John Grunewald, Oct-02-2006

Brick Masonry Insulation

Project overview

The vitalization of the historical building stock demands planning of reconstruction measures that increasingly aim at protection of our cultural heritage and energy-efficient renovation as well. But these requirements can be contradictory sometimes. Questions arise, e.g.: What is the potential and the risk of a thermal insulation? Which materials and which thickness would be appropriate for application in historical buildings? Two internal insulation options were discussed, one based on vapor-tight cellular glass and another one using capillary-active calcium silicate. Both variants and, as a reference case, the existing construction without insulation were investigated by application of numerical simulation software. Results are presented here for undisturbed one-dimensional wall constructions exposed to climate conditions of Amsterdam on an hourly basis.

Construction

Two insulation options were investigated, cellular glass and calcium silicate, in comparison to the existing non-insulated wall construction. The three build-ups used for analysis of the undisturbed wall area are represented in Figure 1.

The numerical analysis includes:

- annual courses of temperature, relative humidity and water contents,
- temporal courses of integral moisture contents and condensate mass,
- proof of condensation risk at internal wall surfaces as well as compliance of humidity criterion concerning mold growth (short term exceeding of 75% R.H. for maximum 10 days),
- quantification of energy savings.

The initial conditions were chosen to account for the experimental results of the brick moisture measurements. According to the authors investigations, the inner brick range (historical brick) was assumed entirely saturated by about 20Vol%. The outer clinker layer and the insulation layer were set initially to moisture contents in equilibrium to 80% R.H. The initial temperature of the whole construction was 10°C.

After a certain settling time, the physical quantities (e.g. water content and temperature) in every part of the construction recur in the simulation over the year. This means that they reach, according to the cyclic climatic conditions, a quasi-stationary state. This process can take years, but the main changes take place during the first months. This process is pronounced by the material properties and by the chosen initial conditions. The duration of simulations of five years was long enough to reach almost quasi-stationary conditions.

