Two-Dimensional Transient Heat and Moisture Simulations of Rising Damp with WUFI 2d

Holm, A.
Künzel, H.M.

Fraunhofer-Institut für Bauphysik
(Director: Univ.-Prof. Dr.-Ing. habil. Dr. h.c. mult. Dr. E.h. mult. K. Gertis)

Abstract

the phenomenon of rising damp and the effectiveness of rehabilitation measures have recently been at the center of lively discussions. Two-dimensional simulations with a program for calculating the transient heat and moisture transport (WUFIZ) allow exemplary case studies of situations with rising damp and the discussion of appropriate countermeasures. We could show that with the aid of modern simulation methods it is possible to assess the effectiveness of rehabilitation measures without the need for time-consuming, often difficult and expensive experiments. Therefore these methods are a valuable tool for use in the planning, assessment and optimisation of rehabilitation measures.

Key Words

Rising damp, hygrothermal simulations, WUFI2D, capillary transport

Introduction

One can often observe damages at the foundation walls of old buildings. They become evident by discolorations and stains on the wall surfaces, often accompanied by salt efflorescences. In many cases rising damp is diagnosed as the cause. For this reason, a great variety of methods for reducing the water absorption from the ground has been developed and applied in practice more or less successfully. The phenomenon of rising damp and the effectiveness of rehabilitation measures have recently been at the center of lively discussions. Künzel argues that in many cases increased salt content is interpreted as rising damp [1]. Two-dimensional simulations with a program for calculating the transient heat and moisture transport (WUFIZ) [2] allow exemplary case studies of situations with rising damp and the discussion of appropriate countermeasures.

Moisture Transport in Masonry

In homogeneous materials in contact with liquid water the amount of absorbed water increases in proportion to the square roof of the elapsed time and is described by the material-specific water absorption coefficient A or the liquid transport coefficient D_w. In masonry composed of different capillary-active materials, however, only the water absorption in the lowest material layer behaves according to the simple law expressed by the A-value. The water absorption of the masonry as a whole depends mainly on the comparative suction pressures in the contacting materials and on the non-ideality of the contact [3]. In the calculations, the non-ideality is represented by a "transfer resistance". The introduction of such a transfer resistance is justified by numerous observations in practice and in the laboratory [4] [5].

Simulation of rising damp

The hygrothermal behaviour of different 2 m high masonry constructions exposed to groundwater has been examined with the PC program WUFIZ for the simulation of the coupled heat and moisture transport in building components, which was developed at the Fraunhofer Institute for Building Physics in Holzkirchen and has repeatedly been verified experimentally. The object under investigation is a 60 cm tick wall facing north. This excludes heat gain by solar radiation which might accelerate the drying, as well as driving rain which might shift the visible moisture front at the surface. The examined variants are detailed in Table 1. The strongly absorbing brick (A-value > 14 kg/m²√h) serves as an extreme case. In practice, most bricks have lower A-values. In order to reduce computing time, only the four lowest stone courses (20 cm high) have been modelled as separate layers. The remaining part of the total height has been approximated as monolithic stone. This is permissible in view of the maximum expected capillary rise. The hygrothermal properties for each material were taken from the WUFI database and are shown in Table 2. The rendering on the interior surface has been modelled by a vapour diffusion thickness (s_d-value) of 0.2 m.

Table 1: Investigated variants

Case	Description
1	60 cm natural sandstone masonry (only horizontal joints)
2	60 cm natural sandstone masonry (horizontal and vertical joints)
3	60 cm brickwork
4	8 cm mineral wool ETICS on 60 cm natural sandstone masonry
5	5 cm EPS interior insulation on 60 cm natural sandstone masonry
6	60 cm natural sandstone masonry with reduced moisture absorption from the ground (borehole injection in the lowest stone course)
7	As in cased 6, but with high initial moisture content in the masonry

The daily mean temperatures and relative humidities of a year typical for Holzkirchen were used as the climatic boundary conditions. The room climate was modelled by a sine wave varying between 20 °C, 40 % RH in winter and 22 °C, 60 % RH in summer, which corresponds to a normal moisture lead. The initial moisture content of the used materials was the equilibrium moisture at 80 % RH. The simulation periods began on January 1. The evaluated quantities were the temporal course of the total moisture content, the moisture content in different layers of the construction (as dependent on height) and the distributions of relative humidity across the masonry.

