Summary of WUFI Report on the Future Risks of Moisture in Internal Wall Insulation

The Climate Change Act of 2008 requires large scale improvements in the energy efficiency of buildings in the UK which can be partly achieved through the installation of insulation either externally or internally.

- External insulation: layer of insulation applied to the external face of a property. Can be unattractive, difficult to install and covers up the existing building façade

- Internal insulation: layer of insulation installed to internal faces of exterior walls of the building. Again can be difficult to install but does not affect the exterior appearance of the property or character of the building fabric

Although internal insulation has a clear aesthetic benefit, there are potential issues of interstitial moisture accumulation that could cause long-term deterioration of the building fabric.

Safeguard Europe has been investigating this issue in conjunction with the AECB (now the Sustainable Building Association) and the Building Life Consultancy. The work includes an assessment of the effect of Stormdry Masonry Protection Cream in reducing the moisture content of building elements. This R&D 67 report gives a brief summary of the findings.

Data Modelling

The hygrothermal assessment was carried out by Building Life Consultancy using *WUFI Pro* to model moisture and temperature profiles in a building wall. Different types of brick were modelled and analysed, including untreated and impregnated with Stormdry. The wall construction was internally insulated with 150mm open-cell spray foam resulting in a total u-value of 0.2 W/m^{2}K, meeting the Building Regulation requirements.

The modelling incorporated laboratory data from Safeguard Europe that measured the reduction in water absorption and its effect on vapour permeability from using Stormdry Masonry Protection Cream.

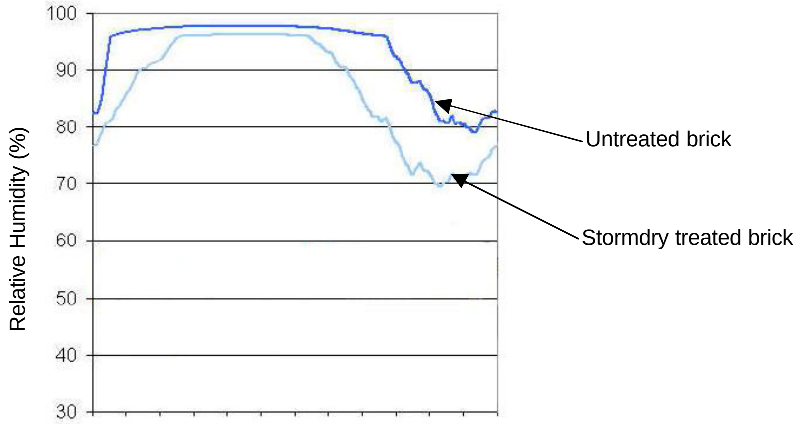
Summary of Conclusions

1. The report has found that the use of internal wall insulation can generate conditions such that mould growth and timber rot are very likely to occur.

2. The local climate is an important factor. Wetter and windier climates such as Dublin and Glasgow are more prone to creating these situations of potential damage to the building fabric.

3. Use of a vapour control layer can exacerbate moisture accumulation in the building fabric in certain climates (i.e. Dublin), whereas in others it can reduce it (i.e. Great Malvern).

4. Stormdry is of benefit in all cases. This is particularly so in climates such as Dublin, where there is a more marked effect.



Annual RH cycle in Dublin with no vapour control layer

This is a summary of the findings. The full report is also available upon request or can be downloaded from www.safeguardeurope.com.

C. Negus

19 March 2013

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Hygrothermal assessment using WUFI Pro in support of a measured study of an IWI retrofit of a solid wall in Brook House, Herefordshire

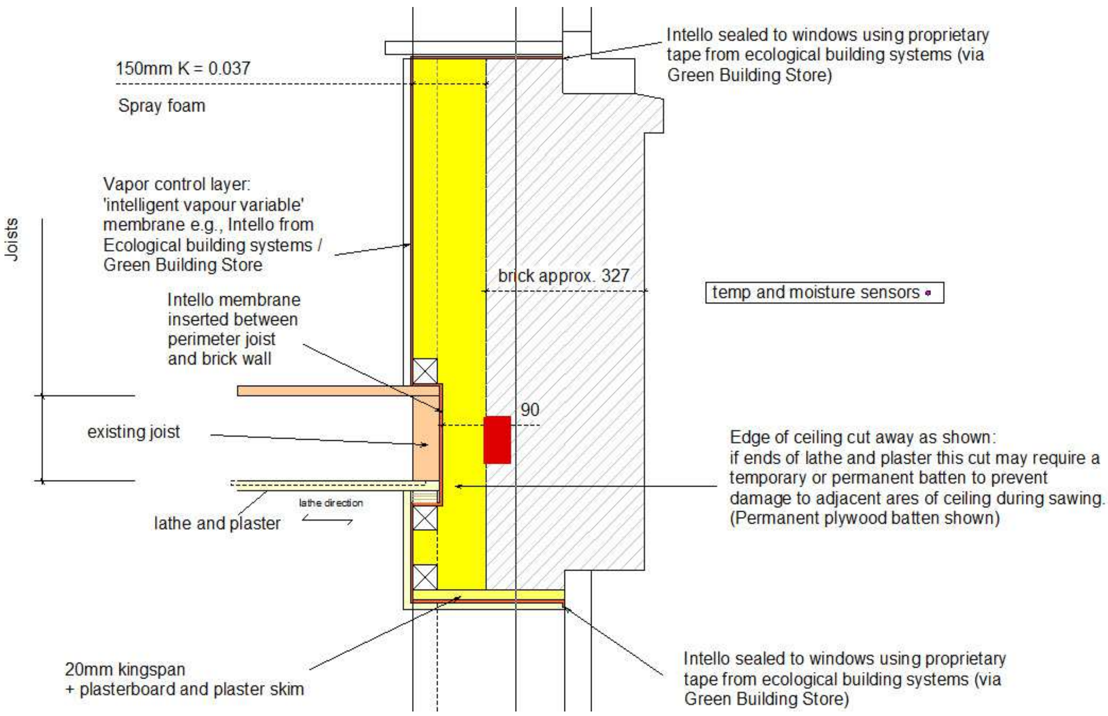

Figure 1: *Build-up of analysed wall (construction drawing submitted by client)*

Ref: 5157.20120911.BA~1 Simmonds Mills (Brook House)
Date: 26th November 2012, rev. 1st March 2013

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1.0 Request for analysis
Our client, architect Andy Simmonds, requested that we carry-out a hygrothermal assessment to assist a measured study of an IWI retrofit of a solid wall in Herefordshire, illustrated in Figure 1 above. The existing exposed brick wall (~327mm wide) has been internally insulated with 150mm open-cell spray foam resulting in a U-value of ~0.2 W/m^2K[1]. An internal timber studwork is erected over the inner 50mm of this insulation zone, attached to an Intello diffusion-variable vapour control layer to the room side with plasterboard & skim plaster as an internal finish.

Using hygrothermal simulation, this report assesses the effect and benefit of Stormdry Masonry Protection cream (from Safeguard Europe Ltd) on reducing the level of moisture that may build up within the different timber elements of the wall construction, i.e. internal timber studwork *and* existing built-in pieces of oak within the brickwork (e.g. around windows and at corners).

2.0 Software & relevant standards
WUFI from the Fraunhofer Institute of Building Physics is the world leading software for hygrothermal numerical simulation and is fully validated under BS EN 15026:2007, the relevant standard. It deals with the inter-related effects of heat, liquid water and water vapour moving through components over any length of time with inputs and outputs taken (usually) every hour, where boundary conditions (such as external weather) vary. It can be used to assess risk of interstitial condensation, mould risk, freeze-thaw events and transient thermal performance over the specified period (as opposed to a steady-state U-value) among other uses.