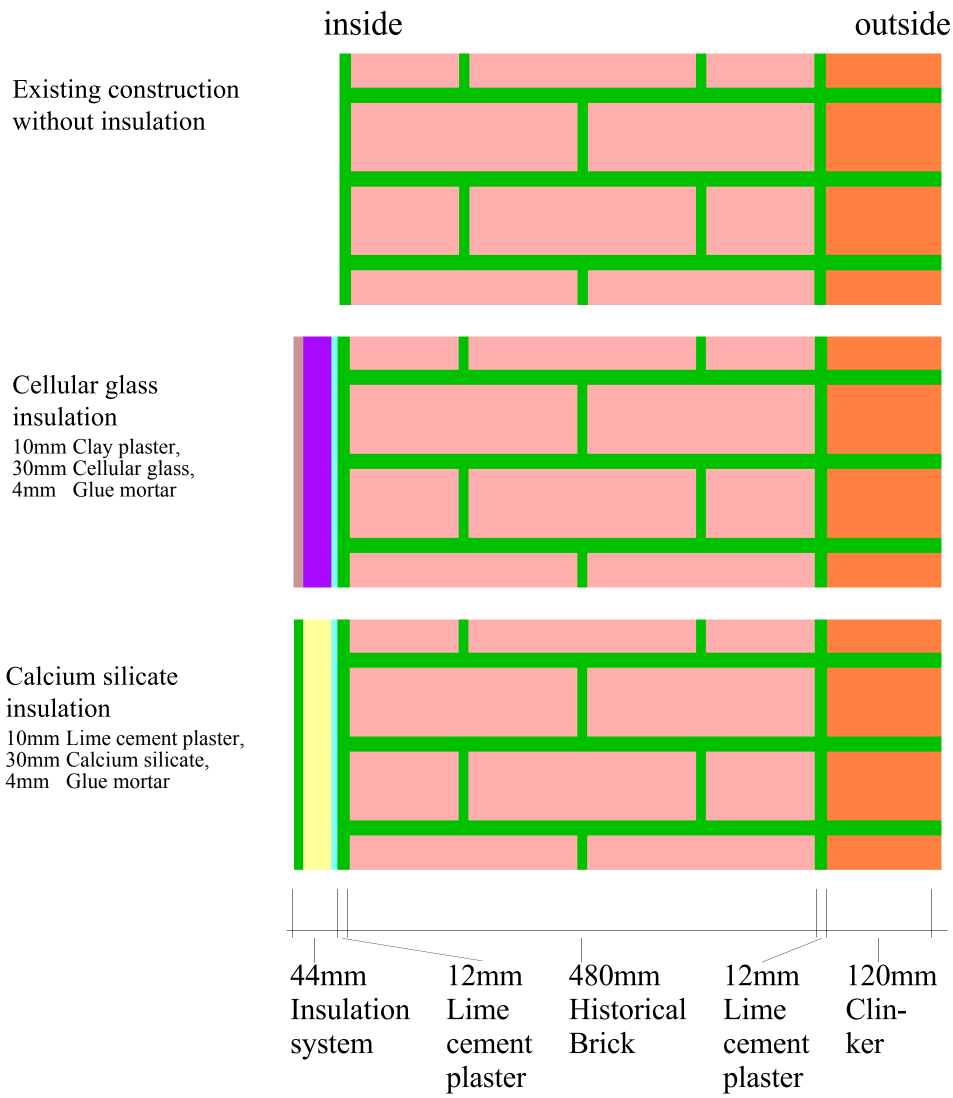


Fig. 1: Build-up of the existing non-insulated construction (top), insulation option one with cellular glass (middle) and insulation option two with calcium silicate (below)

Climate conditions

During the simulation, the constructions are exposed to non-steady-state climatic conditions at interior and exterior sides. The annual course of temperature and relative humidity, the impact of driving rain, short and long wave radiation were taken into account on hourly basis. An climatic data set of Amsterdam provided by *Arup (2004)* was used for the external conditions; the set contained temperature, relative humidity, radiation and wind measured over one year. Hourly rainfall values were taken from the weather station most close to the city of Amsterdam. The monthly rainfall values (in total 848 l/m²·a) used in the analysis are slightly higher than the monthly average rainfall data of Amsterdam from 1981 to 1990 (in total 832 l/m²·a).

The driving rain density on the wall surfaces is calculated from wind direction, wind speed and rain fall density on a horizontal surface area (Figure 3). The highest rainfall density is reached at constructions exposed to the west, here, about 1/4 of the rain fall density on a horizontal surface area. That is the reason why, in order to be on the save side, all wall constructions have been analyzed as west-facing. The impact of direct solar radiation has been calculated for a west-facing wall as well. In addition, the diffuse solar radiation and the long wave radiation balance were taken into account. The simulations are usually conducted for a time period of several years. It was assumed that the climatic conditions will recur periodically every year. Interior conditions are described according to the ambient design conditions communicated by *Arup (2002)* (summer 23°C / 54% r.h., winter 20°C / 50% r.h., tolerance ±2K / 5% r.h.). The interior climate has been modelled by sinusoidal functions as shown in Figure 2. The temperature curve represents exactly the proposed conditions, without the allowed tolerance of 2K.

