CLR CASE STUDY 1A+B: HYDROPHOBIC BRICK CREAM ON SOLID WALL + IWI

APPROVED CLR VERSION a: 11.08.16

Contents

1. OVERVIEW AND INTERIM CONCLUSIONS

Key Details	
Assembly	Brick cream *or* no brick cream, 9 inch solid brick wall, lime mortar, spray foam within spaced timber studwork, vapor control membrane, plasterboard and skim
Insulation	**BASF 'Elastospray 1601/7:** zero ODP, low GWP, fully water blown, open celled (permeable) polyurethane spray system.
Vapour control	**Variable Vapour Resistance (VVR)** membrane directly on inner face of insulation
Airtightness	3.1 ACH @ 50 Pa
Ventilation	MVHR installed
Area of interest	Insulation-masonry interface
Concerns	1. Risk of mould growth at interface. 2. High moisture contents affecting various embedded timber elements **To test the effect of a hydrophobic brick cream** and compare with the adjacent untreated wall
Sensor type	Omnisense S-900-1 Wireless T, %RH, WME Sensor

1.1 RETROFIT OVERVIEW

Internal Wall Insulation (IWI) consists of 150mm of BASF PU sprayfoam inside a softwood timber frame. Walls were stripped back to the brick as shown. Brickwork with lime mortar has embedded timber elements (oak). The new IWI treated softwood timber frame also supports a variable vapour resistance membrane and plasterboard to the interior of the house. There are no joists ends present in the roadside, west facing wall, they run parallel and are set off the brickwork by c. 90mm.

An injected DPC was installed in all solid brick walls.

Half of the exterior of the IWI treated wall (west wall only) is treated with a hydrophobic brick treatment, the other half is not: these areas of wall are termed "Treated" and "Untreated", otherwise the IWI construction is the same. There are a limited number of sensors in place due to limited funding which means caution is required when drawing conclusions.

Interior of wall before installation of insulation, showing embedded timbers.

1.2 INTERIM CONCLUSIONS

In this wall the brick cream creates a thin hydrophobic zone in outer few millimeters of the masonry where no capillary action is possible - but where water vapour can still freely pass through in either direction via diffusion. Results indicate that the masonry of the wall in treated areas appears to dry out better after retrofit than untreated areas, resulting in no mould or rot risk to timber components. Warm spells helping drive the rate of drying on both wall areas. Significant inward vapour flows occur during these warm spells. Due to the vapour permeable insulation, membranes and decorative finishes inward vapour flow is possible. In the treated walls the wall assembly components monitored appear to avoid problematic build-ups of humidity and moisture, with no on-going risk of rot or mould growth. In contrast, despite the vapour open nature of the assembly, the untreated masonry areas experience higher moisture contents and higher humidity, with associated increased risk to embedded timbers and mould growth at the insulation/masonry interface.

A recent microwave based handheld WME meter survey of the outside of the wall was undertaken, attempting to validate through a greater number of survey points, conclusions drawn from the readings of the original embedded sensors. As with all Protimeter type moisture meters, the survey produced *relative*, not absolute readings and a number of caveats need to be borne in mind relating to the microwave method, particularly depth of penetration of the microwave beam, and reflection effects. The inconsistent and relatively poor quality repair and repointing work to this brick wall, carried out as part of the improvement works, combined with the nature of the materials means that the consistency of performance of the assembly may vary between even individual bricks and mortar joints. The survey results reflect this variability, and a less clear picture emerges from this survey. Overall however, the survey has been interpreted to confirm that the treated walls areas *are* slightly drier than the untreated areas. However, as a result it will be recommended to improve the pointing of the walls *before* completing the remaining brick cream treatment as the poor condition of the pointing is the weak point in this rain protection strategy.

The performance of the injected hydrophobic DPC into the variable quality brickwork is not known, it is assumed on the basis of the precautionary principle that a certain level of residual rising damp may be present in some areas. Theoretically if the brick cream surface treatment is continued below the line of such a DPC - and a high enough level of 'evaporative pumping' is present - then salt deposits may build up over time just behind the surface of the masonry potentially giving rise for concern. This is an area that requires more research; meanwhile retrofitters should adjust their 'at DPC level' strategies and accordingly to find a balance between the various residual risks.

1.3 PROJECT INFORMATION SUMMARY

Case Study 1a,b — U value: 0.22

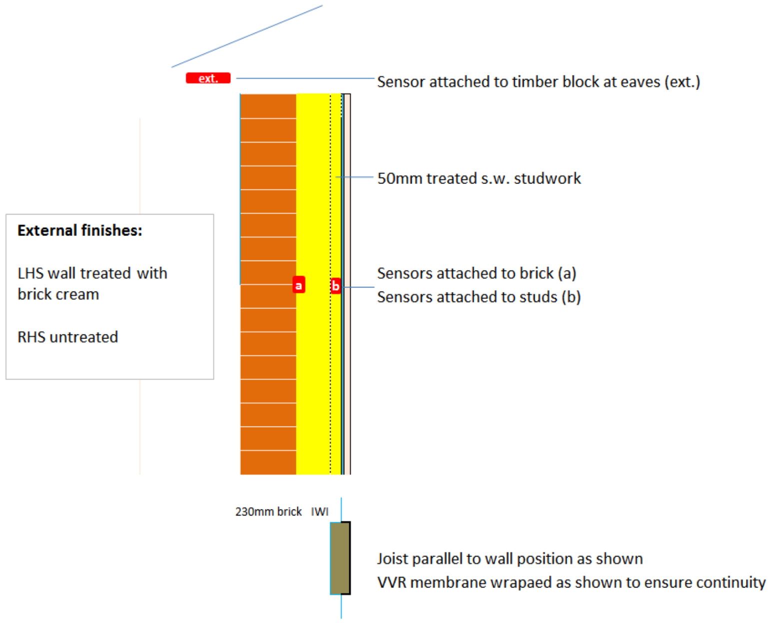
Solid Wall, PU Foam IWI without brick cream
West Midlands rural solid brick end terraced house