Unlike the more common but often mis-applied Glaser method (under BS EN ISO 13788:2002) it is suitable for use in assessing hygroscopic, capillary active and porous building materials like those in the present report.

3.0 Disclaimer
We have assumed that the information provided to us by the client and Safeguard Europe Ltd is accurate.

WUFI Pro has been used for this assessment. This allows hygrothermal numerical assessment of one-dimensional build-ups; however discontinuities & bridged elements that could affect the hygrothermal performance of the component locally, sometimes in a significant way, are excluded. In WUFI 2D these effects *can* be assessed alongside the 1D.

One-dimensional simulation in WUFI Pro will assume that the brick wall and the spray foam insulation are continuous, even if they are partially bridged by mortar and timber studs.

However it is known that *relative humidity* (RH) within discontinuous timber elements will be relatively close to RH in adjoining materials (e.g. brickwork and spray foam) albeit the *moisture storage function* of each material for the same RH can differ significantly. It is therefore reasonable to start assessing the buildup one-dimensionally as done here. Bear in mind at all times that RH levels shown are a qualitative (but not quantitative) indication. For a more accurate hygrothermal assessment, two-dimensional simulation is necessary.

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[1] This plane element performance will vary depending on the actual thermal conductivity of the brick

4.0 Simulation settings

The external climate data (hourly inputs including driving rain) has been created using Meteonorm 6.1, based on interpolated weather data for Great Malvern, Herefordshire. We understand that the conditions of this site are comparable. Note that climate plays a huge role in determining the performance of this build-up (see *Impact of climate on simulation outputs*). The internal climate is assumed to have a "normal moisture load" with sufficient ventilation, and it has been calculated based on the external climate data (using empirical correlation as per BS EN 15026:2007).

Simulations are limited to the west wall, as it is the only wall internally insulated. Coincidentally it is also the most exposed orientation.

9 different scenarios have been simulated:	Uninsulated wall	Internally insulated	
		untreated	impregnated
Brick type 1	Case #1	Case #4	Case #7
Brick type 2	Case #2	Case #5	Case #8
Brick type 3	Case #3	Case #6	Case #9

***Table 1:** Range of scenarios simulated*

The existing brick wall (with no insulation) has been simulated for 10 years, and the equilibrium moisture resulting for this simulation has been used as a starting point for the final simulations. These incorporate the internal insulation and have been simulated for 10 years further.

For the new materials introduced into the build-up (spray foam insulation, Intello membrane and plasterboard) typical figures of construction moisture extracted from WUFI database have been used.

The one-dimensional model is described by Figs. 2 and 3 below.

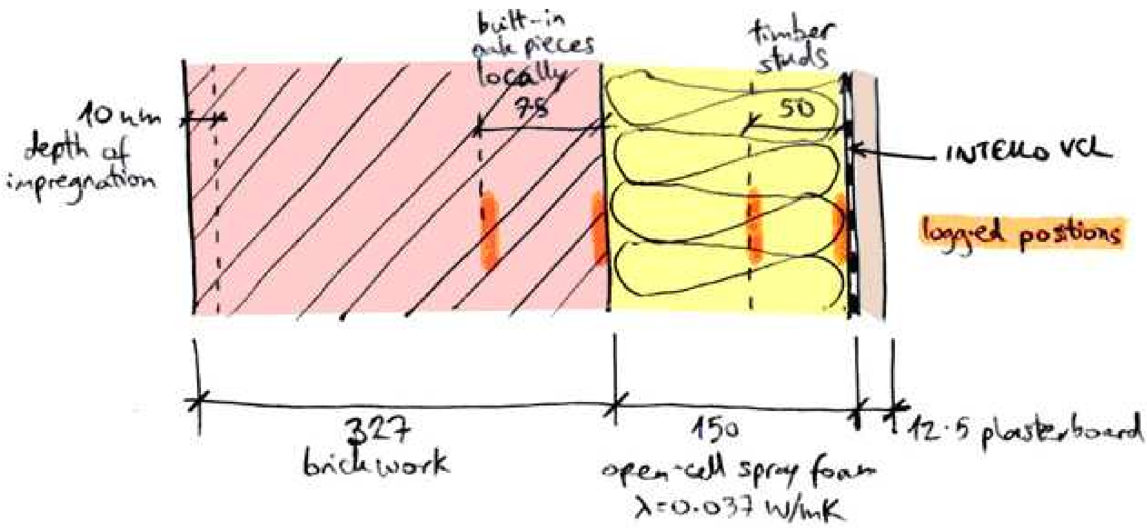

***Figure 2:** Preliminary sketch of one-dimensional build-up*

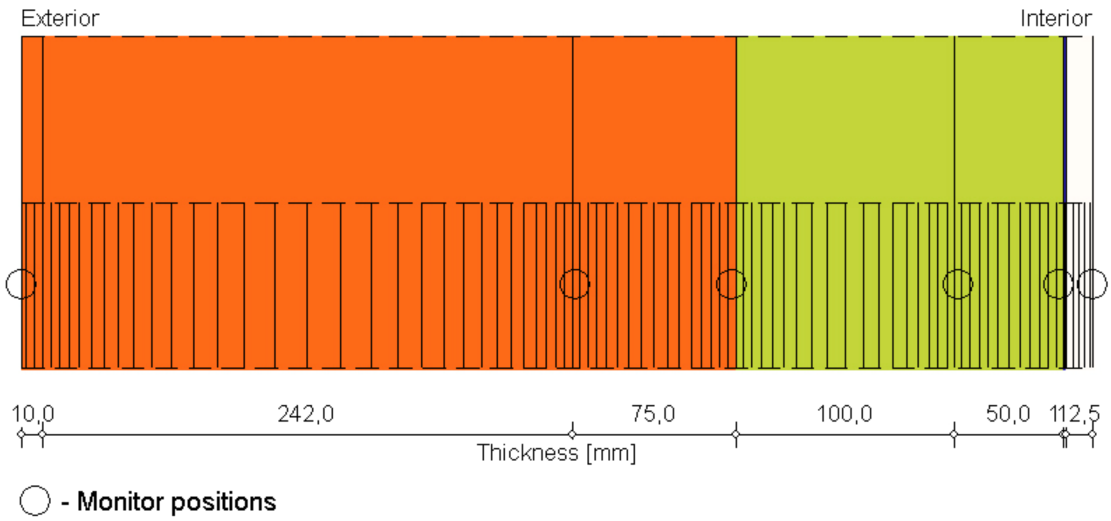

***Figure 3:** One-dimensional build-up as modelled in WUFI Pro*

We have selected materials that we believe are the closest 'fit' from the WUFI database of laboratory-tested materials.

See Table 1 below for a comprehensive list of the material data used in our model. Note that, due to limitations in one-dimensional simulation (see *Disclaimer* above), mortar joints and timber studs are left out of the model.

