rising damp in walls does not only create an unpleasant climate in buildings, but it also enhances damage processes as frost action, salt crystallization and biological growth, with possible consequences on the health of the inhabitants, and threatens obviously the durability and cultural values of the building. It is therefore obvious that it is of the utmost importance that rising damp is treated as much as possible, in order to preserve the buildings, and to maintain a steady and healthy indoor climate in the buildings.

It is interesting to note that many contemporary interventions against rising damp have older or even ancient predecessors: the idea that rising damp is negative, is not modern. Also in the past (decades and centuries ago) many attempts were made to stop rising damp while constructing buildings, or to reduce the degradation of building materials by rising damp. Some of such principles survive even today, evidently in a modern version. It is important to indicate that such older interventions were integrated during the construction of the building, and not afterwards. Moreover, even though the techniques existed, such old examples of techniques against rising damp remain scarce.

Interventions against rising damp on **existing** buildings is a more recent phenomenon. It is also much more complex. During the construction of a building, it is quite easy to integrate some sort of protection. This becomes much more complex if the building is already standing, and works on the building become more difficult, as interventions against rising damp should be carried out at the base of the walls, where problems regarding stability become important.

Nowadays there is a large variety of products or intervention techniques on the market. Moreover, they tackle the humidity problems on different levels: some techniques aim at completely stopping the infiltration of humidity through rising damp. Within this category, we find the mechanical interruptions at the wall bases, physico-chemical injections, methods that accelerate the drying rate in order to remove possible humidity as fast as possible (such as Knapen siphons and drying stones), and finally the methods in the domain of electro-osmose and methods employing electromagnetic waves, the so-called electrokybernetic methods. Other techniques treat symptoms: the rising damp is not stopped, but the technique merely aims at reducing the negative impact of the humidity. A detailed overview of the phenomenon of rising damp, possible solutions and references, will be given in the state-of-the-art (see below).

This wide and differentiated offer of intervention techniques offers the possibility to make a choice that is adapted to each individual building. Unfortunately, the scarce and fragmented scientific information on the effectiveness of the methods, make it difficult (even) for the professionals working in the field to choose a suitable intervention on a sound basis. At this very moment, we still see the national differences in the approach of rising damp in buildings, and how to treat it.

The two main objectives of this project are therefore:

- to come to a scientifically based evaluation of the effectiveness of different methods against rising damp. This will be obtained by
    - testing a series of different intervention techniques on different existing buildings, in Belgium, the Netherlands and Italy.
    - Actual buildings have the disadvantage that we do not know exactly their composition, material properties, other influences (like the presence of salts). In combination with these case-studies, a series of scale-models of masonry is constructed, exposed to rising damp, and treated with different types of techniques against rising damp. This approach has the advantage that techniques can be compared exactly on to another, and they thus form an interesting parallel approach to the actual case-studies.
- to define a decision support tool for a conscious choice and successful use of these methods in the practice of conservation. This tool will help the conservation professional to make the best choice for an intervention against rising damp, depending on the specific situation of each individual building. The aim is to integrate as much as possible existing techniques (not necessarily known in all European countries) into the same tool, which will enable different European countries to learn from each other's experiences.

The nature of this research and the ambitions of the project need a European dimension to be successful. The involvement of the selected partners is necessary when considering the diffusion of the problem at European scale and the urgency of finding effective solutions. Collaboration allows to:

- share knowledge and join efforts towards a common objective; the sharing of knowledge is of great importance, because of the simple fact that building traditions, building materials and the climate (which is determining for the type of degradation that takes place) are different all over Europe. Therefore we note also a severe difference in techniques and products that have been used to tackle the problem of rising damp.
- Such a collaboration will therefore guarantee a complete overview of existing methods,
- And will make dissemination of the research findings easier and more efficient
- Thanks to this collaboration, a European network of experts with state-of-the-art knowledge will be established, and will no doubt lead to future developments or improvements of intervention techniques and to the normalisation of evaluation methods and the evaluation of intervention techniques.

1.2. Nederlands

Opstijgend grondvocht is een vaak voorkomend probleem bij oude gebouwen in Europa, en het belang ervan zal nog toenemen in de toekomst, ten gevolge van klimaatwijzigingen. Opstijgend grondvocht veroorzaakt niet alleen een onaangenaam en ongezond binnenklimaat in gebouwen, maar het veroorzaakt ook verweringsprocessen zoals vorst-dooi cycli, zoutschade en biologische schade. Dit beïnvloedt de gezondheid van bewoners en gebruikers, en bedreigt vanzelfsprekend de duurzaamheid en de erfgoedwaarden van het gebouw. Vanzelfsprekend is het daarom uiterst belangrijk om opstijgend grondvocht zo veel als mogelijk te bestrijden, teneinde het gebouw optimaal te bewaren, en om een gezond en constant binnenklimaat in het gebouw te bekomen.

Het is interessant om op te merken dat veel hedendaagse ingrepen tegen opstijgend grondvocht oude tot zeer oude voorgangers hebben: de idee dat opstijgend grondvocht een negatief gegeven is, is niet nieuw. Ook in het verleden (decennia tot eeuwen geleden) werden pogingen ondernomen om nieuw op te trekken gebouwen te beschermen tegen opstijgend grondvocht, of om tenminste verwering tengevolge van opstijgend grondvocht te verminderen. Sommige van die oude methodes overleven tot op vandaag, vanzelfsprekend in een hedendaagse vorm.

Het is evenwel belangrijk om op te merken dat men dergelijke technieken destijds vooral op nieuw te construeren gebouwen toepaste, waar ze vandaag ook intensief bij renovaties van **bestaande gebouwen** worden toegepast. Ook dienen we op te merken dat ook die oude methodes zeker niet algemeen werden toegepast: oude voorbeelden van zulke beschermingen blijven schaars.

Momenteel bestaat er een grote variëteit aan interventietechnieken tegen opstijgend grondvocht. Bovendien hebben ze niet één enkel werkingsprincipe: sommige technieken hebben als doel om de toevoer van vocht compleet te stoppen of om het vocht sneller af te voeren. Binnen deze categorie vinden we mechanische onderbrekingen, fysico-chemische injecties, methodes die de droogsnelheid van de muren verhogen teneinde het vocht zo snel mogelijk te verwijderen uit de muren, en tenslotte de methodes in het domein van de electro-osmose en de methodes die gebruik maken van elektromagnetische golven, de zogenaamde electrokybernetische methodes. Andere methodes zijn eerder symptoombestrijdend: de aanvoer van het vocht wordt niet gestopt of verminderd, maar de techniek mikt op het vermijden van schade door dit vocht. Een gedetailleerd overzicht van opstijgend grondvocht en de interventiemethodes wordt gegeven in de state-of-the-art (zie beneden).

Dit grote en gedifferentieerde aanbod van technieken is zeker een opportuniteit: het biedt de mogelijkheid om een keuze te maken, die het meest aangepast is aan elke concrete situatie. Helaas is de wetenschappelijke literatuur omtrent deze methodes, gezien en enorme impact van het probleem, eerder schaars, en vooral erg fragmentarisch. Vanzelfsprekend helpt dit de conserveringsprofessioneel niet bij het maken van een gegronde keuze. Op dit moment zien we trouwens nog steeds hoe nationale verschillen een grote rol spelen, in de benadering van opstijgend grondvocht.

De twee belangrijkste doelstellingen van dit project zijn daarom:

- Opstellen van een wetenschappelijk verantwoorde evaluatie vande efficiëntie van verschillende methodes tegen opstijgend grondvocht. Dit wordt bereikt door:
    - Het testen van verschillende technieken op diverse oude gebouwen in België, Nederland en Italië.
    - Bestaande gebouwen hebben het grote nadeel dat we niet exact weten hoe e opgebouwd zijn, wat de materiaaleigenschappen zijn, en welke andere invloedsfactoren er zijn (zouten bijvoorbeeld). Daarom zullen er, parallel met de metingen op gebouwen, ook een serie schaalmodellen opgebouwd worden. Deze zullen onder gecontroleerde omstandigheden blootgesteld worden aan opstijgend grondvocht, en vervolgens behandeld met diverse technieken. Deze benadering heft als grote voordeel dat verschillende technieken op precieze wijze met elkaar vergeleken kunnen worden, en vormt derhalve een boeiende parallel met de case-studies op gebouwen.
- Opstellen van een beslissingshulpmiddel om tot een goede en gegronde keuze te komen voor het oplossen van een probleem van opstijgend grondvocht in de conservering van erfgoedgebouwen. Dit hulpmiddel moet de conservatieprofessioneel bijstaan in zijn zoektocht naar de meest gepaste oplossing voor opstijgend grondvocht, afhankelijk van elke specifiek geval. Het is de bedoeling om zoveel mogelijk bestaande technieken te integreren, ook als de technieken niet overal even gekend zijn in Europa, hetgeen verschillende Europese landen zal toestaan om van elkaars ervaringen te leren.

De aard van dit onderzoek, en de ambities van het project, hebben een internationale Europese context nodig om te slagen. Het engagement van verschillende partners uit verschillende landen is noodzakelijk wanneer we het belang van de problemen en de hoogdringendheid tot efficiënte oplossingen beschouwen. Dergelijke samenwerking laat toe om:

- Kennis te delen en de krachten te bundelen voor het bereiken van gedeelde doelstellingen; het delen van informatie is belangrijk, omwille van de eenvoudige reden dat bouwtradities, bouwmaterialen en het klimaat (dat bepalend is voor het type schade dat optreedt bij opstijgend grondvocht) verschillen over gans Europa. Dat is één van de redenen waarom we een dergelijke rijkdom aan technieken kennen, hetgeen ook nu toelaat om oplossingen op maat voor elk gebouw te vinden.
- Aldus te komen tot een compleet overzicht van technieken,
- Een betere en efficiëntere disseminatie van de projectresultaten te bekomen,
- Een Europees netwerk van experts op te zetten, waar state-of-the-art kennis beschikbaar is, en ongetwijfeld zal leiden tot toekomstige ontwikkelingen, innovaties of verbeteringen aan bestaande technieken, en tot de normalisatie van evaluatiemethodes en interventietechnieken.

1.3. Français

L'humidité ascensionnelle est un danger récurrent pour les bâtiments anciens en Europe et sa pertinence devrait augmenter à l'avenir, en raison des changements climatiques. La présence d'humidité ascensionnelle dans les murs ne crée pas seulement un climat désagréable dans les bâtiments, mais elle renforce également les processus de dommages tels que l'action du gel, la cristallisation des sels et les developpements croissance biologiques, avec des conséquences possibles sur la santé des habitants, et menace évidemment la durabilité et la culture valeurs du bâtiment. Il est donc évident qu'il est de la plus haute importance que l'humidité ascensionnelle soit traitée autant que possible, afin de préserver les bâtiments et de maintenir un climat intérieur stable et sain dans les bâtiments.

Il est intéressant de noter que de nombreuses interventions contemporaines contre l'humidité ascensionnelle ont des prédécesseurs plus vieux, voire anciens: l'idée que l'humidité ascensionnelle est négative n'est pas moderne. Dans le passé également (il y a des décennies et des siècles), de nombreuses tentatives ont été faites pour arrêter les remontées capillaires lors de la construction de bâtiments, ou pour réduire la dégradation des matériaux de construction par l'humidité ascensionnelle. Certains de ces principes survivent encore aujourd'hui, évidemment dans une version contemporaine. Il est important d'indiquer que ces interventions plus anciennes ont été intégrées lors de la construction du bâtiment, et pas après. De plus, même si les techniques existaient, ces anciens exemples de techniques contre l'humidité ascensionnelle restent rares.

Les interventions contre les remontées capillaires dans les **bâtiments existants** sont un phénomène plus récent. C'est aussi beaucoup plus complexe. Lors de la construction d'un bâtiment, il est assez facile d'intégrer une sorte de protection. Cela devient beaucoup plus complexe si le bâtiment est déjà existant, et les travaux sur le bâtiment deviennent plus difficiles, car les interventions contre l'humidité ascensionnelle doivent être effectuées à la base des murs, où les problèmes de stabilité deviennent importants.

Aujourd'hui, il existe une grande variété de produits ou de techniques d'intervention sur le marché. De plus, ils abordent les problèmes d'humidité à différents niveaux: certaines techniques visent à arrêter complètement l'infiltration d'humidité par les remontées capillaires. Dans cette catégorie, on retrouve les interruptions mécaniques au niveau des bases des murs, les injections physico-chimiques, les méthodes qui accélèrent la vitesse de séchage afin d'éliminer au plus vite l'éventuelle humidité (comme les siphons Knapen et les pierres de séchage), et enfin les méthodes dans le domaine de l'électro-osmose et les méthodes employant les ondes électromagnétiques, les méthodes dites électrokybernétiques. D'autres techniques traitent plutôt les symptômes: l'humidité ascensionnelle n'est pas stoppée, mais la technique vise simplement à réduire l'impact négatif de l'humidité. Un aperçu détaillé du phénomène de l'humidité ascensionnelle, des solutions possibles et des références, sera donné dans l'état de la technique (voir ci-dessous).

Cette offre large et différenciée de techniques d'intervention offre la possibilité de faire un choix adapté à chaque bâtiment. Malheureusement, les informations scientifiques rares et fragmentées sur l'efficacité des méthodes font qu'il est difficile (même) pour les professionnels travaillant sur le terrain de choisir une intervention appropriée sur une base solide. En ce moment même, nous voyons encore les différences nationales dans l'approche de l'humidité ascensionnelle dans les bâtiments, et comment la traiter.

Les deux principaux objectifs de ce projet sont donc:

- parvenir à une évaluation scientifique de l'efficacité des différentes méthodes contre l'humidité ascensionnelle. Ceci sera obtenu par
  - tester une série de différentes techniques d'intervention sur différents bâtiments existants, en Belgique, aux Pays-Bas et en Italie.
  - Les bâtiments réels ont l'inconvénient que leur composition, les propriétés des matériaux, d'autres influences (comme la présence de sels) ne sont pas exactement connus. En combinaison avec ces études de cas, une série de modèles réduits de maçonnerie est construite, exposée à l'humidité ascendante et traitée avec différents types de techniques contre l'humidité ascensionnelle. Cette approche présente l'avantage que les techniques peuvent être comparées exactement les unes aux autres, et elles forment ainsi une approche parallèle intéressante aux études de cas réelles.
- définir un outil d'aide à la décision pour un choix conscient et une utilisation efficace de ces méthodes dans la pratique de la conservation. Cet outil aidera le professionnel de la conservation à faire le meilleur choix pour une intervention contre l'humidité ascensionnelle, en fonction de la situation spécifique de chaque bâtiment. L'objectif est d'intégrer autant que possible les techniques existantes (pas nécessairement connues dans tous les pays européens) dans le même outil, ce qui permettra aux différents pays européens d'apprendre les uns des autres.

La nature de cette recherche et les ambitions du projet nécessitent une dimension européenne pour réussir. L'implication des partenaires sélectionnés est nécessaire lorsque l'on considère la diffusion du problème à l'échelle européenne et l'urgence de trouver des solutions efficaces. La collaboration permet de:

- partager les connaissances et unir les efforts vers un objectif commun; le partage des connaissances est d'une grande importance, du simple fait que les traditions de construction, les matériaux de construction et le climat (qui est déterminant pour le type de dégradation qui se produit) sont différents dans toute l'Europe. Par conséquent, nous notons également une différence importante dans les techniques et les produits qui ont été utilisés pour résoudre le problème de l'humidité ascensionnelle.
- Une telle collaboration garantira donc un panorama complet des méthodes existantes,
- Et rendra la diffusion des résultats de la recherche plus facile et plus efficace.

- Grâce à cette collaboration, un réseau européen d'experts dotés de connaissances de pointe sera mis en place, et conduira sans doute à des développements ou améliorations futurs des techniques d'intervention et à la normalisation des méthodes d'évaluation et à l'évaluation des techniques d'intervention .

2. STATE OF THE ART AND OBJECTIVES

2.1. Rising damp - introduction

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 (Franzoni (2014)). 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 (Hall (1977)).

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. It may well be that these buildings were originally protected against rising damp, but the protection became ineffective due to changing circumstances (environmental, change of phreatic surface, higher tides, …).

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 (van Hees (1980)).

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 (l'Anson (1986)), 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 (Franzoni (2014), van Hees et al. (2008)). Furthermore, the presence of moisture can strongly affect the thermal performance of masonries, resulting in increased energy costs in heating or cooling of buildings (Kamran (2012)). 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 (Sabbioni et al. (2006), Sabbioni et al.(2010), Brimblecombe (2010), Nijland et al. (2010)).

2.2. 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 1, arrow A)
- by horizontal transport of moisture from the ground adjacent to the wall (Figure 1, arrow B)
- by surface water (rainwater that accumulates in the ground) (Figure 1, arrow C)

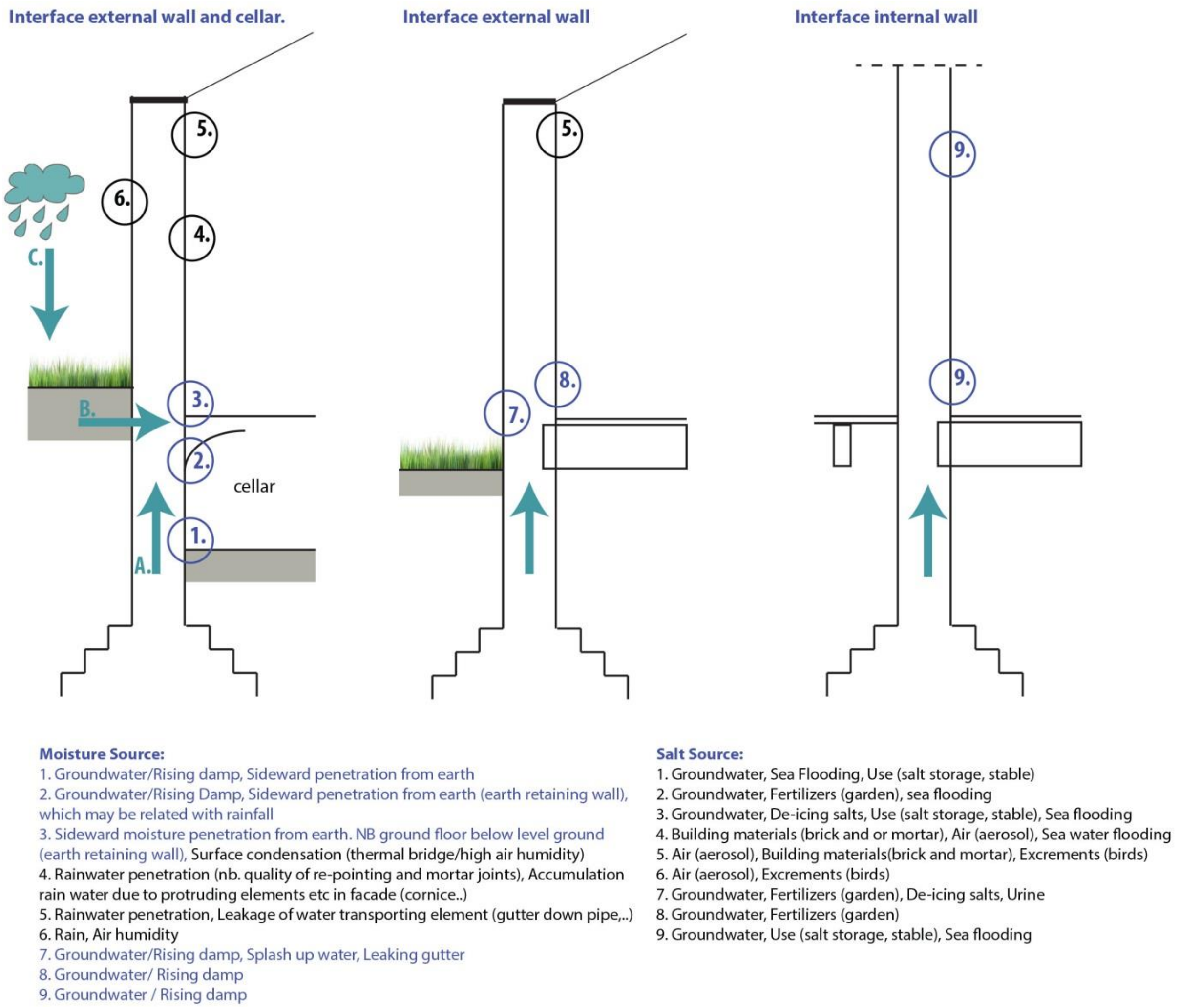


Figure 1: Moisture and salt sources (Miedema, L. /based on MDDS)

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 this capillary zone, rising damp may still occur in the wall. The presence and thickness of this capillary zone depends on the type of soil and its moisture transport properties.

A wet wall may also be the result of rainwater (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.

Capillarity is the mechanism governing rising damp in a wall (l'Anson et al.(1986), Hall (2007)). 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 (Hall (2007)). Because of the attraction between water and the building materials of the pore walls, 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 (Franzoni (2014)). 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 [Hall 2]. Similarly, very strong drying conditions may reduce the water content resulting from capillary rise, whereas poor drying conditions may exacerbate the problem (l'Anson et al. (1986)).

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 one meter, even though it might go higher, depending on, for instance, façade claddings, renders, salts, ….. Rising damp causes a characteristic distribution of water content inside the affected wall, with a 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 efflorescences are visible. Usually the soluble salt are deposited at different heights in the wall depending on their solubility (fractionation): the less soluble salts (e.g. sulphates) precipitating in the lower part and the more soluble (chlorides and nitrates) in the higher part of the wall (Arnold (1989)). But things become more complex when dealing with salt mixtures, and taking into account the circumstances such as evaporation/condenstation phenomena, properties of the capillary system (tortuosity), dishomogeneities of the substrate, …

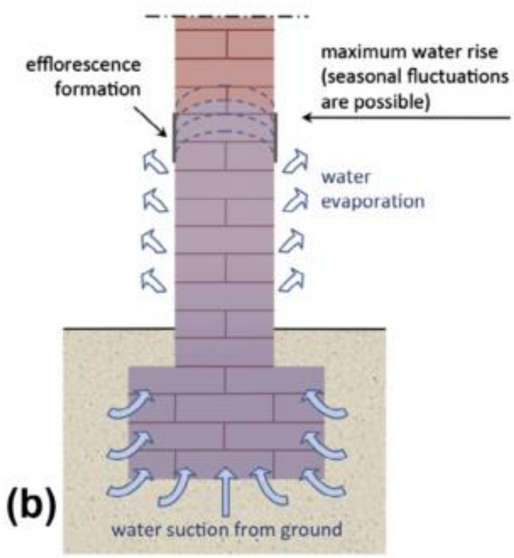


Figure 2: Schematic representation of capillary rise in masonry (Franzoni (2014))

2.3. Intervention methods against rising damp

2.3.1. A short historic perspective

The treatment of rising damp, or at least, dealing with its consequences, is definitely not something from the present. Throughout history, we notice in historic buildings attempts to try to treat rising damp in existing buildings, or trying to avoid it in new constructions.

These techniques can be roughly divided into two categories:

- methods that tackle the symptoms, without resolving the source of the humidity itself. These methods were usually applied to buildings that already existed, possible undergoing a thorough retrofit:
    - application of dense renders/plasters (usually cementbased, or lime-mortars with additions, such as puzzolanes, trass, fly ash, in the early 20th century even some forms of resins or other organic compounds, such as tar or bituminous compounds in an emulsion).
    - Application of dense watertight coatings, such as tar
    - Application of ceramic tiles, or slabs of dense natural stone, such as blue stone or marble.
    - Application of a wooden wall panelling, often equipped with a ventilation of the space between the old wall and the wall panelling. In the 20th century such wall panelings were often cheaply produced with cementbased materials containing asbestos.
    - Application of textile on a frame, enabling the walls to dry, without damaging the textile.
    - In many older buildings we can observe ‘ventilation’ stones (bricks put on their side, so that the perforations of the bricks become visible), or ‘ventilation grates’. Quite often near the base of the walls, but often also higher in facades. Their aim is to increase evaporation by increasing the evaporation surface of the walls, and hence drying the walls.
- Methods that tackle the humidity problems themselves, by applying a kind of permanent barrier near the base of the walls. Many of these techniques have been described in old manuals, such as (Scholten (1914))
    - Application of a layer of dense natural stones at the base of the wall. For instance a layer of blocks of Belgian blue stone, or a rather thin layer of slate. As long as this stone was applied over the entire thickness of the wall, and no humidity transfer through mortar in between the stones was possible, this would be an excellent protection.
    - Application of a layer (or layers) of dense masonry mortars at the base of the wall. This dense mortar was, for instance obtained by applying fly ashes, puzzolanes, trass, or resins to the mortar before using it into the masonry. In our experience, this protection is definitely better than no protection whatsoever, but it also does not

form a watertight protection, as might very often be observed nowadays, where even such buildings show signs of degradation.

- Application of a thin, watertight, material, in between to layers of bricks near the base of the wall. In old literature we see lead, zinc, even glass. Another option was to apply a layer of tar when the masonry reached a certain height, after which the masonry was continued (see figure 3).

Figure 3: an example of an old (successful) attempt to avoid rising damp in a wall. The layer of tar is still efficient nowadays. Clearly the layer of tar was not applied in a very careful way, but this does not affect its efficiency.

2.3.2. Existing techniques nowadays

Many of these old interventions have a contemporary counterpart. The big difference with the past is, that there are nowadays efficient methods that can also treat existing buildings, whereas this was not evident in the past (usually treating the symptoms was the maximum one could to on existing building with rising damp). On the other hand, there are nowadays intervention techniques (regardless whether they are efficient or not) that did not exist in earlier times. We specifically mention all electric methods, the application of salt buffering plasters, and drainage techniques.

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 4). 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.

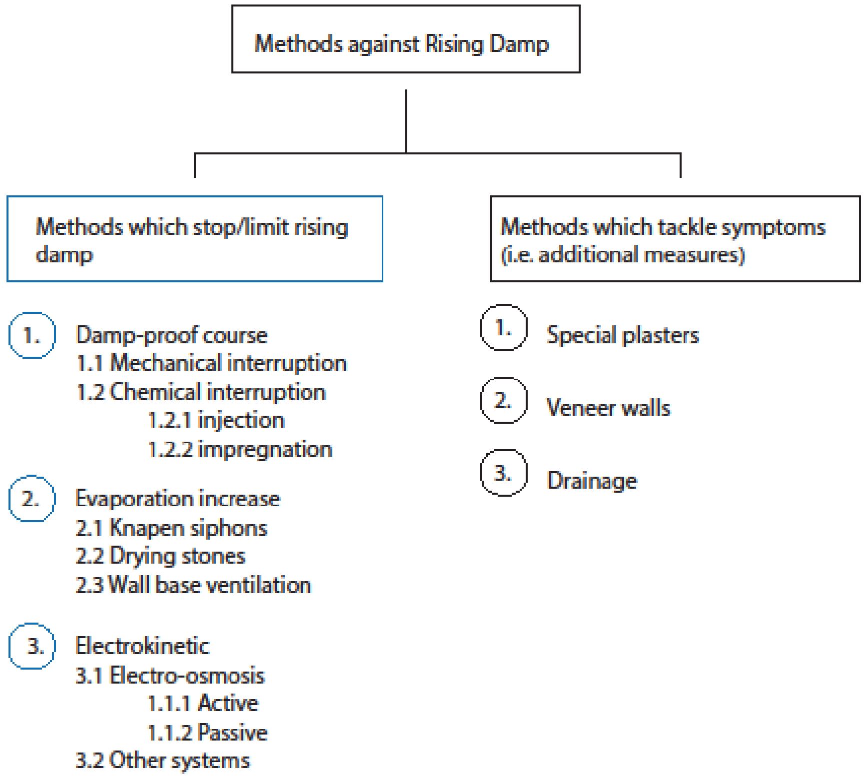


Figure 4 Overview of current methods (Miedema, L.)