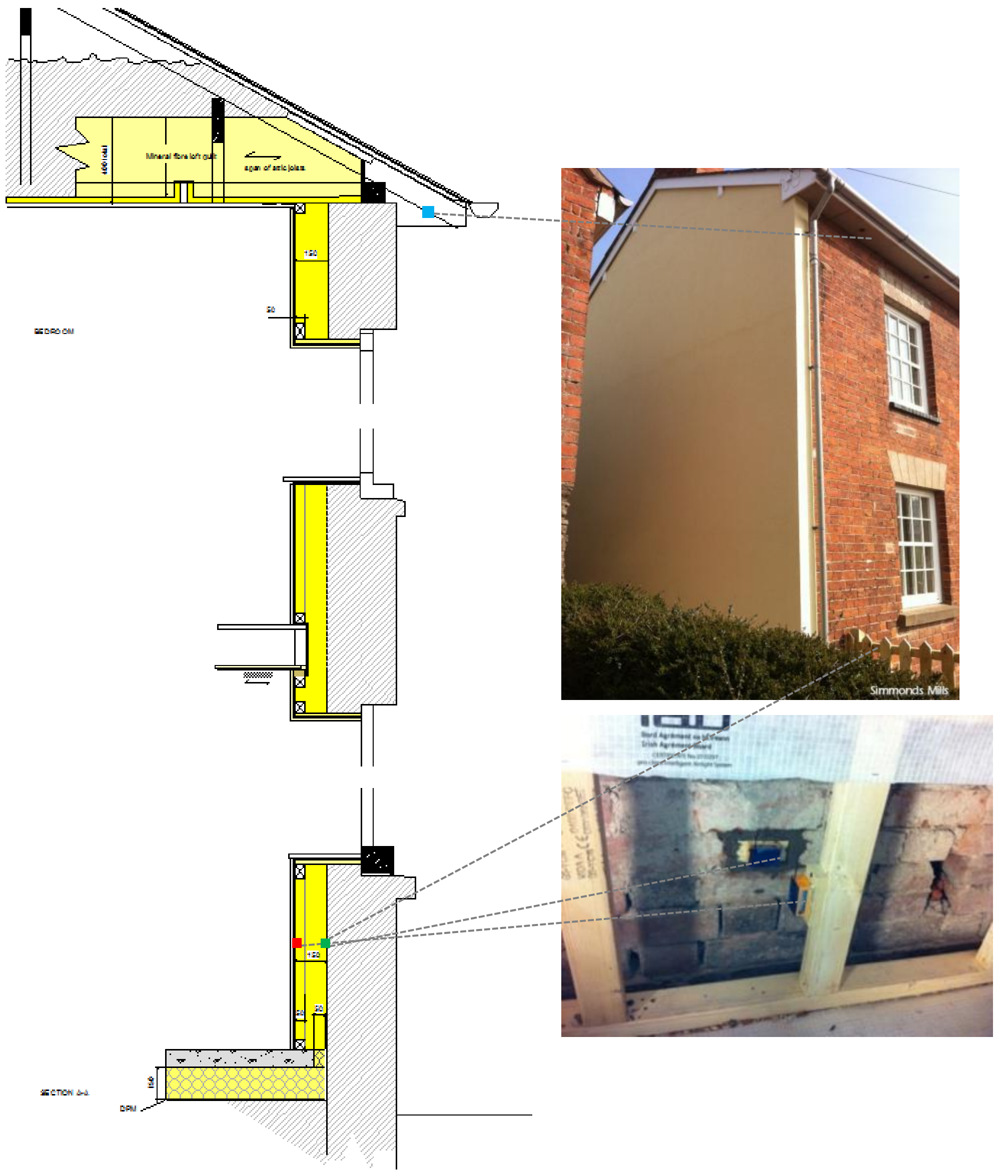
		thickness mm	λ W/mK	Vapour Resistivity MNs/gm	Substrate Class
Inside	Plasterboard & skim	15	0.25	50	
	Intello membrane	0.1	0.04	1.2 - 50	
	BASF PU spray foam	150	0.037	11.9	3
Outside	Treated Brick (assume dry) OR Untreated Brick (assume damp)	230	0.56 0.77	50	2

Potential Moisture Influences

Interior med: Variable Vapour Resistance membrane, insulation continuous at 1st floor, joists parallel to wall
ground low: Injected DPC
rain low/ high: with or without hydrophobic masonry cream wall treatment
rain cat: 2 Medium 33-56 l/m2 per spell   wall faces West (afternoon sun and driving rain)

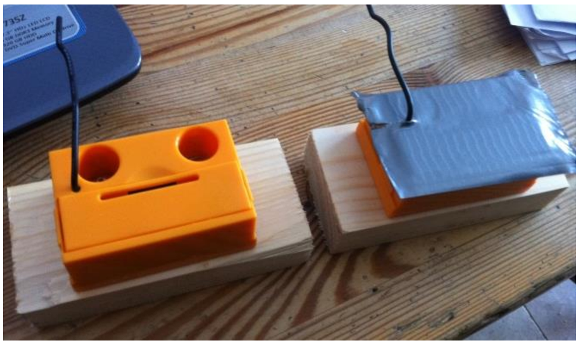
1.4 SENSOR LOCATIONS





1.5 SENSOR INSTALLATION METHOD

Sensors fixed to untreated softwood timber blocks, sensor legs cut short to set body 10mm off face of timber, edges and back of joint between sensor and timber sealed to protect from spray foam insulation. Timber block set flush into void in brickwork and mortared in place, sensor body within insulation zone. RH and T readings relate to 10mm zone adjacent to face of timber. Moisture content readings (via screws into timber) relate to the timber block, with the intention to assess the condition of timber in full capillary contact with the masonry/mortar at the insulation-masonry interface. The sensor is subsequently surrounded by 150mm of insulation, less over the body of the sensor.

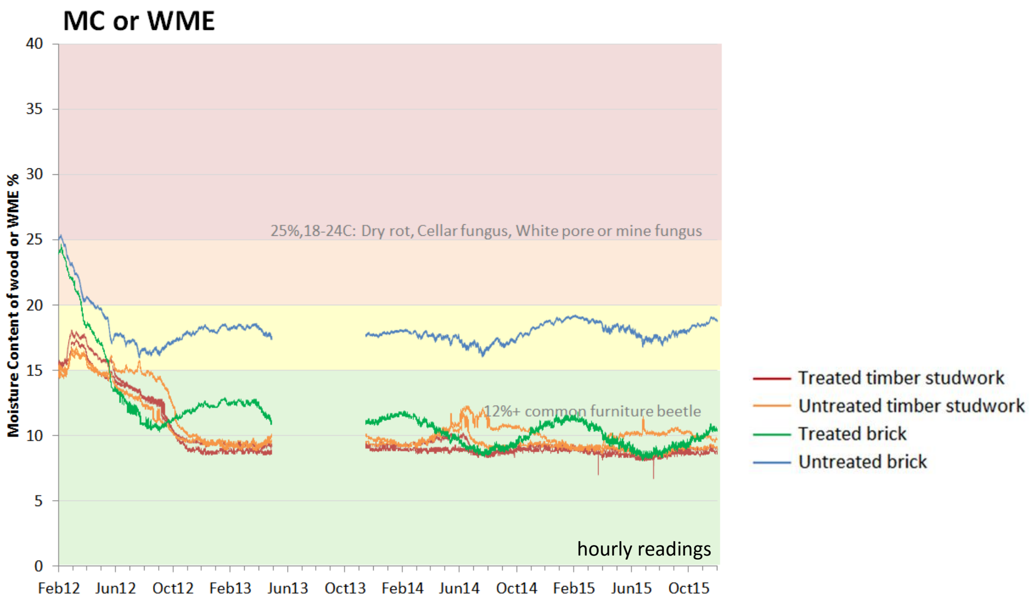


The sensor at the insulation/masonry interface behind the upstairs bedroom (treated) brickwork unfortunately failed fairly soon after retrofit due to water ingress through an unfilled mortar joint in the brick subcill directly above the sensor. The second sensor in this set – attached to the timber frame element on the warm side of the insulation - was unaffected. This underlines the critical nature of ensuring that gaps and cracks to prevent bulk water ingress are paramount when applying IWI (and EWI).

2. ANALYSIS

2.1 IS THE INSULATION WORKING SAFELY?

a. What's the moisture content inside the wall?



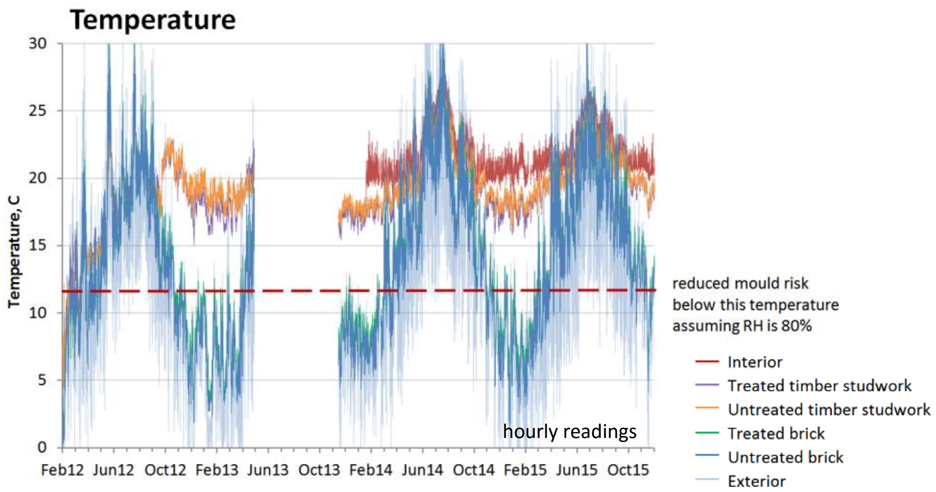
The WME of the masonry-insulation interface area is shown above over approximately 4 years. The WME at the masonry-insulation interface doesn't dry as much behind the untreated wall compared to behind the brickwork treated with brick cream.