5.0 Material data
(refer to Figure 3)

	Bulk density [kg/m³]	Porosity [m³/m³]	Specific heat capacity [J/kgK]	Thermal conductivity [W/mK]	Vapour diffusion resistance	S_d value [m]
Brick 1 (Wienerberger Brick*) 327mm	1744	0.33	889	0.544	μ = 15	4.91
Brick 2 (Solid Brick ZA*) 327mm	1845	0.30	794	0.518	μ = 16	5.23
Brick 3 (Solid Brick ZO*) 327mm	1873	0.29	823	0.907	μ = 45	14.72
Sprayed polyurethane foam, open-cell** 150mm	7.5	0.99	1470	0.037	μ = 2.38	0.36
Intello variable diffusion membrane***	115	0.086	2500	2.4	n/a	26 – 0.25
Gypsum plasterboard*** 12.5mm	850	0.65	850	0.2	μ = 8.3	1.04

Source of material data:
- * MASEA database in WUFI
- ** Generic North America database in WUFI
- *** Fraunhofer IBP database in WUFI

***Table 2:** Material data for simulated wall assemblies*

In absence of detailed, tested data for the specific brick in this building, we have established 3 “bracket scenarios” by simulating different bricks from the MASEA database[2] in WUFI. We deliberately selected 3 bricks with different characteristics to test the impact of the impregnation on a reasonably wide range of bricks (see Table 2 above for general characteristics and Table 3 below for moisture absorption characteristics).

	Water absorption coefficient, A-value [kg/m²√s]	Reference water content, w_{80} [kg/m³]	Free water saturation, w_f [kg/m³]
Brick 1 (Wienerberger Brick)	0.300	2.5	287
Brick 2 (Solid Brick ZA)	0.183	5.2	216
Brick 3 (Solid Brick ZO)	0.068	3.4	126

Table 3: *Water absorption data for the analysed bricks*

As materials become wet their thermal conductivity generally dis-improves. The thermal conductivity of Wienerberger Brick, for instance goes, from 0.52 to 1.33 W/mK as humidity levels increase from 0% to 100% RH. While a dry brick (due to being protected by a naturally low A-value, or a render coat or impregnation) is therefore more insulating, this insulation value is minor compared to the value of the main insulating material applied. The chief value of protection from driving rain is hygrothermic: that is to say it reduces the amount of liquid water deposited and therefore contributes to a reduction in the risk of mould and rot. In general a dry wall is also likely to be a longer lasting one.

Figure 4 below shows the (physically measured) moisture storage function for these three bricks (dependent on the size and lining of the pores). The colours correspond with the ones used in Tables 1 – 3 above. Note the different shapes for the profiles: e.g. at ambient relative humidities (40 – 85%) Brick 2 takes up most water, while at higher RH (85 – 95%) Brick 3 will take up more. However, when free water saturation is reached (~100% RH), Brick 1 is the one that takes up most water (see also Table 3 above).

For the bricks in the MASEA database, liquid transport coefficients (m²/s) for suction and redistribution have been generated by WUFI from the water absorption coefficient (A-value)[3]. This is an approximation (the shape of the suction profiles may not be exact) that, according to WUFI, proves successful in many cases.

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[2] The MASEA database is a compilation of detailed hygrothermal material characteristics of typical construction materials from old buildings. The investigation was conducted by the Fraunhofer Institute for Building Physics, in collaboration with the Institute for Building Climatology (IBK) at the TU Dresden and the Centre for Sustainable Building (ZUB) in Kassel.

[3] For simulating the effects of impregnation, following available information, we have also generated the liquid transport coefficients from the A-value.

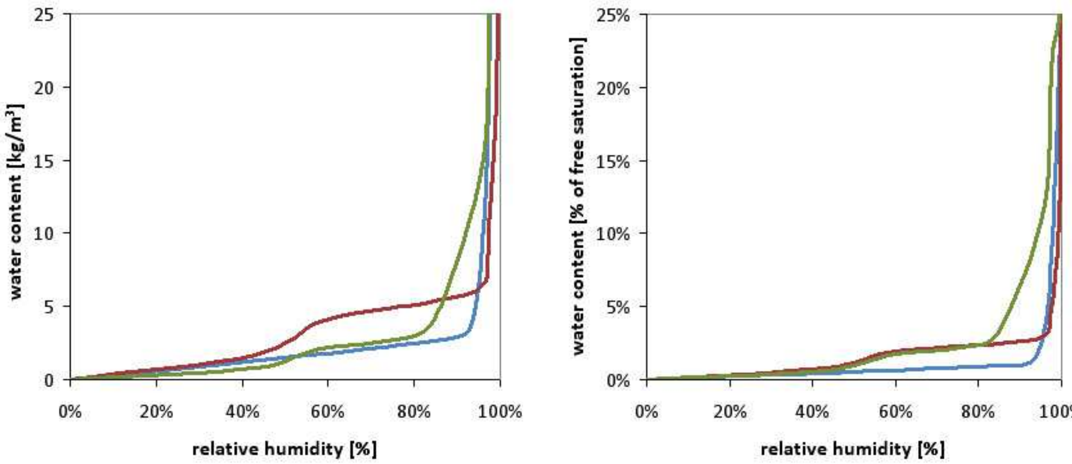

Figure 4: *Moisture storage function for Brick 1 (blue), Brick 2 (red), and Brick 3 (green) – water content expressed in absolute terms (left) vs. as percentage of free saturation of material (right)*

The obtained profiles are shown in Figure 5 below. Note that the scale on the y-axis is logarithmic: the impregnation reduces rainwater suction (left) by a factor of 1,000 in the outer section of the wall, while it makes no change to redistribution properties (right). Again, note that the three brick types perform differently depending on their range of water content. Each brick has a specific range of water content where it is more absorptive than the others.

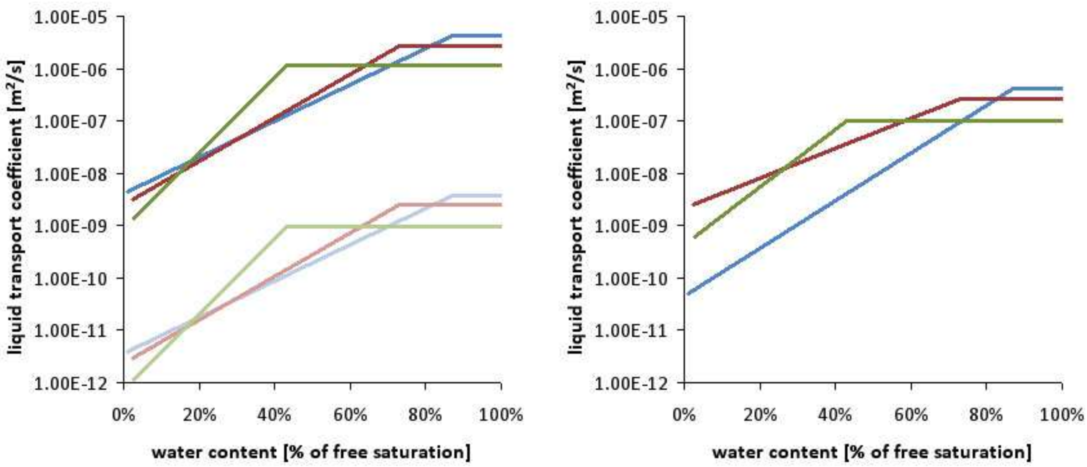

Figure 5: *Suction (left) and redistribution (right) profiles for Brick 1 (blue), Brick 2 (red), and Brick 3 (green) – impregnated bricks are shown in a lighter shade*

6.0 Effect of impregnation on hygrothermal characteristics

Where the masonry is impregnated, we have assumed that the impregnation:

- penetrates 10mm into the brick;
- reduces the water absorption coefficient (A-value) of the brick by 97%;
- reduces the water vapour permeability (μ) of the brick by 10%.

