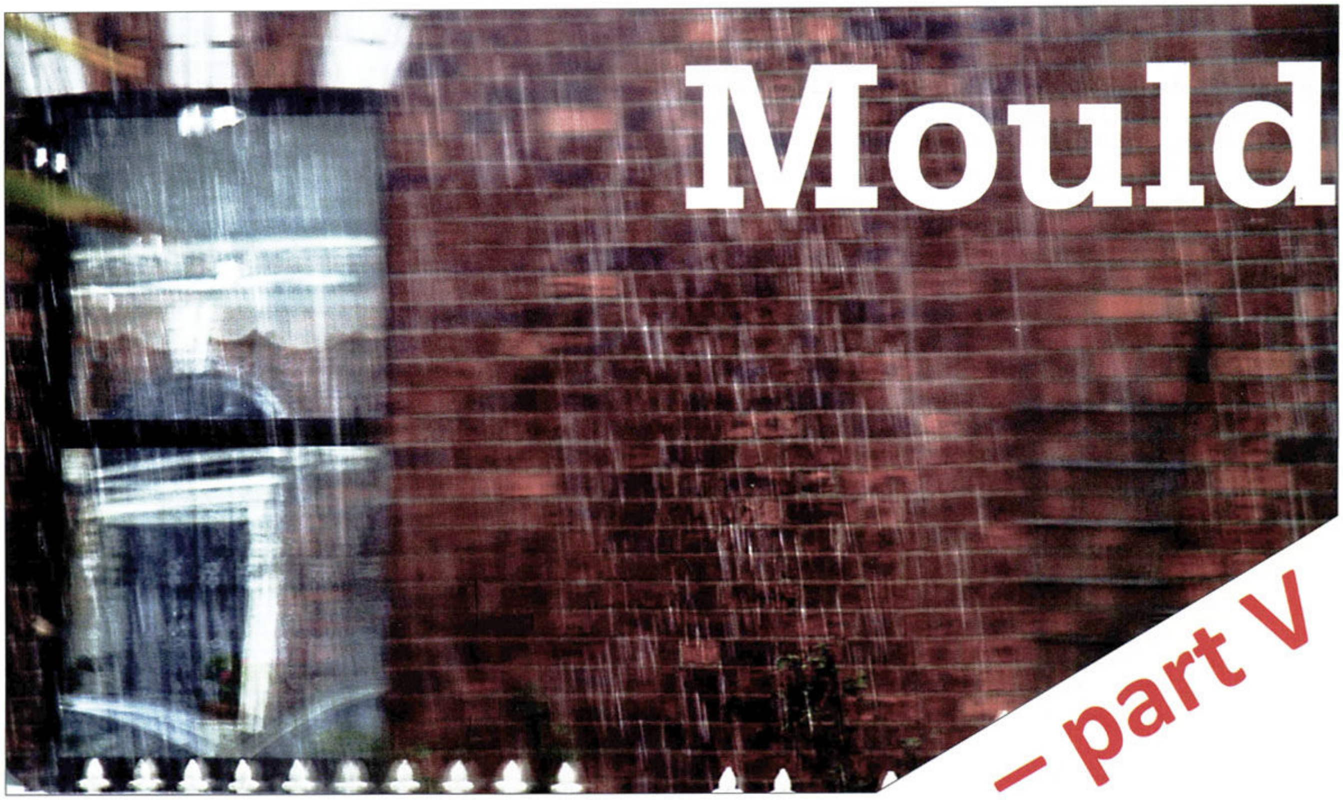
Breaking the Mould – part V



COMPARATIVE SIMULATIONS OF INTERNAL INSULATION SYSTEMS

Over the last year, **Joseph Little's** articles for Construct Ireland on the interstitial condensation risk associated with insulating single leaf walls have raised crucial questions at a time of unprecedented interest in retrofitting insulation. This fifth and final article in the series compares simulations of several internal insulation options on common wall types, with worrying conclusions.

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Breaking the Mould V

Comparative simulation of internal insulation systems

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Special thanks to Doctors Mike Lawrence of the University of Bath and Lothar Moll of Pro Clima GmbH for their careful review and critique of this article and the simulations it's based on. Thanks also to engineers Niall Crosson of Ecological Building Systems and Christoph Zürcher of Natural Building Technology for their inputs. Finally thanks to Philip Thompson of Roadstone Wood for data on Irish concrete blocks.

Reality, simulated reality and clear guidance

In the last edition of Construct Ireland 'Breaking the Mould IV' established the standard that should be used to evaluate thermal upgrades of single leaf walls, described steps to physically prepare the wall, explained some of the mechanisms that affect the likelihood of mould and gave criteria for judging the simulations outputs. The next step is to simulate a number of permutations of typical internal insulation systems using WUFI Pro under IS EN 15026.

The simulations show a troubling amount of the internally-insulated, west-facing Dublin wall buildups simulated experiencing Relative Humidity levels above 80%, which is a commonly used benchmark to indicate likelihood of mould and therefore risk of failure, some dramatically above. Industry members may say that this doesn't accord with their experience and therefore that the simulations are faulted. While the simulations have been extensively checked by a number of people they do indeed need further validation through additional simulation and in particular testing (including opening-up of walls).

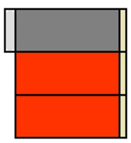
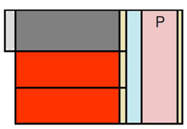
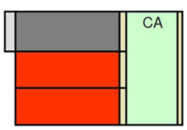
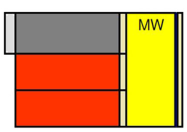
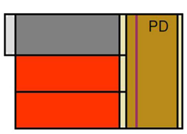
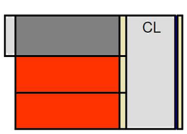
However *can* we claim that the simulations presented here don't agree with experience? How many Irish houses were internally-insulated to 0.27 W/m^2K before the advent of the HES Scheme? How many of these were solid brick houses? Not very many this writer suggests. We have only recently gone down this path. While there are some dreadful cases of obvious, dramatic building failure in Irish houses (subsequent to insulation being applied), mould growth behind an internally insulated wall is not obvious or dramatic and the situation could take years till a poorly-prepared substrate and inappropriate specification could result in failure that we can recognise as such, unless the wall is opened-up beforehand.

It is hoped that this series of articles generates a debate and a research programme leading to a code of practice for refurbishment with clear, useful guidance as early as possible. Readers can make this more likely by writing to the Departments of Energy (in relation to the HES Scheme) and Environment (in relation to guidance on construction and energy efficiency) to add their voices to this call.

Setting up a series of comparative simulations & key questions

Initially nine internal insulation systems were selected: for reasons of time and manageability this was cut down to five systems. Three of them are generic (featuring phenolic, cellulose, mineral wool and vapour control layers): two of them are proprietary ('Calsitherm' and 'Pavadentro'). The two proprietary systems were chosen because they were designed with a special focus on internal insulation, are unique in the Irish market and because they were the only ones for which the writer had full WUFI data. All the systems are presented in Table 1 below. It should be understood that the term 'system' is used, other than the two named systems, in its non-proprietary sense.

Table of key inputs for simulations

representation of buildup	Name & fixing method	materials	Bulk density, ρ (kg/m^3)	Porosity (m^3/m^3)	Specific Heat Capacity, c_p (J/kgK)	Thermal Conductivity, λ (W/mK)	Water Vapour Diffusion Res. Factor,
	**original wall, block and brick** 20mm lime render on 215mm conc blockwork on 20mm lime plaster finish	render *	1219	0.3	850	0.25	10.8
		block **	1900	0.2	1000	1.33	15
		brick #1 †	1700	0.24	850	0.77	10
		brick #2 ††	1700	0.31	850	0.77	15
		lime plaster	1600	0.3	850	0.7	7
	**Phenolic & air cavity** insulation mech. fixed to studs, often composite with gypsum plasterboard finish	air cavity	1.3	0.001	1000	0.18	0.46
		phenolic	43	0.95	1500	0.04	30
		plasterboard	850	0.65	850	0.19	8.3
	**"Calsitherm"** calcium-silicate boards bonded to (lime-plastered) substrate, with lime plaster	"Calsitherm"	240	0.9	920	0.059	6
		lime plaster	as above				
	**Mineral Wool** friction-fixed between studs or pinned in place by proprietary system, VCL & plasterboard finish	Mineral Wool	60	0.95	850	0.04	1.3
		"Intello" VCL ‡	115	0.086	2500	2.4	26000
		plasterboard	as above				
	**"Pavadentro"** woodfibre boards 'mushroom head'-fixed against substrate, lime plaster finish	"Pavadentro"	180	0.883	2100	0.045	3.3
		lime plaster	as above				
	**Cellulose** cellulose fibre insulation blown into voids between studs thru' VCL, gypsum	Cellulose	70	0.95	2500	0.04	1.5
		"Intello" VCL	as above				
		plasterboard	as above				

* Values listed are for 14mm of the 20mm thick two-coat external lime-cement render measured by Fraunhofer Inst.
** Values for solid block supplied by Roadstone Wood
† Brick #1 described in the WUFI material database as 'historic & very inhomogeneous'
†† Brick #2 is a more modern brick, includes for mortar joints
‡ Variable diffusion vapour control layers (VCL) like "Intello" and "Vario" are more vapour-closed in Winter and vapour-open in Summer thereby allowing back diffusion.

Table 1: showing the insulation systems studied and the key values

The focus here is to assess objectively the appropriateness of various internal insulation systems under a range of conditions. Inappropriateness in this case relates to whether the application could result in (1) damage to the original wall or insulation materials, and (2) excessive inter-stitial condensation and mould growth. Three variants (out of many) were chosen for their possible effect on the appropriateness of the internal insulation systems [1]:

a) The internal moisture load: i.e. normal (such as in a bedroom) or high (such as in a shower room).
b) The masonry substrate: i.e. rendered blockwork plastered or brickwork plastered.
c) The U-value of the completed wall: i.e. 0.45 or 0.27 W/m^2K. In the case of Calsitherm however 0.60 and 0.45 W/m^2K were judged more typical of performance usually sought.

