Appendix C: WP4 – Bench testing

Prepared by UCL, CEGE

Authors: Dina D'Ayala, Yasemin Didem Aktas, Henry Zhu

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Section Contents

1. Introduction

The main products and types of waterproofing treatments have been reviewed by BRE in WP2. Four products were shortlisted. CEGE undertook bench testing of small masonry specimens with different types of brick and the four water proofing treatments with the aim of identifying the best performing ones, and progress to the full masonry specimens test with up to two waterproofing products. The bench testing investigates the ability of waterproofing treatments to cover/penetrate into the masonry surfaces thoroughly and evenly by two different application techniques, i.e. brushing and spraying. Three different sets of tests were performed with the objective of measuring the extent to which each of the treatments altered the uptake and release of moisture by the masonry.

- Water vapour permeability test
- Wettability test
- Water absorption test

2. Selection of materials

2.1 Bricks

The bricks are selected from new products based on the main principles shown below:

- Clay, ‘standard’ size 215x102.5x65 mm, machine-made wire-cut new bricks manufactured following methods used in the ‘50s and ‘60s; with frogs or holes. Among these:
    - A more porous/less dense brick (high moisture absorption) with a rough surface finish (Forterra Moray Red Mixture)
    - A less porous/more dense brick (low moisture absorption) with a smooth surface finish (Forterra Atherstone Red)
    - A more porous/less dense brick with a smooth finish (Forterra Belgravia Gault Blend)

The three brick types chosen from the Forterra catalogue are:

Forterra Moray Red Mixture | Forterra Atherstone Red | Forterra Belgravia Gault Blend

Figure 1: brick types

Table 1 summarises the specifications of each brick in relation to the bench testing from the data sheets and CE certificate provided by the manufacturer Forterra.

Table 1: Technical specifications of the selected brick types as provided by the manufacturers

Brick Type	Water absorption (%weight)	Configuration (Voids)	Dry weight per brick (kg)	Gross density (kg/m3)
Moray Red Mixture	≤ 10	Vertically Perforated	2.35	1600
Atherstone Red	≤ 13	Frogged	2.20	1550
Belgravia Gault Blend	≤13	Frogged	2.36	1700

2.2 Waterproof treatments

Four different waterproof treatments have been selected from different companies in WP3. They are labelled as B, C, D and E while A represents untreated samples.

Among the four treatments, only C is a cream product, the rest are all liquid. Besides the selected products, each of the manufacturers has also sent some alternative products, such as cream substitutes to the selected spray and products for repointing and gap-bridging (cracks), which respond to some of the concerns raised by the partners on the effectiveness of spray products on defective walls. The suggestion of these additional products has not been used in the project after joint discussion from the working group to maintain the original agreed selection.

As some of these products contain toxic chemicals, appropriate Health and Safety measure were put in place during handling and application. The products have all been registered into the CEGE COSHH database. In addition, as the performance of the products is expected to differ on different types of bricks and the performance depends on the quality of the application, the data sheets from the company do not provide any numerical specifications of the performance.

3. Water vapour transmission test

The movement of moisture within hygroscopic capillary building materials such as bricks is a combination of vapour and liquid flows which have complex interactions with the temperature and humidity gradients and the properties of the materials present. Three stages can be identified.

1. At very low humidity, transport is by vapour diffusion alone and the transmission can be derived from dry-cup tests.
2. At higher relative humidity in the hygroscopic region, up to about 95 % relative humidity, there is a mixture of gas and water filled pores with simultaneous flows of vapour and liquid. The increasing liquid flow causes the exponentially increasing transmission measured by cup tests under isothermal conditions. However, under practical, non-isothermal conditions this liquid flow could increase, or decrease, the total mass flow. The wet-cup tests derived a more controllable method to monitor the transmission of the material.
3. Above about 95 % relative humidity, the total mass transport is governed by transport in the liquid phase. This is the situation that arises when a material is dipped in water or severely wetted e.g. by driving rain. The water moves under the hydraulic pressure, the negative suction pressure. After the water source is removed, the hydraulic pressure ceases and the liquid is redistributed within the material at a different rate.

Both stage 1 and 2 are defined in ISO 12572 water vapour transmission test while stage 3 is defined in ISO 15148 absorption test. The water vapour transmission test is aimed at monitoring the movement of moisture at higher humidity conditions mentioned in stage 2 without direct contact to liquid water. The “Wet cup” tests (condition C) is giving guidance about the performance of materials under high humidity conditions. At higher humidity, the material pores start to fill with water; this increases the transport of liquid water and reduces vapour transport. Tests in this area therefore give some information about liquid water transport within materials.

3.1 Scope

In this study the water vapour permeance of brick, mortar and masonry specimens is determined following the cup tests detailed in the BS EN ISO 12572:2016. Among the different sets of test conditions specified in the standard, as the objective of the test is to study the water vapour resistance performance at high humidity conditions simulating rain conditions, the “Wet cup” tests is used, which best reflects the environmental circumstances corresponding to waterproofing of cavity walls in high exposure zones.
The standard suggests testing under a temperature of 23 ± 1°C in the environmental chamber with a dry state set at 50 ± 5% RH and a wet state set at 93 ± 5%.

3.2 Specimen design

The cup method is commonly used in the determination of water vapour transmission properties of building materials and products. Similar to the semipermeable coating for building materials proposed by Ruid et al. (2005), the waterproofing products tested here are claimed to be essentially watertight but water vapour permeable, i.e. “breathable”, which is a critical property in determining the propensity to envelope decay in case of water ingress through defects in the fabric or capillary suction. In order to define the overall water vapour resistance, small-size masonry specimens were used to ensure a better representation of the composite nature of masonry constructions than brick or mortar alone (Binda et al., 2000; Larbi, 2004) and hence a more accurate representation of the actual breathability of the composite. To this end, two sleeves cut from the external surfaces of bricks were then bonded together with a 10 mm mortar joint to produce specimens for the water vapour transmission testing.

According to the British standard ISO 12572 (2016), if the specimen test area is less than 0.05 m^2, a minimum of 5 specimens for any material assembly shall be tested, hence given 3 brick types and 5 surface treatments including the reference untreated case, 75 specimens were produced. No specific criteria have been used to select the individual bricks for these tests, except that they all belong to the same batch.