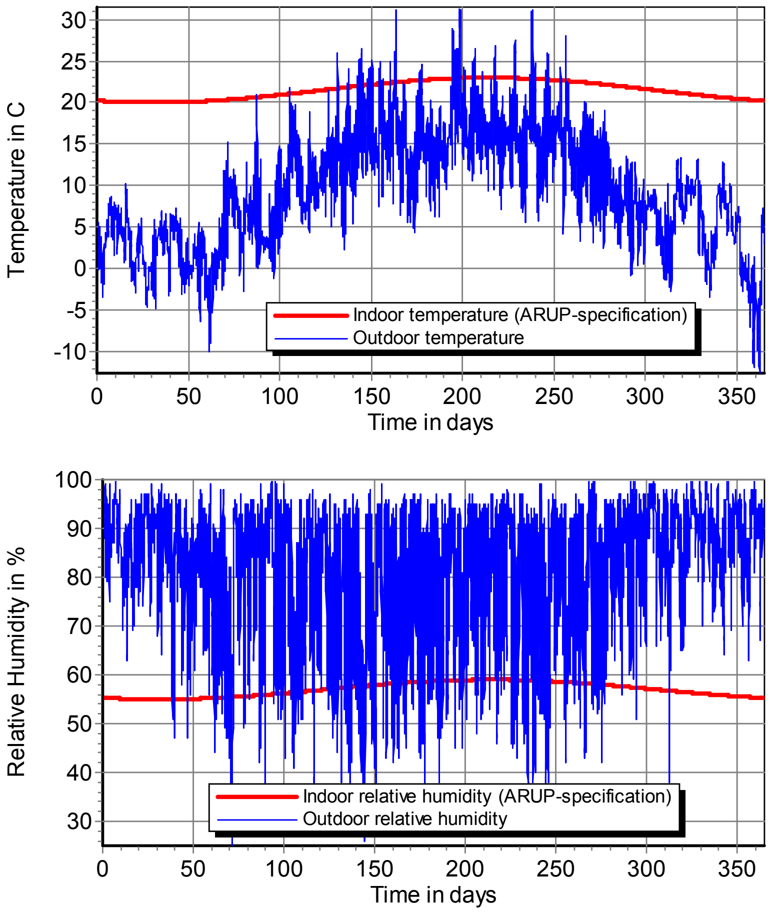


Fig. 2: Courses of indoor and outdoor temperature and relative humidity used for simulation

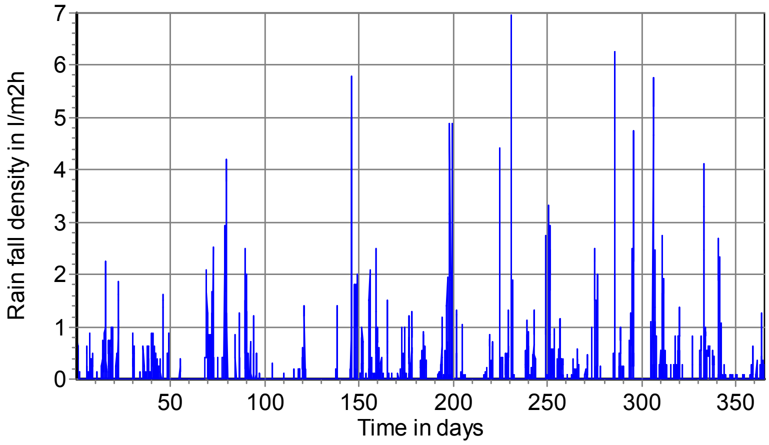


Fig. 3: Rainfall on a horizontal surface (data from nordic coast region of Germany)

Material data

The most important material parameters used for simulations are collected in Table 1. The two insulation materials have oppositional properties. Cellular glass has no liquid water conductivity and a very high resistance to water vapor diffusion, whereas calcium silicate is characterized by high liquid water conductivity (capillary activity) and low water vapor diffusion resistance.

