Dow Performance Silicones

Impact of water repellent on energy demand of building

Use of water repellents has been promoted for a long time as a solution to insure increased durability of construction material and reduced maintenance

In view of today's environmental concern, it is interesting to realize that hydrophobing treatment can lead as well to reduced energy consumption in existing building. This is of course due to the fact that water absorption by construction materials has a detrimental impact on some properties such as heat transfer coefficient or leads to energy extraction due to water evaporation. This paper discusses the potential impact of hydrophobic treatment of construction material on some processes which lead to energy consumption in existing building.

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Dow

1. Heat Transfer / Thermal Conductivity and Impact of Materials Damping

Heat transfer is the transition of thermal energy or simply heat from a hotter object to a cooler object. Heat transfer always occurs from a higher-temperature object to a cooler temperature one, as a result of the thermodynamic law.

Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed.

There are three main processes by which heat can be transferred: conduction, convection and radiation.

1.1 Conduction

Conduction is the transfer of heat by direct contact of particles of matter.

Conduction is greater in solids, where atoms are in constant contact. In liquids (except liquid metals) and gases, the molecules are usually further apart, giving a lower chance of molecules colliding and passing on thermal energy.

As density decreases so does conduction. Therefore, gases are less conductive.

To quantify the ease with which a particular medium conducts, the thermal conductivity, also known as the conductivity constant or conduction coefficient, k is used. In thermal conductivity k is defined as "the quantity of heat, Q, transmitted in time (t) through a thickness (L), in a direction normal to a surface of area (A), due to a temperature difference (ΔT) [...]."

Experimentally, thermal conductivity is measured by placing the material in contact between two conducting plates and measuring the energy fluxes required to maintain a certain temperature gradient.

1.2 Convection

Convection is the transfer of heat by movement of a heated fluid. Unlike the case of pure conduction, now currents in fluids are additionally involved in convection. This movement occurs into a fluid or within a fluid, and cannot happen in solids.

1.3 Radiation

Radiation is the transfer of heat energy through empty space. All objects with a temperature above absolute zero radiate energy at a rate equal to their emissivity multiplied by the rate at which energy would radiate from them if they were a black body. No medium is necessary for radiation to occur; radiation works even in and through a perfect vacuum.

An additional source of hear loss is related to the evaporation of water. As most liquid to vapor state transition, water evaporation requires heat. This heat is partially extracted from the substrate which means that water evaporation in a construction material will lead to the decrease of its temperature.

It is also known that wetting of construction materials increases their heat transfer properties.

As Dow is proposing materials which can decrease water absorption of porous materials, both when applied as post-treatment or used as “admixture”, it was interesting to assess to which extend reducing water absorption could also impact heat transfer properties and other heat loss mechanisms.

2. Water Repellent Based on Silane and Siloxane

Siloxane and alkoxysilanes have become a very important class of materials used for water-repellent treatment of masonry, where durability and minimal impact on substrate appearance are important.

Silicone is a generic term describing polymers encompassing a siloxane backbone (based on the repeating unit: Si-O-Si). Polydimethylsiloxanes or PDMS (illustrated in Figure 2) are the most common siloxane used worldwide, both in terms of volume and application.

Polydimethylsiloxane are available as linear fluids, cyclics, viscous polymer and even gums depending on their degree of polymerization and cross-linking. Terminated by a silanol group (as in Figure 2), they are reactive and can be anchored on appropriate substrates.

Silicones have many interesting properties that make them suitable for a wide range of applications. In the field of hydrophobic treatment, low surface tension, ability to react with cementitious material, improved UV resistance vs. organic polymer and high gas permeability are of most interest.

