Appendix G: WP8 – Hygrothermal modelling

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Section content

1. WP8: Hygrothermal Modelling

1.1 Scope of WP8

The scope of this work package is to identify the validity and shortcomings of current hygrothermal modelling for the moisture risk assessment of cavity walls.

The analysis aims at identifying the advantages and disadvantages of the state-of-the-art hygrothermal simulations method and identifying valid approaches for an improved adequacy of hygrothermal simulations for cavity walls. This can help support the development of guidance for the moisture risk assessment of cavity walls in the UK.

This work package addresses the following questions:

- How accurate are hygrothermal simulations for cavity walls?
- How can existing hygrothermal simulations be improved?

1.2 Methodology

Hygrothermal simulations were performed using the boundary conditions set in the laboratory experiments and described in 1.2.1.

The first set of simulations was performed considering the material data described in 1.2.2. Then, the results of a subset of the hygrothermal simulations were compared with observations from the laboratory experiments; the method for collecting these observations is described in 1.2.3 and the material files for the simulations are presented in 1.2.4.

Finally, the direct comparison of simulation results and laboratory measurements was performed integrating the results of bench tests (Appendix C) into the hygrothermal simulations. The modified material properties for these hygrothermal simulations are presented in 1.2.5.

1.2.1 Boundary conditions

The boundary conditions in the models were set to match those used in the laboratory experiments, and consisted of at least 4 daily cycles of temperature and relative humidity under *dry conditions*, followed by *wetting* and at least 4 daily cycles after wetting (i.e. *wet conditions*). The daily cycles are presented in Table 1.

Table 1 Boundary conditions set for the hygrothermal modelling – daily cycles (under dry and wet conditions)

	Test 1 uninsulated (1U)	**Test 2 uninsulated (2U)**	**Test 3 uninsulated (3U)** **Test 1, 2, 3 insulated (1I, 2I, 3I)**
T_{ext} (air)	11 ^{0}C ± 3.7 ^{0}C	11 ^{0}C ± 3.7 ^{0}C, truncated for T < 10 ^{0}C	11 ^{0}C ± 3.7 ^{0}C, truncated for T < 10 ^{0}C
T_{int} (air)	18.4 ^{0}C ± 1.5 ^{0}C	18.4 ^{0}C ± 1.5 ^{0}C	18.4 ^{0}C ± 1.5 ^{0}C
RH_{ext} (air)	75 %	75 %	75 %
RH_{int} (air)	50 %	70 %	50 %

During wetting, the temperature and relative humidity in both chambers were set at constant levels, as described in Table 2. The table presents the settings for each wetting cycle. A wetting cycle consists of 20 minutes when water was sprayed at 2.25 l/m^2/min followed by a 40-minute rest.

Table 2 Boundary conditions set for the hygrothermal modelling – wetting

Test No.	Samples	Wetting – day 1			Overnight conditioning		Wetting – day 2		
		No. wetting cycles	T_e [ºC]	T_i [ºC]	time [h]	T_e, T_i [ºC]	No. wetting cycles	T_e [ºC]	T_i [ºC]
1U	A1, B1 uninsulated	2	15	20	14	20	8	15	20
2U	A2, C1 uninsulated	2	15	20	14	30	2	15	20
					4.5	20			
3U	B2, C2 uninsulated	2	15	20	14	20	2	15	20
					4.5	25			
1I	A1, B1 uninsulated	2	15	20	14	20	8	15	20
2I	A2, C1 uninsulated	2	15	20	14	20	8	15	20
3I	B2, C2 uninsulated	2	15	20	14	20	8	15	20

For all tests, the initial conditions for the simulations were set at a temperature of 17.5 ºC and a relative humidity of 50 %, uniform throughout the wall, to align with the pre-conditioning of the samples.

1.2.2 Material files for the comparative analysis of example bricks

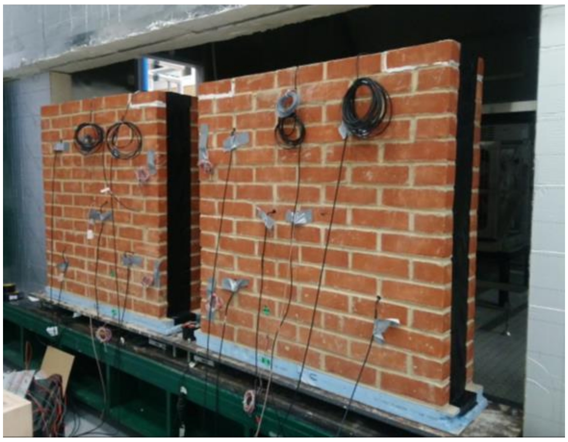
First, a set of hygrothermal simulations were performed using the software Delphin[1], compliant with the standard BS EN 15026:2007[2]. The comparative analysis was carried out using material files from the in-built Delphin software database and the MASEA database[3] (the result of a research project to characterise a number of German construction materials), excluding specific bricks that were clearly unsuitable for the purpose of cavity walls (e.g. modern perlite-infilled bricks or solid bricks from old/historic buildings). Such material files are likely to be the only reference sources available to hygrothermal modellers at this time.

Table 3 Bricks considered in the comparative analysis of example bricks

Brick no.	Brick name
1	Normal brick 512
1a	Normal brick 264
2	Normal Brick 507
3	Brick Joens 34
4	Brick 686
5	Brick Bernhard 33
6	Brick Schlagmann (solid brick) 552
7	Lime-Sandbrick 685
8	Lime Sand Brick 509
9	Lime Sand Brick 510
10	Lime Sand Brick 511

1.2.3 Laboratory measurements

For the purpose of this work package, the results of laboratory experiments were collected by installing temperature and relative humidity sensors located in layers that allow comparison between experimental results and simulations, as shown in Figure 1 (right). The temperature and relative humidity were measured with type T thermocouples (accuracy ± 0.5 ºC) and Honeywell HIH capacitance sensors (accuracy ± 3.5 %) respectively. The sampling time was 5 minutes. Four wall depths were considered, including the internal surface (T_{int}, RH_{int}), the external side of the inner leaf (two sets of sensors: T_{it}, RH_{it} for the top location, and T_{ib}, RH_{ib} for the bottom location), the internal side of the outer leaf (two sets of sensors: T_{et}, RH_{et} for the top location, and T_{eb}, RH_{eb} for the bottom location), and the external surface (T_{ext}, RH_{ext}) (see Figure 1). The results at the internal side of the outer leaf and the external side of the inner leaf could be compared with the results from hygrothermal simulations.