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 dehumidifying and/or macro porous and/or salt resistant plasters. In the first place these are materials that are supposed to stay durable on a wet masonry. Ideally they do not influence the evaporation of the humidity (some plasters are supposed to even increase the drying rate of the underlying wet masonry). Other types of plasters simply block the humidity, and therefore cause the humidity to migrate upwards in the walls.
- the use of veneer walls, including the applications of all sorts of watertight membranes on which a 'classic' plaster can be applied. Such membranes block all drying, and therefore cause the humidity in the masonry to migrate higher in the walls. When applied on salt-contaminated, yet dry, walls, they form a good protection against the salts, and their application has little technical drawbacks (even though often not accepted in heritage buildings)
- drainage is somewhat in between a true solution against humidity, and an intervention against symptoms. It is almost never a complete solution against rising damp. But it definitely may have, depending on the type of soil, a positive impact on the humidity in the wall. It reduces the amount of humidity in the walls, therefore causing the humidity to reach only the lower parts of the walls, and therefore causing less damage. But it is usually almost impossible to thus protecting completely the building. One would be able to drain all of the

soil surrounding the foundations of the building, which is usually not possible, or very expensive.

- An important remark is that interventions, that tackle symptoms without resolving the humidity problem, are in many cases a good and appropriate intervention. However, generally they are not recommended, as they may even increase the amount of humidity in the walls (especially the interventions that decrease the drying rate of the walls) and may therefore intensify degradations due to frost.

2.3.3. 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 (Alfano (2006)). These systems can be further subdivided in mechanical interruption and chemical interruption methods.

2.3.3.1. 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 (Sandrolini and Franzoni (2007)). For example, in Venice traditional construction method use Istria stone curb or base with a low porosity (figure 5). In other cases, layers of masonry with specific brick and mortar, with a low porosity, were used; in Dutch this is known as “trasraam” (Van Hees et al. (2008)).

Figure 5: 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.

Cavalieri San-Bertolo (Cavaliere 1832) 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 (Franzoni (2014)) to reduce rising damp. Other techniques, such as using a layer of tar, glass, lead, … have all been described in old literature, even though they only applied to new constructions, not to a posteriori-interventions.

Different techniques exists for creating a mechanical interruption of a wall (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014), van Hees et al. (2008)). The so called wedge-method consist in removing, meter by meter a brick/stone course, inserting a foil of pvc, polyethylene or other, 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 (Massari (1985)), 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 6).

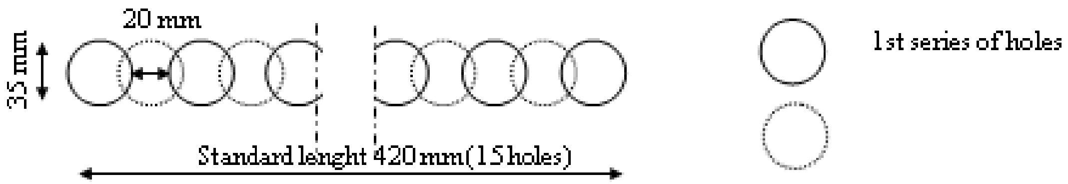


Figure 6: The Massari method: two series of overlapping holes are cored and filled with water repellent mortar (Massari and Massari (1985))

Another method has been developed, based upon stainless steel slabs which are inserted by hammering or vibrating 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) (Franzoni (2014)). 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 7).

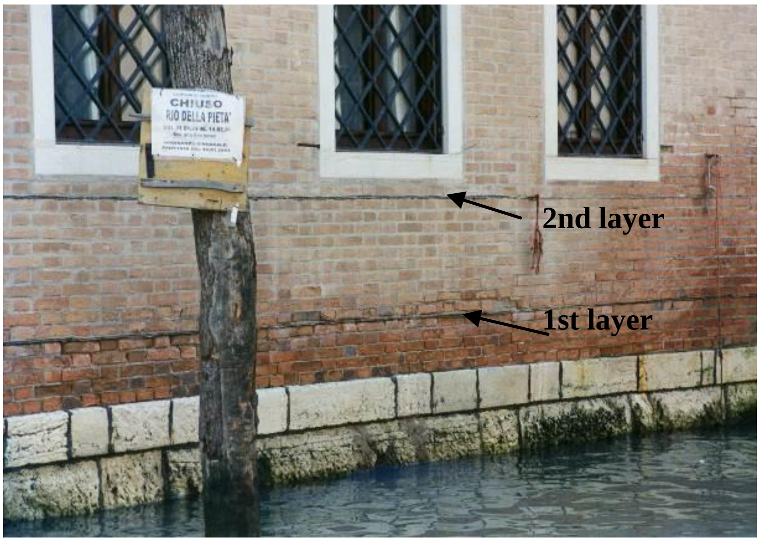


Figure 7: Presence of mechanical interruption (2 layers) in a building in Venice

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 (Alfano et al. (2006), De Bruyn et al. (2003), Herinckx and Vanhellemont (2014)). 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 (Franzoni (2014), Lubelli et al. (2011), Lubelli et al. (2013)).
- In some cases, as for example in thick or irregular stone masonry, the method is not applicable (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014), van Hees et al. (2008)).
- 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 (Franzoni (2014)). The use of plasters or other finishing layers below the level of the mechanical cut may be therefore inappropriate.
- 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 8: applications and result of a mechanical interruption

2.3.3.2. 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 (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014), van Hees et al. (2008)). 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)

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 (Alfano (2006)).

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 these liquid products, also products in the form of cream exists (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014)). They are usually emulsions in water, with a high viscosity, enabling an easier treatment, and a more efficient treatment of masonry of low quality (with lots of cracks and cavities), because there won't be important product losses when applying an injection cream in such situations. However, the migration of the hydrophobic molecules inside the substrate is very different from liquid products. Where liquid products are absorbed by the capillary system of the stones and mortars, the following migration processes occur when injecting a wall with a crème:

- Evaporation of volatile molecules, they migrate through the pores under the form of vapour. Evidently this is only possible if the pores do not contain humidity: this form of migration is specifically efficient in substrates that are not too moist.
- Migration of the active molecules through the pore water. The molecules 'leave' the injections cream, and migrate through the water that is already present in the pores.
- It has been observed (Herinckx and Vanhellemont (2014)) that injection creams, depending on the type of product, have better efficiencies when the materials are drier or wetter.

Chemical injections against rising damp were introduced in the 1960's (Massari (1985)). 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 (Franzoni (2014), l'Anson and Hoff (1988), Lubelli et al. (2011), Lubelli et al.(2013)). 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 (Franzoni (2014)). 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 (l'Anson et al. (1988), Sharpe (1977)) 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 (Balak (2007), van Hees et al. (1995), Venzmer et al. (2005)). 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 (BBA (1988), van Hees et al. (1995), Vanhellemont et al. (2006), WTA (2003)) (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 (Herinckx and Vanhellemont (2014)). 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 (Lubelli et al. (2014)). 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 (Alfano (2006)) 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 (Lubelli et al. (2013)). These conclusions correspond to (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014)).
- 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 could require the use of moderate pressure to be successfully injected in walls with a high saturation degree (Lubelli et al. (2013)), even though good results might be obtained without pressure (Herinckx and Vanhellemont (2014)). On the other hand, products in organic solvent are believed to have, once sufficiently spread through the pore system, a better effectiveness (Herinckx and Vanhellemont (2014), Lubelli et al. (2013)).
- 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 product in water. The use of high injection pressures should be avoided when not necessary, since it may damage soft materials, as lime mortars. On the other hand, application of pressure might accelerate the time needed for the injection: when using pressure, the tiny cracks and cavities around the injection hole are faster filled. A ‘stock’ of injection product is formed in the wall, from where the product can migrate into the pore system. Moreover, the application of pressure enables the worker to evaluate if the masonry has sufficient good quality: if the worker is not able to build up pressure, then he knows that the wall might be too damaged to use a liquid injection product.

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.

2.3.4. 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.

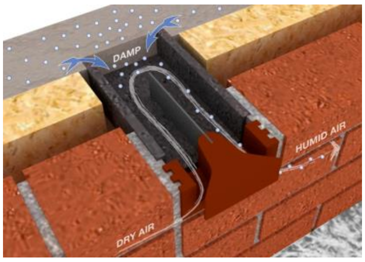
2.3.4.1. Knapen siphons

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 (Camuffo (2013)). The principle behind this atmospheric drainage siphons is that damp air is heavier than dry air (Torres (2007)). 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 [Heiman]. 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. This reverse action might also be possible in case of high outdoor air relative humidity (supply of moisture to the wall) (Franzoni (2014)). It should be noted that these tubes may form a thermal bridge, and thus responsible for heat losses in the building (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014)).

Figure 10: Different types of Knapen Siphons in a wall (Lubelli, B.)

2.3.4.2. 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 30 cm 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.



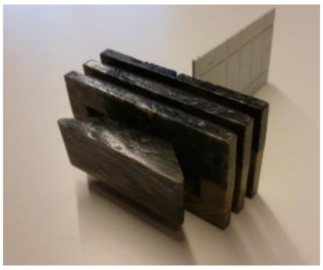



Figure 11: Schrijver System principle (www.schrijversysteem.nl)
Figure 12: Schrijver system in the past (Van Hunen, M.)
Figure 13: Current Schrijver system (Lubelli, B.)

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 (van Hees (1984)). As for the Knapen siphon, 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 14.

Figure 14: Before and after application Schrijver Systeem, Raamsingel 42, Haarlem (Google Maps september 2009 - Miedema, L. 2014)

2.3.5. 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 15) (Torres (2007)). 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 (Guimaraes and Peixoto de Freitas (2009), Torres and Peixoto de Freitas (2007)).

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. Besides, this method is only applicable when the groundwater is lower than the base of the wall. Scientific literature is largely lacking, even though we might expect that this technique might be extremely difficult and even hazardous to the building materials when salts are present. The method will cause an increased crystallisation of salts, and thus causing severe damage.

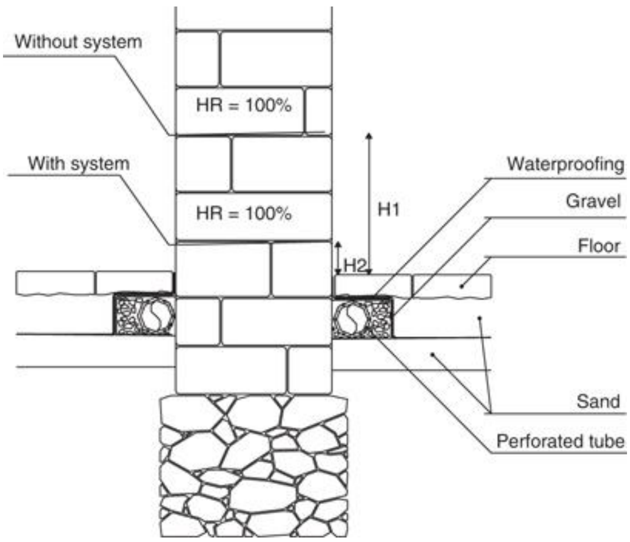


Figure 15: Principle of the wall base ventilation system

2.3.6. 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 (Franzoni and Bandini (2012)). 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.

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 (Sandrolini and Franzoni (2007)). The spontaneous dc voltage is not related to moisture amount, but to the occurrence of differences in salts amount along the masonry height (Franzoni and Bandini (2012)).

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.

2.3.6.1. 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 16. The application of an external electric field can therefore lead to a motion of water in pores in porous solid, i.e. electro-osmosis (Franzoni (2014)). 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.

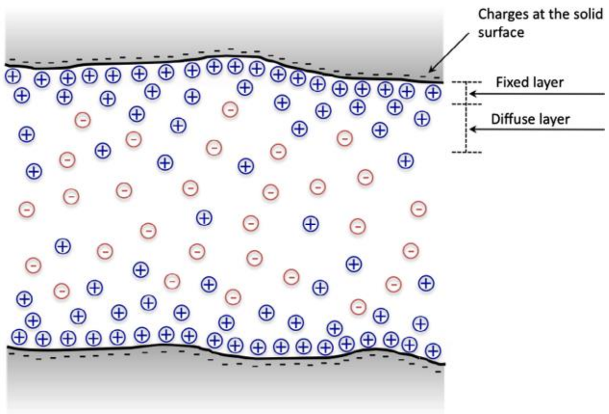


Figure 16: Schematic representation of the double layer at the pore surface (Franzoni (2014))

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.

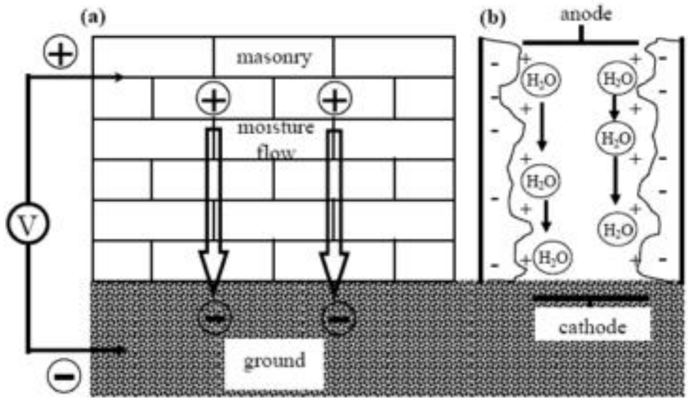


Figure 17: Schematic of an electro osmosis setup used on a masonry wall (Massari and Massari (1985))

The principle of electro-osmosis is used for treatment of soils with satisfactory results (Cien et al. (2009), Sumbarda-Ramos et al. (2010)). 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:

- The chemical nature of the building materials and its pH which are strongly affecting the results (Bertolini et al.(2009), Ottosen and rorig-Dalgaard (2006)).
- 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 the original 30% could be reduced to 5% - by volume (Massari and Massari (1985)).
- 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 (Bertolini (2009)).

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 (Ottosen and Christensen (2012)) 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 (Kamran (2012)).
- In spite of these unsolved issues, active electro-osmosis has already been applied in the practice of conservation since the 1960s (Franzoni (2014)). 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” (Massari an Massari (1985)). Also other authors seems to be of similar opinion (Vos (1971)). Also experimental results are controversial, with some authors reporting positive results (Ivliev (2007), Ottosen and rorig-Dalgaard (2006)) and some others assessing the ineffectiveness of this method when applied in the practice (Bertolini et al. (2009)).

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) (Franzoni and Bandini (2012)). In damp masonry, spontaneous potentials up to about half a volt have been measured between the base of the wall and the damp zone (Franzoni et al. (2011), Franzoni et al. (2014)).

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 (Massari and Massari (1985)).

Many authors (De Bruyn et al. (2003), Herinckx and Vanhellemont (2014), Massari and Massari (1985), Vos (1971)) agree on the absolute inefficacy of this method in the field. Experimental results confirms the inefficacy of this method as well (Heiman et al. (1973), Vogeley (1985)).

A positive aspect of electro-osmosis (active and passive) in the case the methods would work, is its good compatibility with monumental buildings. It is an almost completely reversible intervention which does not alter the monumental value of the building, except for the risk of rust stains due to corrosion of the electrodes. This might be, next to the easiness of installation, one of the reasons why is often adopted in monumental buildings in spite of the lack of scientific proof of its effectiveness.

2.3.6.2. 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 18).

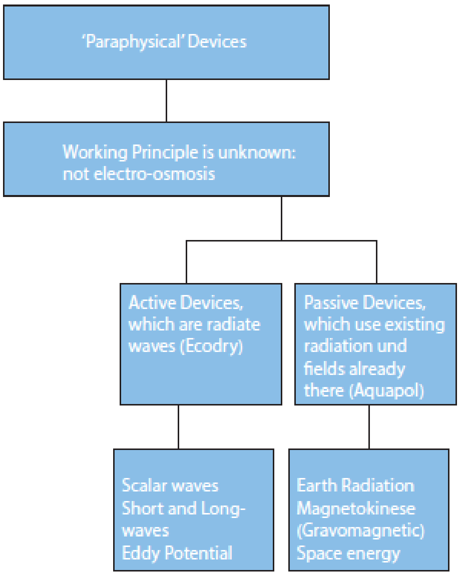
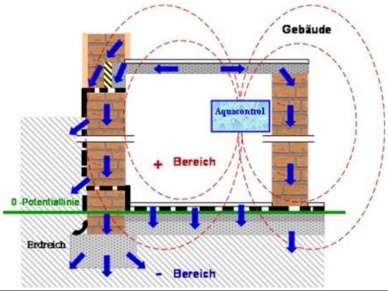
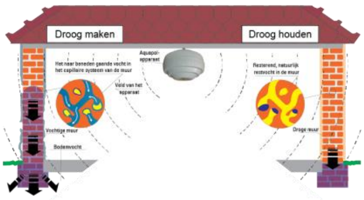
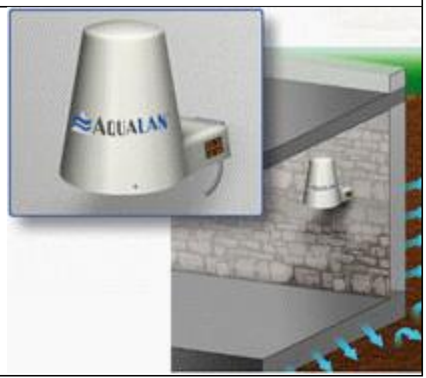


Figure 18: Classification of methods (Miedema, L. based on (Weber and Schulz (2014)))

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.

Table 2. a series of examples of systems for dehumidification of walls by means of electromagnetic waves

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]	

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. In Belgium such devices are mainly used in individual housing, since the heritage administrations do not accept such devices as a solution to humidity problems, and as such they cannot decrease the damage caused by humidity. The actual effectiveness of the system on rising damp is generally left to measurements performed by the producer.

2.4. Preliminary conclusion

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

- the treatment of rising damp in buildings is of the utmost importance, in order to preserve heritage buildings, since humidity and other linked phenomena (i.e. frost, salts, moulds, …) are a serious threat to the building materials. Moreover it should be mentioned that high humidity in walls causes an unpleasant and even unhealthy environment inside buildings. And last, but definitely not least, too high humidity levels in walls causes energy losses, due to the fact that the thermal resistance of materials decreases when they are wet. Moreover, while these walls dry, they consume energy that is actually supposed to heat the buildings, instead of drying walls.

- There is unfortunately no method that can be applied with success in every 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 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.

2.5. project objectives – positioning in the federal competencies

As such, this project positions itself in 'axis 3 – cultural, historic and scientific heritage' of the federal competencies: the project examines materials and techniques to resolve problems due to rising damp in historic buildings, which is a serious threat for the Belgian, European and international heritage in general. A threat that is expected to become more important due to predicted climatic changes:

- Damage to building materials due to several decay phenomena linked to rising damp: salt weathering, damage to frost, corrosion of metals (such as steel structures inside buildings), damage to all sorts of biological phenomena, such as moulds and wood rot.
- Indirectly the presence of rising damp in heritage buildings may cause great discomfort for the users or owners of the building. This is caused by too high ambient humidity, the formation of moulds, and moreover excess energy losses due to damp walls, thus increasing seriously the energy consumption of the building. Damp buildings are therefore less likely to find users and/or owners, which is a prerequisite for the optimal conservation of a building.
- Finally there is an important social end ecological aspect to the research, which goes beyond the realm of cultural heritage. A large portion (estimates range between 20 and 30%) of housing and existing buildings may be subject to rising damp, due to their age and period of construction, when protecting building against rising damp was not a general building tradition. The treatment of these building against rising damp will be of the most utmost importance to improve the life quality in such buildings, and will have a serious impact on the total energy consumption of this building stock. It is in any case necessary to treat humidity problems in houses, before improving their technical behaviour, since it is known

that damage due to humidity may increase when thermal insulation, air-tightness etc. are applied in buildings that have humidity problems.

The main objectives of the project is to perform tests and to develop support tools that will lead to better interventions against rising damp, and to enable building professionals to make the most appropriate choice for the techniques to be used on site. The main objective of this is evidently to obtain better restorations or retrofittings of buildings, while optimally using financial and labour-resources. This will lead to more and better restorations, enabling to better preserve the European heritage. We will aim at this main objective, by defining and obtaining following partial objectives:

- Definition of a European-wide overview of existing methods to tackle rising damp and of their diffusion, compatibility and effectiveness on the basis of the collected existing information.
- Definition of a common procedure and criteria for the evaluation of interventions against rising damp, to be defined on the basis of the existing experience of the partners. Due to the monumental nature of the investigated buildings, non-destructive and little-destructive techniques will be preferred in the case studies. More invasive investigation methods can be used on scale models, also for calibration of non-destructive techniques.
- Performing the necessary tests, on site and on scale models, to assess the efficiency of different intervention techniques against rising damp.
- Decision support tool on feasibility and risks of existing methods. As an easy-reference manual, this document will provide insight into the feasibility and risks of existing methods against rising damp and help actors involved in conservation to come to a conscious choice and application of the methods against rising damp in the practice. Via a decision tree the user will be guided towards the choice of a suitable intervention and informed about conditions which might affect the success of the intervention and about possible advantages and limits of the methods. Next to technical aspects, aspects related to the compatibility/reversibility of the different interventions will be included. The decision support tool will address professionals involved in conservation and maintenance, as architects, authorities and private stakeholders. The developed document will be a first step towards a digital support tool which can be implemented in a future project.
- Build up a European network of experts with state of the art knowledge in this field. This network is meant to constitute the core of a European network of experts, which can be broaden in the future, by including other European countries as Germany and Austria, where the problem of rising damp is present as well, but which are at the moment not taking part in the JPI program.

3. METHODOLOGY, SCIENTIFIC RESULTS AND RECOMMENDATIONS

3.1. Introduction

The work in the project was mainly concentrated around 5 topics, for which there was no common methodology. The methodology for each individual part was different, so there is no separate chapter 'methodology'. Instead, methodology and output will be discussed together in this chapter.

Summarized, the project had 5 distinct parts:

- Literature and exchange of knowledge between partners, which delivered the input for the practical case-studies (cfr. Infra). The information gathered in this part is summarized in chapter 2 'State-of-the-art'.
- A survey on user's satisfaction, regarding interventions against rising damp;
- A comparative study on different techniques against rising damp, on case-studies: application of techniques on buildings, followed by a surveillance of the humidity in the building. We mention specifically that the names of products and distributors/producers will not be mentioned in this report, at the explicit request of the companies. The products/techniques are described in a generic way (i.e. type of molecule, concentration, solvent, …).
- A comparative study on different techniques against rising damp, on scale models: application of techniques on scale models, followed by a surveillance of the humidity in the models. We mention specifically that the names of products and distributors/producers will not be mentioned in this report, at the explicit request of the companies. The products/techniques are described in a generic way (i.e. type of molecule, concentration, solvent, …).
- The development of a decision-support tool, i.e. an aid for the conservation professional to make a choice between different techniques, depending on each individual building.
- Dissemination, this will be treated in the chapters 4 and 5 regarding valorisation and publications.

3.2. User’s satisfaction Survey

The aim of this part was to survey the way the problem of rising damp in building is tackled in the everyday practice. Specifically, an answer to the following questions has been looked for:

- Is the presence of rising damp assessed before an intervention and how?
- What is the diffusion in the field of the different methods for tackling rising damp?
- What are the criteria for choosing an intervention method?
- Has the effectiveness of the intervention been determined and how?
- What is the satisfaction degree of the users of the building for each of the methods?

To answer these questions an online questionnaire has been developed and distributed. In total, 51 participants filled out the questionnaire. 31 Dutch cases, 12 Belgian cases and 8 Italian cases were collected.

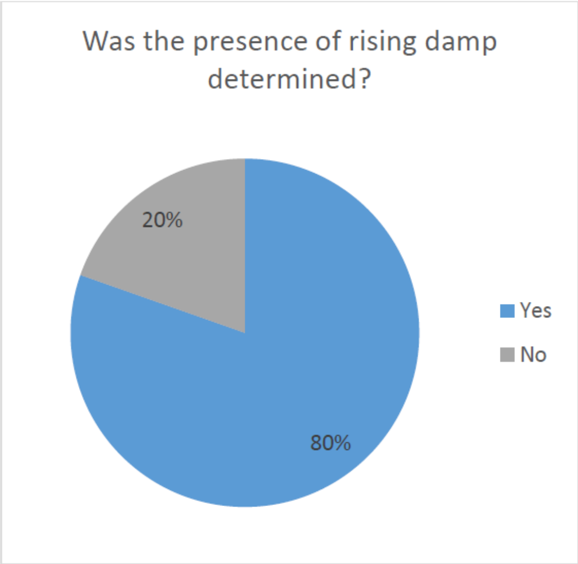
In what follows, the results from the questionnaire are reported and discussed. It should be mentioned that some limitations apply to these results:

- The number of cases is limited and statistically not significant.
- Most of the Dutch cases were provided by the producer/seller of the methods. This caused some methods to be overrepresented and others to be not considered, as no information was available. In all cases the questionnaire was filled in by the users.

3.2.1. Assessment of the presence of rising damp

In most cases, around 80%, the presence of rising damp was assessed prior to the intervention. In most cases, quantitative methods were used – including the gravimetric method (cfr. Infra). In some cases, qualitative methods were used; these methods are easier and faster to use, but do not always give reliable results. In about one fifth of cases, the presence of rising damp was assessed only visually.

In many cases the company responsible for the diagnosis is also selling (one or more types of) intervention methods to tackle rising damp.



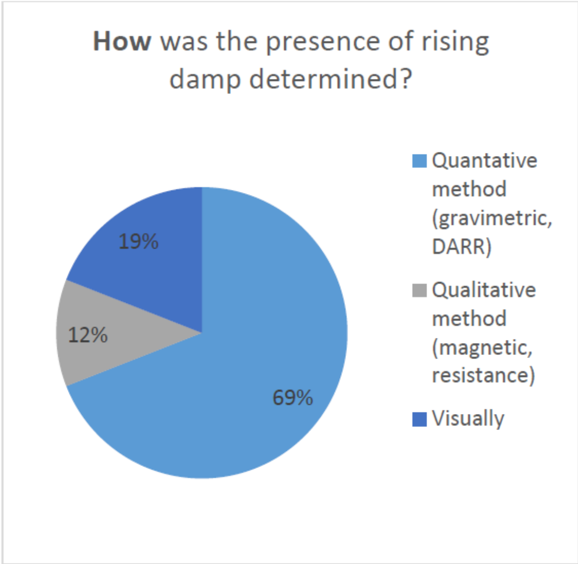


Figure 19: statistics regarding preliminary research before treating rising damp.

3.2.2. Methods

As shown in the graph below, many different interventions are applied in the practice to tackle the problem of rising damp. However, when interpreting this graph, it is important to take the following considerations into account:

- The electro-based method is overrepresented. Many of the participants of the questionnaire were found via producers of electro-based methods.
- Often, a combination of methods is used, such as an electro-based method and a drainage system. In these cases, it is difficult to assess the effectiveness of each single method, because it is not clear to which extent each of the methods contributes to the total effectiveness.