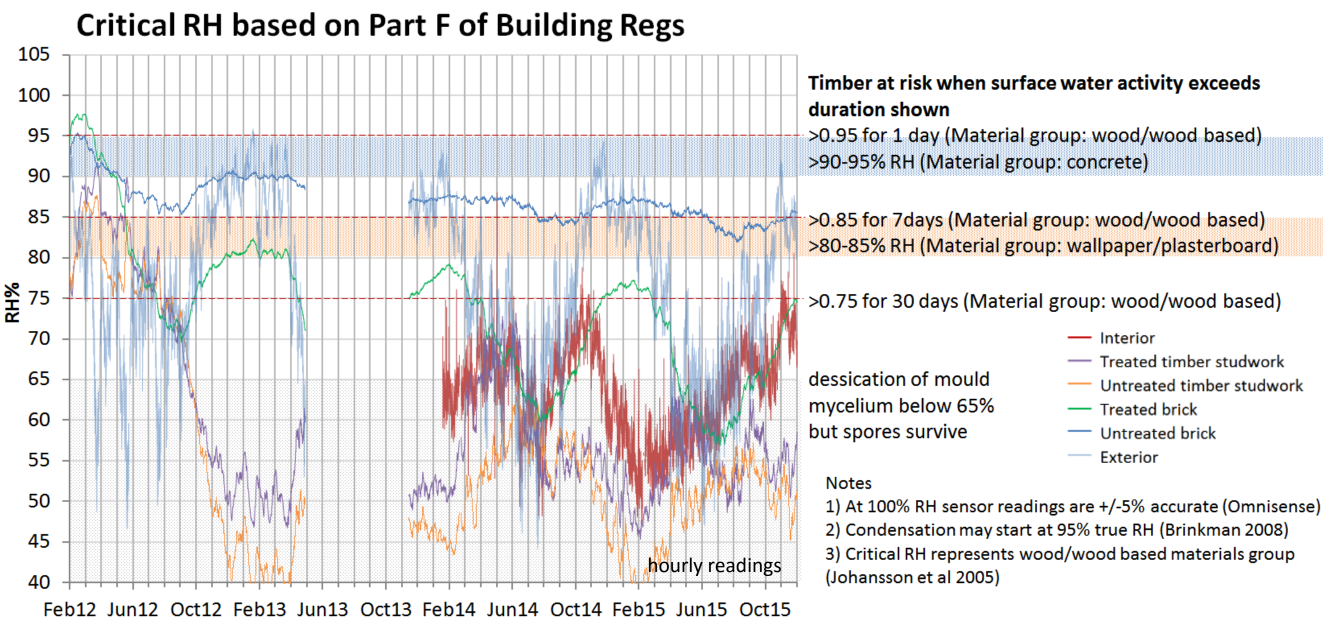
b. What is the rot risk for any timbers?

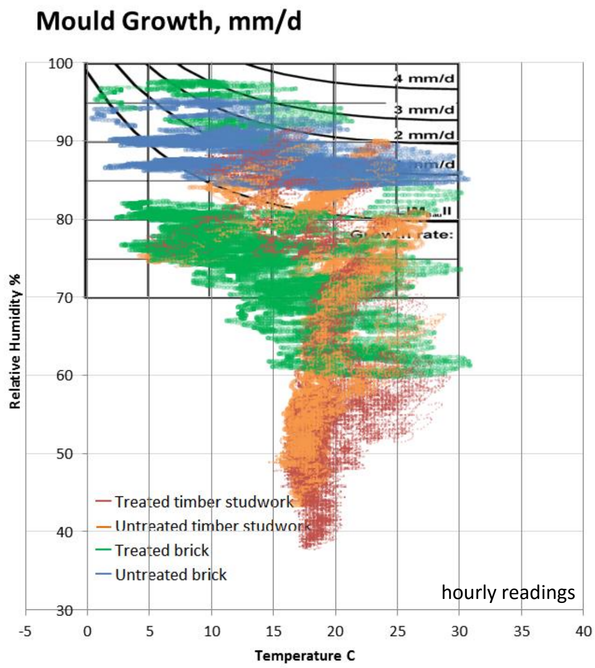
Moisture contents are also shown in the graph above for the adjacent softwood timber stud at the point where the 'variable-vapour-resistance' membrane is attached i.e. the warm side of the IWI assembly. This doesn't seem to be so dramatically affected by the treatment v. lack of treatment. Embedded timbers in the masonry are at a higher risk on the untreated wall.

c. What's the risk of mould?

Interface RH levels associated with brick with cream are lower than for the untreated brickwork (below). Even allowing for 5% error in the readings near 100% there is no sign of condensation, apart from possibly at the very start, post retrofit. This assessment of mould risk suggests brickwork surfaces are not at risk but untreated studwork may have been briefly at risk in 2014.

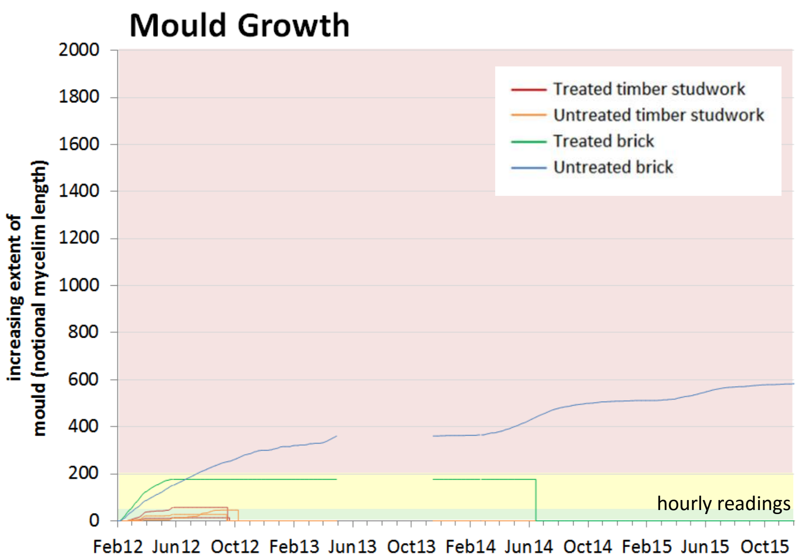






Left: the first 3 years of temperature and RH is plotted. The horizontal axis shows the masonry-insulation interface temperature (°C) and the vertical axis shows relative humidity (%). The overlay of mould growth rate is from Sedlbauer for Category. II substrates, *"Building materials with porous structure such as renderings, mineral building material, certain woods as well as insulation material"*. Wallpaper, plaster, cardboard, and other biodegradable materials such as woodfibre would be Category. I.

The sensors at the interfaces and on the inner timber frames do suggest some mould growth potential at different times. The main focus of this case study is the masonry-insulation interface (green dots): the next stage is to look at how the data varies with time, and whether clear trends suggesting increasing or decreasing risk are evident - and the characteristics of any such trends.



