Hygrothermal analysis of external walls within the reconstruction of the Rijksmuseum Amsterdam

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Abstract

In the framework of the refurbishment process of the Rijksmuseum Amsterdam, it is intended to provide an adequate internal insulation of the exterior facades, which increases indoor climate quality, ensures hygric durability and reduces heat losses. This contribution shows the suitability of a capillary active internal insulation in order to distribute the interstitial condensation and the penetrated rain water. Foam glass prevents the drying potentials and leads to the destruction of the brick wall.

1 Introduction

This expertise investigates the hygrothermal behaviour of two different internal insulation options: cellular glass and calcium silicate. Of course, as a reference case, differences to the behaviour of the current construction are also analysed. The façade of the Rijksmuseum (fig. 1) is worth preserving and can not be covered with an outside insulation material.

All important results are summarized and recommended one insulation system with a specified thickness of the insulation layer. The analysis is carried out with the simulation software DELPHIN [1], which has been developed at the Institute for Building Climatology for research purposes. With this software tool the coupled heat and moisture transfer through porous media with known material functions can be calculated.

During the simulation, the construction is exposed to hygrothermal loads. Unsteady influences i.e. the annual course of temperature and relative humidity, the impact of driving rain, short and long wave radiation are taken into account. Air and salt transport will not be considered.



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2 Construction

Apart from the current construction with 600 mm brick and 12 mm lime plaster on the interior, the results of build-ups with two different internal insulation options will be compared.



Figure 1: Rijksmuseum Amsterdam.

Option 1 uses 25mm calcium silicate, attached with 4mm glue mortar, option 2 assumes 30mm cellular glass (foam glass), also attached with 4mm glue mortar, and 20mm clay plaster layer on the interior. Different variants with other thicknesses of the calcium silicate layer are also examined. The three constructions are represented in fig. 2.

Most material data for the heat and moisture transport and storage has been measured in the Institute for Building Climatology and taken from the material data base of DELPHIN. Figure 3 contains the values of density, specific heat capacity, the thermal conductivity and the parameters of the moisture storage function (hygroscopic moisture content by a relative humidity of ϕ=80%, saturated water content by completely filled pores) and for the moisture transport function (water uptake coefficient in case of the direct water contact, vapour diffusion resistance coefficient).

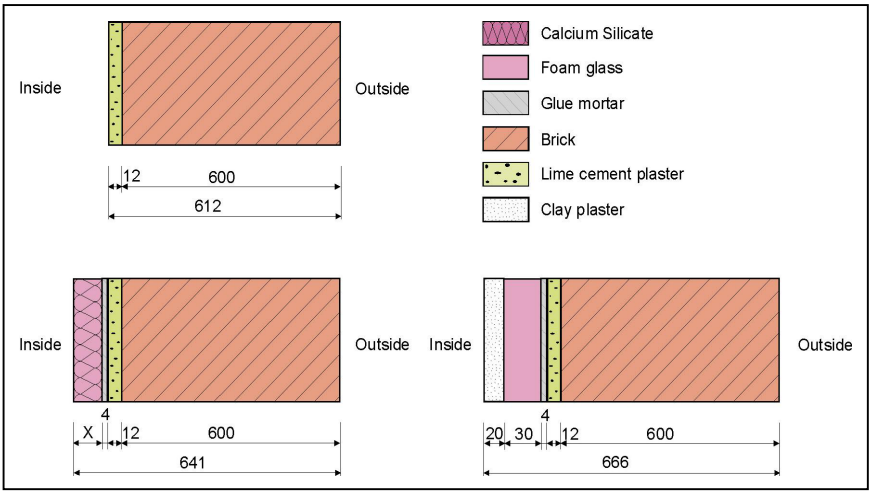


Figure 2: Build up of the construction (top left), insulation option 1 with calcium silicate (bottom left) and option 2 with foam glass (bottom right).