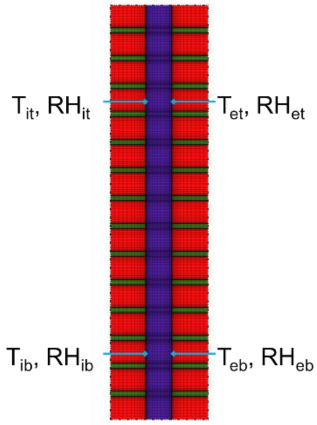


Figure 1 Experimental walls (left) and sensors locations (right)

Two types of waterproofing treatments onto cavity walls were analysed. Two waterproofing systems were applied onto the brick wall, here called *waterproof masonry treatment* (walls B1 and B2) and *masonry protection cream* (walls C1 and C2). Two untreated walls (walls A1 and A2) were used as control samples. The brick used in laboratory experiments was Atherstone Red by Forterra, a stock-pressed brick with a smooth sand-faced finish. The manufacturer's datasheet provides the following thermophysical properties: density (ρ = 1550 kg/m³) and thermal conductivity (λ = 0.51 W/mK). Hygric properties were not available in the brick datasheet.

The laboratory measurements first considered the six cavity wall samples as uninsulated, and then the samples were insulated with expanded polystyrene (EPS) beads and tested again. More information on the methodology for the laboratory experiments is available in Appendix E.

1.2.4 Material properties for the direct comparison of simulations and laboratory measurements

For the comparison of hygrothermal simulations and experimental results, similar bricks to the one used in the laboratory experiment were selected for the simulation from the Delphin database. The similar bricks were selected based on density and thermal conductivity; not on hygric properties, due to the lack of availability. However, some hygrothermal properties are presented in Table 4.

Table 4 Material files for comparative analysis; material properties from Delphin database, manufacturer datasheet (*) and measured values (**). The properties considered are water vapour diffusion resistance coefficient (μ), thermal conductivity (λ), water absorption coefficient (A_w), density (ρ), specific heat capacity (c_p), and moisture content at effective saturation (θ_{eff}).

Wall	Brick no.	Original materials	μ [-]	λ [W/(mK)]	$A_{w, brick}$ [kg/(m²s⁰·⁵)]	ρ [kg/m³]	c_p [J/(kg K)]	θ_{eff} [m³/m³]
A	1	Normal brick 512	18.0	0.548	0.1987	1786	889	0.319
A	1a	Normal brick 264	19.0	0.550	0.1773	1400	1000	0.319
A	1b	Old building brick Tivoli Berlin 796	11.3	0.546	0.2266	1566	964	0.357
A	-	Measured brick (mean)	18.2**	0.51*	0.1908**	1550*	-	-

1.2.5 Modified material properties for the direct comparison of simulations and laboratory measurements

The last part of the comparison considered the three different surface conditions analysed in the laboratory experiment: untreated walls (walls A in the laboratory experiment), walls treated with waterproof masonry treatment (walls B) and walls treated with masonry protection cream (walls C). The water vapour diffusion resistance coefficient (μ [-]) of the materials was taken from the results of the bench tests, and the water absorption coefficients A_w [kg/m²/s$^{0.5}$] of brick were calculated from the measured water absorption curves. The coefficient is calculated as the slope of the water absorption curve as a function of the square root of time.

Table 5 Material properties from bench test results (see Appendix C)

	Walls A (untreated)	Walls B (waterproof masonry treatment)	Walls C (masonry protection cream)
μ [-]	[16.59, 17.08, 17.92, 19.50, 20.07]	[13.29, 17.75, 18.70, 19.12, 19.98]	[19.76, 20.04, 22.25, 22.60, 22.85]
$A_{w, brick}$ [kg/m²/s$^{0.5}$]	[0.1891, 0.1956, 0.1877]	[0.0037, 0.0137, 0.0767]	[0.0013, 0.0012]

For the direct comparison, the "similar bricks" identified in 1.2.4 were modified with the average values of the measured hygric properties (see Table 5): the water vapour diffusion coefficient μ (-) and the water absorption coefficient A (kg/(m²s$^{0.5}$)). The material files were modified through the material generator in Delphin 5 [4].

Table 6 Material files for comparative analysis, constructed by integrating the measured data (from results of bench tests) in the material database

Wall	Brick no.	Original materials	μ [-]	λ [W/(mK)]	$A_{w, brick}$ [kg/(m²s$^{0.5}$)]
A	1	Normal brick 512	18.23	0.51	0.1908
A	1a	Normal brick 264	18.23	0.51	0.1908
A	1b	Old building brick Tivoli Berlin 796	18.23	0.51	0.1908
B	1	Normal brick 512	19.27	0.51	0.0314
B	1a	Normal brick 264	19.27	0.51	0.0314
B	1b	Old building brick Tivoli Berlin 796	19.27	0.51	0.0314
C	1	Normal brick 512	21.50	0.51	0.0013
C	1a	Normal brick 264	21.50	0.51	0.0013
C	1b	Old building brick Tivoli Berlin 796	21.50	0.51	0.0013

1.2.6 Method of analysis

1.2.6.1 Comparative analysis of example bricks

First, simulations were conducted for all the bricks available in the database but excluding specific bricks that were clearly unsuitable for the purpose of cavity walls. These simulations aimed at showing the difference of hygrothermal performance among bricks, and did not consider the influence of waterproofing. The simulations considered the material properties of bricks available in the database of the hygrothermal simulation software.

1.2.6.2 Comparisons of simulations and laboratory measurements

Then, we compared the observed laboratory results with the simulation results considering three bricks with values that were closer to the values declared in the datasheet for the used bricks (as shown in Table 4). The selection of bricks was informed by the knowledge of the values found in the datasheet.