3.2.1 Cutting Bricks

BS EN ISO 12572:2016 states that the minimum thickness of the specimen exposed to transmission should be 20mm. By considering the different frog/perforation locations on each type of brick, the final thickness of the specimen was determined as 28 mm to ensure that there is no brittle failure of the brick or development of cracks during cutting.

The bricks were cut with a wet saw to the required dimension and subsequently dried until constant weight in the laboratory environment at a temperature of about 22 °C and 45% RH.

Figure 2: a) Brick wet saw cutting *b) 28mm specimens cut from one side of brick*

3.2.2 Mass change during drying process

After completing the wet saw cutting, the specimens were dried until constant weight conditions were achieved The code requires drying until the daily mass change is within 10% of total weight, however the specimens were dried to within 5% difference to ensure shrinkage is avoided in the dimension measurement.

During the drying process, 10 specimens of each brick type were selected and the mass change were measured and recorded every day while checking the drying status of the specimens at the same time by visual inspection, to ensure homogeneous and sufficiently slow dry to prevent bending or cracks due to uneven shrinkage. Figure 4 shows the drying layout of the specimens and flipping was done every day to ensure the specimens were dried evenly.

Numbering of the specimens was carried out during the drying stage for easier recording of the dimension measurement. In general, all the bricks were sorted by thickness and matched in pairs to form the masonry specimens. They were then divided into 5 batches, each batch including 5 pairs of bricks ready to get bonded by mortar in the next stage, for the 3 different types of bricks .

Figure 3: a) Numbered specimens in drying process

Figure 3: b) Specimens grouped by similar thickness in 5 batches for the three brick types, ready for bonding

3.2.3 Dimension Measurement

As soon as the specimens reached constant mass 7 days after cutting, accurate measurement of the dimensions were taken. While the length and width were measured by an electronic calliper, the thickness was measured by a micrometre. All dimension data were accurate to 0.01mm as required by the standard. Based on the shape of the specimen, a total 10 measurements, 2 for the length, 3 for the width and 5 for the thickness, were carried out on each specimen to ensure accuracy in further calculations.

Because of the unavoidable error in wet saw cutting, the thickness of each specimen is within a certain range around 28mm. Extra bricks were cut to replace those specimens which were either too thick or too thin. Then the bricks were matched in pairs with similar thickness for bonding with mortar in the next stage. The average brick thickness of each brick type is shown in the Figure 5.

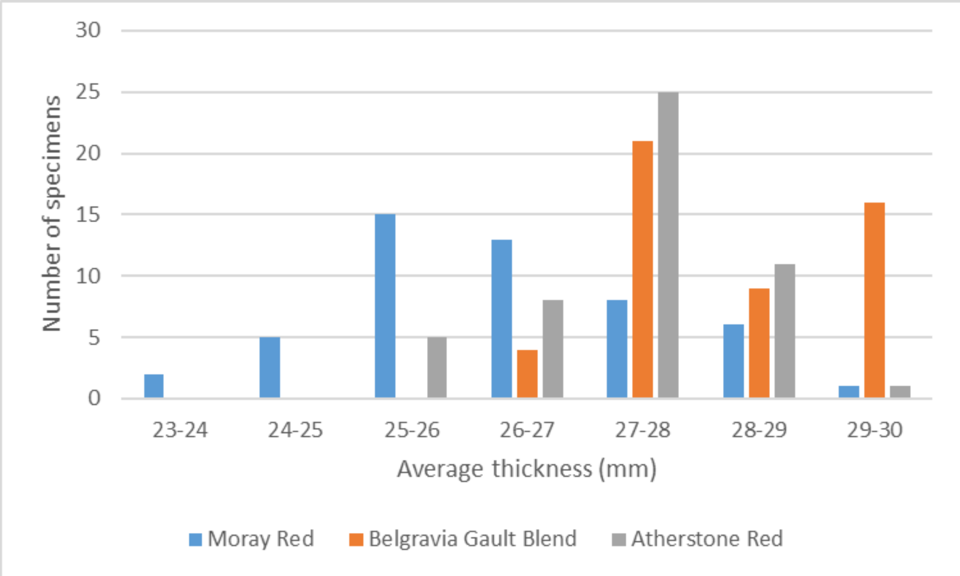

Figure 4: Distribution of Average brick thickness of each brick type

3.2.4 Mortar

Based on the field and background study from previous work packages, the lime:cement:sand ratio of the mortar used to bond the bricks was determined as 1:1:6. According to the standards and recommendations from the Brick Development Association (2014) and National Lime Association Building Lime Group (2000), this is a mix suitable for brickwork, and recommended for moderate exposure (class M4).

Considering the background of the period the studied masonry walls were built, the mortar-joint profile was selected as bucket handle joint not only because of its wide adoption in the history of brick constructions, but also the more durable profile it is able to provide.

Figure 5: Bucket handle joint profile (Brick Development Association, 2018)

While preparing the mortar mixture, in order to ensure that the particle content was suitable to the requirements of the standard that was in effect when the building stock under examination was being built, BS 1199 and 1200

(1976) were used for the sieve analysis. A sample was taken from each bag of sand for grading. The grading curves for the two batches of sand used in the test as well as a reference grading curve, and upper and lower limits for the grading of building sands from natural resources for mortar for brickwork from the mentioned standards are shown in Figure 6.