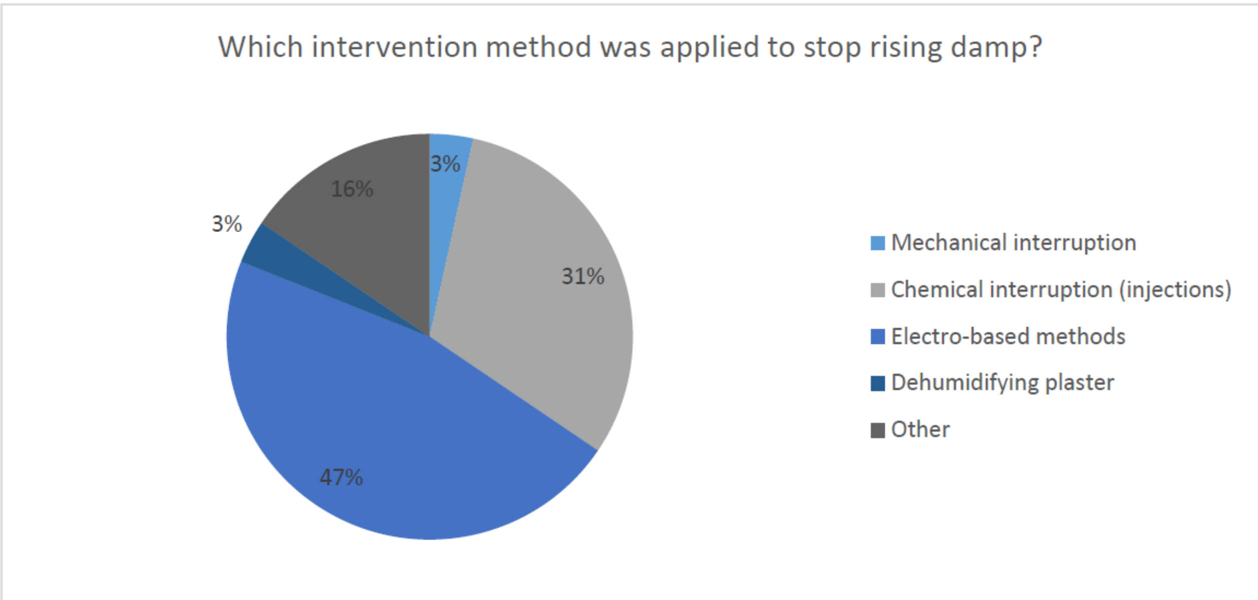


Figure 20: methods used to treat rising damp

3.2.3. Criteria for the choice of a method

The participants were asked why they chose a certain method over another. Their answers are summarized in the graph below. The participants could select multiple answers.

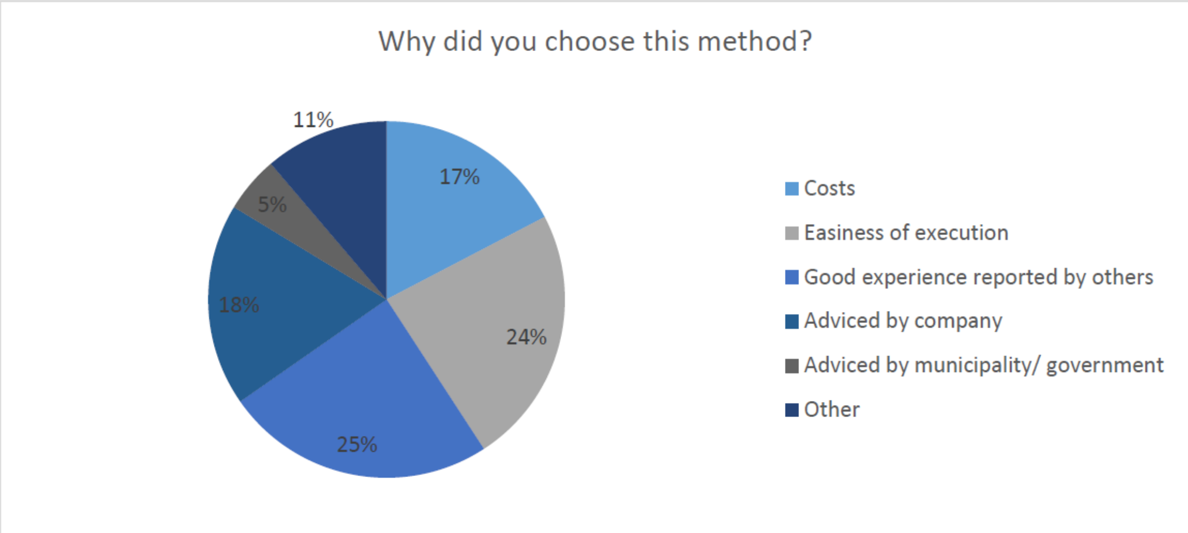


Figure 21: statistics regarding the choice for a method, including its evaluation

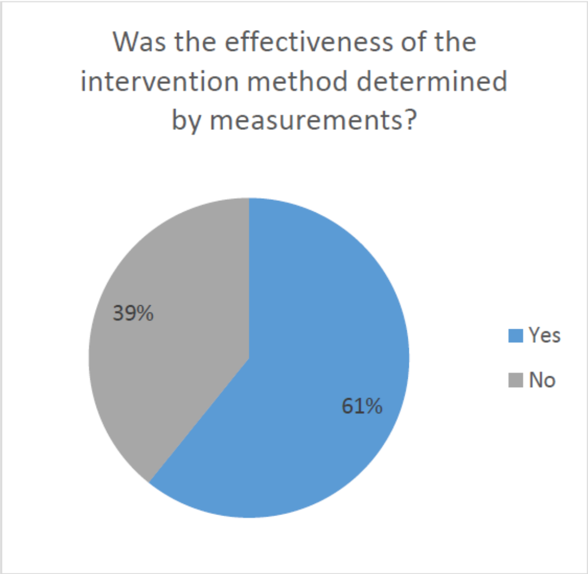
About half of the participants chose the method based on good experiences reported by others. In many cases, the users followed the advice of the company performing the investigation and selling one or more types of intervention methods.

Another important factor in the choice of the method is its easiness of execution: this is especially true in the case of electro-kinetic systems.

3.2.4. Effectiveness

In 61% of cases, the effectiveness of the intervention method has been determined by measurements. In most cases, quantitative methods were used.

In those cases where the presence of rising damp was assessed visually and/or by means of qualitative methods (magnetic, resistance), the effectiveness of the intervention was often not determined at all.



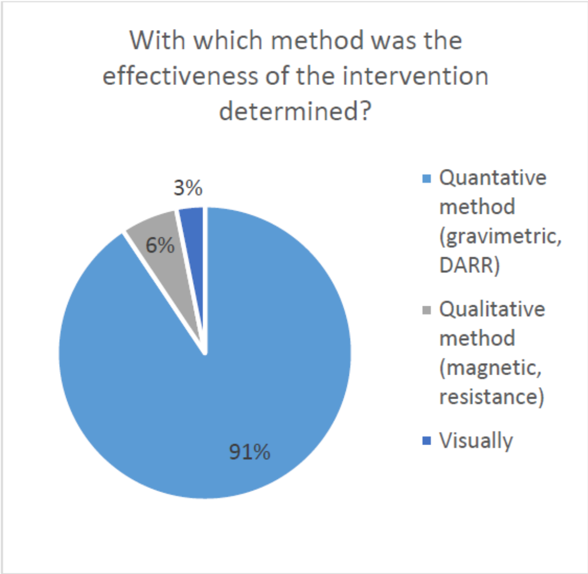
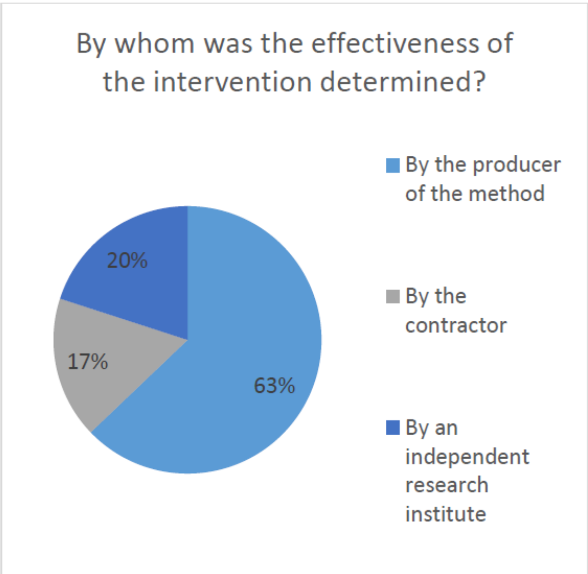


Figure 22: statistics regarding the evaluation of an intervention

In most cases, the effectiveness was determined by the producer/seller of the methods themselves. Only rarely is an independent research party involved. In many of the cases where an independent party did measurements, these measurements were part of the EMERISDA project (Italian cases).



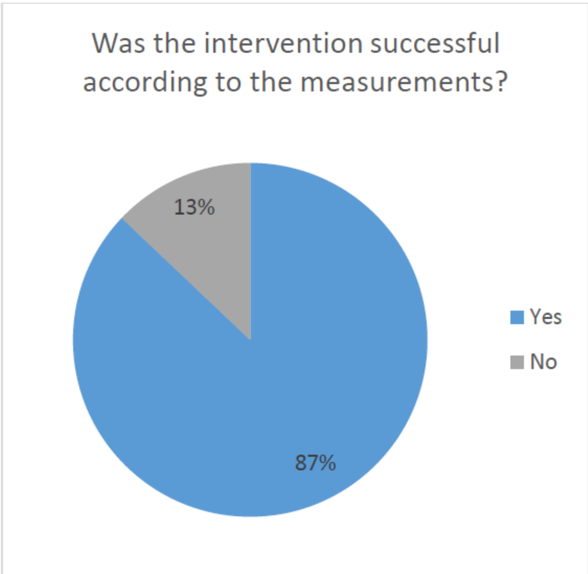


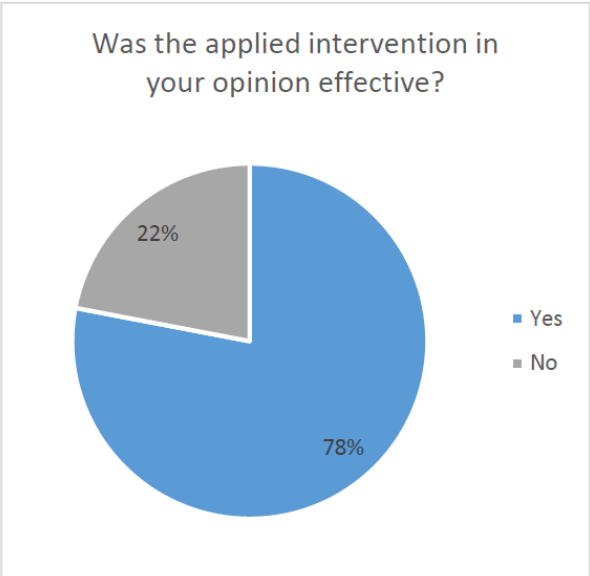
Figure 23: statistics regarding who performed the evaluation, and the result of the intervention

In the cases where the effectiveness was measured, most interventions were found successful according to the measurements. However, some users mention that, next to the intervention against rising damp, additional interventions (e.g. painting, new plasters) were carried out. In these cases, it is not possible to draw definitive conclusions about the actual effectiveness of the intervention against rising damp.

Some users report that the measurements show no clear difference or even an increase in moisture content. In most cases, the measurements were done one year after application. Several users report that the measurements will be repeated later.

3.2.5. Degree of user satisfaction

Most users report that the applied intervention is, in their opinion, effective. Some users are satisfied with the result even though the measurements show no decrease in moisture content, while others are not satisfied despite the positive results shown by the measurements.



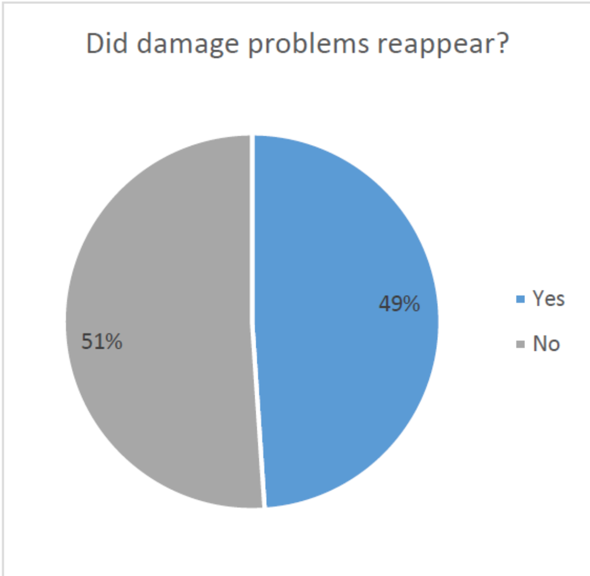


Figure 24: statistics regarding user’s satisfaction

Users were asked to grade the comfort level they experienced in the building, both before and after the intervention, on a scale from 1 (very uncomfortable) to 5 (very comfortable), and to explain why they gave that mark.

The average mark for the comfort before the intervention is 2.92 out of 5. Many users report to notice a musty smell, moist air and often stains of mould and fungi. Damage to plasters and paints and rotting wood are also mentioned.

The average mark for the comfort after the intervention is 3.86 out of 5, which indicates an improvement. However, the improved comfort does not always correspond to a measured decrease in moisture content in the wall. Moreover, almost 50% of users gave the same mark before and after the intervention. This suggests that many users do not experience an increase in comfort.

Almost 50% of the users report that damage has reappeared after the intervention. In some cases, a new plaster layer was applied after the intervention. It is plausible that in these cases, damage will reappear at some time, but is not yet visible on the surface.

3.2.6. Main results from the questionnaire

Despite the limited number of cases and the possibly biased data, some general conclusions can be drawn from the questionnaire.

- Independent research for the assessment of the presence of rising damp is rarely done. We add that in some cases, the presence of rising damp can be deduced from visual observations, especially when considering inner walls, where no other obvious humidity problems can be suspected. Also the presence of a horizontal humid band at the base of the walls is a very evident visual sign of rising damp. However, testing at least the humidity content of the building materials, and trying to obtain an impression of the distribution of the humidity throughout the wall, is not a complex measurement, and can easily be done by a building professional.
- Independent research for the assessment of the effectiveness of the applied method is rarely done, however this could easily done by the building professional himself, at least some control of the humidity content of a wall, a while after applying a solution, should give at least some idea of the efficiency of the intervention.
- A high degree of user satisfaction is measured, even if the problems related to the presence of rising damp reappear after a few years. A very strange result, even though some psychological effect may play a role there ("I tried to solve the problem, but it seems to be impossible, so I stop worrying about it").

3.4. Methodology: description of techniques, procedures and criteria for assessment of effectiveness of intervention

3.4.1. Introduction

The measurement of the effectiveness of an intervention is evidently determined by the moisture content of the materials after the intervention, compared to the moisture contents of the same material in (mor or less) the same spot in the building. There are however many different methods of measuring moisture content of a material. The fundamental method, which is always employed during the project, is the gravimetric measurement. It is definitely the most precise measurement, it is quantitative, and the sample is not destroyed, enabling us to perform possibly other analyses on the same sample.

Other types of measurement are described below, and they have been used during the project, even though not generally.

3.4.2. Determination of the moisture content (MC) and hygroscopic moisture content (HMC), by means of gravimetry.

3.4.2.1. General

This method should be employed by each partner, as it forms the most precise method to determine the humidity of the masonry. As far as low-invasive techniques are allowed on the test cases. The principle of the method is as follows (see for instance (Herinckx and Vanhellemont (2014))):

- Sampling the masonry, by slow drilling, of the masonry. The sample eight should be in the range 5-10 g.
- Drying of the samples at a low temperature, in order to obtain the moisture content (MC). Usually this temperature is taken at 60°C, even though it is perfectly fine to take another temperature (i.e. 40°C). One should always use the same drying temperature, as this might influence the measured moisture content, and the measured hygroscopic moisture content. The duration of the drying depends on the size of the sample and the drying conditions, but the samples have to be dried until constant mass.
- The actual Moisture Content (MC) is calculated as MC(%) = 100% x (initial mass of the sample - dry mass of the sample)/(dry mass of the sample)
- Subsequently the determination of the Hygroscopic Moisture Content (HMC) by conditioning the samples in a wet atmosphere (e.g. 96% RH) at normal temperature (23°C), to equilibrium or for 4 weeks (whichever comes first). The choice of 96% RH is somewhat arbitrary. One could easily choose another, yet high, RH. The choice for this is rather free, as long as one always employs the same RH to determine the HMC of the samples for a given site.

- The hygroscopic moisture content HMC, is calculated as HMC (%) = 100% x (mass conditioned sample-dry mass of the sample)/(dry mass of the sample)

Important remarks, regarding the interpretation of the results:

- MC is the moisture content of the sample, it represents the amount of humidity that is simply contained in the sample, without there being a kind of special binding to the material of the sample. It can be considered as the amount of moisture in the sample, that is supposed to be drying out when there is no supply of moisture towards the material. It is this kind of moisture that indicates the seriousness of the problem with rising damp, and it is also this kind of moisture that will allow us to evaluate whether an intervention against rising damp has been effective.
- Nevertheless, the MC measured as such, is higher than the MC one would measure in more 'normal' circumstances (for instance, at 20°C). The reason is obvious: the higher the drying temperature, the more 'hygroscopic' moisture will escape from the sample, and will be measured as actual moisture. However, we prefer to measure the MC at 40°C (or higher) for the simple reason that it accelerates the process.
- The measured hygroscopic moisture (HMC) does not necessarily represent the real hygroscopic moisture in the sample when it was taken. It is rather difficult to define exactly how much hygroscopic moisture was present in the sample. One could define the amount of hygroscopic moisture in the sample as the amount of moisture in the sample, that is not actual moisture content. But as stated above, this is not an absolute value, as it depends on the drying conditions of the sample (RH and temperature). Therefore it is not evident, and not even possible, to identify exactly how much hygroscopic moisture was present in the sample.
- Moreover, the HMC as measured above, is not even directly linked to the hygroscopic moisture that was present in the sample. The HMC as measured above, indicates the hygroscopic behaviour of the sample. It indicates whether the sample is eager to take up much hygroscopic moisture. As such it is also an indication for the presence of hygroscopic salts in the sample.

It is therefore obvious that the line between the actual and hygroscopic moisture content is a very clear one: depending on the drying temperature, we will measure hygroscopic moisture as actual moisture. One should always keep this in mind while interpreting the test results.

In order to tackle this issue, we will also work with patterns or distributions of MC and HMC. This is a much clearer way of looking at the results, and it may reveal whether MC is hygroscopic moisture or not.

A final remark concerns the maximal MC that is allowed in a masonry. There are no international standards regarding such maximal values, and the absolute values will therefore not be used directly for the evaluation of the seriousness of the humidity problems. We will look more to evolutions (increasing or decreasing of MC) instead of the absolute values. Nevertheless, we do like to indicate an interpretation of MC, as indicated in (Herinckx and Vanhellemont (2014)):

- MC < 3% : no humidity problem, and no intervention required.
- MC between 3 and 5 %: not directly a humidity problem, but if there is a humidity pathology visible, then an intervention should be considered, as apparently the building material cannot support this low humidity content. Even if there is no pathology visible, but one considers to apply vapour-tight ‘layers’ (such as vapour-tight paints, membranes, or thermal insulation, tiles, …) one should apply an intervention against damp, since the humidity problem might get worse behin these layers.
- MC > 5%: there is a definite problem, and an intervention against rising damp should be carried out;

3.4.2.2. Application of the method in the EMERISDA-project.

Sampling:

- Sampling is carried out on a vertical line, at different heights:
    - 0.2 m, 0.5 m, 1 m,1.5 m, possibly higher if the height of the space allows it. Intermediate steps of 0.5 m. Height measured above the floor level of the space.
- Sampling at different depths:
    - 0-2 cm, 2-5 cm, 5-15 cm, 15-25 cm, as deep as possible, but not deeper than the centre of the wall, if the situation is symmetric (for instance wall is open to air at both sides). If there is an asymmetry in the wall (for instance a vapour-tight layer on one side, one might consider to take deeper samples).
- Possibly variations of these depths and heights, depending on the possibilities of each site, can be employed, but care has to be taken that during each subsequent campaign the same depths and heights have to be maintained, in order to be able to evaluate the evolution in the masonry.
- The samples have to be stored into air- and vapourtight vessels (e.g. small bottles) until they can be weighed. Evidently the vessels have to be weighed prior to the sampling.
- The vertical sampling profile should be as close to the centre of each test zone, in order to avoid as much as possible side-effects.
- If possible, samples should be taken in both bricks and/or stones and the mortar. This is the ideal situation, even though it might turn out to be very difficult in reality, as old masonry is often very irregular: drilling into a mortar joint does not lead necessary to a mortar sample when one arrives 10 cm deeper.
- If it is impossible to harvest sufficient sample (a few grams should be ok), then a bigger drill might be used. Or one can sample in two holes next to each other.
- Important remark: sampling should take place in all treated zones, but also a reference zone (without any treatment) needs to be identified and sampled, at the condition that such a zone can be identified.

Determination of the MC:

- As fast as possible after the sampling, the vessels with the samples should be weighed. The required precision is at least = 0.01g. As such, with a sample of a few grams, one can express the MC to a precision of 0.1%. Possibly the samples can be weighed on site, but it proves to be difficult to perform very precise weight measurements on site: the sensible balances suffer from air currents. So the weighing may take place in the laboratory.
- The drying of the samples takes place in a stove (40°C, 60°C) until constant weight is reached. One has to make sure that during all the campaigns, the same drying temperature has to be used.

Determination of HMC:

- The dried samples will be stored for 4 weeks in an atmosphere of high relative humidity (96%), at normal temperature (according to European standards, that is usually 23°C, but 20°C should be possible too, as long as the same temperature is used during the different campaigns).
- It is possible that no equilibrium will be reached after 4 weeks, but as long as this period is always used in the subsequent campaigns, results can be compared.
- The atmosphere of 96%RH can be obtained in a climatic chamber, or in a closed space where there is sufficient amount of saturated salt solution available (solution of K_2SO_4). The amount of salt sol<ution, specifically the surface of the salt solution into contact with the atmosphere in the space, should be much more than the total amount of samples, in order to avoid that the salts in the samples can influence the RH in the space.
- Using $NH_4H_2PO_4$, a RH of 93% can be established. It is important to note that there should always be an amount of solid salt in the saturated salt solution, to be sure that the solution remains saturated when more water is absorbed in the solution.
- This experiment may be repeated with the same samples under a much lower RH, for instance around 70 or 80%. By using a saturated NaCl-solution, one obtains 75% RH. With a saturated KCl-solution, one obtains 85% RH.

Presentation of the results:

- Per zone and per depth, one vertical profile, indicating both MC and HMC should be represented, in order to easily evaluate the humidity situation: when considering both lines together, it should be easily recognizable whether the humidity problem arises mainky from rising damp (external moisture source) or mainly from hygroscopic moisture, or possibly both.

Frequency of the sampling:

- Each campaign should be repeated every 6 months, unless this is considered to be too invasive for the monument under investigation. Within the project we then have the initial situation, followed by 3 campaigns after the treatments. This should be sufficient to evaluate the evolution of the humidity situation.
- At each campaign, the sampling zone should remain as close as possible to the centre of the test zone. The presence of an older borehole does not seem to influence a lot the humidity around that borehole if the hole has been properly closed (e.g. with a stopper or with mortar) after sampling. So in order to compare results from subsequent test campaigns, the new samples should be taken as close as possible to the older samples.

3.4.3. Capacitance/resistance moisture meters

As these methods are to be considered as indicative, even though useful, methods, we consider them as optional in the project. However, in order to evaluate their reliability, these measurements might prove useful. Proposition:

- 4 measurement around each borehole (the sampling holes from the determination of MC and HMC, see point 3 above). The average value of these 4 measurements is the final result.
- The results should be expressed as a vertical profile, per test zone, such as with the MC- and HMC-measurements, and compared to the vertical profiles measured according to the MC and HMC-measurements.
- The measurement should always be executed with the same apparatus, as it has been observed that results may differ a lot between devices of different brands, and even devices from the same brand (Herinckx and Vanhellemont (2014)).

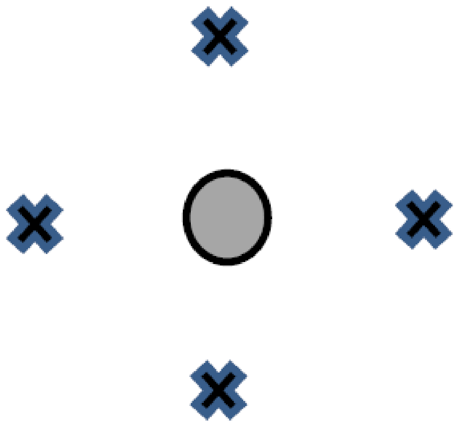


Figure 25: measurement with capacitance/resistance meters

3.4.4. Monitoring of RH in boreholes

This method will not be employed in all zones, but it is a method that will be tested in order to verify if this method may be suitable for a permanent monitoring of the drying process.

At several heights in a test zone, a hole is drilled, to a depth of 20 cm. a probe is inserted, that measures every 10 minutes the RH in the hole. This curve will be compared to the MC and HMC in order to see a possible correlation between the two measurements.

3.4.5. Infrared thermography

This method may prove to be a fast indication of the spatial distribution of humidity problems in walls:

- Humidity in walls causes a larger thermal conductivity in these walls. When the walls separate cold and warm spaces, there should be an influence on the surface temperature of the walls.
- Humidity evaporates, and thus extracts warmth from the wall, causing the wall to cool down. This could be visible on a thermal image, as long as the humidity is evaporating from the surface. When the ‘evaporation front’ lies under the surface of the masonry, it is less likely that the cooling effect will be visible at the surface.
- Measurements at each campaign might prove the practical usefulness of the method.

3.4.6. Microwave

The measurement of microwave might be a useful method to evaluate the drying process of the wall. The heterogeneity of masonry might cause important interferences with the measurements.
Possibility to perform microwave measurements in each brick composing the masonry, not only nearby the sampling holes.

3.4.7. Porosity measurement

On bulk samples of the wall, the porosity of the materials, combined with the MC-measurements, could be an indication of the saturation degree of the walls, and an explanation of the spatial distribution of the humidity in the wall.

3.4.8. Sclerometric test.

The presence of humidity in materials might influence the mechanic properties of materials. For instance, the capillary forces cause a ‘compression’ force on the materials, causing the materials to behave more stiff. As different materials behave differently under the mechanical action of such a sclerometer, it is difficult to extract exact quantitative data. The method should be merely

considered as indicative and comparative (measurements on exactly the same location on the masonry surface in order to monitor the drying process).
Possibility to perform sclerometric tests like in point 3.4.3. (capacitance/resistance measurements, in 4 points around each sampling hole).

3.4.9. Ion chromatography

The salt content and types of salts may give an explanation about the drying behaviour and the hygroscopic water uptake. Based on the results of the HMC of samples, a selection of the most hygroscopic samples may be tested with ion chromatography.

3.4.10. Conductivity

A conductivity measurement of samples mixed with water is another indication of the salt content of the samples, and might prove useful to explain anomalies in drying behaviour of walls, and of HMC. It should be kept in mind that some materials, such as mortars and limestones, contain lightly soluble components, that might influence the conductivity.