Two samples of untreated walls - A1 and A2 - were studied. Comparisons between the measured and simulated values for the relative humidity profiles in samples A1 and A2 were performed, considering the relative humidity behind the external and the internal leaves.

A first iteration of the direct comparison of simulations and laboratory measurement considered a subset of the bricks analysed in 1.3.1.1, selecting similar bricks based on a similar density and thermal conductivity to the bricks used in the laboratory experiment (i.e. bricks 1 and 1a). In addition to those, a brick from a historic building (brick 1b) was added, as it showed similar density and thermal conductivity.

1.2.6.3 Comparisons of simulations and laboratory measurements[a], with the integration of measured material properties

Finally, we compared the observed laboratory results with the simulation of the three bricks tested above but changing the material properties of such bricks, using data from bench tests (as shown in Table 6). All this analysis was performed for uninsulated walls first, and then for insulated walls.

The second iteration of the direct comparison of simulations and laboratory measurement considered the same subset of similar bricks analysed above (in 1.2.6.2), but modifying the material properties to include the results of bench testing. Given the availability of material properties to describe the influence of waterproofing treatments on building materials, it was now possible to perform the direct comparisons of simulations and measurements for the treated walls B and C.

1.2.6.4 Uninsulated and insulated walls

The cavity walls were first analysed without cavity wall insulation. Afterwards, the samples were filled with expanded polystyrene (EPS) insulation beads and the analysis was repeated for the insulated case.

1.3 Results and discussions

1.3.1 Uninsulated walls

1.3.1.1 Comparative analysis of example bricks

First, we investigated the possible responses to set boundary conditions by comparing the outcomes of simulations, using 11 bricks available on the Delphin and MASEA databases (shown in Table 3). Figure 2 shows the outputs of the hygrothermal simulations, represented by the time-series of relative humidity behind the external leaf.

The bricks named “brick”, “solid brick” or “normal brick” (bricks 1, 1a, 2, 4, 6, in blue), showed a fast increase of relative humidity, some with a more marked first bounce during the overnight conditioning period occurring after the first 2 wetting cycles. A similar behaviour was found for bricks 3 and 5 (in green). On the other hand, lime-sand bricks (bricks 8, 9, 10, in orange) showed a very different behaviour under wetting, characterised by a slow/no increase of relative humidity. However, another “lime-sandbrick” (brick 7, in yellow), showed the fastest increase of relative humidity of all bricks.

[a] *It should be noted that this is not a perfect direct comparison as thermal properties are based on manufacturers data sheet and the dependency of thermal conductivity on moisture content is assumed; and the lab measurements did not include moisture storage function.*

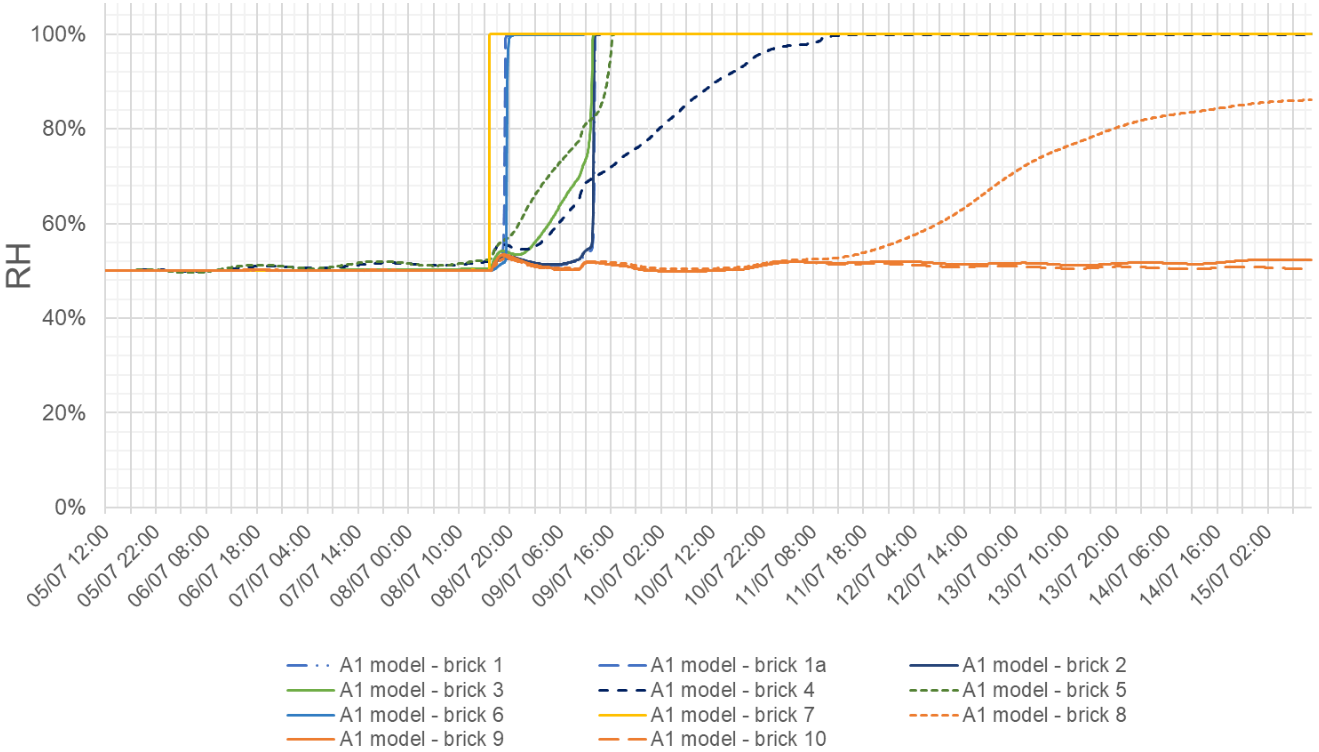


Figure 2 Model predictions for wall A1, untreated and uninsulated. Relative Humidity behind external leaf.

This initial analysis shows the importance of knowing the type, or *cluster,* which the brick is belonging to. In new buildings, it is possible to identify the right type by looking at the datasheet; however, not all datasheets contain relevant hygrothermal properties that could be used for this purpose. In existing buildings, identifying the correct cluster is more difficult, because of the lack of information historically available on the bricks used.