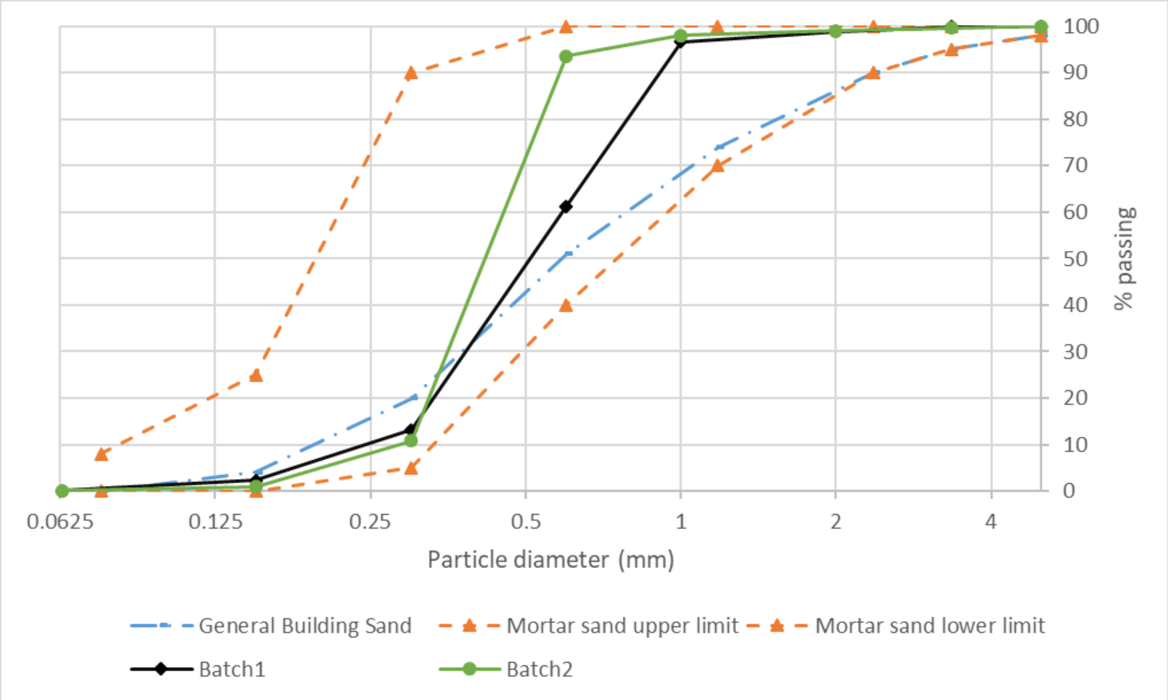

Figure 6: Grading curve of 2 sand samples, reference sand, and upper and lower bounds

In general, the grading curve of both bags of sand were within the range provided by the abovementioned codes. However, it is also observed that both bags had fewer sharp particles of large size and the content size was more concentrated on the medium size particles. In relative terms, more fines in a sand will demand more water, due to higher surface area to be wetted. A higher proportion of fines in sand and the consequent high-water content in the mortar will promote shrinkage and would lead to higher risks of de-bonding and cracking in lime mortars (Reddy and Gupta, 2008). As a result, particular care was taken during the curing of the mortar to avoid cracking. Once assembled using concave joints, all masonry and mortar specimens were covered with an impermeable sheet to act as a vapour barrier for 3 days, and then stored for 25 days at 23±2°C and 50±5% RH for curing covered with a hessian cloth. Concurrently six mortar cubes of dimensions 40 x 40 x 40 mm were also cast for the compressive strength test after each mix. This is to verify that the mortar complies with the M4 standard characteristics. The dimensions of the specimens were measured after the curing and were used in the calculation of the vapour flow rate. The specimens were carefully cleaned to remove small particles before applying the selected waterproofing treatments as per the application procedure recommended by the manufacturers (Figure 7).

Figure 7: Bonded samples, mortar cubes and vapour barrier

3.3 Wet Cup (box) design

3.3.1 Box

In this study, instead of the standard cup detailed in BS EN ISO 12572:2016, an at purpose box (wet cup) was designed to accommodate the larger size masonry specimens. It's constituted by a top layer frame, which holds the specimen and a bottom layer box containing the salt solution to maintain the required level of relative humidity, which is 93%. The air gap between the salt solution and the face of the specimen was 15 mm in line with the BS EN ISO 12572:2016.

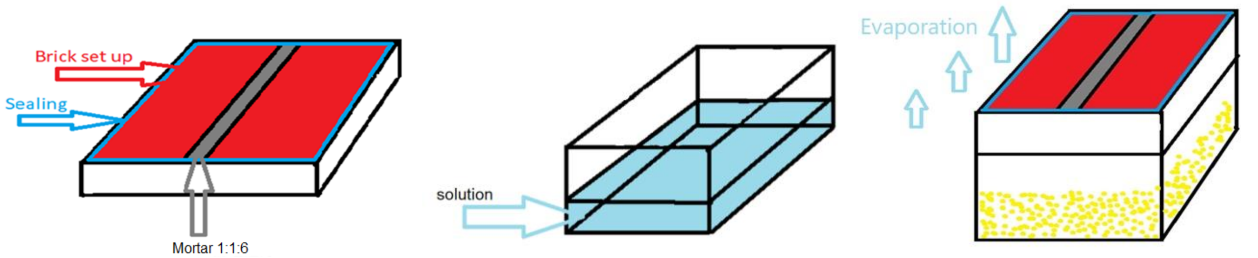

Figure 8: a) Top frame with bricks set up; b) Bottom box with salt solution; c)Specimen and box assembly

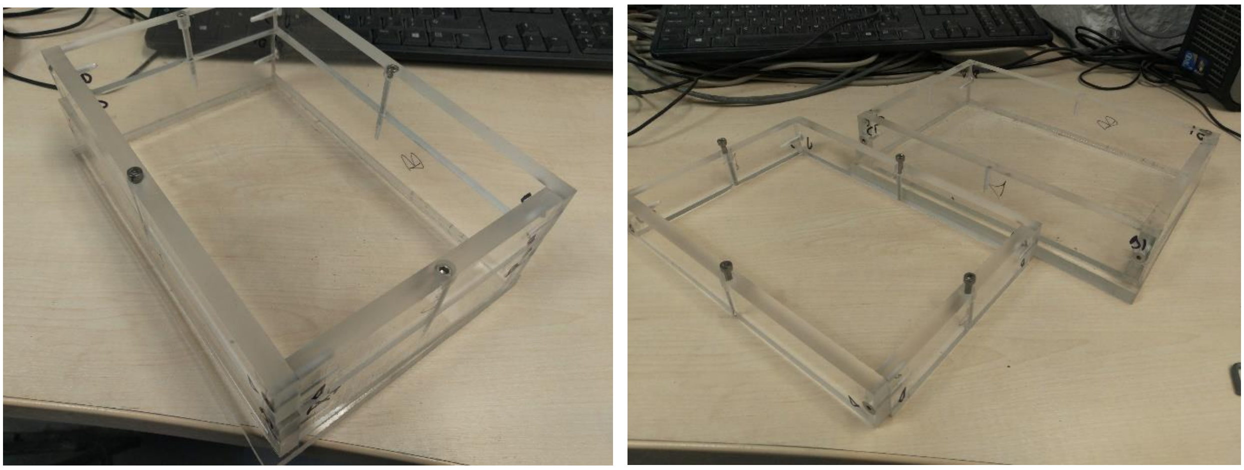

Figure 9: Plexiglass boxes ready for assembly

The box was built of plexiglass for transparency and durability, and cut by a laser cutter to ensure precision and hence the airtightness of the boxes once the masonry specimens were fitted, as shown in Figure 10. Screws were used on the box frame to add additional reinforcement and pre-compression to avoid moisture leakage and keep the box perfectly sealed during the test. This is necessary as each specimen is slightly different, although the nominal dimensions are the same.