These assumptions are based on the information below. We received a laboratory report of Water Uptake Tests (R&D 13) from Safeguard Europe. The water absorption of several masonry materials was measured according to EN ISO 15148:2002 (E).

	Brick West Hoathley	Brick Fletton	Mortar New	Mortar Old	Blaxter sandstone	Sheffield sandstone	York sandstone	Limestone Portland	Concrete Paving	Granite Work top
Untreated	0	0	0	0	0	0	0	0	0	0
Stormdry 200g/m2	10	12	4	8	6	_	6	nv	4	0

Table 4: *Tested depth of hydrophobic zone (mm) for masonry materials, extracted from Safeguard Europe Ltd report R&D 13*

There are two types of bricks analysed: West Hoathley and Fletton. In common with all other bricks from the British Isles, the full hygrothermal properties of both of these are as yet unmeasured - what is known is a reduced dataset. Table 4 above shows the depth of the hydrophobic zone after the Stormdry Masonry Protection cream is applied. This depth is 10mm for West Hoathley brick and 12mm for Fletton brick. We have therefore assumed a depth of 10mm for the hydrophobic layer in all bricks (the most conservative of both).

	Brick West Hoathley	Brick Fletton	Mortar New	Mortar Old	Blaxter sandstone	Sheffield sandstone	York sandstone	Limestone Portland	Concrete Paving	Granite Work top
Untreated	6.1	12.9	5.4	5.0	2.6	2.7	2.2	3.8	2.2	0.06
Stormdry 200g/m2	0.5	1.3	0.3	0.2	0.2	0.2	0.2	3.5	0.1	0.02

Table 5: *Tested water absorption (kg/m²) of masonry materials in 24 hours, extracted from Safeguard Europe report R&D 13*

Table 5 above shows water absorption results (in kg/m²) in 24 hours. Both bricks are tested un-impregnated and with Stormdry Masonry Protection cream applied at coverage of 200 g/m². Even if their absorption characteristics differ (Fletton absorbing more than twice water than West Hoathley), the reduction in the amount of water absorbed achieved by the impregnation is similar: ~90% for both bricks.

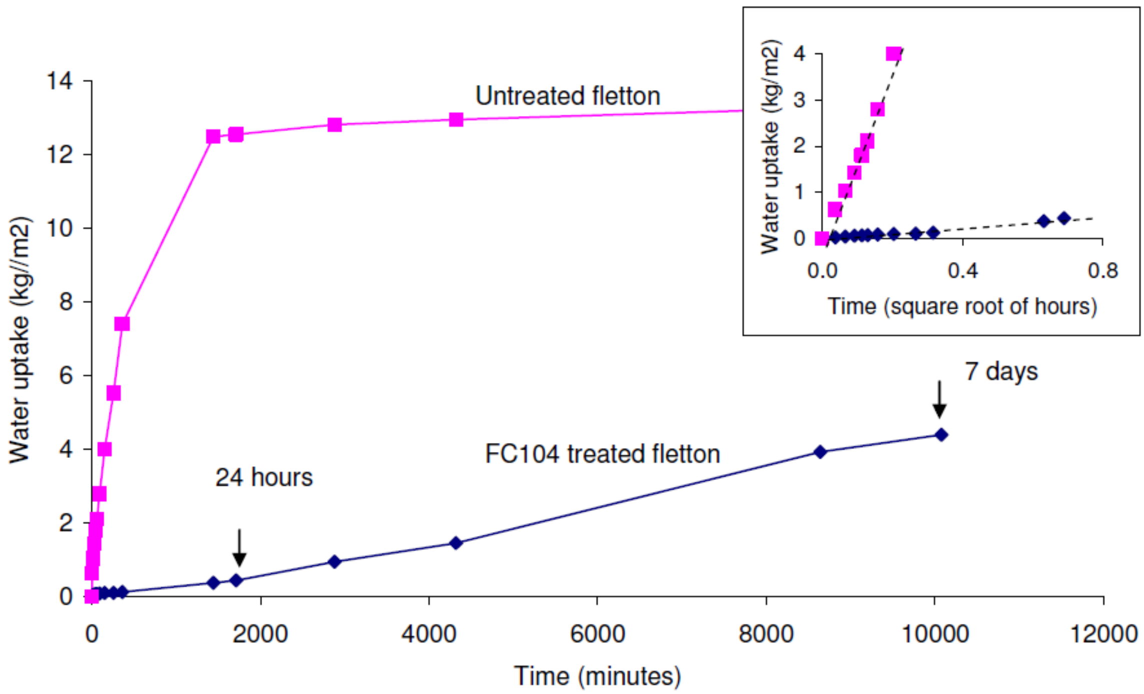

Figure 6: *Tested water absorption (kg/m²) of Fletton brick, extracted from Safeguard Europe report R&D 13*

The graph in Figure 6 above shows tested water absorption for Fletton brick (the most common of tested bricks): note that for the untreated brick most water absorption occurs in the first 24 hours, while the treatment has the effect of reducing the rate of water absorption and the final amount of water absorbed.

The water absorption coefficient (A-value) describes *how quickly* water is wicked (or sucked) into the masonry. It is the gradient of water uptake (in kg/m^2) against square root of time (in hours or seconds). The inset on Figure 6 shows the data over the first 24 hours plotted against the square root of time. The gradient was measured to be 19 $kg/m^2\sqrt{h}$ for the untreated brick and 0.59 $kg/m^2\sqrt{h}$ for the treated one. When converting to SI units, these figures are 0.317 $kg/m^2\sqrt{s}$ to 0.010 $kg/m^2\sqrt{s}$ respectively. Therefore, the Stormdry treatment causes a reduction of ~97% in the water absorption coefficient (A-value) of the brick.

We also received a laboratory report of Water Uptake Tests (R&D 49) from Safeguard Europe Ltd. This report states that Stormdry is a pore-lining rather than pore-blocking material and, in principle, this should allow water vapour to permeate after the cream has been applied and cured.

The water vapour permeability of a material is a measure of the rate at which water vapour can pass through that material. A test method to determine it is described in EN ISO 12572:2001.

		kg/sec	area m2	Flow Rate kg/s/m2
Stormdry (50% RH)	0.083g/ 1 day	9.26E-10	0.00102	9.10E-07
Control (50% RH)	0.092g/ 1 day	1.06E-09	0.00102	1.05E-06

Table 6: *Water vapour permeability of impregnated and un-impregnated brick, extracted from Safeguard Europe report R&D 49*

Following results in Table 6 above, Stormdry Masonry Protection cream reduces the water vapour permeability by 10% - in other words, the material retains 90% of its ability to allow water diffuse through it.

The water vapour diffusion resistance factor (μ) is an inverse measure to the vapour permeability. Therefore, a decrease of 10% in water vapour permeability is equivalent to an increase of 10% in the water vapour diffusion resistance factor (μ).

7.0 Impact of paint on room surface

We have simulated the impact of a vapour permeable paint (S_d = 0.05 m) and a typical modern microporous paint (S_d = 0.50 m). We have found that the impact on the hygrothermal performance of the wall is negligible (well below ±1% RH).

Bear in mind that the paint makes no significant change in vapour resistance, as plasterboard (S_d = 1.04 m) has twice the vapour resistance of the microporous paint and the Intello membrane is well above that (S_d = ~7 m at 50% RH). S_d for all materials in the build-up can be checked in Table 2.

