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Fraunhofer Institute for Building Physics IBP

Whitepaper

Water damage on buildings

New efficient drying methods

www.ibp.fraunhofer.de/en/expertise/hygrothermics/climate-simulation-field-studies/technical-drying.html

Background

Damage to buildings is usually caused by water or moisture. The causes can be manifold: 1.1 million insured cases of damage caused by mains water per year alongside damages due to construction moisture or inadequate measures to protect against moisture. Heavy rain, flooding, condensation, rising damp in walls are further causes of damage to technical installations, e.g. heating, ventilation, power supply, or to furniture, machinery and manufacturing equipment. Sometimes even people and animals are affected. Consequential damage can be, for example, hidden mold growth, frost damage, structural problems, unpleasant odors, or restrictions of use.

According to the GDV (Gesamtverband der Deutschen Versicherungswirtschaft - German Insurance Association), damage caused by mains water alone amounted to an average of around 3,000 euros in 2020. With 1.1 million claims per year, this amounts to a total of 3.3 billion euros. Of this, more than 1 billion euros is spent annually on technical drying, with estimated proportional electricity costs of 200 to 400 million euros.

Damage caused by mains water occurs both in older buildings and in new buildings shortly after construction has been completed. Drying and renovation measures tend to be more expensive in newer buildings, because of their more complex features such as multi-layered wall and floor constructions, air and vapor control layers, waterproofing and underfloor heating. For this reason, costs for professionally drying and restoring buildings after water damage are expected to continue to rise in the future.

Professional drying is essential to repair direct damage caused by water and to minimize consequential damage. The following applies: the faster professional drying is started, the lower the consequential damage and the restoration costs.

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Fraunhofer IBP has conducted many experimental and computational studies on repairing damage due to mains water and has tested the effectiveness of various typical drying techniques on artificially soaked wall, ceiling and floor constructions. Adsorption dryers, condensation dryers, turbines, foil tents and heat panels were used in the test series.

The results confirmed the effectiveness of the drying techniques used.

Reference cases showed that certain types of water damage also dry naturally - i.e. without technical support - but without the certainty that the initial state will be restored within a reasonable period of time and that consequential damage can be ruled out. Natural drying is highly dependent on the outdoor climate and ventilation possibilities, which makes it very difficult to determine reliable drying times.

The tests showed: in case of water damage, professional drying is highly recommended!

The drying systems used consume a **great deal of energy.** The drying process, which is based on capillary transport and vapor diffusion as well as convection in some cases, cannot be accelerated at will. Whether intermittent operation of the drying equipment reduces energy consumption should therefore be carefully examined.

It was shown that with slightly longer drying times, **significant energy savings** could be achieved during restoration.

Conventional professional drying methods are energy-intensive.

Contents

Drying methods

Indirect drying methods

Natural drying
- Heating and ventilation

Foil tent drying
- Adsorption dryer

Room air drying
- Adsorption dryer
- Condensation dryer

Direct drying methods

Building component drying
- Heating rods and elements
- Lance drying

FastDry
- FastDry™ drying module

Infrared drying
- Infrared radiant heating panels

Microwave drying
- Microwave emitter

Suction and blow-in method for cavity drying
- Adsorption dryer
- Turbines

Energy savings potential in professional drying

1. Evaluation of the various drying methods

Energy consumption was analyzed in more detail by professionally drying a wet wall. Two techniques were used: a foil tent drying system, with adsorption dryers transporting the dried air to the surface of the wall, and infrared drying panels.

The reference value for the measured energy consumption was the evaporation enthalpy (hv = 0.7 kWh/kg) of the water extracted from the wall. This is the heat that must be added to convert the amount of water removed (determined by weighing) into vapor, which is then released into the indoor or outside air. In the case of infra-red drying, the energy consumed in our experiment was about 30 times the evaporation enthalpy of the water, and even 60 times in the case of foil tent drying. It is clear, of course, that more energy is required for the drying process than is theoretically necessary to evaporate the existing water.

Heat losses to the environment and, above all, the energy consumed to heat the masonry to be dried or to pre-dry the room air in the case of foil tent drying lead us to expect a multiple of the pure evaporation enthalpy. However, even taking these aspects into account, the measured energy consumption appears to be far too high. In addition, when comparing foil tent and infrared drying, it was found that the latter not only consumed less energy but was also significantly more effective, i.e., wall drying required only about half the time.