3.3.2 Sealant and adhesive

Sealant and adhesive were used to provide airtight and fixation between the specimen and the plexiglass frame. Sealants should be easily handled, remain flexible and not crack over the test period and have good adhesion to the specimen and the frame. As the boxes were reused after each test, it's also important that they can be easily removed to start with a clean set of boxes for each batch. The adhesive that is used between the sealant and specimen is the 'Bitumen Waterproofer' from Wickes, which is usually used in roof maintenance. It provides good seal and adhesion while it does not penetrate dip into the brick's surface. (see Figure 10).

Figure 10: a) Adhesive over the brick surface; b) cross section penetration; c) foam tape

To fill the gaps between the samples and frames, foam tape and rubber are used. Foam tape can act as a buffer to transfer the compression evenly from the frame to the specimen avoiding damage to the specimen. Then the rubber seals the edges of the foam tape to form an airtight layer around the frame.
It is essential that the sealant and adhesive are used on these types of cups to provide a well-defined upper specimen surface area free of sealant, as per the Standard's requirements. Applications should only be around the specimen edges. During the application the creation of "masked edges" should be avoided, otherwise it is necessary to correct the actual surface area in the calculation of the vapour flow rate.

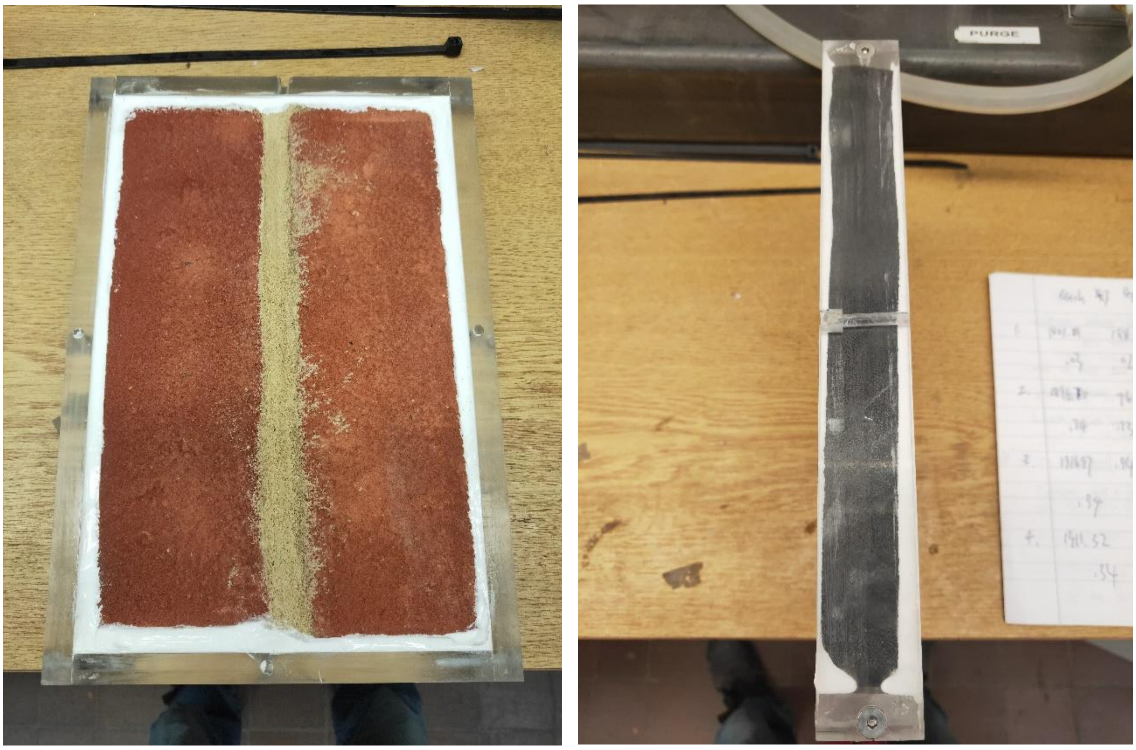

Figure 11: Combined specimen sealed with rubber and foam tape around the edges

To reach the same airtightness on the connection between the top layer with the specimen and the bottom layer containing the solution, silicone grease was used on the contact surface to avoid possible air leakage.

Figure 12: Silicone grease and fully assembled box sets, before tightening with screws

3.4 Test process

As the aim of this test was to study the water vapour transmission properties in high moisture circumstances, the ‘wet cup’ method was considered the most suitable of the two proposed by the standard. The test setup was composed of the specimen with surface of interest facing down sitting on top of a cup containing an aqueous saturated solution based on ammonium dihydrogen phosphate ($NH_4H_2PO_4$) maintaining the target humidity level, i.e. wet state (93±5% RH according to BS EN ISO 12572:2016).

The test was divided into 5 batches with 1 reference batch without waterproofing treatment and 4 batches, each treated with a selected waterproofing product. Each batch consisted of 15 boxes with every 5 boxes using one of the three brick types as a minimum of 5 specimens of the same material as required by the standard.

Before assembling the whole box, the specimens encased in the top frame were kept in an environmental chamber for 2 days of conditioning at a temperature of 23°C and 50% RH. Then, 15 boxes were fully assembled for each batch, with $NH_4H_2PO_4$ solution at the bottom of the box maintaining 93% RH, weighed and placed back in the test chamber (Figure 13). Due to the humidity difference between the test box and the chamber, a vapour flow driven by the partial vapour pressure occurs through the specimens.

A total of 72 continuous hours of mass change were recorded with a weighing interval of 24h, thus 4 values were used in the calculation of water vapour resistance for each box. Each box was weighed 5 times at each interval. BS EN ISO 12572:2016 suggests carrying out the weighing of the specimens in an environment with a temperature within ±2°C difference of the test condition, and wherever possible, within the test chamber. In this study the weighing was carried out on a stable bench next to the chamber using a scale with accuracy of 0.01g, as required by the code. The boxes were exposed to the lab relative humidity and temperature for approximately 5 minutes in each weighing cycle. This was not considered to lead to any significant alteration in the specimens’ moisture content.

