CORNET: IN2EUROBUILD - CONSISTENT EUROPEAN GUIDELINES FOR INTERNAL INSULATION OF BUILDING STOCK AND HERITAGE

Guideline part 1: **Building Assessment**

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INSTITUT FÜR BAUKLIMATIK

Dresden University of Technology
Institute for Building Climatology (IBK)

Fraunhofer IBP

Fraunhofer Institute for Building Physics
Holzkirchen (IBP)

bbri.be

Belgian Building Research Institute (BBRI)

IHD

Institute for Wood Technology Dresden (IHD)

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Content

1 Introduction

1.1 (Internal) insulation of buildings

The consumption of heating energy in existing buildings represents a large share of total energy consumption and therefore contributes significantly to the production of climate-damaging CO_2. In order to halt climate change and make a substantial contribution to climate protection, heating energy consumption must therefore be further reduced. The most effective way to do this is to maintain and renovate uninsulated buildings. This measure reduces not only heating costs but increases living comfort as well as the value of the building.

In many cases, exterior insulation cannot be installed, e.g. for reasons of monument protection, exposed brickwork or buildings setbacks. In these cases, interior insulation is used, for which many system solutions and decades of positive experience are now available. To ensure the success of the insulation measure, an assessment of the building is first necessary. Then the planning and installation of the interior insulation system can begin.
Therefore, the first part of these guides describes the assessment and condition assessment of buildings. In many cases, unproblematic conditions are found, so that this assessment can be brief. This guide concentrates on cases where damage already exists or is to be feared.
Typical damage patterns, some of which can also have an impact on interior insulation, are shown and explained. Finally, existing damage must also be repaired independently of the use of interior insulation to ensure the long-lasting success of the renovation measure.
The second part of the series of guidelines describes the preparation of a renovation concept and also imparts what needs to be considered in the planning, dimensioning and execution of an interior insulation measure.

NOTE: At the end of this guide there is a flowchart that illustrates the process of an inventory analysis. Use the buttons in the text (see below) to open the appropriate section of the flowchart. Corresponding buttons in the flowchart lead back again.

1.2 Who are these guides aimed at

This series of guides are aimed at people who want to study the subject of planning, execution and design of interior insulation systems in more detail. This group of people can include, for example, building owners, investors or public authority employees, but also architects or engineers who rarely deal with internal insulation and therefore do not know the different planning principles and dependencies in detail. Readers should be enabled to assess a factual situation and select a suitable interior insulation system in the numerous, unproblematic cases where specialists do not need to be consulted.
However, there are also conditions that are more complex and cannot be assessed easily. In such cases, it is then explicitly recommended to consult experts.

Flowchart

2 Building assessment and humidity in buildings

The main cause of damage to buildings is moisture. Moisture is omnipresent in buildings, be it in the form of vapour in the air, or in the form of humidity inside the pore system of building materials (uptake of water vapour through hygroscopicity or absorption of liquid water, for instance coming from driving rain on facades). A certain amount of humidity in the air is necessary for assuring a sufficient comfort for the people living or working inside the building. Moreover, depending on the boundary conditions, a certain moisture content is also to be regarded as unavoidable and normal in the building materials.

However, too much humidity causes many pathologies in buildings, for instance a potential uncomfortable or even unhealthy indoor climate. When planning thermal insulation, the moisture conditions in a building and in the constructions must be taken into account.

Moreover, too much humidity causes, in itself, heat losses, since damp building materials are better in conducting heat, and the drying of such damp materials in itself consumes heat.

It is therefore obvious that humidity problems need to be tackled in order to preserve the building, to increase the comfort, and as a necessary preparatory work to reduce the energy consumption of a building (e. g. application of thermal insulation).

But before treating humidity problems, it is necessary to know

- Whether there is excessive moisture present at all, or if there is a risk for excessive moisture in the future.
- How best to examine the existing condition. This is absolutely necessary, to determine the best technology to stop high humidity. This is in many cases not an easy task, as different humidity sources may cause similar pathologies.
- How to find out which treatment is the most appropriate, and ideally to evaluate the efficiency of the treatment.

3 Which types of walls are considered?

Within the context of this short guide, it is not possible to address every possible humidity problem in a building. This guideline concentrates on massive masonry or concrete walls. This excludes cases such as

- Cavity walls; for more information on the diagnostics of such walls, see BBRI's Technical Information Note 246 (only available in Dutch and French)
- Special wall types, such as
  - half-timbered and timber frame constructions
  - veneer walls
  - prefabricated walls (for instance prefabricated concrete columns, beams and plates that are assembled on site)
  - not concrete structures, as their treatment is very specialized

In the case of concrete structures, it is often advisable to call in appropriate experts. Many of the aspects for massive walls (pathology, possible solutions etc.) are often applicable to such walls. However, the specific properties of the other wall types require often another approach.

In case of cavity walls, it is important to make sure that it is a true cavity wall. Indications such as openings (so-called drainage openings, to leave out excess water and for drying purposes) may be a valid indication. If doubt remains, the partial removal of the outer masonry (or, less invasive, an endoscopic survey through a small borehole) will make sure whether or not there is a cavity.

4 Planning phases

When planning energy-efficient refurbishment measures with interior insulation, a project schedule divided into three phases has proven successful. It begins with a building inventory to record the relevant information and the structural condition of the building.
Subsequently, the renovation concept can be created on this basis, starting with the façade renovation concept. Here an insulation system is defined and verified under the terms of damage prevention, reduction of heating energy losses, cost specifications, monument preservation requirements as well as design and construction requirements.
In the last step, the relevant, i.e. representative connection details are selected and dimensioned. The last two façades are dealt with in part 2 of the guide.

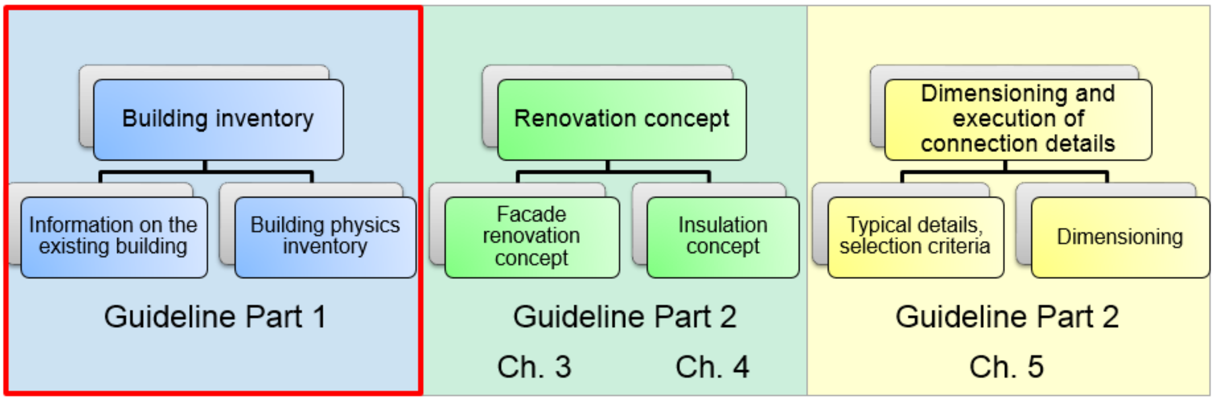


Fig. 1 Project schedule in energy refurbishment with interior insulation systems, division of the two guides

5 Planning and completion of on-site investigations

When planning an internal insulation measure, a precise analysis of the historic building is of major importance. Without, it is possible that humidity problems reoccur or, in some cases, even increase the damage. Good planning can also avoid not exploiting the full potential of insulation.

5.1 Information about the building

For historic buildings, there are sometimes any sources of information that should be considered for the evaluation of a building. These information are very helpful to become familiar with the building in advance and to identify interesting areas, e. g. where a building was extended or repair work took place. The building permission, implementation planning, notes, papers, photos, letters, surveys and bills reveal building constructions, applied materials or past damage events.

After all, the consequences of a particular use can have an impact up to the present day, for example salt contamination by a former stable. Such documents, also from the city's building archive, may also explain uncommon constructions, e. g. by exceptional extensions or repair

Flowchart

measures. Changes and conversions already carried out become transparent. A very important source of information are also (former) users and owners.
The more comprehensive the knowledge about the building's past is, the better existing flaws and causes of damage can be explained from the conditions of its construction and the changes made.

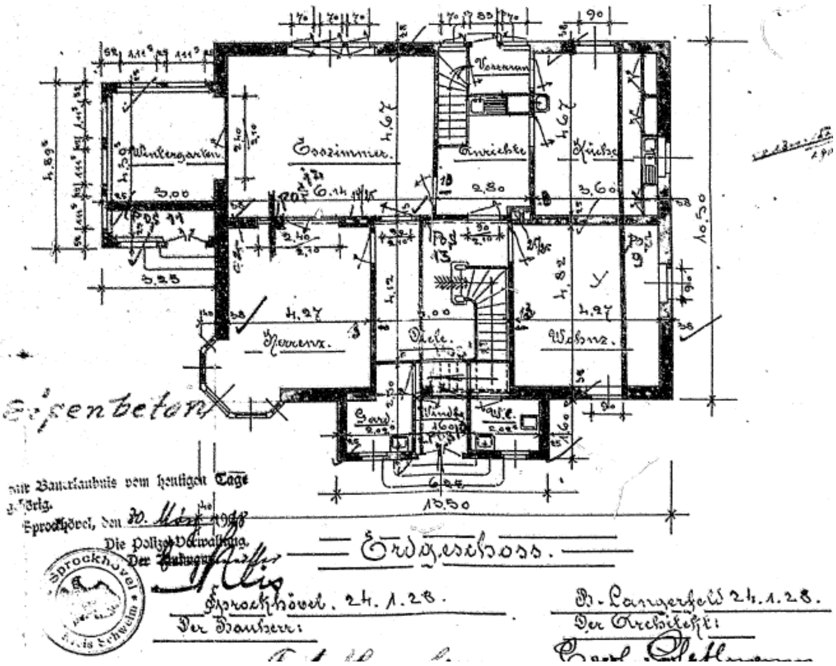


Fig. 2 Excerpt of an old German building permission

5.2 Planning

It is recommended to carry out the examination of a building in two stages. The following picture (Fig. 3) describes the general procedure which is visualised in more detail in the flowchart.

During a first on-site appointment (“Sensory phase”), an orienting inspection of the building is carried out to gain an overview of its condition. Based on this visit, it is possible to assess which next steps are necessary for a more thorough building assessment and which examination methods will be used in the second inspection, the testing phase.
Ideally, the first inspection takes place after a rainfall in order to be able to evaluate the moisture absorption capacity of the façade. This is done by visual inspection of the surface colouration of the wall, e. g. in the splash water area and along the roof drainage. The findings are to be documented.

Flowchart

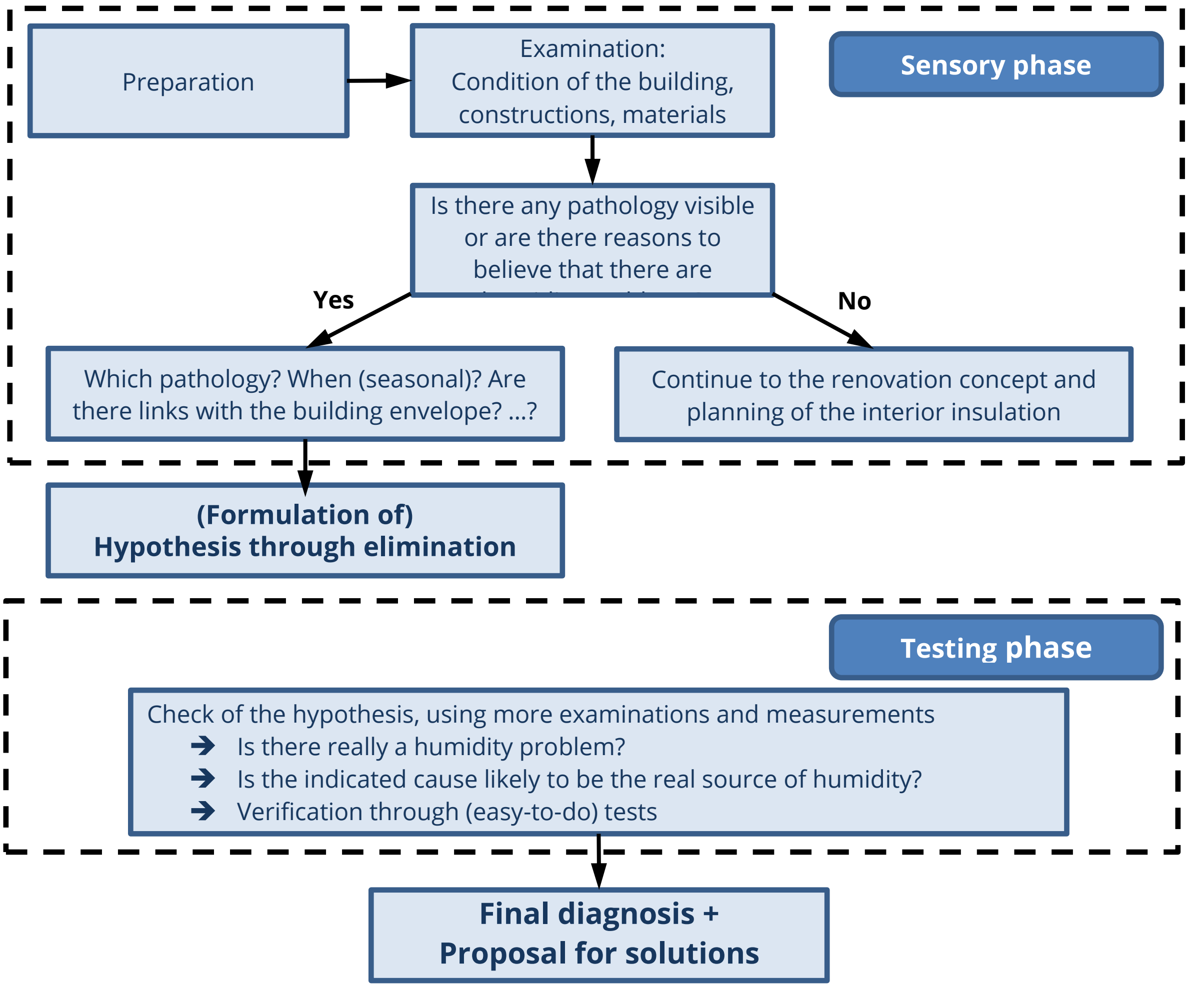


Fig. 3 Overview of the on-site investigation process

It should be clarified in advance whether electricity and water are available (if they are needed). If not, a generator and water must be organised. It may also be necessary to provide scaffolding, a climbing frame, or at least a (longer) ladder. It is possible that vegetation will have to be removed. In the appendix is a list of things that may be useful during an inspection.
In the appendix A 3 there is a list of tools, measuring instruments and equipment that can be useful during an inspection and necessary preparations in advance of an inspection.

The second inspection / investigation ("Testing phase") is planned and implemented based on the findings and assumptions of the initial inspection. In doing so, (further) measurements are taken and samples are taken if necessary.

5.3 Implementation

5.3.1 Initial inspection

The first important findings in the recording the conditions of a building can be obtained with a “sensory phase” without the use of extensive technical aids. The flow chart for the on-site inspection presents a proven procedure and sensory testing options are listed in Tab. 1.