Results

Figure 1 presents the temporal course of the mean total water content for the different cases. In the top figure, sandstone masonry and brick masonry are shown. In both cases, a stationary state is reached after ca. 1.5 years. The mean water content is ca. 50 kg/m³ in the brick. In order to assess the effect of vertical joints, too, the water content for sandstone masonry with both horizontal and vertical joints is also shown. For symmetry, a 2.0 cm thick vertical mortar joint was made to pass straight through the middle of the wall. As a result, the total moisture content rises by about 5 %. For the remaining investigations, only horizontal joints were considered.

The effect of different insulation measures is illustrated in Figure 1, bottom, using the example of sandstone masonry. In order to improve insulation quality, a 5 cm thick EPS interior insulation or an 8 cm thick mineral wool ETICS have been added to the 60 cm thick masonry which, without insulation, represents the standard situation (solid line). While the course of total water content changes only slightly under the ETICS, it continues to increase after application of the interior insulation. Even after two years no equilibrium state has been reach yet.

Table 2: The hygrothermal perameters of the usesd materials

		Brick	Sand-stone	Mortar	Ext. Ren-dering	Mineral wool	EPS
Bulk density	[kg/m³]	1725	2200	2000	1900	60	30
Heat capacity	[kJ/kgK]	0,85	0,85	0,85	0,85	0,85	1,50
Heat conductivity	[W/mK]	0,6	1,8	1,2	0,8	0,035	0,035
Porosity	[Vol.-%]	38	17	30	24	95	95
Free Saturation	[Vol.-%]	20	14	28	21	-	-
Diffusion Resistance Factor, dry	[-]	15	40	25	25	1,3	50
A-value (hor.)	[kg/m2√h]	21	3,0	4	0,5	-	-
A-Value (vert.)	[kg/m2√h]	14	3,0	4	0,5	-	-
Reference Moisture content u_{80}	[Vol.-%]	0,27	1,0	3,5	4,5	-	-

In a further variant of the standard case, the water absorptivity of the lowest stone course has been decreased: reducing the liquid transport coefficients by a factor of 100 simulates the effect of a bore-hole injection. As should be expected, this reduction of moisture absorption from the ground results in a markedly lower total moisture content (ca. 30 kg/m³).