	Density	Specific heat capacity	Thermal conductivity	Water content at 80%	Capillary saturation	Water uptake coefficient	Vapour diffusion resistance
Symbol	ρ	c	λ_R	Θ_{hyg}	Θ_{cap}	A_w	μ_{dry}
Unit	kg / m³	J / kgK	W / mK	m³/m³	m³/m³	kg / m²s^{0,5}	-
Brick	1700	840	0,850	0,004	0,32	0,240	9
Lime plaster	1800	1050	1,050	0,021	0,25	0,050	21
Foam glass	200	1470	0,045	0,0002	0,80	-	70000
Glue mortar	1516	1000	0,700	0,078	0,30	0,030	32
Clay plaster	1700	1000	0,870	0,014	0,30	0,100	12
Calcium silicate	270	1000	0,065	0,006	0,79	0,975	5

Figure 3: Material parameter used for the calculation of the moisture fields.

3 Interior and exterior climate conditions

It was assumed that the climatic conditions will recur periodically every year. As a result, all climate conditions, in particular the boundary conditions, remain unchanged on wall surfaces, which means that the room climate or boundary conditions are not influenced by the hygrothermal behaviour of the wall. According to the ambient design conditions (summer 23°C / 54% r.h., winter 20°C / 50% r.h., tolerance ±2°C / 5% r.h.), the interior climate has been defined with sinusoidal curves as follows:

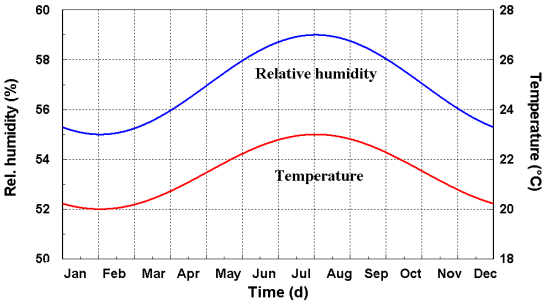


Figure 4: Temporal course of internal relative humidity and internal temperature.

The temperature curve represents exactly the proposed conditions, without the allowed tolerance of 2°C. To achieve conservative, "worst-case" results, the relative humidity is assumed to be at the upper limit of its tolerance (5%) band, which could be caused by high visitor frequency. A higher relative humidity in rooms leads to higher relative humidity on the inner surface and increased water vapour transport from the inner to the outer side during the heating period. As a result the risk of surface condensation and the amount of condensate in the construction increases.

An hourly climatic dataset of Amsterdam was used for the external conditions; the set contained temperature, relative humidity, radiation and wind measured over a year. Figure 5 pictures the hourly rainfall values on a vertical surface, used in the simulations. The highest rainfall density is reached at constructions exposed to the west. Again, to achieve a safer level with the results, all built-ups have been analysed as west-facing.

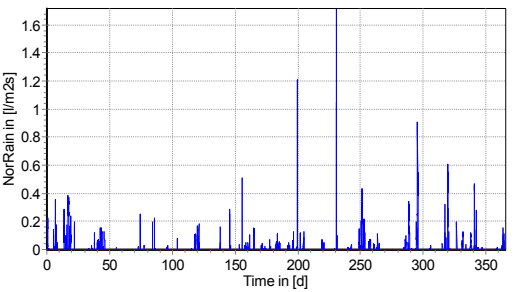


Figure 5: Hourly rainfall on a wall in Amsterdam, exposed to the west.

4 Results

In this chapter the current construction will be compared with two insulation options: calcium silicate and foam glass. In particular the depth of penetration of driving rain, the development of the inner condensate, the relative humidity and

temperature on the inner surface, the cooling of the current construction, the long-time behaviour, the U-value and the heat loss are observed.

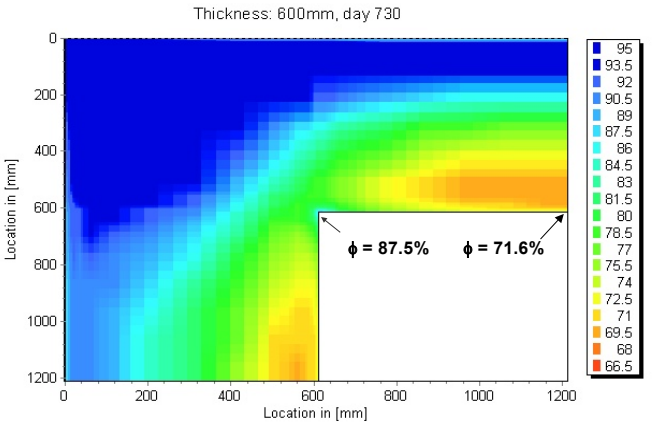


Figure 6: Distribution of relative humidity within the structure, day 1460-Jan. 1st.