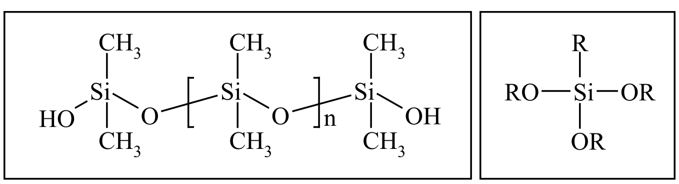


Figure 1: polydimethyl siloxane and alkyl trialkoxysilane

Silanes are molecules based on one silicon atom which bears four substituents. Alkyl trialkoxy silane (as described in Figure 1) show a good reactivity towards construction material (reactions during which alcohol is released as leaving groups). They can be viewed as materials bearing latent silanol groups (Si-OH), yield by hydrolysis, which can bond covalently to masonry materials through condensation reactions with metal hydroxyl moieties. Silanol self-condensation also leads to cross-linking of the treatment, which leads to outstanding durability of water resistance. The R groups (most often, isobutyl or octyl chain) confer the hydrophobic character to the substrate to which the silane is anchored.

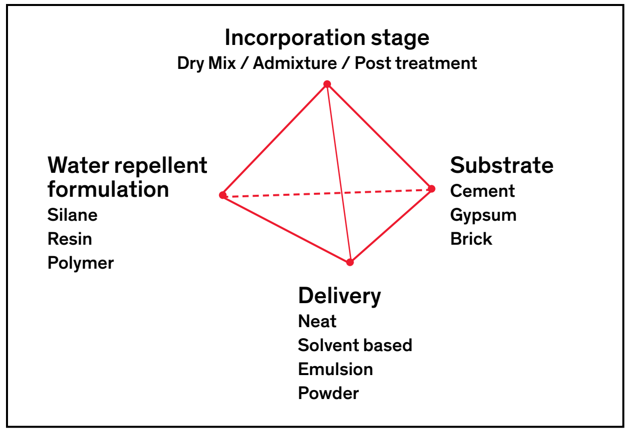


Figure 2: The “hydrophobic tetrahedron”.

Figure 2 illustrates the need for the water–repellent material formulation (hydrophobic active + the delivery system around the hydrophobic active) to be adapted to the type of substrate and the expected incorporation stage. The water repellent active materials have to match the chemistry of the construction material. Cement-based materials are not reacting the same way as gypsum or wood. The chemistry of the water repellent has to be adapted to properly react with the construction material in order to provide the expected protection against water.

The way the water repellent active material is formulated can be described as the delivery system. Water repellent can be used “neat” (as such), as solvent based solution, as emulsion or yet as powder. The delivery system has to be adapted to the requirement of the application method. For example, the water repellent can be added in a cement based wet slurry, after the cure of cementitious material in a post-application step (in this report, we used fiber reinforced cement boards which were post-coated) or even added before the addition of water, in what is called nowadays “dry mix”. The delivery system (neat hydrophobing material, emulsion or powder) has then to be adapted to fit the stage of application of the water repellent.

3. “Heat Extraction” Due to Water Evaporation

Besides the change of thermal conductivity which drives the rate of heat transfer through construction system, water absorption by the construction material can increase the energy demand of buildings. Comfort in a building is amongst other dependent on the temperature of the walls. Energy consumption in a building will then be used to keep walls at a temperature which insure comfort inside the building. Additional process which may lead to decrease of wall temperature will lead to extra energy consumption in the building.

The water absorbed by the building component (i.e. the walls) may eventually evaporate if water comes to the surface of the material. During the evaporation process, water will “extract” energy to the substrate (as the change of state from the liquid to vapor state requires energy) and decreases its temperature. This is the same phenomena when alcohol is left on the skin. Cold feeling is due to heat extraction from the skin to enable the ethanol to go from the liquid to the gas phase.

This is illustrated by the following pictures. A small “house” (10 cm * 5 cm * 10 cm) was carved in Aerated Light Concrete (referred as ALC in the following part of the test). Half of the house was treated with a water repellent emulsion (DOWSIL™ IE 6683 diluted @ 7.5% solid content and applied at 200 g/m^2) and left for cure for at least two days.

After cure of the water repellent emulsion, the little ALC house was immerged into water for a couple of hours, removed from water and then left at RT for 30 minutes in the lab. The house was analyzed with an infrared camera (IR picture is reproduced hereafter).

The analysis of the picture shows without ambiguity that the untreated side of the house is colder than the treated side. This is resulting from the fact that the un-treated side did absorb water much more, and become colder due to the fact that water extract energy when evaporating. The treated side did not absorb much water and the energy “extraction” required to evaporate water at the house surface was much lower, resulting in a higher temperature.