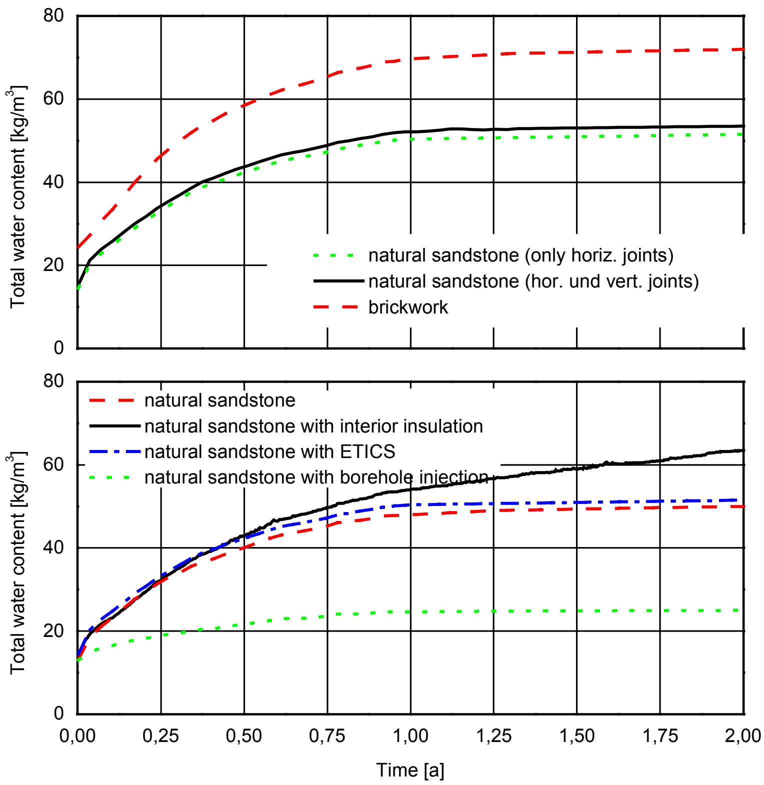
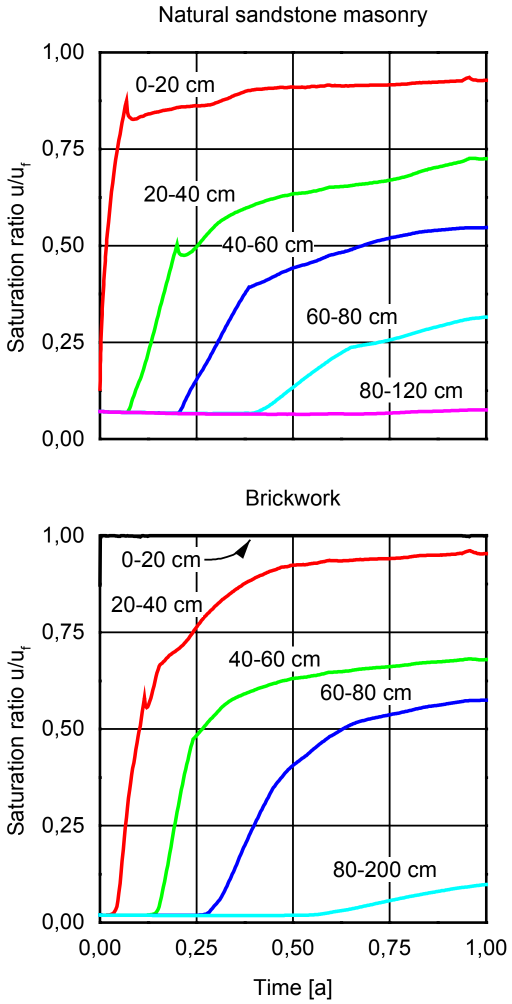


Figure 1: Course in time of the water content per unit of area for the examined variants

The course in time of the fractional water content (u/u_f) at different heights (i.e. stone courses) during the first year is shown in Figure 2, top, for the sandstone masonry, and in Figure 2, bottom, for the brickwork (cases 1 and 3). While in the brickwork the first stone courses (0 – 20 cm) is already completely saturated after a short time, the saturation ratio of the corresponding stone course in the sandstone masonry never exceeds ca. 90 %. The saturation ratio is always higher in the brickwork than at the corresponding height of the sandstone masonry, as expected.



<u>Figure 2:</u> Course in time of the saturation ratio at different heights of the examined construction.
Top: Natural sandstone masonry.
Bottom: Brickwork.

In the sandstone, the water content remains at a constantly low level at the height of the fifth stone course (i.e. 80 cm) and above. The capillary rise height is therefore 60 – 80 cm. In the brickwork, on the other hand, the water content in the fifth stone course increases slightly after about half a year, but reaches only a saturation of ca. 10 % after one year, corresponding to a capillary rise height of slightly more than 80 cm.