2. Analysis of the efficiency and effectiveness of professional drying

The following considerations make it easier to further analyze the effectiveness and energy saving potential of professional drying measures. A wet component is dried by transferring water vapor from its surface to the surrounding air. The resulting flow of water vapor is proportional to the difference between the partial water vapor pressure on the surface and in the environment, multiplied by the water vapor transfer coefficient (reciprocal of the transfer resistance). The latter depends on the airflow conditions close to the surface. Air blown to the surface can enhance the surface transfer, but at the same time, the cooling of the surface by evaporation reduces the partial vapor pressure.

For a wet surface, the vapor pressure at the surface corresponds to the saturation vapor pressure of the surface temperature. A change in surface temperature therefore results in an exponential change in surface vapor pressure. **As a rule, therefore, an increase in partial vapor pressure difference is more effective as well as easier to implement than an increase in water vapor transfer coefficient.**

In many technical drying processes, the vapor pressure difference between the wet component and its environment is increased by drying the ambient air, thus increasing the drying rate. Room air can be dried using condensation dryers or adsorption dryers. Under normal room climate conditions, a maximum reduction in room air humidity to 30 percent (condensation drying) or approx. 10 to 15 percent relative humidity (adsorption drying) can thus be achieved.

Another way to increase the vapor pressure difference is to heat the wet component. This has the advantage not only of increasing the vapor flow from the surface into the room, but also of improving vapor diffusion within the pore structure of the component. The figure on the right shows the vapor pressure difference between a wet wall surface and the room air, when either no professional drying takes place (black), when the room air is dried with the aid of an adsorption dryer (blue) or when the dried air, which is slightly heated by the adsorption dryer, passes over the wall surface with the aid of a foil tent (green). In comparison, the same figure shows the vapor pressure differences which result when the wall surface is heated to 40°C (orange) and 60°C (red) without additionally drying the room air.

It is evident that heating the building component has a greater effect on the vapor pressure difference than drying the room air. This, of course, also has an impact on the drying rate. However, the question of whether more energy is consumed if drying is speeded up remains unanswered at this point.

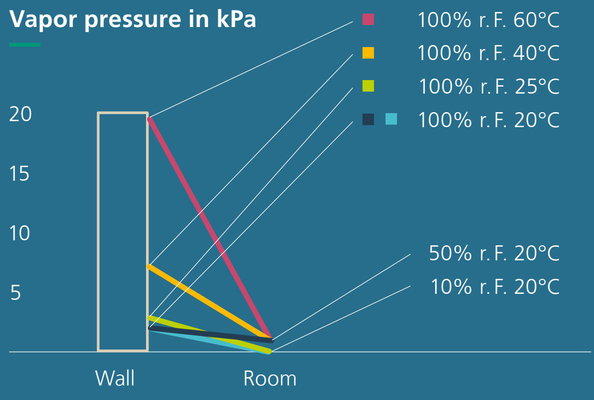
In many technical drying processes, drying the ambient air increases the vapor pressure difference between the wet component and its environment, thus increasing the drying rate.

Increasing the temperature of the component surface has a much greater effect on the drying rate than lowering the humidity of the air.

Partial pressure and difference

Influence of reduction in air humidity and temperature increase on the vapor pressure difference between wet masonry surface and ambient air (measure for drying rate)

Vapor pressure in kPa

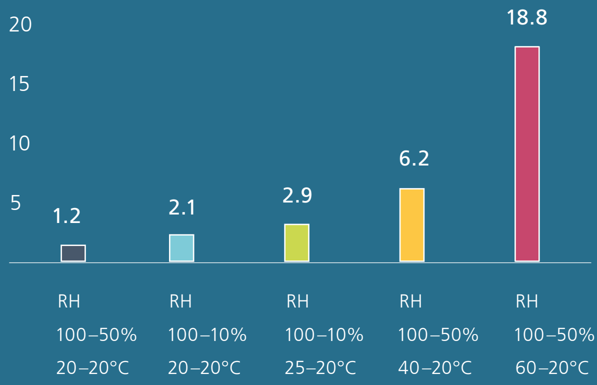


Increase in wall surface temperature

Reduction in air humidity by adsorption drying

Natural drying

Vapor pressure difference in kPa



Differences in relative humidity (RH) and temperature

3. Heating building components vs. drying the room

Fraunhofer IBP took a closer look at the effectiveness and energy efficiency of different professional drying methods (heating building component vs. drying the room) under reallife conditions. For this purpose, the researchers built partition wall elements made of vertically perforated brickwork in a climate chamber (see figure above) and set them under water from below by flooding the chamber floor until the rising damp reached a height of about 60 centimeters through capillary suction. They then started to dry the wall elements, using either a foil tent with an adsorption dryer or an infrared heating panel. The heating panel was placed at a typical distance of about 10 centimeters in front of the wet wall and the heating temperature was set so that the wall surface reached a temperature of about 50°C. As an alternative to the infrared heating panel, a new type of thermally insulated heating panel was used for drying in another test. For better comparability, a wall surface temperature of 50°C was also targeted during this drying test.