Flowchart

Tab. 1 Possibilities of sensory examinations during object inspections

Sense	Possible information
Seeing	- Discoloration of surfaces as a result of moisture, mould or bacteria growth or algae/moss grow - Salt or lime efflorescence - Condition and dimensions of building components - Cracks and deformations - Weathering - Corrosion of metal materials - Wood destroying fungi - Inclined components - Building components of high thermal conductivity (steel or concrete) penetrating the *thermal envelope*
Feeling	- *Sanding* of surfaces (*scratch or tape test*) - Moisture load - Soft, porous surface character (wood) - Draught phenomena (*lighter or smoke test*) - Deformations as shrinking or swelling - Soft, bouncy spots while walking on ceilings or inclined or deformed floors
Smelling	- Musty smell - Plastic components in plaster surfaces (*lighter test*)
Hearing	- Knocking on structural elements to detect cavities, material change, loose plaster

The first inspection focuses on the roof, the roof connection, the plinth area inside and outside, cellar rooms, window connections, building corners and – as far as known - places where damage has occurred in the past or repairs have been carried out. Also, areas around water-bearing pipes (inside and outside) should be checked in particular. Especially on façades with single-skin exposed brickwork, check the condition of the joints, e. g. whether pointing mortar is missing or cracks are visible. Transitions of building extensions or conversions should also be part of the inspection.

If the impact of driving rain is relevant, the A- resp. A_{cap}-value (see glossary A 4) of the façade should be measured. It may also be advisable to determine the A-value for rendered façades in order to check whether the driving rain protection still is sufficient. With which method such measurements are carried out, in the laboratory or on site, depends on the possibilities and the relevance. However, in many cases simple on-site measurements are sufficient (see chapter 8.2).

The effect of driving rain can be important for walls that face the weather, mostly west and south walls (see chapter 3.4. in part II Insulation Concept). This is usually the case when the walls are oriented west or southwest. The driving rain load also increases with the building height and exposure if an exterior wall is not protected by other buildings or vegetation, for example. This is particularly relevant for thin, single-skin walls or exposed masonry. In order to assess the exposure to driving rain, orienting measurements may be necessary in individual cases. For this purpose, measurements with driving rain measuring plates [5] can be carried out (see also chapter 8.5).

All sensory impressions, such as damp spots, salt contamination, cracks and mould etc. are to be documented conscientiously in their position, form and time (winter or summer, after rainfall or

Flowchart **Flowchart II**

high occupancy) and entered into corresponding building plans, room by room. Sketches and photos support the memory and discussions. The results of a damage mapping in plans helps to find correlations between different patterns of damage and can be used to derive measures to eliminate the damage itself as well as its causes.
During the examinations it may be necessary to remove elements like tiles, a brick or wall paper. For certain damage cases, a further expert is required (e. g. statics, wood protection).

Time and again, it happens that the conditions found on site do not match the information collected in advance. In such cases, the as-built documents should be updated, if possible, or reference should be made to this in the documentation.

In case of conspicuous damage, such as long, wide cracks in load-bearing components, suspicious crackling while walking on a ceiling or conspicuous misalignment, immediate consultation of a structural engineer is essential. If necessary, immediate measures should be taken to avert danger or (re)establish operability in order to avoid further damage. In these cases, the on-site inspection must be stopped until the expert's opinion is known and, if necessary, measures have been taken.

In some cases, the cause of the detected structural damage can be easily removed, e.g. by replacing a defective roof drainage system or provisionally closing defects in the envelope structure. In the case depicted in Fig. 5, a down pipe had to be fixed to avoid moisture accumulation in the wall.

- ➔ The output of this “sensory phase” is a series of hypothesis respectively a list of possible humidity problems that might explain the observed pathologies.

5.3.2 Second investigation

In the second investigating phase, the “testing phase”, measurements are to be carried out to confirm or to contradict the previously formulated hypothesis. Some examinations may require major intervention, which I the case of listed buildings must also be clarified with the monument conservation authorities. These include, for example, the supports of the ceiling beams, where there is often damage that cannot be seen. At least selectively, an opening should be made here in endangered areas (weather side, under damp rooms/kitchens). This second phase is not necessary when the conclusions of the first, sensory phase are obviously uncritical.

Basically, two types of examinations are available:

- **Non-destructive tests** usually give fast results, which makes them suitable to more easily find out where a potential humidity problem is (even when no direct pathology can be observed). Such measurements are usually indicative, which means that there may be major deviations in the result without comparative sampling, depending on the specific circumstances in the building. Their advantage is that they are non-destructive and can thus at least help to roughly divide into different areas with regard to the moisture load.
- **Destructive tests**, where samples are taken and analysed, have the advantage that the results are correct. It requires however more effort and time (sampling plus subsequent measurements), and is invasive/destructive. A relatively small number of samples is mostly sufficient: the sampling locations are usually strategically chosen in consultation with the client or planner, based on previous sensory observations and non-destructive tests.

- ➔ The output of the “testing phase” is a final confirmation of the probable humidity source(s) and damage cause.

Flowchart Flowchart II

It is always helpful to take samples of masonry, as this enables a more precise knowledge of the behaviour of the masonry and the energy-saving potential can also be better quantified. Even the comparatively simple determination of the density allows a more profound assessment of the thermal conductivity. The A-value is particularly important for the short-term moisture transport behaviour. Long-term drying processes are determined by the μ-value (each see appendix A 4). Removing and measuring pointing mortar is usually too time-consuming. Here it is important to ensure that in unrendered masonry the joints are intact or that they are refitted if necessary.

6 Main sources of moisture in facades

There are only a few main sources for moisture in facades and the moisture distribution reflects its origin. High moisture in the core of building components, e. g. by rising damp, indicates longer lasting moisture load than superficial moisture (see Fig. 4 below). The following sections explain the different types of moisture distribution.

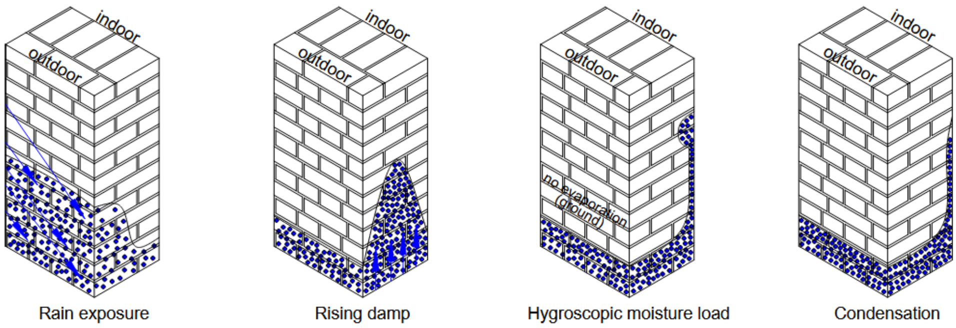


Fig. 4 Schematic representation of moisture distribution in masonry

Please note, that there is also a mixture of different causes and distributions possible that make the interpretation more difficult. Evidently, some of the pathologies described later occur due to the malfunctioning of other elements and not due to the sources of moisture described here. They may be for instance linked to installations, pipes, connections of the wall with window frames, roofs, gutters … but will be mentioned briefly here.

6.1 Infiltration of driving rain through facades, façade elements or façade openings

6.1.1 Description

The most obvious moisture source in facades is driving rain penetrating the external wall surface. The amount of absorbed water and the moisture distribution (in Fig. 4 on the left) is dependent on the capillary transport properties of the coatings, plaster and masonry. Structural damages such as cracks and gaps increase the moisture uptake.
Much lesser in terms of quantity but yet not negligible is condensation of ambient humidity on the external surface. This takes places for instance as morning dew and can induce the growth of organisms.

The quickest moistening takes place when there are defects in the façade and rain water can enter directly. Such defects may for instance be caused by

Flowchart

- stability problems, structural changes or thermal dilatation,
- frost or manufacturing defects, or
- missing building elements.

Badly or not maintained gutters and rainwater pipes are a frequent cause for humidity problems in walls (Fig. 5, left). Besides this kind of damage, the infiltration of rainwater is undesirable, as it augments unnecessarily the moisture content of facades, which is a negative factor when applying interior thermal insulation.

6.1.2 Visual examination

Degradations on the inside of a building should be, if possible, linked to aspects on the outside of the building. However, even if no pathology is visible on the inside of the building, it is still necessary to perform a control of the outside. Even if no moisture damage is visible on the inside, it might be possible that excess water infiltration might cause damage in the future when applying interior thermal insulation.

It might be beneficial to perform a visual assessment during rainy weather, or in a rainy period. This allows directly to check if certain façade areas are very exposed to rain, and which areas are protected (Fig. 5, middle and right).

Fig. 5 Inspection after a rain event to visually check the moisture distribution on façade surfaces. Left: visible moisture load due to defective temporary rain water downpipe; middle/right: exposed parts become visible

Moreover, visual signs of runoffs, such as the pattern of pollution of a façade, may offer a clear view on the exposure. Depending on the kind of dirt (soot, bacteria, algae, etc.) one might observe a different intensity of dirt on facades (Fig. 6 and Fig. 7). Soot usually is more present on parts of facades that are less exposed to rain, whereas bacteria or algae are usually more present on parts of facades that are more exposed to rain or humidity and dry out slower (for instance north faced facades). Sometimes differences in rainwater exposure are shown by a changing intensity of damage to façade materials (Fig. 8 and Fig. 9).

Fig. 6 Biological growth of moss, algae and bacteria showing where facades are exposed to rainwater

Fig. 7 Differences in pollution under a window sill. Left: apart from some runoffs, the surface under the window sill is well protected from water, as it is sooty; middle: cleaner surface under the sill, indicating it is exposed to rain; right: the runoffs of water under the sill can easily be observed

Fig. 8 Different condition of the surface, in this case the washing out of the binder, may indicate differences in driving rain load exposure

Fig. 9 Often, rainwater infiltration causes $Ca(OH)_2$ to be washed out of concrete or mortars and deposited on surfaces where it turns into calcite. Such white run-off, sometimes even visible as stalactites, is a very clear sign of infiltrations. The presence of such run-off indicates a serious problem. It can lead (in concrete structures for instance) up to significant material damage and stability problems (degradation of mortars, increased corrosion of steel reinforcement bars in concrete)

Following aspects need to be checked visually (possibly complemented with measurements):

- Window sills
- Protection of wall base
- Cap stones
- Cornices
- The presence of large cracks in the façade
- The quality of the stones (no degradations, no cracks)
- The quality of mortars (no degradation, no missing joints)
- The quality of renders or paints, as well as their water vapour permeability
- The joints between window or door frames and the wall
- The presence of vapour blocking finishing materials (some type of render or paints, glazed tiles, glazed bricks, ...)
- The presence of elements that protect walls, such as balconies

Furthermore the type and orientation of the walls plays an important role:

- Interior walls should not directly suffer from rainwater infiltration. An interior wall in contact with an exterior wall may absorb some humidity coming from the outer wall, but that (not visible) effect should be gone at a distance of more than one meter from the exterior wall. If one notices wet spots or material degradation on interior walls far from their contact with exterior walls, the humidity source is most likely not rain water infiltration.
- Usually only facades oriented towards the south or west are exposed to intense driving rain, and consequently, damage caused by rain is usually only expected on these facades. Driving rain coming from the east or north is rare (even though possible). Wind turbulence might play a role too, caused by surrounding buildings.
- Often the upper parts of walls suffer more than lower parts. So usually problems with rain exposure, if any, become more apparent and intense higher in the building.
- The humidity is present in the volume of the wall, as it migrates from to the outside of the building towards the inside. This means that one should measure the presence of humidity

well below the surface of the wall. If there is only humidity at the surface of the wall, it is not very likely that it is about rain water infiltration.

6.2 Rising damp

6.2.1 Description

Rising damp usually occurs in older buildings in case of a defect or missing horizontal or vertical sealing in connection with groundwater contact. Humidity present in the soil surrounding a building, is capillary absorbed by the porous foundation materials, and rises up in the walls. Buildings that date from the 2nd half of the 20th century, or more recent, are much less likely to suffer from rising damp, even though it is still sometimes possible, mostly because of errors during the construction.
The pathology shows itself usually as a horizontal band in the basement and ground floor area. The humidity can rise up to a height of about one meter, in the presence of salts and dense plaster higher. In the wall centre the moisture mostly ascends higher, when the outer parts of the masonry can dry out (Fig. 4, 2nd picture).
Rising damp causes massive material degradation, is the source of high energy losses and affects negatively the inner climate.

6.2.2 Examination

Rising damp usually affects outer walls, but it can also affect inner walls (depending on the location of the ground-water level and the type of soil). When there is a ventilated basement under the building, the walls at ground level should suffer less (or not at all) from rising damp.
Moisture measurements can be used to determine whether rising damp is actually present. Walls with rising damp are driest on the surface and become wetter inside the wall. Walls are also dampest near the base of the wall and become drier higher up the wall.

Fig. 10 Rising damp visible on the interior surface of an inner wall (left) and an outer wall (right)

It is important to notice that not all horizontal moisture bands are caused by rising damp. The following are sometimes confused with rising damp:

- **Hygroscopic salts**: Such salts often show themselves as random irregular damp spots. In many cases though, they are visible as a horizontal wet band, thus giving the impression of rising damp. Hygroscopic salts can be distinguished from rising damp by either measuring the humidity level of the masonry at a certain depth (for instance 10 cm), as the moisture content of the masonry should be very low, or by performing a salt identification test to check whether too many hygroscopic salts are present (check the presence of nitrate or chlorine ions, as these are most likely to be found in hygroscopic salts).

- **Plaster bridges**: If there is a humidity barrier at the wall base, but the plaster on the wall is in contact with the damp masonry underneath the barrier, the plaster becomes wet and transports moisture across the barrier, again in the form of a horizontal band. Plaster bridges can be distinguished from rising damp either by looking at the height of the damaged zone (usually maximum 20-30 cm and much lesser than the 1 meter in the case of rising damp) or measuring the moisture content of the masonry behind the plaster (this should not be very high and at least lower than the humidity content of the plaster itself).
- **Splash water**: This may cause damp wall bases in a horizontal band. It can however be distinguished from rising damp because the height of the damp zone is limited (about 30 cm max). A visual inspection of the exterior wall can confirm this hypothesis: splash water is expected when there is no or insufficient protection against splash water (plinth) or there is no gutter present (causing excess splash water).
- **Thermal bridge at the wall-to-floor connection**: This connection can be a somewhat colder area during winter, which can cause a horizontal band of moulds (Fig. 10). The effect of this thermal bridge can be distinguished from rising damp because the impacted zone is usually much lower than one meter and the moisture content in the wall is very low (the humidity is only situated at the surface of the wall, and not deeper in the wall).

Fig. 11 Purely visually, it is not always easy to distinguish the moisture source. Left: dampening caused by rising damp. Right: dampening caused by hygroscopic salts

6.3 Hygroscopic moisture and hygroscopic salts

6.3.1 Description

Even when a building material is not in direct contact with water, it will still contain a certain amount of moisture, as it will absorb humidity from its surrounding environment. With normal room conditions (temperature around 20°C and relative humidity up to 65%), the amount of so-called hygroscopic moisture is usually very low and far beneath the total amount of moisture the building material can absorb. It is unlikely that this will cause any damage.

The amount of hygroscopic moisture may (strongly) increase when there are hygroscopic salts in the building material. These salts originate from the material ingredients or from an external source (rain, rising damp, industrial or agricultural activities ...). Depending on the type and amount of salts, it can attract a considerable amount of additional water, which can cause the appearance of visible damp spots and sometimes material degradation.
Is the water content high enough, the salt goes into solution again and may be transported even higher where it can accumulate and attract more water. This can lead to a distribution as shown in

the third picture of Fig. 4. If the salts are brought in from the outside, e.g. by road salt, the moisture profile will be higher on the outside.