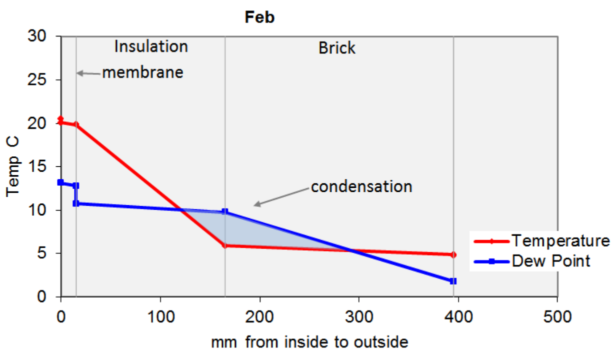
Left: results show that (assuming the presence of mould spores, a nutrient supply and the presence of oxygen) mould could have started growing at the masonry-insulation interface at an early stage soon after the retrofit - particularly for the interface behind the untreated brickwork, where mould growth continues over the monitoring period. For the treated brickwork the mould risk is comparatively lower immediately after retrofit and the mould mycelium later die as RH drops below 65%. However the microwave survey (Appendix A) shows window cills and lintels are wetter: there would be a higher mould risk behind these.

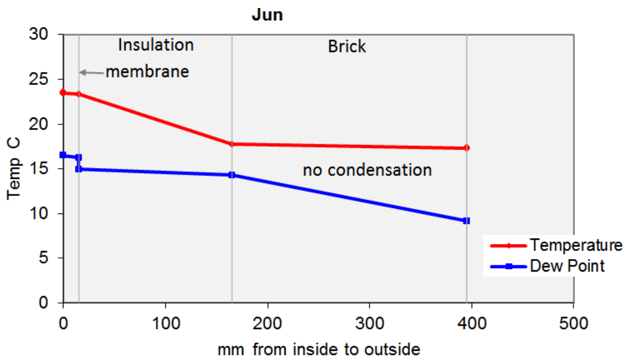
2.2 IF NOT, WHERE IS THE MOISTURE COMING FROM AND HOW?

a. Rain and rising damp via capillary flow?

In the WME graph shown in section 2.1a the difference in WME at the masonry-insulation interface for treated and untreated brick suggests the brick cream treatment is effective. However the microwave survey (Appendix A) showed large variations in results across the wall and that sensor appears to be in a 'better-than-average' position. The base of the wall is damp but this appears to be below the DPC, immediately above it is drier on the treated side suggesting that the DPC may be performing effectively in these areas.

b. Inside the house via vapour diffusion?



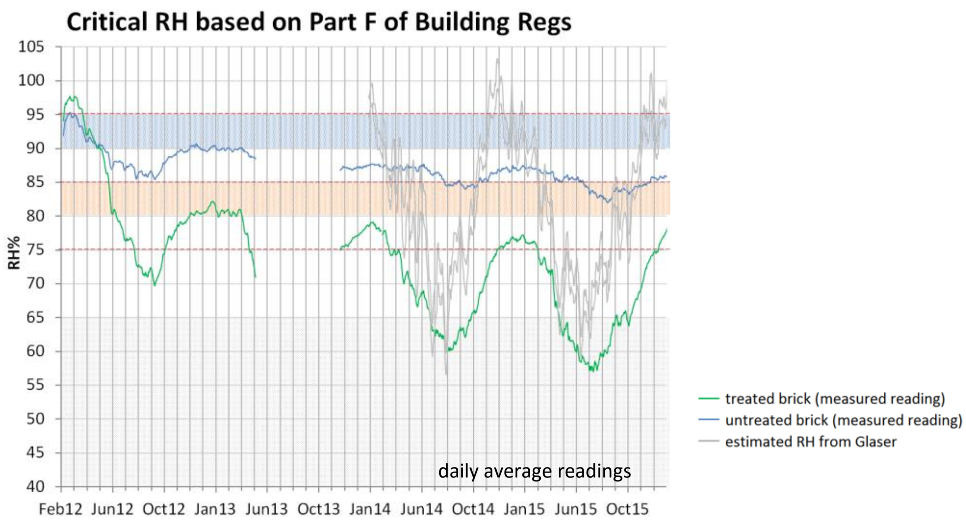


The Glaser method has been used as a first estimate of condensation risk: condensation appears to be likely in winter. On this basis a retrofitter may either avoid this build up, or consider a more detailed analysis using WUFI or similar. A WUFI analysis was carried out and this can be downloaded separately: it suggested that in this particular situation the proposed assembly should work where brick cream is used.

Values used for Glaser calculation

Internal and External vapour pressures	*Measured* monthly averages, from internal and external sensors, of temperature and Relative Humidity as in BS5250:2011.
K values	BS5250:2011 typical values
Vapour Resistances	BS5250:2011 typical values, manufacturers' values for the insulation and manufacturers documentation for the Intello based on measured RH at membrane.

Seven day average Glaser estimates of RH's at the masonry-insulation interface (grey) for treated and untreated brick follow the same trend as measured data but predict much higher humidity. The discrepancy between predicted and measured (between the grey and coloured lines on the graph) suggests a hygroscopic effect is also present, discussed in the next section. Adsorption could effectively lower the RH and could partly align the grey peaks of this RH graph closer to the measured readings.

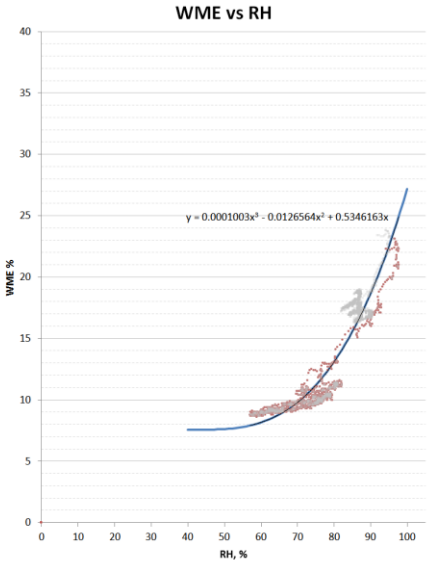


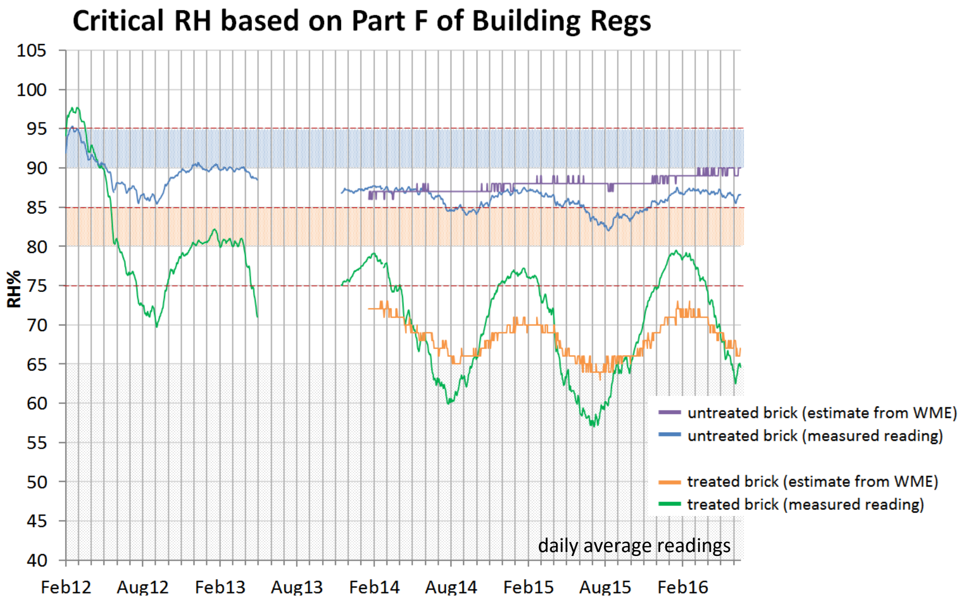
The measured RH accords reasonably well with the WUFI calculation for brick type 1 (see Fig. 7, p.9 of report) and WUFI RH graph below.

c. Hygroscopic Effects?