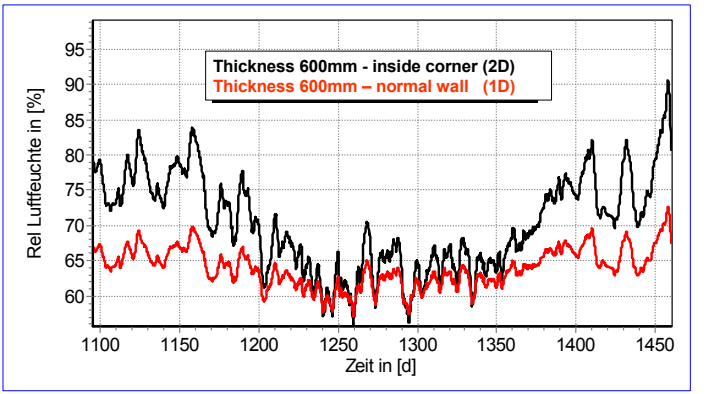


Figure 7: Course of relative humidity on inner surface and corner in the 4th year.

Figures 6 and 7 show the current situation. The penetration of driving rain is visualized in the profile of the relative humidity (ϕ =95%) in Fig. 6. Caused by driving rain and the bad thermal resistance of the brick wall (U=1.22W/m²K) the relative humidity on the corner can reach 87.5 % (despite of the mild Dutch winter climate) and indeed mould has been observed in the past. That means the heat protection of the wall has to be improved (e.g. U=0.7W/m²K).

High water content in constructions favours the degradation of building materials by frost, chemical and biological damages. For this reason, the humidity penetration should not exceed a certain level. This level is exceeded with the build-up with foam glass. In contrast to calcium silicate, foam glass has

no liquid water conductivity and water vapour conductivity to reduce locally the water content; this allows water to flow at certain points towards the inner surface through gaps, joints etc., and enables at these locally limited areas condensation, mould growth or stains on the inner surface. Moreover the vapour resistance is very high and the structure can not dry out to the inside. Fig. 8 shows the integral moisture content for the three cases. Rainfall, temperature and relative humidity on the outer surface are responsible for the rise in late summer, autumn and winter. An additional inside insulation with foam glass is the worst case (14kg/m²).

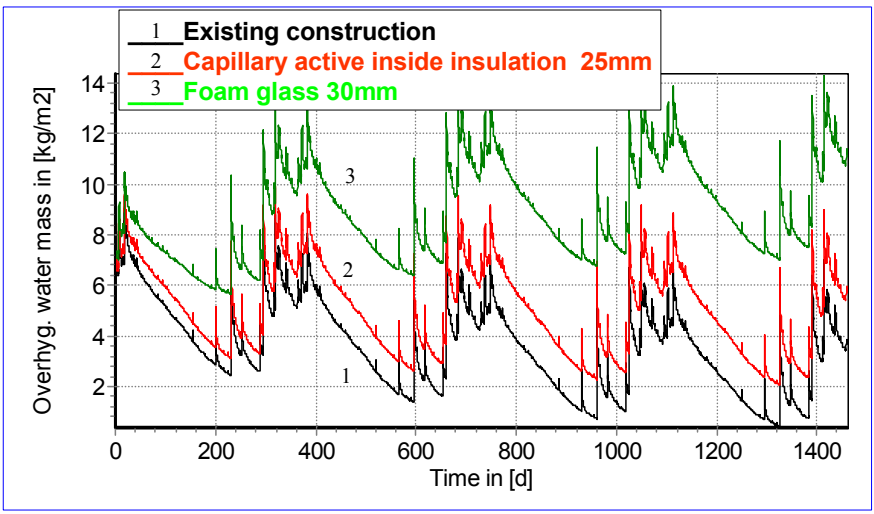


Figure 8: Course of integral moisture content in the structure in time.