8.0 Assessment of relative humidity and moisture content

Figure 7 below portrays relative humidity (RH) for the three brick types analysed, 75mm into the brick (corresponding to the monitor position within the masonry shown in Figs. 2 & 3, see also red rectangles in Figure 9). This location has been chosen because it is a good guide for humidity conditions in the built-in oak pieces of the masonry wall.

Clearly, seasonal oscillations correspond to external humidity conditions. The first two years (to the left of the vertical dashed line) represent conditions in the original, uninsulated wall. The last three years (to the right of the discontinuous line) correspond to conditions after the internal insulation is applied. Lighter shades of colour represent walls impregnated with Stormdry Masonry Protection cream.

As is apparent from the simulations:

- Internal insulation cools down the wall, therefore increasing RH and risk of interstitial mould growth
- Most of this increase in RH is immediate: moisture contents are stabilised after one yearly cycle
- All but two of the six retrofit approaches go above the 80% RH threshold at various stages (see comment in paragraph below).
- The impregnation reduces peaks in RH (and therefore risk of mould growth and rot) in all 3 types of brick analysed
- Brick 3 has the highest RH in the original wall because its higher vapour resistance (measured by μ) prevents it from drying-out to a certain degree (note also the delay in seasonal RH peaks). When insulated, it still has the highest average RH (even if peaks are lower)
- The benefit of the impregnation is also highest in Brick 3 (the most vapour resistant)
- During Summer when reverses diffusion typically occurs vapour will move towards the room. The resulting lowering of RH is somewhat compromised after the works (i.e. the lowest RH is now ~5% higher). Albeit that the foam is very open and the vapour control layer is diffusion variable, the latter is still more vapour tight than the materials present before.

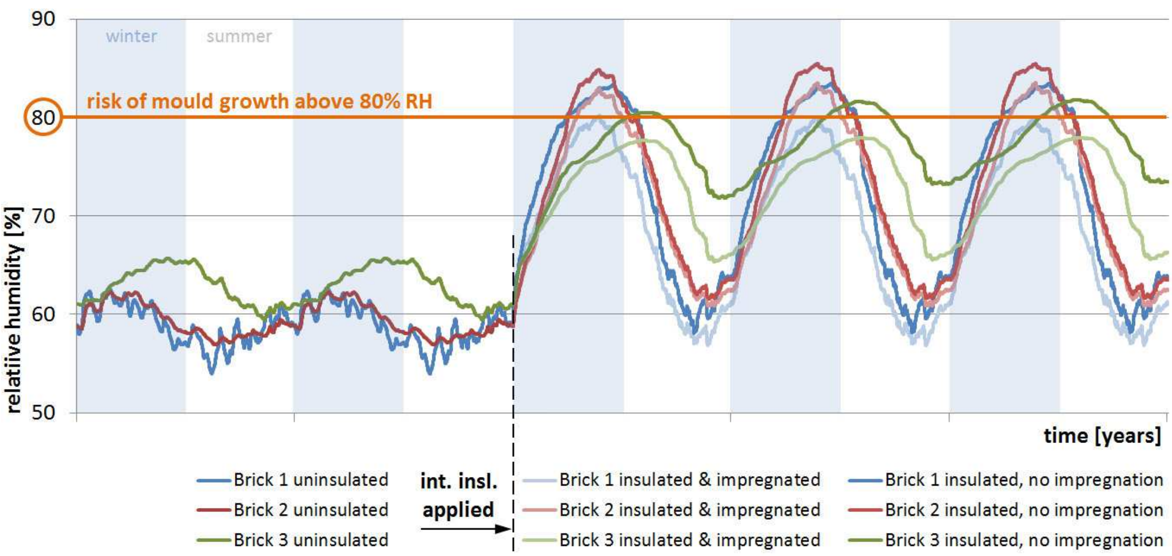

***Figure 7:** Relative humidity in the brick wall at 75mm from its internal surface, before & after internal insulation*

80% RH (orange line in Figure 7) is considered a conservative threshold to stay below in order to avoid growth of mould[4]. More recent studies take into account that in addition to relative humidity, several other factors can affect mould: cold temperatures, the absence of oxygen and the presence of biologically adverse substrates can inhibit mould growth[5].

For assessing the moisture content in the built-in pieces of oak, we can look at its moisture storage function at Figure 8 below. This graphs link RH conditions at the pores of the material with its water content.

WUFI guidance states that timber should not exceed 20 mass-% of moisture for a prolonged period (especially if temperatures are warm). For oak, this is equivalent to ~86% RH (see brown curve in Figure 8 right). Note that this is a less conservative threshold than the 80% RH mentioned above, which would correspond to ~17 mass-% moisture in oak (see brown curve in Figure 8 right). Bear in mind whether the timber present in the wall is heartwood or sapwood can greatly affect its susceptibility to rot. Modern construction timbers typically have a higher sapwood content.

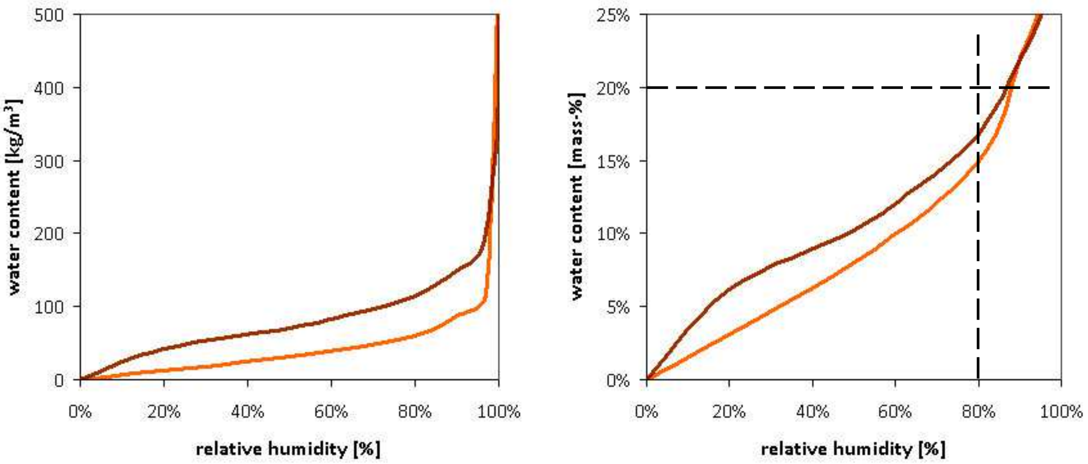

Figure 8: *Moisture storage function for oak (brown) and softwood (orange) – water content expressed in absolute terms (left) vs. as mass-percent (right) Source of data: Fraunhofer IBP database in WUFI*

Further useful information can be drawn from Figure 9 below, showing RH profiles (green) in the insulated build-up for the 3 bricks analysed. The thin green line represents the final conditions of the simulation (1st October, 10 years after insulation is applied). Light green represents all RH conditions during a yearly cycle.