Tab. 1: Basic material parameters for simulation

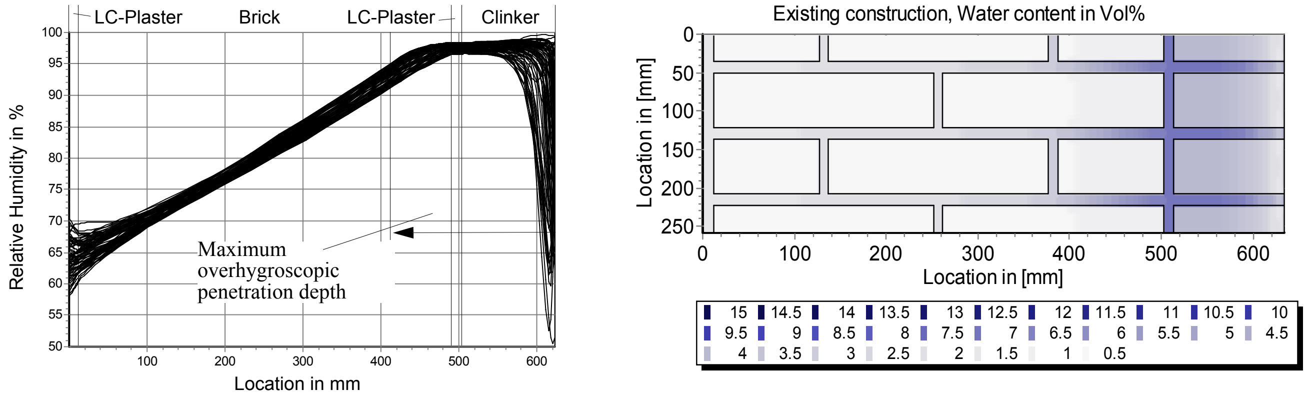
	Density	Specific heat capacity	Thermal conductivity	Vapour diffusion resistance	Water content at 80% R.H.	Capillary saturation	Water uptake coefficient
Symbol	r	c	λ_R	μ_{dry}	θ_{80}	θ_{cap}	A_w
Unit	kg / m^3	J / kgK	W / mK	-	m^3/m^3	m^3/m^3	kg / m^{2}s$^{0.5}$
Historical brick	1700	840	0.850	9	0.006	0.320	0.25
LC-plaster	1800	1050	1.05	21	0.022	0.250	0.052
Cellular glass	200	1470	0.045	70000	2e-4	0.001	0
Glue mortar	1516	1000	0.700	32	0.073	0.300	0.012
Clay plaster	1700	1000	0.870	12	0.014	0.300	0.052
Calcium silicate	270	1000	0.065	5	0.006	0.820	1.24
Clinker	2100	920	0.960	25	0.008	0.180	0.03

Results

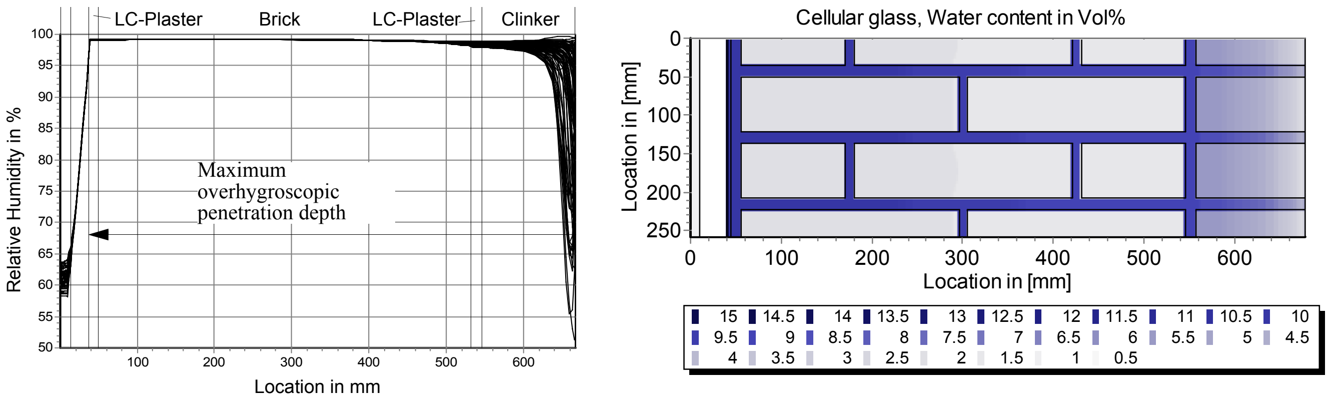
In the graphs in Figure 4, the simulation results are represented in terms of relative humidity and water contents as function of location and time. The water content fields on the right side document the drying stage of the three build-ups reached at Dec.31 after 5 years drying time. The image presentation allows a quick overview of the moisture situation and gives a descriptive impression about the differences in drying behavior of the constructions. For the reference build-up without insulation, moisture distribution has reached a maximum between outer clinker layer and inner brick layer. While drying can take place in both directions, the only possible moisture penetration is that from outside caused by rain.