3.4.11. Colouring the water that is being absorbed by the wall.

This method should only be used with the scale models, as the addition of colour in walls might prove to be irreversible. It might give a quick visual indication on the height of the the rising damp. The method is indicated here, because there may be a useful application during the project: if a wall (especially a scale model) turns out that it does not dry out after the treatment against rising damp, and one doubts that this is due to the effects of hygroscopic salts, on might add colour to the water in which the scale model is standing. It may reveal quickly of humidity is still able to cross an interruption at the base of the wall.

This method is a variation on the Rubidiumcarbonate method (De Bruyn et al. (2003)) or even more delicate operations such as using radioactive markers.

In order to be sure that the size of the molecules is not affecting the absorption of the colouring agent into the wall, it might be recommended to use colouring agents with small molecules, or ions. An example might be $CuCl_2$, which is highly soluble in water, and gives a vivid blue colour to the water.

- This test should be carried out at the very end of the test campaigns on the scale models, as the colouring agent (or the salt) might influence the drying behaviour of the wall. For instance, $CuCl_2$ is highly hygroscopic, which will influence without any doubt the drying of the masonry.
- The height at which the colour rises into the wall may be an indication of the effectiveness of the treatment.

3.5. Case Studies

3.5.1. Saint Mark's Basilica, Venice (Italy)

3.5.1.1. Introduction

Rising damp of salty water is a phenomenon particularly diffuse and severe in venetian buildings, that reach heights till 2.5-3 meters with moisture content till 30% in the lower part of the brick masonries typical of this city. The presence of high amounts of salts (till 15-20% on the brick weight) worsen the degradation features with delamination and internal decohesion.

Among the several methods used in Venice to tackle the problem of rising damp of salt solution, a bars system was developed by DLK, and claimed to work on the principle of the so-called "passive electro-osmosis" (http://www.dlk2002.it/). This method envisages the insertion of conducting steel bars electrically insulated by a polymeric sheath in the water-flooded zone of the brick masonry. Electrostatic induction from the steady-state, self polarized charges in the moist masonry provides an electrical field opposing the self polarization system and should lower the water height.

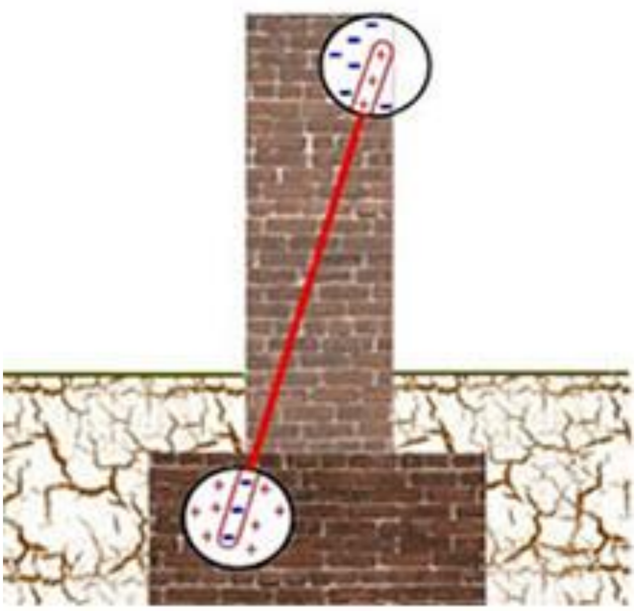


Figure 26: Scheme of the bars system applied in a brick masonry

The system has been applied in 1998 in a pillar of the Narthex of Saint Mark's Basilica near St. Zeno's Chapel. The treated pillar was monitored by moisture content determination in the years 1998-2003 and during the present project (in 2015 and 2016), thus providing significant information for the evaluation of the effectiveness of this technology.

3.5.1.2. Background information and history

Position: Saint Mark Square, Venice
Ground level on Comune Marino according to Ramses system (Insula): around +80 cm on comune marino (C.M.), Crypt: -18 cm on comune marino.

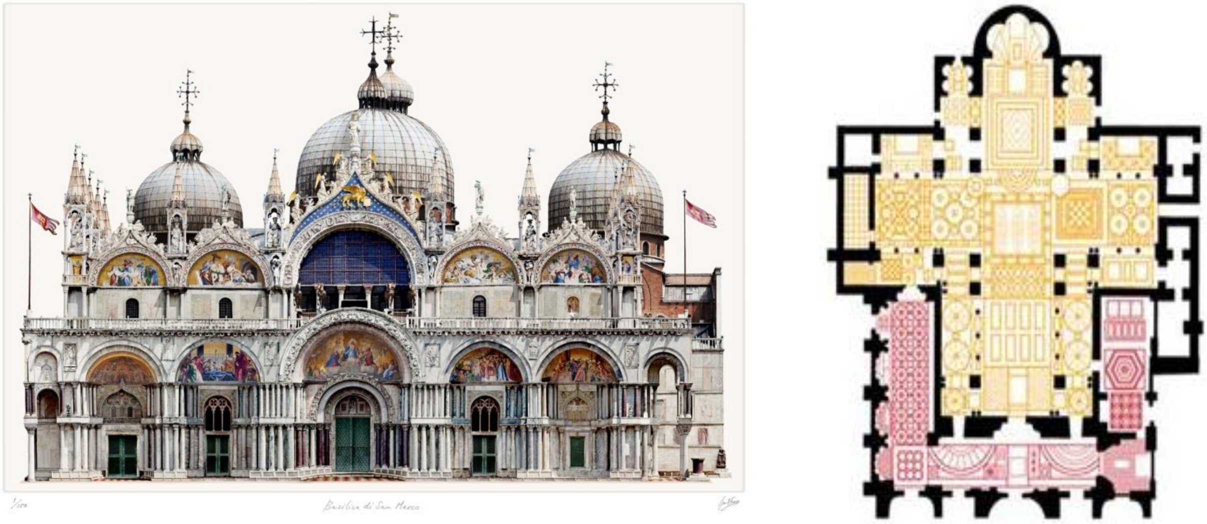


Figure 27: Front and plan of Saint Mark's Basilica, Image by Ian Fraser

The Saint Mark's Basilica is the Patriarchal Cathedral of the Roman Catholic Archdiocese of Venice and, since 1807, the seat of the Patriarch of Venice. It is the most famous of the city's churches and one of the best known examples of Italo-Byzantine architecture (Lonardoni (2002), Lorenzetti (1974), Vio (1993), Vio (1995)).

Different construction phases are recognizable in its structure:

- 1st church was started in 828 as the chapel of the Doge, directly connected to the Doge's Palace, to host the supposed relics of Mark the Evangelist.
- 2nd Church in 978.
- 3rd one built around the second half of the XI century by Contarini and consecrated in 1093.
- In the first half of XII century the narthex and the new façade were built, moreover the domes were covered by higher domes made of lead-covered wood with flamboyant gothic decorations.

The original configuration of the early buildings is unknown but for sure local materials, e.g. Aurisina and Verona stones, Trachite , recovered materials, mortars of slaked limes with cocciopesto and low quantities of sand sometimes also with marine salts were used by the local technician mureri, tajapiera, marangoni e favri (bricklayers, stonemasons, carpenters, smiths).

The present Basilica, the third one, was built with a mixture of Italian and Byzantine features around the second half of the XI century using the “muro a sacco” technique (faced concrete) to sustain the chapels, the roof and the domes and irregular screeds of lime mortars with sand from the river deltas not always pure (presence of salts). In 1106 the church, and especially its mosaics, were damaged by a serious fire in that part of the city.

In the first half of the 13th century a narthex and a new façade were built, most of the mosaics were completed and the domes were covered with second much higher domes of lead-covered wood in order to blend in with the Gothic architecture of the redesigned Doge's Palace .
The basic structure of the building has not been much altered since then, but its decoration has changed greatly over time.

Gradually, the exterior brickwork became covered with marble cladding and carvings.
The latest structural additions include the closing-off of the Zen Chapel (1500s).

Nowadays, the exterior of the west façade of the basilica is divided in three registers: lower, upper, and domes. In the lower register five round-arched portals open into the narthex. The upper level of mosaics in the lunettes of the lateral ogee arches has scenes from the Life of Christ and the history of the relics of Saint Mark. The stone sculpture is relatively limited at the lower level, where a forest of columns and patterned marble slabs are the main emphases. In the upper register, from the top of ogee arches, statues of Theological and Cardinal Virtues, and Saints watch over the city. In the centre of the balcony the bronze horses face the square.

The interior is based on a Greek cross, with each arm divided into three naves with a dome of its own as well as the main dome above the crossing. The dome above the crossing and the western dome are bigger than the other three. The marble floor (12th century, but underwent many restorations) is entirely tessellated in geometric patterns and animal designs. The lower register of walls and pillars is completely covered with polychrome marble slabs. The upper levels of the interior are completely covered with bright mosaics covering an area of about 8000 m2.

3.5.1.3 Degradation

The degradation of the Basilica is due to the construction materials and techniques, the environment and the touristic presence:

- Instability and subsidence of the soft soil
- Structural factors due to an intrinsic weakness of the ancient building. Good foundations but on the contrary→ fast construction with poor materials, feeble mortars.
- Presence of high tide events, the Narthex of the Basilica is often a pool.
- Rising damp of salty water which led to serious degradation phenomena, worsen by the presence of marble panels on the walls leading to higher level of rising damp.

- The increased tourism presence, e.g. the tourists pace inside the Basilica involves a fast and serious erosion of the floors, the emission by breath of CO_2 and water vapor which condense on cold surfaces.

3.5.1.4. Restoration works (Lonardoni (2002), Vio (1993), Pertot (1988))

- Continuous restoration intervention since the XI century, after the XIX century systematic documentation
- XIX century structural works: Meduna (alteration of original parts), Zorzi (conservative conservation), Saccardo (wide use of Portland cement and fluosilicates)
- Manfredi 1903 →need of more scientific and precise diagnostic and monitoring instruments, new approach based on a better knowledge of the ancient structures and materials.
- The restoration restarted with Forlati in 1948, after World War II, with traditional materials instead of new bricks and cement mortars, too rigid for the ancient structures of the Basilica.
- After the flooding of 1966 → impermabilization of the Crypt and consolidation by micropoles of Mascoli Chapel. Rusconi (1972-75) and Scattolin (1975-80) → synthetic resins for the first time.
- 1994 Restoration under the direction of Arch. Vio, when epoxy resin injection overall the Crypt were carried out.

3.5.1.5. Rising damp in the Narthex (Lonardoni (2002))

Figure 28: Altimetry of the Saint Mark’s Square area according to the Ramses system (Municipality of Venice)

Figure 29 Picture of the Narthex during a high tide event (water level +85 cm)

The narthex of the Basilica is frequently flooded by water due to its low height (+64-80 cm on the average sea level at Punta della Salute ZMPS) becoming a pool of salty water.
In the last conservation intervention the narthex have been treated with traditional techniques by injection of hydraulic lime mortars with low content of soluble salts, cement mortars were used only in few spots. The damages are linked mostly to rising damp moisture even if condensation phenomena could occur, too.

During April 1998, an experiment of dehumidification took place in the Narthex: a system based on charge compensation technology was placed in the wall on the right side of the narthex near Zen Chapel (figure 30) after the removal of surface marble panels.
Underneath the panels, the wall was described as a masonry wall developing over a masonry step 80 cm height still covered with “Rosso di Verona” marble panels, covered by a porous rough render till 260 cm on ground level, constituted of permeable lime mortar, applied as sacrificial render to host salt efflorescences.

A double row of metal bars of around 200 cm longs and 30mm in diameter made of mild carbon steel chemically and electrically isolated with a neoprene cover were inserted diagonally on 06/04/1998 into the wall every 50 cm.

Since the intervention, the pillar was let free of the marble panels. The intervention was monitored over time for almost 5 years and was object of further investigation campaigns within the Emerisda framework after 17 and 18 years.

Figure 30: Pillar of the Narthex, near Zen Chapel, treated with the bars system. The bars' heads are visible on the upper part of the masonry

No photographic documentation related to a visual inspection of the pillars nearby the Zen Chapel before the insertion of the bars is available, however data regarding the moisture content of the wall on the repeated monitoring campaign are collected and discussed in the master thesis of Sara Lonardoni (Lonadoni (2002)). Moreover data regarding a nearby pillar, non treated were also collected between 2002 and 2003.
The thesis reports moisture content data, soluble salt analysis, and porosimetric data of the following campaigns, in addition we performed two sampling campaign during the Emerisda project.

Table 3. overview of sampling campaigns

nr	date	Campaign carried out by	Time from the intervention	Available data and collection methodology
1	06/04/1998	Procuratoria of Saint Mark's, DLK firma	Before intervention	MC% by gravimetric determination on powders collected by drilling at 105, 185, 286, 344,424 cm on ground level, depth 0-5,5-10,10-15 cm
2	26/08/1998		5months	
3	01/02/1999		10 months	
4	07/05/1999		13 Months	
5	07/06/01		3 years and 2 months	
6	30/09/2002	Procuratoria of saint Mark's, University of Bologna (Sandrolini, Franzoni, Lonardoni)	4 years and 5 months	Fixed sampling point obtained by coring the wall (holes of 3 cm in diameter) at 80, 235,310 cm on ground level and measuring HR%, T, MC% of powders and fragments stored within the obtained holes over time. Soluble salt and Porosimetric evaluation of the collected cores
7	18/02/2003		4 years and 11 months	
8	26/02/2015	Procuratoria of saint Mark's Basilica, EMERISDA Project (UNIVE)	17 years	**Within the framework of EMERISDA project.** Damp determination by microwaves, IR thermography, MC%, HMC% on powders collected by drilling at 110, 185, 255 on ground level, depth range 0--15 cm
9	16/03/2016		18 years	

The methodologies of investigation used during the previous campaigns and within EMERISDA project will be described in the next paragraph, while the results obtained within EMERISDA project are presented in the result section and discussed in relation to the data reported in the thesis "Il problema dell'umidità in edifici monumentali antichi: il caso della Basilica di San Marco in Venezia" (Lonardoni (2002)).

Considering the particular location of the narthex and the presence of frequent high tides it is necessary to discuss the results considering also this important phenomenon. Unfortunately no data regarding tides are reported of the first 5 sampling, while the tides evolution in the 10 days prior to the 6th and 7th sampling are reported within the thesis. However, the entire yearly evolution of tides should be considered and data regarding tides higher than 80 cm can be found in the archive of the Venice Municipality.

3.5.1.6. Research approach

The DLK bars system has been installed in April 1998, in the pillar nearby S. Zeno's Chapel.

In order to assess the effectiveness of the system, the moisture content of the walls has been determined before its application, then a repeated monitoring campaign allowed to observe the effectiveness not only on the mid-term (2-3 years) but also on the long term (more than 15 years).

Over time, the moisture content (MC) has been determined gravimetrically on samples collected from the walls (1-6th ,8-9th sampling) or stored within fixed sampling points (6-7th sampling) (see 3.2).

The salt content and distribution has been indicatively assessed by measuring the hygroscopic moisture uptake HMC, conductivity (8-9th sampling) and by Ion chromatography on few specimens (6, 8-9th sampling). Moreover non-invasive techniques such as IR- termography and microwave measurments were carried out.

The opportunity to work again on a system studied for a long period with similar sampling and MC% determination method constitute a rare chance for the system effectiveness evaluation.

3.5.1.7. Non- Invasive investigation

Non-invasive investigation methods were used during the campaigns carried out under the EMERISDA framework.

An accurate visual observation allowed to individuate the bars, the metal conditions and precedent sampling points. Moreover the extension of wall covered by a render layer was visually compared with pictures taken in 2001.

Thermal imaging measurements were carried out using a Flir B400 Infrared Camera, working in the spectral range of 7-13 µm, with an IR resolution of 320X240 pixels, thermal sensitivity of 0.05°C at +30° on 26/02/2015 in collaboration with prof. Romagnoni of IUAV university and with a NEC

TH7800 Infrared Camera (-20°C to 100°C emissivity 0.95) on 16/03/2016 in collaboration with CNR-ISAC. Both passive measurements and after heating the surfaces for 20 minutes with IR lamp were performed.

On 26/02/2015 it was possible to perform also microwave measurements of absolute humidity with the microwave hygrometer Trotec T600. The absolute humidity is given (max penetration depth 30 cm).

3.5.1.8. Sampling

Powder samples were collected by drilling during each campaign with the exception of the 7th campaign (18/02/2003) when fragments stored within the cored holes were measured and then replaced.

During the EMERISDA-project, drilling was carried out at different heights, 110, 185, 255 cm on ground level (corresponding to 180, 255, 325 cm on ZMPS), and at different depths along a vertical profile. On 26/02/2015 it was possible to collect samples at 0-5, 5-10, 10-15 cm, while on 16/03/2016 more sampling ranges (always covering a 0-15 cm depth) were necessarily in order not to heat the brick powder with the drill bit. Table 1 summarize the heights and samples collected.

Table 4: Samples collected during the two EMERISDA investigation campaigns

26/02/2015		16/03/2016	
height cm	depth cm	height	depth
110	0-5	110	0-2,5
110	5-10	110	2,5-5
110	10-15	110	5-10
185	0-5	110	10-15
185	5-10	185	0-5
185	10-15	185	5-10
255	0-3	185	10-12,5
255	3-5	255	0-1
255	5-10	255	1-2
255	10-15	255	2-4
		255	4-7
		255	7-9
		255	9-12,5

The samples were collected in the same brick unit drilled before the intervention and during the precedent campaign.

The drilled powder were collected in glass vials hermetically closed and transported to the laboratory for the MC and HMC determination, according to the previously described method.

3.5.1.9. Results - Sampling Campaign 26/02/2015

Rising Damp in the Narthex is mainly due to high tides phenomena that transform the Narthex in a pool, moreover the Narthex is not a completely close space since 4 main doors are open all day ensuring a fast exchange of humidity with the external environment, in particular in case of fogs.
2014 and the beginning of 2015 were rainy periods in Venice (1184 mm of rains in 2014, only 2008 was a rainier year in the last decade).
189 high tides episodes over 80 cm were recorded in 2014 and other 22 since the beginning of 2015, the last one before the sampling occurred on 9th February.
Therefore, no recent episode of high tides occurred in the days before the sampling, however the walls were subjected to continuous water income during the whole 2014.
In the framework of the Emerisda Project, a first visual inspection was carried out in February 2015
Sever damage of the marble panels in “Rosso di Verona “ covering the lower part of the walls was observed. The panels were affected by detachments and spalling, salts crust were visible within the silt clay veins of the stone. External salt efflorescences were not visible probably due to the high relative humidity conditions and the presence of high tides phenomena directly washing the surfaces on the previous days.
Most damage to the surfaces is salt-related. Efflorescences, powdering and crumbling were visible on the bricks over the Rosso di Verona panels till around 3 m where mosaics decorating the ceiling are.
The sacrificial render layer applied on the bricks during the intervention of 1998 is consumed, fragments and a thin render layer still cover part of the bricks, but the conservation state is bad, and the render is powdering.
The bars’ heads are visible at 250 cm over the ground. The bars are only slightly oxidized and still cover by neoprene., the bars are consistent and rust is present only on the external surfaces exposed directly to the environment.
Several holes ascribable to precedent sampling are visible. The remaining walls of the Narthex are still cover by marble panels, therefore it was not possible to verify the conservation state of the underlying walls. Rising damp of salty water is the most probable moisture and damage source, in particular since the Narthex underwent tides flooding becoming a pool.

The thermal images showed a quite homogeneous surface, and no particular thermal differences. The passive observation of the surface by IR thermography did not give clear results (figure 32) and a long heating (more than 2 hours) would have been necessary to better observe the surfaces in active observation. However, as visible in figure 33, the analysis of the surfaces after 30 minutes heating pointed out the presence of efflorescences and areas with lower temperature near the corner. The holes due to precedent sampling are clearly visible.

Figure 31: images of the treated pillar, the bars head and the holes of the previous sampling campaigns are clearly visible in the second picture.

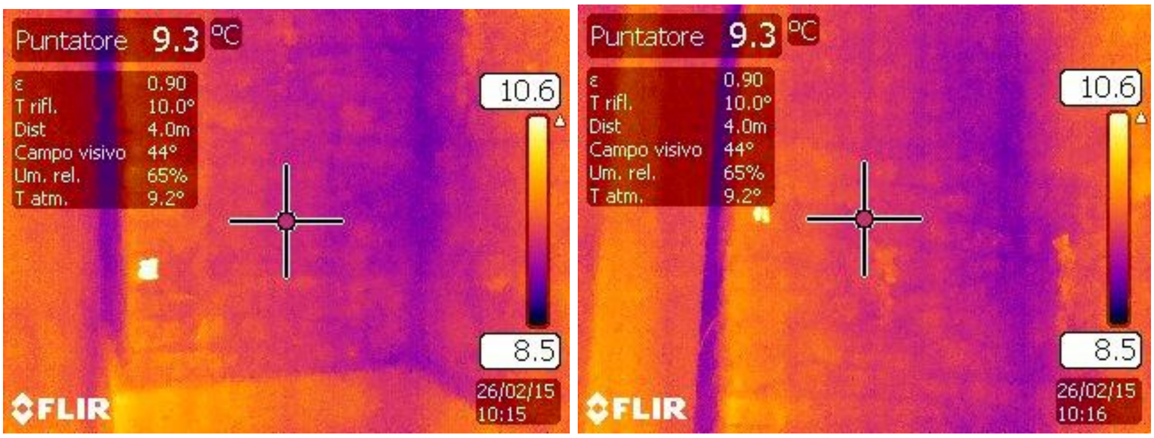


Figure 32: IR images of the wall in passive observation

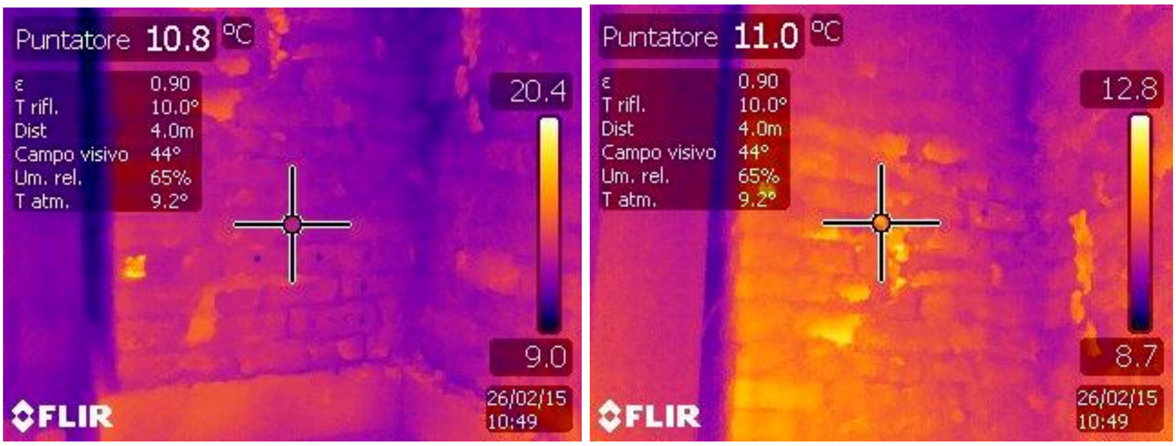


Figure 33: IR images of the wall after 30 minutes of heating

The moisture content was measured with a microwave thermohygrometer and a distribution maps was elaborated (figure 34).

It is possible to notice a quite homogeneous area in the lower part of the wall with measured relative humidity of 70-76%, the water content seem to decrease with the height reaching values around 55% at 260 cm on floor level.

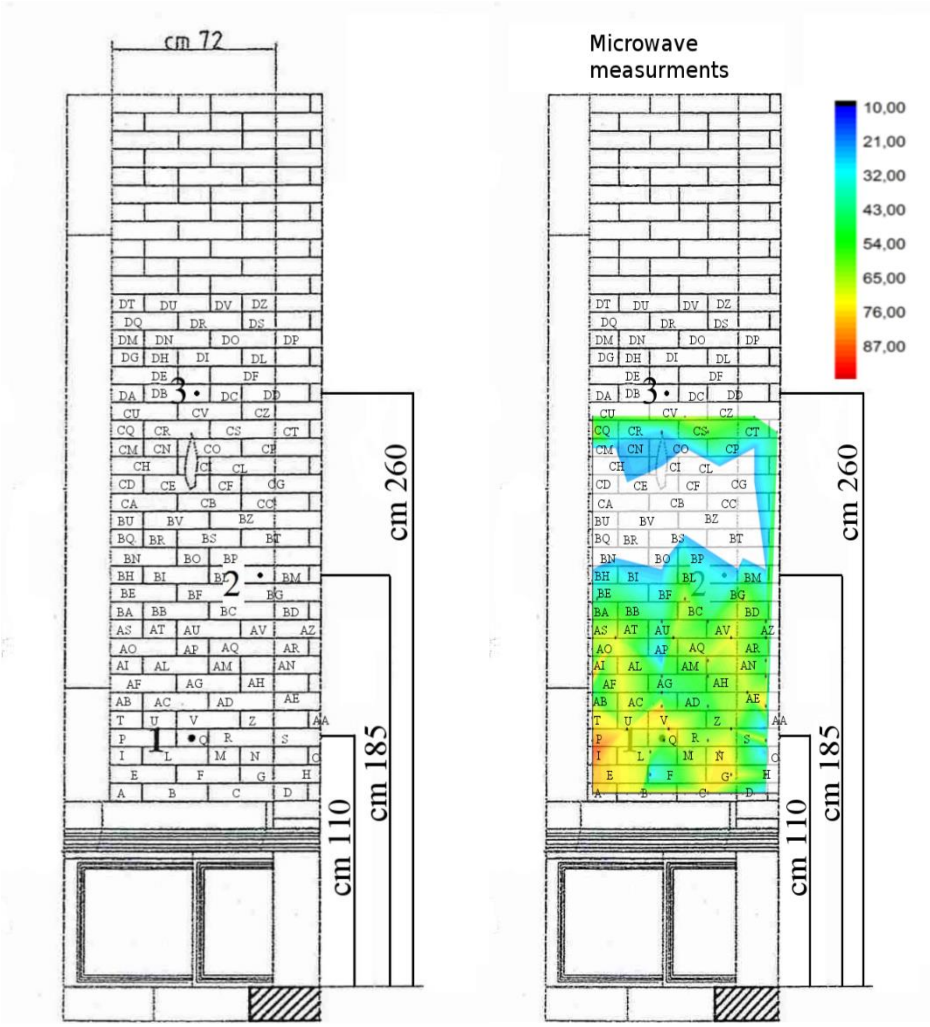


Figure 34: Left: Scheme of the sampling points and of the bricks investigated by microwave measurements; right: HR% moisture distribution map according to the values collected by microwave measurements

Figure 35 reports the maps of the moisture distribution, hygroscopic moisture content and the conductivity of soluble salts within the wall.

The height is referred to the average see level at Punta della Salute.

Moisture content ranging from 7% to 18% were measured. The moisture content do not diminish with the height in the considered part, only a slight drier area was found at 250 cm on the see level (185 cm above the floor level). The HMC% and the soluble salt distribution indicates both a higher presence of soluble salts over 250cm on the see level (185 cm above the floor). Possibly the evaporation zone is located very high in the Narthex.