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[4] BS 5250 states that *"Mould spores can germinate if the relative humidity at the surface exceeds 80%. Once established mould spores can continue to grow at a moisture level lower than 80%"*

[5] K. Sedlbauer, M. Krus, K. Breuer: *Mould Growth Prediction with a New Biohygrothermal Method and its Application in Practice*, Łódź, 2003 http://www.hoki.ibp.fhg.de/ibp/publikationen/konferenzbeitraege/pub1_43.pdf

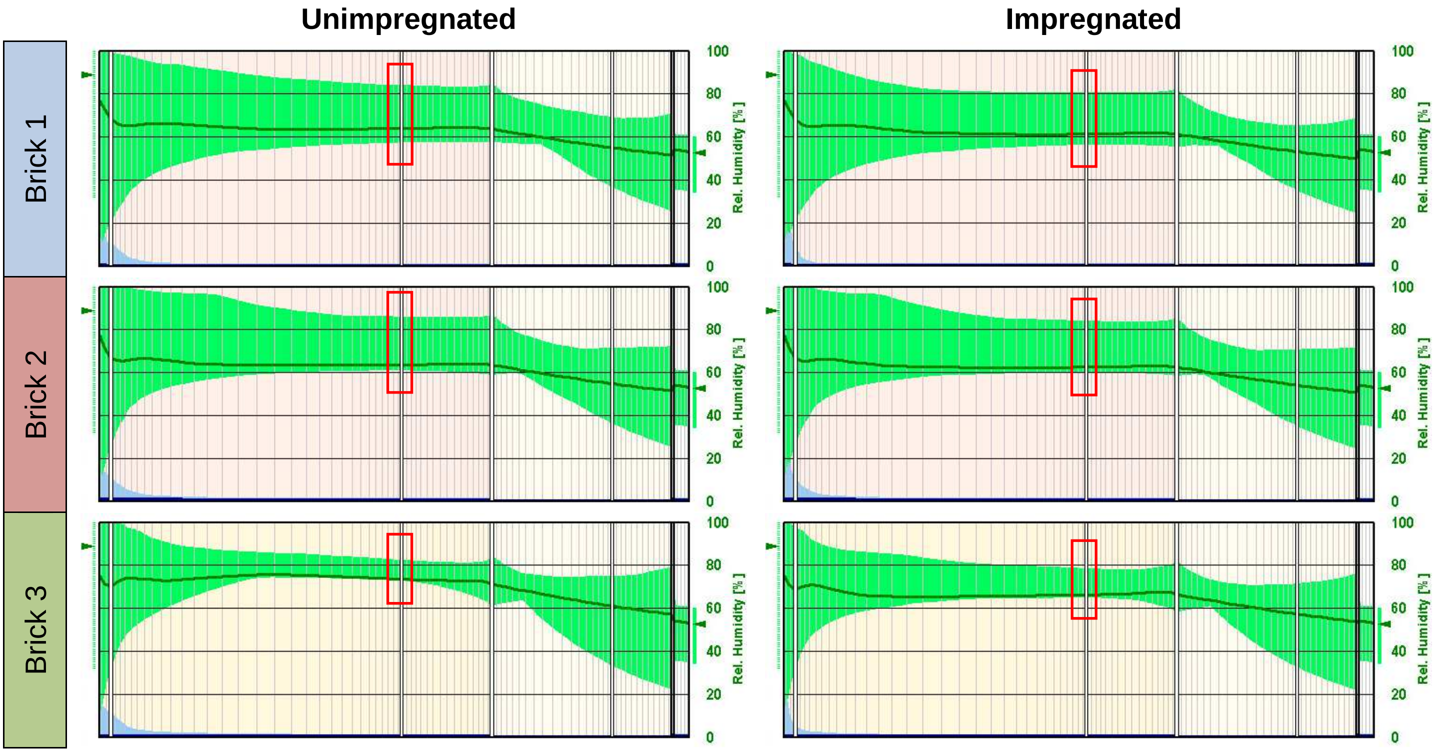

Figure 9: *Relative humidity profiles for analysed bricks, unimpregnated (left) vs. impregnated (right). Check build-up against Figure 3*

- The liquid water content of the outer portions of the Bricks (see blue areas in Figure 9) is lower after impregnation, most clearly in Bricks 1 and 3.
- The location analysed in Figure 7 (represented by the red rectangles) is the portion of the built-in timber facing the highest RH conditions throughout the year. The peak RH at the junction of brick and insulation is not dissimilar.
- The RH of the spray foam insulation adjacent to internal timber studwork does not go over 80%. For softwood this equates to <16% mass-% moisture (see Figure 8), and therefore it does not appear to be a cause of concern.
- Note that Brick 3 has a much shallower RH range for the masonry wall, presumably due to being the most vapour resistant: it doesn’t dry out as much.
- The impregnation reduces RH in both the built-in oak pieces and the internal timber studwork.
- Again the benefit of impregnation is highest for Brick 3 (the most vapour resistant). Interestingly the range of RH in the middle of this brick actually increases after impregnation: that is to say it can now dry better: this suggests that higher moisture contents restrict its vapour permeability.

It must be noted firstly, that this is an assessment of a *built* project therefore the amount of insulation shown cannot be changed, and secondly that the client deliberately wished to see how much internal insulation could be used and still result in acceptable conditions. Comparing the U-value of the wall before and after it would appear that an ~89 - 91% reduction in plane element heat loss should have occurred[6]. This is a huge reduction. A smaller amount of insulation giving a final performance of 0.45 W/m2K would result in a reduction of ~75 - 79%. Still a sizeable reduction, it would allow some residual heat through to warm the masonry substrate

[6] Depending on the conductivity of the original masonry wall, which may be between 2.1 and 1.8 W/m2K. There are some excellent measured studies on brick conductivities by SPAB

resulting in a lower RH thereby aiding evaporation and drying of the material[7]. We are certain that post-works RH levels of such a retrofit would be uniformly lower than those shown in Figure 7. This approach is less risky and suitable for a wider range of future projects, particularly where greater levels of driving rain are present (such as in Dublin or Glasgow) or less moisture control measures are used. Further energy savings then have to be found elsewhere (in the floor, roof, heating system, airtightness achieved etc). The following quote illustrates the issue:

> *"It is not enough to select the 'right' insulation material; all relevant conditions must be assessed. The actual level of insulation and energy efficiency must be considered and, at times, limited to that which is 'safe', i.e. has no detrimental impact on the building fabric and occupant's health."*
>
> Historic Scotland Technical Paper 15

9.0 Assessment of freeze-thaw damage

We are not assessing freeze-thaw damage in this report. We understand that Safeguard Europe Ltd have conducted experiments on the freeze-thaw cycling of Fletton bricks which show improvements in frost resistance due to a Stormdry treatment.

10.0 Impact of climate on simulation outputs

For internally insulated solid walls, water uptake from driving rain can be a crucial issue: climate plays a huge part in determining this. Indeed we have found that climate is a key factor for the appropriateness of the build-up analysed in this report.

Figure 10 below compares climate files, generated in Meteonorm, for three different locations: note the difference in numerical scale. While a west-oriented façade annually gets 80 mm driving rain in Great Malvern, it would be exposed to 200 mm driving rain in Glasgow and 280 mm in Dublin. This is due to variations in both rainfall and wind speed. This quantitative difference in the amount of driving rain makes a qualitative difference in the performance of the wall: this can be checked in Figure 11 below.