This could be called the "wet pullover effect". In order to keep in-house atmosphere comfortable, there is a need to bring extra energy to maintain the wall at a constant temperature if the walls are wet or damped.

This is the same effect if one wears wet clothes. Skin temperature will decrease due to the fact that water is “extracting” heat from the skin when evaporating. This energy extraction, due to evaporation and also due to increased thermal conductivity leading to extra heat loss, is leading to a very cold feeling.

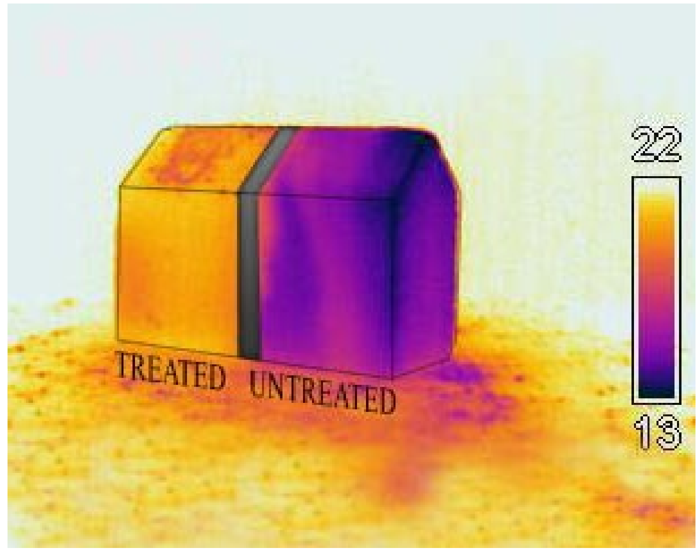


Figure 3: Aerated light concrete house (10*5*10 cm) half treated with diluted DOWSIL™ IE 6683 water repellent emulsion, cured for at least two days, soaked for a couple of hours, left at room temperature for 30minutes and observed with infra-red camera.

This phenomenon can be observed with different construction materials. This is illustrated hereafter with cment-based and gypsum-based materials. Two sets of Fiber reinforce cement boards (referred as FRC boards in the document), gypsum and mortar blocks were prepared. One set was treated with a water repellent additive and the other was left as such, untreated.

Fiber reinforced cement boards: FRC board was treated with DOWSIL™ 520 water repellent emulsion (DOWSIL™ 520 emulsion diluted at 7.5% solid content and applied so as to reach 100 g/m^2 loading level and cured for at least three days).

Gypsum blocks: As mentioned in the introduction, construction material with different chemical composition can only be treated with corresponding water repellent. Gypsum "boards" were prepared in the lab by preparing a gypsum-based slurry and casting it into silicone mold of dimension 10 * 10 cm. One gypsum blocks was modified by the addition of Si-H functionalized siloxane (1% addition level vs dry gypsum composition) sold under the trade name DOWSIL™ 1107 Fluid.

Mortar blocks: Mortar blocks were admixtured with silane/siloxane hydrophobic agent. This enables the complete mass of the mortar to be treated and to have much reduced water absorption. A silicone hydrophobic powder under the (SHP 50) was dry mixed with cement and sand (0.5% SHP 50 in the dry mix composition). Water was added to produce a mortar slurry, which was cast and left for cure for 28 days.

After complete cure, the treated and untreated blocks (gypsum and mortar blocks) were tested alongside with the treated and untreated FRC boards.

After setting, cure and drying of all blocks and boards, the two series (treated or admixtured and untreated) were immerged for one hour to insure deep water absorption by the untreated construction materials. The complete set of materials was removed from water and left for 1 hour at room temperature in the lab.

The picture (with optical photography) hereafter shows the appearance of the blocks after one 30 minutes immersion, removing of excess water with some clothes and storage for a 30 minutes "holding" time at room temperature.

On the left hand side of the pictures are standing the treated blocks/boards (from the top to the bottom : 1: gypsum, 2: FRC board, 3: cement block) after immersion. On the right hand side are standing the untreated boards/blocks after immersion.