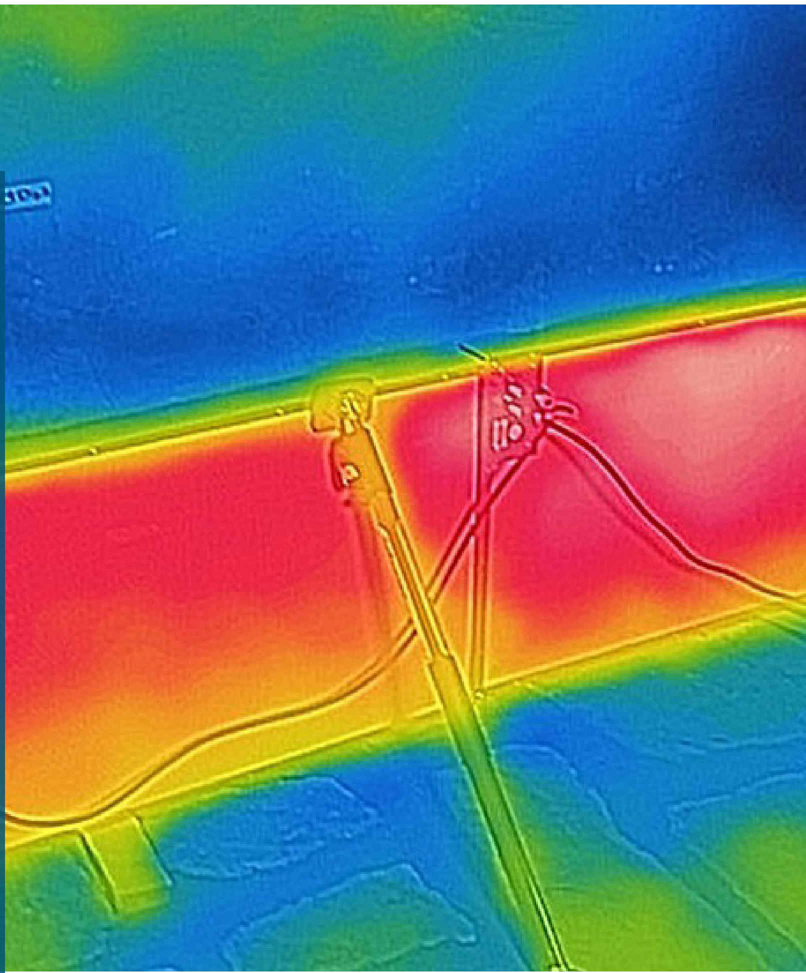
The design of this heating panel is described in more detail in [1]. In principle, it consists of an electric heating wire, which heats the wall surface directly, covered by a layer of thermal insulation which prevents the heat from dissipating into the room. However, in order for the moisture to escape from the wall, the thermal insulation must be sufficiently permeable to vapor.

This ensures that the heat remains in the wall while the moisture dries out unhindered.

The figure on the right shows the drying curves of the wet wall sections determined with the aid of moisture sensors and by weighing. This confirms that the heat-based methods achieve significantly faster drying rates than the foil tent method, which uses dried air. However, while the drying curves of the two heat-based methods are almost identical, the energy consumption shown on the right in the same figure at the bottom differ greatly. In a direct comparison, the heat-insulated drying panel consumes only a fraction of the electrical energy of the other two methods, at 10 percent and 15 percent respectively. This result cannot be transferred 1:1 to similar practical cases or to other conventional drying methods. However, it clearly shows the great energy savings potential that can be achieved through targeted measures to increase energy efficiency. This not only cuts electricity costs, but also allows larger areas to be dried with the same connected electrical power.