When a dissolved salt dries out (for instance because the indoor conditions become drier), salt crystallisation at the interior or exterior surface occurs which in itself does not constitute material destruction. Damage might occur in case of crystallisation in the material pores (crypto-efflorescence).

6.3.2 Examination

Moist spots due to hygroscopic moisture can appear practically anywhere: inside, outside, near the wall base, on the upper floor of a building, on interior or exterior walls etc. The appearance can be a regular band or irregular spots (Fig. 12), sometimes with very sharp edges, sometimes with blurred ones. Their appearance changes: they become larger as the relative humidity increases, and become smaller (or even disappear) as the relative humidity decreases. Often these (salt) stains are due to humidity problems in the past, combined with contamination by seawater, de-icing salts or decomposing organic compounds (rotting plants, sewage, animals, urine, faeces ...).

Hygroscopic salts may be present in all building parts:

- roof problems (water containing degrading moss, faeces, carcasses; often linked with former problems with gutter and rain pipes, or presences of animals in attics),
- ground water (rising damp, loaden with salts due do organic materials, or sewer water),
- rainwater infiltrations (especially in coastal areas),
- previous use of the building: stables, dunghill, storage room for fertilizers, etc.,
- building materials, especially recycled (and not well cleaned) bricks or stones, may be salt-loaden due to their previous usage

Fig. 12 Hygroscopic moisture and salts on an outer (left) and inner wall (centre); right: on the surface, salt crystallises out

The humidity due to hygroscopic salts is mainly present at the surface. This may give the impression that the walls are very damp, however in most cases, the masonry behind the damp spots is rather to very dry. A salt identification test can be carried out in order to confirm that there are too many hygroscopic salts present. When using a simplified test with test strips, one should look mostly at the presence of nitrate or chlorine ions, because these ions are most likely to be found in hygroscopic salts.

In exceptional cases, hygroscopic moisture can be very abundant. More accurate measurements that show what and how much hygroscopic salts are involved (or are not) are more complex than "simple" measurements and require the measurement of test specimens in a laboratory.

6.4 Thermal bridges (condensation, mould)

6.4.1 Description

Thermal bridges are zones on internal wall surfaces where the surface temperature is lower than on the surrounding area. These lower temperatures lead to a locally increased surface humidity and may induce mould growth or surface condensation.
As a rule, thermal bridges cannot be completely avoided, but their effect can be limited by flanking measures. For instance, a corner of a building is an example of a constructive thermal bridge: the cold external climate impacts on a much bigger area than the warm internal climate.
Steel girders of a ceiling that penetrate the outer wall and on which a balcony still rests or a continuous concrete ceiling would be examples of constructive and material-related thermal bridges, since steel and concrete have a much higher thermal conductivity than the masonry bricks. The steel and concrete therefore cool the adjacent wall area considerably.

Condensation and mould growth often appear together on the same spot. However, it is possible that condensation appears without mould formation, for instance when the substrate does not contain nutrients, or when the time span of condensation is sufficiently short. Vice versa, certain moulds can develop starting from a relative humidity of 70 % (in dependency of temperature and time period), thus without the presence of condensation.
On the other hand, condensation only occurs when the air is completely saturated, but this can also be the case within a very short period of time. If this period is sufficiently short and no nutrients are present, mould will not develop even if there is plenty of condensed water.

6.4.2 Examination

Mould, damp stains or water droplets can be easily identified on surfaces. They are often located

- behind or under large objects (furniture, carpets, …),
- on evident cold surfaces such as (single) glazing,
- in plinth areas or corners which may lead to very characteristic ‘hyperbole’-shape cold zones with condensation or mould (Fig. 13) or
- on other thermal bridges as described above or for instance on a steel girder in lintels.

Fig. 13 Mould/condensation in the area of thermal bridges

7 Assessment of findings

7.1 Damage patterns associated with moisture

This section describes damage patterns in more detail that may indicate a humidity problem. Many examples with pictures can be found in the appendix A 1.

Biological damage: Façade (see e. g. appendix A 1, Case 4)

- Algae, lichen, bacteria (usually visible as black zones): even though they require water to develop and grow, their presence does not always indicate a serious humidity problem. They may occur when circumstances are good (no direct sunlight, high ambient humidity during sufficient long periods).
- Moss, fungi, mould or higher plants: their presence almost always indicates a serious humidity problem. Especially the presence of higher plants indicates serious humidity problems, as they require lots of moisture during a longer period of time. Moreover, their roots may rapidly increase a pre-existing damage.

Biological damage: Internal spaces

The presence of any organism on inner surfaces is undesirable and indicates a problem that urgently requires attention, for the sake of the building, but also for the sake of the health of people inside the building. In case there is a mouldy odour present but no visual signs, one should consider looking behind wallpaper, underneath carpets or vinyl floor coverings, behind furniture or wall panelling, even underneath floor tiles. Inside buildings, the following can be found:

- Mould: appears when there is humidity inside the wall, but also when there is a problem with the inner climate of the building (high air humidity over sufficient long periods), be it generally in the building, or in the vicinity of cold spots (thermal bridges).
- Fungi: require much more humidity. When these are present, walls, ceilings etc. are too humid. It is required to inspect thoroughly wooden element nearby, as they might be damaged and have lost part of their strength.

Corrosion of iron

On the outside of a building, the corrosion of (unprotected) iron is inevitable, as high moisture (rain or vapour) is very often present. On the inside of a building, a too humid interior climate results in superficial corrosion. When the corrosion goes beyond the superficial level, especially on parts in contact with walls, it indicates a more intense humidity problem in the wall, caused by e.g. rainwater infiltration or rising damp.

Flaking, crumbling, powdering, cracking of building materials
can be a consequence of several degradations, usually all linked to humidity:

- Degradation of gypsum-based plasters on the inside of a building, caused by a too humid indoor environment, the presence of salts in the plaster (in combination with a too humid environment), or too much moisture in the wall.
- Degradation of natural stones, bricks, mortars or other mineral wall formers by the action of
  - Frost/thaw cycles: usually outside, in combination with a wet wall. This may also occur inside, in unheated (maybe neglected?) buildings.
  - Salt efflorescence: repeated cycles of humidification and drying cause salts to dissolve and re-crystallize. Depending on the boundary conditions (temperature, air humidity and wind) and the building materials, these salts may crystallize at the surface or inside materials, thus causing structural damage in the material.

Damage to finishing layers (inside or outside)

- Flaking of coating: usually because of salt crystallization behind the paint layer, or frost at the interface between the paint and the material underneath.
- Damage to renders or plasters, under the form of cracking, losing cohesion, flaking … usually due to salts or frost.
- Wallpaper peeling off: usually because of dissolving glue when getting wet. In addition, in the case of very diffusion-tight paints and PVC wallpapers, excellent growth conditions for microbial growth can be present behind this layer (Fig. 14).

Fig. 14 Significant mould growth behind a removed PVC wallpaper (Wiss J. Elstner Associates, Inc.)

Visible humidity

- Visible drops due to condensation are usually a consequence of a too large moisture production in the building (due to e.g. human activity or the presence of humidity problems), insufficient ventilation, dense surfaces, and/or the presence of cold surfaces (thermal bridges). Condensation on external surfaces however is very normal.

- Infiltrating water, that flows from the wall into the interior of the building happens relatively often in cellars due to ground water pressure, in connection with cracks. Above the ground it is very rare, but occasionally it does happen. This problem will not be dealt in detail with, since it does not occur often in buildings, even when it is in a mediocre condition. Evidently the presence of such infiltrations is unacceptable.
  When encountering a steady drip, look at
    - leaks in water pipes, pipes for waste water or water pipes for central heating. Leaks could be detected by checking whether the water meter reading has changed between two readings
    - leaks or blockages in gutters or rainwater pipes
    - leaks in roofs
    - large cracks in facades or openings that allow relatively large quantities of water to enter the construction, especially in facades facing the south or west
    - Damaged or missing sealing between walls and window or door frames
    - Damaged or missing sealing between roofs, terraces and walls, chimneys, …
- Damp zones, either caused by hygroscopic salts in the masonry (humidity is typically very superficial) or by an external humidity source (humidity is typically also deeper in the wall, possibly throughout the entire thickness of the wall).

7.2 Façade materials influencing or accentuating humidity problems

Certain materials or layers partially or completely prevent moisture in masonry from drying out efficiently, thus intensifying an already existing humidity problem.

Drying of a masonry is essentially being influenced by two parameters:

- **capillary movement of liquid water** in the pores of materials. As a consequence, in dense materials the drying will be slower. But also in materials with a more open pore structure, but treated with a water repellent agent (e.g. hydrophobisation), the capillary movement of humidity is difficult, thus possibly resulting in a slower drying rate.
- **water vapour permeability** of materials, in the masonry and at its surfaces. Logically, the more a material is blocking the transport of water vapour, the slower it will dry.

In most cases, humidity will preferentially be found in the mortar of a masonry, as this material has lots of capillary pores, more than for instance bricks or natural stones. Though, this is not a general rule, there are exceptions.
It is important that a façade is conceived such that it absorbs only a minimum of water and allows a maximum of drying. Drying is necessary because even a façade that is totally rain-proof still might encounter humidity, for instance due to leaks in gutters, roofs, or cracks in the façade or its protecting layers.
Weswegen die Fugen oft vor deren Anwendung neu verfugt werden müssen.
The following materials and treatments influence the drying rate of a masonry in a negative way:

- Old masonry, repointed with contemporary **dense cement mortars**. Drying of old masonry (with mortars based on hydraulic lime or hydrated lime, which is the case for most buildings constructed before about 1930) is usually done mainly through the mortar. A masonry that has been repointed with a dense cement mortar is considered to be a serious blockage of the drying.
  In rare cases, old mortar joints are being painted (often with oil paints) or have small vapour-tight elements (such as glass or tiles) attached to them. This additionally impedes the drying of the masonry.

- Application of a **water repellent agent**. The penetration depth of such treatment is about 8-12 mm. In this zone at the surface, they block the capillary movement of water, preventing rain to enter. To ensure a good result, firstly products should be chosen that reduce drying as little as possible, i.e. diffusion resistance should not or hardly be increased. Secondly, the hydrophobing agents must be adapted to the particular façade. Thirdly, the façade should be in good condition, which is why before the application, joints often need to be repointed. Fourthly, any existing moisture source (e.g. rising damp) should be resolved first. Finally, the effectiveness of the agents must be checked every 5 to 15 years, depending on the product and material, and renewed if necessary. Methods for determining the A-value can be used to check water absorption (see chapter 8.2)
- Depending on their condition and composition, **renders** have a beneficial or a negative impact on the humidity in facades and the drying behaviour.
    - Renders with a high cement content are considered to be blocking the drying of the underlying masonry. Their negative effect may be accentuated because they often show shrinkage cracks where water can enter the masonry. These quantities are not very large, but combined with a render that blocks the drying, a humidity accumulation behind the render might be observed.
    - Renders based on hydraulic lime, or hydrated lime, show usually better drying properties. The fact that such renders show often less shrinkage cracks, improves their performance in protecting a façade against driving rain.
- **Paints** or other **coatings**. Depending on their composition, coatings might be having hardly any influence on the drying rate, to a very serious influence.
    - Paints such as limewash, silicate paints and siloxane paints have little influence on the drying rate.
    - Most organic paints, such as acrylic paints, reduce the drying rate moderately to significantly, increasing with thickness and amount of paint layers applied.
    - Specific organic paints, such as epoxy- or polyurethane coatings (quite often applied as protection against graffiti) block almost all vapour transport and thus have a very negative influence on the drying rate. Oil paints are very vapour-tight and thus seriously slow down the drying of a wall.
- **Water- or vapour-tight façade claddings** that are applied with a mortar to the underlying masonry (claddings that are separated from the underlying structure by a void are excluded). Usually, such claddings are carried out with dense durable materials, such as dense limestones, marble, granite, but sometimes also glass or plastic plates. Often such façade claddings have narrow joints in between them that may behave as leaks (see glazed bricks below).
- **Bituminous façade claddings**, glued to facades. Such protections were very popular a few decades ago and are often decorated with an imitation of masonry. They reduce the drying rate of a façade to almost zero. Their removal is not evident, as it is almost impossible to remove all traces of the tar/bitumen with which the claddings were glued to the façade. This may mean that after removing these bituminous sheets, the entire outer layer of the masonry has to be removed. An additional external thermal insulation might be the best way to deal with such claddings.
- **Glazed bricks** block all water vapour transport and have therefore a negative influence on the drying behaviour of masonry. This is not necessarily problematic for old (lime based) mortar, the masonry has still significant drying possibilities as most of the drying occurs through the mortar. In more contemporary masonry (starting in the 1930s) with thinner joints and pointing mortar, such glazed bricks may cause serious problems related to the drying behaviour of the masonry.

- In a similar way, glazed **tiles**, or dense (but unglazed) tiles or **mosaics**, may have a serious negative impact on the drying behaviour of masonry. If cracks have formed in the fine joints, more moisture penetrates from the outside than can dry out. Damage was therefore frequently observed in such wall claddings.

Ideally, all materials that have a negative influence on the drying rate of the wall should be removed and, if necessary, replaced by another material which has a more favourable impact on the drying, but that still protects the façade against driving rain. In many cases, the removal of the existing layer is not possible or desirable, especially when it comes to heritage protected façades. In such cases, the following is possible:

- protect the masonry against other humidity infiltrations (for instance rising damp)
- allow maximum drying towards the interior by applying vapour permeable (lime-based) renders on the internal surface or, in case of serious humidity problems, special renovation plaster with vapour-open paints or wall paper; panelling should be avoided.
- ensure low room air humidity or change the usage
- pay attention when applying interior insulation, as it generally decreases the drying rate of the wall (lower temperature + decreased drying possibilities towards the interior). Depending on the conditions on site, it may be appropriate to use capillary active (vapour open) insulation systems, to choose a low insulation thickness, or even no interior insulation at all. In such cases, hygrothermal simulations can support.

The implementation of mortar joints has an influence on the penetration of moisture into the masonry. From a moisture perspective, mortar joints that are flush with the stones are ideal. They are however often considered as architecturally 'dull'. Therefore, often protruding beaded joints are used, which are less efficient in protection the façade against rain as the water film on the surface of the façade runs off slower, or deeper laying joints, (also called shadow joints), which protect the façade even worse against rain. Changing the type of mortar joint has however an important visual impact, and removing mortar joints that are in good condition can cause severe damage to the bricks. If there is no damage, the joints can be left as they are.

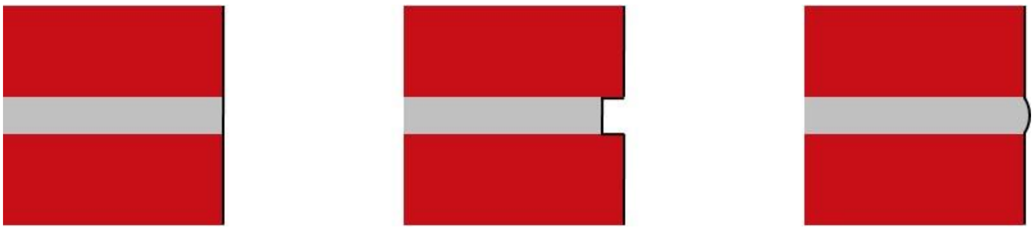


Fig. 15 Typical form of mortar joints: left: flush with the wall, middle; a shadow joints, right: a beaded joint

8 Measuring methods

Moisture measurements are very useful to verify the presence and source of a certain damage pattern during the "testing phase" of the on-site investigation (see chapter 5). In addition to the occurrence of the damage patterns already presented, there are other reasons why a moisture measurement may be justified. For example, if a building is temporarily unheated, if there is no basement waterproofing or if many cracks are found in the wall, these are all indications prone to induce high water content and as a result moisture damages.