The main drying trend is illustrated well by the moisture content of the treated and untreated brick. Another trend line (below left) was created using data from sensors behind both treated and untreated brickwork: extrapolating from this single curve, the purple and orange readings shown on the right hand graph represent an ***estimation** of RH from the measured WME's* at those respective positions. These estimated RH values do match the average of the measured RH values readings quite well. This exercise suggests that RH is primarily dependent on the WME of the brick. The brickwork mass behind treated and untreated wall areas have different moisture contents: this gives rise to different RH's in the air next to the sensor, which is essentially tending towards equilibrium with the brick next to it.

This simply illustrates how the adsorption of water vapour by the brick and mortar, particularly during winter can explain the discrepancy between humidity levels as predicted by Glaser and those actually measured. A comprehensive comparison on a similar basis with the WUFI calculations would of course be interesting, time and funding permitting.





Below: RH graph from WUFI report, showing humidity reduced with brick cream for all brick types after the insulation:

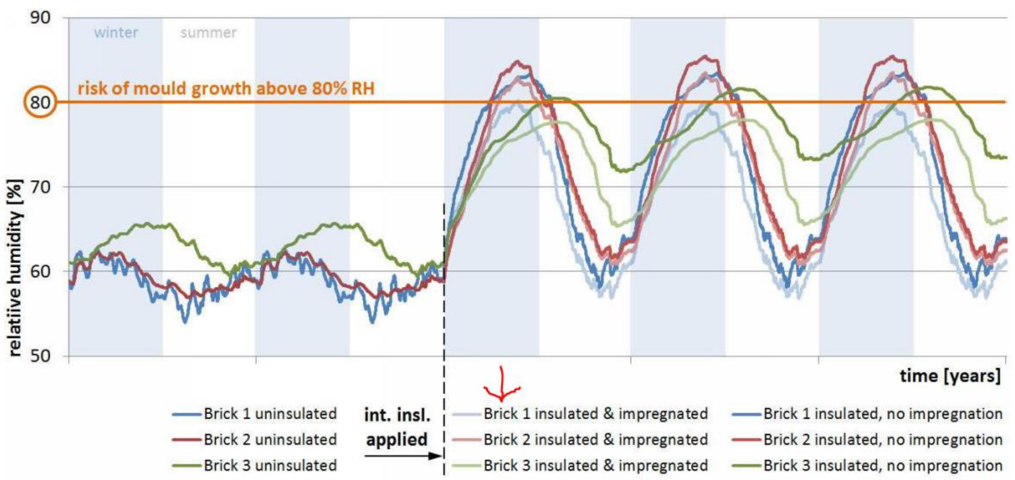
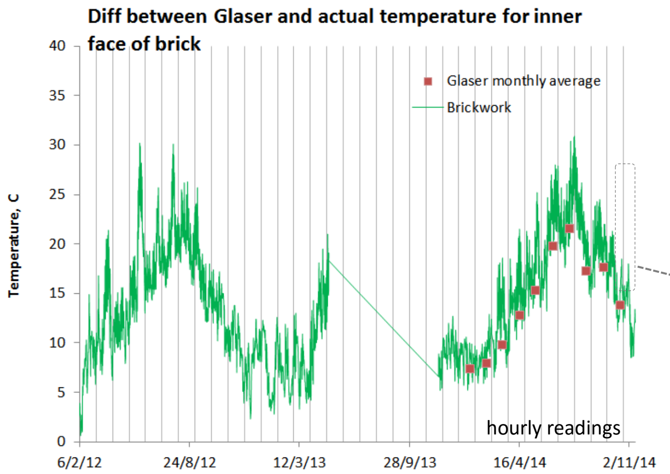


Figure 7: *Relative humidity in the brick wall at 75mm from its internal surface, before & after internal insulation*

2.3 HOW ACCURATE IS GLASER?

The two sections above show that Glaser isn't very accurate in this situation because hygroscopic effects are large and this partly explains why measured RH's never rise to the level where there condensation – as predicted by Glaser - would occur.

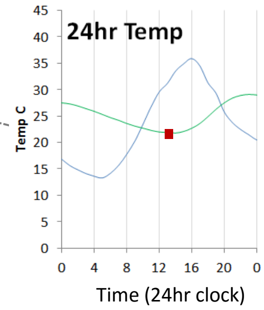
There is another reason why Glaser isn't accurate: in this project we can see that over the 'typical' 24 hour period illustrated below the Glaser predicted temperature is close to the *lowest* temperature actually recorded. This means that the average monthly Glaser temperature predictions (shown as red dots on the left hand graph below, at the masonry-insulation interface and the right hand graph, taken from case study 1a) are consistently lower than actual measured temperatures - particularly following brighter or sunnier days.



Solar irradiance drying effect 24/7//14

Sunny period, West facing wall:

The localised external temperature peaks at about 4pm, the peak at the inner face of the brick (interface) occurs around midnight. Vapour pressure follows the same pattern.

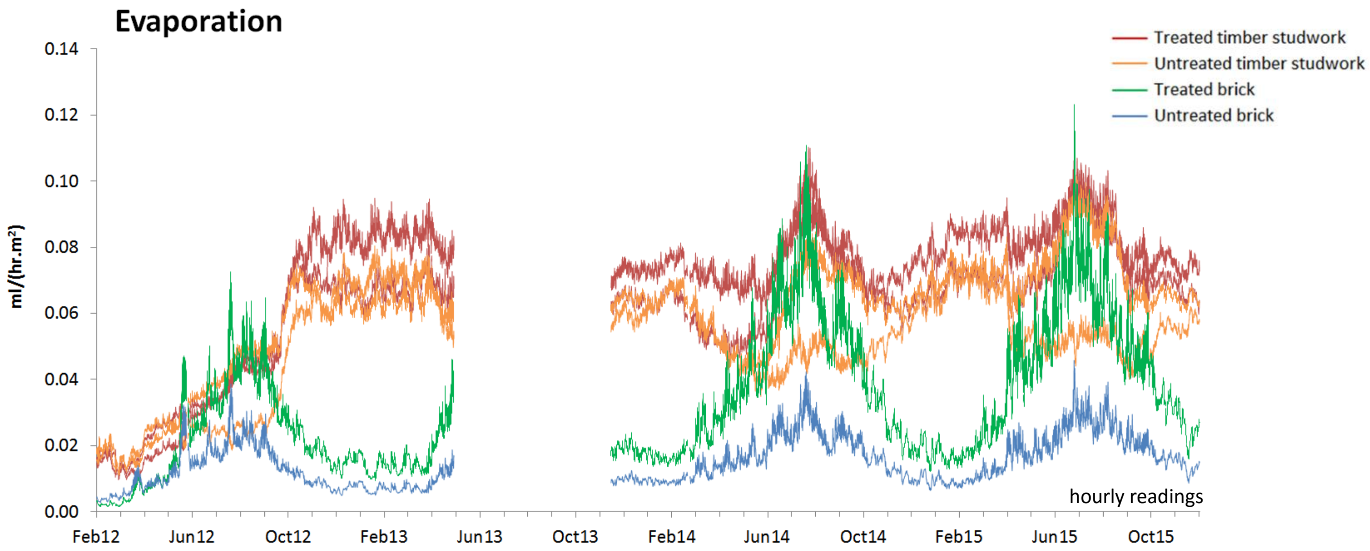


The difference in temperatures at the interface (i.e. they are higher at night than predicted) plus the hygrothermal effects can explain why there is in reality no interstitial condensation over the entire monitoring period. This would not necessarily hold true for north facing or well shaded walls or different climates – all of which WUFI factors in. As can be seen, by those interested to read the WUFI report, the analysis captured the overall trends well, but was less accurate concerning the magnitudes.