Figure 13: Humidity and temperature control chamber with testing boxes

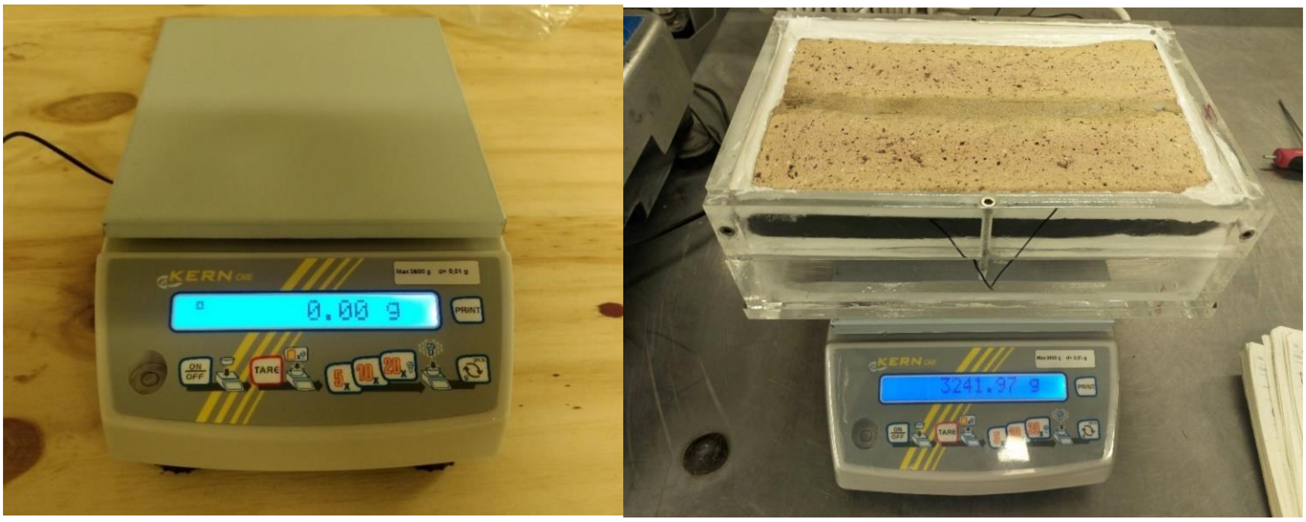

Figure 14: a) Scale used for weighing *b) weighing box test setup*

3.5 Calculation of water vapour transmission

For each set of successive weighing of the specimens, the mass change rate (G, kg/s) was calculated and averaged over five measurements. Then, water vapour permeance (W, kg/(m^2.s.Pa)) was calculated for each test case by dividing the average mass change rate (G) by surface area of the specimen (arithmetic mean of the free top and bottom surfaces (A, m^2) and water vapour pressure difference across the specimen (Δp, Pa), which was chosen as 1207 Pa as recommended by Table 2 in BS EN ISO 12572:2016 for set C defined as 23°C and 50/93% RH testing conditions. Based on this, water vapour permeability (δ, kg/(m.s.Pa)) was calculated by multiplying water vapour permeance (W, kg/(m^2.s.Pa)) by the specimen thickness (d, m). Finally, the water vapour resistance factor (μ, unitless) was calculated by dividing the water vapour permeability of air (δ_{air}) by the calculated water vapour permeability of the specimen (δ), producing the equation shown below:

$$\mu = \frac{\Delta p * A * \delta_{air}}{G * d} = \frac{\Delta p * \delta_{air}}{g * d} \tag{1}$$

where g is the density of water vapour flow rate, calculated by dividing the water vapour flow rate through the specimen (G, kg/s) by the surface area (A, m^2) for each specimen, and d (m) is the mean thickness of specimen.

The water vapour permeability of air (δ_{air}) is estimated as 1.95x10^{-10} kg/(m.s.Pa) using the standard barometric pressure based on Figure 2 of BS EN ISO 12572 titled "Water vapour permeability of air as a function of barometric pressure at 23°C". This value is further verified using two versions of the Schirmer formula shown in Eq. (2) (Maillard et al., 2014), and Eq. (3) (Slanina et al., 2009) adjusted to the units used in the present study,

$$\delta_{air} = \frac{2.306 \cdot 10^{-5} \cdot p_0}{R \cdot T \cdot p} \left(\frac{T}{273}\right)^{1.81} \tag{2}$$

$$\delta_{air} = \frac{1.97 \cdot 10^{-7} \cdot T^{0.81}}{p} \tag{3}$$

where R stands for the gas constant of water vapour and is equal to 462 Nm/(g.K), T stands for temperature and is equal to 296.15K (equivalent to 23°C), p_o stands for standard barometric pressure equal to 101325 Pa and p stands for barometric pressure in the lab. This last parameter was measured during all water vapour transmission tests and was taken equal to p_o in the calculation as it was observed not to diverge more than 0.001% from the standard barometric pressure in the environmental chamber.

4. Hydrophobicity/ Wettability Test

4.1 Specimen design

The objective of this test is to quantify the level of hydrophobicity (or wettability) of the masonry surfaces after treatment by waterproofing products. The specimen sizes were dictated by the testing equipment chosen for the test, the Drop Shape Analyzer (DSA)100 manufactured by KRÜSS, whose testing platform allows specimens of a maximum size of 100 x 56 x 28 mm. Therefore, in this study for the hydrophobicity test brick specimens of this size were used. Mortar specimens were not tested for this parameter as producing specimens of this size was not possible.

4.2 Test process

The method codified in BS ISO 19403-2:2017 requires determining the surface free energy of a solid surface by measuring the contact angle of different liquids on it. The contact angle is representative of the surface tension and the surface free energy of the specimen, hence providing a quantitative basis for the “wettability” of the surface. The higher the contact angle the higher the hydrophobicity is, i.e. the lower the wettability is. The DSA100 allowed calculating the surface tension automatically with successful determination of the contact angle.
The test was carried out at the UCL electrochemical lab, where the ambient temperature and relative humidity levels were constantly controlled at 23 ± 2°C and 50 ± 5% in line with ISO 3270 (1984), to ensure all test media were under the same hygrothermal conditions.   Water was the only test liquid used in this test. The flat surfaces of all 15 specimens, 5 for each brick type untreated or treated with one of the 4 different surface waterproofing products, were each dosed onto by 8 water drops on different parts of the surface, and for each drop the contact angle was measured.