8.1 Measuring water content

Various methods for measuring the moisture content exist with different requirements and accuracies. A basic distinction is made between indirect (non-destructive) and direct (destructive) measuring methods (Fig. 16). The direct measuring methods are more accurate but require material samples of different sizes. Indirect methods are less accurate but do not destroy (small parts of) the façade. The following compilation is not complete but lists the common methods. Chapter A 2 in the appendix gives a small introduction in their application.
Depending on the condition of the building, it is recommended to carry out at least comparative measurements between dry and damp wall sections using a simple, near-surface indirect method.

Non-destructive methods have varying accuracy depending on the method, but can give clues to the source of moisture:

- In the case of rising damp, one finds too high humidity levels in the lower areas, though they may also be linked to the presence of salts, and not necessarily to the presence of actual humidity (Fig. 4).
- When measuring the highest values at a height of about 1 or 2 meters, it is a clear indication that a 'salt band' is present (Fig. 4). This is very typical in the case of rising damp, but this phenomenon remains when the source of the rising damp has been taken away. It may therefore be necessary to perform a control measurement with a destructive method or a salt determination.

Destructive methods are more laborious but enable clearer insights:

- In the case of rising damp, humidity levels are supposed to be the highest inside the wall and decrease when looking higher. Above one meter height, they are supposed to be below 3 M% (value based on experience).

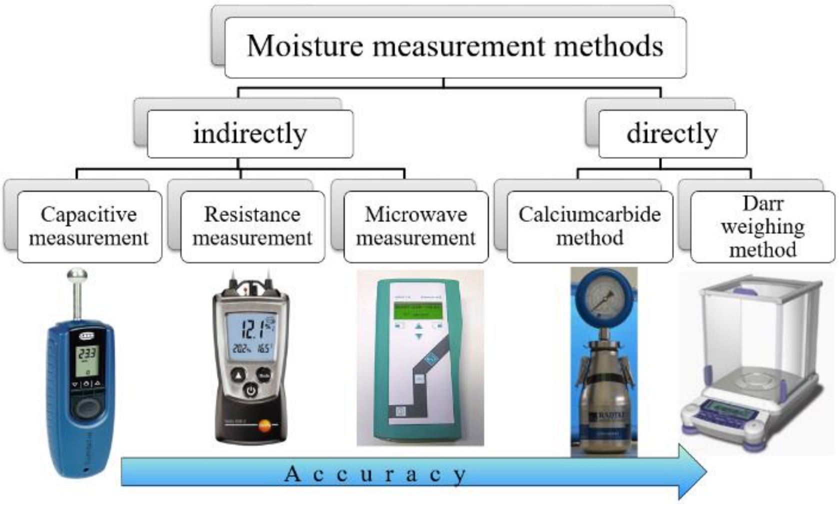


Fig. 16 Common devices for measuring moisture in constructions

Flowchart

Tab. 2 Overview of common methods for measuring moisture content

	Non-Destructive			Destructive	
	Capacitive Measurement	**Resistance Measurement**	**Microwave Measurement**	**Calcium Carbide Method (CM)**	**Kiln-dry/Weighing Method**
Method	Electric	Electric	Electric	Chemical	Gravimetric
Measurement on-site practicable?	Yes	Yes	Yes	Yes	No
Quantitative assessment possible?	No	No	Yes, partially	Yes	Yes
Precision	Imprecise, only qualitative comparison possible	Imprecise for mineral materials, only qualitative comparisons, comparatively precise for wood	Comparatively precise	Comparatively precise (± 3%)	Very precise (± 0,5%)
Evaluation	+ Measured values instantly available + On-site measurement possible + No material removal necessary + Economic measurement technology + Grid measurement possible - Only distinction between dry and moist areas possible - Only measurement of depths near the surface possible (up to 4 cm)	+ Measured values instantly available + On-site measurement possible + No material removal + Economic measurement technology + Additional measurements of lower construction layers possible (by boreholes) - Only differentiation between dry and moist areas possible - Measuring depth depending on electrode length (usually up to 3 cm)	+ Measured values instantly available + On-site measurement possible + No material removal + Measurement of different construction depths possible (up to 80 cm) + Grid measurement possible - Indirect measurement method - Expensive measurement technology	+ Measured values instantly available + On-site measurement possible + Recognized measurement method (appropriate for expert reports etc.) + Economic measurement technology - Moderate precision - Removal of (small) samples necessary - Results only for sampled areas	+ High measurement accuracy + Standardised generally accepted measurement method + Applicable as calibration method for other measurement methods - Measured values not instantly available - No on-site measurement possible - Material removal necessary - Results only for sampled areas
Measurement Principle	Capacitor principle, measuring of dielectric constants: non-conductive materials with ca. 2-10 differs from the one of water ca. 80; the higher the moisture content, the higher the electric conductivity and dielectric constant	Electrode tips are inserted (screwed or hammered) into material and power applied; measurement of resistance or rather conductivity; the resistance of dry materials is higher than the resistance of moist materials	Dielectric resp. radar reflection measurement method, measurement heads are placed on the material, waves are reflected while passing through the material and registered; dielectric constants of non-conductive materials ca. 2-10, of water ca. 80	Removal of material samples, weighing, grinding and mixing with calcium carbide in a pressure vessel => Quantity of acetylene gas (is measured by increase of pressure) indicates the moisture content of the sample	Removal of material samples, weighing, airtight packing, transport into laboratory, drying up to mass constancy, further weighing, water content results from the difference between moist and dry material sample weight
Possible Measurement Errors	• Choice/number of measuring points non-representative • Insufficient contact between sensor and surface of material (e.g. due to unevenness) • Combination of different materials in wall (e.g. pipes) • Inhomogeneous materials • Salt load in material (moisture increase) • Inaccurate material curves as base for interpretation	• Choice/number of measuring points non-representative • Combination of different materials in wall (e.g. pipes) • Inhomogeneous materials • Salt load in material (moisture increase) • Inaccurate material curves as base for interpretation • Influence of temperature not considered	• Choice/number of measuring points non-representative • Insufficient contact between sensor and surface of material (e.g. unevenness) • Combination of different materials in wall (e.g. pipes) • Inhomogeneous materials	• Measurement of too small or non-representative measurement points • Incomplete reactions due to insufficient contact with calcium carbide • Evaporation of material humidity due to development of heat while drilling	• Measurement of too small or non-representative measurement points • Evaporation due to development of heat while drilling

Flowchart

Tab. 3 Overview of common methods for measuring capillary water absorption

	Non-Destructive				Destructive
	Wetting Test	**Test Tube by Karsten**	**Test Panel by Franke**	**Water Uptake Measurement Device WAM 100 B**	**Measurement in Laboratory**
Measurement on-site practicable?	Yes	Yes	Yes	Yes	No
Quantitative assessment possible?	No	Yes, but very imprecise	Yes, but imprecise	Yes	Yes
Expenditure of time	Very short	Short	Short	Medium	High
Evaluation	+ Measured values instantly available + On-site measurement + No material removal + Very economic measurement technology + Unlimited test area + Test conditions correspond real conditions (horizontal capillary absorption, no hydrostatic pressure from water) - Only very rough assessment possible - High influence on results by environmental conditions	+ Measured values instantly available + On-site measurement + No material removal + Economic measurement technology + Measurement of mortar and brick bond possible + Grid measurement possible + Test conditions correspond approx. real conditions (horizontal capillary absorption but hydrostatic pressure of water column) - Low measurement accuracy - Small area covered per measurement (diameter 3-5 cm) - High influence of measurement conditions on result	+ Measured values instantly available + On-site measurement + No material removal + Economic measurement technology + Measurement of mortar and brick bond possible + Grid measurement possible + Test condition correspond approx. real conditions (horizontal capillary absorption but hydrostatic pressure of water column) - Low measurement accuracy - Small area recordable per measurement (25 by 8,3 cm) - High influence of measurement conditions on result	+ Very high accuracy + Measured values instantly available + On-site measurement + No material removal + The behaviour of the entire wall is determined + Large area per measurement recordable (30 by 40 cm) + Test conditions correspond real conditions (horizontal capillary absorption, no hydrostatic pressure of water column) - Expensive measurement technology - Certain influence of measuring conditions (partially corrected) - On-site effort comparatively greater and longer lasting	+ Very high accuracy + Standardized measurement method - High expenditure of time - Laboratory equipment required - Sample removal necessary - Assessment of bond quality between mortar and brick not possible - Test conditions not in accordance with real conditions: gravity in opposite direction as capillary absorption
Procedure	Spraying surface with water, visual evaluation of distribution on the surface and absorption into the material	Fixing measurement device with contact material (putty) on the surface, filling indicator tube with water, reading water level (scale) in preset time steps, measuring of preferably dry surfaces at temperature above 5°C	Fixing measurement device with contact material (putty) on the surface, filling indicator tube with water, reading water level (scale) in preset time steps, measuring of preferably dry surfaces at temperature above 5°C	Fixing measurement device with contact material (putty) on the surface, during measuring, the surface is permanently impinged with water, the water loss is measured, measuring of preferably dry surfaces at temperature above 5°C	Bottom of a dry sample is constantly contacted with water (water bath), the porous material absorbs water due to its capillary suction until mass constancy, weighing the sample in preset time-steps
Possible Measurement Errors	• Choice of measurement points and number non-representative • Little experience of the examiner • High influence of boundary conditions during measurement (moisture content and temperature of wall etc.)	• Choice of measurement points and number non-representative • Very high influence of the edge area, at uneven surfaces fixing of putty at edges is significant • High influence of boundary conditions during measurement (moisture content and temperature of wall etc.)	• Choice of measurement points and number non-representative • High influence of the edge area, at uneven surfaces fixing of putty at edges is significant • High influence of boundary conditions during measurement (moisture content and temperature of wall etc.)	• Choice of measurement points and number non-representative • High influence of boundary conditions during measurement (moisture content and temperature of wall etc.)	• Very low if the test procedure is followed • not measured long enough

Flowchart

For the gravimetric or calcium carbide method sampling with slow drilling is recommended, preferably from mortar. Samples from renders or plasters should be avoided. If it is possible to remove renders or plasters it becomes clearly visible where mortar joints are. Samples may be taken on different heights and different depths.

Measuring wood moisture: When measuring wood moisture, the measurement with the resistance method has been established for many years. There the electrical resistance of a material is measured between two electrodes inserted into the material. When carried out correctly, it is very reliable, whereby it must be kept in mind that woods by nature have a certain scattering of properties, which is particularly dependent on the growing conditions. Thus, a pine from the Alpine region will have different properties than a pine that has grown in the sandy soils in warmer regions. It should be noted that the measuring device should be able to take into account the dependence of the measurement on the ambient temperature. It should also be possible to adjust the type of wood.

8.2 Measurement of the capillary water absorption of the facade

One of the most important criteria for the planning and design of interior insulation measures is the assessment of the driving rain load and protection of the building façades.
There is sufficient protection against driving rain if one of the following conditions is met:

- locally low precipitation
- façades that are practically not exposed to driving rain, e.g. due to neighbouring buildings or the geographical orientation of the facade.
- constructive driving rain protection, e.g. with large roof overhangs or curtain walls
- sufficient transport resistance of the wall, e.g. in the case of thick masonry or masonry blocks with low water transport capacity
- renders and coatings that sufficiently protect against driving rain (WTA MB 6-5)

If this protection is not present, it may be necessary to take additional measures such as renovation of the surface or hydrophobisation. The capillary water absorption capacity over a façade surface can be determined by an appropriate measurement. Fig. 17 and Tab. 3 list various measuring devices for capillary water absorption and briefly explain them.

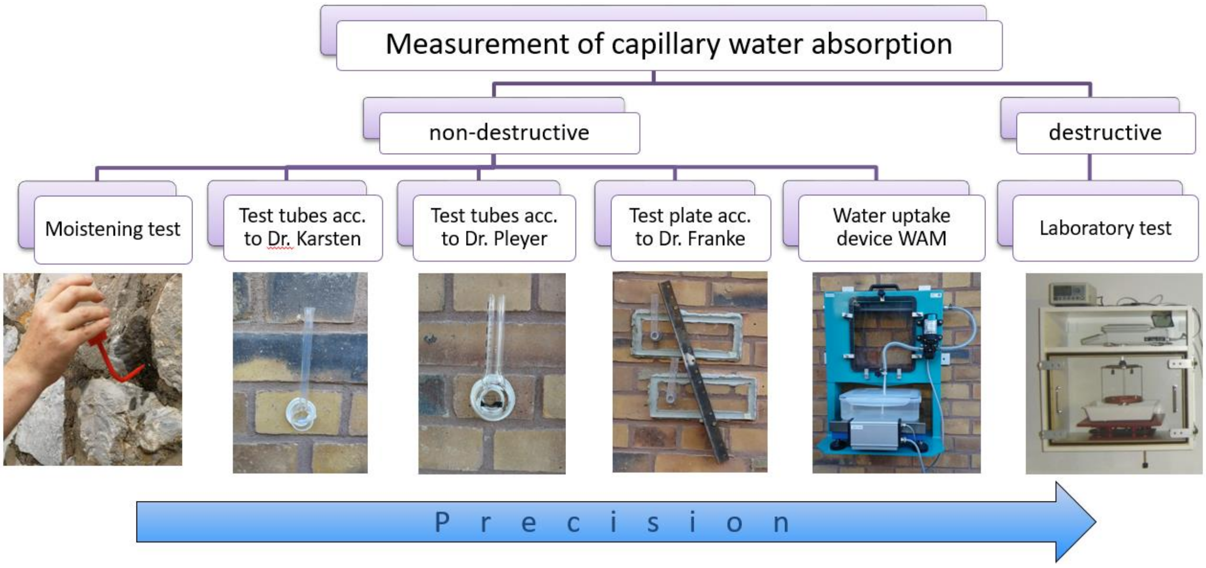


Fig. 17 Overview of common measuring methods for water absorption capacity of building surfaces

Flowchart

Depending on the required accuracy, either an orienting estimation (moistening test, test tube or test plate) or an exact measurement (e.g. controlled water absorption device or laboratory measurement) can be performed. It is important that representative and a sufficient number of measurements are carried out, e. g. covering several façade areas. In general, the smaller the device's test area, the more measurements are required. This leads to different fields of application for the individual in-situ measurement methods, which are justified by the different accuracy of these methods. A decision support from [3] is given in Fig. 18. An overview with an evaluation of the different methods can be found in Table 3 on page 23.