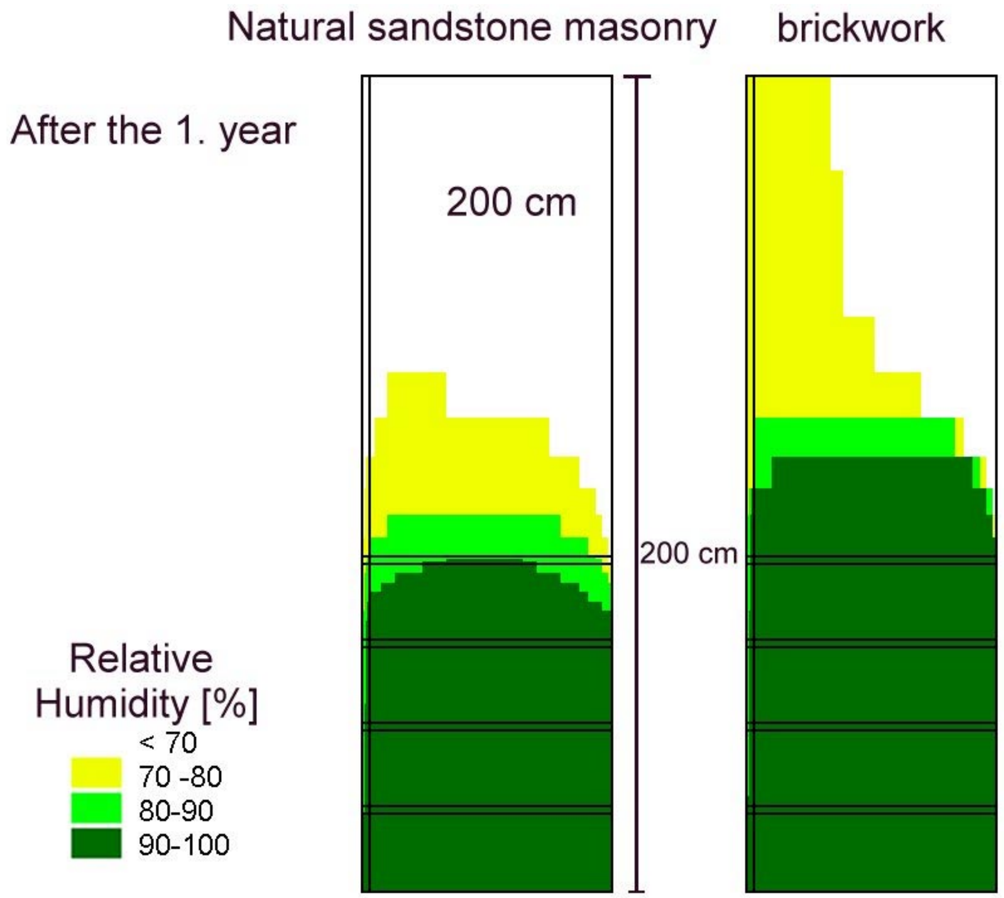


Figure 3: Distribution of relative humidity in the wall after the first year in cases 1 and 3.

The distribution of relative humidity over the cross-section of theses 2 variants at the end of the first year is shown in Figure 3 (left: sandstone masonry, right: brickwork). The different rise heights are clearly evident. In the sandstone, the relative humidity of the interior wall surface falls below 80 % for heights above ca. 80 cm. The slightly higher capillary rise in the brickwork is due to the higher capillary water absorption from the ground and the more favourable suction pressure ratio between mortar and brick. In both cases, the rising damp results in typical moisture content distributions with a maximum in the middle of the wall.

Figure 4 shows the effect of insulation added onto the sandstone masonry. The distribution of relative humidity over the wall cross-section at the end of the first and the second year is shown for 5 cm thick polystyrene foam slabs applied to the interior wall surface as well as an 8 cm thick ETICS with mineral wool slabs. Application of the ETICS does not increase the visible rise height noticeably. The permeable mineral wool leaves the evaporation potential through the outer surface unimpeded. The equilibrium between moisture rising through capillary effects and moisture drying out across the wall surfaces remains unchanged. The interior insulation, however, distorts this equilibrium. The reduced roomside drying potential – due to the less permeable insulation material – increases the rise height markedly.

