Contribution to International Symposium, Varenna 27-30 September 1994. **"Dealing with Defects in Building"**

METHODS OF DIAGNOSING MOISTURE DAMAGE IN BUILDINGS

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ABSTRACT

Damage in buildings due to moisture is frequent. The cause of the damage must be known in great detail so that the proper remedial measures may be recommended and liability correctly determined. However, such a diagnosis is almost never based on scientific grounds but is more or less a 'qualified guess'.

This paper suggests a number of requirements which a diagnosis must satisfy for it to be complete and correct:

a. Show **that** the damage is due to moisture and nothing else!
b. Show **where** the source of moisture is located!
c. Show **why** the damage could occur!

The paper gives details of how this procedure is run and some examples from practice of how the different parts are treated.

RÉSUMÉ

Les dommages dans les bâtiments à cause d'humidité sont fréquents. Pour pouvoir recommander des propres mesures de restauration et établir la responsabilité correctment, il faut connaître la vraie cause de ces dommages. Cependant, un tel diagnostic n'est presque jamais basé sur un fondement scientifique mais sur une 'conjecture' plus ou moins qualifiée.

Cet exposé propose un nombre de demandes auxquelles un diagnostic doit répondre pour être complet et correct:

a. Montrer c'est un dommage causé par l'humidité et pas par autrechose!
b. Montrer où la source de l'humidité est situé!
c. Montrer pourquoi les dommages sont apparus!

Cet exposé donne des détails sur quelle est la procédure à suivre, illustré de quelques exemples sur la façon de traiter les différentes parties.

1 INTRODUCTION

Damage in buildings due to moisture is frequent. The cause of the damage must be known in great detail so that the proper remedial measures may be recommended and liability correctly determined. However, such a diagnosis is almost never based on scientific grounds but is more or less a ′qualified guess′.

To make a diagnosis is to decide the cause of damage which has occurred. A diagnosis is built on data concerning the damage history and findings from an investigation. By analysing this information the cause is decided in such a way that it explains relevant findings and is shown to be able to give rise to the damage history in question. If this cannot be done completely, the diagnosis has a certain degree of uncertainty. If the result of the analysis is that several causes may be possible, additional information or investigations are needed to distinguish between them.

To give support for forming an opinion on the question of liability, it is usually required to force the diagnosis so far that it is possible to show that causality exists, i.e. that there is a causal connection between the precise cause of the damage and what some party is responsible for. If, on the other hand, the purpose of the diagnosis is ′only′ to give support for repair measures, the diagnosis does not have to distinguish between different causal connections that require the same measures.

To be able to make a correct diagnosis it is required to have access to

a) knowledge
b) common sense
c) measuring techniques
d) ability to conduct a searching examination
e) lack of preconceived opinions

It is not enough to have detailed knowledge of the damaged material, the structure and the phenomena that gave rise to the damage in question and to have access to the latest measuring equipment. A logic analysis and a searching examination of one’s own and others’ data and findings are equally important parts of the process of diagnosis.

To obtain a correct diagnosis in every separate case the investigator also has to manage his preconceived opinions in order not to be satisfied with showing that the cause he believed in already from the beginning **may** explain most of the findings and **may** explain the origin of the damage. The true cause may be something quite different.

2 REQUIREMENTS FOR A DIAGNOSIS

Unfortunately there are several questionable ways of determining something that is called a diagnosis of damage due to moisture. Some of them are obviously inappropriate and quite incorrect.

One bad example is ′diagnosis by means of elimination′. A list of ′possible′ causes is made and the investigation is done in such a way that causes on the list can be eliminated one by one. The one finally remaining is ′the probable cause′. This is a dangerous method! Possible causes (may be including the true one!) may be missing on the list. Use such a list only to plan the investigation but for diagnostic purposes add one more possible cause to the list: ′A cause I did not expect′. Let the findings show what it finally is, see below!

Another frequent but questionable method is ′diagnosis based on measures′. A limited investigation does not give support for a correct diagnosis. Instead the diagnosis is based on a guess, on a ′qualified guess′ at the best. Measures eliminating the guessed cause are taken and a follow-up is made. If the measures do not help, the guessed cause may be the correct one anyway but the measures were not sufficient. If the measures help it may be because the measures were so extensive that they eliminated also the true cause besides a number of other causes that needed no measures. May be the measures did nothing; the problems may have had disappeared anyway! In all three cases the ′diagnosis based on measures′ has a fundamental drawback: no precise experience is gained to use in other similar cases.

′Diagnosis by comparison′ is another frequent but irrelevant method to find the cause of damage due to moisture. The ′investigation′ is limited to comparing the structure in question with what was said in the codes of practice, drawings, documents etc. A divergence may under certain circumstances be regarded as an ′error′ from a juridical point of view. It is, however, a gross error to claim that such a divergence, between what was planned and what was carried out, is the cause of the damage. It may be so, it may not, but it must be properly shown in each case, of course taking other alternatives into account.