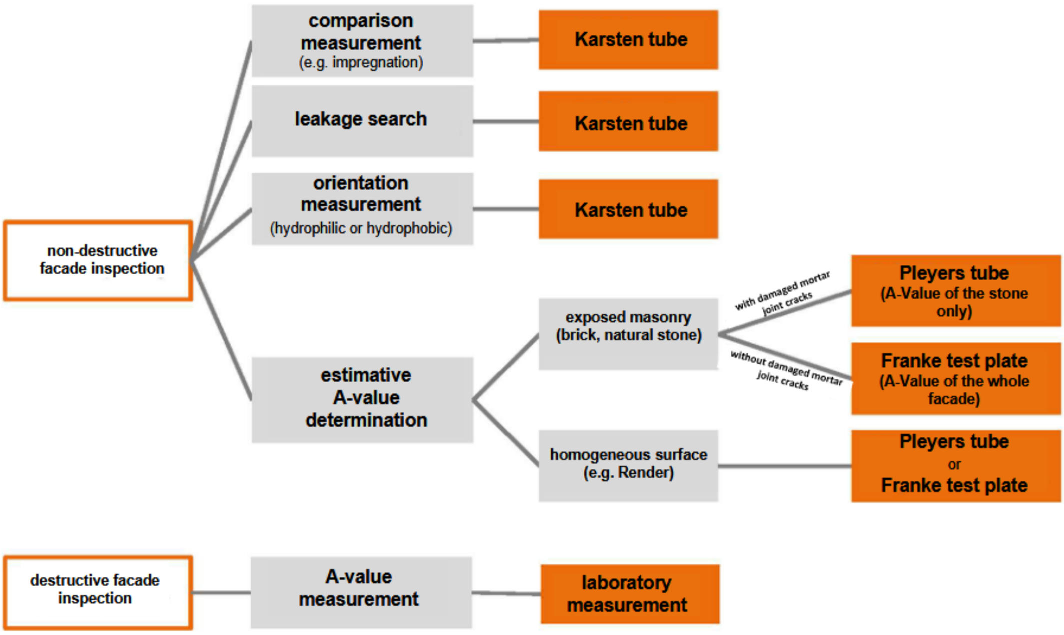


Fig. 18 Decision support for the selection of a suitable in-situ A-value measurement method

If basic tests indicate that the driving rain protection of the masonry is not sufficient, a laboratory measurement is recommended, which would require material samples. The samples taken can be used for further measurements, for example, to find out the appropriate concentration for an adaptive hydrophobisation.

8.3 Measuring room climate

During an on-site assessment, it is helpful to measure the actual room climate. High room moisture often is a reason for moisture damage. After detecting a high room humidity, the reason must be find and resolved. The possible causes for high moisture load in apartments are manifold:

- not sufficient ventilation (in winter)
- too much ventilation of rooms with cold walls during warm and damp summer days ("summer condensation in basement rooms"). The warm, humid outside air then condenses on the wall surfaces.
- room usage with high moisture development (e. g. many inhabitants, many plants, often drying clothes, kitchen etc.)

As part of the project, a simple and inexpensive measuring system was developed, which can also be used to measure the indoor climate. A detailed description can be found in the final report "IN2EuroBuild - Consistent European Guidelines for Internal Insulation of Building Stock and Heritage" under chapter 7 "Smart monitoring system". A self-assembly instruction is attached.

Flowchart

8.4 Salt measurements

Salts must be taken into account in renovation planning, as they have a high damage potential and may require special measures depending on their content. There is still little experience about the application of interior insulation systems on salt-contaminated walls. Only recently have insulation systems appeared on the market that are approved for use on salt-contaminated masonry. The first observations are promising, but a long-term proof of concept for these systems is still pending. For larger glass surfaces (window surfaces, conservatories) it is important that heat sources are not "reflected" in the surface, as this also falsifies the measurement.

First of all, the source of the salt contamination should be found out, e.g. is there a former stable use or a missing horizontal barrier, are road salts used in the plinth area etc.? A qualitative rough estimate for salt determination can first be made on site or in the office using inexpensive test strips. In many cases it is sufficient to determine the anion content using semi-quantitative methods. If a higher accuracy is required, the total salt content and the salt composition of the samples taken on site can be measured in the laboratory.
According to Tab. 4 and Tab. 5 from [4], it can be assessed from which magnitude measures are required:

Tab. 4 Evaluation of the salt load of an old plaster or a long-term unplastered masonry surface in 0 - 2 cm depth from WTA guideline 2-9 [4]

	wt. % related to the dry mass of the samples		
Sulphates *)	< 0.5	0.5 – 1.5	> 1.5
Chlorides	< 0.2	0.2 – 0.5	> 0.5
Nitrates	< 0.1	0.1 – 0.3	> 0.3
Easily soluble anions **)	< 0.5	0.5 – 1.5	> 1.5
Total salt content ***)	< 0.75	0.75 – 2.25	> 2.25
Evaluation of the salt load	**Low**	**Medium**	**High**

*) If the salt load consists exclusively of a medium to high sulphate content, the calcium, magnesium, sodium and potassium cations should also be determined for evaluation.
**) Sum of sulphate, nitrate and chloride content.
***) Determined via the specific conductivity of the aqueous decomposition, unanalyzed ions also have an effect

Tab. 5 Evaluation of the salt load of a previously exposed masonry surface in 0 - 2 cm depth from WTA guideline 2-9 [4]

	wt. % related to the dry mass of the samples		
Sulphate *)	< 0.1	0.1 – 0.5	> 0.5
Chloride	< 0.05	0.05 – 0.2	> 0.2
Nitrate	< 0.03	0.03 – 0.1	> 0.1
Easily soluble anions **)	< 0.1	0.1 – 0.5	> 0.5
Total salt content ***)	< 0.15	0.15 – 0.75	> 0.75
Evaluation of the salt load	**Low**	**Medium**	**High**

*) If the salt load consists exclusively of a medium to high sulphate content, the calcium, magnesium, sodium and potassium cations should also be determined for evaluation.
**) Sum of sulphate, nitrate and chloride content.
***) Determined via the specific conductivity of the aqueous decomposition, unanalyzed ions also have an effect

Flowchart

In the case of higher salt concentrations, precise knowledge of the salt content and the type of salt can be of decisive importance for renovation planning, which is why a specialist should be consulted. Many system providers of waterproofing or renovation systems have analysis facilities for determining the occurring harmful salts and offer this service cheaply or for free.

8.5 Further measurements

As a supplement, **thermographic examinations** of components and component connections can be carried out. This allows identifying “invisible” heat losses and their causes. These include thermal bridges, air leaks, defects and cavities in the construction. In some cases, locally occurring moisture damage may also be detected with the help of thermography. Depending on the purpose of the thermography, certain boundary conditions must be observed: for example, it makes sense to take outdoor shots without direct sunlight, i.e. before sunrise or after sunset and there should be larger temperature differences. Furthermore, it should be noted that all thermographic methods react very sensitively to the emissivity, which means that, for example, bare metal surfaces require pre-treatment ("painter's crepe" or special paint) before a correct measurement can be made.

An **endoscopy** (see glossary A 4) device enables to examine parts of the constructions only by a small drilling hole. Without having to open larger parts of a structure, it is possible to check whether there are air layers in a wall structure or whether there is damage in ceiling cavities. However, the field of view is limited and depends on the device

Measurement of driving rain intensity: if it is not clear during the preparation and on-site inspection which orientation of the building experiences the greatest driving rain load and what the magnitude of this is, it is possible to measure the driving rain load on the façade. Simple driving rain measuring plates have proven effective for this purpose [5].

9 Literatur und Links

[1] DIN 4108-3. (2018). Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 3: Klimabedingter Feuchteschutz – Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung. Berlin: DIN Deutsches Institut für Normung e.V.

[2] WTA-Merkblatt 6-15. (2014). Technische Trocknung an durchfeuchteten Bauteilen, Teil 1: Grundlagen. München: Fraunhofer IRB Verlag.

[3] Haindl K, Schöner T, Zirkelbach D, Fitz C. Was ist bei Karsten & Co. zu beachten? Bautenschutz + Bausanierung, (2017) Heft 3, S. 33-37

[4] WTA-Merkblatt 2-9. (2020). Sanierputzsysteme. München: Fraunhofer IRB Verlag.

[5] Schöner T, Hevesi-Toth T, Zirkelbach D, Fitz C. (2018) IN-SITU Messgerät zur Bestimmung der Schlagregenintensität, IBP-Mitteilung 561, 45

[6] https://www.researchgate.net/profile/Mario-Stelzmann/publication/330566777 _Praxisleitfaden_Schlagregenschutz_von_Fassaden/links/62c8c44fd7bd92231fa34560 am 14.7.2022

[7] Stelzmann S. (2020) Entwicklung und Validierung eines Verfahrens zur Untersuchung des Schlagregenschutzes von Fassaden denkmalgeschützter Bestandsgebäude, Dissertation, Fraunhofer IRB-Verlag

Appendix

A 1 Examples for typical damage patterns

This chapter gives a series of examples of humidity-related issues. Regardless of the implementation of interior insulation measures, most of the issues presented should be addressed, as they can reduce the value of a building and trigger damage. Each of the following examples of damage are briefly described and suitable methods of investigation are pointed up. The cause and a possible solution are then briefly discussed.
In the following list, only common cases are discussed. In practice, deviating or further reasons for the damage or its repair may occur. In case of doubt, a specialist should be consulted

Remark: there may be overlaps between the different topics, as a specific damage pattern may have been triggered by several cause: sometimes by a degradation phenomenon, sometimes by a humidity source, and sometimes it is only the physical appearance of a degradation phenomenon.

Group 1 Typical damage patterns due to humidity

The first group of damage examples is about damage patterns due to humidity. When these damage patterns are observed, the source of the degradation must be treated and the wall must dry out, in order to be able to apply interior thermal insulation.

The following cases are discussed:

- Spalling of bricks or plasters outside
- Spalling of bricks or plasters inside
- Mould growth on the inside of a building
- Algae/bacteria/mould/moss growth on the outer surface
- Pushing out of mortar joints
- Degradation (powdering/flaking) of mortar joints
- Degradation (powdering/flaking) of bricks or natural stones
- Damage to protective finishing layers
- Expulsion of surface layers of building materials
- Degradation of materials due to salts

Case 1 Spalling of bricks or plasters outside

The surface of the bricks, mortar and plaster loses its strength and gradually crumbles or breaks off in larger pieces. The plaster does not adhere to the substrate.

From the surface, the bricks crumbles away

No adhesion between plaster and base. The plaster crumbles away

EXAMINATION
Careful tapping with a hammer, moisture measurement of the wall, measurement of salt content

POSSIBLE CAUSES
- Excessive moisture content (caused by splash water, rising damp) in combination with low frost resistance.
- Excessive salt content can worsen the damage pattern. Possible salt sources are de-icing salts and salts from the soil or from usage.
- Bonding agent is washed out.

POSSIBLE SOLUTIONS
- Find and eliminate the moisture (and salt) source
- Replace defect bricks, restore joints or plaster. If possible, use materials that are more resistant to degradation.

REMARKS
If the source of the damage can be eliminated, internal insulation is applicable

Case 2 Spalling of bricks or plasters inside

The surface of the materials is losing its cohesion: spalling, flaking, powdering, detaching from the surface.

Degradation of plaster due to infiltrations through the façade

Coating and plaster are spalling off

EXAMINATION
Careful tapping with a hammer, moisture measurement of the wall, measurement of salt content

POSSIBLE CAUSES
Moisture too high, salt content too high, plaster/mortar/coating: surface too vapour-tight.

POSSIBLE SOLUTIONS

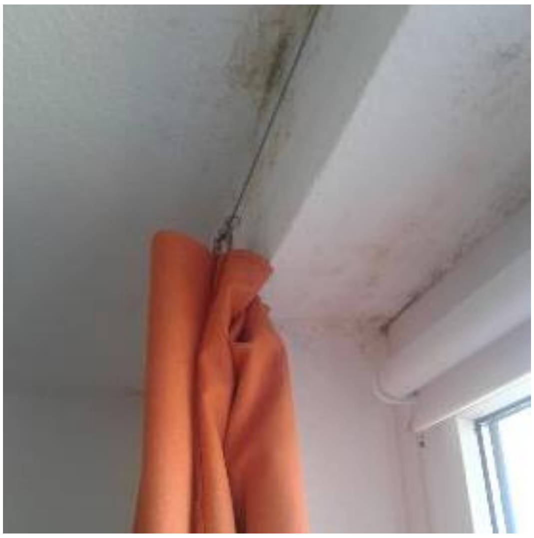
- Find and eliminate the moisture source, reduce salt content if possible
- Restore joints, plaster layer or coating. Apply coating or plaster with lower vapour resistance, or apply a salt-buffering plaster (if no insulation is applied after all)

REMARKS

- These degradations are mainly due to the action of moisture, possibly combined with salts. When the moisture source can be treated, thermal insulation can be applied.
- The presence of salts on the inside of the building is compatible with interior insulation if the insulation is not capillary absorbent or if the insulation is designed to absorb salts. Unsuitable insulation systems may cause damage to the insulation or leakage of salt.
- Before applying internal insulation, gypsum-plasters should be removed. Lime-based or cement-based plasters may remain (if they are in good condition). Certain (especially cement-based) plasters may partially block capillary and vapour transport, which can be advantageous or not.

Case 3 Mould growth on the inside of a building

Visible red, brown, yellow, white, green or black spots, possibly behind wallpaper or coverings. In general, in surfaces in contact with the outside or ground. Typical musty odour of "wet earth".



Mould due to thermal bridges (window opening and ceiling connection)

Mould due to low surface temperature in corner of a non-insulated wall

EXAMINATION
Visual inspection, moisture measurement of the wall, analysis of the type of mould, monitoring the building's indoor climate, measuring surface temperature (e.g. IR-camera)

POSSIBLE CAUSES
Mould growth typically happens on surfaces with an increased humidity:
- An underlying humidity problem (rising damp, rainwater infiltration, leaks of gutters or rainwater pipes)
- Increased relative humidity in the air (high moisture production / insufficient ventilation)
- Thermal bridges (locally lower surface temperatures and thus higher relative humidity)

POSSIBLE SOLUTIONS
- Find and resolve the cause for humidity
- Improve the inner climate (decrease moisture production, increase ventilation)
- Improve thermal bridges, usually by adding insulation. A good design is necessary, because in some cases, the situation might become worse after adding insulation

REMARKS
Mould can pose a serious threat to health and should be avoided in buildings. The removal of mould and contaminated materials can be dangerous. In serious cases, a specialist company should be contacted as mould-contaminated dust can also affect people's health. In exceptional cases of water infiltrations (generally not by thermal bridges or high indoor air relative humidity), dry rot or similar wood decomposing fungi may infest wood. In this case, experts must be consulted.

Case 4 Algae/bacteria/mould/moss growth on outer surface

Visible covering of external surfaces in different colours (black, grey, green or red)

Green algae growth

Bacteria growth above window lintels

Algae and moss growth due to a defect external downpipe

EXAMINATION

Examination of build-up and properties of its products, moisture measurement of the wall internally, general humidity diagnostics

POSSIBLE CAUSES

High, longer lasting moisture on the outer surface, mostly on north facing facades or caused by rain, condensation, leaks, or other humidity sources.
The architecture of the building and its orientation plays a key role in this kind of degradation.

POSSIBLE SOLUTIONS

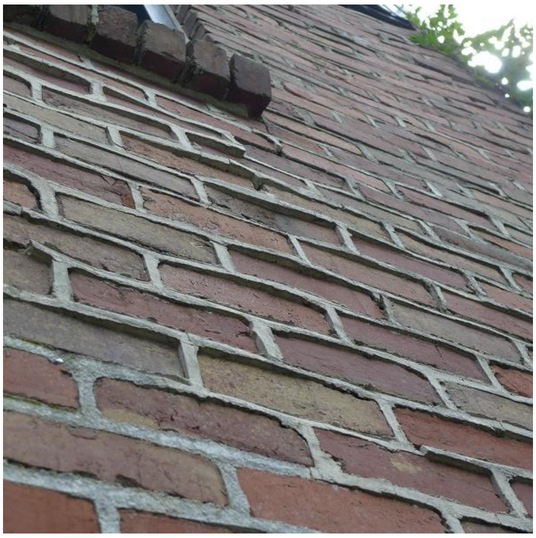
- Reduce the humidity load (humidity due to leaks or rising damp, or by an insufficient detailing of window sills, gutters or cornices, or other humidity sources)
- Sometimes, reducing humidity load is not possible (for instance condensation on the exterior face of the wall by its natural cooling during the night). In such cases it may be a solution to apply a preventive biocide solution, even though this has environmental consequences. Regular application of certain enzymatic solutions may be beneficial.
- In some cases, it helps to apply a new render with low water absorption. It temporarily reduces the moisture at the surface due to its moisture and heat retaining properties.