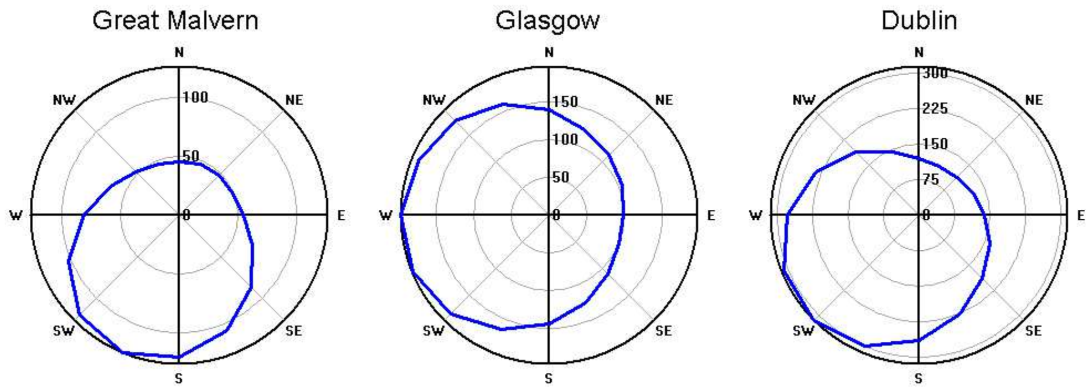

Figure 10: *Driving rain sum (mm/year) from climate files of 3 different locations*

Please note, Meteonorm climate files for European sites are considered sufficiently accurate and are in common usage; however questions have been raised at times

[7] The federal government in Germany has set minimum U-values (not less than 0.35 W/m^{2}K) for internal insulation of solid wall buildings for this reason.

about the accuracy of their driving rain data. Clearly measured data from the site or a design year file created by the Met. Office would be better. Whatever the exact figures we do believe differences of the order we're showing here would be evident between the various locations.

The graphs of Figure 11 show a yearly cycle (October to October) for relative humidity in two different locations within the wall (see sketch on top of figure for the blue/orange colour code). The graphs show how moisture moves within the wall during the typical winter/summer cycle. The masonry wall (blue) has its highest RH in winter, when it is colder. On the other hand, the inner part of the insulation (orange) has higher RH in summer (due to reverse diffusion).

The darker shades of blue and orange colour indicate un-impregnated walls; lighter shades indicate walls impregnated with Stormdry Masonry Protection cream.

Note the significant difference in RH levels for Great Malvern (top graphs in Figure 11) and Dublin (bottom graphs in Figure 11). If this wall were located in Dublin, this internal insulation strategy would bring RH within the masonry wall (blue) *above* acceptable levels, causing risk of rot for built-in timbers (ref. Section 8.0 and Figure 8).

In Great Malvern RH levels are much lower, and installing a vapour control layer (VCL) appears to be desirable. This would indicate that, for this particular climate, the benefits of the VCL (i.e. limiting vapour ingress from room to wall) outweigh its drawbacks (i.e. preventing the wall from drying out to the inside). In the top graphs of Figure 11, note how the VCL decreases RH levels within the masonry wall, while it increases RH levels next to the membrane. The overall effect is beneficial and helps lowering RH peaks.

Please note the vapour barrier with a fixed diffusion characteristic (S_d = 1500m) appears to result in an even lower RH in the masonry. However we believe the variable characteristics of the Intello VCL give greater protection in that *if* a greater amount of moisture does accrue behind the barrier it can allow drying to the room far in excess of that possible with the fixed diffusion barrier.

In conclusion it appears therefore that the analysed build-up featuring a variable diffusion VCL, is able to dry out successfully to the outside, when exposed to the climate of Great Malvern.

The opposite is true for Dublin: the VCL exacerbates the moisture accumulation. In this climate, retaining the ability to dry out towards the room side is more critical than preventing vapour ingress. Moisture uptake from driving rain appears to be much more significant than vapour ingress from the room.

This corresponds with the findings of Historic Scotland Technical Paper 15[8]: VCLs are no longer beneficial when the vapour pressure of the wall exceeds that of the room. As shown by the present report, climate appears to have a large bearing on determining if this tipping point is reached.

[8] J. Little, C. Ferraro: Historic Scotland Technical Paper 15 – *Assessing insulation retrofits with hygrothermal simulations* (to be published in Winter 2012-13)

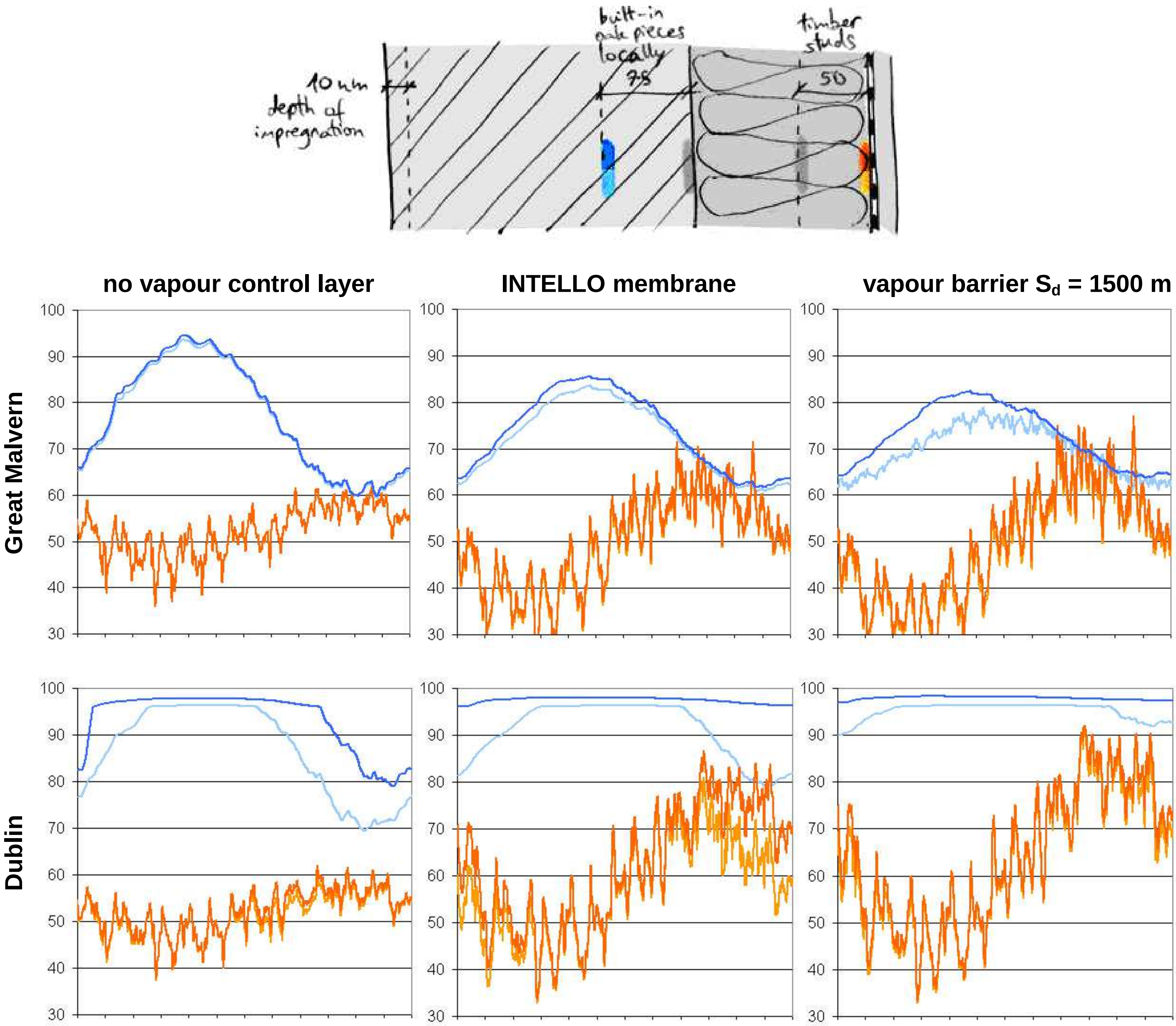

Figure 11: *Annual RH cycle (Year 2, starting in October) for Brick 2 after internal insulation has been applied. See sketch on top for blue/orange colour code. Light shades of colour correspond to impregnated walls.*

Impregnated versions (or those given a traditional render coat of similar a-value) perform better than their counterparts without such surface treatment. While this is true for both climates simulated, the improvement achieved by the impregnation is more significant in the wetter climate of Dublin. However, it appears from the simulations that this improvement would not be enough to overcome the moisture-related problems, if the internal wall insulation buildup, as installed, were located in Dublin.