The effect of location (i.e. exposure, strength of driving rain, humidity levels and altitude) and other wall substrates (such as rubble wall and hollow block) on appropriateness are obvious variants that are omitted from this study. The key questions surrounding the three variants chosen are that:

a) It is clear that a shower room will have higher humidity levels than a bedroom but can this affect the middle of a drylined wall, and can the insulation type or a VCL prevent a condition that might otherwise be unhealthy?
b) We know that brick will absorb greater moisture from the atmosphere and driving rain than rendered block, but is this problematic? Should the presence of certain substrates rule-out certain internal insulation solutions, or should additional protective steps be taken?
c) Under the HES Scheme a U-value of 0.27 W/m^2K is a key target to achieve to qualify for grant aid when upgrading single leaf walls with either drylining or external wall insulation. Is this appropriate? Does the location and amount of insulation affect the risk of interstitial condensation? Critically should the target U-values be changed to reduce risk of interstitial condensation and mould?

These are all heavy questions, particularly so when taxpayers' money is helping to fund work in people's homes, when SEAI and utility companies are in control of the specification standard and want to hugely increase the amount of work done, and where health may be at risk.

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[1] Apologies to those living outside 'the Pale'! Local climate conditions vary greatly and are of great importance. Conditions can vary within a few hundred yards due to height, exposure, or say the presence of a stand of trees. All these simulations can be re-done for different parts of Ireland.

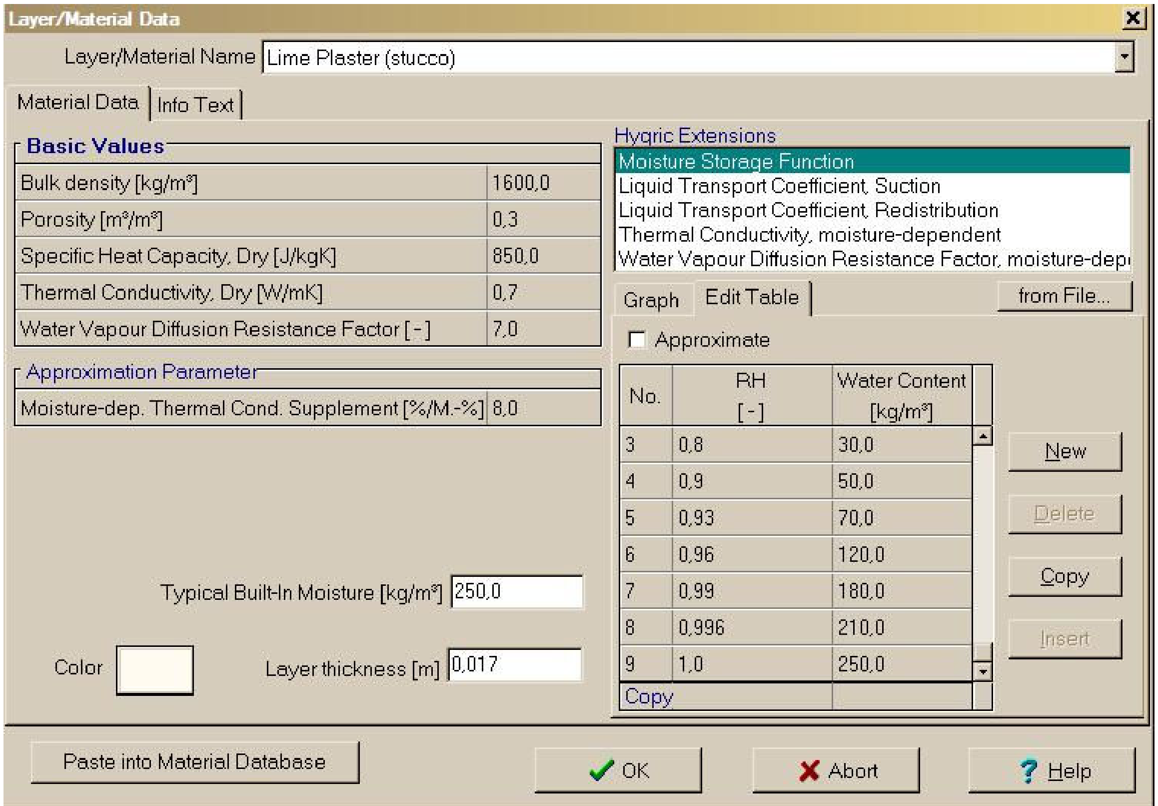

Figure 1: showing material data for lime plaster in WUFI Pro

Common conditions for setting-up the comparative simulations

The following common conditions were created to make this comparative study as transparent and replicable as possible:

- The notional building is located in Dublin facing west.
- The weather file used is a '.try' design year for Dublin city imported from Meteonorm. When a simulation is three years long, for instance, the same weather file is used three times as per usual practice.
- Every simulation was started 1st October and ran for either two or three years till end of September (bear this in mind looking at the six monthly bocks of time in the graphs).
- Rain load has been calculated according to ASHRAE Standard 160P which takes account of wind velocity: exposure was set at medium, for a building less than 10m high under a pitched roof,
- The Rain Water Absorption Factor is left at the default 0.7 (which means that 70% of driving rain is absorbed, the rest splashes off.
- The internal moisture loads (normal and high) are pre-determined by IS EN 15026 (see comment below).
- In almost all cases the data listed in WUFI's library of materials was used without change for each component. The exceptions to this were the data for the concrete block and the bricks. The former was supplied by Roadstone Wood while the latter was assembled by adding the thermal conductivity and density listed in Table A1 of TGD L to the data of real bricks tested by the Fraunhofer Institute (see Table 1 above).

- Insulation thicknesses were adapted so that exact U-values were achieved, even if unrealistic insulation thicknesses resulted (i.e. 0.0575m thick). This was to allow the closest comparison of what happens in each buildup at that exact U-value. [2]
- The heat resistances of internal and external surfaces are German values. The external one has been made wind-dependent as in reality wind would effect the degree to which is acts as a heat conserving layer.
- All simulations are saved, recorded and stored separately: data sheets can be created for each. The author is willing to show interested parties the data and outputs in the interest of advancing understanding & Industry co-operation.

The reason why WUFI's material data was used without change is that the material characteristics are established (in most cases) from extensive physical tests carried out by the Fraunhofer Institute, or partner institutes in four continents. The extensive MASEA database is the most recent to be added in WUFI Pro 5.0. While a particular material listed in Table 1 above may not match every aspect of a particular product supplied to the Irish market each was judged as the nearest equivalent. To half change inputs of sensitive materials like insulants in a comparative study like this could discredit the work or result in a buildup being simulated that is 'neither fish nor fowl'.

The minimum data required to carry-out a hygrothermal simulation are its bulk density, porosity, Specific Heat Capacity, Thermal Conductivity and its Vapour Diffusion Resistance Factor (μ-value). Typically the Fraunhofer lists a far greater range of data in the WUFI materials library (see Figure 1 above), however a user-created material can be simulated quite closely when these five characteristics are known.

Unfortunately it's still uncommon for many UK and Irish manufacturers to list Vapour Diffusion Resistance Capacity values, or the comparable values of Water Vapour Diffusion-Equivalent Air Layer (Sd value) or Vapour Resistivity (MNs/gm) all of which are numerically-related [3]. These long-winded terms describe how vapour moves through materials. The result of this absence is that, for now, most products available here can't be modelled sufficiently closely. It would be a great advance for the Industry if this information were tested and included in data sheets. Then again, as soon as the relevant authorities in Ireland and the UK start insisting that data supplied for certification conforms with IS EN 15026, suppliers will have to test and publish the missing data.

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[2] Note that as WUFI Pro simulates one-dimensional movement of vapour, moisture and heat there is no allowance for the impact of bridged structures. If however the bridging member is a timber stud, for instance, it is clear that conditions suitable for timber should be occurring at that position.

[3] Some significant manufacturers quote MNs/g values (the Vapour Resistance of a material), or state that 'the vapour resistance is greater than XXX', in their literature *without* reference to the material's thickness. As this unit is totally based on thickness (unlike Vapour Resistivity, MNs/gm or Vapour Diffusion Resistance Factor) this is a non-scientific approach and can only confuse or mislead the specifier. In one particular case the company's technical support section were unaware of the difference and couldn't give the material's actual Vapour Resistivity.

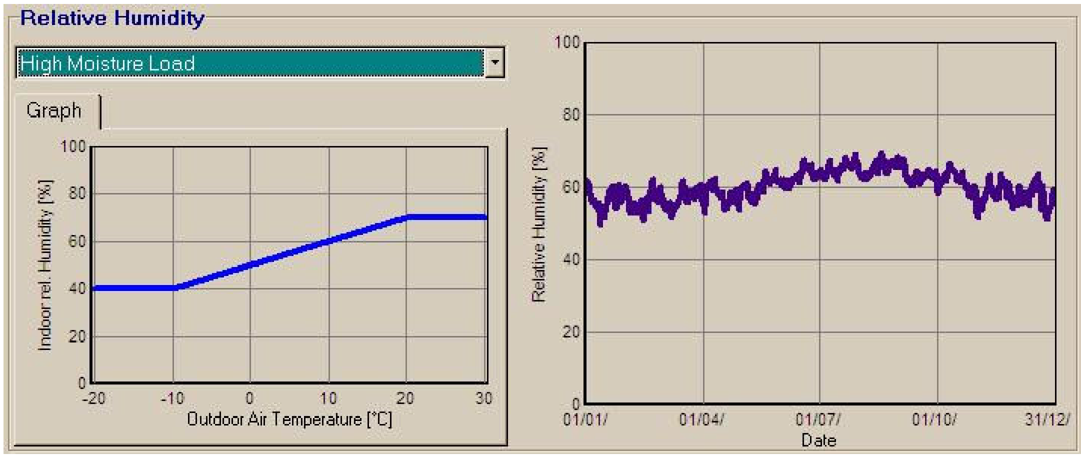

Figure 2: a screenshot from WUFI Pro showing high moisture load

Internal moisture load is an interesting issue. EN ISO 15026 sets out the way in which it should be generated. The graph on the right in Figure 2 above is created by the inter-relation of the graph on the left with the external Relative Humidity data for the Dublin weather file. It can be seen that the high internal moisture load oscillates between ~50 – 60% in Winter and ~60 - 70% RH in Summer. The normal moisture load oscillates between ~40 – 50% in Winter and 50 - 60% RH in Summer. Relative Humidity in Summer is typically higher than Winter because heating systems are turned-off, windows are more commonly opened and typically internal and outdoor temperatures equalise.