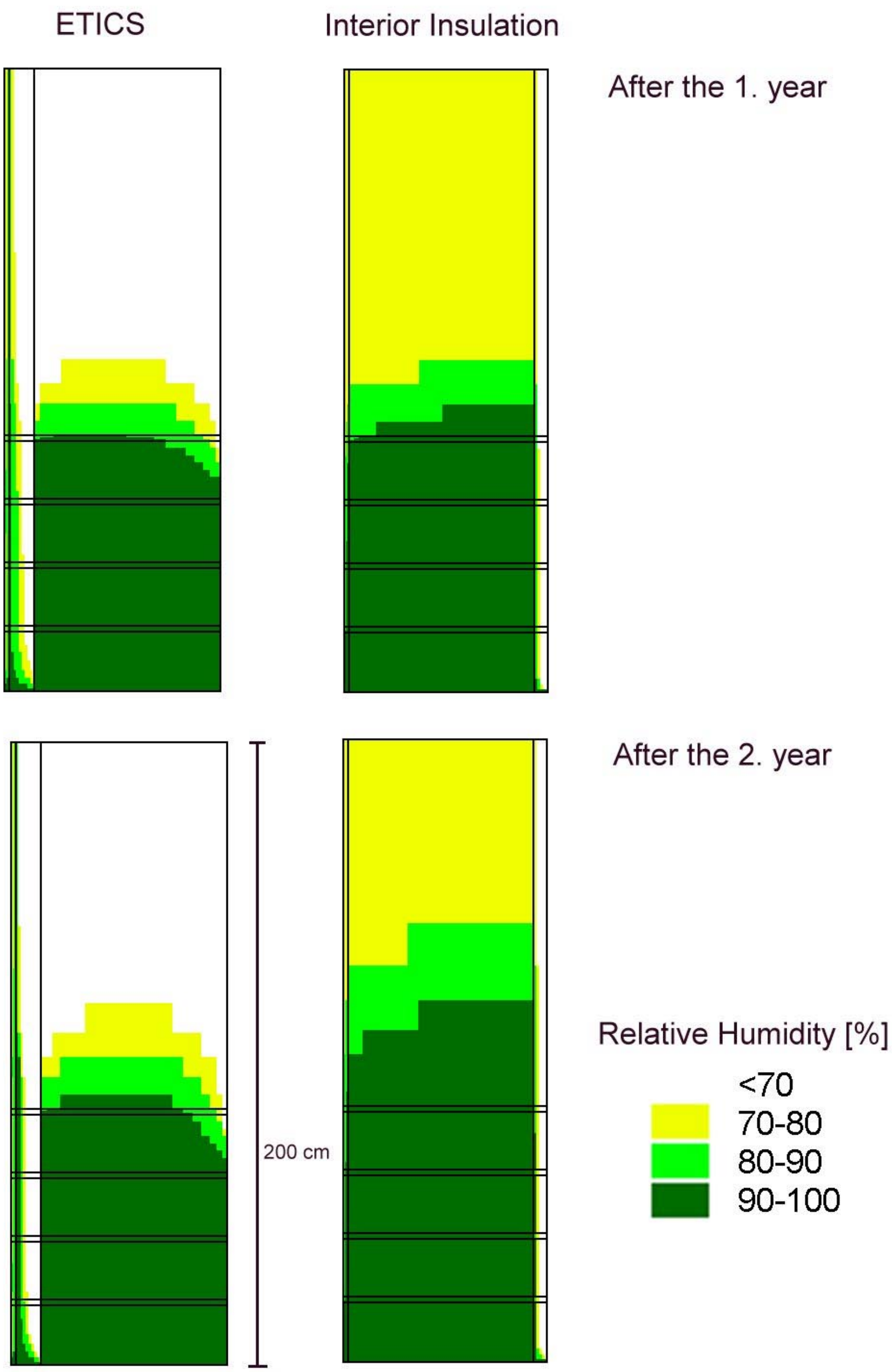


Figure 4: Distribution of relative humidity in the insulated masonry after the first (top) and the second year (bottom).
Left: Exterior insulation with 8 cm mineral wool ETICS.
Right: Interior insulation with 5 cm EPS.

Figure 5 shows the course in time of the moisture content of an initially moist masonry after application of a borehole injection. The initial moisture distribution was assumed to be that of case 1. The top figure shows the mean total water content in the sandstone masonry. After ca. two years, the rehabilitation measure has reduced the total water content by one half. In the bottom figure, the course in time of the water content is displayed separately for each of the lower four stone courses. In the final equilibrium state, the water content in the lowest course (0 – 20 cm) has been reduced from initially 150 kg/m³ to 100 kg/m³. The reduction of water absorption from the ground reduces the equilibrium moisture content in the second stone course (20 – 40 cm) to only 40 kg/m³.