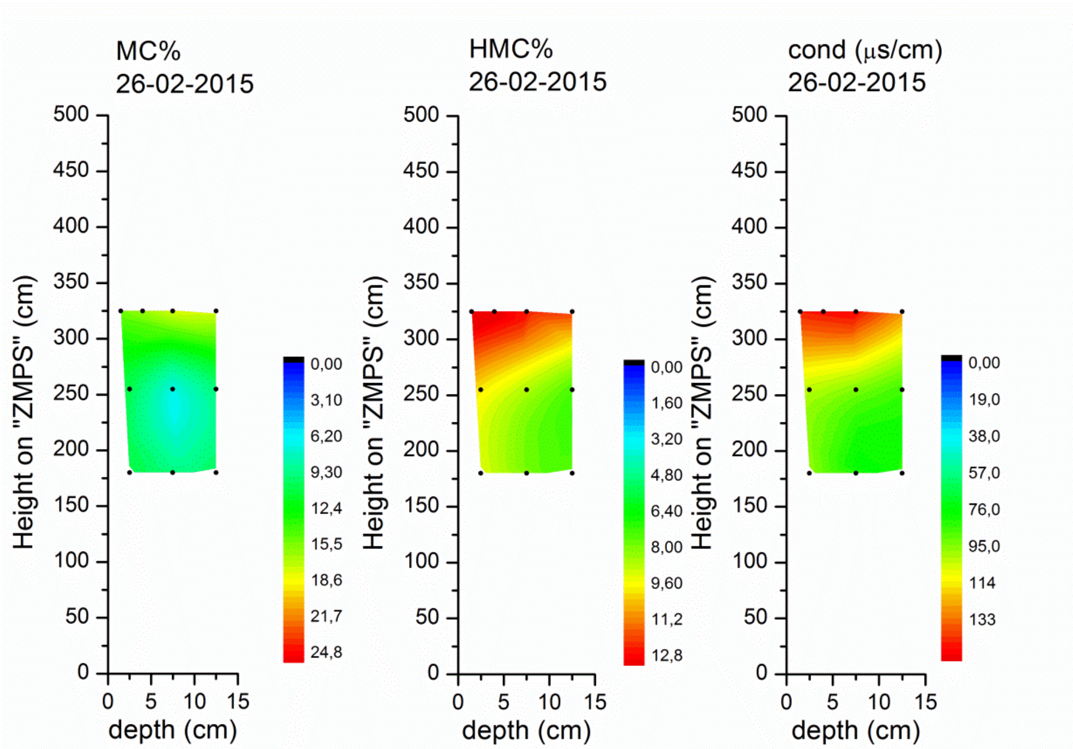


Figure 35: Moisture content, hygroscopic moisture content HMC and conductivity distribution in relation to the wall's height on sea level ZMPS and wall's depth.

3.5.1.10. Results - Sampling Campaign 16/03/2016

2015 and the beginning of 2016 were dry periods in Venice, a long drought period lasted from march till the end of 2015. 700 mm of rain fell during the entire 2015 on the Municipality of Venice, only with February-March 2016 the precipitation became regular and slightly over the average.
Only 94 high tides episodes over 80 cm were recorded in 2015, and other 35 in 2016 before the sampling campaign (the last one on 10th March 2016). Even if a high tide episode occurred few days before the sampling the walls add an entire drought year to dry out.

The visual inspection carried out during the second sampling (16/03/2016) evidence a situation similar to the previous one, but salt efflorescences were more diffuse also over the Rosso di Verona panels and over the bricks (figure 36).

During this second campaign IR thermograms of the wall surfaces were collected (see figure 37), that showed a quite homogeneous surface, and a slight thermal difference near the corner (possibly due to a different exposure to the air). Also during this sampling it was observed that passive observation of the surface did not give clear results, and a long heating (more than 2 hours) would have been necessary to better observe the surfaces in active observation.

Figure 36: Pictures of the pillar before the second sampling campaign.

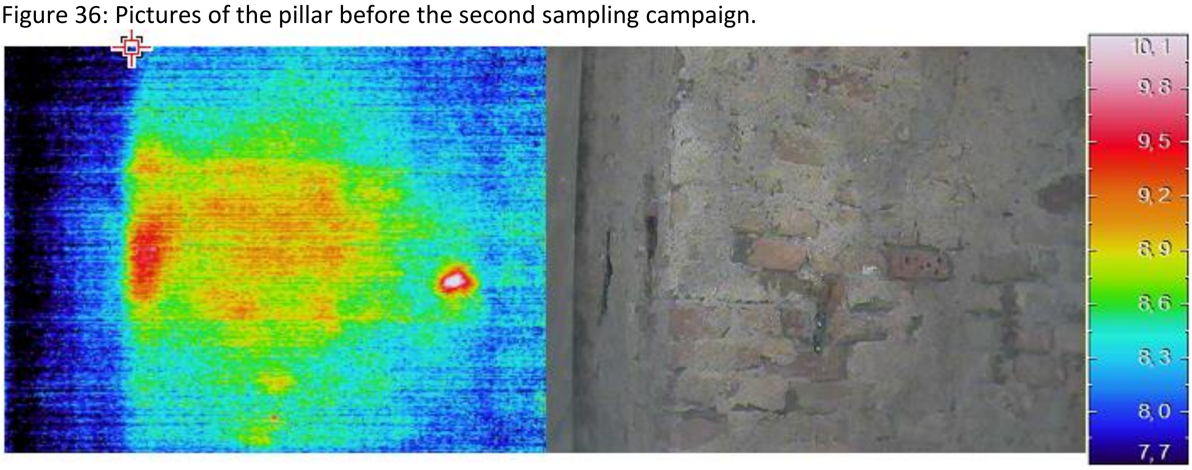


Figure 37: IR image of the wall surface during the second campaign, passive mode.

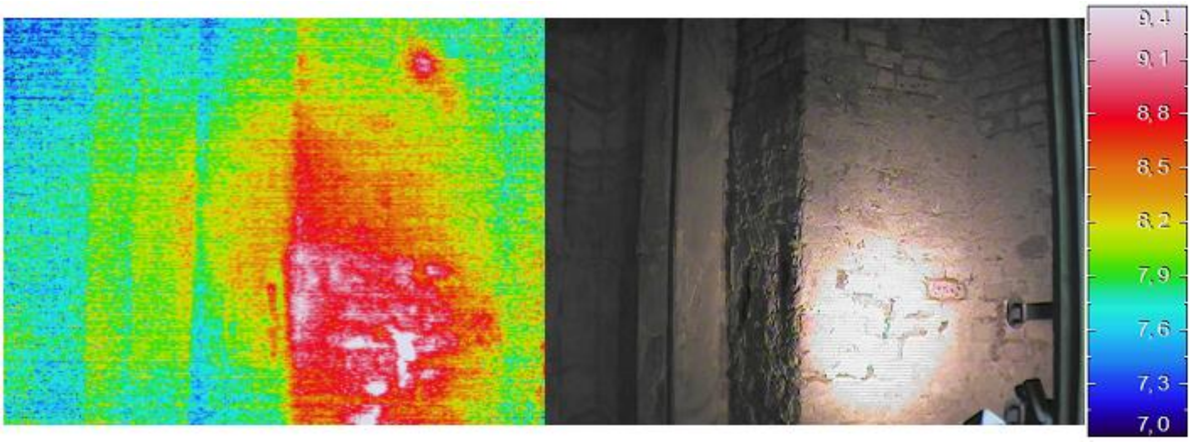


Figure 38: IR image of the wall surface during the second campaign, after 2 hours heating.

Figure 39 shows the maps of the moisture distribution, hygroscopic moisture content and the conductivity of soluble salts within the wall. The height is referred to the average see level at Punta della Salute, thus allowing to consider the recursive high tides reaching the Narthex.

Moisture content ranging from 1.5% to 16.7% were measured, lower than the previous sampling campaign. The moisture content decrease at increasing heights, as in rising damp phenomena, moreover the moisture decrease at increasing depth. The wall is dryer in comparison to the previous measurement and drying also in the internal parts.

High soluble salt content were measured (higher HMC and conductivity in comparison to the previous campaign) in particular at low height. A salt profile similar to what commonly observed in case of rising damp was found: higher salt content in the external and medium part of the wall, lower inside.

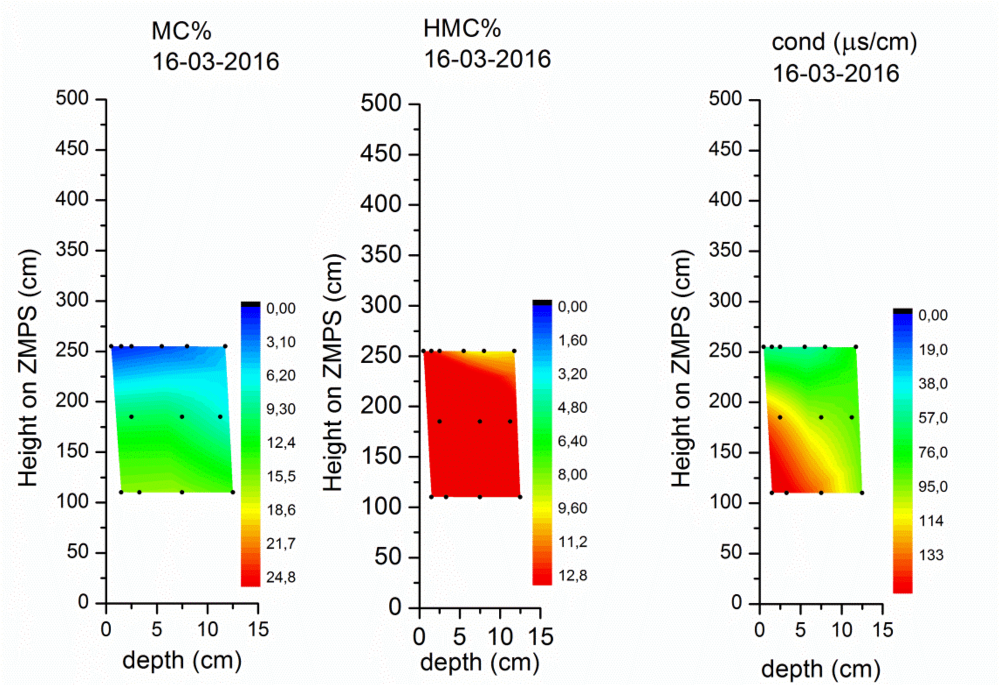


Figure 39: Moisture content, hygroscopic moisture content HMC and conductivity distribution in relation to the wall's height on sea level ZMPS and wall's depth.

3.5.1.11. Discussion in relation to previous sampling campaigns

Figures 40 and 41 report the MC% distribution measured over time in the different campaigns. Moreover table 2 summarizes the nr. of high tides events in the 12 and 3 months before the sampling in order to observe if the contribution of incoming water is stronger than the possible effects due to the bar method.

The distribution show a general slight increase of the water content both on the surface and in the internal part till 2015 and in particular for higher heights. The major percentages observed on higher heights might be due to the presence of soluble salts, which unfortunately were not properly measured in the campaigns before EMERISDA project.
A decrease of moisture content can be observed only in 2016.

The trend seem to follow the high tides frequency, more than the presence or absence of the methods against rising damp. In fact, high tides events duplicate in the last years.
However, despite the exacerbated environmental condition the MC% did not increase dramatically. It is also possible to presume that if this external source of water is removed, the wall is free to dry out, as observed for the "drought" year 2015-begin of 2016, and that the method is partially counteracting the tides effect.

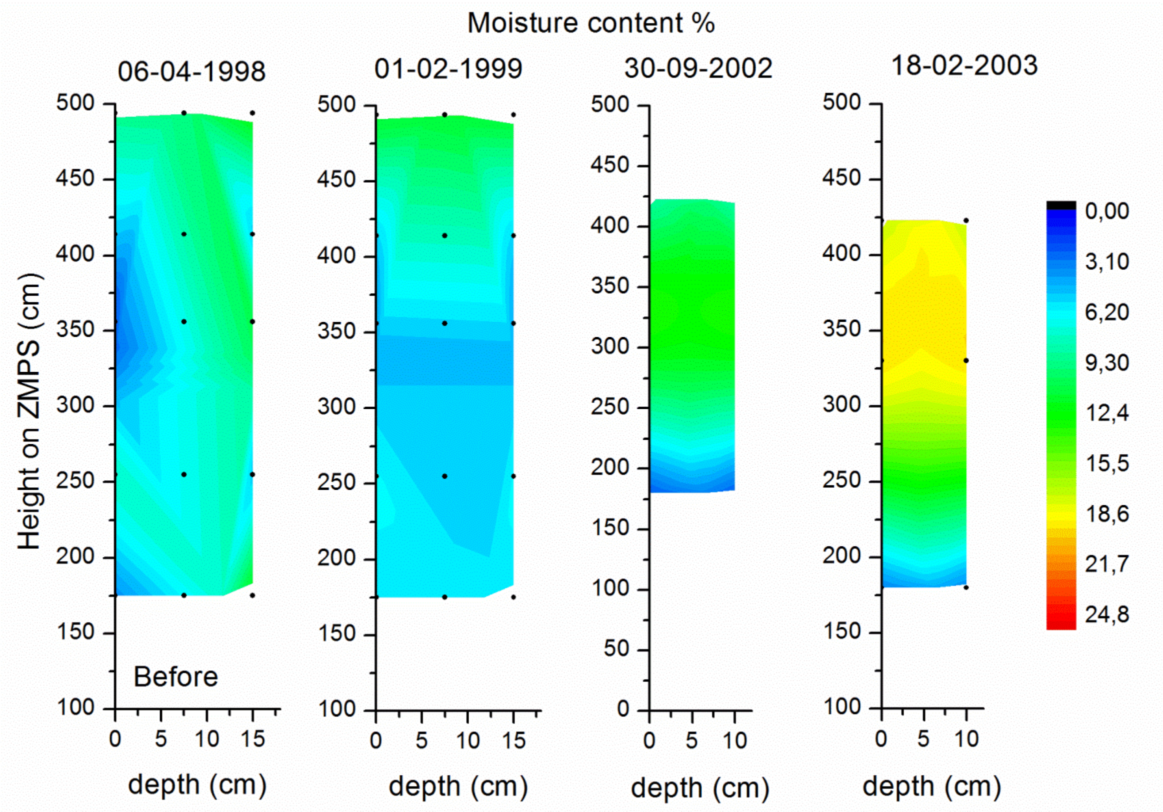


Figure 40: Moisture content distribution during the repeated sampling campaigns from 1998 to 2003

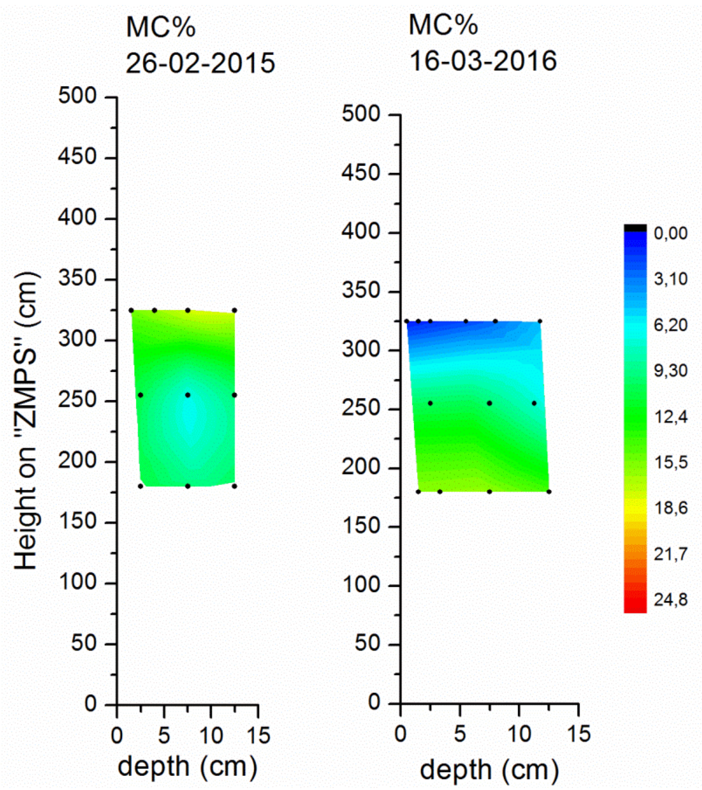


Figure 41: Moisture content distribution measured during the EMERISDA project

Table 5: Tides over +80 cm on ZMPS registered in the periods preceding the sampling campaigns

Sampling campaign	Tides over 80cm in the previous 12 months	Tides over 80cm in the previous 3 months
6/04/1998 (before)	64	1
1/02/1999	53	17
30/09/2002	57	21
18/02/2003	132	44
26/02/2015	160	42
16/03/2016	106	35

3.5.1.12. Conclusions and recommendations

This research continues a series of investigations aimed at assessing the effectiveness of the Bars system based on an induced electro-osmosys principle, that remain partially non well explained by the producer.

Thanks to the availability of previous research and data and the investigation carried out during the EMERISDA project , the Saint Mark's Narthex demonstrated to be a precious information site for long term evaluation of the method effectiveness. In fact, in this case there was the unique opportunity to continue a monitoring campaign lasted 15 years, even if not in continuous way. The MC% was determined always according to the same procedure. Moreover, the analysis of the environmental situation and of the high tides give interesting insights for the data evaluation, at least of the last 2 campaigns.

However, the results are not completely clear since the MC% changed without a clear trend. No significant and consistent reduction of the moisture content was observed, neither a clear increase, even if the high tide phenomena exacerbated during the monitored period.

3.5.2. Church of St. Bavo, Haarlem (Netherlands)

3.5.2.1. Introduction

This chapter summarises the results of an investigation to assess the effectiveness of a so-called device that employs 'wireless electro-osmosis'. The system has been applied in the St. Bavo Church in Haarlem in 2009 and an additional device has been placed in January 2015. This research evaluates the effectiveness of the device placed in 2015. The effectiveness of the system has been assessed by measurements of the moisture content in the walls, before application of the system and one year after application.

Figure 42: Installed Hydropol system in the coffeecorner. Picture by L. Miedema, 11-9-2014.

3.5.2.2. Background information and history

The St. Bavo Church (Dutch: 'Grote Kerk' or 'St. Bavokerk') (figure 43) is one of the largest churches in the Netherlands; it was built between 1370 and 1520, replacing an earlier church which was severely damaged in a fire. It was originally built as a catholic church, but was converted to Protestantism in 1578. The St. Bavo is a cruciform church in gothic style and consists of:

- A central nave, mainly in natural stone, constructed from ca. 1400;
- Two side aisles in brick, with parts in natural stone, completed in 1483;
- A transept, constructed in brick in the 15th century, but modified later on with parts in natural stone;
- A choir in natural stone, part of a brick chancel, completed in 1483;
- A crossing tower in timber, covered with lead, reaching a height of 78 meters;

- A remarkable vaulted roof construction (net vault) in timber covering the chancel (completed in 1531) and central nave (completed 1538);
- A series of annexes to both naves and chancel.

Several restorations have taken place since 1876, the most recent in 1980-1985. The crossing tower has been restored in 1964-1969.

Figure 43: View on the St. Bavo Church. Image: zangstudiohaarlem.nl

3.5.2.3. Visual Inspection

We carried out a first visual inspection in the autumn of 2014. Severe damage, in the form of efflorescence, crypto-florescence, sanding, scaling of the natural stone, is present in the lower part of the columns (figures 44-46). In the lower part of some of the walls, locally, damage in the form of peeling of the paint and sanding of the plaster is visible (figure 47-48).

Most damage to the stone surface is salt-related: efflorescence of soluble salts and scaling and sanding of the stone due to cryptoeflorescence (figures 49-51). For this kind of damage to occur, not only the presence of soluble salts is necessary, but also a source of moisture. In the St. Bavo church, considering the location of the damage in the lower parts of walls and columns, rising damp is the most probable moisture source. The relative humidity (RH) of the air, may provide an additional moisture source.

Figure 44: Efflorescence and stone damage at base of column (L. Miedema, 11-09-2014)

Figure 45: Efflorescence and stone damage at the base of columns. Right: detail of fig. 3.1. Note the pink colour on the base of the column (L. Miedema, 11-09-2014)

Figure 46: Efflorescence and stone damage at base of column. Damage to floor (L. Miedema, 11-09-2014)

Figure 47: Damage to plaster as a result of efflorescence (L. Miedema, 11-09-2014)

Figure 48: Damage to plaster as a result of efflorescence. Right: Detail showing damage to plaster and paint (L. Miedema, 11-09-2014)

Figure 49: Scaling of stone (B. Lubelli, 09-10-2014)

Figure 50: Efflorescence and scaling of stone (B. Lubelli, 09-10-2014)

Figure 51: Efflorescence on stone (B. Lubelli, 09-10-2014)

3.5.2.4. Research Approach

The Hydrosecco system has been installed in January 2015, close to the southern entrance of the church (see figure 52). In order to assess the effectiveness of the device, the moisture content in the walls has been determined before its application and one year afterwards.

The moisture content (MC) has been determined gravimetrically on samples collected from the walls. The salt content and distribution has been indicatively assessed by measuring the hygroscopic moisture uptake (HMC) of the samples. On a selection of samples, the type and quantity of salt ions has been determined by Ion chromatography (IC).

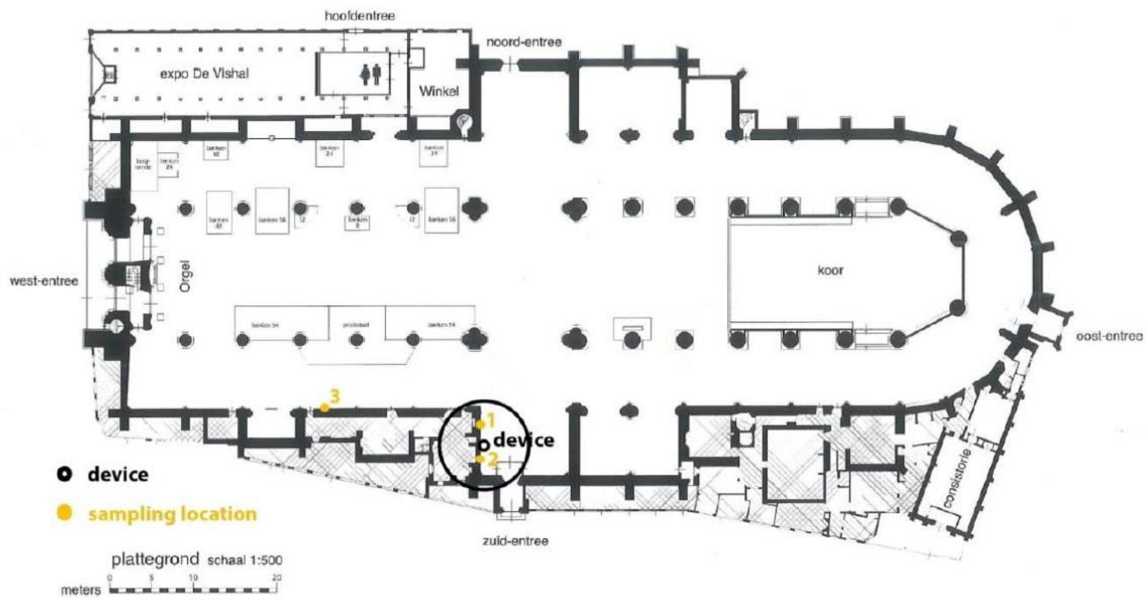


Figure 52: Plan of the St. Bavo church with indication of the position of the device, its area of influence (circle) and of the sampling locations. Locations 1 and 2 are within the area of influence of the device; location 3 is outside and is thus considered as reference.

3.5.2.5. Sampling

Powder samples were collected by drilling. Drilling was carried out at different heights (0.2, 0.5, 1, 1.5, 2.1 m up to the undamaged area) and depths (0-20 mm, 20-50 mm, 50-150 mm and 150-300 mm up to the middle of the wall) along a vertical profile. As the moisture content depends also on the type of material, all samples were collected in brick. Information on the type of material and on the presence of damage was recorded.

Samples were collected both at locations within (location 1 and 2) and outside (location 3) the area of influence of the device. By comparing location 1 and 2 with location 3 (reference), changes in the height of rising damp due to seasonal variations of the ground water level can be distinguished from variations due to the effect of the device.

During the sampling campaign one year after the intervention, care was taken to collect samples, as far as possible, in the same brick unit drilled before the intervention, as the heterogeneity of (historical) building materials may lead to relevant differences in their moisture content.
The powder samples were collected in bottles or plastic bags, which were then hermetically closed and transported to the laboratory for the measurements of the MC and HMC, according to the earlier explained methodology.

3.5.2.6. Determination of the type and amount of soluble salts

Ion Chromatography (IC) analyses were carried out on a selection of samples, chosen on the basis of the HMC results, in order to determine the type and amount of soluble salts present. In the IC procedure, the salts are dissolved in water, and positive and negative ions are quantified. The IC tests were performed by the university of Ancona (Italy).

3.5.2.7. Moisture Content before application of the system

In January 2015, measurements were carried out at the three locations. See figure 53 for the results.

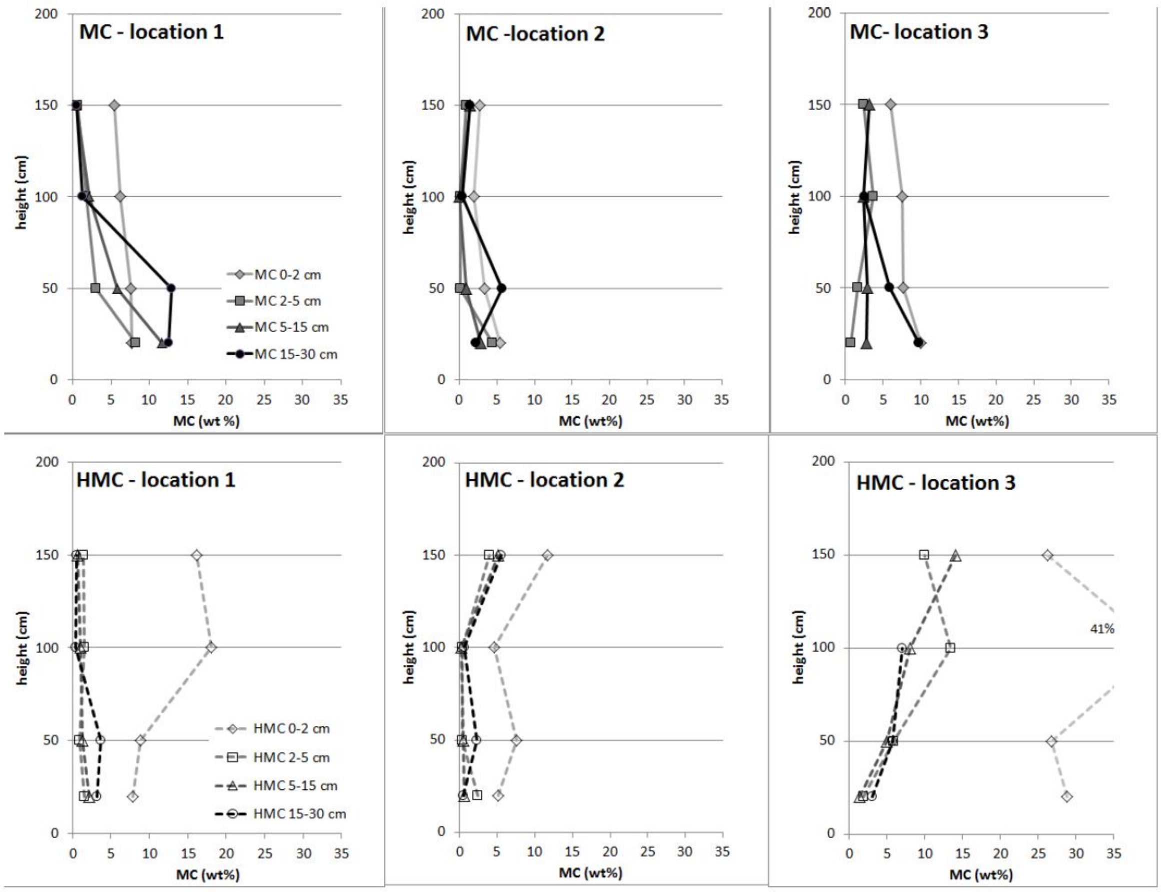


Figure 53: MC and HMC (weight %) in the masonry walls of the St. Bavo church before the application of the dehumidification device.