Fig. 9 and 10 represent the three-dimensional illustration of the water content's profile in the 4th year (compare [2],[3]). Again, the influence of rain, radiation and temperature can be recognized on the outer surface of the walls (upper right side) by the very alternating profiles. The moisture retarder of glue mortar is responsible for the relatively high but not critical water content, in the brick wall caused by penetrated driving rain in fig. 9. On the other hand the capillary active calcium silicate inside insulation distributes the interstitial condensation and the inner part of the renovated structure is relatively dry. Moreover, the inner surface temperature is quite high and the mould formation will be avoided.

In fig. 10 it can be seen that the glue mortar and brick is very moist due to the total vapour barrier of the foam glass preventing the drying out effect of the penetrated rain water to the inside. Hence, moisture and frost damage can follow.

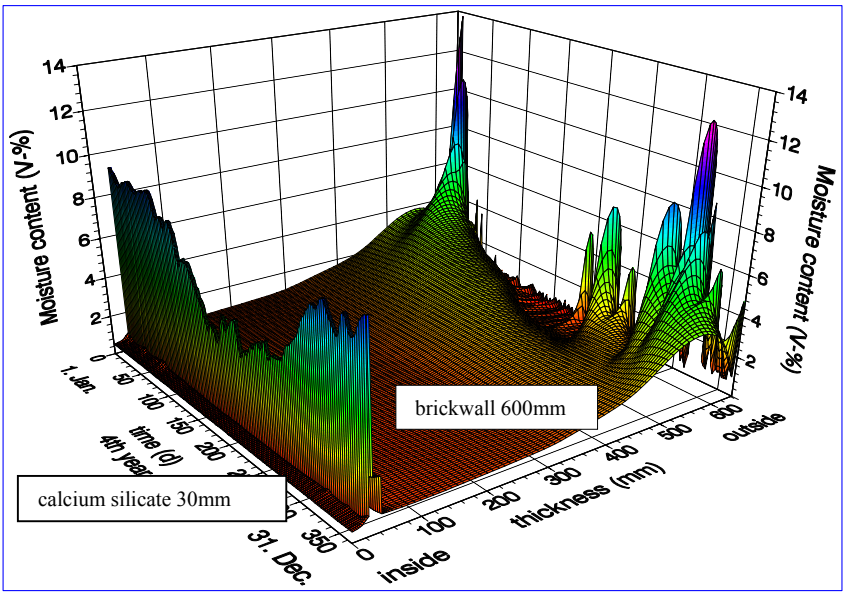


Figure 9: Profile of water content in the whole construction (build up with 25 mm calcium silicate, 4th year).

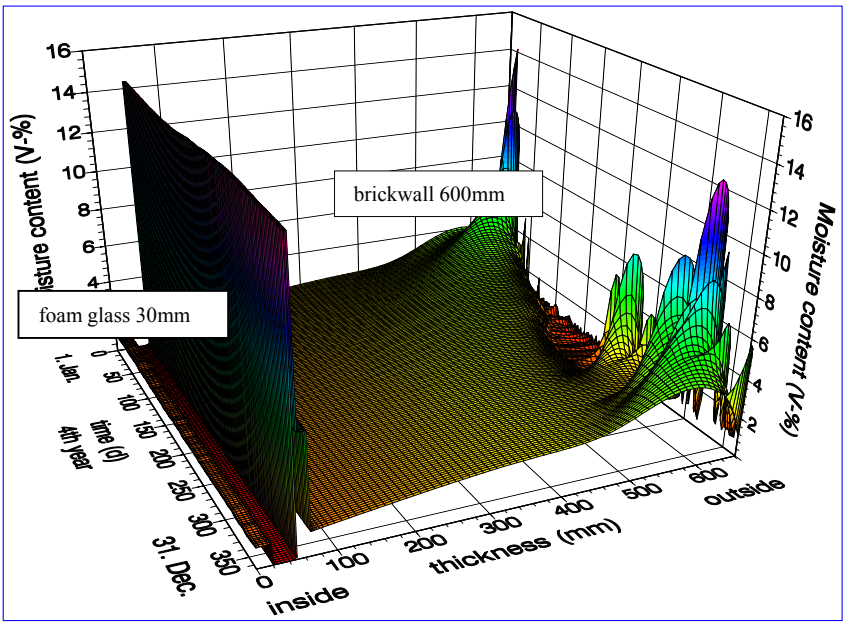


Figure 10: Profile of water content in the whole construction (build up with 25 mm calcium silicate, 4th year).