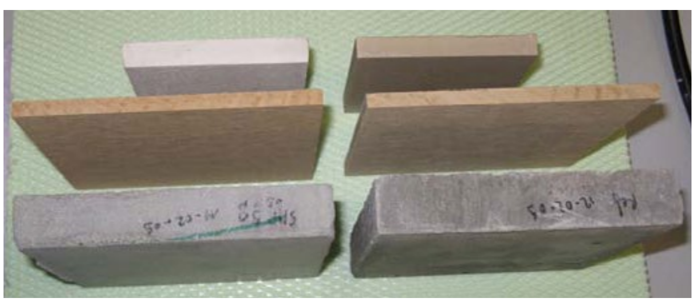


Figure 4: Optical picture of treated and untreated gypsum, FRC and mortar blocks after immersion in water and 30 minutes holding time.

Untreated blocks do absorb a significant amount of water which can be visually assessed by the fact that their appearance change and that they become darker. Blocks which were treated have not absorbed so much water, which can be simply visually assessed by the fact that they kept their original appearance and did not become dark due to water absorption. Measure of the water uptake upon immersion demonstrates the reduction of water absorption when the materials are post-treated or admixtured (not shown).

Observation of the same two set of blocks after immersion and 30 minutes holding time with an IR camera illustrates the same 'wet pull over' effect, as the camera picture reveals untreated blocks/boards are much colder. This is always due to the same fact that water is extracting heat from the substrate when evaporating from the substrate surface.

The post treatment or admixture are insuring that the materials are not absorbing so much water. This leads to a much reduced evaporation process and by this, to a much decreased "energy extraction" from the material surface.

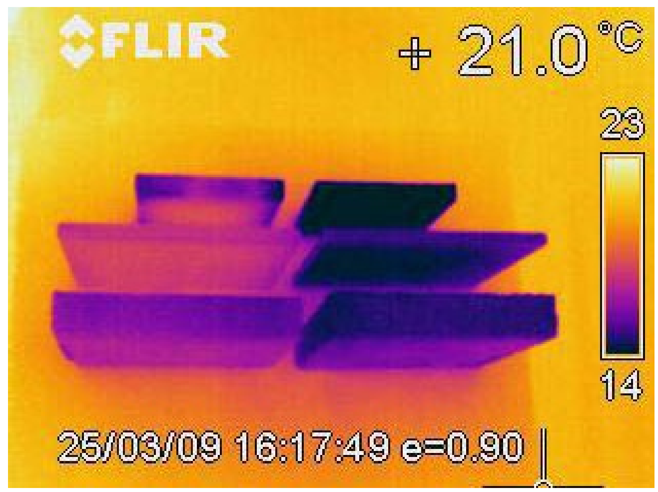


Figure 5: Infra red picture of treated and untreated gypsum, FRC and mortar blocks after immersion in water and 30 minutes holding time.

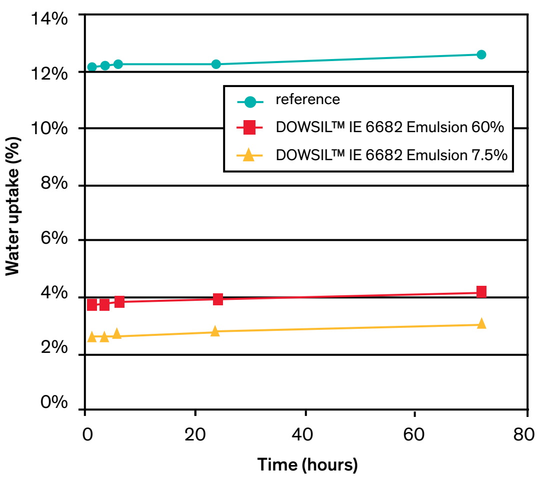
4. Impact of Injection Material

This can be observed in other application such as Damp Proofing Coursing (referred as DPC hereafter).

The issue of capillarity rise of water is observed in most cases in old houses. Rising of water from the ground into the walls leads to wet walls. This often leads to mold growth, wall papers falling off and also to very humid and cold feeling in the buildings. This phenomenon was reproduced in the lab to demonstrate the positive impact of hydrophobic treatment of the bricks.