While the following quote relates to a particular case study of an internally insulated stone wall in Glasgow, the conclusions are directly relevant to this report:

> *"It should be noted that the performance of the Intello and PE membranes yield very similar results here, despite the variable diffusion characteristics of Intello; this warrants further discussion. (…) This is a clear demonstration of why it is*

important to understand materials in the context of the construction they are in. In timber frame constructions (whether roofs or walls), for which Intello was designed, or indeed other constructions where water absorption due to capillary action is much less important, the benefits of its variable diffusion would be much more apparent. (…) Despite its many simplifications we think this case study shows results that are of interest, and directly contradictory to the results of the Glaser method assessment and the general perception of many in the construction industry that VCLs are always 'best practice'. In this case (as is often the case for unrendered brick or stone walls), because the primary source of moisture at the critical location is rainwater moving inward by capillary action, the VCL actually traps moisture within the construction. Dr. Andreas Worch makes the same point in a paper that looks at different levels of driving rain absorption, different U-values and the presence or absence of a VCL."

Historic Scotland Technical Paper 15

A relevant graph from Dr. Worch's paper referenced above is included in Figure 12. Note how a VCL reduces the moisture content of the wall when there is no rain absorption (yellow), while it actually increases it if different levels of driving rain are taken into account (green & blue).

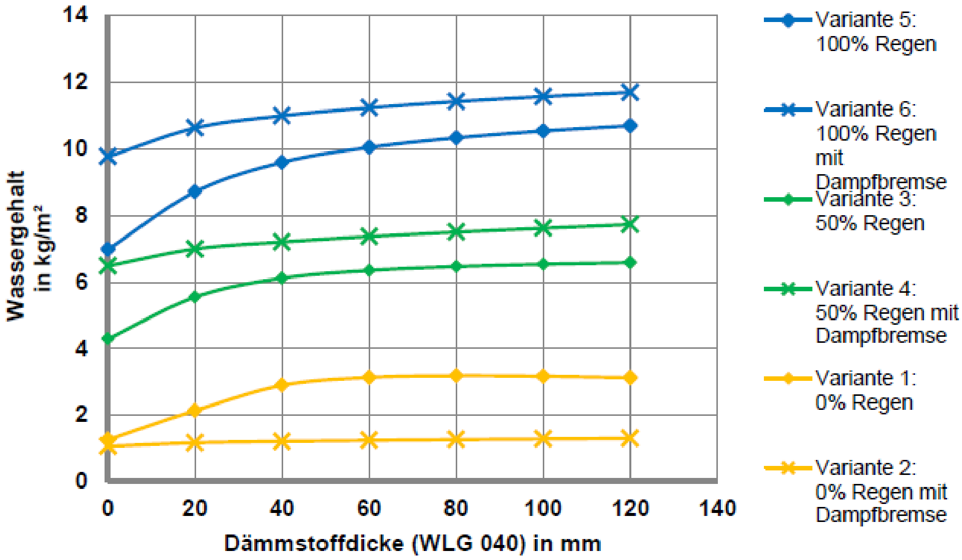

Figure 12: *Water content (Wassergehalt) as function of insulation thickness (Dämmstoffdicke), rain (Regen) and use of VCL (Dampfbremse)*

Extracted from A. Worch: Innendämmung: Bauphysikalische Aspekte, Probleme und Grenzen, Lösungswege für die Praxis

11.0 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 effect 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[9], 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 Intello) 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[10]. 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

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[9] The term 'breathable' is often mis-used or used loosely. In hygrothermal terms it means that the material is hygroscopic, vapour permeable *and* capillary open

[10] When interpreting the results, note that specific RH figures shown in these report are a qualitative (not quantitative) indication (see *Disclaimer*).

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.

27th November 2012, rev, 1st March

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Guidance

WUFI Online states that there are no general criteria which are applicable for *every* case. Different materials and applications require different criteria. It does however give some guides:

1) The most important criterion: moisture must not accumulate over time. Water condensing in a building component must be able to dry out again. If the moisture content in the component keeps increasing (even slowly) problems will arise sooner or later
2) The building materials which come into contact with moisture must not be damaged (e.g. by corrosion or mould growth)
3) Microbial growth may start below 80% RH if temperature > 12℃
4) If it takes longer than the first six months of a simulation for RH to drop below 80% at a critical point in the build-up the specification is likely inappropriate
5) It is advisable that, excluding the outer portion of the wall which is directly affected by driving rain but also has the best drying ability, RH levels in internally insulated walls should only ever rise above 80% for short periods to ensure good drying: far better if they stay well below
6) Wood should not exceed 20 mass-% of moisture (if temperatures > 10℃) during a prolonged period; otherwise mould growth may result

WUFI Online regards the following rules from the German standard DIN 4108-3 as useful though it adds that the Fraunhofer IBP staff considers the specific figures somewhat arbitrary given their own research:

a) The amount of condensing moisture in roof/wall assemblies must not exceed 1 kg/m²
b) At interfaces between materials that are not capillary-active, no moisture increase exceeding 0.5 kg/m² is permissible. This is meant to avoid moisture running or dripping off, which could accumulate elsewhere and cause damage
c) The moisture increase in wood must not exceed 5 mass-percent; the moisture increase in materials made of processed wood must not exceed 3 mass-percent

Caveat & Context

- This simulation was carried out with WUFI Pro 5.1, one-dimensional hygrothermal simulation software developed by the Fraunhofer Institute of Building Physics in Germany under BS EN 15026. As it deals with one-dimensional geometries it is not ideal for bridged structures, however if used correctly it can usually give useful guidance for these structures.
- Most of the data available within the WUFI Pro materials database are physically tested and analysed by the Fraunhofer IBP or sister building physics institutes in various parts of Europe and America. There are only a few building materials used in the UK & Ireland that are listed within this growing database.
- When client-selected materials appear different to their equivalent within the WUFI Pro materials database, this assessor selects the nearest material and changes it based on the values supplied by the manufacturer (usually extracted from their data sheets). This ‘new’ material is then saved in the User Defined materials database (within our copy of WUFI Pro) with notes indicating its provenance.
- The materials used in the simulation presented in this report are as close as we can obtain to the real materials under investigation. Given the above context, while we go to a lot of effort to be as accurate as possible, it is likely the data will differ (between actual and simulated values) for at least some areas of the simulated build-up. In many cases this will not be significant enough to skew the assessment of how suitable a build-up is, but in other cases (such as foils) it can have a big impact.
- We have found that often ‘external’ issues such as the extent of driving rain, the water-absorbing characteristics of the outer surface, the moisture load of the enclosed room, the U-value and the original substrate (in refurbishment or internal insulation projects) have a greater impact of the simulated build-up than the materials themselves. Where external conditions are so great as to cause building failure for one insulation system alternatives may be close behind. The message is that we have to think very clearly of the context in that the build-up in question will be located and used.