At location 1, the moisture content (MC) measured in the wall increases with depth and decreases with height, suggesting the presence of rising damp from the ground. It is striking to observe that the MC distribution at locations 1 and 2, at just a few meters distance from each other, is significantly different: at location 2, the MC is much lower. This might be related to differences in the material properties, a common phenomenon in old masonry.

At location 3, a high MC is measured in depth in the wall (15-30 cm), that decreases towards the surface. Also in this case, rising damp from the ground is most probably present.
The hygroscopic moisture content (HMC) is very high in the plaster all over the height of the wall; the highest values are measured at the height where the masonry dries and the salt accumulates. In spite of the very high HMC measured at location 3, neither damage nor efflorescence are visible on the plaster.
When comparing the MC with the HMC, it is possible to conclude that the MC measured in the plaster at higher levels in the wall is due to the hygroscopic effect of salts (and not to other moisture sources).

3.5.2.8. Moisture Content one year after application of the system

The MC of the wall was measured again after one year from the application of the dehumidification device. At location 1, the sampling had to take place about 70 cm to the right from the originally measured location, due to the placing of a tombstone against the wall at the location of the original sampling. The MC, before and after one year of application of the dehumidification device, is reported in the figure below. For clarity, the MC between 5 and 30 cm has been averaged.

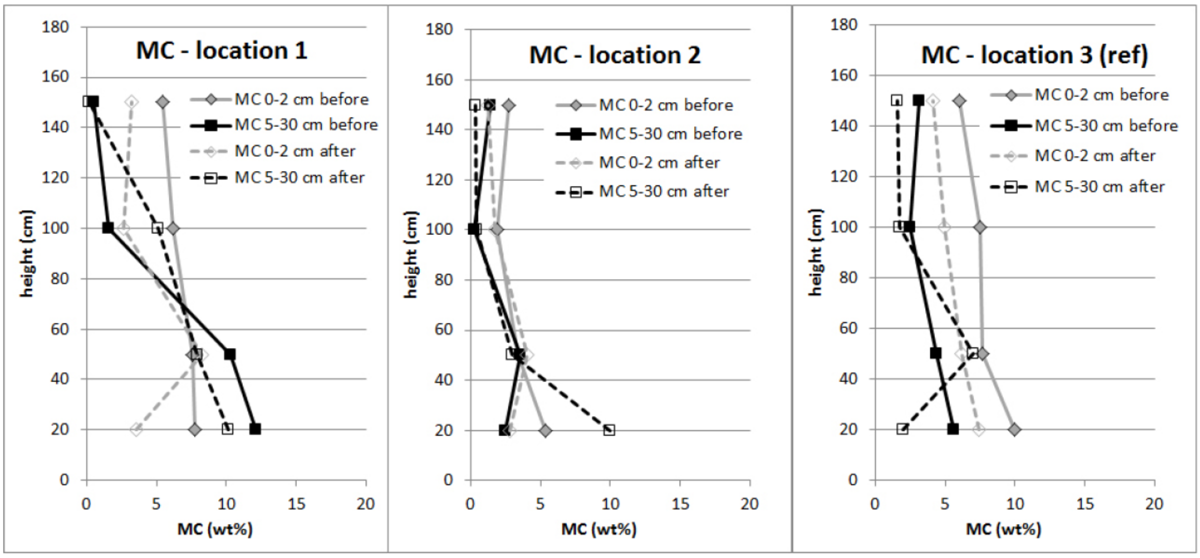


Figure 54: Difference in the MC in the masonry of the St. Bavo church, before (solid line) and 1 year after (dotted line) application of the dehumidification device.

No consistent and significant decrease of the MC at locations 1 and 2 is measured. At location 2, in depth and in the lower part of the wall, the MC has even increased.
As no clear difference in moisture behaviour between the area near the device (location 1 and 2) and the reference measurements (location 3), the fluctuations in MC are likely to be the result of natural seasonal variations. Circumstances, such as the amount of rain, groundwater level, inside and outside temperature and changes in the relative humidity of the air, can influence the MC in the walls.
Based on these measurements, it can be concluded that the dehumidification device did not lead to a decrease of the moisture content in the wall.

3.5.2.9. Results Ion Chromatography

For a selection of samples, the type of soluble salts has been determined by Ion chromatography (IC).

Analyses were carried out by the Italian partner. All samples were taken before application of the device, so the device has not influenced the results in any way.

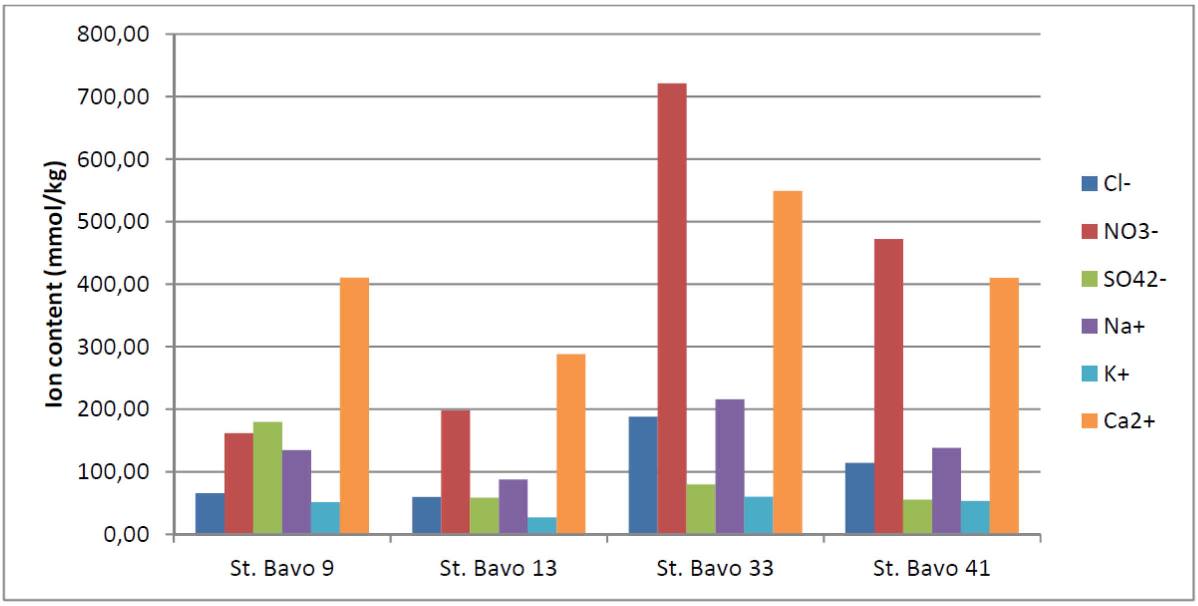


Figure 55: Ion chromatography results for samples 9, 13, 33 and 41 (in the plaster layer of the brick walls).

All samples contain elevated levels of calcium and nitrate, especially samples from location 3 (samples 33 and 41). At this location, the hygroscopic moisture content is very high as well. However, there is no visible damage to the surface.

The samples are likely to contain a large amount of calcium nitrate. Considering that the RH in the church is probably high (no heating is present), calcium nitrate will, most probably, be present in solution most of the time, and almost never in crystallized form. In fact, the relative humidity of equilibrium of calcium nitrate in its highest hydrated form, $Ca(NO_3)_2 \cdot 4\,H_2O$, is 53,1% (Steiger (2011));

this RH value can be supposed to be lower than the RH present in the church. This can explain the absence of damage at this location, in spite of the high HMC and high ion content measured in the samples.

3.5.2.10. Conclusions and recommendations

This research aimed at assessing, in the field, the effectiveness of the 'Hydropol' dehumidification system in the St. Bavo church in Haarlem. As the working principle of the system is not clearly defined and/or explained by the producer, research has been limited to assess whether, one year after application of the system, any significant and consistent reduction of the MC in the walls

occurs. To ensure soundness to the research, the moisture content has been assessed gravimetrically, sampling before and after application has been carried out in the same season of the year and reference locations, outside the range of action of the device, have been sampled as well.
After 12 months from the application of the device, in the location within the area of influence of the device, the MC in depth in the lower part of the wall does not show a consistent decrease. At one of the two locations the MC has even increased.
The changes in MC at the surface can be the result of natural variations in the environment, such as changes in temperature and/or relative humidity, affecting the hygroscopic moisture uptake of the salts present in the plaster.
Based on the results of this research, it can be concluded that in this case no significant and consistent reduction of the moisture content has been measured after 12 months from the application of the device. Over this period, no clear effectiveness of the device is found.

3.5.3. Artillery warehouse, Paardenmarkt, Delft (Netherlands)

3.5.3.1. Introduction

This chapter summarises the results of an investigation to assess the effectiveness of an electrokentic device, that employs electromagnetic waves to dehumidify walls. The effectiveness of the system has been assessed by measurements of the moisture content in the walls, before application of the system and 10 months after application.

3.5.3.2. Background information and history

The former Artillery warehouse located at the Paardenmarkt, is a listed monument in the centre of Delft. It was constructed around 1671. The buildings are constructed in brick masonry, and are subject to rising damp and salts. The salts cause the typical decay of disintegration of renders and flaking of paint. It is worth mentioning that the groundwater level is constantly high.

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Figure 56: Artillery Warehouse, Paardenmarkt (Delft, Netherlands), exterior and damage in the interior

3.5.3.3. Sampling

Powder samples were collected by drilling. Drilling was carried out at different heights (0.2, 0.5, 1, 1.5, 2.1 m up to the undamaged area) and depths (0-20 mm, 20-50 mm, 50-100 mm and 100-200 mm up to the middle of the wall) along a vertical profile. As the moisture content depends also on the type of material, all samples were collected in brick. Information on the type of material and on the presence of damage was recorded.

Samples were collected both at two locations within the area of influence of the device, and two reference locations (outside the area of influence of the device).

During the sampling campaign 10 months after the intervention, care was taken to collect samples, as far as possible, in the same brick unit drilled before the intervention, as the heterogeneity of (historical) building materials may lead to relevant differences in their moisture content.
The powder samples were collected in bottles or plastic bags, which were then hermetically closed and transported to the laboratory for the measurements of the MC and HMC, according to the earlier explained methodology.

3.5.3.4. Results

The graphs show the moisture content MC, in function of height and depth, for four of the sampling locations, before and 10 months after the application of the device.

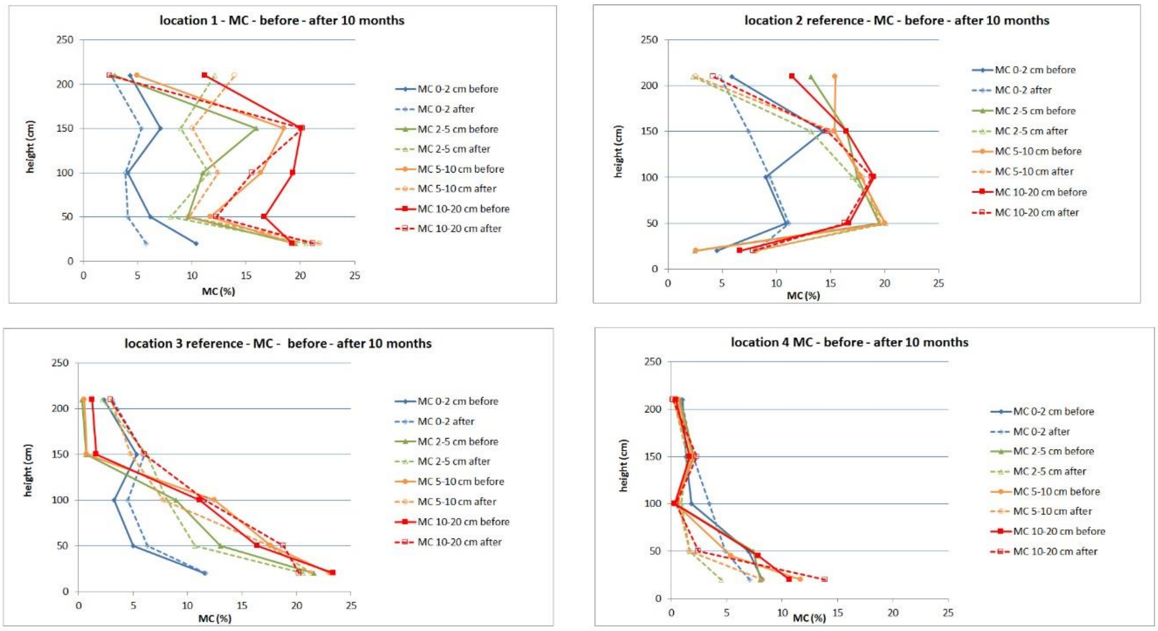

Figure 57: Comparison of MC at different heights and depths, initially and 10 months after de dehumidification device was installed.

The evolution of the moisture content at the location within the radius of influence of the electro-kinetic devices is comparable to that of the reference locations. There are local changes in MC, but in general, the curves describing the moisture content in the walls does not change significantly. observed. The effectiveness of the method 10 months after its application can thus not be confirmed.

3.5.4. Interbellum villa, Humbeek (Grimbergen, Belgium)

3.5.4.1. Introduction

This chapter is dedicated to a particular treatment by injecting the walls of a villa with a chemical product against rising damp. The treatment is special, since it was done by a product that is usually not used for treating rising damp. The villa is an example of a building built with a special kind of mortar, that was used in some cases in the 1st half of the 20th century. The composition of this mortar makes it almost impossible to treat it with 'normal' injection products.

3.5.4.2. Background information

The villa is located very near the Brussels-Scheldt maritime canal between Brussels and Willebroek. The canal itself is old, and constructed between 1550 and 1561, under the reign of Mary of Hungary.

Figure 58: Location of the villa, near the Brussels-Scheldt Maritime canal.

Due to the vicinity of the canal, the area is very damp, which is reflected in the construction of the villa (constructed in the late 1920's):

- The ground floor of the villa is not living area. On the ground floor there is storage area and a garage. There is no actual (underground) cellar, probably because it would be virtually impossible at the time of the construction to protect the cellar from flooding, due to the high groundwater level. The actual living areas are located on the 1st and 2nd floor.
- The masonry near the ground level is constructed with a normal type of brick, but with a special kind of mortar. It is a mortar based on sand and hydraulic lime, with an addition of a bituminous compound. We were not able to determine exactly its composition (which is difficult anyhow, since bitumen or asphalt is a mixture of organic compounds). It is important to note that old literature (see for instance Scholten (1914)) mentions the

possibility to add an emulsion of bituminous compounds in water, to the mortar mixture before it hardens. This will make the mortar denser, les capillary active, and will protect the building against rising damp. The problem remains that such mortars are never impermeable for moisture. So the protection is existing, but the mortar cannot be considered as completely damp-proof.

- The presence of such organic compounds could be suspected because of the abnormal dark colour of the mortar.
- The presence of the bituminous compounds has been demonstrated by applying a strong organic solvent (such as methylene chloride) to a solid sample of the mortar: it started to fall apart and changing colour, clearly indicating that certain components in the mortar were dissolving.

Figure 59: Front view of the villa.

The floors of the villa are made out of reinforced concrete, that is resting on the masonry. The exterior of the villa has a plaster with a very rough texture, which was very fashionable during the Interbellum. It is cement-based, and contains possibly also additions to make it more watertight, which was in those days a very important reason to apply such renders. Such renders have the serious drawback that they do not allow drying of humidity that is present in the masonry under the render.

The interior of the ground floor has been plastered with a contemporary cement-based plaster with resinous additions, that are often used to apply in damp caves. Such plasters have the tendency to block drying of humidity in the underlying masonry, but cannot be considered as completely water- or vapour-tight.

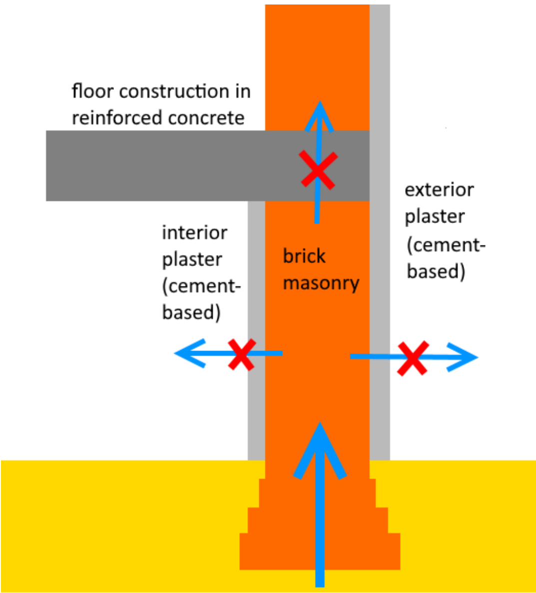

Figure 60: structure of the walls of the ground floor. The presence of the plasters with low capillarity and low water vapour permeability, and the concrete floor, cause the humidity to be trapped in the masonry on the ground floor.

Figure 61: a photo of the degraded interior plaster.

The plaster on the ground floor show on the inside degradations, even though principally aesthetical. The plaster shows efflorescence, humid spots, and superficial flaking. Nevertheless, it adheres well to the brick masonry underneath.

Because of the humidity problems, the walls have been injected twice between 2000 and 2012, with a commercial product of good quality (it has been successfully used in the following case study, see below). The humidity problem remained.

Through contacts with manufacturers, we learned that the polymerization of classical silicone-based products (among the best and most versatile on the market) cannot take place in a matrix that contains lots of organic matter, as is the case in this building (and many other buildings from the end of the 19th century and 1st half of the 20th century).

This case was selected to check whether it could be possible to use other products for the treatment of rising damp.

3.5.4.3. Sampling

Powder samples were collected by drilling. Drilling was carried out at different heights (0.2, 0.5, 1, 1.5, 2 m) and depths (0-20 mm, 20-50 mm, 50-150 mm) along a vertical profile. As there was a plaster which could not be removed, we could not see where we drilled exactly, so all samples were mixed samples (brick + mortar). The initial sampling was followed by the injection of the product. Further sampling campaigns were carried out 6 months, 1 year and two year after the injection.

The powder samples were collected in small plastic containers, which were then hermetically closed and transported to the laboratory for the measurements of the MC and HMC, according to the earlier explained methodology.

3.5.4.4. Initial situation

Figure 62 shows the humidity profiles, both MC and HMC, at difference depths.

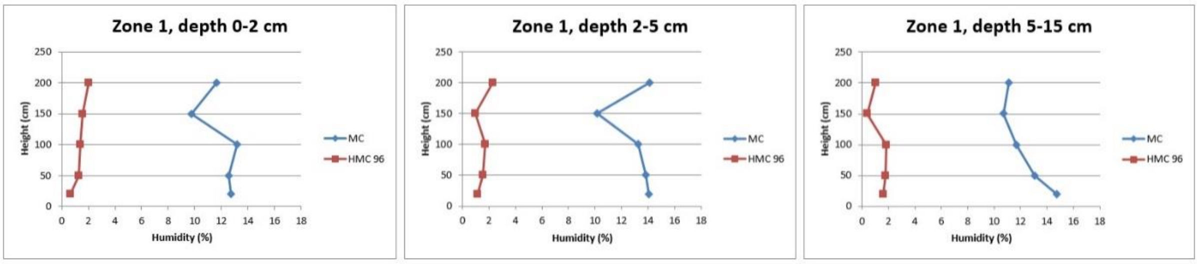

Figure 62: MC and HMC initially.

We can observe the following:

- HMC is always very low compared to MC. It is therefore highly probable that the salt content of the masonry is low, causing a low hygroscopic moisture uptake. This will make interpretation of the results much easier.
- MC is always very high, and there is hardly any evolution in height nor depth. MC is always comprised between 10 % and 14%. This is a very high value, the walls are very humid, and the humidity is distributed over the entire volume between floor and ceiling, and over the entire thickness of the wall. This is logic, since the finishing layers of the walls do not allow lots of vapour or capillary transport, causing the humidity to be caught in the masonry, from which it is distributed evenly over the volume of the wall.

3.5.4.5. treatment of the wall: injection

For this case, an oleophobic product has been selected. These products form an oleophobic (and therefore also hydrophobic) layer at the base of the wall. Such products can develop their oleophobic behaviour, even in a material that contains lots of organic matter.

The selected injection product is actually not a normal injection product. Normally it is used as an antigraffiti impregnation (applied to the surface of a façade), composed of fluorinated copolymers, diluted in an organic solvent, in a concentration of 5%; This is rather low for an injection product (where concentrations around 10% are considered to be normal).

Injection parameters:

- Distance between injection holes: 12 cm
- Quantity applied: 15 litres per m² of horizontal wall section (normally 10 litres should be enough, but 15 litres were chosen because of the low concentration of the product).
- Applied pressure: 3 à 5 bar

3.5.4.6. Evolution of the humidity after the treatment

Figure 63 shows the average MC of the wall, during the different sampling campaigns. We mention the average, which gives a clearer view. One should realize that these are averages, and that the number of actual samples was much larger than results on the graphs.

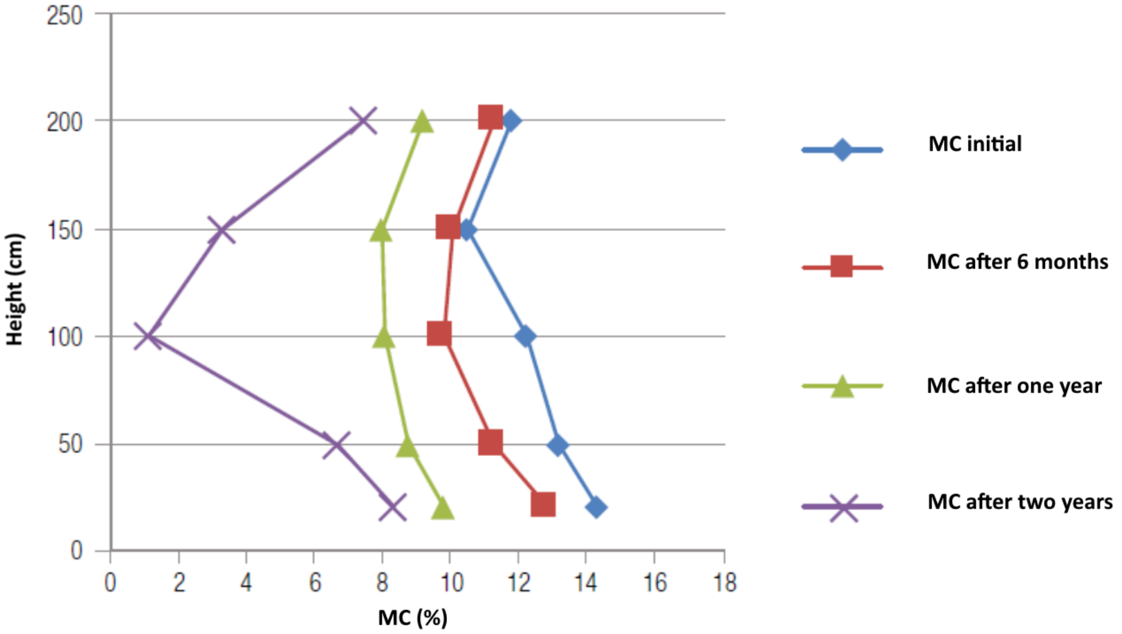

Figure 63: evolution of the average of the MC during the two years following the injections. HMC is not represented in this graph, as the hygroscopic moisture uptake of the masonry turned out to be is insignificant.

3.5.4.7. Conclusion

This case clearly shows that in some cases, injections products that are considered as efficient, may not develop the required hydrophobicity. This is probably caused by the presence of organic matter in the building materials, that prevent silicone-based products to develop their protective properties.

Even in such situations, it is possible to obtain a good protection against rising damp, by injection of oleophobic products. The efficiency of the method is clearly demonstrated. Starting from a rather homogeneous humidity distribution, with a MC between 10 and 14%, we see after two years a clear and constant decrease: MC varying between 1% and 8%. This is still not completely below the required 3 à 5 %, but we must indicate that in this special case, the drying of the masonry goes slow, because of the cement-based renders on both sizes of the wall. Moreover, it is obvious that the drying goes the fastest at a height of about 1 meter, which is logic, since air currents over the wall surface will be the highest in the middle of the wall, and less at the level of the floor or the ceiling.

3.5.5. St Martin's church, Ways (Genappe, Belgium)

3.5.5.1. Introduction

This chapter is dedicated to a practical case, where 4 different injection products are applied to a thick historic masonry, together (at a fair distance) with a treatment using an electrokinetic device, that is supposed to dehumidify walls by means of electromagnetic waves.

3.5.5.2. Background information and history

The St Martin parish in Ways dates back to the beginning of the 13th century, but the current church (that replaced its predecessors) was constructed in 1763, except for the tower, which is presumably older. Since 1963 the building is a listed monument. The church contains still many objects from the earlier churches, such as sculptures and tombstones.

The church is constructed in massive brick masonry, with elements in natural stone, for instance around the windows and entrance door and at the base of the walls.

The church is located at about 20 meters from the river Dijle, which is located around a meter under the level of the ground. It indicates clearly that the soil around and under the church much be constantly damp. This is actually the case: the lawn around the church is never dry, and the church shows multiple humidity problems.

Figure 64: the exterior and interior of the St Martin's church in Ways.

3.5.5.3. Pathologies

The church shows signs of different pathologies due to infiltrations through gutters and roofs, but it was assured to us that these infiltrations have been resolved, even though the damage due to these infiltrations has not been repaired completely. We should add that these damages are not very striking.

The construction shows signs that the builders in the 18th century took into account the presence of rising damp and the vicinity of a river.

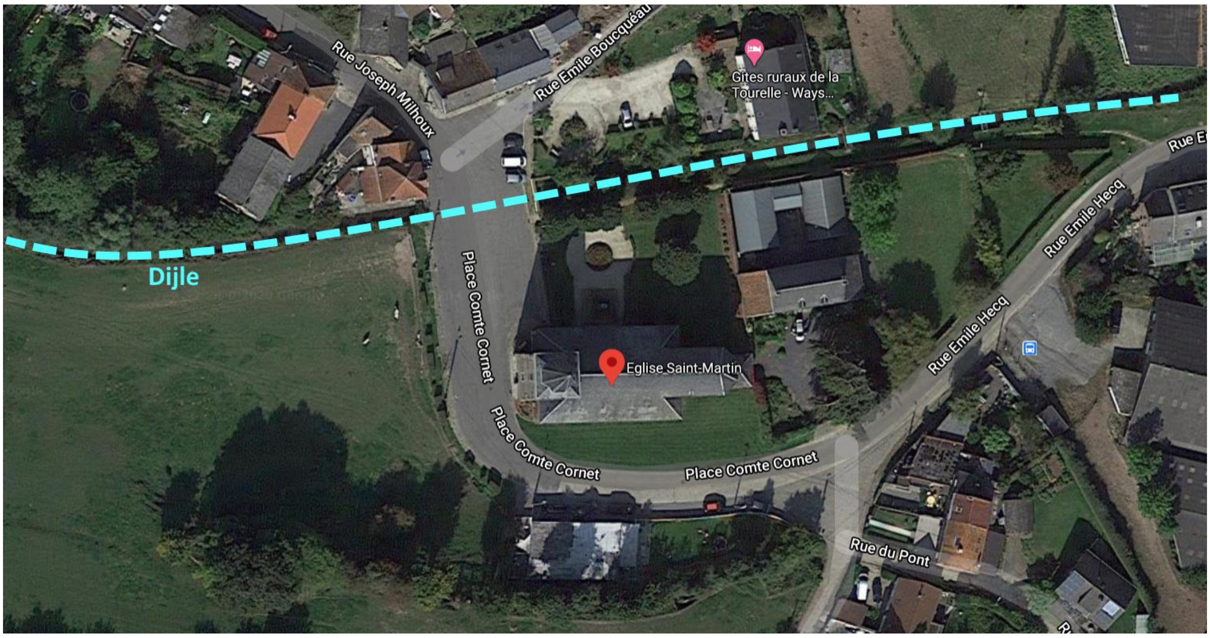

Figure 65: location of the church, near a river.