In this set of experiments, holes were drilled into clay bricks. Silane-based materials were injected into the holes as it would be in real life application. Bricks were then left for cure for several weeks to allow diffusion and reaction of the silane based formulation. We reproduce the data of the experiments where a silane emulsion is injected into bricks. Two dilutions of the emulsion were tested such as the liquid treatment contains either 60% of active or 7.5% of active. The same final quantity of silane was injected into the bricks, meaning that larger quantity of the diluted emulsion was injected into the holes. 3 g of the silane emulsion @ 60% was injected in 4 mm holes compared to 24 g of the same silane emulsion @ 7.5% injected in 7 mm holes. This dosage is lower than real life application.

After one month, the bricks were dried overnight in an oven and tested. The test consisted in placing the bricks into a basin filled with 2 cm of water. The bricks were left with the bottom of the bricks immerged in water to enable water absorption via capillarity rise (see picture). Both treated and untreated bricks were tested in order to assess the impact of the treatment on the water absorption and the behavior of “heat extraction by evaporation”.



After 24 hours of capillarity rise, bricks were then removed from the container and left for a couple of hours at room temperature to allow some evaporation of water. Both optical photography and Infrared photography were used to characterize the bricks. IR picture reproduced hereafter shows clearly that reference bricks, which absorbed more water, is much colder than the treated bricks. The untreated brick absorbed more water and then get colder due to water evaporation at the brick surface.

Figure 6: Water uptake of clay bricks injected with DOWSIL™ IE 6682 Emulsion @ 60% or 7.5% as a function of immersion time. Picture showing the experimental set up to measure water uptake by capillarity rise.