A more detailed quantitative image give the graphs on the left side of Figure 4 where the relative humidity profiles are depicted during a full course over the fifth year. The black range indicates the local variation of the relative humidity over the year at the respective position.

1. Reference case without insulation



2. Build-up with 30mm cellular glass insulation



3. Build-up with 30mm calcium silicate insulation

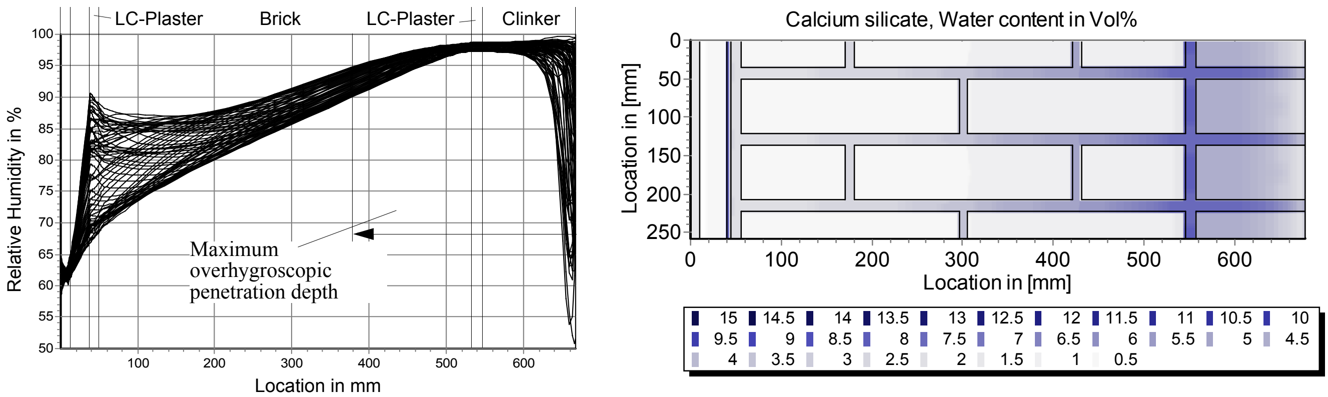


Fig. 4: Profiles of relative humidity versus location during the 5th year (left) and water content fields at the end of five years simulation (right). Existing construction (top), 30mm foam glass insulation (middle) and 30mm calcium silicate insulation (below).

The integral moisture mass of the wall cross section is an indicator for the long term behavior. The comparison of the three build-ups, shown in Figure 5, demonstrates a clear difference between cellular glass and calcium silicate.

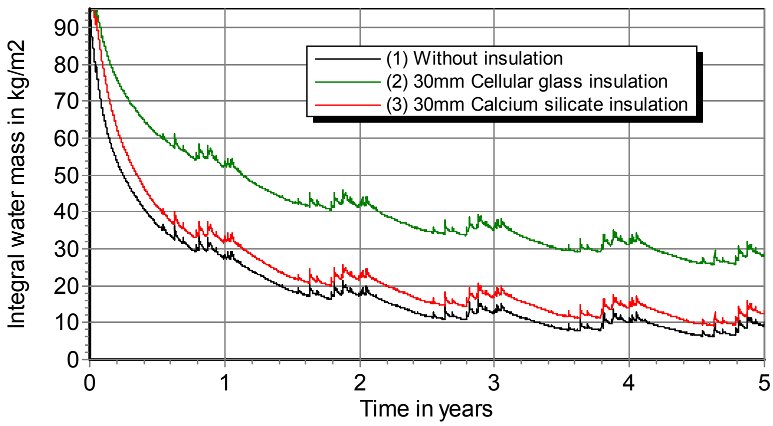


Fig. 5: Integral moisture content for different build-ups over 5 years

The curves in Figure 6 show the integral moisture contents of build-ups with 30mm, 40mm and 50mm thick calcium silicate insulation. While the curves for 30mm and 40mm are practically identical, a slight increase can be noticed for 50mm. This slightly increased moisture content is interstitial condensation that forms due to the lowered temperature in the condensation layer between calcium silicate and glue mortar. However, the course of the integral water mass is dominated by rain penetration.