2.1 A formulation of the requirements

A ′diagnosis′ must satisfy some requirements to be regarded as a reliable diagnosis. These requirements may be expressed in this way.

A diagnosis **must**

a) **show** a connection between moisture and damage, i.e. show **that** the damage is due to moisture and not something quite different!

b) **show** the origin of the moisture, i.e. **from where** the moisture was supplied!

c) **show** the causality, i.e. **why** this moisture source could cause the damage!

If these requirements are not satisfied by a diagnosis it cannot be trusted and needs improvement.

How this is done is shown in the following. However, all the details in collecting information and investigating the conditions of the building and the damages are not shown in this paper.

3 CORRELATION OF DAMAGE WITH MOISTURE

That it really is a damage due to moisture is shown partly with a material analysis to determine the type of damage and partly by a moisture measurement in the damaged material. The moisture measurement shall prove that the material is too wet, i.e. its current state of moisture is well above the critical state of moisture for the type of damage in question. Expressed in terms of relative humidity RH in the materials one gets

$$RH_{curr} > RH_{crit} \qquad \text{[Eq 1]}$$

If this is not true, but the analysis of the material shows that it has been damaged by moisture, the continuation of the diagnosis must show that the material was wetter before, i.e. include a ′moisture historiography′.

It will be even more obvious that it is a moisture damage if the connection between moisture and damage is verified by more than one moisture measurement. Measurements also in undamaged parts of the material and in parts with less damage may show a connection between the distribution of the damage and moisture, i.e. between the degree of damage and the state or content of moisture. If there are some doubts concerning the role of moisture in the occurrence of the damage, showing such a connection may be a suitable foundation for a judgement.

When comparing the current level of moisture (RH_{curr}) and the critical one (RH_{crit}), one has to remember that, in principle, moisture damage has one (or a combination) of these two causes: a) A material became too wet, i.e. RH_{curr} was too large (due to errors in the design or production or due to abnormal moisture sources) or b) A material was too sensitive to moisture, i.e. RH_{crit} was lower than expected (but the structure behaved as planned).

4 ORIGIN OF MOISTURE

The source of moisture can be discovered by measurements. Two quite different techniques are used depending on whether the structure is ventilated or not. In some structures both techniques are used; the first one to interpret the results of the second one.

4.1 Additional moisture to the ventilation air /2/

Differences in vapour content in the ventilation air between different parts of a ventilated structure are direct indications of moisture sources within the structure itself. If the increase in vapour content is too high or enough to cause the damage, it requires to be explained. The production of moisture may be too high or the ventilation may be too low; both aspects have to be examined.

4.1.1 Example 1: Crawl spaces

Crawl spaces in Sweden are usually very wet each summer when the outdoor air is warm and humid and the crawl space is fairly cold. To detect a possible moisture source in the crawl space the vapour content in the crawl space is measured and compared with the vapour content in the outdoor air. If the vapour contents are identical no moisture source is to be searched for in the crawl space. The cause of high humidity is moisture supplied from the outdoor air and the cold conditions in the crawl space.

4.1.2 Example 2: Ventilated, heated slab on the ground /2/

A floor structure with a concrete slab on grade, where the foundation and the concrete slab were heated every night, had extensive condensation in a wood particle board on top of the concrete slab. The structure was ventilated below the slab with indoor air. The moisture source was determined by measuring the vapour content in the ventilation air before and after it passed through the floor structure. Since they were identical it could be shown that the moisture originated from excess moisture in the concrete slab itself and not from the ground.

4.2 Moisture flow directions

To explain the moisture source to a damaged part of a structure it is of decisive importance to determine the direction of moisture flow to that part. If this determination gives erroneous results it is highly improbable that the diagnosis will be correct.

In structures that are not ventilated and have no air leakage, the source of moisture can be determined by evaluating the moisture flow directions from measurements of the moisture and temperature distributions in the structure.

Vapour flow occurs parallel to the gradient in vapour content c from regions with a higher to regions with a lower content. The distribution of vapour content is determined from measurements of the distribution of relative humidity RH and temperature T in sections of the structure.