Data logged by this writer in a client's tiled ensuite shows moisture levels can be far higher than is healthy for long periods when an intermittent fan switches off too soon, when occupants use purge ventilation only occasionally (see Figure 3 below) and when room surfaces have no hygroscopic or mould-inhibiting ability (such as a lime plaster would give) [4]. In the 11 days in July 2009 graphed below Relative Humidity levels averaged from 60% in the first few days to 75% in the latter, however peaks reached almost 90% at times. These figures were not unusual over the months measured. It is therefore not surprising that the ceiling has flaking paint and mould was visible on ceilings, grouting and windows (see Figure 4).

[4] It is little appreciated that absorptive surfaces can significantly reduce the peaks in Relative Humidity experienced in a wet room even allowing for a good ventilation system. Lothar Moll of Pro-Clima has memorably described floor-to-ceiling tiling in a wet room as suitable for a slaughter house not a home!

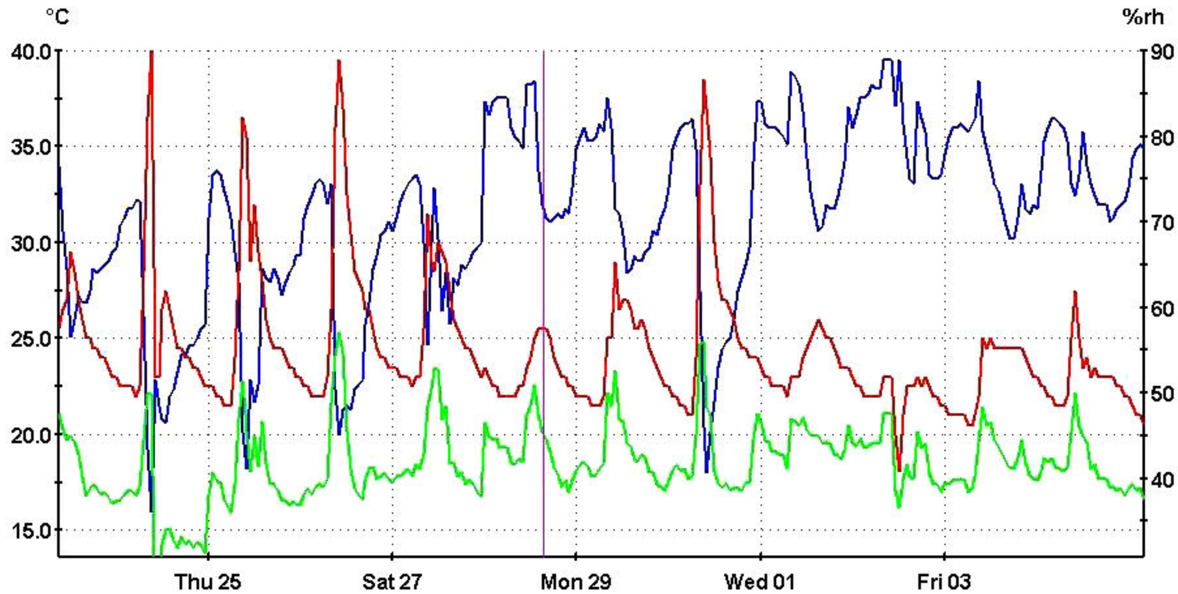

Figure 3: Temperature (red) and Relative Humidity (blue) in a shower room in July.

Figure 4: mould visible in the shower room where Figure 3 was measured

The comparative simulations

Working with Building Life Consultancy the writer focused on the Relative Humidity levels within the 1mm of original (20mm thick) wet-applied, internal plaster finish that faces the room. Figures 5 and 6 below show the monitor position (in pink). The previous article makes clear why Relative Humidity and not moisture is the key focus. There were several reasons for focusing on what happens in that 1mm zone and not on the insulation itself. They are:

1) In previous studies we have found that the original plaster finish when retained behind the drylining buildup either reduces the moisture content in the insulation significantly or has little effect. The difference is mostly due to the presence or lack of an external render. It is therefore common to all the drylining buildups simulated. As can be seen some insulation systems have a fibrous insulation, some rigid, some have a vapour control layer, some an air cavity, but all cases studied here retain the original plaster finish.
2) This plaster is at the beginning of the masonry substrate which the newly installed insulation will leave cooler than heretofore. It is thus the most likely place for significant portions of vapour to condense as moisture (i.e. the dewpoint).
3) Five out of the six criteria listed by WUFI Online to evaluate inter-stitial condensation (see 'Breaking the Mould IV') can apply to this layer of plaster.
4) Lastly it is not proprietary: none of the insulation manufacturers specify it or claim ownership over it.

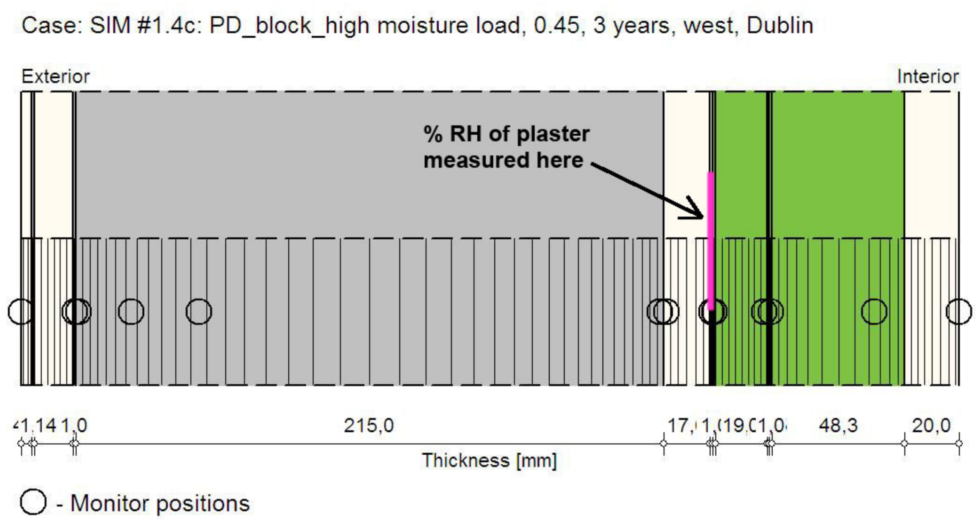

Figure 5: showing % RH monitor position in one of the block internal insulation systems

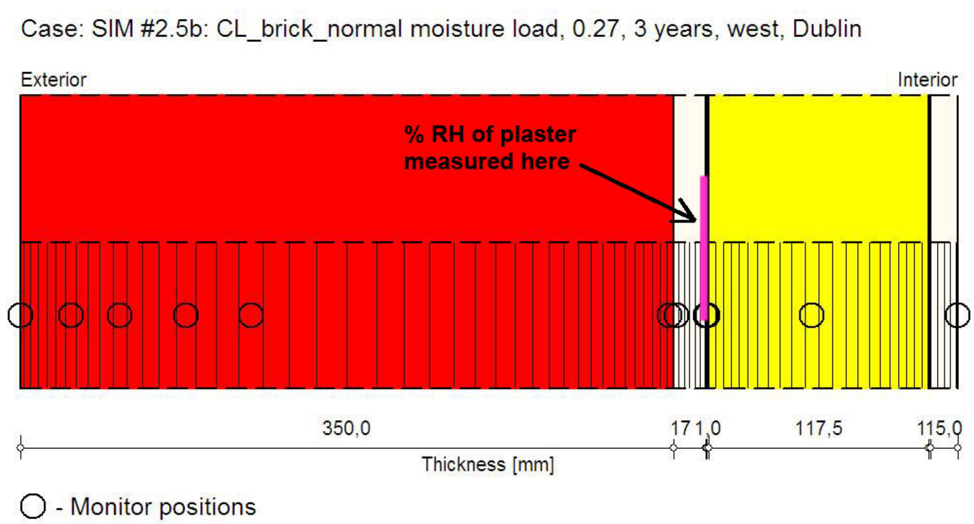

Figure 6: showing % RH monitor position in one of the brick internal insulation systems

As we are considering the internal insulation as a retrofit as opposed to new-build installation there are two ways that one may run the simulations. The first is to simulate the original wall for several years, then to add the new materials at appropriate moisture levels and continue the simulation. The second is to give all the materials an initial Relative Humidity of 80%, which corresponds to the 'reference water content' (or w_{80}). The latter starting position is generally nearer the future condition of the wall once its reached equilibrium (however good or bad that is) and is therefore less like the conditions of the first two years when it is still adjusting. Nonetheless this approach was chosen here as it allows any moisture content increase to be measured as per DIN 4108-3, and because it is more easily validated by other simulators. The significance of w_{80} and the DIN 4108-3 test were referred to in the last article.

