Measurement of water retention properties of plaster. A parameter study of the influence on moisture balance of an external wall construction from variations of this parameter

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KEYWORDS: *water retention, moisture balance, plaster*

SUMMARY:
In sever climate layers of plaster are put on the external surface of masonry to prevent or reduce penetration of driving rain into the wall construction. The material properties of the plaster are important for the moisture balance of the wall. This paper describes measurement of water retention properties of one type of plaster. It takes a long time to produce results from one material. Plaster are available in hundreds of qualities due to different compositions from the manufacturer, how it is mixed and applied on the building site, the weather conditions during the construction period and influence from the material it is applied on. Due to possible differences regarding properties from the laboratory test, numerical calculations have been carried out to check the influence from varying water retention properties on moisture balance for a wall construction. This paper gives the result from calculations using the WUFI program and calculation for periods of one year.

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1. Introduction

Moisture balance of an external wall depends on climate load from external and internal climate in combination with how it is constructed and the material properties of each building material. Due to variations in quality it is not possible to know exactly the properties for the materials used in one building or part of building. In this work we will focus on influence from variations of one parameter of one material in one wall type. The development of computer programs has made it possible to make numerical simulations on many combinations of material parameters in a short time. This paper presents measured suction data for one type of mortar and results from long time simulation on one wall with rendering on brickwork. The suction parameter is varied.

2. Measurement of suction

Suction curve is a way to describe the water balance of a porous building material in the over-hygroscopic region. That is conditions near 100% relative humidity. It is not possible (or very difficult) to establish moisture conditions stable enough to produce sorption or desorption curves by the common method when the relative humidity becomes higher than 95%. The pressure plate method is an indirect way to find the connection between air humidity and water content. The testing procedure is described in part 2.3 and the transformation from pressure to relative humidity in part 2.4.

This method is also time consuming and demands accuracy and many labour hours to produce data for one material. Even though it is possible to run two or three materials in parallel it is time-consuming.

2.1 The tested material

Mortar for external rendering on masonry is tested. The mortar is a lime/cement/aggregate 35/65/520. Maximum diameter of aggregate is 3,5mm. Further description and other moisture related material properties of this mortar is given in (Time, Kvande, Terjesen and Sæter, 2004).

The test specimens are squares with sides about 50mm and thickness from about 9 to 12mm. Seven of the specimens are cut from a moulded cylinder and three from thinner layers of mortar. Therefore four of the specimens (including the top of the cylinder) have a normal surface for a rendering and have higher density then the rest. The cut surfaces are less smooth compared to a normal surface of a rendering.

2.2 The apparatus

FIG. 1: Pressure plate apparatus, compressor and high pressure chamber.

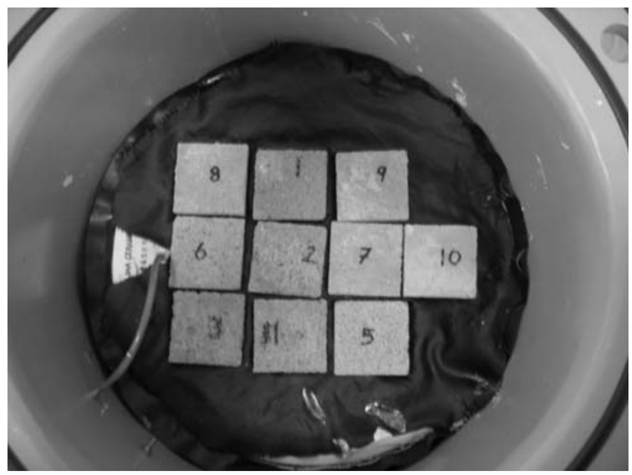


FIG. 2: Test specimens on fine meshed cloth, kaolin clay and ceramic plate in the chamber.