1.3.1.2 Comparisons of simulations and laboratory measurements (wall A, untreated)

Figure 3 and Figure 4 show the direct comparisons of simulations and laboratory measurements for the untreated walls A1 and A2 (respectively), in the uninsulated case. The model predictions for the three similar bricks showed an increase of relative humidity up to 100% relative humidity at the (internal surface of the) external leaf during wetting, in agreement with the experimental results for untreated brick. Also, the model predicted an increase in relative humidity at the internal leaf, in line with experimental results. However, for all considered bricks this increase was higher than observed in the experimental results. Moreover, the speed of increase of relative humidity is different among the similar bricks and it is not possible to identify what brick best represents the behaviour of the bricks tested in the laboratory.

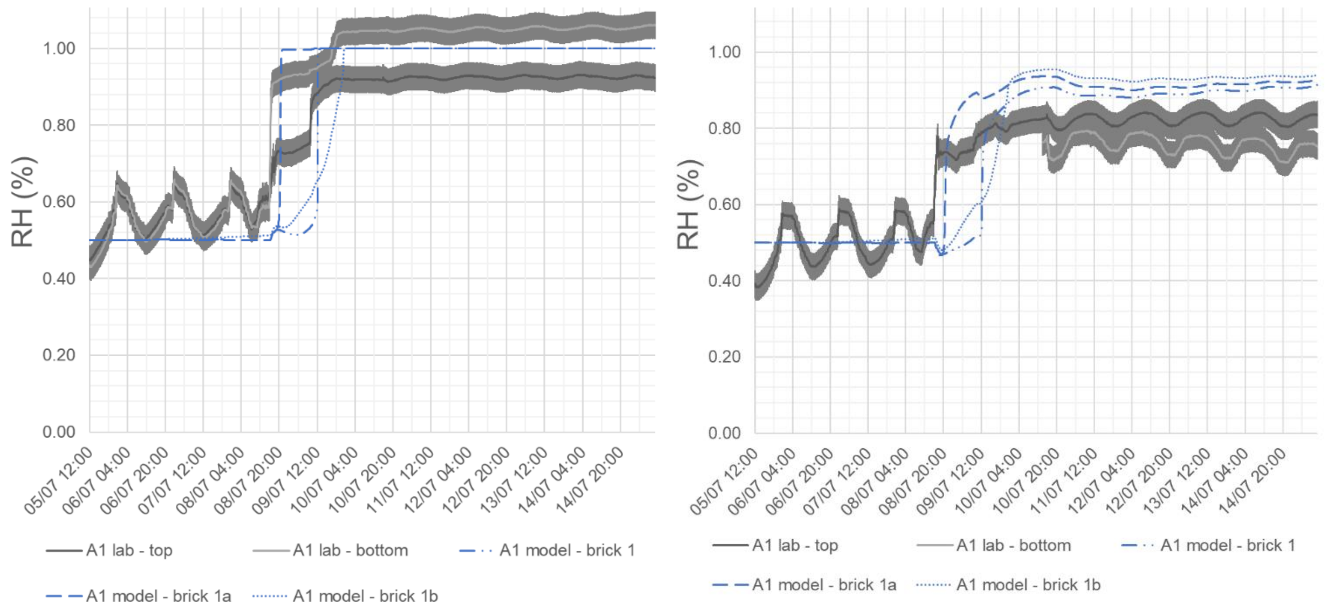


Figure 3 Sample A1 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error)

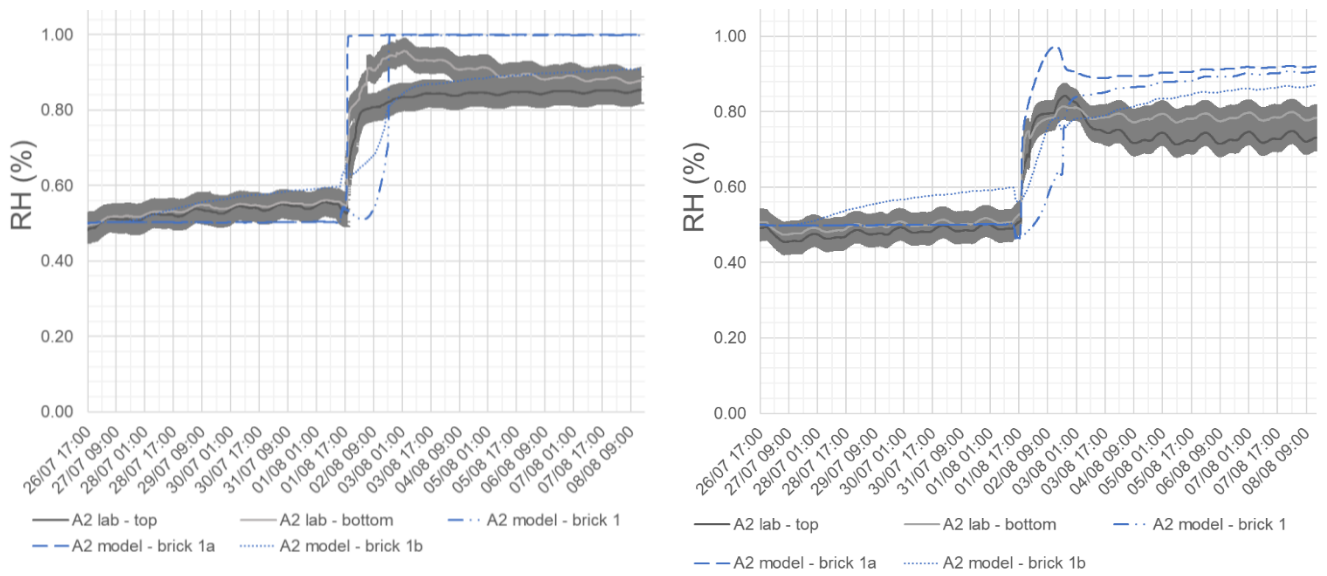


Figure 4 Sample A2 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error)

1.3.1.3 Comparisons of simulations and laboratory measurements, with the integration of measured material properties

Walls A (untreated)

The results of the direct comparisons in untreated walls (A) were closely aligned with the results in 1 .3.1.2. As shown in Figure 5 and Figure 6, the simulations predicted an increase of relative humidity up to 100% at the external leaf during wetting and an increase in relative humidity at the internal leaf, with very little difference from the previous results. This suggests that, in the untreated case it was possible, knowing some basic properties of the brick, to perform hygrothermal simulations that were fairly representative of the behaviour of the laboratory wall assemblies.