'Breaking the Mould IV' gave a list of criteria for judging acceptability of an insulation strategy. The main criterion is that moisture should not accumulate: clearly a % RH vector that constantly rises is a sign of impending failure. Using criterion (4) of that list is more complex. It stated '*if it takes longer than the first six months of a simulation for % RH to drop below 80% at a critical point in the buildup the specification is likely inappropriate'*. This criterion gives a conservative position, based on the likelihood of mould growth, but may be quite restrictive if (i) the original (uninsulated) wall has been carefully prepared following *all* the steps described in the previous article and even more so if (ii) the insulation itself is also mould-inhibiting or at least provides no nutrients for mould.

Lothar Moll of Pro Clima argues that in case (ii) the % RH at the dewpoint can be frequently higher than 80%, as long as moisture levels are also acceptable and reduce sufficiently every Summer. Of the internal insulation systems studied Calsitherm is highly alkaline with excellent mould-inhibiting characteristics, its high capillarity also means it wicks away moisture from the dewpoint. Phenolic provides no nutrients for mould (though mould may still flourish on its surface), mineral wool may provide some level of nutrition for mould while cellulose and wood fibre are both timber-based so require the most conservative assessment, though some woodfibre products are engineered to remove the nutrients that moulds seek.

For case (i) above, a key element of the relaxation may be the adoption of 83% as the threshold Relative Humidity. This is because temperature at the dewpoint will be lower than 12°C for most of the year, at about ~5.5 to 8.5°C (see Figure 17 of this article and Figure 5 of the last one). The same location will be warmer than this temperature for parts of the Summer (due to solar radiation warming the wall's external surfaces) however as this would be for less than six months it may not be significant.

Perhaps the safest approach to judging the simulations is to say that:

A. When the wall hasn't been prepared as advised in the last article Criterion (4) should be rigidly applied,
B. When it *has* been prepared as advised the rule may be used with some flexibility, and
C. When the insulation is also mould-inhibiting higher Relative Humidity levels may be accepted for longer, as long as other relevant criteria are met.

Note that full preparation of the original wall as listed in the last article includes a surface impregnation to reduce rainwater penetration: this is *only* simulated in Figure 17 with marked results. Therefore we should apply approach (A) above in judging *all* other cases of this particular set of simulations. As we will see even the closest attention paid to **micro issues**, such as insulation type and membranes, are not enough if **macro issues** like driving rain, substrate type & U-value haven't been dealt with.

Comparing the outputs

The titles to the figures below clarify which graph relates to which type of wall. In general the Relative Humidity (% RH) for the 1mm of plaster is shown on the left side for an internally-insulated **rendered blockwork wall**, in the middle for a **poor quality historical brick** and on the right for a **better quality brick and mortar**. Each graph shows time in six monthly blocks along the X-axis and % RH on the Y-axis. Colour is used consistently to represent the % RH for a particular U-value and internal moisture load.

The first to be reviewed is the cellulose internal insulation system which features cellulose fibre insulation blown into voids between studs through 'Intello' and intelligent vapour control layer (VCL) with a gypsum plasterboard finish. Applying Criterion (4) it can be seen in the left graph of Figure 7 that the yellow line, representing % RH within the 1mm plaster of a wall insulated to meet 0.45 W/m^2K and enclosing a 'dry' room, dips briefly below 80% RH at about 10 months (i.e. slower than the ideal 6 months) but stays mostly above. While its general trajectory *is* downwards it spends too long above 80%: this simulation therefore fails Approach (A). The other three vectors perform worse. If the outer wall had been impregnated it is likely that the yellow and possibly cyan vectors would have passed.

It is interesting to see that the lines are paired in accordance with their moisture load: where the internal insulation faces a wetroom (blue and magenta lines) the trajectories follow the same upward path regardless of U-value. Criterion 6 (of the previous article) states that the moisture load of wood-based insulants should stay below 20% by volume. A quick check in the WUFI file for the wall insulated to 0.45 W/m^2K enclosing a 'dry' room shows that the insulation stays below 20% at all times but moisture levels are too high in the three other cases.

The reader may notice that the yellow line, representing the lowest U-value and driest internal conditions has the greatest daily and seasonal oscillations. This is because this variant also has the best ability to dry out. The relatively dry fibrous insulation beside the plaster can absorb and release moisture while the insulation and Intello membrane allow good back diffusion in Summer (as described in 'Breaking the Mould I'). However as moisture levels at the dewpoint grow (see the blue and magenta vectors) the ability to dry-out is compromised and oscillations reduce.

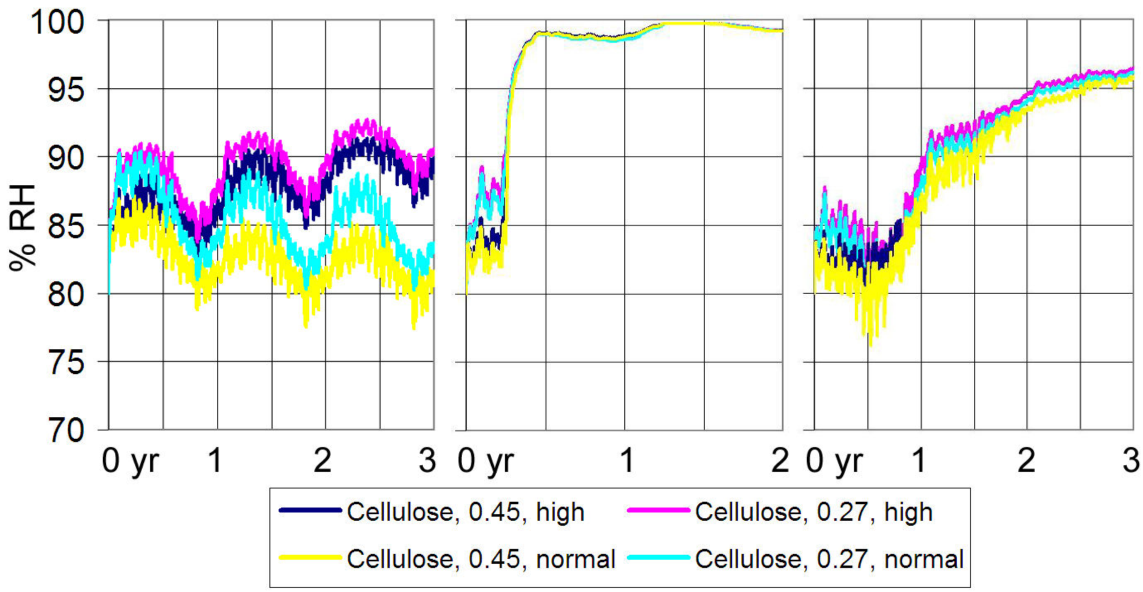

*Figure 7: **Cellulose system** – graphs showing % Relative Humidity in plaster abutting Insulation – (left to right) rendered block, inhomogeneous brick #1 and brick #2*

The middle graph has a result that can only be described as shocking. The brick surface must be allowing a large percentage of the driving rain that hits it to quickly alter the moisture content of the whole wall. An inspection of the WUFI material file reveals that it is 'historic and inhomogeneous'. This real brick, measured by the Fraunhofer Institute, is likely to have fissures and uneven firing etc. Whereas no insulation, a roaring fire and a high level of infiltration would have allowed a large amount of moisture (resulting from driving rain) to evaporate and dry during the building's early life, the internal insulation now seems to slow or block this. As can be seen in Figure 1 above the moisture content of lime plaster which reaches 99% RH is 180 kg/m^3. This quantity of vapour and humidity can't be good for the brick itself. However at this % RH mould is inevitable in the plaster, the insulation system will fail and sadly the homeowners will regret the day they ever got work done to this particular wall.

Nobody wants to see results like that. Realising that this brick is probably uncharacteristic of most bricks used in Ireland the team selected what was judged to be a more representative, homogenous and weather-resistant brick. It is striking though that the change in brick was the *only* change made in simulating the right-most graph: substrate is clearly emerging as a hugely significant issue. In this last group of simulations the plaster begins to dry-out during the first six months (from 1st October to 1st April) in all cases, but a strong reversal happens after that which causes all four vectors in that graph to fail. We will explore the cause of this striking change later.

The 'Pavadentro' drylining system features woodfibre insulation boards 'mushroom head'-fixed against the substrate without battens or studs. It has a wet-applied lime plaster finish. It is shown above in Figure 8. 'Pavadentro' is very clever in that it has a 'functional layer' (so named by its manufacturers) about three-quarter way towards the dewpoint which forces vapour being driven through the buildup wall to condense as temperature at that point has already dropped but it is not yet at the dewpoint temperature. As this layer is *within* the insulation it allows moisture and vapour to dissipate more easily, some back to the room.