Remarkable is:

- The base of the walls is constructed in Belgian Blue stone, with a masonry of local lime-sandstone. Especially the blue stone is a dense limestone, with hardly any capillary action, possible used to protect the base of the building against rising damp. This protection does not turn out to be very efficient, since the walls clearly show signs of very intense rising damp on the interior. On the outside of the church, there is hardly any sign of rising damp present. On the inside however, the humidity levels are high, and cause degradation to the 18th century wooden wall panelling, which is everywhere (and may be even installed in order to hide humidity in the walls).
    - The blue stone base of the church must be 'leaking' somewhere. We notice that this layer is constructed with very thin vertical joints, which is positive in itself (as such, the mortar won't transmit a lot of humidity). We suspect however that the layer is not continuous over the entire thickness of the wall, and therefore lets rising damp pass through.

- The base of the columns inside the church, are made in one massive piece of blue stone. This turns out to be very effective, since the columns show no signs of degradation whatsoever.

Figure 66: historic attempts to protect the building against rising damp. On the left: wall base constructed out of dens blue stone, and local sand-limestone. Notice the very thin vertical joints between the blue stones. On the right: the bases of the columns in one piece of dense blue limestone, which turns out to be a very efficient protection for the upper parts of the columns.

Most of the humidity pathology is not visible, but noticeable anyhow:

- There is a high relative humidity inside the church. Especially in summer, when it is warm outside and cool inside the church, this is very noticeable, including odours from moulds.
- Also especially in summer, one notices that the floor is damps: around the joints in between the tiles, the stones are dark and often condensation can be seen.
- The 18th century wooden wall panelling shows degradation and deformation, indication a possible humidity problem behind the panelling.

3.5.5.4. Sampling

In this church, we intended to test 4 types of chemical injections, and one electrokinetic dehumidification device. 5 test zones have been identified on the north side of the church. We chose the north side, because of the fact that there was no possibility to take samples on the inside of the church. The omnipresent wooden wall panelling could evidently not be taken away, so samples had to be taken from the outside. In order to rule out effects from driving rain, the choice for the north façade was evident: in Belgium, there is hardly any driving rain which is driven by wind from the north, so this façade is supposed to be free of rainwater infiltration.

The situation in the outer walls is very asymmetric: on the outside there is a brick masonry visible, mortar joints in lime mortar. On the inside, there is a wooden wall panelling against this façade. We are pretty sure that the air between the panelling is in contact with the interior of the church, but we suspect anyhow that the panelling has a severe and negative influence on the drying of the outer wall. Therefore it was decided to sample throughout the entire thickness of the wall. Samples taken from outside, until almost the other side of the wall. The thickness of the wall was established at 87 cm, so we took samples, from the outside up to a depth of 80 cm, which is a real challenge: not only

one has to drill very deep, and should be able to collect the drilling sample, one should also take into account that the drilling samples should not be mixed. Therefore the following method was used:
One takes a sample with a narrow drill. Then this same hole is widened with a larger drill. A long plastic hollow tube is inserted into the borehole. Then the next sample is taken, using the first narrow drill. This enables us to collect all of the deeper sampled dust (by taking out the plastic tube end emptying it in a plastic container). And this goes on for every depth, which is evidently a very time-consuming operation.

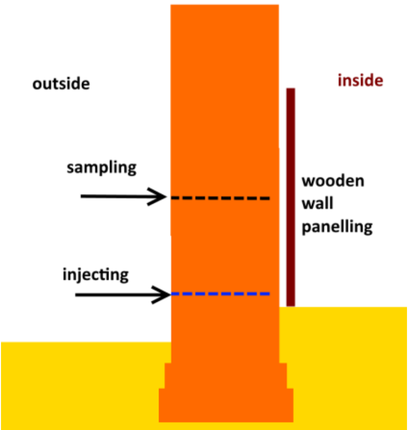

Figure 67: section through the wall and the panelling, indicating from where the sampling was carried out, and from where the injections would take place.

- Powder samples were collected by drilling. Drilling was carried out at different heights (0.2, 0.5, 1, 1.5 meters) and depths (0-7 cm, 7-15 cm, 15-30 cm, 30-50 cm, 50-80 cm) along a vertical profile. The samples ware taken in a mortar joint, but deeper in the wall, the samples were always mixed mortar+brick, as could be expected from an irregular old masonry.
- The powder samples were collected in small plastic containers, which were then hermetically closed and transported to the laboratory for the measurements of the MC and HMC, according to the earlier explained methodology.

This was done for every of the 5 test zones.

Figure 68: indication of the 5 test zones.

3.5.5.5. Initial situation

We will not indicate the situation in each test zone, as they are very similar. As an example, the full data for test zone 1 are shown in figure 69.

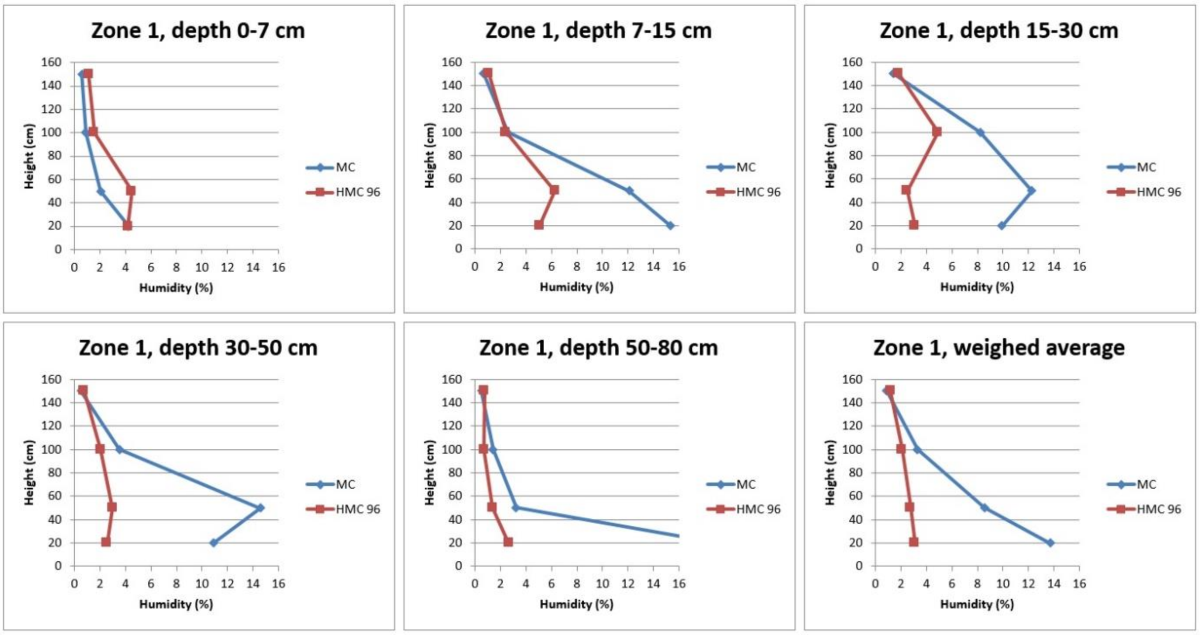

Figure 69: indication of the 5 test zones.

The final graph shows the MC and HMC as an weighed average of the individual sampling results.

- It is obvious that the HMC is always rather low. Even if the MC rises to very high values, the HMC remains limited. We therefore conclude that there are no real serious problems with hygroscopic humidity.
- The curves behave as expected. On the outer surface of the walls, the MC remains low and may even be considered as not problematic. Deeper in the walls the MC rises, and goes up to values in the order of 20%, which is dramatically high. This indicates that the drying of the walls, at the interior of the church, is not efficient. The wooden wall panelling clearly blocks the evaporation, causing such high moisture contents. It also clearly shows that the blue stone base of the walls does not perform well to protect the wall against rising damp. We suspect that the blue stone is only present in the outer parts of the wall, since the buildings in the 18tch century possible thought that the humidity came merely from outside, instead from the ground.
- The curves follow almost exactly what we would expect from rising damp: high humidity levels at the base of the walls, low more upwards in the walls, and the problem almost disappears at a height of 1 m à 1.5 m.
- It is clearly shown that the curve that shows the weighed average, shows exactly the same tendencies. For reasons of simplicity, we therefore only will show the average curves for the MC in what follows.

3.5.5.6. Treatments

In five test zones, different methods against rising damp have been applied: 4 injections, and one electrokinetic device. The injections were all carried out from outside the building, as it was impossible to drill holes from the inside of the building. The depth of the holes was about 82 cm (for liquid products) to 85 cm (for products in the form of a cream). One should never drill throughout the entire thickness of the wall, since the product just would run out of the other side of the wall, if the hole was drilled through the entire wall. Nevertheless, we always worked blind: we were never able to check whether there would be product losses via the cavity between the wall and the wooden panelling during injection. Therefore someone constantly monitored the situation on the inside of the church, during injection. This person checked whether product would run under the wooden panelling over the church floor. This is undesirable, since it would influence our test, and since it might cause stains to the wood and the church floor.
The amounts of product that was injected, is monitored through a meter at the injection pump. This is however not possible for the products in the form of a cream. The method for injecting a cream is to connect the injection device to a long hollow ‘needle’ in stainless steel. This is pushed into the borehole to the very end. Then the product is pumped into the borehole, while slowly pulling back the injection needle. Due to the high viscosity of the products, it is not possible to measure directly the amount of product that went into the injection hole. Therefore it is necessary, afterwards, when the injection needle is completely out of the borehole, how much of the product went into the borehole. This is a rather intuitive operation, and needs some building up of experience to perform such an injection correctly.

The choice of products was based on the following considerations:

- The products, used in this research, are not representative for the products found on the European market. However, they are definitely representative for the Belgian market. The difference between both markets is a series of products that almost completely disappeared from the Belgian professional market, but are still present in other European countries. A major reason for this difference is a laboratory test methodology that exists at the BBRI since 2005, that has shown that several products are ineffective, and therefore slowly disappeared from the Belgian market.
- This does not mean that the products that are available on the Belgian Market, are generally accepted. On the contrary, the controversy remains for the wide range of products from the silicone-family. The fact is that that there is a large variety in products.
    - depending on the monomers, possible pre-polymerisation of the monomers, the type of water repellent organic group onto the monomers
    - depending on the formulation: the classical solution in an organic solvent, next to emulsions in water, emulsions in the form of a crème and solutions in the form of a gel

- In this research, products have been chosen that may prove to be efficient (products from the silicone-family) but whose efficiency is under discussion. In order to be as much representative as possible, four products with a different formulation have been chosen.

Four products have been chosen and applied to each test zone:

- Zone 1: a liquid injection product, 10% concentration, of mainly siloxanes in a solution in isoparaffine. Per m² horizontal wall surface, a quantity of 13 à 14 litres was injected, through boreholes of 12 mm diameter, at a distance of 12 cm from each other. The amount of product is slightly more than the usually recommended 10 litres/m² of horizontal wall section, but this amount was decided based on the assumption that there would be some product loss in ancient thick masonry. This is the normal practice in reality. The pressure was always between 3 and 5 bar.
- Zone 2: an injection cream, water-based, 80% concentration, of silanes. Per m² horizontal wall surface, a quantity of about 1 litre was injected, through boreholes of 12 mm diameter, at a distance of 12 cm from each other.
- Zone 3: an injection cream, water-based, 65% concentration, of silanes and siloxanes. Per m² horizontal wall surface, a quantity of about 1 litre was injected, through boreholes of 12 mm diameter, at a distance of 12 cm from each other.
- Zone 4: a liquid injection product, 10% concentration, of mainly silanes and siloxanes in a water-based emulsion. Per m² horizontal wall surface, a quantity of 13 à 14 litres was injected, through boreholes of 12 mm diameter, at a distance of 12 cm from each other. The amount of product is slightly more than the usually recommended 10 litres/m² of horizontal wall section, but this amount was decided based on the assumption that there would be some product loss in ancient thick masonry. This is the normal practice in reality. The pressure was always between 3 and 5 bar. <u>This was actually also the same product that has been injected twice in in the past, in the walls of the Interbellum villa in Humbeek (Grimbergen), where it did not have the desired effect.</u>

- Zone 5: electrokinetic device, installed by the supplier inside the church, near the outer wall.

3.5.5.7. Results

During 1.5 year, in three campaigns, the moisture content was monitored, in function of height and depth in the wall. The average moisture content values are presented in figure 70. We emphasize the fact that these curves are simplified: we only mention the weighed average of the humidity in the entire wall. This constantly shows the same trend as the measurements on individual depths in the wall, and makes the conclusions much clearer.

Moreover, the curves of HMC are left out, since they were constantly low, indicating hardly any salt problem in the walls, which makes the interpretation much simpler.

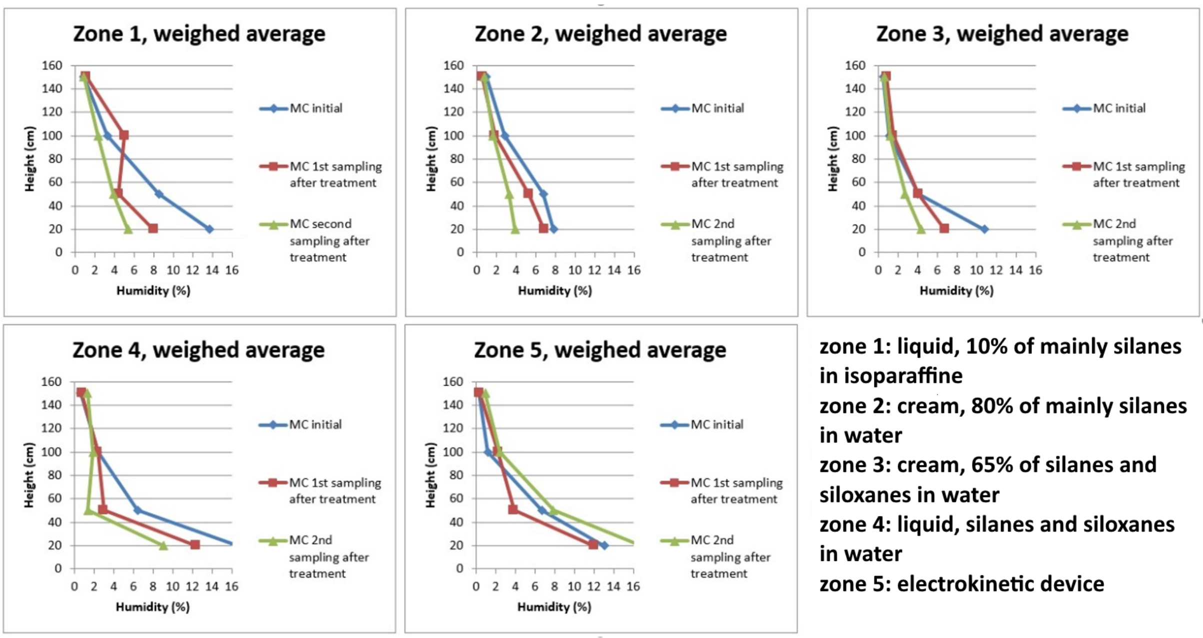

Figure 70: evolution of the average moisture distribution in the 5 test zones.

When drawing conclusions, one should keep in mind that a wall with a thickness of 87 cm, which can dry at only one side, takes an awful lot of time to reach sufficiently low humidity levels (3 à 5 %). As a comparison (Herinckx and Vanhellemont (2014)) we mention that a wall of about 30 cm thickness, that can dry on both sides, needs usually 4 months to 1 year to dry out. One can imagine that a wall with thrice the thickness, and only drying possibility at one side, might take more than triple this drying period.

- Zone 1: in 1.5 year, the MC was reduced by a more than a factor 2. At the base of the wall, the humidity is still higher than the required 3 à 5%, but a clear decrease of the humidity can be observed: at the lowest point a decrease from 14% → 8% → 5.5 %
- Zone 2: in 1.5 year, the MC was reduced by a factor 2. At the base of the wall, the humidity is still higher than the required 3 à 5%, but a clear decrease of the humidity can be observed: at the lowest point a decrease from 8% → 6.5% → 4 %
- Zone 3: in 1.5 year, the MC was reduced by a more than a factor 2. At the base of the wall, the humidity is still higher than the required 3 à 5%, but a clear decrease of the humidity can be observed: at the lowest point a decrease from 11% → 6.5% → 4.5 %
- Zone 4: in 1.5 year, the MC was reduced by almost a factor 2. At the base of the wall, the humidity is still higher than the required 3 à 5%, but a clear decrease of the humidity can be observed: at the lowest point a decrease from 17% → 12% → 9 %
- Zone 5: in 1.5 year, the MC has increased with about 50%. At the base of the wall, the humidity is still higher than the required 3 à 5%, but a clear decrease of the humidity can be observed: at the lowest point a decrease from 13% → 12% → 17 %

It is clear that all injected zones behave more or less in the same fashion. The speed at which the wall dries is always comparable (reduction of the humidity by a factor 2 in 1.5 years). We emphasize that this is an average. The distribution of humidity inside the wall will remain heterogeneous, and there are still zones that are very damp, but this will also escape, when given time. In this case several more years will be required to let dry out the wall completely.

The zone with the electrokinetic device shows no positive evolution. There is even a substantial increase in the humidity content of the masonry. This is evidently not caused by the device, but it shows that the device has no or only a very small influence on the evolution of the humidity inside the wall.

3.6. Scale models

3.6.1. Introduction

Besides the tests on site, a series of comparative tests on scale models have been performed. The purpose of this was to eliminate unknown parasitic effects that one can encounter on real buildings, but of which one is not aware. The advantage of tests on scale models is that one knows exactly the type of brick, mortar, structure of the masonry, and one can determine freely the type and amounts of salts one wants to add to the structure.

3.6.2. Description of the scale models

The construction of scale models was scheduled in the project to verify in new masonry, specially designed and placed outdoors, the effectiveness of some of the interventions against rising damp selected. Scale models represent an intermediate level between the laboratory tests and the field application, allowing the achievement of a higher degree of simulation of the real conditions. By performing experiments in real environment with scale models, a monitoring of selected variables of the building materials and the environmental conditions is reachable. In addition, novel methods against rising damp of still unknown effects can be tested, alongside with calibration of non-destructive techniques that requires a comparison with invasive ones.

The scale models were designed and built by Restauri Speciali, the SME involved in the project. They were located in a delimited zone of the CNR campus “Bologna Research Area”, in the green area between the buildings of Institutes ISAC and IMM in July 2014. They were set in an area fenced-in with wire mesh temporary used inyard, in such a way to avoid the animal intrusion. The area had a dimension of 7 m × 3.5 m × 2 m (L × D × H) and one door access to allow the entrance to authorized personnel. The scale models were protected with a transparent sloping plexiglas roof in order to avoid the direct impact of rainfall and the snow accumulation during the winter period. The scale masonries were hosted in euro pallets to allow the stability of the structure and the anchoring of the shelter.

Bricks and mortars were combined to form four single walls each one of the dimension of 77 cm × 25 cm × 100 cm (L × D × H). San Marco “facing bricks”with the dimension of 12 cm × 5.5 cm × 5 cm (L × D × H) and a lime-cement mortar (*malta bastarda*) were used. Each wall consisted of fourteen courses laid in stretching bond, with one course comprising six bricks in a double width. The walls were erected in plastic trays and left for 30 days for the mortar curing.

Figure 71: an overview of the 4 scale models on the campus of the Bologna University.

3.6.3. Preparation of the scale models: initiating rising damp and salts.

The effects of rising damp on scale models was simulated through partial immersion (until a height of about 12 cm) of the walls in a salt solution (5 wt% NaCl in water) from January 2015 to September 2016. This salt was chosen for its high solubility and mobility into the wall, in addition to the lower cost with respect to sulphates, in order to permit an easy check of the distribution of moisture due to rising damp using ion chromatography. The trays were covered with a layer of removable plexiglas and the saline solution concentration was monitored over time with a conductivity meter.

3.6.4. Treatment of the scale models

The scale models were treated as follow:

- SM1: application of a dehumidifying plaster, in two layers:
    - Layer 1: Dehumidifying regularization with anti salt barrier properties. Premixed mortar based on natural hydraulic lime and mineral additives selected with a suitable granulometry (0.5–1 mm). In a thickness of 1 cm.
    - Layer 2: Dehumidifying premixed product fibre-reinforced with cork (gran. 0–4 mm), clay, natural hydraulic lime NHL 5, diathomaceous earth. This is a very fine porous

medium, that is expected to be more capillary active than the substrate, and thus extracting the humidity from the masonry below, thus drying the masonry. This layer was applied after hardening of the 1st layer. The applied thickness was 1.7 cm.

- SM2: chemical injection of the scale model, with a liquid product containing mainly siloxanes in an organic solvent. The injection was carried out in pre-drilled holes in the bricks, with a diameter of 10 mm, distance between the holes was 10 cm. Injection took place under a pressure of 4 bar.
- SM3: chemical injection of the scale model, with a liquid product containing a mixture of silanes and siloxanes in an emulsion in water, 10% concentration. The injection was carried out in pre-drilled holes in the mortar, with a diameter of 10 mm, distance between the holes was 10 cm. Injection took place under a pressure of 4 à 6 bar.
- SM4: reference, no treatment was applied

Figure 72: an overview of the 4 scale models, right before the treatments were applied. The humid zone, together with the expected salt efflorescenses above the humid zone, are clearly visible. It is necessary to indicate that at this stage, no equilibrium is obtained: the rising damp has not yet reached its full height (usually in the order of 1 meter). But as the injection zone is already damp, at this stage the treatments can be carried out. It should be emphasized that at that very moment, the most salt-loaden zone (indicated by the efflorescenses) is at a height around 20 cm above the water level. This is an important factor to fully understand the humidity distribution graphs (see below).

Figure 73: detail, showing the two layers of dehumidifying plaster on Scale model 4. One can clearly see the different thicknesses of the two layers, and their difference in nature.

3.6.5. Sampling

- Powder samples were collected by drilling. Drilling was carried out at different heights (0.2, 0.5, 0.8 meters) and depths (0-2 cm, 2-5 cm, 5-10 cm, 10-15 cm) along a vertical profile. The samples were taken in a brick.
- Extra samples were taken, according to the same heights, in the dehumidifying mortar. The depths were 0-1.7 cm, and 1.7-2.7 cm.
- The powder samples were collected in small plastic containers, which were then hermetically closed and transported to the laboratory for the measurements of the MC and HMC, according to the earlier explained methodology.

3.6.6. Constations

As was expected with the addition of a hygroscopic salt in a large concentration (NaCl), the visual aspect of the walls change dramatically, depending on the weather and season. During warm dry weather, the humidity front will be much lower, compared to humid and cold weather (see figures 74 and 75).

Figure 74: November 2015, 7 months after the treatment. One can clearly see lots of humidity in the scale models. At least part of this humidity is hygroscopic humidity, caused by hygroscopic water uptake by the salts in humid cold weather.

Figure 75: April 2016, 12 months after the treatment. The scale models seem to be dry (even the untreated scale model on the right). This effect arises from the fact that the weather is drier and warmer, thus causing the salts to dry out, as the relative humidity outside goes under the critical relative humidity of NaCl, around 75% RH.

Since no equilibrium was reached when the treatments were applied, it is not very useful to compare the results after treatment with the humidity in the walls before treatment. On the other hand, it remains very useful to compare the results of the treated walls, with the results of the untreated wall at the same moment. All scale models are constantly exposed to the very same atmospheric circumstances, making results from the difference scale models very comparable.

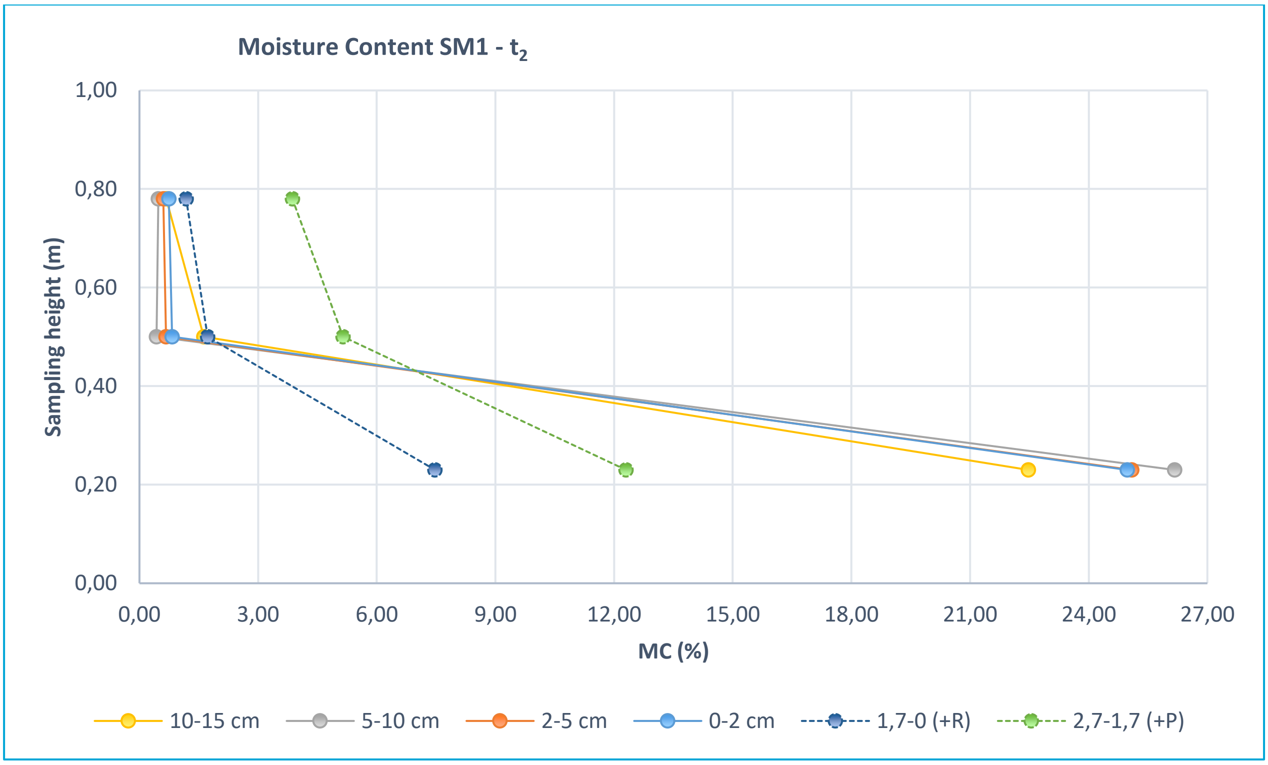

Figure 76: February 2016, 9 months after the treatment. This scale model is the model with the dehumidifying plaster. The full lines are the values of MC inside the masonry. The dotted lines are the MC inside the plaster.