The apparatus shown in Fig. 1 is made by Earth Systems Solutions. The maximum pressure in the equipment is 15 bar. The pressure is automatically adjusted by the control unit connected to the compressor. To get stable and accurate measurements the chambers must be airtight and the drain hoses from below the ceramic plates must be rigid enough to resist the pressure in the chamber. In our test we went up to 12 bar pressure. Due to problems with air leakages or collapse of the draining hoses we stress that the hoses or pipes must be checked out at maximum pressure before the experiment starts.

2.3 Testing procedure

The measurement was carried out as described in (Nordtest, 1997). Saturated specimens were brought in moisture equilibrium at a number of different air pressures which control the suction. The air in the test chamber is supposed to be saturated. The mass of the specimens was determined when in equilibrium at each applied pressure. Finally, the specimens were oven dried at 105°C, and the moisture content was calculated. The laboratory set-up of the pressure plate and pressure membrane apparatus is shown in Fig. 1. Ten specimens of the material were tested as shown in Fig. 2.

2.4 Nomenclature and theory

The results from test can be displayed in many ways. The water content is given directly from the measurement as a function of pressure. To relate it to pore size, formula (1) can be used.
Pore radius, r in (m). The corresponding figures to our retention test are given in table 1.

$$r = \frac{2\sigma \cos\alpha}{s} \qquad (1)$$

Where pore radius = r, m

Surface tension of water σ = 0,078*(1-0,0032*t) N/m^2, t = temperature , °C

Contact angle: α= 0 $\Rightarrow$ cos α = 1,00

Pressure : s = suction, Pa

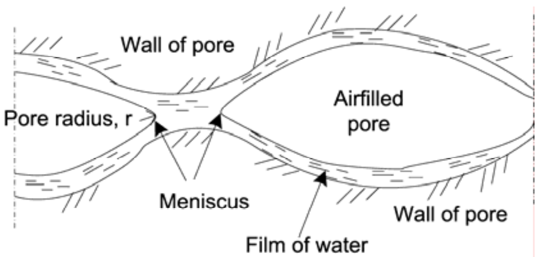


FIG. 3: Pore radius and meniscus in a pore structure.

The relation between pore radius r and relative humidity ϕ is given by the Kelvin equation. See Fig. 3 for the geometry.

$$\phi = \frac{p_v}{p_{sat}} = e^{-\frac{2\cdot\sigma\cdot\cos\alpha\cdot M_w}{\rho_w\cdot r\cdot R\cdot T}} \qquad (2)$$

Where ϕ = relative humidity

p_v = reduced saturation pressure over the water meniscus, Pa

p_{sat} = saturation pressure at normal conditions and temperature, Pa

M_w = molar mass of water = 18,015 kg/kmol

ρ_w = density of water $\approx$1000 kg/m^3

R = universal gas constant = 8314,41 m/kmol K

T = temperature, K

Table 1: Sorption pressure with corresponding relative humidity.

Pressure (bar)	0	0,03	0,06	0,15	0,3	0,6	1,5	3	6	12
Pore radius (m)	∞	5,00E-05	2,50E-05	1,00E-05	5,00E-06	2,50E-06	1,00E-06	5,00E-07	2,50E-07	1,25E-07
Relative humidity (%)	100	99,9978	99,9957	99,9893	99,9787	99,9574	99,8935	99,787	99,575	99,151

From Table 1 we see that to be able to cover the whole over-hygroscopic region a much more powerful unit is needed. There is no data from about 95 to 99% relative humidity.

The water content is given as kg/m^3 in order to correspond with the databank in the WUFI program. In the graphic presentations the pore radius at zero pressure is set to 1,0E-3 m instead of ∞ in order to make it fit into the logarithmic scales.