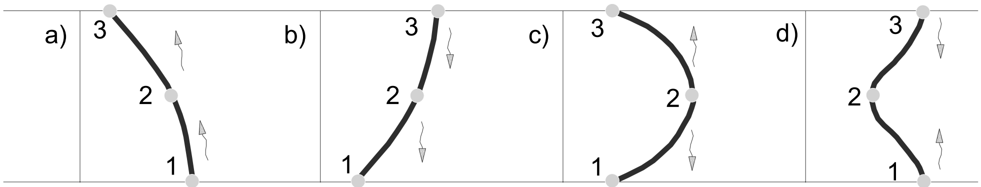
Liquid moisture flow occurs parallel to gradients in pore water pressure P_w, provided a continuous liquid phase exists in a part of the pore system. Since P_w is extremely difficult to measure directly the direction of liquid flow is estimated in other ways. The RH (φ) is a good alternative for cement based materials like concrete where some liquid flow takes place well below 100 % RH. With V as the molar volume of water the relation is

$$P_w = \frac{RT}{V} \ln \varphi \qquad \textbf{[Eq 2]}$$

From Eq 2 it is obvious that the gradient in RH also shows the direction of liquid flow except for materials with large temperature gradients. Extremely precise measurements of RH are needed, however, to show the flow direction.

In most other materials the direction of moisture flow can be estimated from distributions of moisture content or degree of capillary saturation, although with some uncertainty because of hysteresis and variations in the material composition.

The interpretation of the measured directions of moisture flow must include information on the structure, material properties, type of moisture flow (vapour or liquid) and (moisture) conditions in adjacent parts of the structure. This interpretation is further treated in the next chapter. Figure 1 gives the interpretations in the most simple case.



a) Flow passing point 2 upwards. Originates from point 1 or further below or from sideways flow to point 2.
b) Flow passing point 2 downwards. Originates from point 3 or above or from sideways flow to point 3.
c) Flows from point 2 upwards and downwards. Originates from point 2 (excess moisture?) or sideways flow to point 2.
d) Flows to point 2 from below and above. Increases the moisture content in point 2 or ′escapes′ sideways

Figure 1 Interpretations of moisture flow directions at one point (No 2) in a homogeneous material

4.2.1 Example 3: Slab on expanded clay on the ground /2/

A concrete slab on the ground had an underlying heat insulation layer of expanded clay particles. The results of measurements are shown in Figure 2 including the vapour content.

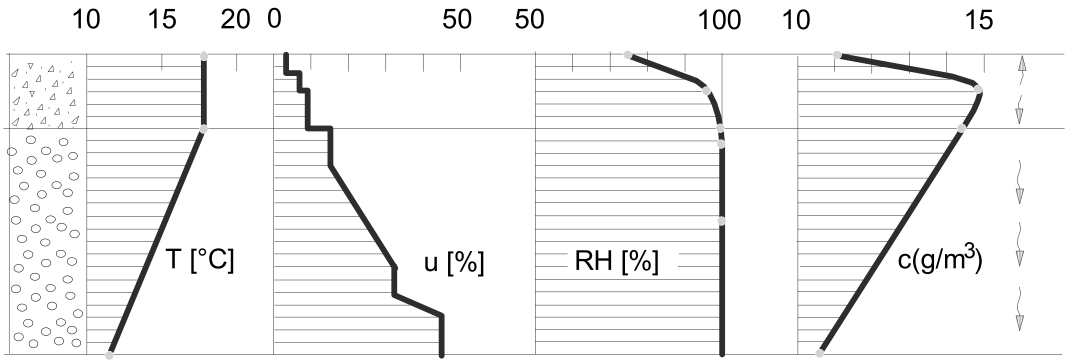


Figure 2 Distribution of temperature T, moisture ratio u, relative humidity RH and vapour content c

The vapour distribution shows a downward flow **and** an upward flow from the center of the slab! It seems as if there is a moisture source in the slab. The distribution of u and RH, however, shows a liquid flow from the ground to the center of the concrete slab. The capillary suction through the expanded clay layer and part of the slab is the moisture source for the vapour flow!

5 CAUSALITY

To show **why** moisture from a certain direction could give rise to excessively wet conditions a number of means are used:

- Precise observations
- Measured moisture distributions
- Analysis of material properties
- Calculated moisture distributions

The causality is shown by analysing the precise observations of the type of damage and the damage distribution and by comparing measured moisture distributions with predicted ones. Uncertainties regarding material properties may require a material test to be done.

5.1 Precise observations of damage

Detailed observations of the damage may be of significant help, and sometimes completely decisive, for the diagnosis. In order to achieve this, however, the observations must be precise.

5.1.1 Precise observations of where there is damage and where there is not

Precise observations of how the damage is distributed in the structure and of the degree of damage are essential. Any connection between such a distribution and differences in the design of the structure, material properties, surroundings of the structure etc will be a significant contribution to the final diagnosis.

Examples of such observations are: condensation on window glasses, outer or inner pane?; wet spots, 'free water' or only colour change?; efflorescence of salts and corrosion products as an indication of liquid moisture flow; local damage, problems or wet conditions must have a logical explanation: local variations in the design of the structure or local moisture sources?