Test set-up

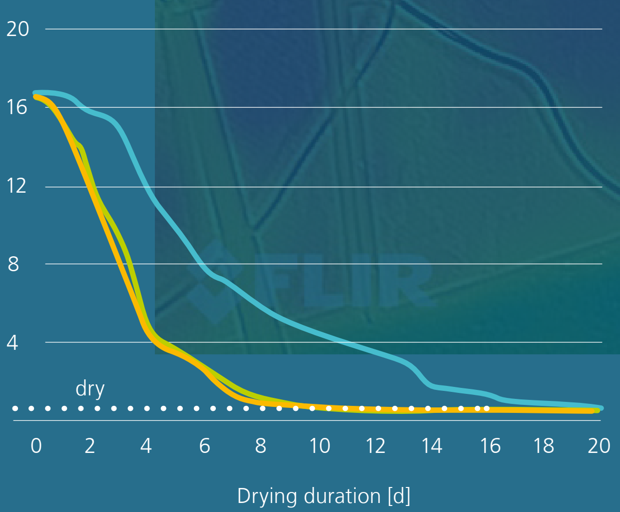
Comparative studies to assess how two brick wall elements, wetted from below, dry out using different drying methods under constant ambient conditions in a climate chamber. The wall elements are equipped with moisture sensors to record the water content distribution. The total water content is measured by weighing. The drying rate and energy consumption of conventional foil tent and infrared plate drying as well as of various prototypes of the thermally insulated heating wire module were determined in several test series.



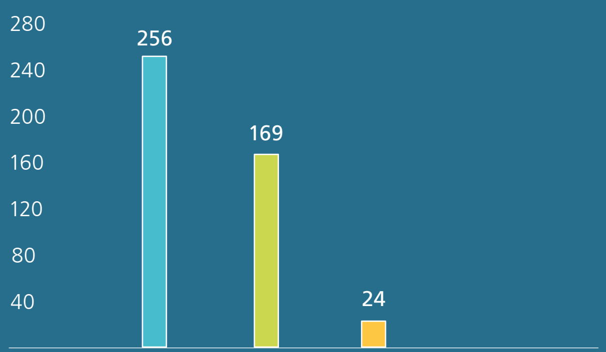
Drying and energy consumption

Top: drying curves of wetted wall elements using different drying techniques. Bottom: measured energy consumption as a function of the respective drying technique.

Water content in M-%



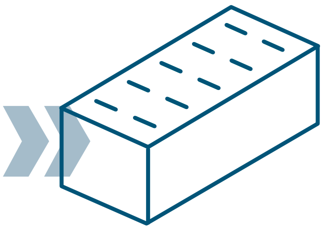
Energy consumption in kWh

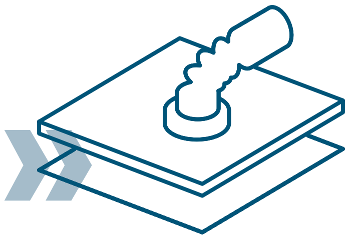


- Foil tent drying
- Conventional infrared heating panel
- Thermally insulated heating panel

Energy-saving drying techniques pay off! Larger areas can be dried with the same energy consumption.

Questions and answers on professional drying





1. When is a building material considered dry?

Under normal room conditions, most building materials are never completely dry. In particular, most porous mineral building materials or those made from renewable raw materials are hygroscopic, i.e. they bind water molecules to their inner surfaces. The resulting humidity is equivalent to the relative humidity in the room. If the relative humidity is below 80 percent, building materials are considered "air dry" despite a certain sorption moisture, and their moisture content is harmless. However, if their water content is higher, as can occur, for example, through contact with liquid water, there is a risk that mold will grow or that signs of corrosion will be observed on the surfaces of the building materials. In the case of thermal insulation materials, their insulating effect is also reduced by the influence of moisture. To prevent mold growth, a building material should contain no more water in its surface layers under usage conditions than corresponds to its equilibrium moisture content at 80 percent relative humidity. However, this condition should not last longer than a maximum of four weeks. An equilibrium moisture content of less than 60 percent relative humidity is considered absolutely safe.

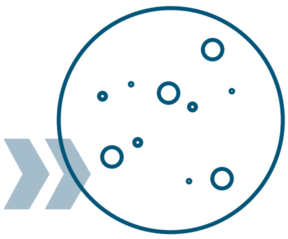
2. When is subfloor drying finished?

According to WTA 6-16 [2], subfloor drying can be terminated when the relative humidity (RH) of the exhaust air falls below 30 percent. Studies have shown that the relative humidity of the exhaust air can rise again after drying. This can be due to cooling of the dried area or so-called remaining moisture pockets causing re-humidification.