2.5 The results from the measurements

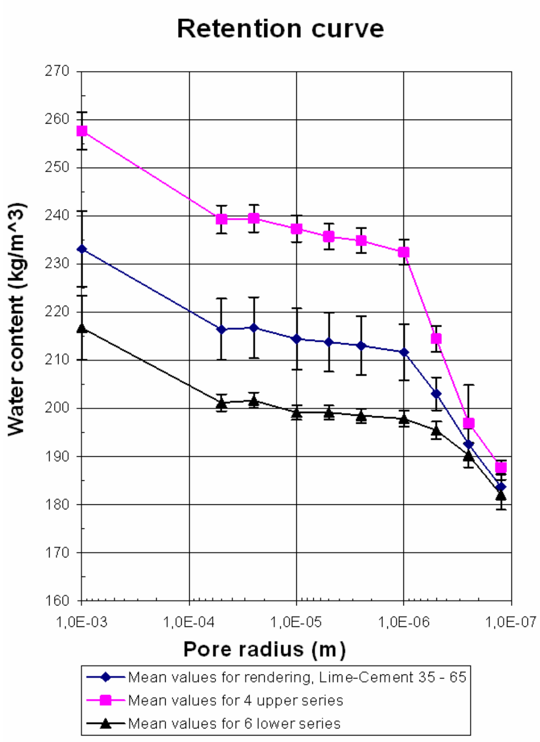


FIG. 4: Mean values for water content. The range marks show the standard deviation of the mean values.

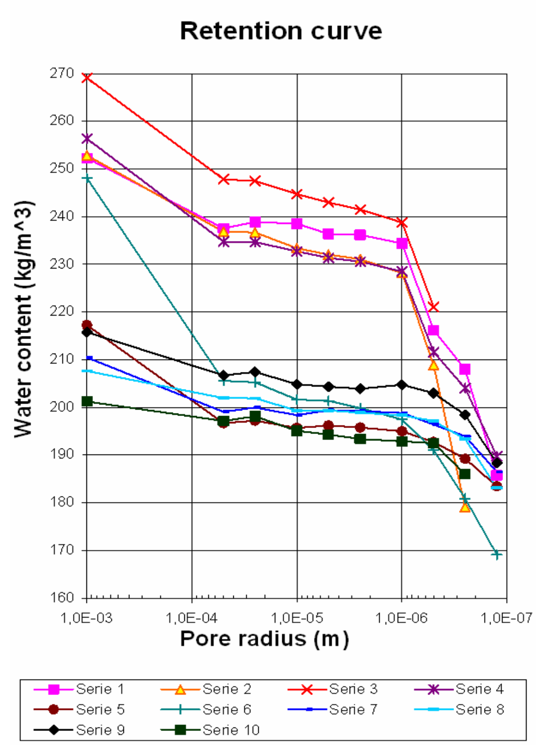


FIG. 5: Water content measured for each specimen at different pressure levels.

The results from the retention measurement are given in Figure 4 and 5. The upper four series in figure 5 are differing from the rest of the specimen. As mentioned in part 2.1 these four specimen differs from the rest by looking and feeling smoother and less porous then the rest. It is probably a result from the surface treatment of the rendering during moulding. It is normal that the concentration of cement increases in the surface of fresh concrete and mortar during mechanical surface finishing. The mortar is also better compressed near the surface.

These data from the measurements will be used in the numerical calculation on a wall construction. In order to use them in WUFI, the data are transformed from pore radius to relative humidity. The values are presented in Table 2.

3. Simulations

3.1 The computer program

In this work the program WUFI, version 3.3 (pro) has been used to calculate the moisture balance of a wall for a period of one year using local climate data for Trondheim. Material parameters including hygroscopic and over-hygroscopic region can be specified or selected from a built in material property database.

3.2 The wall constructions

The simulated wall construction is chosen to be of a type that fulfils the building code in Nordic countries regarding thermal insulation. The chosen construction is a cavity wall shown in Fig. 5. WUFI can do only one-dimensional calculations so the wall must be simplified from a real wall construction. The brickwork is modelled with material properties for a combination of lime mortar and bricks. There is a 20mm air gap between the masonry and the insulation. The rendering on the outside is 15mm thick. The quality of all material except the external rendering is kept constant during the different simulations.