5.1.2 Precise observations of moisture conditions

Precise observations of whether 'free water' is, or has been, present or not are decisive. Free water can only arise from condensation or leakage and not from capillary suction. Traces of running water or species transferred by water, visible water tables, visible mould growth etc prove the presence of true free water, currently or earlier, which is another significant contribution to the diagnosis.

5.2 Comparison of measured and predicted moisture profiles

The moisture source (cf. 4.2) that has given rise to the current RH, higher than the critical one, consequently caused the damage, but may be a natural consequence of the design of the structure and the choice of materials. This is shown by a comparison with a predicted moisture distribution, usually from a calculation. If the two distributions are identical the cause of the damage is an error in the design.

If, on the other hand, the measured and predicted moisture distributions do not coincide, the deviation must be explained. That explanation forms another important basis for evaluation of the causality, cf. 5.3.

These alternatives must be closely examined:

a) one (or more) material has **properties** different from the ones assumed or expected, such as moisture flow and binding properties.

b) the **boundary conditions** are different from the ones assumed or expected, such as temperature distribution, abnormal conditions during measurements and occasional wetting.

c) the **initial or earlier conditions** were different from the ones assumed or expected such as climatic conditions during construction, amount of excess moisture absorbed during manufacturing, construction or from an earlier leakage.

If the damage occurred some time ago and the damaged material is currently dry, a moisture history has to be 'written' from the time of construction or from the time of an occasional wetting. Such a prediction is of course a difficult task. If the current moisture profile still shows a certain moisture flow that can be believed to have prevailed for some time it is possible to estimate earlier distributions quite accurately.

5.2.1 Example 4: Slab on expanded clay on the ground /2/
The expected moisture distribution in Example 3 is compared with the measured one in Figure 3.

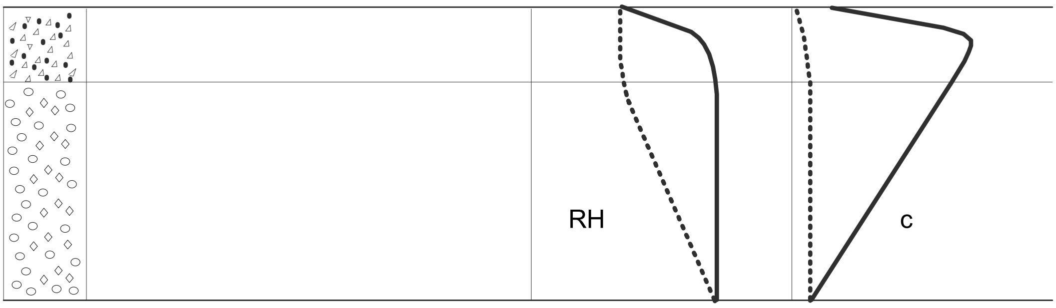


Figure 3 A comparison of measured and predicted (dotted line) moisture distribution. It is assumed that there is no capillary suction, cf. Fig 2.

In the predicted distribution, vapour flows from the ground through the structure but the measured distribution shows a downward flow of vapour and an upward flow of liquid. The assumption is obviously incorrect. The high capillary suction capacity of the expanded clay can explain the difference and was shown in a separate material test.

5.3 Final evaluation
In the final evaluation all the information, data and findings are put together to find the cause that explains all of them, satisfies the requirements in Clause 2.1 and leaves no loose ends! If this is not possible the investigation has to be improved.
These tasks are to be treated one by one:

1) **Collect** all the information, data and findings concerning the structure, materials, damage history and distribution, moisture levels, flow directions, moisture distributions and moisture history.
2) **Question and analyse** all of it and judge its reliability!
3) **Enough?** Evaluate whether it is a complete basis for conclusion!
4) **Improve** the parts not satisfying 2) and 3)!
5) **Conclude** and state the cause of the damage!

5.3.1 Example 5: Wet spots at a basement floor /2/
Occasional, and local, wet spots at a basement floor were investigated. Moisture measurements showed a continuous moisture flow from the ground, liquid flow at the bottom but vapour flow closer to the top surface. This could not explain occasional wet spots even though the bottom of the floor slab was partly and continuously immersed in water. By showing a correlation between the surface temperatures, the history of vapour contents in the outdoor air and the history of the wet spots, it was concluded that surface condensation from the indoor air was the cause of the problems!

6 CONCLUSION

A diagnosis must be based on a number of things:
- precise information and observations of the structure and the location and type of damage,
- accurate measurements of vapour contents in ventilated parts of the structure,
- accurate measurements of moisture distributions in the structure close to the damage and at some distance
- analysis of material deterioration and material properties,
- questioning and thorough examination of all the collected information,
- improvement of the information if necessary.

The causality is shown if the requirements in Clause 2.1 are satisfied and a cause is found if it explains all the information and findings and leaves no loose ends!

If this foundation does not exist as a basis for the conclusion, the diagnosis is not a reliable one!

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