REMARKS

If these organisms grow due to an abnormal humidity load on the facades, these humidity problems should be solved, otherwise the application of internal thermal insulation is not recommended. In many cases organisms just grow on facades due to condensation phenomena on the outer façade, which is compatible with the application of inner thermal insulation.

Case 5 Pushing out of mortar joints

The pointing mortar is pushed out of the masonry.



EXAMINATION
Analysis of the bedding mortar, humidity diagnostics

POSSIBLE CAUSES

- The repointing was not deep enough.
- The new pointing mortar blocks the drying of the masonry, causing it to get wetter. When the underlying bedding mortar is frost sensitive, it might freeze, swell, and push out the pointing mortar. In that case the bedding mortar shows a specific crack pattern.

POSSIBLE SOLUTIONS
Restoration of the pointing mortar, considering:

- The depth (minimal 1 cm, and ideally at least 1 - 1.5 times the height of the joint)
- Use a mortar that is durable, but does not block the drying of the masonry
- Compatibility between bedding and pointing mortar is required, especially in the case of historic buildings.
- Any underlying humidity problem should be resolved as much as possible.

REMARKS
Finding a compatible pointing mortar is not always easy: it should be compatible with the bedding mortar (this might require a laboratory analysis) and should not block the drying. In most cases it is possible to restore masonry such that the drying out becomes more efficient, thus enabling the application of inner thermal insulation.

Case 6 Degradation (powdering/flaking) of mortar joints

Degradation of the pointing mortar, due to salts, frost, gypsum formation, or other sources (including birds, insects, ...), and combinations of these phenomena.

EXAMINATION

Analysis of salt content, humidity diagnostics, in some cases an analysis of the mortar itself

POSSIBLE CAUSES

- Moisture and frost impact on mortar (especially when not having ideal compositions)
- Salt degradation (with or without moisture)
- Gypsum formation due to acid rain, decaying the mortar underneath the gypsum crust
- Washing out of binder
- In rare cases degradation caused by insects or birds

POSSIBLE SOLUTIONS

Restoration of the pointing mortar, considering:

- The depth (minimal 1 cm, and ideally at least 1 - 1.5 times the height of the joint)
- Use a mortar that is durable, but does not block the drying of the masonry
- Any underlying humidity problem should be resolved as much as possible
- In case of high salt concentrations, the salt should be removed, even though this is not evident. It is advisable to schedule regular maintenance, as degradation may re-occur.

REMARKS

Finding a compatible pointing mortar is not always easy: it should be compatible with the bedding mortar (this might require a laboratory analysis). When the masonry can be restored with a durable mortar, one can consider the application of an inner thermal insulation.

Case 7 Degradation (powdering, flaking) of bricks or natural stones

Degradation due to salts, frost, gypsum formation or other sources (including birds, insects, ...), and combinations.

Degradation of natural stone at a wall base, due to wetting and frost.

Degradation of bricks, due to abnormal wetting (the capstone is not designed well) and frost.

EXAMINATION

Analysis of salt content, humidity diagnostics

POSSIBLE CAUSES

Action of frost, salts, gypsum formation, certain insects, moss, ... This degradation usually only takes place in the presence of moisture and possible other moisture-enhancing materials (for instance an old masonry that has been repointed using a cement-based mortar)

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved as much as possible (splash water, rising damp etc.)
- Restoration of the building materials, keeping in mind the compatibility between new building materials and older materials (ideally comparable mechanical, absorption and drying properties)

REMARKS

- Often laboratory research is required to find out what kind of material has been employed, and what kind of material could replace it.
- When dealing with materials that are frost-sensitive, the application of internal thermal insulation should be avoided, even when humidity sources have been taken away.

Case 8 Damage to protective finishing layers

Degradation of finishing layers due to salts, frost, gypsum formation, UV-weathering, or other degradation mechanisms.

Damage, due to frost, of external render, following the abnormal wetting of the plaster because of a blocked gutter.

Damage to an exterior render, mainly due to salt crystallisation. The differences in porosity and pore size distribution between render, mortar and bricks give this specific damage pattern.

EXAMINATION

Analysis of salt content, humidity diagnostics, analysis of render or paint

POSSIBLE CAUSES

- Action of frost, salts, gypsum formation, sun, certain insects, moss, …
- The degradation may be enhanced if the protective layers themselves are vapour-tight (infiltrated water cannot dry out and increases humidity level in underlying masonry).

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved as much as possible
- Restoration of the building materials
- When the finishing layers are water vapour-tight, it is advised to remove them completely and replace them with a more vapour-permeable layer

REMARKS

- Often laboratory research is required to find out what kind of material has been employed, and what kind of material could replace it.
- Interior thermal insulation is not recommended when the outer finishing layers are vapour tight: layers that are more permeable to vapour transport may also protect the wall from rain while not significantly reducing its drying potential.

Case 9 Expulsion of surface layers of building materials

Surface layers of materials detach, such as salt glazes, normal glazes, or water repellent layers.

Loss of surface layer because of the application of a water repellent agent on a damp and salt-loaden wall

Loss of salt glaze because of frost of the damp material behind the dense finishing layer

EXAMINATION

Analysis of salt content, humidity diagnostics, testing of hydrophobicity of the surface

POSSIBLE CAUSES

- Since no drying out is possible through the dense surface layers, the bricks can become more moist if water penetrates laterally via the mortar or cracks
- Degradation mostly through the action of frost or salts, combined with an underlying humidity problem.

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved as much as possible
- Restoration of the building materials

REMARKS

- The surface layer has a protective function. When damaged, moisture might penetrate in the material and increase the damage
- In case of excessive damage, replacing damaged materials might be unpractical, expensive and (e.g. in case of heritage buildings) not desired. In such cases, the problem cannot be stopped, but may be slowed down when humidity sources are taken away
- Technically, it may prove useful to remove the vapour-tight surface of the entire wall surface evenly by abrasive means. In most cases, this measure will not be accepted due to the historical value of the façade.
- If the surface layer is vapour-tight (e.g. glazed bricks), internal insulation could prove risky, even after restoration of the masonry

Case 10 Degradation of materials due to salts

Humidity stains or salt crystallisation at the interior or exterior surface. Damage might occur in case of crystallisation in the material pores (crypto-efflorescence).

Hygroscopic moisture
due to hygroscopic salts

Salt efflorescence
due to the drying out of a wall

EXAMINATION

Analysis of salt content, humidity diagnostics

POSSIBLE CAUSES

- Damp spots caused by water absorbed by hygroscopic salts
- Salt crystallisation or crypto-efflorescence when a dissolved salt solution dries out

POSSIBLE SOLUTIONS

- Solve humidity problems: they intensify salt problems and might be the source for more salts in the masonry (for instance due to rising damp, or driving rain near the coast).
- Stop all other salt sources (for instance protection of wall base against de-icing salts).
- Remove the salts in some cases (even though no general solution exists yet)
- Apply a membrane so that salts cannot reach plasters or paints on the inside of the wall. As this will eliminate the drying potential, it is essential to remove all humidity sources.
- Apply salt buffering plasters. They might need maintenance or even replacement after some time (depending on product and substrate 5-25 years).
- Control the relative humidity inside the building, so that the salts always remain in the same state. For residential buildings this turns out to be difficult and expensive.

REMARKS

The application of interior insulation is in principle compatible with salts in the masonry: it will not significantly worsen the salt damage. If the insulation is capillary non-absorbent, has no direct contact with the wall or is designed for salt loads, it can even be advantageous, as salt efflorescence on the inside is no longer possible.

Group 2 Pathologies that may influence the presence of moisture in walls

The second group of damage examples is about pathologies that may influence the presence of moisture in walls. These pathologies may or may not be caused by humidity, but their presence definitely has a negative impact on the humidity in the wall. These pathologies should therefore be treated in order to be able to apply interior thermal insulation.

The following cases are discussed:

- Statically or thermally induced cracks
- Cracks in materials (not statically induced)
- Defect external gutters or downpipes
- Defect internal gutters or downpipes
- Degradation of protection materials near the wall base
- Influence of degraded bricks, stones or mortars
- Influence of degraded finishing layers
- Influence of degraded joints between masonry and window frames or doors

Case 11 Statically or thermally induced cracks

Clearly distinguishable cracks (mostly vertical or diagonal, sometimes horizontal), throughout the entire masonry, often near corners of a building, on long facades, near corners of façade openings. They extend over larger surfaces of a façade and are usually not limited to one single material.



EXAMINATION
Determine whether the crack is stabilised, e.g. by non-quantitative follow up of the crack movement (for instance a plaster 'witness'). The services of an engineer is recommended.

POSSIBLE CAUSES
Movement of the building, due to insufficient foundations, a too large building without (or not enough) thermal dilatation joints, an incident that happened in the past, recent works near the building, drying out of the soil, ...

POSSIBLE SOLUTIONS
- If possible and necessary, solve the cause of the crack (e.g. stabilise the building)
- When the crack is stabilised: repair the masonry
- When the crack is still active (e.g. seasonal/thermal movements): durable repair is difficult as the crack will likely reopen after repair. Hence, on rain-exposed facades, it is impossible to eliminate rainwater infiltration, except when a new façade cladding is applied.

REMARKS
- Cracks may be old, and do not necessarily indicate an existing stability problem.
- In cases with severe problems, it might be financially beneficial to demolish and reconstruct (a part of) the building. This is of course no option for heritage buildings.
- Facades with active cracks will not be sufficient watertight. The application of interior insulation might be problematic, unless the crack occurs on parts of facades that are protected or not exposed to driving rain.

Case 12 Cracks in materials (not statically induced)

Cracking of materials due to degradation, or cracks that are inherent to the material (often the case with bricks or cement-based renders).

EXAMINATION

For renders, it may be beneficial to check the condition of the masonry behind the crack and whether the render still adheres to the masonry.

POSSIBLE CAUSES

- Degradation of all sorts, quite often freeze-thaw cycles.
- Inherent material characteristics (e.g. some types of bricks, natural stones or renders - in the latter case often due to shrinkage). These cracks might increase further degradation (e.g. progressive freeze-thaw damage).

POSSIBLE SOLUTIONS

- Treating of the source of degradation (if possible).
- Replacement of degraded materials, possibly with a better material (under the consideration of the compatibility between new and old building materials).
- Cracks due to material behaviour are difficult to treat: replace the material (e.g. bricks or renders), apply a paint layer (or whitewash) or apply a mechanical protection (cladding).

REMARKS

- Removing all cracked bricks can be costly and may not be allowed for heritage buildings
- Water repellent agents have only limited or no efficiencies on cracked materials. In some cases, the wall may get wetter, and might be subject to increased degradation.
- The application of an interior thermal insulation should be avoided when no durable solution for water infiltration through the cracks can be found or when the cracking is caused by degradation of the materials due to frost

Case 13 Defect external gutters or downpipes

Visible dampness, degraded masonry, or algae growth along a (missing, defective or blocked) rain gutter or downpipe. At the interior surface, damp areas, mould growth and wood deterioration are possible.

Discoloration on a facade under a rain gutter

Algae and washed-out mortar due to missing rainwater pipe

Water running over the façade due to a blockage

EXAMINATION
Examining gutter and downpipe connections, moisture measurement of the wall internally and externally

POSSIBLE CAUSES
Water that normally drains away gets into the wall, due to a damaged gutter or a damaged, missing or blocked downpipe.

POSSIBLE SOLUTIONS

- Repair gutter or downpipe or remove blockage and
- Repair any collateral damage (e.g. washed-out mortar joints)
- Apply drying measures if necessary

REMARKS

- Sometimes damage is only visible on the inside because the sun has dried out the outside
- Frost damage to bricks, mortar and plaster can occur if the damage has lasted more than one winter
- Before applying internal insulation, the damage must be repaired, and the walls must be sufficiently dry.
- If the defect lasts for a long time, the wall may be contaminated with hygroscopic salts. Therefore, after fixing the pipes, salt efflorescence may occur due to the drying out of the wall, and damp spots due to hygroscopic moisture may remain.

Case 14 Defect internal gutters or downpipes

Partly detached wallpaper, stains on internal wall, mould stains, humid wall, mouldy smell.

Damp spot in room, partly detached wallpaper

After removing wall paper visible mould stains

Replaced internal pipe

EXAMINATION

Consult floor plans, moisture measurement of the wall, remove wallpaper if existing, opening wall construction, possibly surface temperature measurement

POSSIBLE CAUSES

Wall is moistened by a defective downpipe

POSSIBLE SOLUTIONS

- Repair downpipe and any collateral damage (damaged wall, floor ...)
- Apply drying measures if necessary

REMARKS

- A good understanding of the building and its installations is necessary, because this moisture source could be mistaken for a damage such as the presence of a thermal bridge (unlikely in the presented case because the window is too far away), too high humidity in room (unlikely in the presented case as the damage is very localised).
- Before applying internal insulation, the damage must be repaired, and the walls must be sufficiently dry.

Case 15 Degradation of protection materials near the wall base

Powdering, flaking, cracking, detaching of materials. Usually, the degradation might become very intense, because of the high moisture and salt-exposure.

EXAMINATION
Analysis of the protective material, analysis of salt content, humidity diagnostics

POSSIBLE CAUSES
Mostly through the impact of frost or salts, combined with an underlying humidity problem, for instance rising damp, splash water or ground is inclined towards wall.

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved (e.g. rising damp)
- Restore the building materials. It might be necessary to use materials with a lower water uptake and higher frost resistance.
- Rainwater drainage at the wall base (e.g. through a gravel bed) may be necessary.
- Apply drying measures at the inside if necessary.

REMARKS

- The wall base requires special attention, as it is highly exposed to moisture and salts. Proper protection from splash water is necessary, as this prevents moisture from penetrating deep into the wall.
- When applying internal insulation, an efficient protection against splash water in good condition is required. The minimal height of a splash protection is 30 cm.

Case 16 Influence of degraded bricks, stones or mortars

Powdering, flaking, cracking, detaching of façade materials.

Degraded limestone due to acid rain

Damaged mortar joints

EXAMINATION
Analysis of salt content, humidity diagnostics

POSSIBLE CAUSES
Mostly through the impact of frost or salts or acid rain, sometimes combined with an underlying humidity problem. Damaged stones become more porous, have irregular surfaces, and therefore absorb more water, thus increasing the degree of humidity problems

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved (e.g. rising damp).
- Restore with compatible materials (sufficiently durable so that the rest of the masonry is not harmed). It might be necessary to use materials with better properties.
- When the quality of the facade materials is insufficient, a protective layer (such as paint, render or even a water repellent product) may have a positive influence.

REMARKS

- When restoring facades in a 'conservating' manner (i.e. conserving and consolidating the present, yet degraded state), the water uptake through the façade may be increased. This may have an influence on the possibility to apply interior thermal insulation.
- As mortar is easier to repair than bricks or stones, it may be appropriate in some cases to use self-sacrificing mortars. In this case, the mortar can absorb a lot of humidity to protect the stones, but may also have a more limited durability. In such cases, maintenance of the mortar joints is of the utmost importance, as mortar joints also protect the façade from rainwater penetration.

Case 17 Influence of degraded finishing layers

Powdering, flaking, detaching, cracking finishing layers (paints or renders). Degraded finishing layers do not protect the facade properly.

Degradation of a mineral paint

Degradation of a vapour-tight paint

EXAMINATION

Knocking on renders (hollow sound), analysis of salt content, humidity diagnostics

POSSIBLE CAUSES

- Finishing layers mainly degrade in similar ways as bricks, stones or mortars, due to frost, salts, acid rain, all related to exposure to humidity.
- For (organic) paints, exposure to UV light may cause degradation.