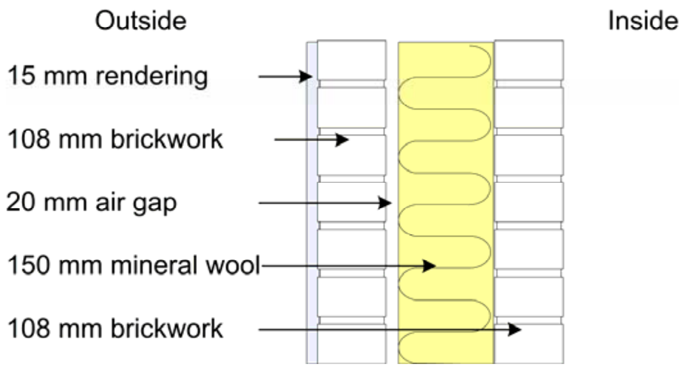
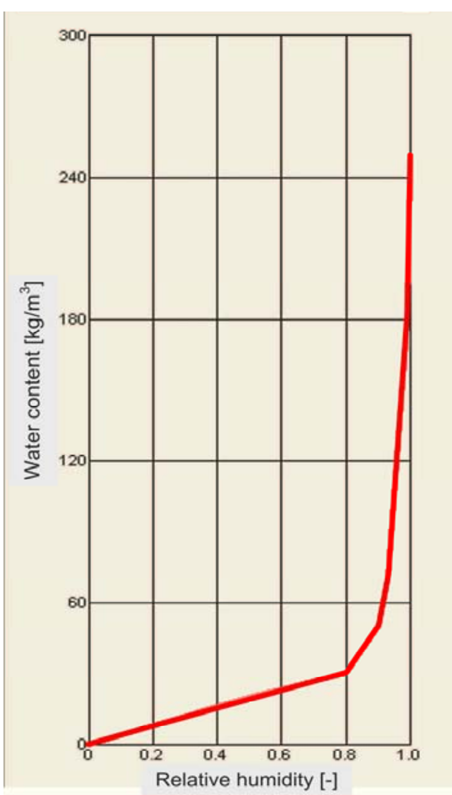


FIG. 6: Wall construction for numerical simulations. Material properties for the lime-cement rendering are given in Fig. 7.

3.3 Material properties used in the simulations



Tabular values for the lime rendering from WUFI database		*Results from our measurement Mean of 10 specimen given by fewer points*	*Results from our measurement Mean of 10 specimen*
RH [-]	[kg/m^3]	Water content [kg/m^3]	Water content [kg/m^3]
0,0	0,0		-
0,5	20		-
0,8	30		-
0,9	50		-
0,93	70		-
0,96	120		-
0,99	180	180 *	180 *
0,991519			183,7
0,995751			192,6
0,996	210	194 **	194 **
0,997873			203,1
0,998936			211,7
0,999574			213,0
0,999787			213,8
0,999894			214,4
0,999957			216,8
0,999979			217,0
1,000000	250	233,1	233,1

Moisture storage function for the lime rendering given in the material database in WUFI

*) extrapolated values
**) interpolated values

FIG. 7: Moisture storage functions for lime rendering in graphical and tabular form. The two columns to the right are measured data.

The data from our measurements corresponds very well with the suction data in the WUFI database.

In Fig. 8 and 9 the results from all 10 spesimens and the split up series of 4 and 6 specimens are compared with WUFI-data.

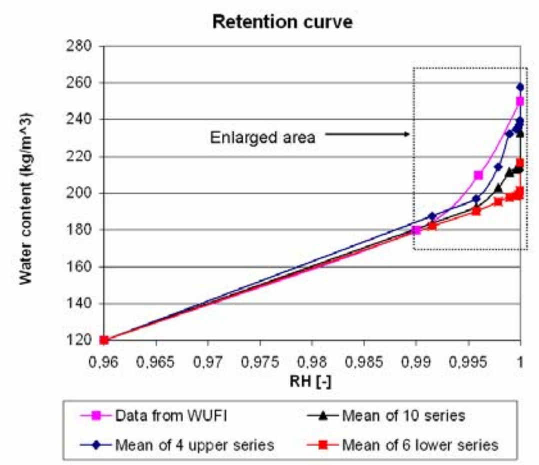


FIG. 8: Linear display of WUFI sorption-data and test results. The point at (0,96, 120) is not measured in the laboratory. It is a point on the WUFI-curve and is chosen as a fixed point for the start of the over-hygroscopic region for measured and varied suction curves.