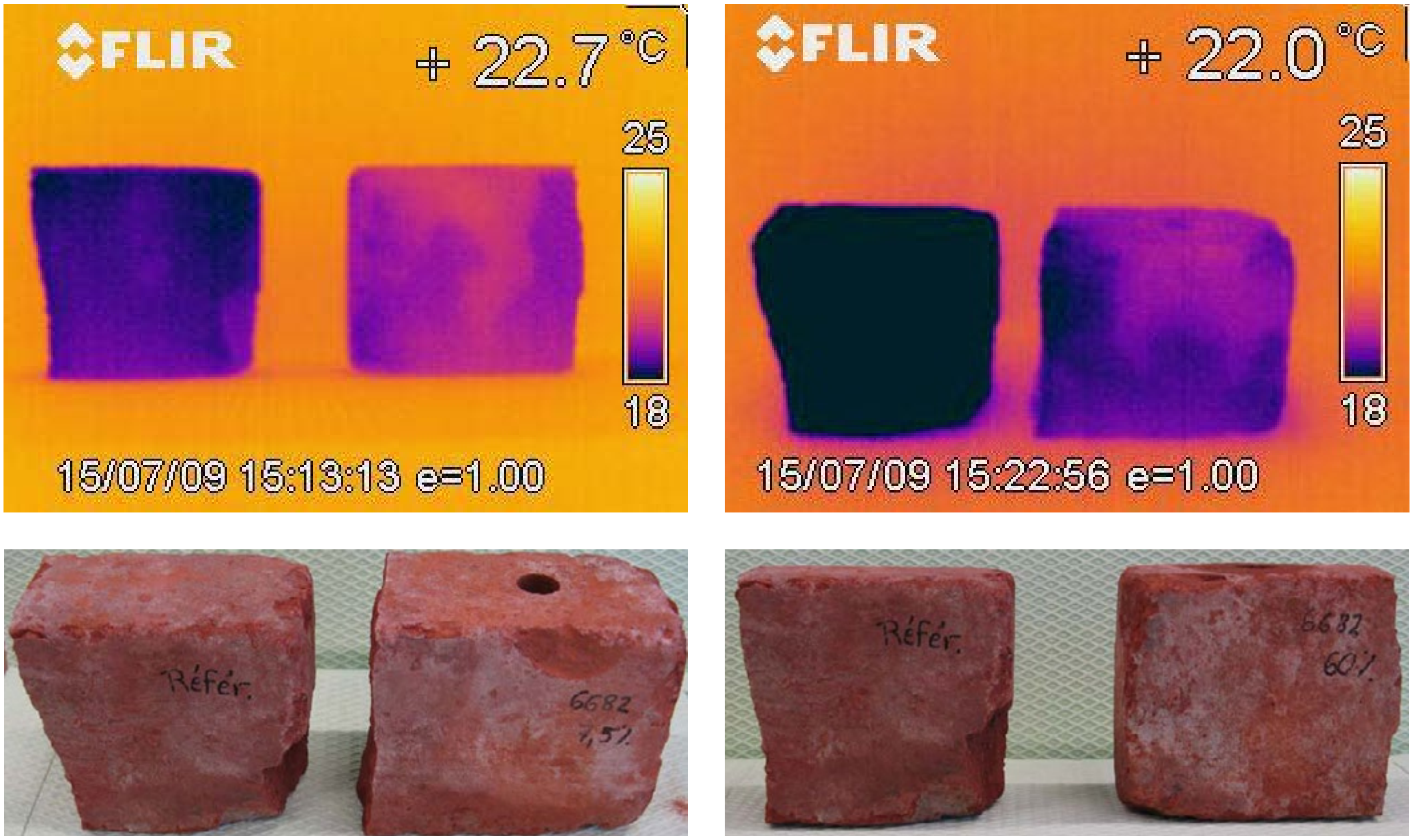


Figure 7: Optical and infra-red photography of bricks treated with silane emulsion diluted at 60% or 7.5%. Pictures were taken after the bricks were placed in water bath to allow capillarity rise and left at RT for a couple of hours.

5. Impact of Water Uptake on Mortar Thermal Conductivity

It is known that damped construction materials have higher thermal conduction than when dry.

We were interested to characterized to which extend using an admixture of silane/siloxane in cement based mortar could minimize the increase of thermal conductivity upon water uptake.

Two set of mortar were prepared. One was left unmodified and the other was admixtured with 0.5% of SHP 50 and SHP 60 silicone hydrophobic powder.

A mixture of 54 g of dried sand, 18 g of cement (CEM II) and 0.36 g of silicone hydrophobic powder (0.5 % of SHP 50 or SHP 60 vs. the dry blend weight) was introduced into a cup and hand- mixed to homogenize the powder blend. Nine grams (9 g) of water was introduced into the mixture and the mixing was continued for 2 minutes till an homogenous mortar paste was obtained.

The resulting mortar slurries were then poured into mould measuring 25x25x10 mm. The mortar pieces were removed from the moulds after 24 hours and allowed to cure in the lab for a further period of 7 days at a temperature of 25°C and at 100% relative humidity.

Thermal conductivity of the different mortar pieces were measured with a Mathis Hot Disk analyzer. Thermal conductivity values of the reference and modified DRY mortar blocks are reproduced Table 1.

The three mortar pieces were then placed under water (soaked), removed from water after 2 hours. Excess water was removed from the blocks with some fabrics and then thermal conductivity was measured again.

Thermal conductivity of soaked mortar sampled are given in the same table.

It is obvious that water immersion of the mortar blocks is leading to an increase of thermal conductivity. The increase of thermal conductivity is related to the absorption of water. Reduced water uptake is obtained thanks to the addition of SHP 50 or SHP 60 in the mortar composition which translates into a decreased impact of soaking on the thermal conductivity increase. Thermal conductivity increase of up to 30% is obtained with unmodified mortar while it is only of 5-10% for modified mortar.

Material	Thermal conductivity (W/mK)	Thermal conductivity (W/mK)	Thermal conductivity increase (%)
	Dry samples	Soaked samples	
Reference mortar	2.62	3.57	36%
Mortar modified with 0.5% SHP 50	2.47	2.59	4.8%
Mortar modified with 0.5% SHP 60	2.78	3.06	10.23

Table 1: Thermal conductivity of reference and admixtured mortar both dry and soaked.

Conclusion

This paper discusses the positive impact of protecting construction material against water absorption and the associated positive impact on the different processes which can lead to energy loss in a building

Water repellent can be added as a post-treatment or can be included in the mass of the material, as a so-called admixture.

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