5. Absorption test

The absorption test was performed following standard EN ISO15148:2002, to determine the level of absorption of different substrata, untreated and treated with the two waterproofing products selected following the other bench testing, i.e. treatments B and C. The standard suggests at least 3 specimens of a face area of 100 cm^2 in contact with water. Three different types of specimens were used for each treatment: 100 mm mortar cubes, 215x102.5x65 mm standard dimension full bricks, laid as in course, 215 x 140 x 28 mm brick and mortar combined specimens used in the vapour transmission tests. We test 3 specimens for each type (brick, mortar and masonry), untreated and treated with 2 different waterproofing products, i.e. 27 tests.

5.1 Absorption Test preparation and protocol

The specimens were dried and stored in the curing room at 22°C and 55% RH after being carefully cleaned from small particles then brushed with the selected waterproofing treatments. The test was also carried out inside the curing room with the same controlled environment. A layer of mesh was placed at the bottom of a tray to support the specimens and ensure the treated surface were in full contact with water. The water level was maintained at 5±2 mm above the base of the specimens during the test (see Figure 15) as required by standard.

To prevent water from being absorbed from the side of the specimens, 48mm brown low noise general use duct tapes were used to seal the edges with an extra layer of silicone at the joint between tape and specimen to ensure the seal was waterproof.

To measure the mass change of the specimens, after removal from contact with water, the wet surfaces were blotted with a damp paper wipe and weighed with a scale accurate to 0.1g on a level platform. A total of 5 readings were taken from each specimen, and the weight at each immersion point was then averaged based on these 5 readings. The procedure of immersion, removal, surface drying, and weighing was repeated at intervals of 5min, 20min, 1h, 2h, 4h, 6h, 8h, 10h and 24h.

Figure 15: Three different types of specimens during absorption test

6. Results and discussion

6.1 Water vapour permeability test results

Figure 16 shows the water vapour resistance factor of different brick types with various waterproofing treatments. The error bars on the columns are the standard deviation between 5 boxes of each brick and waterproofing combination.

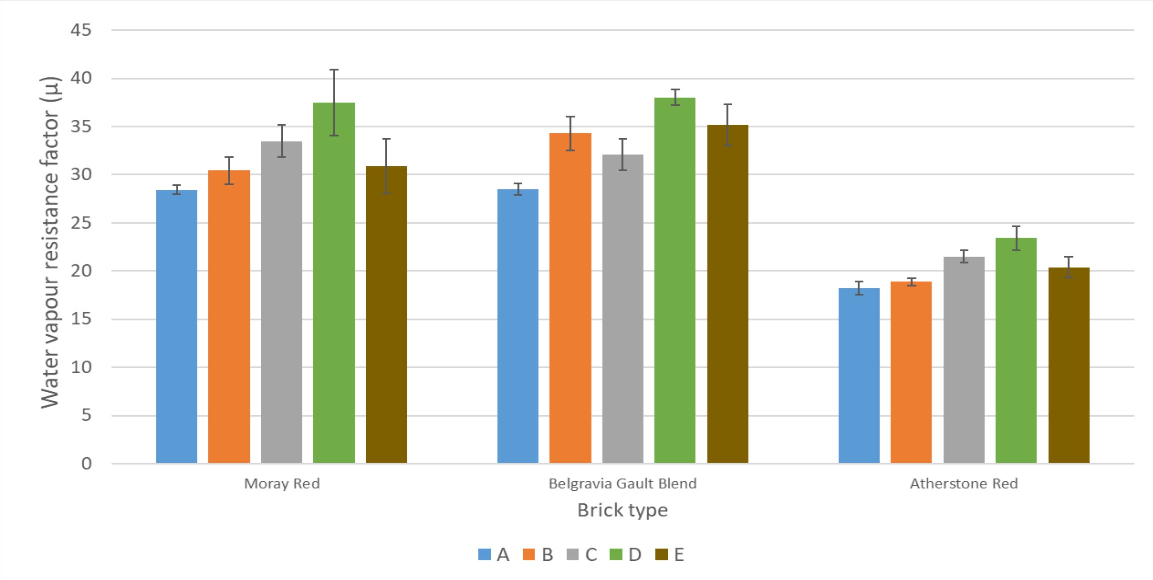

Figure 16: Water vapour resistance factor (μ) of masonry specimens with different brick types and various waterproofing treatments

From the results it's obvious that the water vapour resistance was mainly dominated by the brick's own physical properties. Nonetheless the trend of the relative performance of the treatments for each substratum is consistent across the three brick types.
Results obtained from untreated specimens are very consistent with relatively little standard deviation. The highest variability for the treated cases is observed in specimens built using Moray Red. This is likely due to the visibly more heterogeneous structure of Moray red, with larger particles, leading to a lower uniformity (see Figure 1). Atherstone Red results, for both untreated and treated cases, demonstrate the highest consistency.

A comparative review of the results obtained for specimens treated with individual products shows that among the waterproofing products, D led to standard deviations relatively high among all treatments except in combination with Belgravia Gault Blend. On average, the product provides the highest impact on water vapour resistance over all 4 products but also importantly, there was less consistency compared to other products. B and E have shown similar performance: they both have a relatively low impact on the water vapour resistance while B held a more consistent performance over all brick types. Differently from the other 3 aqueous products, C is a cream product. It was the second strongest waterproofing product in providing additional water vapour resistance for two out of three brick types.

6.2 Hydrophobicity/ Wettability test results

Similar to the previous test, first the untreated specimens were tested to provide the reference case, where the water drops were absorbed fully within 1-3 seconds, depending on surface roughness, uniformity and density of bricks. Due to the rapid absorption, the DSA100 was not able to capture the image and the contact angle could not be measured.

The results obtained from hydrophobicity tests are summarised in Figure 17**Error! Reference source not found.**. B a nd E treated specimens showed very similar results with no obvious absorption in the 20 minutes duration that they were observed after the drops were dosed on the surfaces, and the contact angles were very consistent over all brick types. The average contact angles were also very close with 113.5° for the B specimens and 114.1° for E specimens (Figure 18a and 18c).