POSSIBLE SOLUTIONS

- Any underlying humidity problem should be resolved. This may be difficult in the case of degradation due to salts. In this case, frequent maintenance of the finishing layer is required, or another façade protection may be more appropriate.
- For renders, remove all degraded parts and fill the gaps (often all the old render is removed and replaced). The plaster can be reinforced to prevent cracking.
- For paints, usually all loose parts are removed (or all paint is being removed), and the facade is covered with a new layer. The new coating must be compatible with the substrate and any existing old coating (can be checked by competent manufacturers' representatives).
- Removing the old paint or render may be an opportunity to replace a possible vapour tight layer with a more vapour permeable one.

REMARKS

- A vapour permeable finishing layer protects the wall against rainwater penetration and is a positive element when considering interior insulation.
- When the finishing layer is vapour-tight, interior insulation may only be installed after a more detailed investigation (simulation).
- In case of damaged, vapour-tight layers, rainwater can penetrate, but hardly dries out, leading to humidity accumulation in the facade.

Case 18 Influence of degraded joints between masonry and window frames or doors

The flexible joint between window frames and wall is degraded and starts to leak, allowing rainwater to enter, especially in windy weather.

Infiltrations through leaking joints between window and wall

EXAMINATION
Evaluating the flexibility of the joint, checking for cracks between joint and frame/masonry

POSSIBLE CAUSES
Alteration of the joint due to UV radiation or fatigue (due to fluctuations in temperature and dilatation of the window frame). In exceptional cases, birds damage the joint.

POSSIBLE SOLUTIONS
Fully removal of the joint, and replacing it with a new joint, if possible with a material that is more durable and may support higher dimensional dilatation.

REMARKS

- Since significant amounts of moisture can leak through a weathered joint, a regular check of joints is necessary (recommended every 3 years, even though the expected lifespan of a properly executed joint should be much longer).
- Degraded joints can be even more problematic in combination with interior insulation, as infiltrations may no longer be visible from the inside, but accumulate behind the insulation or in the wall. In this case, an inspection of the joint is particularly important as it is the only way to evaluate the risk of rainwater penetration through the joint.

Group 3 Façade elements and architecture that may influence or accentuate humidity problems

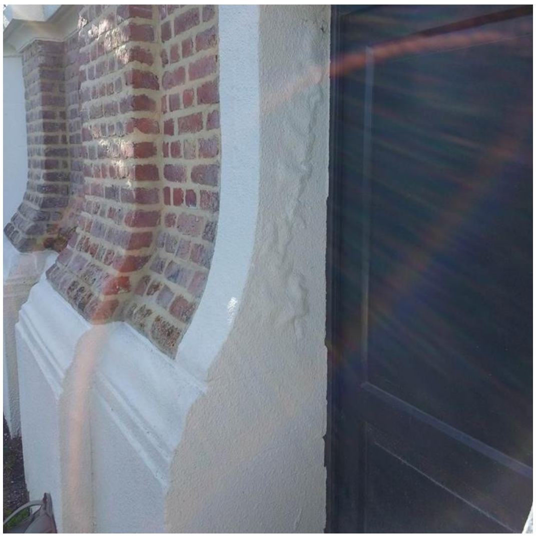
Certain façade features or elements may influence negatively the presence of humidity in walls. It is logic to adapt them when they cause damage. But even if they do not cause damage (yet), it might be possible that interior insulation increases the possibility of damage, as the drying potential typically reduces and the wall gets colder. To prevent this, it is advisable to change or protect these façade elements or details to reduce the risk for future damage.

The following cases are discussed:

- Inclined facades
- Window sills
- Type and form of mortar joints
- Wall covering, cap stones and cornices

Case 19 Inclined facades

Facades may be non-vertical, due to the design or due to deformations, which may lead to increased rainwater penetration in the wall compared to a vertical wall.



Non-vertical lower part of a façade, exposed to falling rainwater

Discolouration of a non-vertical façade due to bacterial growth, caused by rainwater running off a roof without gutter. The bacteria are not the main problem, but a symptom of high rainwater exposure

CONSEQUENCES

- Increased penetrating of rain when the façade is composed of capillary materials. When such façades are clad with dense, non-capillary materials, they provide adequate protection against rainwater.
- Causing enlarged risks to degradation (for facades in capillary materials) and increased growth of bacteria, algae and moss

POSSIBLE SOLUTIONS

- In case of a deformed façade, it must be stabilised after consulting an engineer or architect.
- Increase the rainwater protection, by adjusting the roof or other protective elements, or by adding a non-capillary material or a render.

REMARKS

- Protection of water repellent products is not to be considered as efficient on a non-vertical wall made of masonry of bricks or natural stone. On a non-vertical surface of a massive stone object (without mortars and joints), it may prove to be efficient as long as the pore structure of the material is not too coarse.
- If the amount of penetrating water cannot be reduced, interior insulation is usually not recommended.

Case 20 Window sills

Window sills are supposed to protect the underlying façade against water that runs off windows. Ideally, they are composed of a compact material (no masonry), slope away from the façade, stick out of the façade (> 5 cm), are equipped with a drip underneath, and at both sides equipped with a small upstand. When these requirements are not met, the underlying façade is less protected.

Example of an ideal sill

Water run-off on underlying wall demonstrate less efficient protection of non-ideal sill

Brick window sills protect underlying wall less efficiently

CONSEQUENCE

- In case of a non-ideal window sill, a part of the water that runs off the window will be absorbed by the underlying wall. This may lead to high humidity levels and moisture-related problems as well as water penetration.
- The absence of small upstands at both sides is only slightly negative, as high humidity exposure is only expected where window sill are in contact with the adjacent masonry.

POSSIBLE SOLUTIONS

- Replacement of the entire window sill.
- Application of a thin (metal) sill on top of the existing one. In that case a leak-proof connection of the sill with the window frame is of the utmost importance.
- Application of a small metal sheet with drip underneath the window sill. The metal should be inserted sufficiently deep underneath the sill, and should be robust to withstand vandalism or other mechanical shocks.

REMARKS

- Window sills that do not meet the requirements, but are protected by a balcony, awning or other architectural element, can be acceptable.
- Interior insulation should be limited to cases with good window sills. In case of good protection, favourable orientation (little rain) or favourable façade materials no damages are to be expected.

Case 21 Type or form of mortar joints

Mortar joints protect the façade against rainwater infiltration. Depending on the shape of the joint, this protection may or may not be optimal. The joint that is in level with the surface of the bricks offers the best possible protection as it allows rainwater to run off quickly.

So-called 'shadow-joints' or 'Dudok-joints' offer less protection for infiltration of rainwater, as it has more time to penetrate the brick.

In case of recessed joints, the upper part of the bricks are less protected against rainwater.

CONSEQUENCE

Different types of mortar joints have been used in the past, usually for architectural or aesthetic reasons. Some of them offer a less efficient protection against driving rain, since they allow rainwater to reach a larger area of the surface of a brick, especially where the upper surface of the underlying brick is also exposed to rainwater.

POSSIBLE SOLUTIONS

Removing the old mortar and replacing it with a new one (compatible with the old bedding mortar), filling up completely the joint. Evidently this is often not possible in heritage buildings.

REMARKS

- Completely filled mortar joints or slightly recessed joints are considered to be aesthetically less interesting, resulting in a "boring" flat façade. Furthermore, the replacement of old recessed joints may rise conflicts with heritage values.
- The removal of mortar joints that are in good condition is risky: one may cause severe damage to the bricks, as the mortar sticks to them. If there is no damage, the joints can be left as they are.
- The application of interior thermal insulation is in principle limited to those cases where one can be sure that the mortar joints offer a good protection against driving rain. One should be more careful (e.g. thinner insulation) when the mortar joint is not optimal.
- In the presence of previous damage or increased masonry moisture, interior insulation should only be used after a thorough preliminary investigation (e.g. simulation) and possibly only in a small thickness.

Case 22 Wall covering, cap stones and cornices

Cap stones and cornices are both elements that protect the underlying masonry, when it is not covered by a roof. They are submitted to requirements similar to those of window sills: they should stick out > 5 cm, should be equipped with a drip, and should be composed out of a compact material (such as concrete, dense ceramics, dense natural stones). The joints in between different elements should be well protected, so that no humidity can infiltrate through these joints.

Left: absence of covering gives rise to a serious risk of exceedingly high moisture content in the wall. Middle and right: viable solutions for wall covering.

Cap stone does not stick, providing poor protection. Rainwater on the cap stone is absorbed by the masonry, which degrades.

CONSEQUENCE
When there are no cap stones, or they do not correspond to these requirements, the top of the façades may suffer from high amounts of penetrating rain, as the amount of water that may infiltrate through horizontal or inclined masonry surfaces is large. This may result in rapidly occurring degradation such as frost and biological damage.

POSSIBLE SOLUTIONS

- Apply a wall covering that meets the requirements.
- A metal covering (meeting the same requirements) may be an option when a traditional wall covering is aesthetically unacceptable.

REMARKS

- When there are no cap stones, or they do not correspond to these requirements, the application of interior thermal insulation is not recommended.
- In absence of a wall covering, applying a water repellent (or watertight coating) at the top of the wall is not recommended. It has been observed that in these cases the treatment is not fully efficient, and the excess of water still runs off and penetrates the wall.

Group 4 Façade materials that may influence or accentuate humidity problems

Each material has different properties regarding water uptake and drying properties. Depending on the application of certain materials in facades, the water uptake may be large or small, and drying may be optimal or very limited. Especially the drying properties of façades are very important, as they allow an optimal evacuation of humidity in the masonry.
The presence of some façade materials may limit the application of internal insulation.

The following cases are discussed:
- Old masonry, repointed with modern dense cement mortars
- Water repellent agents
- Finishing layers: renders, paints, anti-graffiti, bituminous layers (including tar)
- Ceramic tiles, mosaics, other types of stone- or glasslike façade claddings
- Glazed bricks

Case 23 Old masonry, repointed with modern dense mortars

Mortar joints protect the façade against rainwater infiltration, but also help to evacuate moisture in the wall (stones, bricks and bedding mortar) as fast as possible. Therefore, only compatible pointing mortars should be used, allowing a quick moisture transport from the bedding mortar to outside the wall. This is usually obtained by using pointing mortars with similar composition (binder, type of sand and the proportions of binder/sand) as the bedding mortar.

An old masonry, repointed with a mortar with white Portland cement as a binder. The new pointing mortar has been pushed out by frost damage in the older bedding mortar.

CONSEQUENCE

When repointing lime mortars with cement mortars, the old bedding mortar may become more humid. This may result in frost damage of the bedding mortar, subsequently pushing out of the pointing mortar or damaging the stones.

POSSIBLE SOLUTIONS

- When repointing, use a pointing mortar compatible with the old bedding mortar.
- When a dense pointing mortar has been applied, remove and replace it.

REMARKS

- The removal of mortar joints that are in good condition is risky: one may cause severe damage to the bricks, as the mortar sticks to them. This is definitely true for contemporary mortars, as they adhere well to bricks and natural stone.
- In the past, many different binders have been used in mortars. Usually, porosity and capillary water uptake decreases with increasing hydraulicity. For example, when a masonry has bedding mortars with very hydraulic lime, the requirement for an ‘open’ pointing mortar becomes less strict and since the bedding mortars themselves are already quite dense.
- The application of interior thermal insulation is in principle limited to those cases where one can be sure that the mortar joints offer a good drying capacity to the wall.

Case 24 Water repellent agents

Water repellent agents reduce the capillary water uptake. To obtain a good protection, a good product (compatible with the type of substrate) should be applied in the correct way under the right circumstances. Moreover, the substrate should be in good condition, showing not too many cracks, and free of excess salts.


Visual indication of the presence of a water repellent agent:
the surface cannot be wetted, water that runs off the façade forms fine runoffs or droplets.

GENERAL PROPERTIES

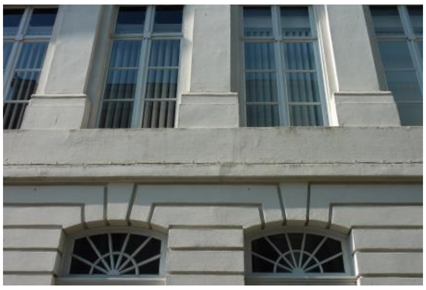
- Water repellent agents reduce the capillary uptake of the masonry and should not significantly lower the water vapour permeability of materials.
- Water repellents change slightly to drastically the drying speed of a material, depending on the type of product and the type of material on which it is applied. However, usually, the masonry will after treatment still be drier, as its water uptake is (drastically) reduced.

REMARKS

- Solve other humidity sources (e.g. rising damp) before applying water repellents.
- Water repellent treatment on damaged masonry or masonry with (too many) cracks is not recommended. Even after treatment, they often suffer from water infiltration. Due to a not sufficient drying speed, the masonry can become wetter after the treatment.
- If a water repellent treatment is applicable, it has a very positive impact when considering interior insulation, as it significantly lowers the moisture levels of the wall.
- The durability of water repellents can be excellent (several decades or longer on brick masonry) or poor (e.g. on limestones with coarse pore structure). In the latter case, periodical re-treatments are necessary; this can be evaluated by Karsten-tube measurements.
- Water repellents are irreversible. When it turns out a water repellent product causes damage, a very thorough restoration of the façade materials or other (more drastic) finishing layers (paints, renders, a mechanical protection) are necessary.
- A slightly higher moisture content of the masonry is not necessarily a problem if the masonry is sufficiently frost-resistant and if this doesn’t affect the interior of the building.
- Products in the form of a cream have a much larger influence on the drying speed of a substrate. Use them preferably only on dense materials (such as concrete, marbles, granites ...) but not on capillary materials (normal brickwork, porous natural stones).

Case 25 Finishing layers: renders, paints, anti-graffiti, bituminous layers (including tar)

Renders and paints reduce the water infiltration in facades by sealing cracks and making the façade more regular (enhancing a more efficient run-off of rainwater). Old renders (before the middle of the 19th century) were lime-based. Starting from the middle of the 19th century, cement took gradually over, resulting in sometimes very hard and durable renders, that however are more vapour-tight and sometimes show clear (shrinkage) cracks.



GENERAL PROPERTIES

The finishing layer should limit water infiltration and not reduce the drying speed too much, as it is always possible that some moisture gets behind the finishing layer. In case of a vapour-tight layer, moisture can hardly escape and accumulates behind the layer and causes damage.

- Siloxane paints, silicate paints, limewash, … have excellent water vapour properties
- Cement-based renders are rather vapour-tight. Lime-based plasters are more vapour-permeable, which increases as the binder's hydraulic capacity decreases.
- Anti-graffiti products have water vapour permeabilities that range between good to extremely low (for instance polyurethane anti-graffiti coatings).
- Bituminous finishes are almost entirely impermeable for water vapour.

REMARKS

- A vapour-tight material that does not cause any damage can stay in place.
- Thermal insulation should be avoided with a vapour-tight finishing layer. Ideally, the layer is removed and replaced by a vapour-permeable one. If this is not possible, a insulation layer of moderate thickness that allows drying towards the interior of the building could be applied after careful examination (e.g. by simulation).
- Most finishing layers have a limited durability. After some ageing, cracks may occur, making water infiltration in the façade possible.
- Cement-based renders are prone to cracking due to shrinkage during hardening. Water tightness can be improved by adding an extra layer of render or by coating the surface.
- For paints, both the layer thickness and number of layers play a role (multiple layers are less vapour permeable than only one layer). As walls will probably be repainted after some time, it is better to apply vapour-permeable paints, especially when the moisture content of the wall should remain limited.
- Removing (permanent) anti-graffiti or bituminous products may be very difficult. Even after a complete removal, reduced water vapour transport has been observed due to residue of these products that are locked in the pores and cannot be removed.

