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Performance of hydrophobized historic solid masonry – Experimental approach

T.K. Hansen [a,*], S.P. Bjarløv [a], R.H. Peuhkuri [b], K.K. Hansen [a]

[a] DTU Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
[b] SBi, Danish Building Research Institute, Aalborg University Copenhagen, Denmark

HIGHLIGHTS

- Evaluation of 16 different hydrophobization agents on brick and lime mortar.
- Investigation of penetration depth, water absorption, drying and vapour diffusion.
- Studying water migration through masonry sections with lime mortar joints.
- The efficiency of hydrophobization varies based on active component and material applied to.
- Silane based showed good performance on brick and masonry with lime mortar.

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ABSTRACT

The hygrothermal conditions in historic solid masonry are expected to change for the worse, with the application of internal insulation. Nevertheless, internal insulation plays a role in a holistic energy retrofit of historic buildings. With careful considerations and correct application, hydrophobic treatment may help remedy moisture ingress from external rain loads. This study includes experimental investigations of the effect on hygrothermal performance of various hydrophobization treatments on both brick and air lime mortar. An investigation of water migration through masonry applied with imitated climatic loads is also reported. The study showed a larger efficiency of hydrophobization on specimens of brick compared to the efficiency of hydrophobization of specimens of air lime mortar, which may be problematic in cases where mortar joints are the primary means for water ingress. Silane-based treatments generally proved to be most efficient in brick, whereas a variety of other active components were most successful in air lime mortar treatment. The investigation of water migration showed a distinct effect of silane, cream hydrophobization, though most evident in the external part of the brick.

1. Introduction

Reducing the energy consumption in the existing building stock is a vital measure in the goal of global reduction of energy consumption. In Europe, the energy consumption from the building sector constitutes 40% of the overall energy consumption [1], yielding a large potential for improvements in the field. The improvements should not be limited to new, sustainable constructions, but can also be attributed historical buildings by means of energy efficient renovations. In Denmark, 60% of the existing building stock of multistory residential buildings were constructed prior to 1950 [2], often yielding preservation worthy façades as the aesthetic expression presents cultural, local and traditional importance. This excludes the possibility of external insulation.

Internal insulation is therefore often the only way to reduce heat loss through the external walls in historic buildings. In addition to the reduction in energy consumption, an advantage of reducing heat loss through façades is the improved thermal comfort, as the surface temperature of the interior wall increases. However, the application of internal insulation to an old façade will dramatically change the hygrothermal conditions of the wall, as the temperature and drying potential is reduced, yielding the possibility for interstitial condensation [3]. The hygrothermal conditions in the construction can reach undesirable states due to both internal (vapour) and external (vapour and liquid) moisture loads, and there are several risks associated with the undesirable moisture conditions, e.g. mould growth, frost damage, decay of embedded wood, and general degeneration of the construction.

* Corresponding author at: DTU Civil Engineering, Brovej 118, DK-2800 Kgs. Lyngby, Denmark.
E-mail address: tekhan@byg.dtu.dk (T.K. Hansen).

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External moisture loads appear in the form of vapour/humidity and wind-driven rain (WDR). WDR is a significant parameter in regards to the hygrothermal performance of external facades [4,5]. When it comes to internally insulated masonry walls, WDR has also proven to be a negative contributor to the hygrothermal performance [6]. Finken et al. state that WDR can be the most critical factor in regards to moisture in a façade of porous building materials, as opposed to interstitial condensation, reduced drying capability and temperature when internal insulation is applied [5]. Through hygrothermal simulations and measurements, Künzel et al. found that an estimated 70% of WDR is absorbed by means of capillary action [7]. This observation was based on a one-dimensional validation of measured water content in three cases of different porous building materials installed in a western wall, and thus susceptible to exterior climate. Odgaard et al. found that hydrophobization had a positive effect on internally insulated walls during summer, however it impeded evaporation of interstitial condensation during winter periods [8].

Hydrophobization treatments may prevent, or at least reduce, penetration of liquid water from external conditions. Thus it may have a positive effect on the moisture conditions within a wall, and impede moisture accumulation due to rain penetration. Therefore, a hydrophobization treatment may enhance the service life of an internally insulated wall, as the risk of moisture related damages such as frost damage, cracking, wood degradation and mould is also reduced. An old-fashioned method for hydrophobization is found in old surface treatments, such as façade painting. However, this is not desired for listed or culturally valued buildings, as it changes the architectural expression. A previous study of internal insulation applied to external walls showed a case with a painted façade yielding excellent results in regards to hygrothermal conditions at critical points [9]. This success may be attributed to the paint serving as a water repellent; however the façade was also northbound and only a thin layer of insulation was applied.