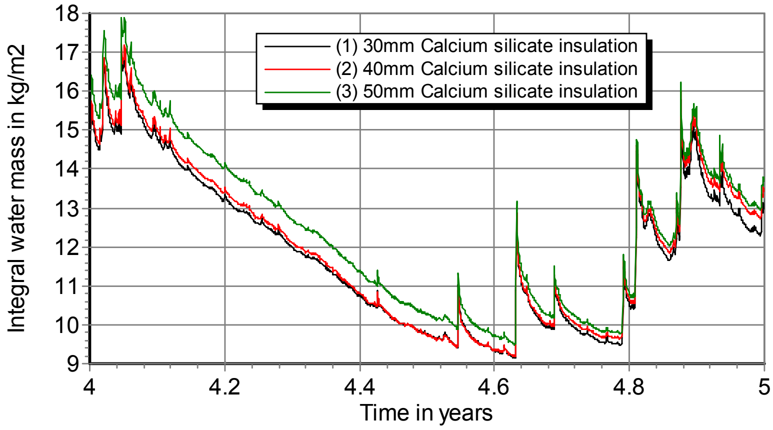


Fig. 6: Integral moisture content for different calcium silicate thicknesses in the 5th year

During the heating period, especially on the inside of wall surfaces and on the cold side of the insulation layer, the occurrence of condensation becomes probable. Condensation can form as surface condensation or as interstitial condensation. For evaluation of the condensation risk, overhygroscopic water mass by condensation and by rain penetration must be distinguished. Therefore, condensate is defined here as a moisture content that is *not* caused by rain penetration and that exceeds the „natural“ moisture content of the material in equilibrium to a relative humidity of 95%.

The graphs in Figure 7 show the amount of interstitial condensate as function of time for different thickness of calcium silicate. The higher condensation values during the first two years are caused by redistribution of the initial moisture of the brick layer. After decaying of the high initial values, the condensate is constantly less than 300 g/m^2.

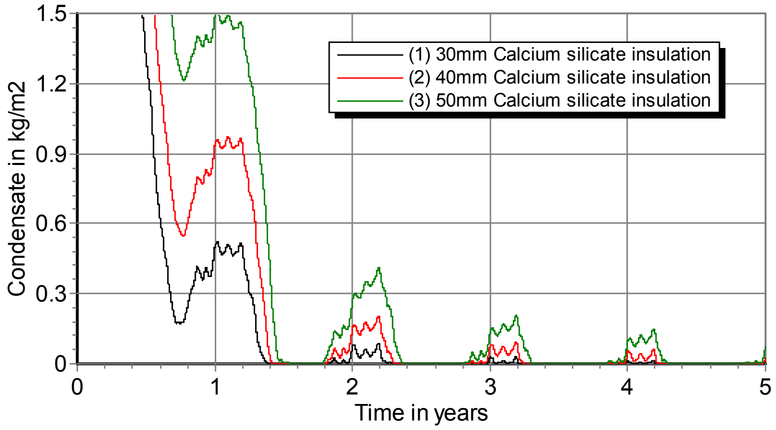


Fig. 7: Amount of interstitial condensate for different thicknesses of the calcium silicate layer over 5 years

The risk of mould growth and surface condensation can be evaluated knowing the temperatures and relative humidity on the inner surface of the walls. Figure 8 shows the course of the relative humidity on the inner wall surfaces during the fifth year.