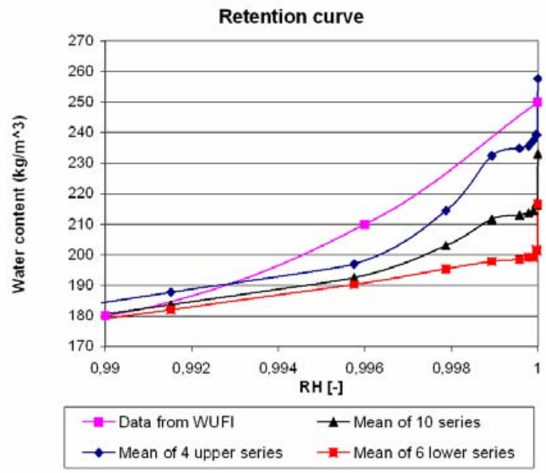


FIG. 9: Enlarged dotted frame from figure 8. This is a tool to select simplified data for the WUFI-simulation.

The selected RH-values for the storage function are based on a note in the "help" part of the WUFI-program. "The pressure plate measurements would even allow a still finer subdivision of the table in the high-moisture region, but then at $\phi \approx 1$ the curve would approach the ordinate so closely that its immensely steep slope might cause numerical problems." Because of this the data are entered as linear values for ϕ = 0,99; 0,996 and 1,000. The very steep part of the sorption curve is not entered correctly for all series. In Table 2 the simplified input datasets are presented. The right column in figure 7 displays the input data for dataset 3 in Table 3.

Table 2: Retention data from measured renderings and data chosen as upper and lower limit of the property to test the influence from a wide variation. Data for the region from 0,96 and down are kept constant.

	Water content [kg/m^3]					
RH [-]	WUFI Lime mortar	Measured mean of all 10	Measured mean of upper 4	Measured mean of lower 6	Lowest water content	Highest water content
0,99	180	180	185	179	144	216
0,996	210	193	198	191	168	252
1,00	250	233	258	207	200	300
Dataset:	1	2	4	5	6	7

The materials: "highest and lowest" water content has 20% higher and lower values than WUFI lime mortar.

3.4 Climate and surface data used in the calculations

Climate data for one calendar year for Trondheim was used. To avoid too much influence from solar radiation the wall was oriented to the east. Because of the insulation inside the wall the temperature in the outer part is near the out door temperature.

The indoor air humidity was set to medium, i.e. it varied between 40 and 60% RH during the year. On a test run with low indoor humidity the moisture content in the external parts was reduced less than 0,3 kg/m^3.

Regarding radiation the rendering was described as light grey. I.e. solar absoptivity = 0,4 and long wave emissivity = 0,9.

3.5 Results from the calculations

Table 3: Water content in external rendering and masonry given as maximum and minimum during the year and at the end of the year depending on sorption data in the calculations.

		Moisture content in rendering and 108 mm brickwork [kg/m^3]						
Rendering data from		WUFI Lime mortar	Measured mean of all 10	Measured mean of all 10, accurate input	Measured mean of upper 4	Measured mean of lower 6	Lowest water content	Highest water content
Lime rendering	Minimum	21,68	21,68	21,68	21,68	21,68	21,68	21,69
	End of year	86,97	86,95	86,95	86,93	86,61	86,34	86,78
	Maximum	194,06	194,39	194,91	196,05	189,28	175,31	208,87
108 mm masonry	Minimum	20,64	20,64	20,64	20,64	20,64	20,63	20,64
	End of year	53,84	53,81	53,79	53,69	52,87	52,87	53,03
	Maximum	53,84	53,81	53,79	53,69	52,87	52,87	53,03
Dataset number in Fig. 10		1	2	3	4	5	6	7