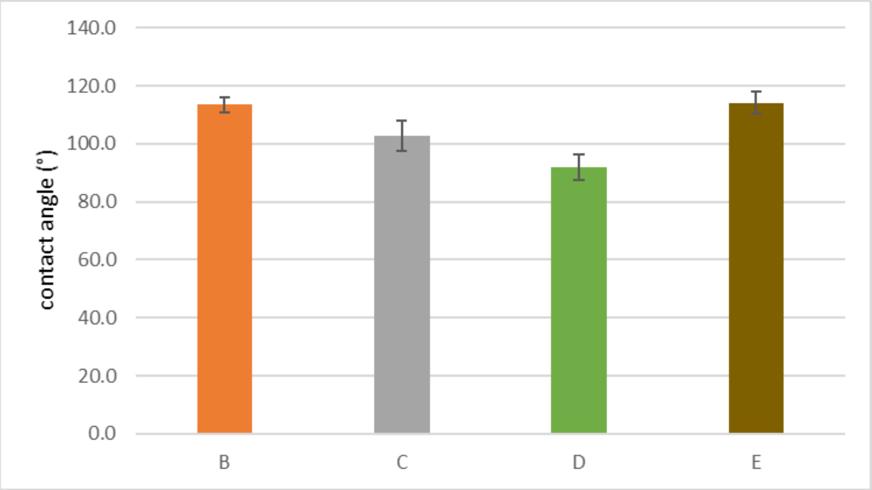

Figure 17: Average water contact angles for each treated specimen

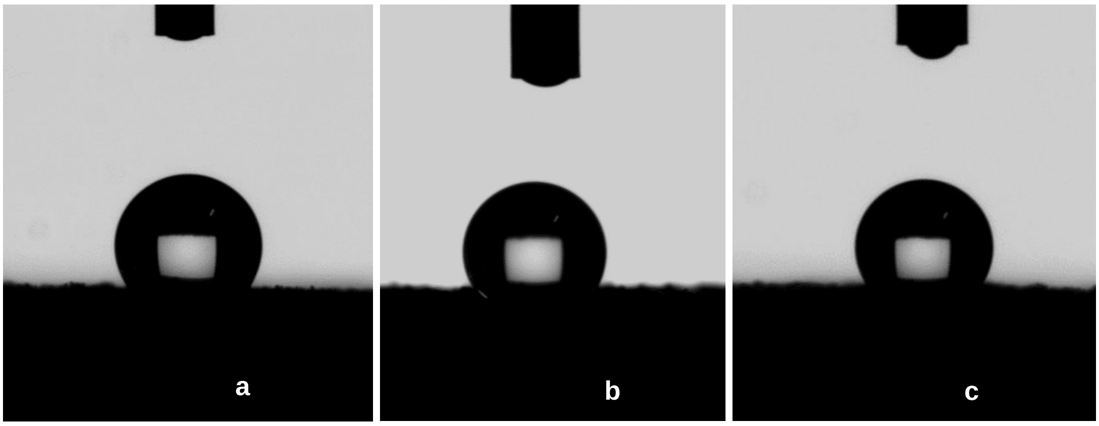

Figure 18: Water drop on specimens treated with product B, product C, and product E

Compared to other specimens, the ones treated with product C have shown some unique characteristics. On the centre of the brick specimens, the absorption started 3 minutes after leaving the droplets on the surface and the water droplets were completely absorbed in 10-15 seconds. After repeated tests on the whole specimen surface, it was seen that the absorption starting time reduced radially from the centre to the edges of the specimen. On the edge water drops absorption started in 0-5 seconds and they were fully absorbed in 10-15 seconds. In most of the surface between the centre and the edges, the absorption started around 1 minute after dosing on the surface, and the droplets were fully absorbed in 10-15 seconds. The average contact angle before the start of absorption was 102.8° (Figure 18 - middle). This rather unique characteristic of the specimens treated with this product is considered to be due to its consistency as cream. It can be assumed that the difference was caused by the uniformity of application caused by the nature of the product and the workmanship quality. Despite all efforts towards best practice in application under ideal lab conditions using a paint roller, the centre of the specimen was rolled over more times than the edge. It should be borne in mind however that this uneven distribution of the product over the surface of the specimen is due to the small specimen size and might not reflect the product spread over a real-life façade when applied with good workmanship.

In case of specimens treated with product D, the absorption started within 5 to 15 seconds after dosing the drops on the surface, and the droplets were fully absorbed between 1 to 3 minutes (Figure 19). However, the contact angles before the absorption started were very consistent with an average of 91.9°, which demonstrated a relatively high wettability of surfaces treated with the blend liquid.

Figure 19: Water drop getting absorbed on brick surface treated with product D

Combined with the findings in the water vapour transmission test, apart from the wettability difference caused by the roughness of the brick surfaces, the quality and uniformity of the application can influence the amount of product penetrating the surface. From the results of both tests, the C product is showing relevantly higher sensitivity in application quality on smaller scale specimens, therefore it can be assumed that good workmanship is necessary to achieve a satisfactory coating with consistent performance on real scale applications. This characteristic is further discussed in appendix E.

6.3 Absorption test results

The aim of an absorption test is to measure the rate and amount of water absorption in specimens when in water. The results in the graphs shown in Figure 20 were averaged from three samples for each building material and waterproofing treatment condition. Weight gain on untreated bricks reduced significantly after 2h, mortar samples in about 4h and combined samples in about 1h, although modest weight gain is still visible up to 5 hours. The water absorption coefficients calculated for the B-treated samples were considerably lower than the ones for untreated samples, indicating a slower absorption, but the brick had a faster rate of absorption than the mortar, while the combined sample had a rate of absorption similar to the mortar. The C-treated samples show a flat curve with almost no water absorption over all three types of sample. In terms of weight gain over 24 hours, the untreated specimen shows a weight gain of 17% in the mortar, 11.6% in the brick and 10.7% for the combined specimens. For B treated specimens the uptake was roughly halved at 5.9%, 7.6% and 6.7%, in mortar, brick and combined respectively. The C treated specimens had weight gain two orders of magnitude smaller at 0.14%, 0.29% and 0.37% in mortar, brick and combined respectively.

From the error bars shown in Figure 20, the performance of the B-treated samples was less consistent and had larger scatter for the brick and mortar samples, when compared to the combined specimens, which showed high consistency. This can be explained by the fact that the combined samples were treated 12 months before the test, while the brick and mortar samples only 28 day before the test, hence the curing time having an effect on the absorption of the sample. Therefore the long-term performance of the treatment should be further investigated, and it is recommended repeating the above set of tests at 6 months intervals.