As can be seen in the left graph below, this system performs better under the simulated conditions than the system before, however using Approach (A) everything still fails. This time when WUFI is checked for moisture (Criterion 6) all four insulation systems pass. It is likely that if we could just reduce the driving rain this system would perform very well. Looking at the other two graphs it can be seen that all variants of the two sets of brick wall simulations continue to fail though some characteristic of the wood fibre insulation buildup, possibly the density or so-called functional layer, is making it slightly less dramatic than heretofore

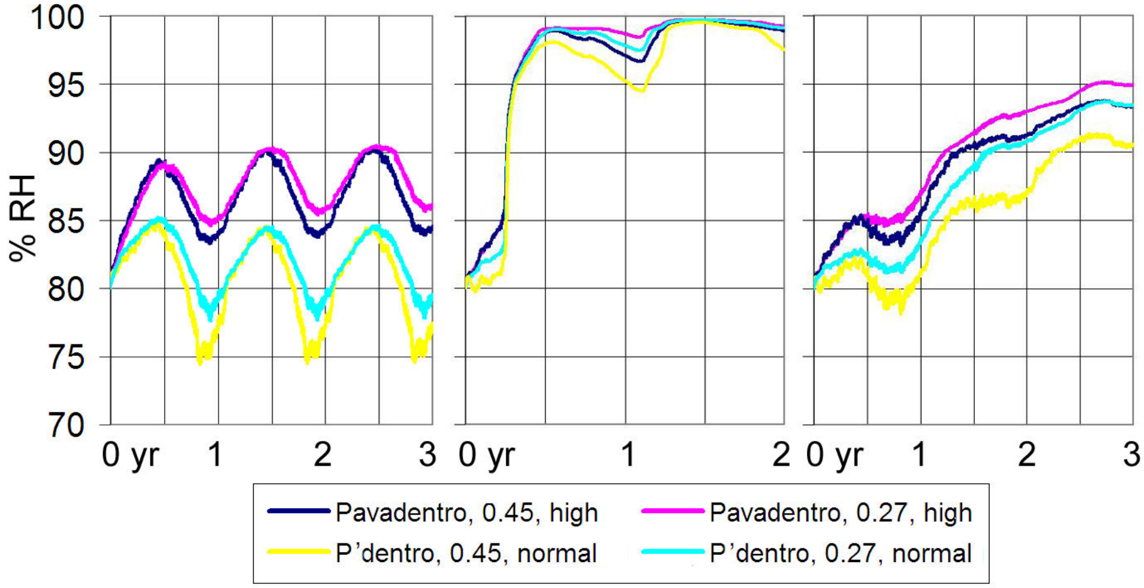

Figure 8: ***Pavadentro system*** *– graphs showing % Relative Humidity in plaster abutting insulation – (left to right) rendered block, inhomogeneous brick #1 and brick #2*

The phenolic and airspace internal insulation system (Figure 9) features insulation mechanically fixed to timber or metal studs with a plasterboard finish. The plasterboard is often supplied bonded to the insulation which makes the installation of a continuous vapour control layer in the ideal position difficult [5]. Table 1 shows the Water Vapour Diffusion Resistance Factor of the phenolic insulation the Fraunhofer Institute tested (30 μ-value or 150 MNs/gm) as being nine and twenty times greater than Pavadentro and cellulose respectively. All versions of this system simulated also fail.

It is interesting to note that:

1) The short-term oscillations in the (fibrous) Pavadentro vectors are less than those of (fibrous) Cellulose but greater than those of the Airspace + (rigid) Phenolic system: these differences broadly reflect the ratio in Vapour Resistivity values, and
2) The fibrous, denser and more vapour permeable insulations are better at dealing with higher internal moisture loads.

[5] A variant of this features a foil interlayer. A senior management figure in one major manufacturer informed the writer in person that they do not consider the foil interlayer of their composite insulation boards the vapour control layer. Despite this many architects appear unaware as they refer to this layer as the VCL on their drawings.

Despite the different chemical and physical makeup of these three insulations the overall pattern of increase in % RH is strikingly similar. Issues such as driving rain, internal moisture load and the level of insulation (macro issues) are clearly having a greater impact than insulation type and the presence or absence of air spaces and membranes (micro issues).

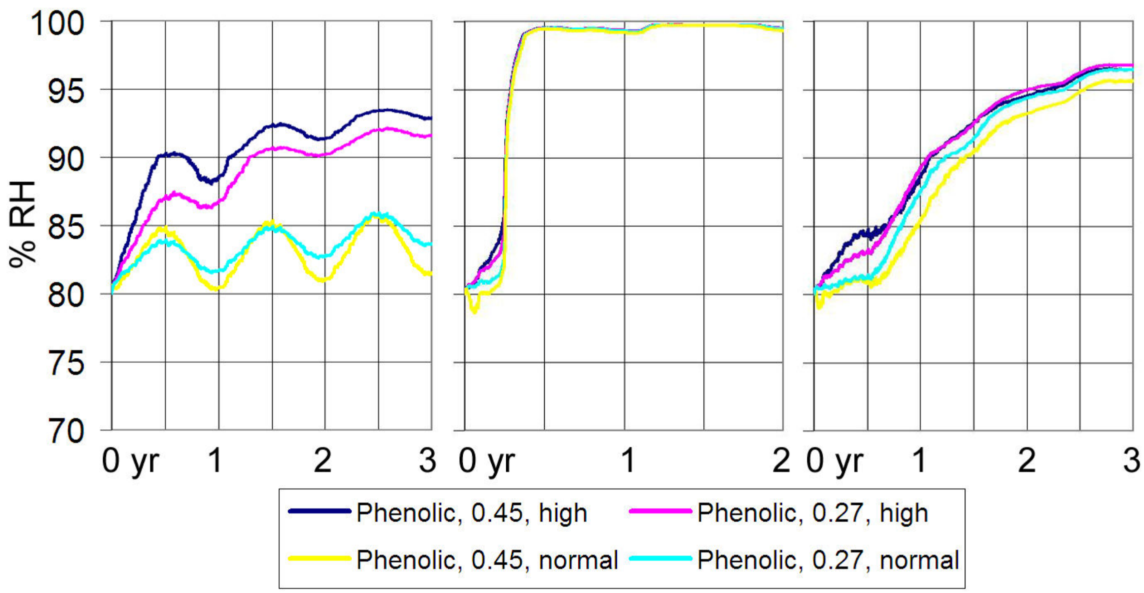

Figure 9: ***Phenolic system with airspace*** *– graphs showing % RH in plaster abutting insulation – (left to right) rendered block, inhomogeneous brick #1 and brick #2*

The 'Calsitherm' internal insulation system (Figure 10) is designed for the specialist conservation market. It features mould-resistant, calcium-silicate insulation boards bonded to a lime-plastered substrate, with a wet-applied lime plaster finish. Partly because the boards are more similar to the masonry materials in density and material and partly because the boards are designed to have high capillarity, (the effect where moisture is literally sucked through capillaries, or narrow tubes) the Calsitherm system performs best of all systems examined in these simulations. Nonetheless there are failures.

In the left graph below, the 0.6 and 0.45 W/m^{2}K variants with normal moisture load just pass Criterion (4), but the versions with high moisture load don't. Bearing in mind Lothar Moll's comments 0.27 W/m^{2}K should also be acceptable. The extraordinary capillary action of this insulation is somewhat in evidence with the rendered block wall but it's very evident in the two brickwork versions. While there are unacceptable % RH levels and an upward trajectory showing in both it is clear that the Calsitherm is literally pulling moisture out of the drenched brick substrate every Summer. If the driving rain ingress could be reduced this system would surely work very well.

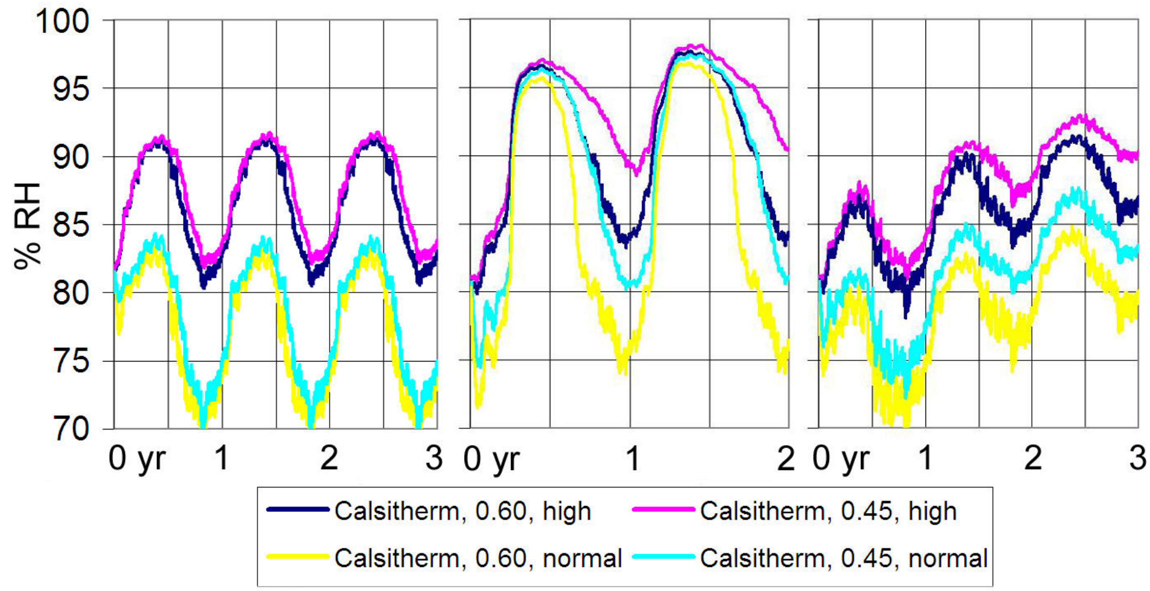

*Figure 10: **Calsitherm system** – graphs showing % Relative Humidity in plaster abutting insulation – (left to right) rendered block, inhomogeneous brick #1 and brick #2*

The mineral wool internal insulation system (Figure 11) features insulation friction-fixed between studs or pinned in place by clips and rails, with an 'Intello' VCL and a plasterboard finish. The graphs here are very similar to cellulose though it absorbs and releases less than cellulose resulting in smaller short-term oscillations. To add to a later discussion 0.6 W/m^{2}K (in green) has also been simulated for the rendered blockwork wall. The green vector is just about acceptable as it drops below 80% RH in about nine months but spends about 7-8 months of the year below the line thereafter, the other lines fail as before.