2.4 HOW IS THE WALL DRYING?

a. Evaporation Rates

Evaporation rates are calculated below from RH and T data at the masonry-insulation interface and timber studwork for treated and untreated brickwork. Units are ml per m^2 of wall per hour. On this graph an evaporation rate of zero would imply condensation (but it's easier to see this on the RH graph). The evaporation rate from the surface of the brick at the masonry-insulation interface for treated brickwork (green) is 2-2½ times that for the untreated areas (blue) after the first 6 months.



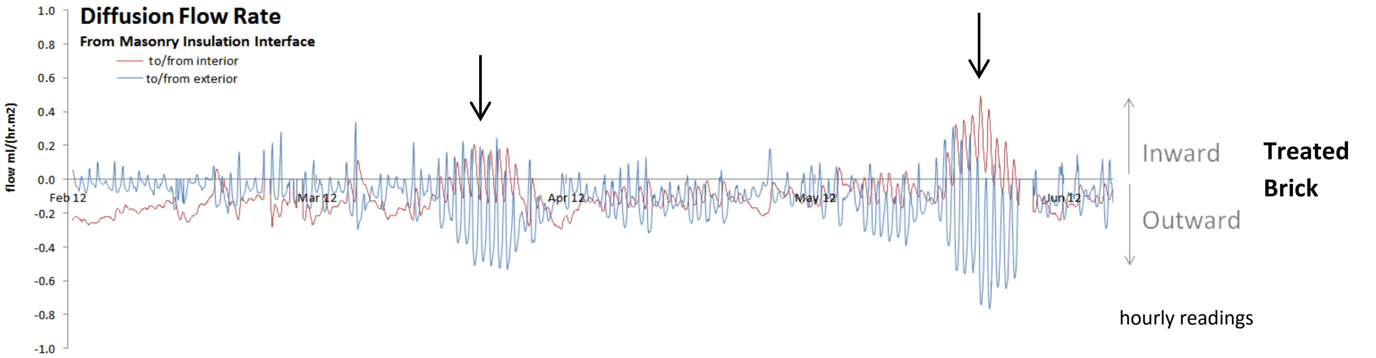
This is related to RH levels which differ between treated and untreated i.e. when RH is high, evaporation is suppressed. There is no noticeable difference between *temperatures* (below) within the wall associated with treated and untreated areas.

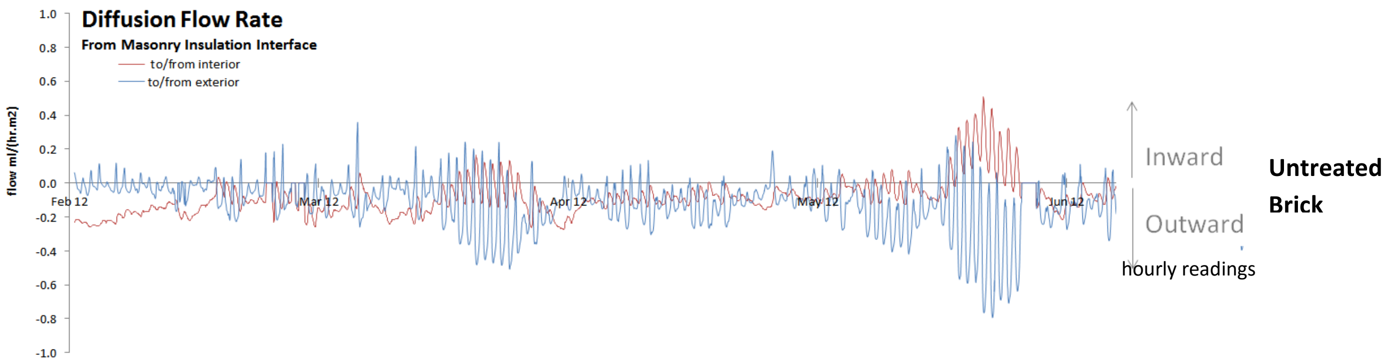
b. Diffusion

Vapour flows can be calculated using the sensors' data combined with assumed/published permeability data. These flow calculations are helpful in bringing to life the *magnitude* of **water vapour** movement via diffusion. However it is important to remember that significantly more moisture can be transported via capillary flow, and liquid sources of water such as from rain and rising damp are often likely to explain higher levels of WME and humidity.

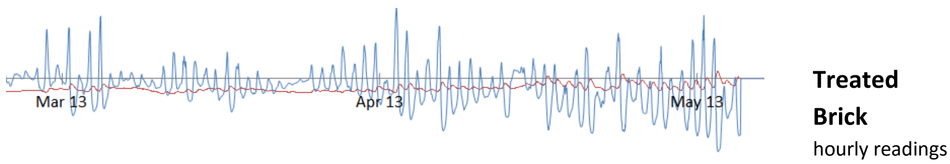
Reliable internal ambient data only became available a year after the original monitoring system was installed as the original internal ambient sensor was in an area (under stairs) that became adopted for drying clothes - leading to far higher than average RH readings. If we make a reasonable estimate of vapour pressure (using figures that agree with the following year, described later) we get the results as graphed **below:** only the red lines in the diffusion graph are based on this estimated data.

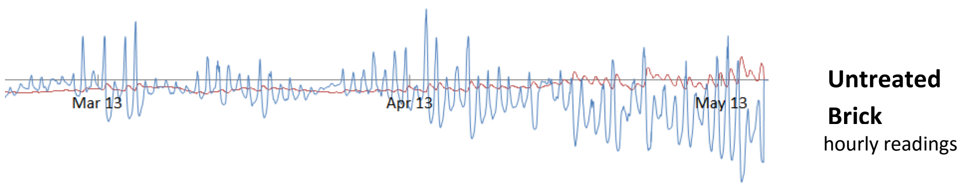
External ambient conditions tend to lead to a *change of direction in the flow of water vapour from the interface over the course of the day*. Diffusion results support this: the wall does dry to the inside - about 25% inward and 75% outward during the warmest drying episodes, two of which are illustrated (black arrows) in the figure below. The *diffusion flow rates* for treated and untreated insulation/masonry interfaces look similar over this period.



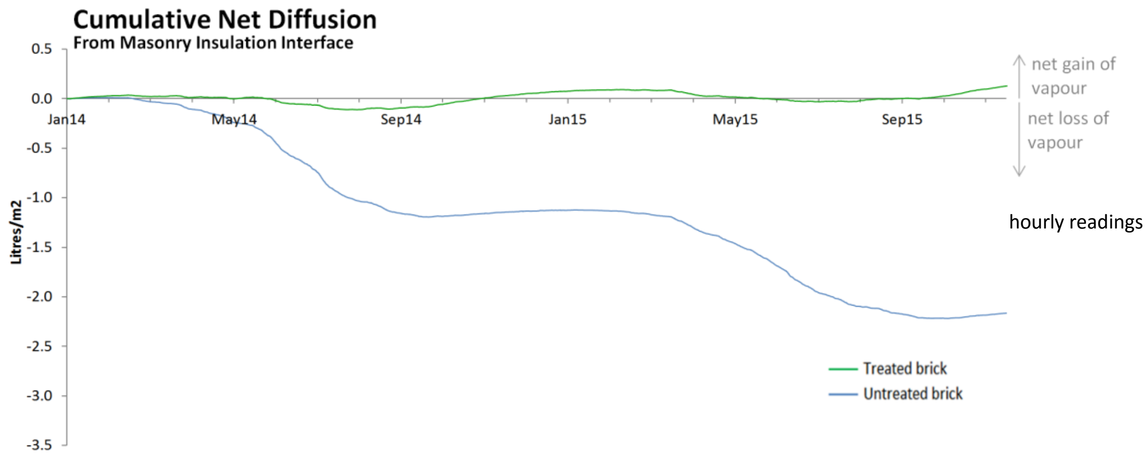


The following year - when the treated wall has dried out - diffusion flow rates are still similar.