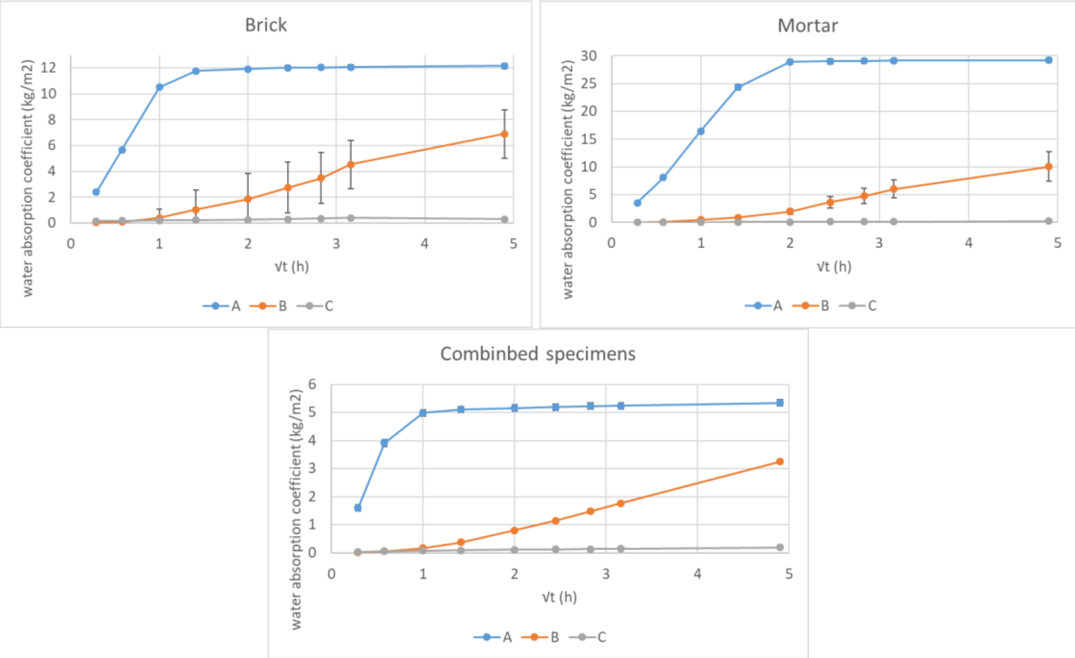

Figure 20: Water absorption coefficient variations for brick, mortar and combined masonry specimens

On the other hand, all C treated samples have shown little water absorption compared to untreated and samples treated with B. The results were also very consistent, with very minor error values. However, it is noted that the rate of weight gain in the first 5 minutes is higher than the rate for subsequent time intervals on the brick samples and the water absorption coefficient curve grew gradually flatter.

The results of the absorption test are supportive of the findings from the WDR tests on insulated walls in WP6. The water absorption coefficients of the B-treated samples were considerably lower, and the water absorption rate was slower than untreated ones while C treated samples almost absorb no water over all three types of sample. Additionally, the combined samples treated with B showed higher consistency in performance than freshly treated brick and mortar samples, possibly indicating an improvement in performance with longer curing time or exposure to high RH environment. Hence the long-term performance of the treatment could be usefully confirmed by repeating the above set of tests at 6 months intervals.

Similar to the WDR test results obtained from insulated walls, all C treated samples have almost no water gain in the absorption test. Furthermore, the increase in water absorption coefficient was faster in the first 5 minutes than the rest of the 24h test.

Table 2: Summary of the findings from hydrophobicity, water absorption and water vapour transmission tests through the lifecycle of a wall response under exposure (green, yellow and red indicate comparatively significant, some/inconsistent and little/insufficient improvement, respectively, and SD stands for standard deviation)

FIRST CONTACT WITH WATER | **WETTING PROPENSITY** | **EASE OF DRYING**

Treatment	**Hydrophobicity test**		**Water absorption test**			**Water vapour transmission test**	**Performance summary and implications**
	Brick III (cured for 1 week)		**Brick III** (cured for 2-4 weeks)	**Mortar** (cured for 2-4 weeks)	**Masonry with brick III** (cured for 12 months)	**Masonry made with brick III*** (cured for 2-3 days)	
	Average contact angle / SD	Time to the start of / for completion of sorption	Average water absorption coefficient at 24h / SD Performance in reference to base-case			Average μ / SD Performance in reference to base-case	
Untreated (base-case)	Could not be measured	0 / 1-3 sec	12.15 / 0.18	29.23 / 0.42	5.34 / 0.12	18.23 / 1.35	Low hydrophobicity, very quick absorption, good vapour transmission.
Acrylic-based liquid	113.5° / 5.07°	No obvious absorption after 20 min	6.89 / 2.02 -43.3%	10.08 / 2.66 -65.5%	3.25 / 0.05 -39.1%	18.89 / 0.80 +3.6%	Good hydrophobicity, low water resistance under intense rainfall, good vapour transmission. Comparatively less likely to trap water within the fabric to lead to moisture induced damage.
Silane/siloxane blend cream	102.8° / 10.33°	0-5 s on edge, 3 min in centre, 1 min between / 10-15 sec	0.30 / 0 -97.5%	0.23 / 0.01 -99.2%	0.20 / 0.01 -96.3%	21.5 / 1.32 +17.9%	Inconsistent performance in hydrophobicity due to difficulty of applying on small specimens, very effective liquid water absorption resistance, low vapour transmission.
Silane/siloxane blend liquid	91.9° / 8.81°	5-15 s / 1-3 min	0.27 / 0.03 -97.8%	0.22 / 0.02 -99.3%	3.45 / 0.16 -35.4%	23.41 / 2.48 +28.4%	Lowest surface water repellence, absorption results suggesting performance decay with time, lowest vapour transmission capacity indicating possible moisture trapping.
Stearate-based liquid	114.1° / 7.37°	No obvious absorption after 20 min	2.37 / 0.79 -80.5%	2.70 / 1.47 -90.8%	2.29 / 0.48 -57.1%	20.39 / 2.11 +11.8%	Good hydrophobicity can provide some resistance to liquid water ingress, low vapour transmission. Comparatively less likely to trap water within the fabric to lead to moisture induced damage.

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