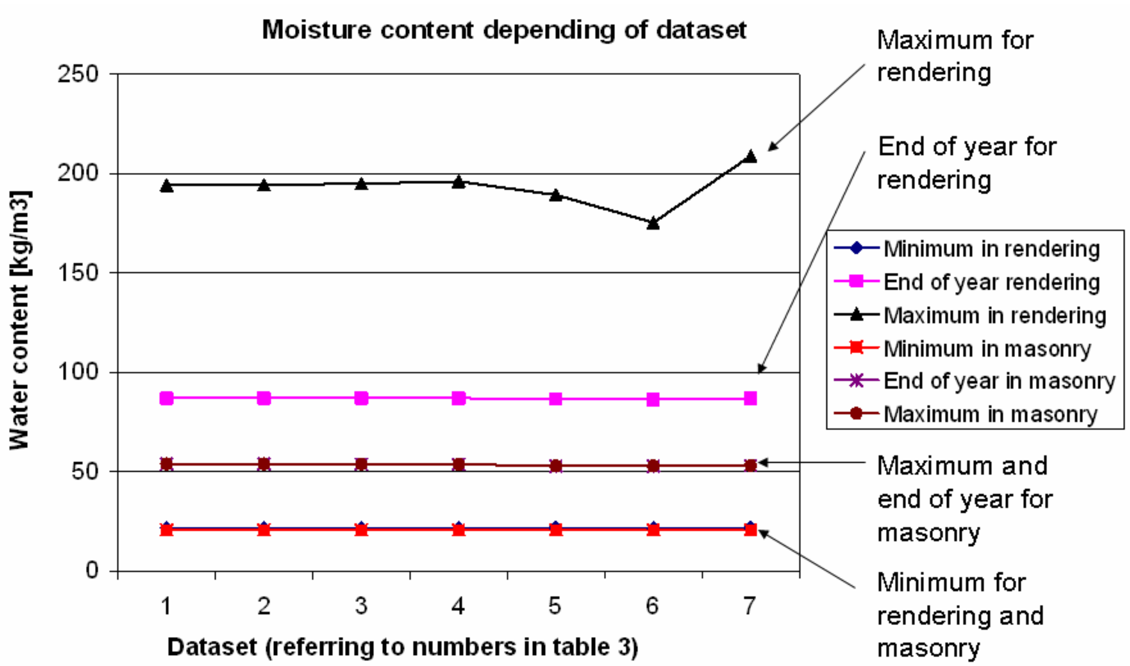


FIG. 10: Moisture content in rendering and masonry from table 3.

3.6 Discussion of the results

The calculated moisture content in the external parts of the wall is hardly influenced by the differences in suction data for the rendering. Only the maximum value for the period is increased and decreased by about 10,5% from 20% change of the sorption curve in the over-hygroscopic region.

The maximum values occur after a heavy driving rain period in September.

The calculations with dataset 2 and 3 show no difference. The form of the suction curve above 99% RH seems to influence the moisture balance very little. The maximum value at 100 % RH is the important parameter.

When doing an extra calculation with data set 3 but increasing the solar absorptivity by 20% (from 0,4 to 0,48) the moisture content (all 3 values) in the masonry is reduce by 2% and 1,1% in the rendering. Except for the maximum value in the rendering the variations in the suction parameter have much less effect than solar absorptivity.

4. Conclusions

Based on WUFI calculations, it seems like the influence on resulting moisture content from inaccurate values of water retention in the over-hygroscopic region is marginal. It does not seem necessary to do accurate measurements for all materials. For calculations of moisture balance of building parts the less precise and time consuming measurements can be sufficient. I.e. decide the maximum capillary water absorbtion for the material and the sorption curve up to 95%. Data for the region 96 to 99,999 can be interpolated (predicted) sufficiently accurate for most purposes by giving the curve a shape that correspond to curves from similar materials.

5. References

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