The figure top right shows the moisture conditions in the floor at the end of subfloor drying and afterwards. A rapid increase in relative humidity during the first 24 hours after switching off the drying equipment is followed by a clear leveling off with subsequent stabilization of the humidity at a level just above 80 percent relative humidity. At values above 80 percent RH, there is a theoretical risk of mold growth. However, the probability of this happening is very low, since the germination of mold spores takes a certain amount of time after drying and the materials in the floor structure normally do not contain any nutrients for the molds.

This changes, of course, if the accident was not pure mains water but rather contaminated water. The situation is also less favorable if the humidity in the floor construction after drying rises above 90 percent RH. Molds could then also develop, which can pose a health risk if their toxins are inhaled.

To date, there are no proven criteria for accurately determining the safe end of the drying period. In buildings with high hygiene requirements, e.g. hospitals, kindergartens and retirement homes, the subfloor moisture level should be measured again at least 24 hours after switching off the drying equipment. The moisture content should be below 70 percent RH.



3. Can it be ruled out that microorganisms form in the floor construction after subfloor drying?

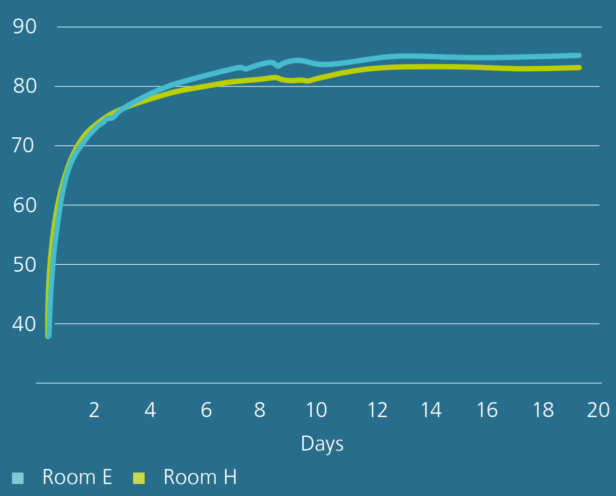
Fraunhofer IBP investigated the risk of mold growth in a subfloor insulation system after mains water damage by introducing defined standard dust containing mold spores into the insulation system [3]. Drill samples provided information on mold and bacterial growth. It can be assumed that the properties of the introduced contamination roughly correspond to the middle substrate group in the figure bottom right. Thus, at conditions above the green line, mold growth would be expected to occur after a certain period time, and would occur faster the more the climatic conditions deviate upward from the green line.

Despite initially high humidity, no fungal growth was observed under the prevailing conditions due to the immediate start of the drying process. Bacteria, on the other hand, did proliferate. After the drying process, some of these microorganisms were still alive. Further studies are required to ascertain whether the incomplete drying of small areas or other circumstances (such as echo effects) are responsible for this result.

Residual subfloor humidity

Humidity of the air emitted from the floor construction after the end of the drying period [4]

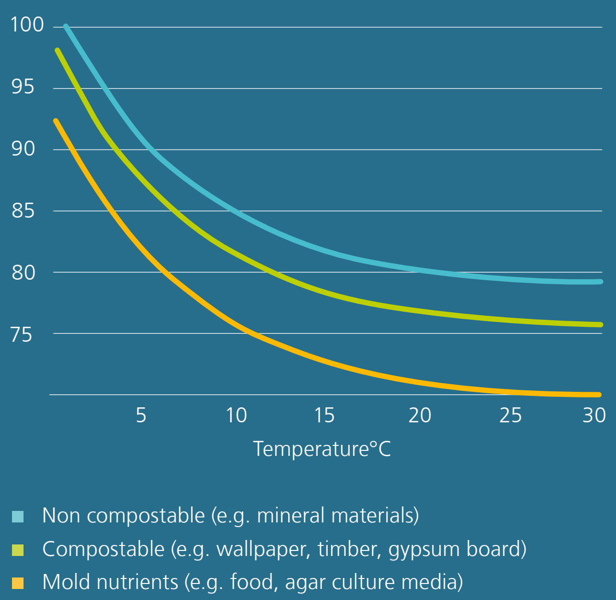
Relative humidity (RH) in%

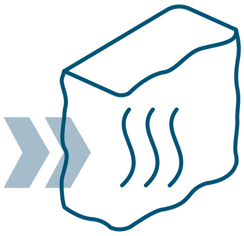


Mold growth limit curves

Mold growth limits for ideal nutrients, bio-based materials and mineral or plastic materials