Case 26 Ceramic tiles, mosaics, other types of stone- or glasslike façade claddings

Several types of thin façade claddings, such as natural stone plates, ceramic tiles, or mosaics, are applied with mortar to a façade. They are waterproof but at the same time also tend to be too vapour-tight: due to the material itself, but also due to the (in most cases) rather vapour-tight cement-based mortar.

Glazed ceramic tiles
(supposed to imitate glazed brickwork)

Decorative ceramic glazed wall tiles, partially fallen off (probably due to water infiltration and lack of drying, combined with frost damage)

CONSEQUENCE

Walls with façade claddings cannot easily dry out. Moreover, they are usually not completely watertight, as the (often very fine) joints between the tiles or stone slabs, or the fine joints in mosaics, often show microcracks, through which rainwater may infiltrate. Making these fine joints between tiles or natural stone slabs completely watertight is almost impossible.

POSSIBLE SOLUTIONS

- Removing the façade cladding and replacing it with a cladding that allows efficient drying (often not desired, as these claddings are decorative and may have heritage value).
- Improving drying out of the wall towards the inside of the building.

REMARKS

- The application of internal insulation with such façade claddings is not recommended. Limiting the thickness and use of capillary active materials may in some cases be possible.
- When there is an air layer between the façade cladding (typically the case with some claddings with large panels of natural stone or concrete) and the underlying wall, ventilation of this air layer should be ensured, thus significantly improving the drying capacity of the wall. Internal insulation may be possible in such cases.

Case 27 Glazed bricks

Glazed bricks are almost completely vapour-tight. Since the second half of the 19th century, very shiny glazed bricks with bright colours are used, usually as an aesthetic detail but sometimes for entire facades. In the 1930s, bricks with a more subtle glazing and a dense and flat surface, but not shiny (and therefore less easy to recognize) were produced and largely applied. Sometimes this thin glazing can be recognized because it is flaking off.

Flaking off of the glazed surface (~1930s)

Glazed bricks (~1960s) degrading due to frost and limited drying potential of the masonry

Glazed bricks (early 20th century); masonry can still dry out through the joints in between the bricks

CONSEQUENCE

Glazed bricks are vapour-tight, so the drying potential depends on type and size of mortar joints:

- Older facades (< 1930) usually have large lime mortar joints, allowing a considerable drying out. Especially when glazed bricks are used as an aesthetic detail and not on the entire façade, the drying out of the façade is unlikely to be significantly slowed down.
- More recent facades (starting from 1930) mostly have cement-based mortar joints, not allowing an efficient drying out of the façade. In combination with the vapour-tight glazed tiles, such facades have on the long term a higher risk of moisture and frost damage.
- Façades with very thin mortar joints (≤ 1 mm) have a very small drying potential.

POSSIBLE SOLUTIONS

- Repair the façade in case of damage
- Decrease the risk of water infiltration, e.g. replacing recessed mortar joints by a completely filled one (this has however a drastic aesthetic impact)

REMARKS

- For older facades (< 1930), the application of internal insulation is usually possible, because one may count on drying potential through the mortar.
- For more recent facades (> 1930), internal insulation is risky. It should not be applied if the masonry shows pathologies. If there is no damage, capillary active insulation with moderate thickness may be considered, enabling the wall to dry out to the interior.

A 2 Notes on the application of the measurement methods

A 2.1 Capacitive humidity measurement

Capacitive measuring devices enable non-destructive moisture measurements in areas close to the surface (up to 4 cm material depth). The devices emit a measuring pulse into the material. The reflection of the pulse is dependent on the moisture content and is measured. The method is suitable for mineral building materials and wood and displays the difference between the dry and the moist building material. Dissolved salts can cause the building material to become an electrolytic conductor, which can result in higher values. Metals also falsify the measurements. This method is well suited for comparative measurements to detect differences between wet and dry areas but is considered unsuitable for qualified moisture measurements. Another serious drawback is that it is limited to near-surface areas. As the method is non-destructive and there are some falsifying factors it is advisable to measure at many positions.

Fig. 19 Measuring instruments for capacitive humidity measurement (left: www.gann.de, right: www. ahlborn.com)

A 2.2 Resistance moisture measurement

Resistance measurements are *nearly* non-destructive. Here, a current is passed through the material to be measured by means of two electrodes which are rammed or drilled into the material. The electrical resistance/conductivity between the electrodes is recorded. The measured resistance is subsequently converted into a corresponding material moisture via transfer curves stored in the device.

With this measuring method, the moisture content can be measured on the surface of the material, but also with appropriate, long electrodes in deeper layers of the building component. The displayed measurement results can be converted into moisture percentages taking into account different building materials. Falsifications of the measurement results are also possible here due to uneven moisture distribution and inhomogeneities in the material, due to other conductive materials in the wall, e.g. cables, pipes or plaster rails as well as salts, surface treatments or poor contact of the electrodes with the material.
There is good, long-standing experience with wood and wood-based materials. Here, it is important to ensure that the type of wood and temperature can be taken into account. Multiple measurements allow a better assessment of the individual measurements.

Fig. 20 Resistance moisture meters (left: testo.com, right: www. trotec.de)

A 2.3 Microwave moisture measurement

This measuring method is also non-destructive. An electrical pulse is emitted into the material and the reflection is evaluated. By using different applicators, various measuring depths can be realized, from near-surface up to a penetration depth of 80 cm. This facilitates the identification of the moisture source. Due to the measuring principle with high power, this method is practically independent of salt, metals still affect the measurements. Devices, that use this method, are quite expensive and therefore not common.

Fig. 21 Microwave moisture meter with different measuring heads (hf-sensor.de)

A 2.4 CM-method (Calciumcarbid method)

This chemical measuring procedure requires only small amounts of material (5 to 20 g) and is suitable for mineral building materials. These are removed, weighed moist, pre-crushed with a mortar and then vigorously shaken sufficiently long in a pressure vessel with steel balls and an ampoule of calcium carbide. The water contained in the sample reacts with the calcium carbide with formation of acetylene, whereby the pressure in-creases sharply depending on the amount of water. The measured increase in pressure allows conclusions to be drawn about the water content of the sample. This method is applied directly on site. The accuracy of approx. ± 3% is sufficient exact for practical building requirements.

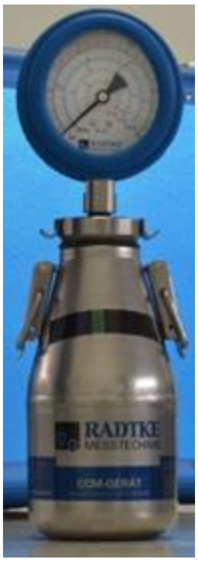


Fig. 22 CM measuring device for humidity measurement (radtke-messtechnik.com)

A 2.5 Gravimetric method

In this classic, destructive method, material samples are taken from the construction, weighed on site in a moist state, packed airtight and dried in the laboratory in a drying oven until the mass is constant. The dry material is then weighed again. The difference in mass between the moist and dried material sample represents the exact water content. This method is an internationally standardized moisture measurement method, requires no calibration and can be used to calibrate other methods due to its accuracy (± 0.5%).

To avoid excessive heating of the specimen, when taking drill cores the drilling time should be kept as short as possible and should be carried out at low rotation, as water can evaporate from the sample. It is also favourable to take larger samples instead of cores with a small diameter. If it is possible to take whole bricks from the façade stretcher are easier to extract than header. Positions where later wall openings are to be made during further renovation are preferable for removal. At the same time, useful information is obtained on the mortar condition and the moisture status behind the brick. Whole bricks are easier to replace in a façade than part of bricks. Often, bricks from the outside differ from stones inside the wall. The outer stones are more important due to the contact with the external climate.

A 2.6 Spray test

The simplest but very subjective method for an approximate impression of the water penetration behaviour is to wet the facade, e.g. with a spray bottle. Herewith it is possible to generally determine whether the facade is highly absorbent or water-repellent and whether there are bigger differences in the different facade orientations or certain areas. This method is useful as a first, very superficial assessment.

Fig. 23 Wetting test on a natural stone façade

A 2.7 Indicator tubes

A simple, proven method for on-site measurement of the capillary water absorption of building materials and components is the measurement with water penetration test tubes, for instance indicator tubes by Dr. Karsten or by Dr. Pleyer. These methods are suitable for the rough assessment of facades.

Fig. 24 Test tubes according to Dr. Karsten, placed on a brick

The water penetration tester is applied to the test surface using putty. After the controlled filling of water into the test tube, the amount of water absorbed is documented at certain intervals. The evaluation of the measuring curve for conversion into a rough water absorption coefficient is carried out with a corresponding evaluation scheme and depending on the suction surface. Due to the small cross-sectional dimensions of the tube, the strong edge influence and other influences, only very limited statements can be made, especially for brick facades with joint proportions. The water absorption coefficient derived from the measurements can be used to estimate the transport of liquid water in a material.
A file is available on the Internet to assist in logging the experiment and calculating the A-value [6]. The basics for this tool are explained in [7].

A 2.8 Testing plates

This measuring set-up is a further development of the indicator tubes above, the measuring principle is the same. The larger measuring surface reduces the deviation and it is possible to measure the joint and the stone at the same time in a masonry. Here too, the test plate is applied

to the test surface using putty. The amount of water absorbed and the corresponding point in time are documented at certain intervals in order to be able to derive a rough water absorption coefficient from the measurement curve.
Due to the larger wetting surface with a rectangular structure in the size of a standard brick format brick plus butt and bed joint (25 x 8.3 cm), the entire system of brick and joint can be measured here.
As well, with this method a multi-dimensional fluid transport with hydrostatic pressure takes place, resulting in higher values. Due to the larger test area, the edge effects are less pronounced here than with the indicator tubes. On the other side it is more often very demanding to seal the test area of uneven surfaces with putty.

Fig. 25 Testing plate according to Franke, detection of water content in brick and joint

A 2.9 Water absorption measuring device

The exact measurement of the water absorption of a façade is only possible with much more complex and costly devices. With the device shown in Fig. 26, the wetting area is 30 x 40 cm. Thus, the water absorption of several brick and joint layers of a brick facade is measured. The test area is exposed to a pressureless water film which is generated by a constant, closed water circuit. The measuring principle is based on the fact that the decrease of the water quantity is determined gravimetrically. Depending on how absorbent a facade surface is, more or less water is withdrawn from the water circuit during the test. This enables an accurate, non-destructive measurement, apart from some screw holes. The influence of multi-dimensional transport is less significant due to the larger test area and is taken into account in the calculation. The accuracy of this procedure is very high.

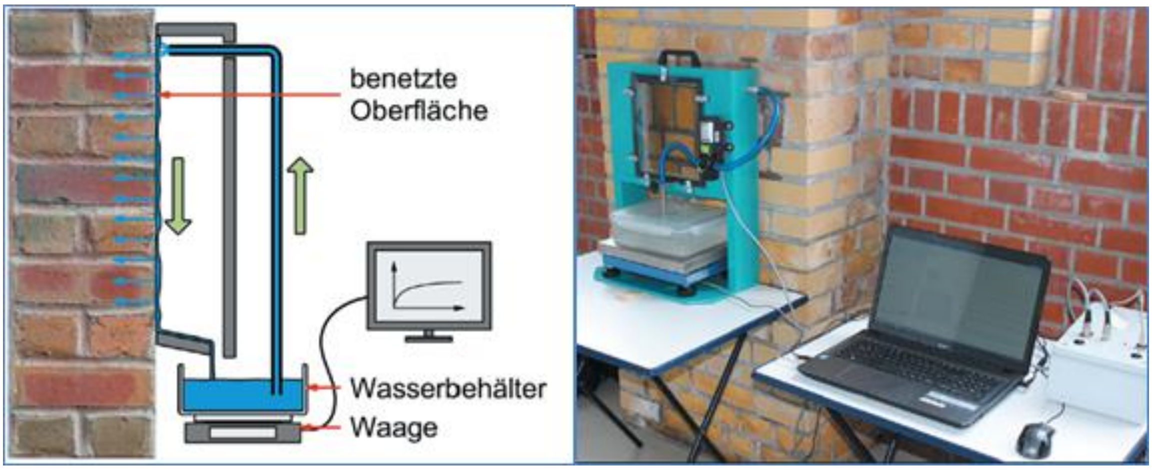


Fig. 26 Water absorption measuring device, measuring principle and practical application [hf-sensor.de]

A 3 Equipment and preparation for an inspection

Prior to an inspection, accessibility to the building or parts of the building and certain areas must first be ensured. This may require: keys (or a responsible persons), the removal of vegetation, a cherry picker, scaffolding or a ladder.

If electricity and, if necessary, water must be available, this must also be clarified in advance. A generator and water canister can otherwise help.

Furthermore, it is often necessary to wear protective clothing on site visits. This may include safety shoes, trousers, gloves, goggles, helmet and hearing protection.

Apart from that, the following equipment should be taken along as required:

Lighting: torch, headlamp, construction site spotlight (batteries charged?)

Distance measuring devices: metre rule, tape measure, laser distance meter

Analysis: Endoscope (with drill), scale, spirit level, angle mirror, magnifying glass, crack ruler, surface/temperature measuring device, air humidity measuring device, material moisture meter

Moisture measuring devices: spray bottle, test tube/test plate (with sufficient putty), CM device

Sampling: (Sealable) plastic bags for specimens, chisel/handle, hammer, core hole/drill, (cordless) hammer drill, tenon cutter, disk drill

Documentation: pens (pencil/permanent pen), chalk, paper, printed plans (if available), A3 field frame/chart, camera/smartphone, laptop/pad

Cleanliness: hand brush, shovel, cloth, soap, bucket, broom, towel

Other: (charged) spare batteries and chargers for all equipment, extension cable/distribution box, rope, fabric tape, (rechargeable) screwdriver, crow bar, knife, warm clothing (winter), sun protection (summer), food and drink

Flowchart

A 4 Glossary

Endoscopy
With the help of endoscopy, the inside of constructions can be examined with minimally invasive effort. For this purpose, a hole is drilled into a construction where the lens can be inserted. The lens can be attached to a rigid or flexible rod or tube. The information from the lens is displayed on a screen and can be stored. For the construction sector, lenses with a diameter of less than 10 mm exist.

Water vapour diffusion resistance coefficient (µ-value)
At low relative humidity, moisture transport in the pores of materials takes place almost exclusively in the form of water vapour. Only at higher humidities from approx. 80 % onwards there is a significant parallel transport of liquid water, which dominates from approx. 95 % onwards. The water vapour diffusion resistance factor (also µ-value) of a building material is a dimensionless material parameter. It indicates the factor by which the material in question is more impermeable to water vapour transport than a layer of static air of the same thickness. Mineral wool, for example, has a µ-value between 1 and 2 and thus conducts water vapour similarly to a static layer of air. For solid old bricks, the range is quite big: it starts at about 8, but can often reach 40 and (much) more.

Water absorption coefficient
At high relative humidity above 95 %, practically all moisture transport takes place in the liquid phase. This is the case when a wall is in groundwater or is temporarily more strongly moistened by driving rain. The water absorption coefficient or water uptake coefficient A or A_{cap} characterises the property of a largely dry building material to absorb water from the surface and to transport it into deeper pore spaces. The water absorption coefficient also changes depending on the water content in the pore space. It is usually given in $kg/(m^2s^{0.5})$, or $kg/(m^2h^{0.5})$.

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Flow chart inventory