The distribution and capillary drying of the interstitial condensation water by calcium silicate can be demonstrated also by the plain software COND 2002 [4]. The user only has to choose the material and the thickness of the construction layers. The display shows the U-value, the moisture content and the moisture distribution etc. The indoor and outdoor climate has been simplified (3 month winter climate outside: -5°C,80%, inside 20°C, 50%).

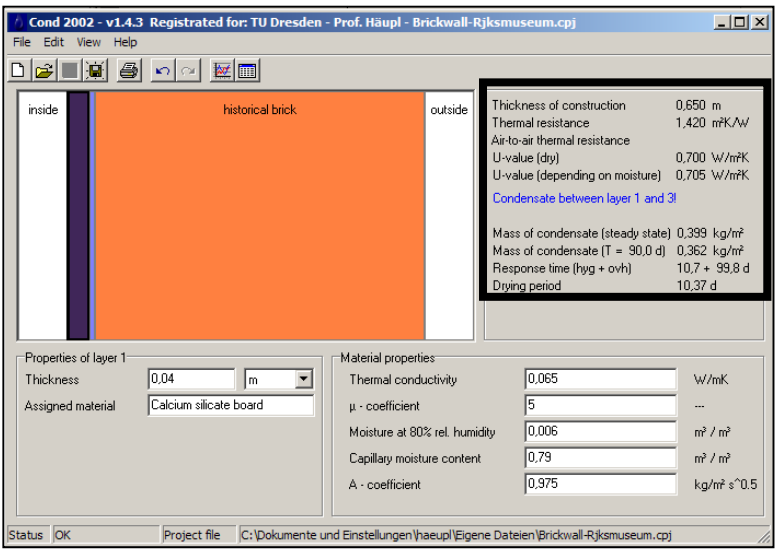


Figure 11: Tableau for the program COND - results in the frame.

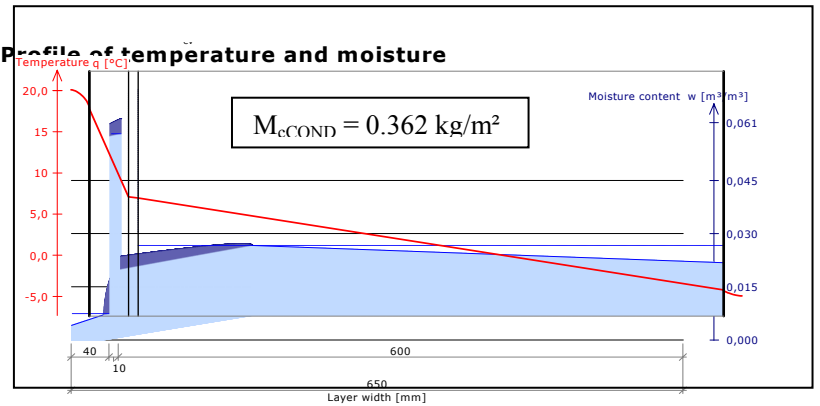


Figure 12: Moisture distribution and overhygroskopic moisture (condensation water 0.36 kg/m²) in the structure.

Without capillary activity of the inside insulation material (EuroNorm 13788) the interstitial liquid water content is 1.11 kg/m² !

The hygrothermal renovation of complicate details is problematic. The following pictures show the situation on the window jamb. The corner (1) and the thermal bridge (steel strip) (2) is still too moist.