During wetting, the experimental results show variability in water accumulation at various locations of the wall (i.e. the top and bottom of the wall), which cannot be captured by deterministic hygrothermal modelling; this is expected and in agreement with other studies.

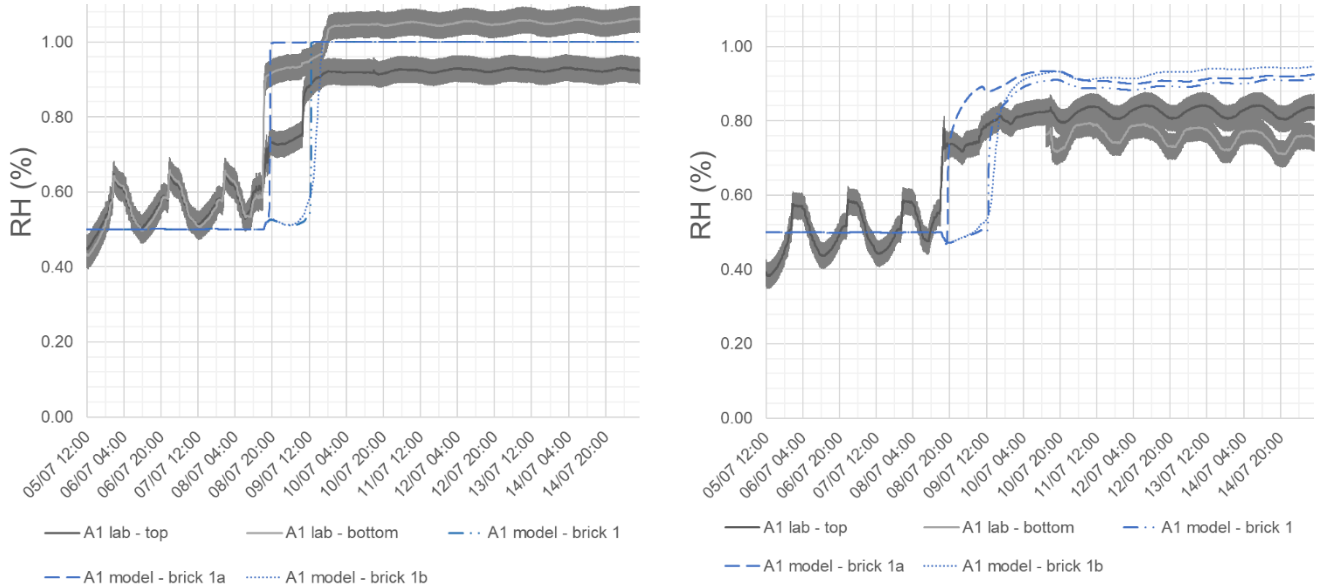


Figure 5 Sample A1, uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

It is worth noting that, in wall A1, the experimental results show fluctuations in relative humidity (particularly during the dry initial period), which could not be seen in the simulations. In wall A2, the observed relative humidity was flatter, and more in line with the simulations. The fluctuations in A1 are likely to be due to unintended air infiltration into the cavity, observed in the first test (A1 and B1 uninsulated).

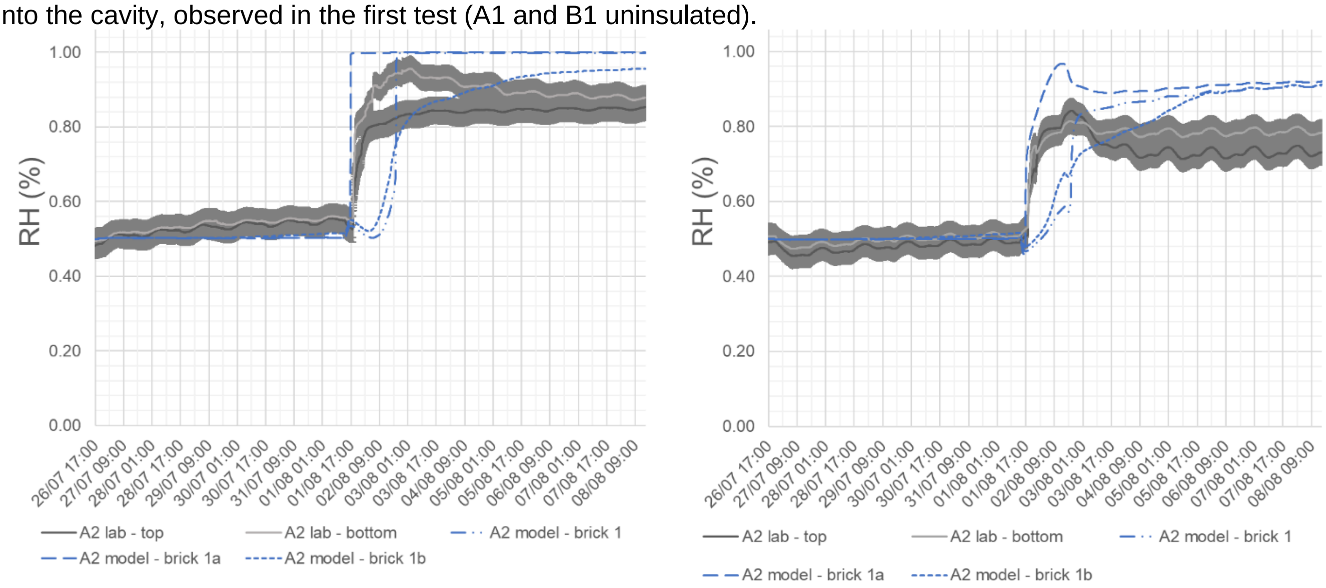


Figure 6 Sample A2 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

Walls B

The material properties were to represent cavity walls treated with the waterproofing product B.