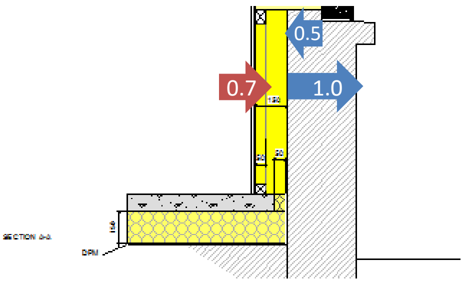
However the *cumulative combined effect of these inward and outward flows* which we call **'net diffusion'** in the graph below shows a difference between treated and untreated walls: this graph uses *measured* data since 2014 – as such it make no assumptions about vapour pressures, hence the evidence is more robust. Hardly any vapour has been lost from the treated wall, presumably because it is already dry - but over 2 litres of water has been lost from the untreated wall. WME readings show that the untreated wall is still not drying to the level of the treated wall, so something must be keeping it wet: the evidence suggests this source is the rain load entering the wall assembly.



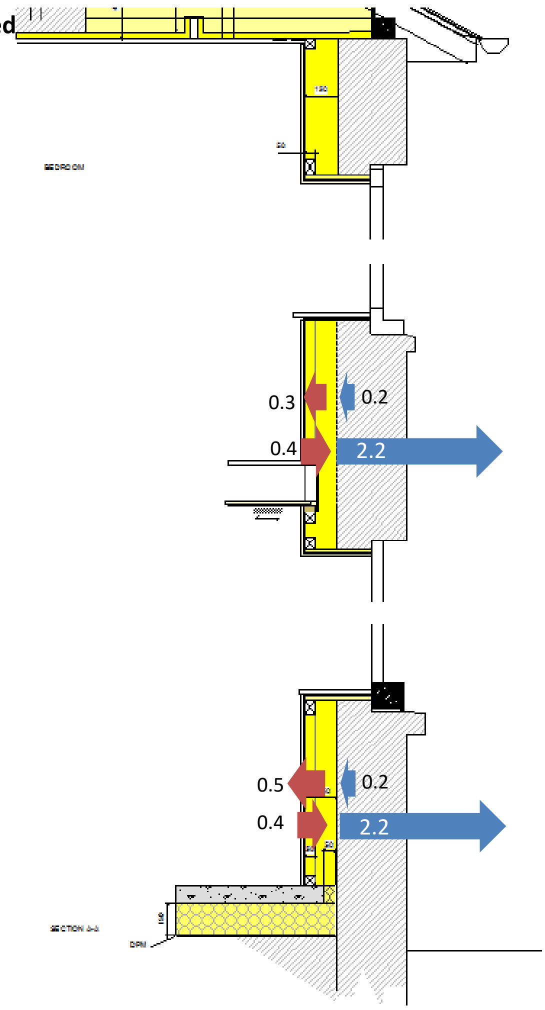
The diagram below shows a summary of water vapour movement (including direction and magnitude) over 22 months. Remember this is only vapour flows – <u>not</u> capillary flows. It can be seen that the untreated wall has a significantly larger amount of water vapour leaving the wall both inwards and outwards. The additional moisture – as before is assumed to be coming from rain loading entering the masonry via capillary action.

- The length of each arrow represents the *total magnitude of the movement of vapour through the wall* in each direction
- Figures are in litres/m^2 over the 22 months up to Dec 2015.

Treated



Untreated



2.5 SUMMARY

1. Is the insulation working safely?

a. Moisture Content of the treated brick interface is about 12% WME whereas that of the untreated is about 18% WME – both areas appear to have stabilized. However the microwave survey suggests a fair amount of variation and these results may not be completely representative of conditions generally.

b. The Rot risk for the studwork is low on both the treated and untreated side. Embedded timbers on the untreated side are still vulnerable.

c. The risk of mould is low on all the timber surfaces, however there is some risk at the interface behind the untreated brick. The microwave survey picked up patchy moisture content so the risk also could be expected to be patchy.

2. If not, where is the moisture coming from and how?

a. The hydrophobic brick cream treatment appears to reduce the rain load though we really need more sensors to be certain. A microwave survey suggests the DPC appears to be effective at preventing rising damp.

b. Vapour Diffusion. Glaser over-predicts the RH.

c. Hygroscopic effects are strong at the masonry-insulation interfaces, but the RH at the interface is dominated by the moisture content of the brick, where capillary transfer from rain or residual rising damp is present. Controlling RH is thus interpreted as reducing rain loading: the untreated area of brickwork will hopefully be repointed and brick cream applied spring/summer 2017.

3. How Accurate is Glaser?

a. Glaser doesn't give very accurate results in this situation because hygroscopic and capillary effects are significant.

b. Glaser doesn't include the effect of sunshine warming the wall so underestimates the temperature, typically by up to 4^{o}C in warmer weather.

4. How is the wall drying?

a. Evaporation rates are very different for the treated and untreated walls. Temperatures are almost identical for treated and untreated walls so it is assumed that the higher RH at the interface and higher WME in the masonry of the untreated wall is suppressing evaporation from within the wall assembly.

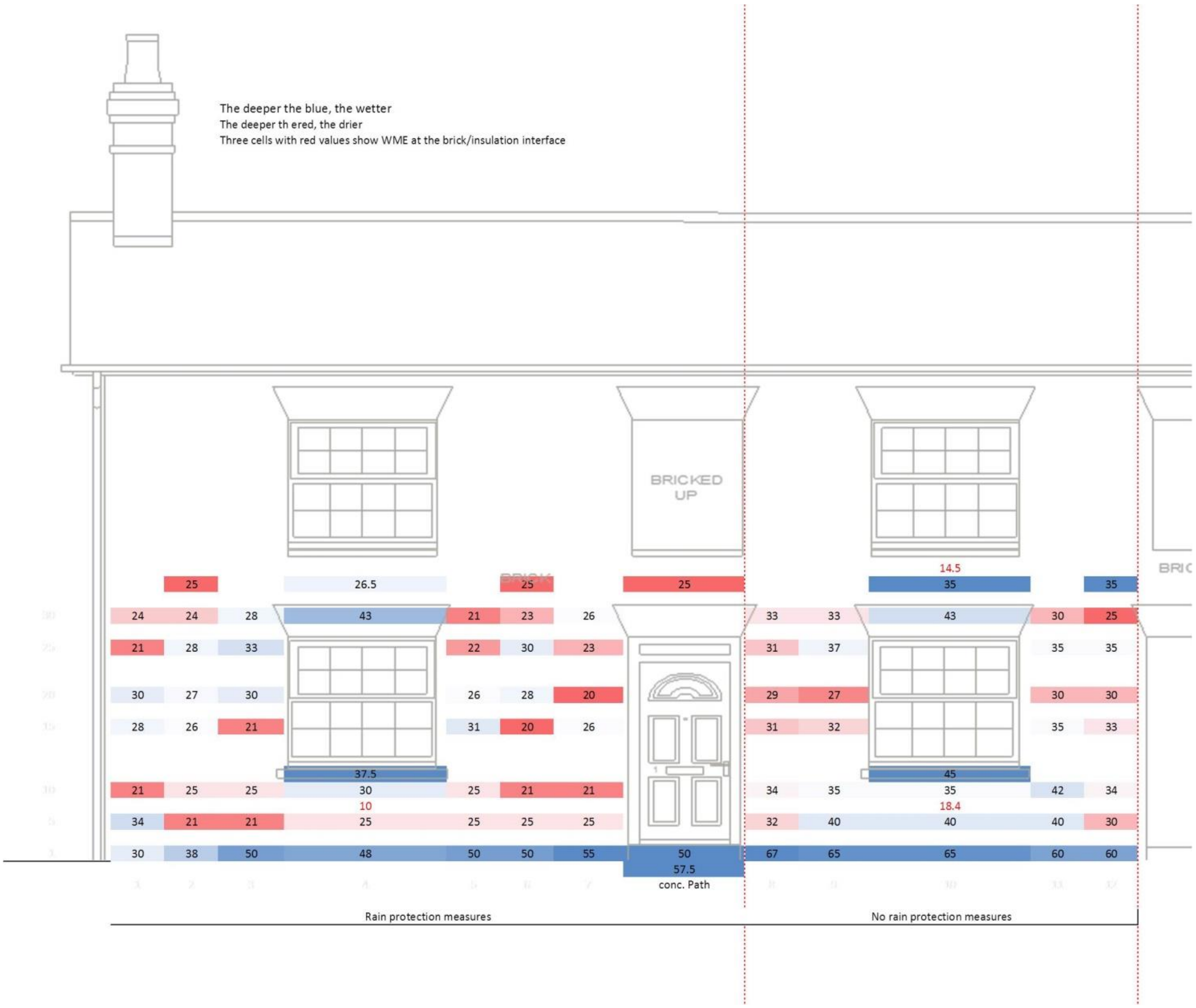
b. We can currently only estimate vapour flows, not capillary flows. Vapour flow direction through the outer part of the wall assembly typically swings during the day and often significant outward flow occurs from the interface at night. For treated and untreated areas most of the drying is mainly to the outside, but during warm weather up to 25% may be to the inside. Greater magnitude flows overall occur for the untreated walls because there is simply more (rain) moisture flowing into the assembly providing more moisture to diffuse back out (albeit more slowly than the treated walls).