Relative humidity (RH) in%



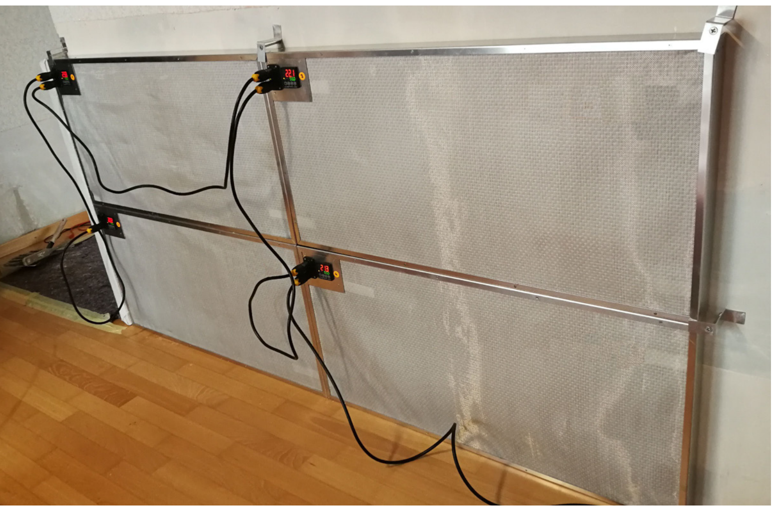


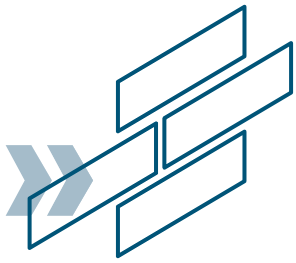
4. Can lightweight walls be dried or does the insulation suffer from the water damage?

Lightweight walls with mineral wool cavity insulation can be dried with little effort and particularly quickly by blowing dry or heated air through them. To start with, however, the water at the base of the wall must be completely extracted. It is crucial here that professional drying is started as soon as possible after the water damage has occurred, since wood and wood-based materials as well as plasterboard are more susceptible to mold growth than mineral-based building materials.

Drying tests conducted by Fraunhofer IBP showed that in drywalls with two layers of plasterboard on the inside and outside of each wall, there is a risk of mold growing unnoticed between the two layers of plasterboard. It is important to check this when professional drying has finished.

Measurement of the thermal and acoustic properties of mineral wool subfloor insulation boards, before mains water damage and after drying measures, did not show any deterioration of the characteristic values [4]. This means that professional drying can fully restore the physical properties of the floor insulation. Replacing the insulation boards is neither necessary nor advisable in this case.





5. Can masonry walls be dried?

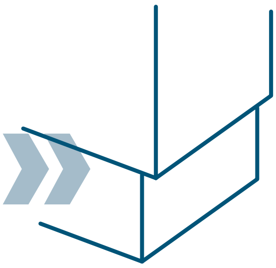
Solid building components are less affected by mold growth, but if the unfavorable conditions persist for a longer period, then infestation can be expected here as well. Therefore, leaving wet masonry walls to dry naturally poses a risk, as the surfaces usually remain damp for a very long time. Professional drying options include adsorption dryers with foil tents and heating devices that heat the wall surface directly. Heating systems that only dry the areas affected by the water damage without heating the air in the room are, as already explained, particularly energy-efficient. In the case of solid walls, the drying rate much depends on the drying temperature. The warmer, the better. However, this is limited by the stability of respective materials in terms of temperature and, above all, personal safety. As the temperature rises, drying becomes more effective, but at the same time the energy efficiency of the measure decreases. Thus, several factors must be weighed against each other in such cases.

As with drying subfloors, drying solid walls raises the question of whether the drying measures have been successfully completed. A dry wall surface is only suitable as a criterion to a very limited extent, since masonry has a high capillary conductivity, i.e. moisture from the substrate can dampen the surface again. On the other hand, it is not always necessary to wait until the last traces of water in the middle of the wall have been completely eradicated. Here it is important to precisely define the goal of the drying measure:

For non-insulating partition walls, the drying objective should be limited to the aspect of hygiene and avoiding damage to the construction. This means that moisture forming again on the component surface due to residual dampness in the core area may not lead to mold growth or any other impairment of the surface layer, nor to a significant rise in the humidity of the room air.

Achieving this criterion requires experience on the one hand, and on the other hand the moisture flows in the component can be estimated with the aid of numerical simulation methods and compared with the moisture transfer at the component surface. If the potential moisture transfer from the surface to the ambient air is significantly greater than the moisture flow from the interior of the component to its surface, then drying can be terminated without hesitation. In the future, however, it would be necessary to quantify this more precisely with the aid of relevant investigations.