Figure 7 and Figure 8 show that the simulations were not able to represent the levels of relative humidity observed in the laboratory experiment for the treated walls B. The experimental results showed a marked increase of relative humidity on both internal and external leaves during wetting, which was not found in the model predictions.

These simulations considered water absorption coefficients measured for bricks; however, the bench tests also considered the measurement of water absorption coefficients, A_w, for combined bricks and mortar. As shown in Appendix C, the combined values for A_w were lower than the values associated to bricks, therefore predicting even lower moisture uptake.

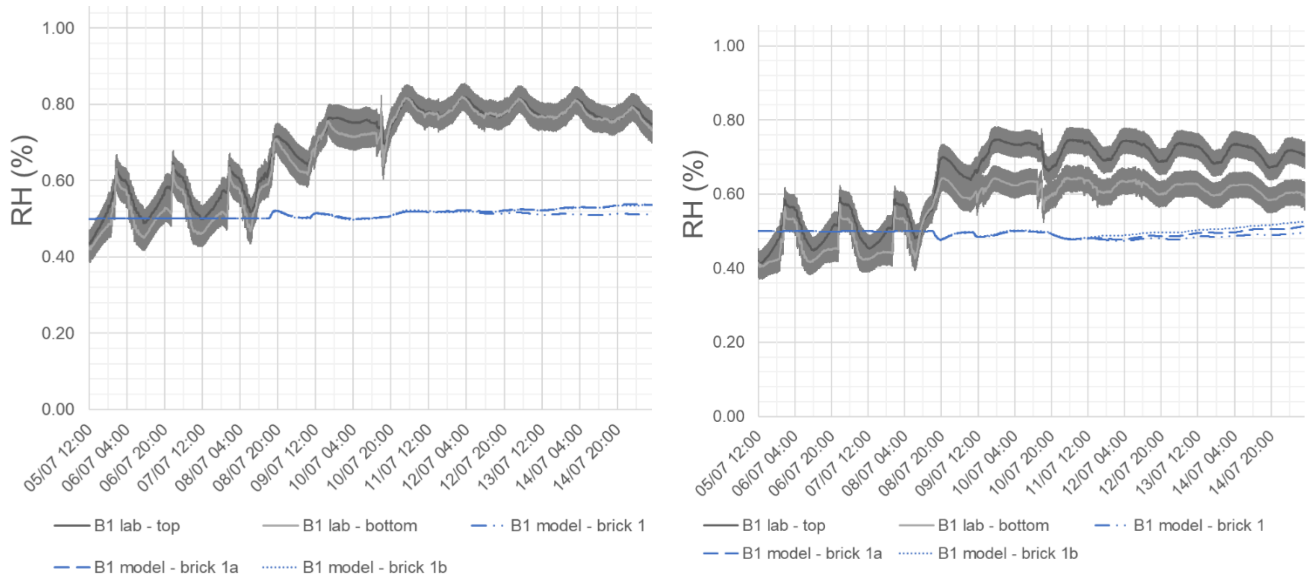


Figure 7 Sample B1 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

As in wall A1, a higher fluctuation was found in B1, which is likely to be associated with unintended air infiltration into the cavity.

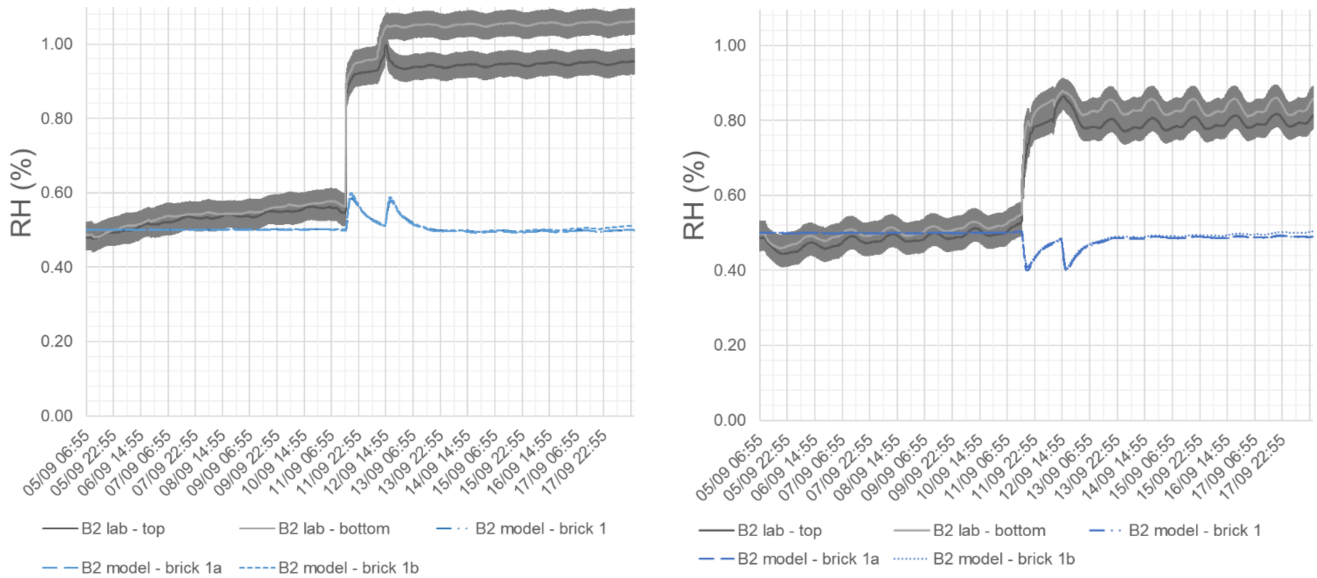


Figure 8 Sample B2 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

Walls C

The material properties were modified to represent cavity walls treated with the waterproofing product C. Similar to walls B, the simulations were not able to represent the levels of relative humidity observed in the laboratory experiment, as shown in Figure 9 and Figure 10. The experimental results showed a marked increase of relative humidity on both internal and external leaves during wetting, which was not found in the model predictions.