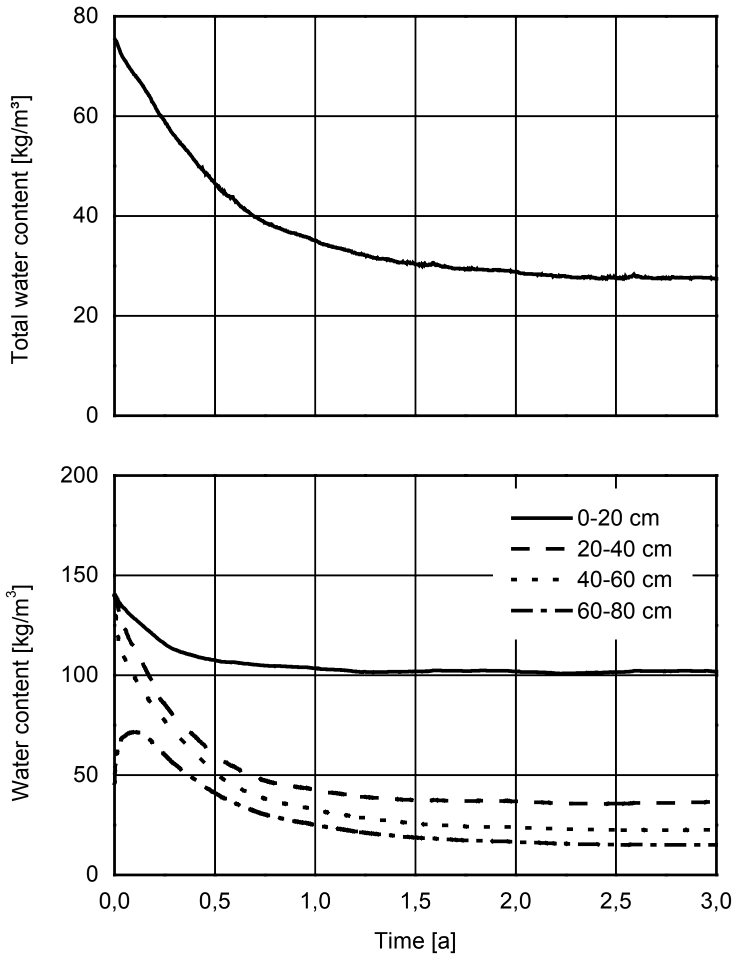


Figure 5: Course in time of the moisture content of an initially moist masonry after application of a borehole injection.
Top: Total water content per unit of area.
Bottom: Water content in different stone courses.

Discussion and practical consequences

The investigations have shown that the phenomenon of rising damp can be simulated with the two-dimensional moisture transport program WUFIZ and the results are in accordance with practical observations. For the calculations, some idealising assumptions were made which are favourable to rising damp. Despite these boundary conditions – which certainly do not occur in practice – only rise heights of ca. one meter result from the calculations. This corresponds with numerous observations in practical cases. Because of the differences in suction pressures of contacting materials and transfer resistances greater rise heights are not to be expected under realistic conditions. If in practice an increased moisture content is encountered at greater heights, we think it cannot be pure rising damp. The real causes should then be cleared up by additional investigations. In many cases, the moisture is due to an accumulation of hygroscopic salts or insufficient rain protection.

One measure to reduce or even eliminate increased moisture – if it is indeed due to rising damp – is the reduction or elimination of moisture absorption from the ground. Several methods are used for this. An overview of same currently popular methods and their advantages and disadvantages is given in [6]. These measures are usually laborious and expensive. With the aid of modern simulation method they can be assessed – as demonstrated – for their effectiveness without the need to perform often time-consuming, difficult and expensive experiments. Therefore these methods are a valuable tool for use in the planning, assessment and optimisation of rehabilitation measures.

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