3. APPENDICES

a. Microwave moisture meter survey February 2016
b. What does WUFI predict? Please also read WUFI report
c. Estimated data in diffusion calculations

A. MICROWAVE MOISTURE METER SURVEY FEBRUARY 2016

Figures are nominally % WME but should be treated as *relative* values. The three figures in the diagram below in red are the WME values measured at the time of the survey by the Omnisense sensors positioned between the brickwork and the internal wall insulation – the microwave meter values are *not* calibrated to be relative to the Omnisense WME values. The microwave WME readings represent a notional 'average' through the depth of the masonry (230mm thick). The readings are consistently higher close the ground, in concrete subcills and also behind sand/cement rendered areas ('lintels' over windows and doors).



Note:

- We are currently unsure as to how consistent/inconsistent the instrument is even if measuring the same wall as well as how the make-up of the wall in terms of mortar-brick-voids etc affects readings
- The beam will be passing through brick, mortar, and embedded timbers and
- - the microwave beam is around 300mm deep and as a result the manufacturer warns of the potential of readings being distorted (reading higher) due to the presence of 'reflections/interference' of the beam at interfaces. In some readings this may be associated with

embedded timbers and in all cases will be associated with the masonry/foam insulation interface lying only 230mm in from the external face of the wall.

- If the outer depth of the masonry (or individual brick) is very wet then the reading will not accurately represent the average across the full masonry depth.

Although it is interesting to explore the use of a deep reach, non-intrusive type of moisture meter we are currently treating these microwave based readings with a high degree of caution. The variable quality of the bricks and mortar joints combined with random cracks and gaps, together with limitations of the device may be swamping any indications of consistency of rain-protection effect related to the brick cream as measured from outside the assembly. It could be argued that desp8ite this there is a faint 'signal' that the brick cream is helping keep the wall assembly drier. The internal WMEs measured by the Omnisense sensors in more 'steady state conditions' confirm this much more strongly - although on the other hand this represents only a limited number of positions on the wall.

B. WHAT DOES WUFI PREDICT? PLEASE ALSO READ FULL WUFI REPORT

WUFI analysis conclusions

"This simulation is based on a number of assumptions about material properties:

Because we do not have sufficient data of bricks in the UK (let alone the specific brick in this building), we used a 'bracketing' approach (using materials with tested data from TU Dresden) in this report. We have sought to cover a wide range of possible performances of UK bricks in this report through selecting three German bricks with diverse characteristics. Onto these German bricks we have 'grafted' data on absorption from two UK bricks. It is reasonable to assume the actual performance is within this range. Of course there can be no certainty on actual hygrothermal performance until full testing is carried out. For instance, if bricks are more water-absorptive than those analysed in this report they might accumulate more water and have a greater dependence on drying-out to the room side.

We have assumed that the impregnation reduces the water absorption coefficient (A-value) of the bricks by 97%, based on the information supplied by Safeguard Europe Ltd. While this was tested by that company for a specimen of Fletton brick (see Figure 6), we do not expect this reduction to be equal for every brick.

We have simulated the impact of the impregnation using an altered A-value which generates a uniform reduction of the water absorption characteristics of the brick, however it may not be uniform. As Stormdry is a pore-lining material, one would think that the reduction in absorptivity will be higher for certain ranges of water content (rather than a uniform reduction). It may also affect its moisture storage function. Again further physical testing is necessary.

In general it appears that the appropriateness of the analysed build-up is significantly dependent on its exposure conditions (i.e. external climate). When exposed to the sheltered climate of Great Malvern, the build-up is able to dry out primarily to the outside. In this context, the key for avoiding moisture accumulation is the breathability of the brick, rather than the vapour permeability of materials to the room side of the insulation. In these conditions limiting the vapour ingress from room to wall (e.g. by means of a VCL) appears to be desirable: therefore the impact of a relatively vapour-closed paint in the room side would not be of concern. If the build-up were exposed to a wetter, windier climate (e.g. Dublin), maintaining the ability to dry towards the room side would be critical: in this case, vapour-closed materials such as VCLs (including VVRs) or commercial paints should be avoided. Yet mould growth and rot of timber appear to be very likely if this build-up (i.e. significant amounts of internal wall insulation with a VCL) is located in a climate similar to Dublin or Glasgow (see 10.0 Impact of climate on simulation outputs).

Following the simulations, impregnation of the wall with Stormdry Masonry Protection cream appears to reduce peaks in RH (and therefore risk of mould growth and rot of adjacent timber) for the three types of brick assessed in this report. While the reduction in RH is not always large, it might prove critical for keeping the moisture content in timber below the threshold of mould growth. More vapour resistant bricks tend to experience higher RH, because they have less ability to dry out to the outside. The benefit of impregnation (by reducing rainwater delivery to inner sections of wall) appears to be more significant for these bricks. This study has been based on assessing the risk of a recently completed retrofit to a traditional solid wall building, which features a large amount of internal insulation, and uses certain moisture control measures (namely an impregnation and vapour control layer) in the context of external and internal climates. While Great Malvern may represent a sheltered climate in which large amounts of insulation with VCL can be used relatively safely, we advise that for future internal wall insulation retrofits projects, particularly in less sheltered climates, that the amount of insulation itself be considered alongside all the other control measures to ensure the traditional solid wall remains dry, long-lasting, and mould and damage free."

C. ESTIMATED DATA IN DIFFUSION CALCULATIONS

It was mentioned earlier that internal vapour pressures used in the diffusion graph were estimated, the following graph shows how it was done. Measured and estimated vapour pressures for the red diffusion graph are shown below. Internal vapour pressure is red, the part that is estimated is on the left. Vapour pressure at the membrane is green. Estimated figures for internal vapour pressure are generally for a pressure of 1.5 kPa except where the vapour pressure at the membrane is above about 1.2, in which case it rises slightly.