Similar to walls B, these simulations considered water absorption coefficients measured for bricks, as the combined values for A_w were lower than the values associated to bricks, therefore predicting even lower moisture uptake.

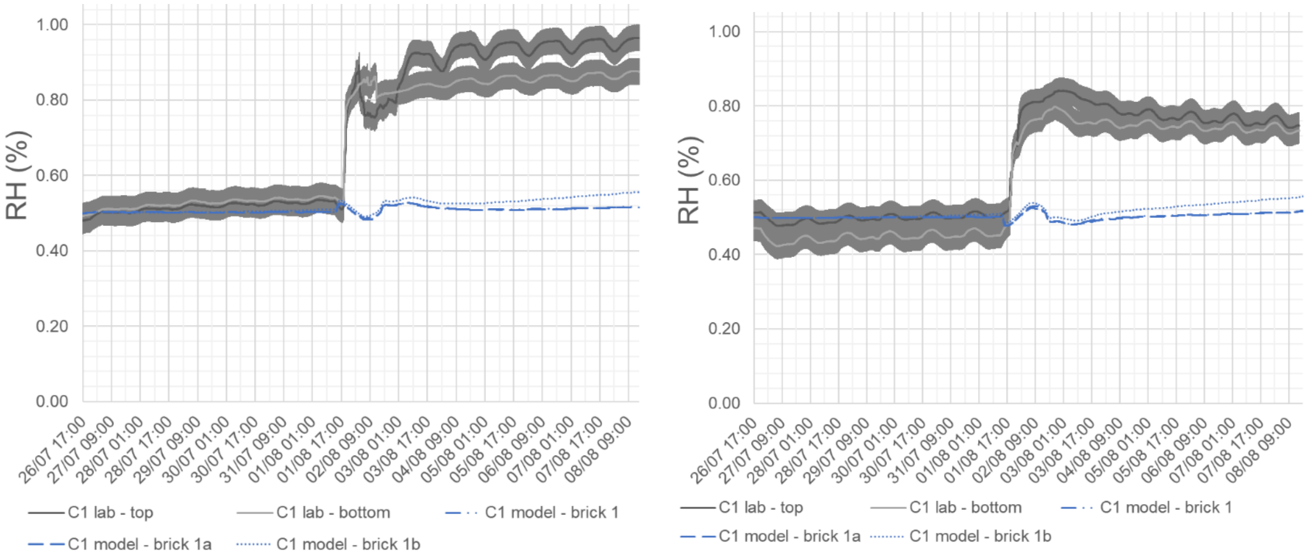


Figure 9 Sample C1 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

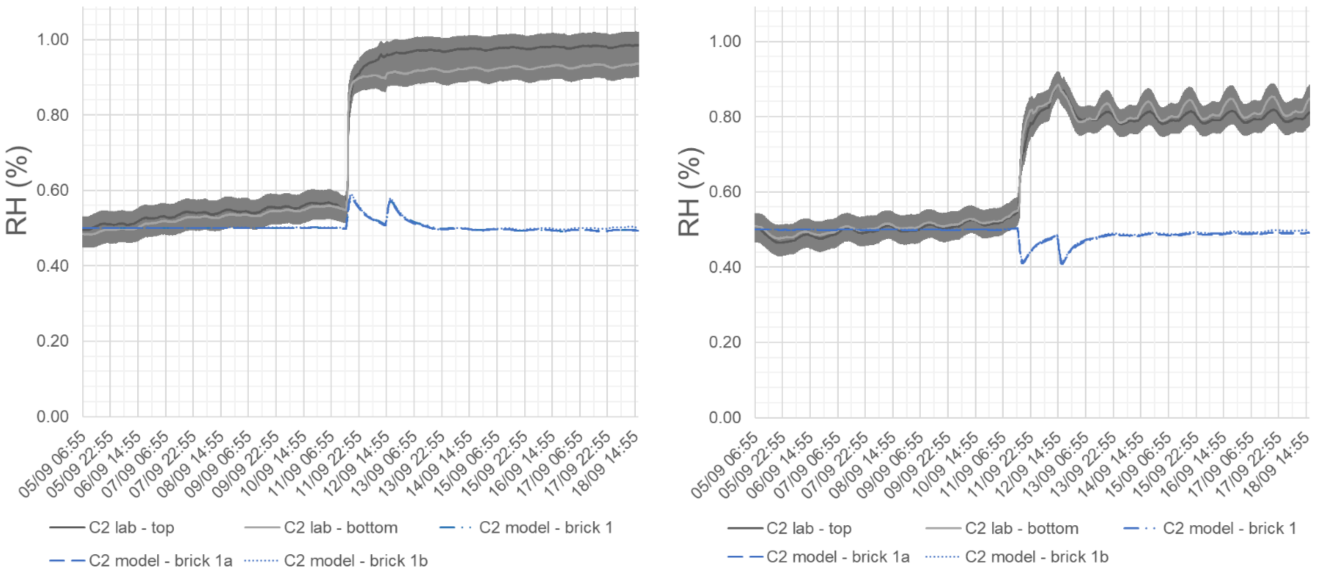


Figure 10 Sample C2 uninsulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

1.3.2 Insulated walls

1.3.2.1 Comparative analysis of example bricks

Figure 11 presents the results of the comparative analysis for the 12 example bricks in the insulated case, which showed similar results to the uninsulated case . This confirms the importance of knowing the type, or *cluster,* which the brick is belonging to, also for the analysis of insulated cavity walls.