If the thermal insulation properties of the affected component play a major role, e.g. as with exterior walls, then as much moisture should be removed as possible because it impairs the thermal insulation performance of the component. Other structural properties, such as sound insulation, are generally not impaired by moisture. Sound insulation even increases with moisture [5].



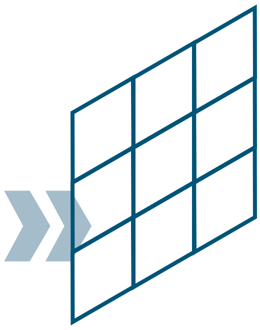
6. What has to be considered when drying exterior walls?

Drying wet exterior walls depends on the wall thickness, material and type of construction – solid, hollow, with insulated cavities or with continuous layers of air or insulation. The quantity of water absorbed during the water damage must also be taken into account. In recent years, Fraunhofer IBP has examined numerous wall constructions: masonry made of solid brick, lightweight concrete, solid plasterboard, vertically perforated bricks with thermally insulated cavities, and lightweight walls.

Drying vertically perforated bricks whose cavities are filled with mineral fiber or perlite is particularly challenging because the insulated cavities obstruct the heat flux necessary to evaporate the moisture. So-called lance drying has proved successful in such cases, whereby lances are inserted through small boreholes in the bricks in a specific pattern. Warm air dried by an adsorption dryer is then blown in through the lances and distributed in the brick through small lateral apertures in the lances, drying both the insulating materials in the brick and the brick itself. To save energy, drying can also be carried out intermittently. With a slightly longer drying time, significant energy savings can be achieved. The effectiveness of this method has been confirmed in laboratory tests.

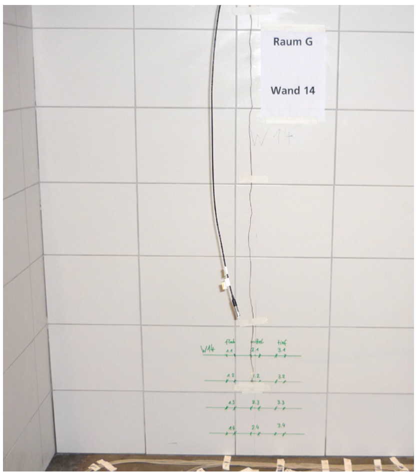
Exterior walls with interior insulation systems can only be dried from inside if air can be blown through the interior insulation from behind or if the insulation can be removed beforehand. Further studies are needed to determine whether drying from outside is feasible without risking damage to the inside.

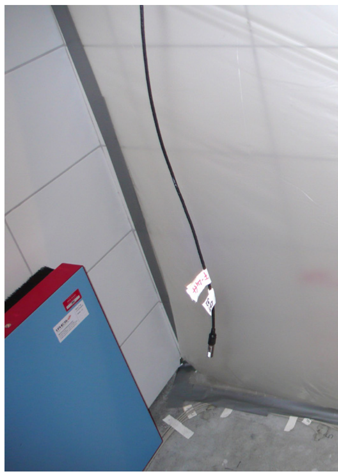
Drying walls with external insulation, for example external thermal insulation composite systems (ETICS), could also pose problems. It is known that building moisture can cause damage to ETICS even without the use of special drying methods. Examples include discoloration or even frost damage to the exterior plaster systems when drying the massive structure [6; 7]. In order to clarify the risk of damage, appropriate preliminary investigations, e.g. hygrothermal simulations, are recommended in certain cases.

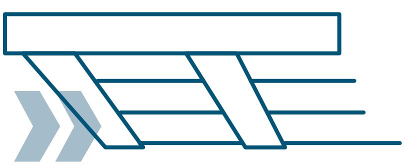


7. How can a tiled wall be dried?

The surface of a tiled wall has a comparatively high water vapor diffusion resistance. Depending on the size of the tiles and of the gaps between them , this diffusion resistance lies between two and five times the diffusion resistance of a 1-meter-thick layer of stationary air (technical term sd value). This is quite high, considering that interior plaster only has a sd value of 0.1 to 0.2 meters. Drying a tiled wall via the tiles is correspondingly slow. Computational studies in [4] have shown that in the case of a wet brick wall tiled on one side, only about 10 percent of the water escapes via the tiles themselves, while 90 percent escapes via the untiled back of the wall. Therefore, if water damage affects a larger area and drying the wall from the back is out of the question, the tiles should be removed before starting the drying process.