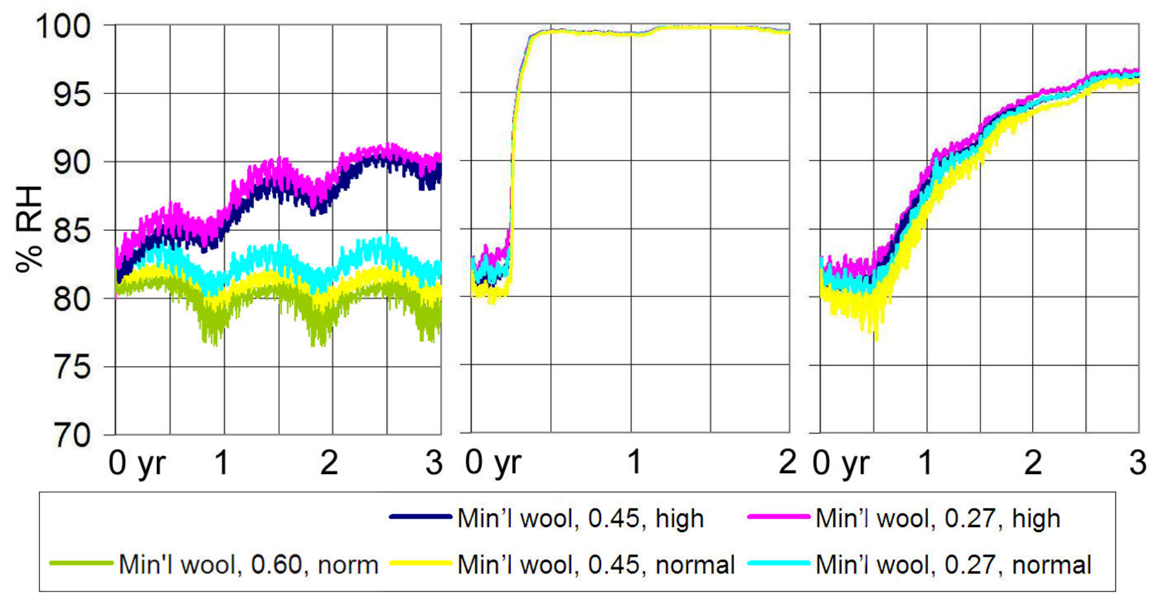

*Figure 11: **Mineral wool system** – graphs showing % Relative Humidity in plaster abutting insulation – (left to right) rendered block, inhomogeneous brick #1 and brick #2*

Studying the % RH in plaster at the dewpoint appears to be a powerful 'litmus test' of the suitability for an internally-insulated system on a particular wall under particular conditions. It is clear, despite real differences in the makeup and thermal and vapour characteristics of those systems, that unless proper account is taken of the macro issues (as described above), an insulation system, regardless of how good it is, can fail. Undoubtedly further simulation and careful physical testing and measuring are needed to confirm and clarify these issues further.

A reader may be left feeling that it is better to do nothing than to internally insulate: that would be a poor lesson to take from this work. If time had allowed all of these simulations would have been carried out again - this time featuring a good external surface impregnation. This writer suggests the results would be strikingly different. Independent corroboration on the importance of dealing with the macro issues first has recently been unearthed in a book published in 2005 by the home of super-insulation strategies: the Passivhaus Institute in Darmstadt. The book's title (translated from German) is 'Factor 4 for Vulnerable Old Buildings – Passive House Components & Internal Insulation'. In one section the author writes that when driving rain and rising damp are dealt with '*then - and only then - is interior insulation better than no insulation*'.

Attempts at improving the results

There must be ways of safely specifying higher levels of insulation for blockwork walls and at least some level of internal insulation work for solid brick walls! To explore these questions one system, the Mineral Wool system, was selected for further simulation [6].

Looking at the rendered blockwork substrate the first step was to reduce the internal moisture load. The second step was to try to reduce the external moisture load by increasing the 20mm sand-cement render to 35mm thick: this is after all a traditional thickness and may reduce driving rain ingress further. See Figure 12 below. Using a foil vapour barrier (μ-value of 1.5 million) in lieu of the 'Intello' VCL totally blocks any movement of vapour or moisture into the wall from inside. The result not surprisingly is that the vectors for higher internal moisture loads disappear behind those of lower internal moisture loads. The ability of the insulation to dry-out to the room is blocked however, so the yellow and cyan vectors lose the healthy downward direction evident in the left graph of Figure 11 and slowly start to rise. The foil barrier is not a good long term solution. The second graph is also disappointing. The extra 15mm of render has resulted in only a very modest improvement.

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[6] This was a random decision and was based on time constraints

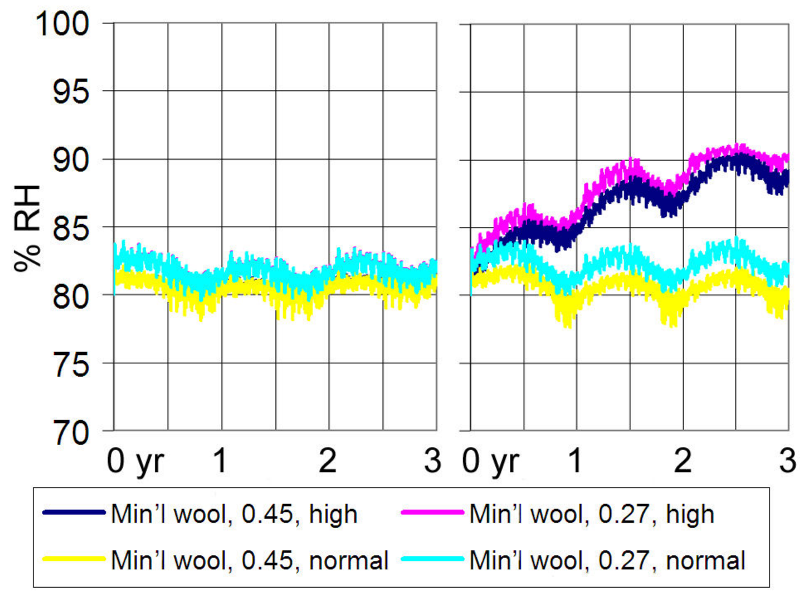

Figure 12: ***Variations on mineral wool system for rendered block*** *– graph showing % RH in plaster abutting insulation – (left to right) Foil in lieu of Intello VCL, and 35mm thick external render*

The next move is to carry-out the equivalent changes to the 'good' brick wall (Figure 13). The foil vapour barrier has a similar effect. In this case drying-out is irrelevant as the brick is literally drenched and the 'tap' of driving rain has not been turned-off. However the second step for brick shows a remarkable change. A silane impregnation has been simulated, in this case by changing the moisture ingress due to driving rain from the usual 70% to 10%. This percentage was used under advice from the technical advisor of a system available in Ireland. Suddenly all four vectors move in a strong downward direction! 0.45 W/m^{2}K performs excellently, 0.27 is marginally acceptable (though better than in any block wall studied) and the other two just fail.

This improvement is clear evidence of the marked negative impact that driving rain has on the internally-insulated buildup of both rendered solid block and brick walls. The blue and magenta lines might further improve if a thicker coat of (hygroscopic) wet plaster, perhaps applied on a mould-inert or -inhibiting vapour permeable board & VCL were installed in lieu of plasterboard & VCL to the wall of a wet room: further research required. Given the impact of impregnating the outside it is suggested that the same approach be taken with the rendered block wall. On the reasonable assumption that this would perform better we could then say that internally insulating a block or brick wall to a U-value of 0.45 W/m^{2}K *when the wall has been fully prepared* appears to be a sensible, robust specification, but better U-values or failure to deal with the other macro issues increases the risk of failure.

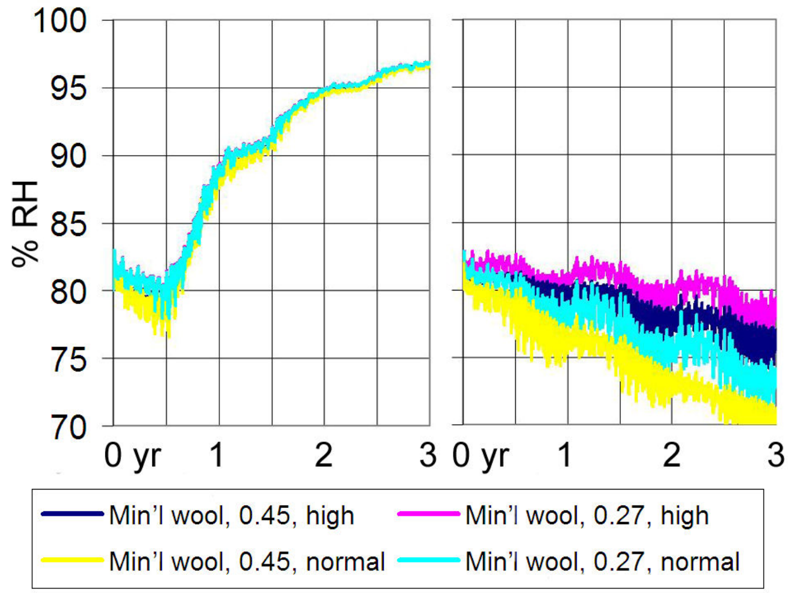

Figure 13: ***Variations on mineral wool system for brick #2***
graph showing % RH in plaster abutting insulation - (left to right) Foil in lieu of Intello VCL, and rainwater absorption reduced from 70% to 10%

Success begs the question of the other obvious approach to insulating brick while reducing driving rain impact: externally insulating with clay brick slips or a brick-effect render to clad it [7]. Ibstock Bricks are bringing their version of the former to the market this Spring (using mineral wool) and Redmond Acrylic have already installed examples of the latter in several places in County Dublin (using expanded polystyrene). Figure 14 below may well be Ireland's first privately-owned terrace of externally insulated houses. For the next simulation Diffutherm, a woodfibre-based external wall insulation system, was chosen to simulate (Figures 15 & 16). It was recently awarded a British Board of Agrément (BBA) certificate [8].

[7] From a Planning perspective, brick buildings that are not listed and have little architectural merit may be externally insulated (especially if they are detached) AS LONG AS the work is carried-out so that the final appearance is not inconsistent with the appearance of its original appearance and that of its neighbours. Planning would be required and likely refused for cladding-over brick buildings that have unusual brick bonds, have architectural merit or are listed.