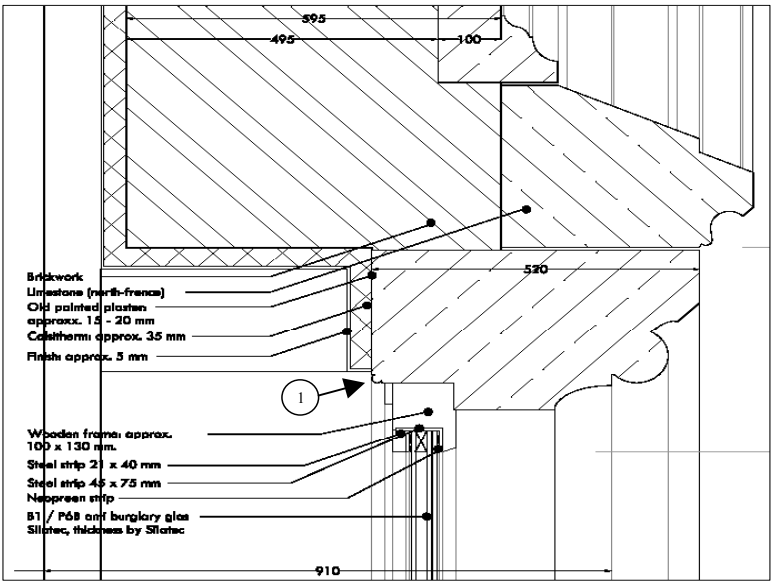


Figure 13: Cross section for the window jamb (vertical cut).

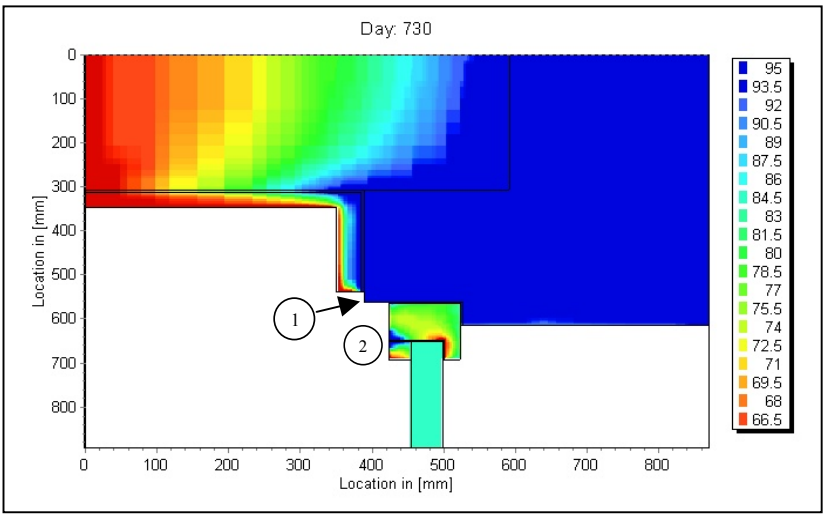


Figure 14: Moisture field on the January 1st within the area of the window jamb.

5 Summary and conclusion

The hygrothermal behaviour of the existing construction and different insulation systems with calcium silicate and foam glass have been analysed with the simulation tool DELPHIN and the simplified tool COND 2002.

Without additional insulation layers on the inner surface, moisture in the wall can evaporate unhindered towards the inner surface. At the same time the risk of mould growth and surface condensation is the highest, especially at corners of the masonry and at window recesses. This is caused by the low heat transfer resistance (U= 1.22 W/m²K), which results in low surface temperatures and high relative humidities.

The application of foam glass leads to a high temperature and a low relative humidity at the inner surface (U=0.68W/m²K). However it leads also to a complete moisture penetration of the existing construction caused by driving rain and drying up towards the inner surface is not possible. With this insulation option, frost damages are most probable, because it has the highest water content of all analysed options.

With calcium silicate, the profiles of water content and over hygroscopic moisture mass are on a reasonable level. Sufficiently high temperatures and low relative humidities on the interior surface would prevent mould growth and surface condensation. High water conductivity and low vapour transport resistance enable the drying up towards the interior and - in case of bad workmanship – reduces the possibility of stains, mould growth and condensation. Depending on the thickness of the calcium silicate layer, heat losses can be reduced by 29% (25 mm) up to 44% (50 mm calcium silicate). The favourite build-up is an insulation system with 40mm calcium silicate (U=0.71W/m²K). With this option the development of moisture in the construction is essential lower than with foam glass, but the thermal resistance is about the same.

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