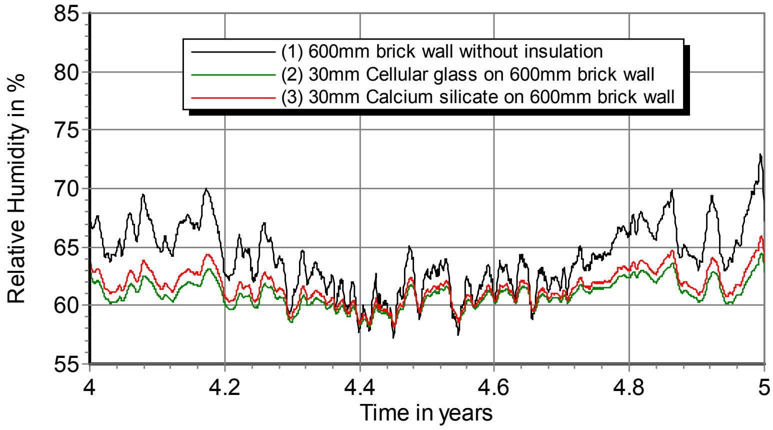


Fig. 8: Course of relative humidity on inner wall surface during the 5th year for a brick wall of 600mm thickness

If a construction with 400mm brick is considered the need for internal insulation becomes more evident, see Figure 9. A difference of about 15% in relative humidity and 3.3°C in temperature between the current situation and the build-up with foam glass can be observed in this case. At the end of December, the surface of the existing built up cools down to 14°C. Here, mould growth and surface condensation is likely, in particular at critical construction details.

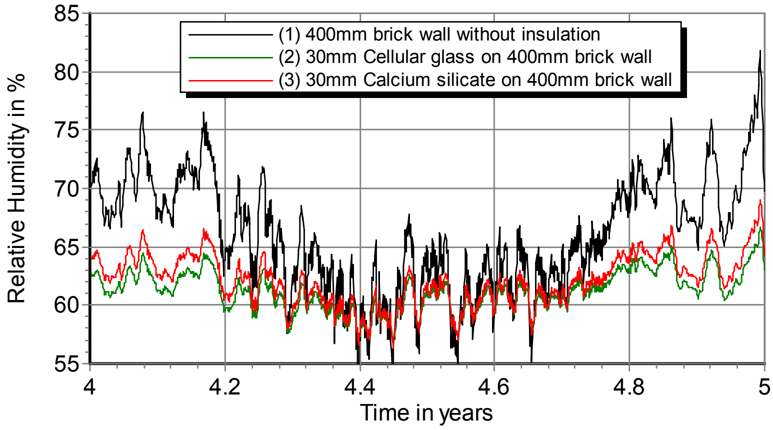


Fig. 9: Course of relative humidity on inner wall surface during the 5th year for a brick wall of 400mm thickness

A comparison of the interstitial condensate between the 400mm and 600mm brick walls is shown in Figure 10. The risk of condensation normally increases with lower wall thickness. Here, the 400mm brick wall shows slightly increased values but lays still in the harmless range of max. 0.1 kg/m^2. In the first winter, it falls below the curve of the 600mm wall due to its faster drying behavior.

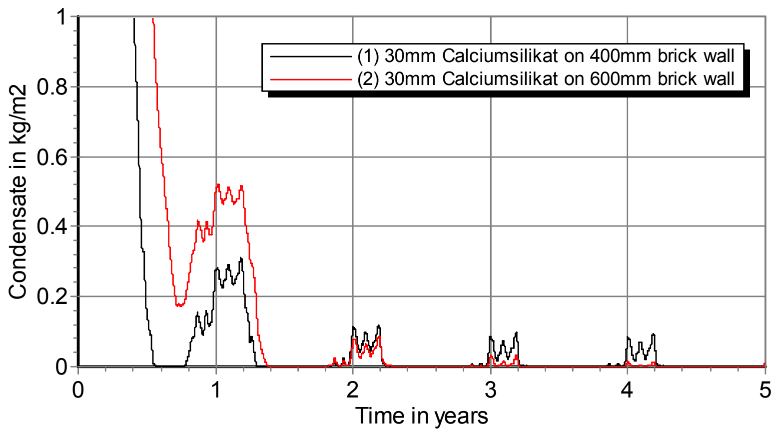


Fig. 10: Course of interstitial condensate during the 5 years for brick walls of different thicknesses