[8] It is critical that a vapour permeable insulation is always used in external wall insulation with a render of equal or greater vapour permeability. Mineral wool, wood fibre or expanded polystyrene systems with a mineral finish meet this requirement.

Figure 14: A terrace in North Dublin where three householders externally insulated with a brick-like render finish to base and a napp finish render above

The Diffutherm external wall insulation system has an 8mm thick finish of mineral render and mesh mounted directly onto the3 substrate: in this case brick #2. As the 1mm of plaster selected before now faces the room it is pointless to simulate % RH in it (as it would be almost identical to room values). This monitor is therefore moved to face the brick. A new monitor is located within the innermost 1mm of insulation too. In this way it can be assessed whether moisture is accumulating in the insulation or brick under the influence of internal moisture load and driving rain.

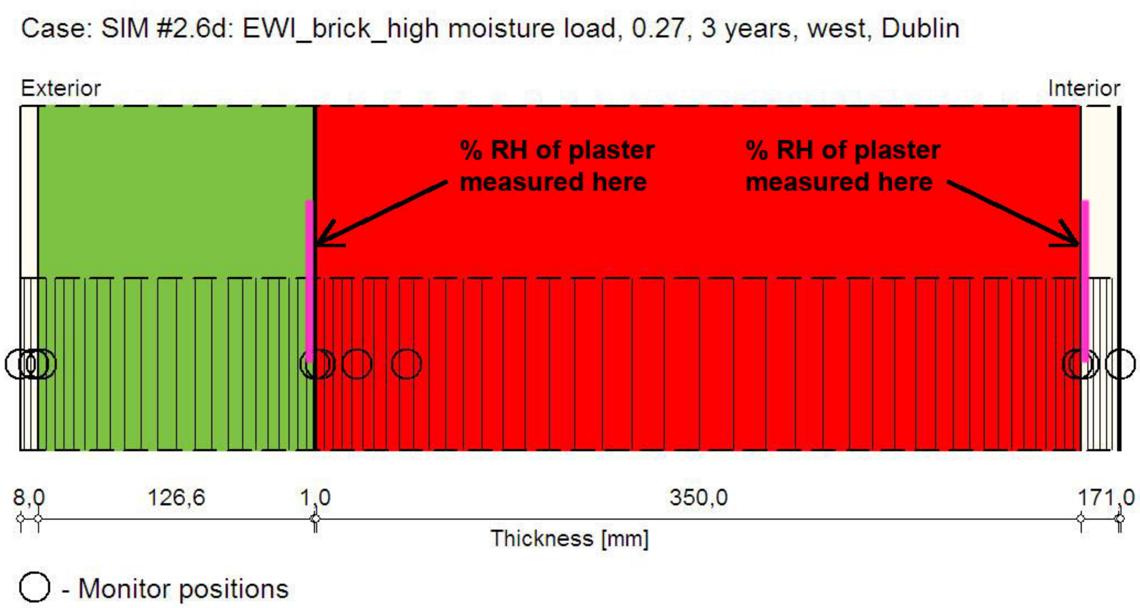

Figure 15: showing % RH monitor positions for a woodfibre external wall insulation system mounted onto brick #2

In the right graph of Figure 16 % RH reflects the level of internal moisture load more than it does the insulation value, which is to be expected, though it is interesting to see that the 0.27 W/m^{2}K vectors result in slightly *lower* % RH this time. This is because more external insulation now keeps the brick substrate *warmer* thus reducing the volume of vapour condensing as moisture when air currents brush against the internal wall surface. The left graph in Figure 16 is even more impressive than the right graph of Figure 13 above: note the scale difference on the Y-axis. Now we see % RH plummet from the starting position of 80% to ~55% RH (i.e. room conditions) despite being on the external side of the brick wall substrate. Another interesting change is that the oscillations of the yellow and blue vectors (representing 0.45 W/m^{2}K) are more violent than the cyan and pink (representing 0.27 W/m^{2}K). This is because higher levels of insulation isolate the monitor more from external climate conditions making conditions at the monitor and the brick behind it more and more healthy and stable.

It seems reasonable to deduce from this that once driving rain is dealt with internally-insulated walls appear to work best with less insulation than 0.45 W/m^{2}K but externally-insulated walls work best with far more. Moving to 0.27 W/m^{2}K internally appears to require careful management of *all* the macro issues and ideally use of specialist insulants. Is it worth it when good external insulation systems properly applied can have lower thermal bridging, less impact on the occupants, lose no floor area, are more robust at higher insulation levels, and when all is said and done are arguably less costly?

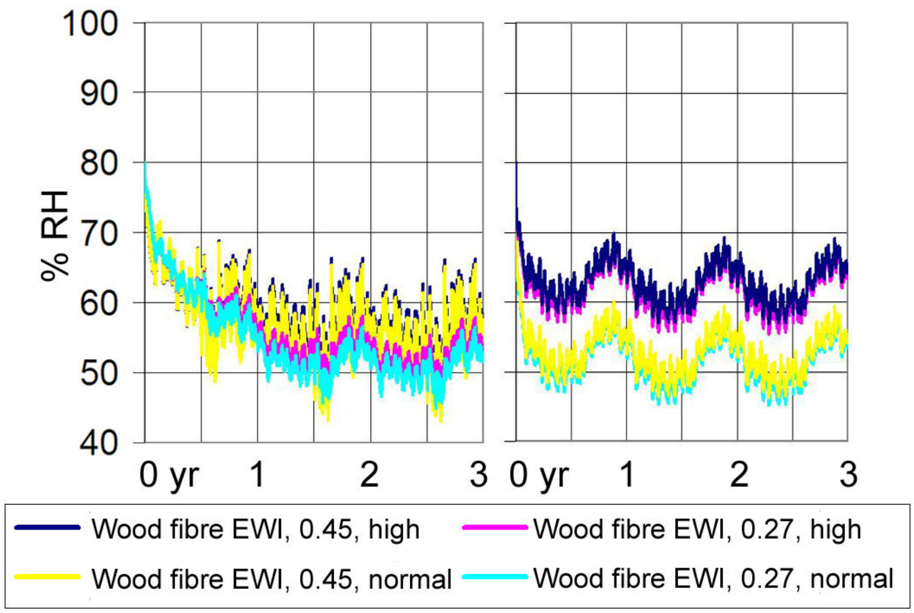

Figure 16: ***External wall insulation on brick*** *– (left to right) % Relative Humidity at inner 1mm of EWI, and at rear of internal plaster*

What's going on?

There are two issues that need a little more exploring:

1) What changes in an internally insulated wall as insulation levels increase?
2) Why is the failure of the unimpregnated brick (#2) walls initially delayed by six months then so dramatic?

Figure 17 relates to the first question and also the Mineral Wool system shown in Figure 11. This image shows a cross-section of four walls super-imposed on top of each other: the original uninsulated wall then the same wall with three levels of insulation, each thicker than the one before. While the graphs above show Relative Humidity at the dewpoint (the heavy blue line in this image) over time, this image shows averaged temperature, moisture and Relative Humidity values, taken for three months of the Winter after the walls have reached equilibrium, across the wall's width.

All bodies of air are constantly striving to reach equilibrium in terms of temperature and air pressure. In this process air pressure and temperature will literally drive vapour-carrying air molecules through cracks and gaps, and against cooler surfaces. Air carrying vapour passes through materials that appear solid but are actually porous, till its vapour-carrying capacity diminishes due to temperature dropping. Condensation then starts to occur. When a marked change in temperature occurs quickly a large amount of moisture can accrue: in internal insulation the worst location, the dewpoint, is often at the junction of the masonry substrate and the insulation. This is all generally accepted.

The following however is a theory that aims to unpick how step-by-step increases in insulation levels result in step-by-step worsening of % RH levels. This theory states that the greater the level of insulation is, the flatter the temperature gradient across the original substrate, and thus the weaker the vapour pressure vector. When this weakens the vapour moves more slowly outwards through the porous plaster and brick or block. Of course its ability to migrate back to the room has also significantly weakened: the more insulation the poorer the ability to reverse diffuse (i.e. diffusion towards the room). Meanwhile driving rain is absorbed by the wall, as it always has, resulting in an overall increase in vapour and moisture levels in the wall.

The colour lines in Figure 17 show how insulation, substrate temperature and % RH cannot be thought of separately. A subtle point can be reached where the temperature gradient is so flat that Relative Humidity in the original plaster creeps up above 80% (see the amber and red lines). Brick provides little nutrition for mould but plaster and insulation can. At this stage the system begins to fail not only because vapour levels are rising high enough to affect overall moisture content of the original wall but also because % RH at exactly the point where mould can flourish has passed a critical point.