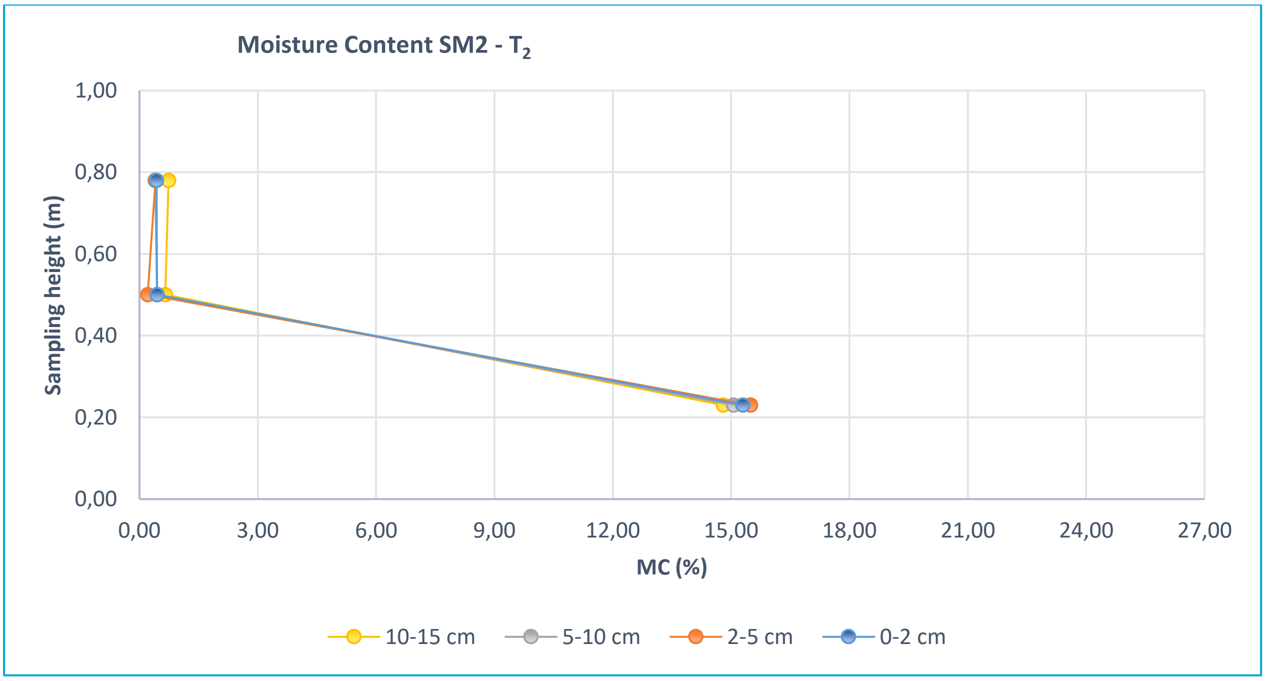

Figure 77: February 2016, 9 months after the treatment. This scale model is the model with the siloxane based product in an organic solvent.

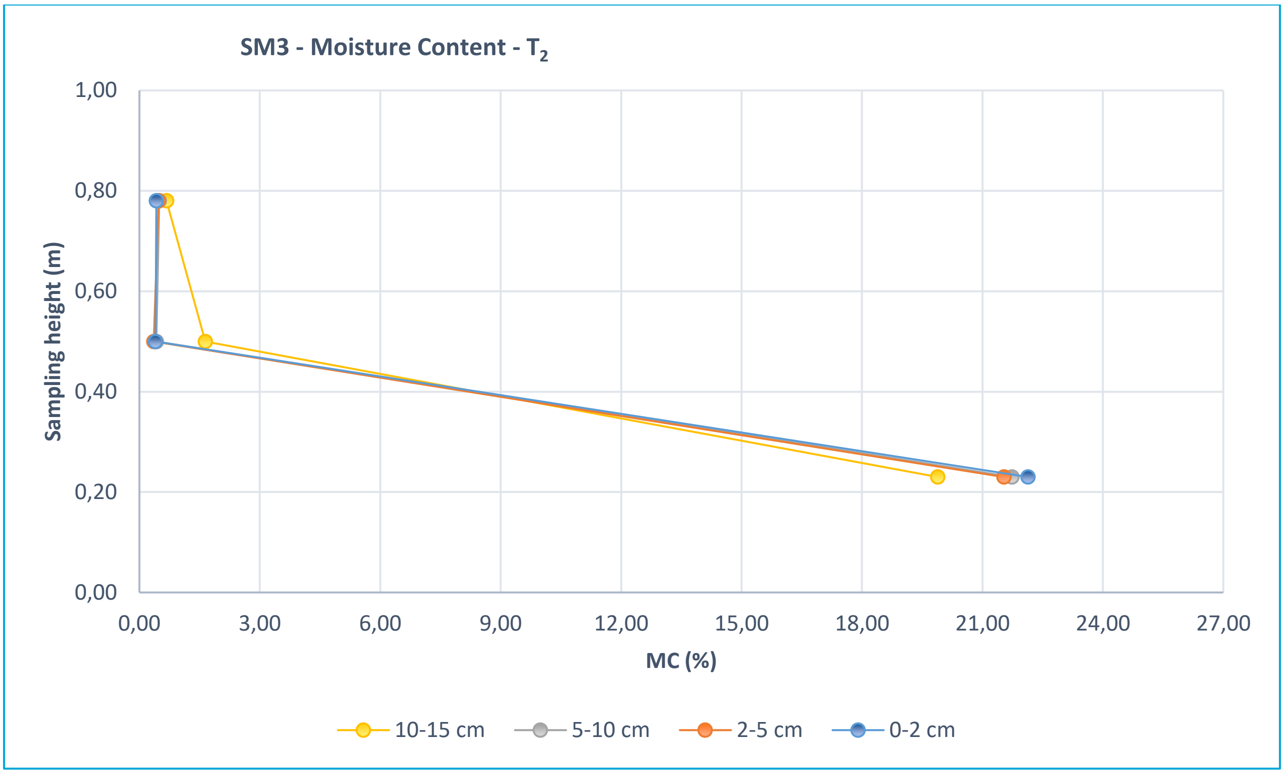

Figure 78: February 2016, 9 months after the treatment. This scale model is the model with the silane/siloxane based product in water.

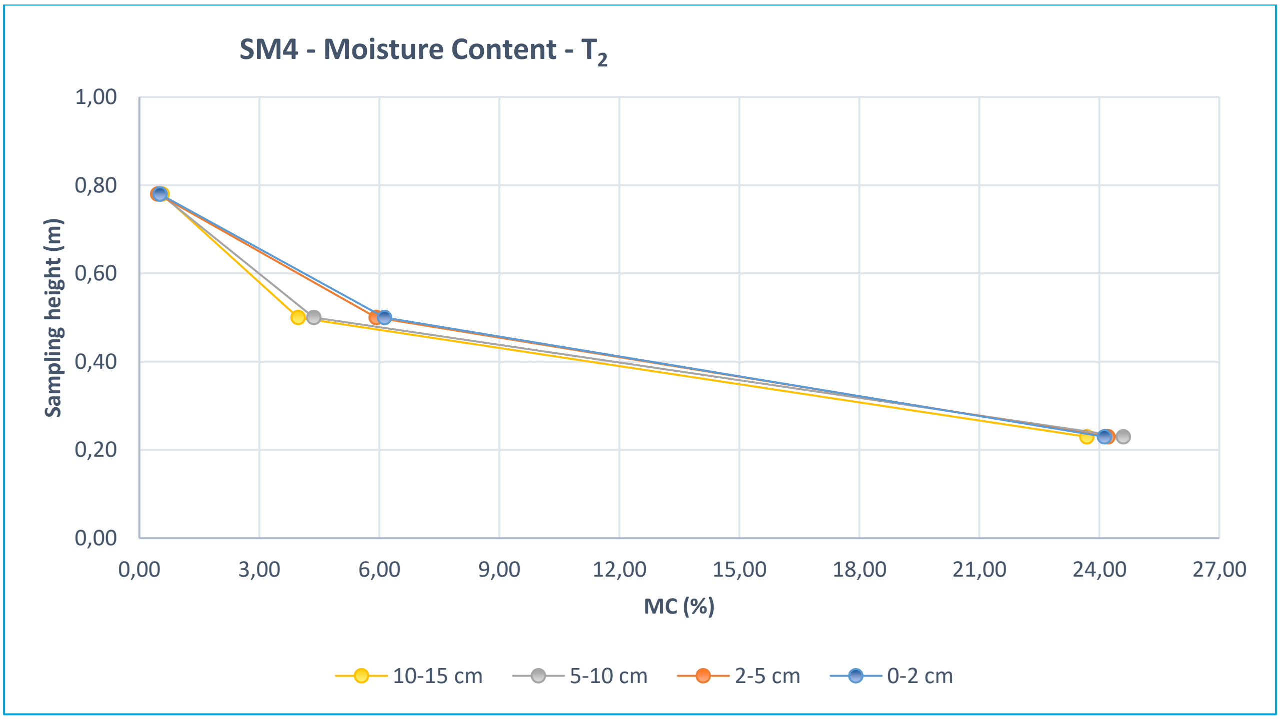

Figure 79: February 2016, 9 months after the treatment. This scale model is the reference scale model.

As is clearly visible on all graphs, is that the MC in the lowest part is always very high, around 24%. When comparing to the HMC-measurements after treatment, on can observe at all depths, for this height, an HMC around 35 à 40%, which is an extremely high value. It is therefore understandable that even the treated scale models show such high moisture contents at this level, which is most probably mostly hygroscopic moisture. One can also note that the two scale models with the chemical injections show slightly lower MC's at the level of 20 cm (with the lowest values in the scale model injected with the solvent-based product). This is understandable: when these scale models were injected, and the injection product started to work, the supply of salt was stopped. In the case of the reference scale model and the scale model with the plaster, salts were still transported into the scale model. 9 months after the treatment, the injected scale models should have less salts at a height of 20 cm, resulting in lower MC, which can be exactly observed.

When looking at the higher points:

- At a height of 1 meter, all scale models show a very low MC.
- At a height of 0.5 meter, there is a huge difference. The reference scale model shows MC's between 4 and 6%. All other scale models show MC's ranging between 1.5 and 3%, wich can be considered as sufficiently dry. While the MC's at the reference scale model are to be considered as too high. In any case, every intervention model could therefore be considered as successful, since they are able to lower the humidity level to acceptable levels.
- In the case of the dehumidifying plaster, it is interesting to note that the plaster itself is
    - Less humid at the level of 20 cm. This might be caused by the fact that the plaster contains less salts, as it is applied much later.
    - More humid at higher levels (where the masonry itself is sufficiently dry). This shows clearly that the capillary active plaster is extracting humidity from the masonry, making the plaster more damp, and thus drying the masonry itself. From the point of view of different pore structures (especially the very fine porous diathomaceous earth) this makes sense.
- However, remarks have to be made with the application of the dehumidifying plaster:
    - as the amount of salts continues to rise (which will happen) it is not sure what the durability of the plaster is, as it may start to suffer from crystallisation of salts.
    - Since the pore structure of the plaster is very fine, one may possible expect, on the long term, effects from freeze-thaw cycles. From experience we know that very fine mortars may suffer much more from frost, than more coarse mortars.

3.7. Development of a decision support tool

The decision support tool and explanatory appendix are attached as separate files (annexes).

3.7.1 Introduction

A final deliverable from the project is a decision support tool. It is a document/tool, which should enable conservation professionals to make the best decision for an intervention against rising damp I a building, if present.

The tool is a synthesis of following elements:

- The state-of-the-art, which is a partial deliverable from the project itself
- The exchange of knowledge and experiences, between the partners of the project, the companies that commercialise products or devices, and other conservation professionals, such as contractors, architects, administrations and academics/experts.
- The results from the case-studies

The aim of the tool is twofold:

- To indicate how one can make a thorough diagnostics of rising damp. As was shown in the user's satisfaction survey, the assessment of rising damp is in many cases not executed. Moreover, often one does not control if an intervention turns out to be efficient. This is negative in several ways:
    - Treatments against rising damp are often invasive, especially the most efficient interventions. For heritage buildings it is therefore of the utmost importance that, if one applies an intervention against rising damp, one should be sure that there is a real problem with rising damp. Otherwise, on could end up with applying a technique to a building (often invasive or irreversible) that has no use whatsoever. Moreover, while concentrating on solving a (non-existing) problem of rising damp, one might ignore another humidity problem that will continue to slowly deteriorate the building. Evidently it is also, in general, not recommendable to perform interventions against rising damp, if they are not necessary.
    - As stated earlier, there are no treatments against rising damp that are universally applicable. For each known technique, cases (some or many) are known where this technique wouldn't be applicable, or wouldn't be efficient. So it could be possible that, once a solution against rising damp is applied, that it does not work. Even though we have a fairly good idea when one can apply certain techniques, there is always an element of trial-and-error, or uncertainty, which is proper to the type of intervention and the building, but also to applied products and the way of applying them. This is particularly true for ancient buildings, from which we do not know the exact composition of the masonry, or previous interventions. It is therefore of the

utmost importance that the efficiency of a treatment is evaluated. By doing so, and one comes to the conclusion that the treatment was not efficient, one might possible re-treat the building with another technique. This will avoid further damage to the structure, and will also avoid that other interventions (new plasters, new paintworks, …) will be damaged in the future because of a humidity problem that has not been resolved. A check whether the intervention against rising damp was successful, is therefore necessary to avoid troubles with damages and their financial consequences in the future.

- The second part of the decision support tool is constructed around the actual choice of an intervention technique. There are many factors that should be taken into account when deciding which technique should be applied. This part of that tool aims at helping the building professional to make a choice, even though we should add that usually several possible solutions remain.

3.7.2. Diagnostics

The diagnostics of rising damp usually takes place in the following steps:

- Checking whether it is likely that there is rising damp. This is done by controlling
  - The presence of damage (efflorescenses, biological damage, corrosion, ….)
  - Where this damage occurs (depening on the floor of the building, and where on the walls)
- If rising damp is likely, the next step is to confirm (or not) that the damage is really due to rising damp. The methodology for this is similar to the methods used during the project. It will enable the end-user to determine if rising damp is present, and therefore, of an intervention is useful.

3.7.3. choice of a method

The decision was taken that a large variety of possible intervention techniques would be taken into account. The tool will provide information on the following techniques:

- Sub-soil drains
- Mechanical interruption
- Chemical injections
- Knapen siphons and drying stones
- Wall base ventilation
- Thermal methods
- Active electro-osmosis
- Passive electro-osmosis
- Elektrokybernetic methods and similar

- No action whatsoever
- Veneer walls, tiles, impermeable walls
- Salt blocking plasters
- Salt accumulating plasters
- Salt transporting plasters
- Air-conditioning or climatization of the building

In order to obtain information regarding the applicability of each technique, and to obtain information about the risks, connected to each technique, a series of questions should be answered by 'yes' or 'no' (in drop-down menu's)

- Is it acceptable that the method needs maintenance?
- Should rising damp be stopped completely, or is it acceptable that it is only treated partially?
- How big is the available budget for an intervention?
- Should the room/building be useable during and directly after the intervention?
- Is aesthetic damage acceptable?
- Is it acceptable that the appearance of the wall changes after the intervention?
- Is loss of original material acceptable?
- Should the intervention be reversible?
- Is there seismic activity, or has the wall limited stability?
- Is the masonry regular or irregular?
- Is the wall thicker than 40cm?
- Are there any finishes that hinder the drying (for instance impermeable to water vapour)
- Is the wall underground?
- Presence of large voids, cracks, cavities in the wall? Or does the wall consist of several layers/leaves?
- Is it a cavity wall?
- Is the saturation of the wall higher than 80%?
- Is the hygroscopic moisture content higher than 5%?

The output of these questions will make it easier to make a decision between techniques. As mentioned above, usually several techniques will be possible. The output has gradations, because it is evidently not possible to create such a tool that is able to give a clear and undisputable answer for any imaginable case.

- 'green' will indicate that the technique is suitable
- 'yellow' will indicate that the technique is suitable, but with some restrictions or points of attention
- 'red' will indicate that there are serious limitations to the application of the technique

3.8. Conclusions and recommendations

3.8.1. Conclusions

The treatment of rising damp is an essential part of the conservation/restoration practice of historic buildings, but is evidently also of main importance in the rehabilitation of existing buildings in general. This is not a new insight, there are many illustrations where measures have been taken, in the past centuries, to protect buildings against rising damp, some of which are still very efficient. Only relatively recently, one has begun to treat existing buildings against rising damp, as this is a prerequisite to fully protect and conserve heritage buildings. Rising damp is an important source of many degradations, and needs to be tackled.

Within the EMERISDA-project, we were able to perform profound on-site evaluations, and measurements on scale models, to assess the efficiency of several methods that are applied to buildings suffering from rising damp. It was evidently not possible to test every possible intervention method, because there are simply too many of them (see the state-of-the-art). For this project, the most used techniques, that are still under discussion, have been considered: chemical injections, electro-osmotic techniques, electrokinetic devices, and dehumidifying plasters.

The results of this research has been systematised, together with information coming from experience and literature, in a decision support tool, that is supposed to help conservation professionals to make a sound choice for a technique to treat rising damp, taking into accounts several aspects such as efficiency, but also cost, durability, reversibility etc.

But before summarizing the results from the tests, the user's satisfaction survey has pointed out that there is a serious lack of diagnostics of buildings before being treated. From experience we know that this represents a risk: not all humidity problems are rising damp. There are several humidity problems that visually look like rising damp, but they have a completely different nature. This is important, since the application of a treatment against rising damp would in such cases be useless (the humidity problem is not solved, and moreover, could still continue to harm the building), it would represent a waste of money, and it would be a possible irreversible intervention that turns out to be useless, which is unacceptable in heritage buildings. Also the control of the efficiency of an intervention is largely lacking in the normal practice, and this is unfortunate. We know out of experience that not all interventions against rising damp are efficient. It would therefore be good to systematically check the efficiency of an intervention. For the sake of the building, and for financial sake: it is only worth paying for efficient interventions.

Purely on the technical level, the general conclusions were:

- for chemical injections positive. In all cases the moisture content dropped after injection. We mention that mostly only products from the silicone-family were applied (one exception, see below). We should mention that there is a tremendous variety in products in this family. Not only in the types of active matter (the water repellent product), but also in concentration and solvent. It is therefore important not to extrapolate this evaluation to every product from this family. Moreover, we should also point out that not only the product, but also the application and the masonry itself (amount of product, pressure, quality of the masonry) plays an enormous role in the efficiency of the technique.

  - One case study in Belgium showed that there are cases, where products from the silicone-family are not efficient. This is the case of old masonry, where organic compounds have been applied in the mortar to make it les absorbant, but which nowadays causes the malfunctioning of silicone-based products. Such constructions can be found everywhere in Belgium (we are not aware of examples abroad, this may be a fine example of a very local building tradition), and the mortars have a very dark, sometimes almost black, colour. They might contain a lot of organic matter, and prevent silicone-based products to polymerize. We have shown that an injection with fluorinated copolymers (usually used as a surface impregnation that is oleophobic, and therefore acts as a water repellent agent, but also a protection against graffiti) is capable of treating such walls correctly, and allowing a rapid drying out of the wall.

- One case-study, regarding passive electro-osmotic effects in the San Marco Basilica in Venice, has shown no significant effect on the humidity content of the building. This confirms the results from other studies, and we therefore do not recommend such intervention.
- Elektrokinetic methods have been applied on three sites, they have the advantage that they are fully reversible, and are easy to install. But intensive testing on several sites showed that elektrokinetic devices did not cause any significant nor consistent decrease of the moisture content of the masonry. We therefore conclude that – based on these on-site field investigations and monitoring campaigns - electrokinetic methods are no valid alternative for existing techniques, such as injections or mechanical cut of the wall.

3.8.2. Recommendations

- The importance of performing a thorough diagnose: not only visual, but at least backed up by some measurements, that indicate clearly that there is an actual humidity problem. Depending on the situation, this might lead to the conclusion of rising damp. We recommend however to perform a more through analysis, by measuring humidity profiles in depth and height of walls, and to measure both the humidity content and the hygroscopic moisture uptake of each sample, in order to define precisely whether or not the problem is rising damp, or another humidity problem.
  - The scale models, and the case of the Saint Martin's church in Genappe, clearly show that visual constations are not enough to determine if the walls are damp or not. In the case of the church, we clearly could see that humidity levels were low in the first 7 cm of the masonry. But deeper in the masonry, humidity levels rose

dramatically to around 20%, something on could not suspect by just looking at the walls. In the case of the scale models, the walls (also the untreated wall) looked regularly dry, but only during warm dry weather. In these circumstances, the untreated reference wall was superficially drying out, while still being damp on the inside, even though the wall looked dry on the outside.

- The correct choice for a solution, that takes into account the efficiency of a method, but also other factors, such as
    - Cost
    - Applicability in monuments
        - Regarding reversibility
        - Regarding invasiveness
        - Regarding the increase of risks of damaging buildings because of an intervention against rising damp.
- We would like to point out that treatments that deal with the humidity source itself, are preferential above treatments that treat the symptoms of the humidity, but not the humidity itself. In many cases the treatment of symptoms is the only possibility, but when one has the possibility to treat the humidity itself, one should aim at doing so. This will be in general a far better type of intervention, preventing future problems in the building.
- In general, the most preferred techniques are therefore the mechanical interruption of the base of the wall (which works always) and the chemical injection, with a good product and according to good application practice. These two techniques are mainly the most efficient ones, with unfortunately the drawback of invasiveness and negative influence on the stability of a building. This goes especially for the mechanical interruption, and luckily to a far less extent for the chemical injections.
- We would like to emphasize that a control after treatment is necessary. There is always the possibility that an intervention is successful. It is therefore necessary to check afterwards (in a similar manner as the diagnostics phase before the treatment) if the intervention was efficient. Otherwise it might be necessary to check why the intervention was not efficient, and try to re-treat the building.

4. DISSEMINATION AND VALORISATION

Dissemination of the projects results took and still takes place on a daily base, while co-operating with building professionals who deal with historic buildings and the treatment of humidity problems. Since its founding, one of the main activities of the BBRI is informing its members (currently about 90.000 building contractors), on a collective and on an individual level, through technical advice on construction sites. The results of the project are well incorporated into such advices. We mention specifically that besides the members of the BBRI, there is also an intense contact with other parties in restoration projects, specifically architects and the heritage administration in the Brussels, Flemish and Walloon region. They too take advantage of the scientific progress that has been made during the project.

During the project, the following project-specific dissemination took place:

- the publication of 3 newsletters
- the website www.emerisda.eu
- The Emerisda-workshop, which took place on the 18th of November 2018. During the workshop, results from the Emerisda-project were presented, while interaction with the audience was enabled during the workshop, and during several networking moments. The workshop was aiming at an audience composed of architects, building contractors, administrations dealing with heritage buildings, and people from the research/academic world.

In the slipstream of the project, we may mention the following collective dissemination activities. They were not project-specific deliverables, but the results of the project have been specifically dessiminated, or integrated into al larger whole.

- Presentation at the workshop COLLABORATE - Cultural Heritage Research in Focus, Dublin, 29th October 2014. During the event, ten innovative transnational cultural heritage research projects, funded under the JPICH's first pilot call for research proposals, were presented. These projects address topics ranging from Heritage Values to Salt Crystallisation in Historic Masonry, and from Archaeological Waterlogged Wood to Historic Concrete and more besides.
- Presentation at the Project parade of JPI, Brussels, 21 and 22nd of february, 2017
- On the 21st of April, 2017, WTA Netherlands-Flanders organized a workshop in Roosendaal, with the treatment of rising damp as the subject. This workshop was organized smiliarly to the Bologna workshop, but aiming at a public from the Netherlands and Flanders. The public consisted of architects, building contractors, administrations dealing with rising damp in buildings, and researchers. The syllabus texts can be freely downloaded through https://www.wta-international.org/fileadmin/user_upload/Nederland-Vlaanderen/syllabi/2017-04-21_Optrekkend_grondvocht.pdf

- During the workshop 'Moisture Detection in historic masonry (Modihma), that took place in Milano, 4th of june, 2018, several contributions were made by partners in the Emerisda-project. We specifically mention the contributions about the efficiency (or not) of electrokinetic dehumidification of masonry (Yves Vanhellemont), general results of the Emerisda-project and the presentation of the decision support tool (Rob Van Hees, Barbara Lubelli, Jan Bolhuis) and the presentation of tests on scale models and in situ (Andrea Sardella, Paola de Nuntiis, Alessandra Bonazza).
- Specifically aiming at companies from the Brussels Region, an infosession 'Opstijgend vocht'/'Humidité ascensionnelle', was organized in Brussels, 15th of february, 2019. The results of the Emerisda-project were presented by Yves Vanhellemont and Julie Desarnaud (BBRI).
- On the 28th of November 2019, the CICRP (Centre Interdisciplinaire de Conservation et de Restauration du Patrimoine) organised a workshop dealing with rising damp in historic buildings. The BBRI contributed with a presentation, showing the results of the Emerisda-project, specifically with the test results of electrokinetic humidity treatments. See for instance http://www.infos-patrimoinespaca.org/index.php?menu=9&num_article=1020&mp=2&cptcom=0
- Within the framework of the Be-reel project, the BBRI organized a series of online courses, dealing with humidity problems in buildings, especially the ones that interact with the application of thermal insulation in buildings. Several cases and results from the Emerisda-project were incorporated into the formations. See
    - https://be-renovatief.be/events/workshops-vocht-in-gebouwen-1-2/ (Dutch version, aiming mainly at a public from Flanders)
    - https://be-renovatief.be/events/3916/ (French version, aiming mainly at a public from Wallonia)

5. PUBLICATIONS

- Y. Vanhellemont et al., Vergelijking van behandelingen tegen opstijgend grondvocht, WTCB-dossiers 2017/4.3 . Reviewed by a reading committee composed of members of the BBRI-Technical committee Ruwbouw/Gros Oeuvre
- Y. Vanhellemont et al., Traitement de l'humidité ascensionnelle : étude comparative, dossiers du CSTC, 2017/4.3 (French version of the above)
- Proceedings of the Workshop 'Optrekkend grondvocht', Roosendaal, 21st of april 2017 (cfr. Supra), see https://www.wta-international.org/fileadmin/user_upload/Nederland-Vlaanderen/syllabi/2017-04-21_Optrekkend_grondvocht.pdf . Each individual contribution is reviewed by members of the board of WTA, composed of staff from the KULeuven, TUDelft, RCE, the Flemish Heritage Agency, Triconsult and BBRI.
- A peer-reviewed contribution to the IMEKO International Conference on Metrology for Archaeology and Cultural Heritage, Lecce, Italy, October 23-25, 2017
- Several peer-reviewed contributions of project partners in the proceedings of the Modhima-conference: Elisabetta Rosina et al (ed.), Modhima 2018 – Innovative techniques for moisture detection in historical masonry, Journal of cultural heritage, volume 31 (june 2018) – cfr. Supra.

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8. LIST OF ANNEXES

Annexe 1:

- Decision support tool (xls)
- Annexe to the decision support tool (pdf)

Annexe 2 (all documents in pdf-format):

- Articles published in the Journal of Cultural Heritage