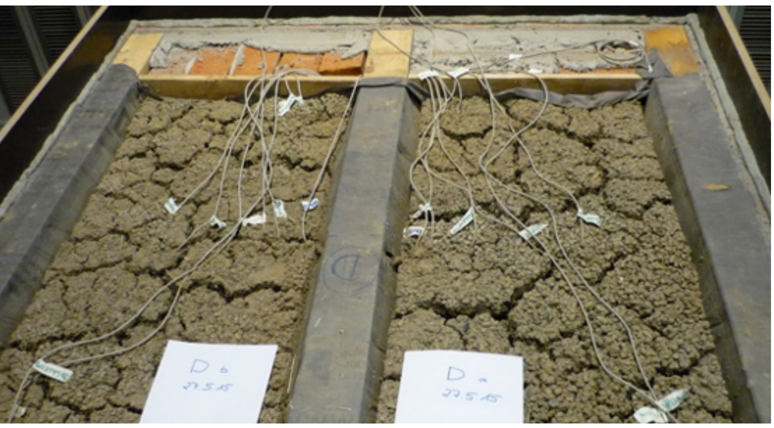




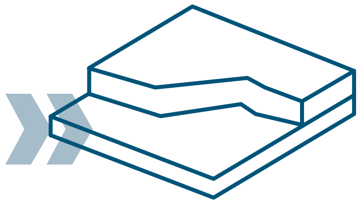
8. Is it possible to dry a wooden beam ceiling with slag or clay filling?

To find this out, the Association of Public Insurers (VÖV) commissioned two studies. After artificially created water damage, two wooden beam ceilings were dried in the climatic simulator, one with a slag filling and one with a clay filling.

Boreholes from below and above conducted dry air intermittently through the insulation layers using the negative pressure method. Both fillings as well as the wooden beams, which were also wet, could be dried. In contrast to the slag-filled wooden ceiling, the ceiling filled with clay could only be dried successfully after a period of five weeks with the aid of a radiant heating panel. This heated the ceiling from below to approx. 100°C, whereby the clay layer formed severe cracks.



Wood-beam ceiling with clay filling after five weeks of drying. The cracking is clearly visible.



9. Can multilayer floor insulation be dried?

To find out whether perlite fillings can be dried, a combined sub-screed insulation layer consisting of perlite insulation and mineral fiber insulation was examined in the laboratory. With the aid of a conventional subfloor drying system with adsorption dryer and turbine in negative pressure mode, the insulation layer was successfully dried over a period of three weeks. Sub-screed insulation consisting of combined EPS/EPS and EPS/mineral fiber insulation layers was also successfully dried using the same principle.

10. What must be considered when drying listed buildings?

Water damage in listed buildings poses a particular challenge, as the historic building fabric should be preserved as far as possible, and no further damage should occur during the drying process. In such cases, drying must not only be carried out very quickly, but also with appropriate care. Knocking off plaster should only be considered in exceptional cases.

Historic buildings with valuable, immovable works of art or decorations suffer not only from acute water damage, but also from the effects of the water damage on the indoor climate. If conventional drying equipment is used without carefully controlled air conditioning inside the affected room, this may lead to unfavorable fluctuations in relative humidity. The consequences may be further climate-related damage to works of art, such as wall paintings or furniture. Continuous control and a stable relative humidity are crucial in order to avoid damage to delicate works of art that cannot be stored outside, e.g. coffered ceilings, frescoes or floor coverings.

Need for research

Climate change and the resulting increase in extreme weather phenomena, such as heavy rain events, as well as the rising complexity of building envelope components, will raise the expenditure for professional drying. At the same time, there seems to be considerable potential to save energy and improve drying effectiveness by applying more sophisticated technologies. This potential will best be exploited by a close cooperation of the various stakeholders, such as restoration and insurance companies, equipment manufacturers and scientific institutes.

The following research and development needs have been identified

1. Improvement in the energy efficiency of drying devices
2. Professional drying protocols in case of damage by polluted water
3. Optimization of the drying process through intermittent operation
4. Smart control of drying processes, including different aspects such as power supply, consequential damage prevention and user demand
5. Drying time prediction as function of construction and material type as well as component thickness and water content
6. Definition of precautions necessary to prevent consequential damage in case of insulated external building components
7. Investigation of application scenarios and limits for high temperature drying methods

The potential to improve drying methods is high. Researchers, restorers, insurers and equipment manufacturers should work closely together to realize true innovations.

Further information

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Project website

www.ibp.fraunhofer.de/en/expertise/hygrothermics/climate-simulation-field-studies/technical-drying.html

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