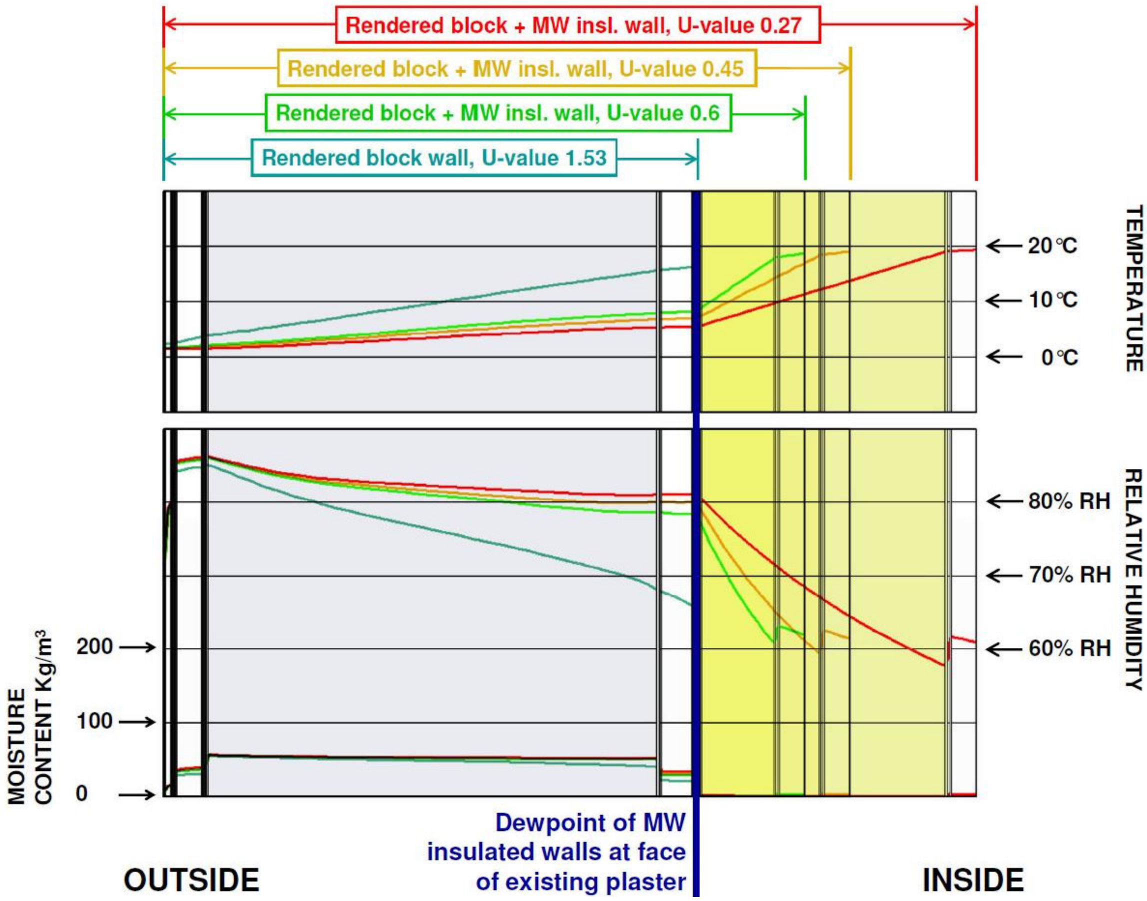

Figure 17: Temperature, % RH and moisture content profiles 2.5 years into simulation for uninsulated block and for three levels of insulation for Mineral wool system

This leads to Question 2 above. While most driving rain is absorbed, held and then dried in the external render of a blockwork wall, a solid brick wall (without treatment) allows moisture to penetrate much deeper into the wall away from the drying effect of the sun. The outer part tends to dry-out substantially but a moist zone remains behind that. In an uninsulated brick wall the room temperature allows some of this to vapourise and dry-out to the room. After internal insulation is applied and the vapour pressure vector slows the moisture absorbed from driving rain begins to grow. Initially the % RH at the dewpoint drops as the vapour diffusion vector is still to the outside. But after a few months the relentless increase in rainwater being stored away from the sun's drying power starts blocking the vapour from escaping to the outside. This part of the increasingly water-saturated brick has in fact become a 'vapour barrier'. The vapour diffusing towards this barrier now turns to moisture and adds to the overall water content at that point. As the diffusion and driving rain don't stop moisture levels balloon and a wave of moisture starts moving towards the inside after about three months into the simulation. When it reaches the dewpoint both plaster and insulation become super-saturated: failure occurs. A video output from WUFI file will be available for download on the writer's website shortly that appears to confirm this theory.

	uninsulated	insulated		
U-value (W/m^{2}K)	1.53	0.60	0.45	0.27
Temperature difference (K)	10.01	3.88	2.91	1.72
Suitability based on Figure 11	n/a	Good	Barely acceptable	Fail

Table 2: Review of average temperature difference for three Winter months between outside surface and dewpoint location

After dealing effectively with driving rain, having an adequate temperature differential (between dewpoint and the outside surface) seems the next most important step to creating a robust internal insulation system. Looking at the simulations carried out by Building Life Consultancy 3.5° Kelvin appears to be a sensible mean temperature difference (see Table 2), sufficient to drive vapour through the wall while allowing a modest U-value of perhaps 0.5 W/m^{2}K.

Seals, siloxanes and silanes

Treating the outside face of a brick or stone wall is a hot topic in the UK and Ireland in certain circles. Grade I and II conservation architects tend to be strongly against it as does at least one brick supplier the author contacted. Some caution is of course necessary: there are a wide range of treatments. Some, particularly in the past, seal the wall surface creating a moisture & vapour barrier sometimes with an unseemly shiny surface. The best silane or siloxane systems do not *seal* but are carefully engineered to *impregnate* the wall and coat the surface of tiny capillaries (or linked pores) at a microscopic level without reducing vapour permeability at all. They also make no visible change to the surface. The question for this writer is therefore, which are the ones that can be proven to work well for Irish brick buildings and Irish conditions? This needs to be conclusively shown with field tests to move the debate forward.

We can draw from testing done elsewhere or at least apply the same rigour. Professors Künzel & Kieszl wrote the following in a 1996 study which united field tests and simulation of a good siloxane impregnation system (see Figure 18 below).

> *'The field tests show that a siloxane impregnation, if properly applied, can repel rain water to such an extent that a complete drying of the masonry is possible… It seems possible that inappropriate impregnation can even increase the moisture content and hence the danger of frost damage… The quality of workmanship and the preparation of the façade, for example by repointing it, appear to be of major importance. If the quality conditions are met, an impregnation can be considered as an effective rain protection. Small cracks up to 1mm do not affect the rain protection if they are thoroughly impregnated and if the walls if of sufficiently low air permeability, e.g. by the application of a plaster on the inside.'*

Künzel & Kieszl (1996)

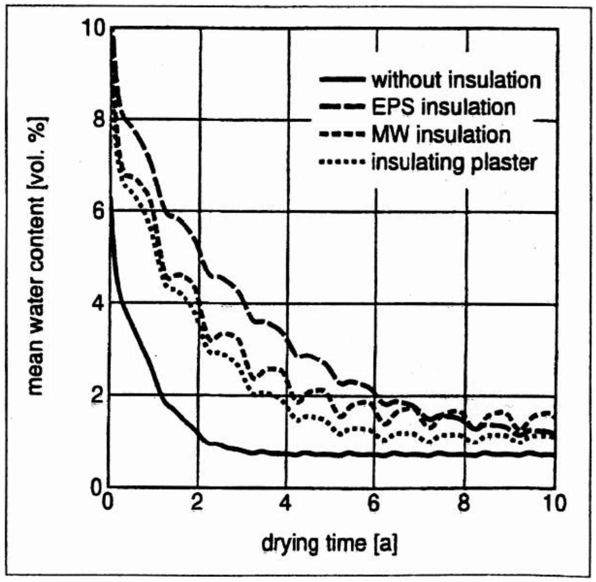

Figure 18: Drying time (in years) and water content of
various internally insulated walls after siloxane impregnation -
Image courtesy of Fraunhofer Institute

There are hundreds of thousands of unlisted single leaf walled dwellings that not only need to be comfortable to inhabit but need to be brought as near to a carbon neutral standard as possible in a robust, appropriate and healthy way. This comparative study clearly shows that reducing rainwater penetration directly impacts upon the amount of insulation that can be successfully used: for single leaf brick building it seems the critical part of any upgrade. Of course it makes sense that 'new' materials that are introduced into old buildings, whether 50 years old or 500, need to be carefully selected and checked to ensure their appropriateness for that function in that specific building. However that is the great gift of software like WUFI or DELPHIN, because now we *can* carry out those checks, once tests establish the key materials characteristics.

Conclusions

Everyone wants to reduce energy demand by insulating as highly as possible, but insulation without due regard to structure or health, or without full understanding of the changes the act of insulating creates, can only cause problems.

Given the volume of refurbishment work expected to commence it is hoped that government bodies, the utilities now entering the refurbishment market under the EDRT [9], and professional institutes will quickly engage with these concerns and contribute to the creation of a detailed, practical code of practice for refurbishment of dwellings. A key initial step is a general acceptance that current guidance on refurbishment is inadequate.

Testing of, for instance, three competing impregnation treatments and a range of typical blocks, bricks, renders, plasters and insulants by an independent third party is needed to form a basis for all simulations and assessment of Irish buildups.

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[9] Energy Demand Reduction Target

With use of new test data the simulations presented in this article would then need to be revised and significantly expanded on as a way to explore the most appropriate, healthy ways to carry-out energy-efficient refurbishments.

One striking conclusion of this comparative series of simulations is that higher and higher levels of external insulation appear to create healthy and ever more stable conditions within the wall buildup, while even relatively modest levels of internal insulation face tougher conditions and either failure or are bordering on doing so. An equally significant conclusion is that the right treatment of the external face appears to allow the installation of internal insulation without risk of growth in internal moisture levels.

Organisations need to be prepared to revise old guidance based on the new results. It is suggested that SEAI re-examines the insulation performance associated with the internal insulation grant. This work is clearly not conclusive but simulated walls internally-insulated to 0.27 W/m^2K clearly failed in more than 35 simulations.

*Joseph Little Architects, using years of experience in domestic refurbishment and building envelope expertise developed by Building Life Consultancy, has created an intensive one-day programme **'Designing Low-Energy Domestic Refurbs - optimising long term value for your client'** with the RIAI. The aim of the course is to highlight issues of particular importance to architects carrying-out energy-efficient refurbishments and to allow them prove the value of their design to the client. It is designed for architects but non-architects are welcome too.*

The first five courses in Dublin, Galway and Cork have sold out, but a sixth date in Limerick in late March and a seventh in Dublin in late May are available. For further information on these courses contact Teresa Harte of the RIAI by emailing <tharte@riai.ie> or by ringing 01-676 1703.

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