Furthermore, both hygrothermal simulation [5] and experimental [10] studies have shown a reduction in heat loss through impregnated external walls, due to the reduced thermal conductivity caused by the dryer state of the wall. In addition, moisture within the insulation material compromises the efficiency [5,3]. There is a large variety of hydrophobic treatments available on the market, however they may not have the same efficiency with use on various materials, and when studying historic masonry holistically, the efficiency on both brick and lime mortar must be taken into consideration.

Many hydrophobic agents are based on silicone in the form of either silane or siloxane, or even a hybrid of both [11]. Both active compounds react with silicates in the building material and create CH_3-molecules which are hydrophobic, like the other non-polar carbonaceous groups CH and CH_2. Lime does not contain silicates in itself, however sand grains as aggregates in lime mortar do. Therefore the silicone based hydrophobic treatments may not bind as well to lime mortar as they do not bind to the binding agent itself as they do on e.g. cement or brick.

The main difference between the silane and the siloxane based agents is that the silane molecules have a smaller structure and lower viscosity, and thus the ability for deeper penetration into porous materials. Silane is also more volatile, and thus higher concentrations are used for achieving good results [12]. Siloxane is a more complex compound and thus larger molecules, decreasing the penetration depth, leaving the porous material more vulnerable if the external surface is damaged. Siloxane is less volatile, and lower concentrations can be used, with good results in regards to repelling water. In some cases, nanotechnology has been implemented in an attempt to improve the efficiency of hydrophobization agents.

Recent research includes investigations of the effect of external moisture loads on the hygrothermal performance of internally insulated walls, and the prevention or reduction of external water penetration, e.g. from wind driven rain. Solar radiation can be a positive contributor to a wet façade by means of increased drying and reduced condensation potential, but it can also drive the moisture further into the construction [13].

The following studies in the field of hydrophobization relate to the present study. A study by Guizzardi et al. from 2015 of masonry walls with severe wetting [21] yielded information about migration of external water loads through masonry. The experiment revealed that interfaces posed as hydraulic resistances/barriers, and that the moisture transport occurred faster in the fine pored bricks than in mortar joints. In contrast, van Hees found that the mortar joints were the weakest part of hydrophobized masonry [22]. He observed a difference in the efficiency of hydrophobization treatments on brick and mortar, yielding mortar joints a possible way for water ingress, Zhang et al. have investigated the efficiency of silane water repellent impregnation on cement based mortars and concrete [10], and found that the capillary suction was significantly reduced. Slapø et al. have found, that fresh mortars with high water content improved masonry's resistance to WDR, as the mortar-brick interface becomes less porous [23]. Engel et al. [24] performed a study on water absorption, drying and vapour diffusion of hydrophobized brick specimens. They examined 5 silane based creams of different concentrations, and two fluid hybrid agents. They found significant water absorption reduction, and with no influence on the vapour diffusion resistance. Their drying experiment showed that specimens hydrophobized with agents of lesser concentration of active ingredients, dried faster, thus an impregnation should be applied with the lowest, effective concentration. An older study from 1995 by Charola [12] found a reduction of 5–10% in water vapour permeability with silicon-based hydrophobization treatments. Couto et al. [25], who investigated silicone-based water-repellents on ceramic brick, also found a reduction in vapour permeability of hydrophobized brick specimens in some water-repellent treatments. Van Hees [22] found a limited effect of hydrophobization on vapour diffusion however, he found the hydrophobization treatments to have a high impact on the drying process, as also found by Couto et al. [25] for most investigated treatments. Lubelli et al. [26] tested the efficiency of two nano-coatings on bricks, and found significantly reduced water absorption, and little effect on the drying, however, the penetration depth was found to be much lower than traditional products. Finken et al. found, through a study of hydrophobization based on several hygrothermal simulations, that hydrophobization has a positive impact on the hygrothermal conditions within an internally insulated façade. In the simulation, the entire wall became dryer, compared to unhydrophobized cases [5]. Finally, Slapø et al. performed a similar large scale study on masonry panels however, the water loads were provided with high pressure for 5 h. They found the tested water repellents to be ineffective to high pressure driving rain after a few minutes of water loads; this inefficiency was attributed the extreme testing conditions.

This investigation focuses on the efficiency and effect of various hydrophobization agents on historic masonry from a holistic point of view. Initially a screening of 16 different hydrophobization agents is performed. The initial investigation includes experiments on brick and lime mortar in regards to penetration depth of hydrophobization agent, water absorption, and drying. Furthermore, the effect of hydrophobization on vapour diffusion is examined as well as a large scale experiment involving monitoring of the migration of water through masonry wall sections and the recorded effects of hydrophobization.