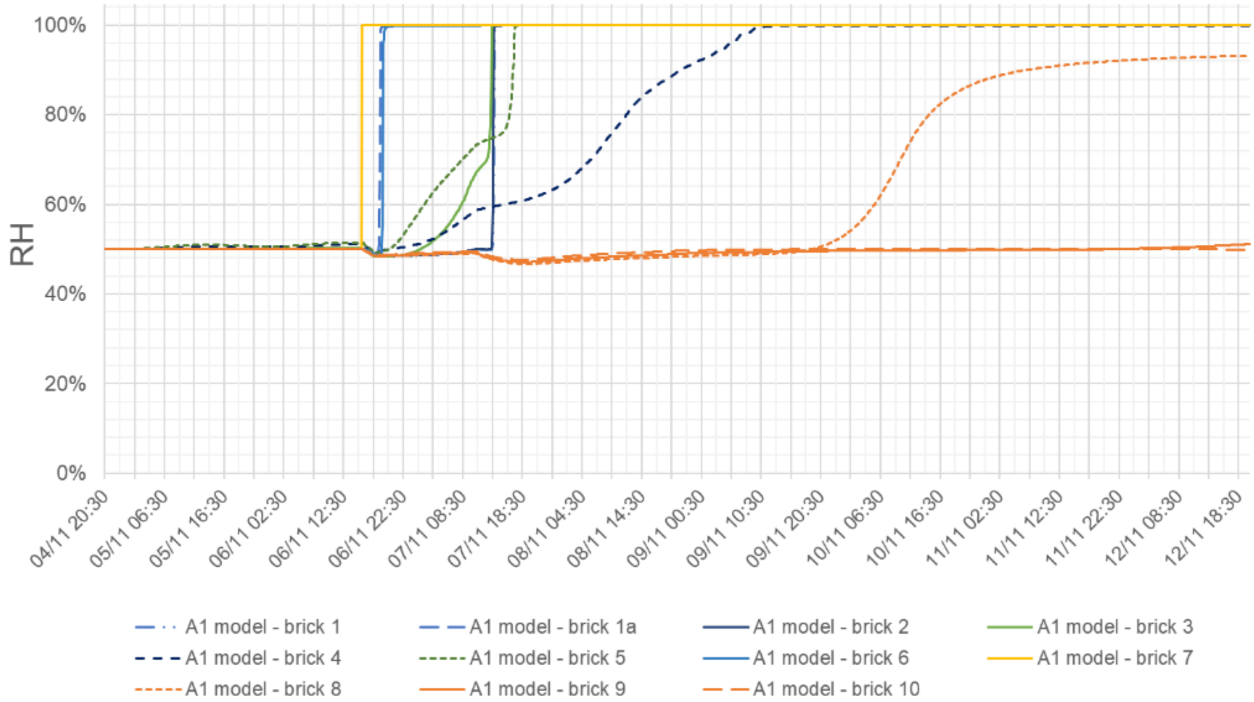


Figure 11 Model predictions for wall A1, untreated and insulated. Relative Humidity behind external leaf.

1.3.2.2 Comparisons of simulations and laboratory measurements (wall A, untreated)

Figure 12 and Figure 13 show the direct comparisons of simulations and laboratory measurements for the untreated insulated walls A1 and A2 (respectively). The model predictions for the three similar bricks showed an increase of relative humidity up to 100% at the (internal surface of the) external leaf during wetting, in agreement with the experimental results for untreated brick. This is in line with the uninsulated case.

However, in the insulated case, the model did not consistently predict an increase in relative humidity at the internal leaf across the three bricks, although this was observed in the experimental results for both walls A1 and A2 (although to a lesser extent in A2). This suggests that the hygrothermal modelling was not able to accurately represent the hygrothermal behaviour of the insulation layer, in particular the vapour flow through insulation.

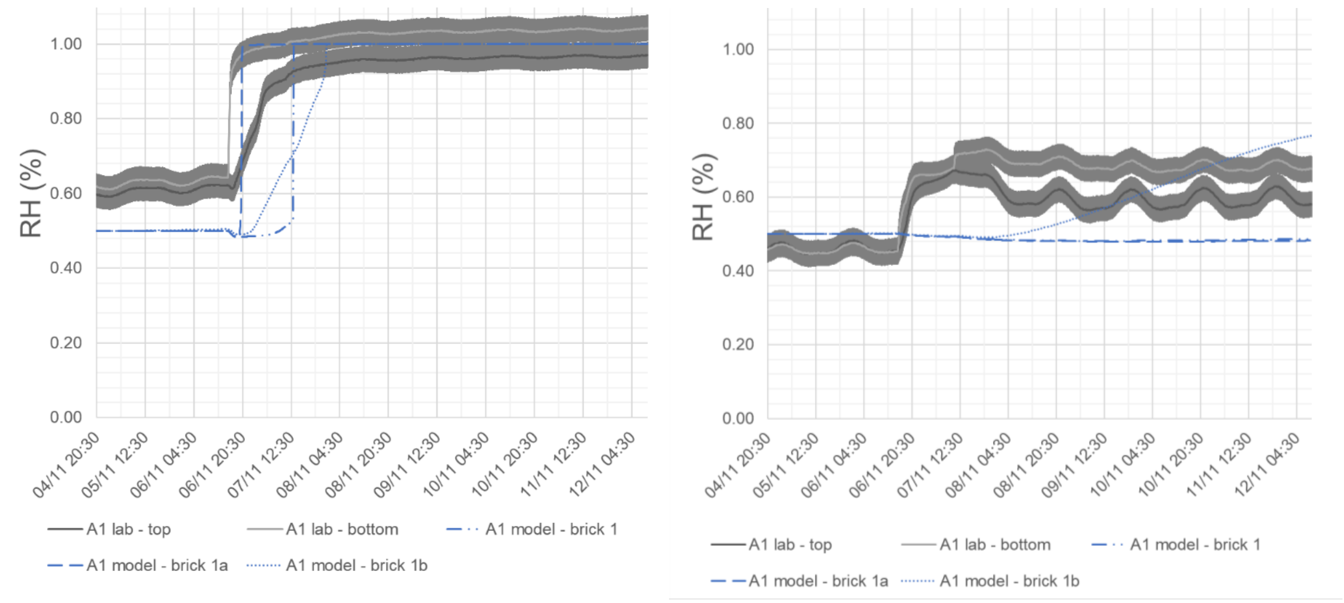


Figure 12 Sample A1 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error).

For the insulated wall A1, the laboratory measurements showed an initial relative humidity that is higher than in the previous case, showing values as high as 60% during dry conditions, affecting – in turn – the hygric balance during the dry conditions. However, for consistency with the previous simulations, the initial conditions were the same throughout the analysis.

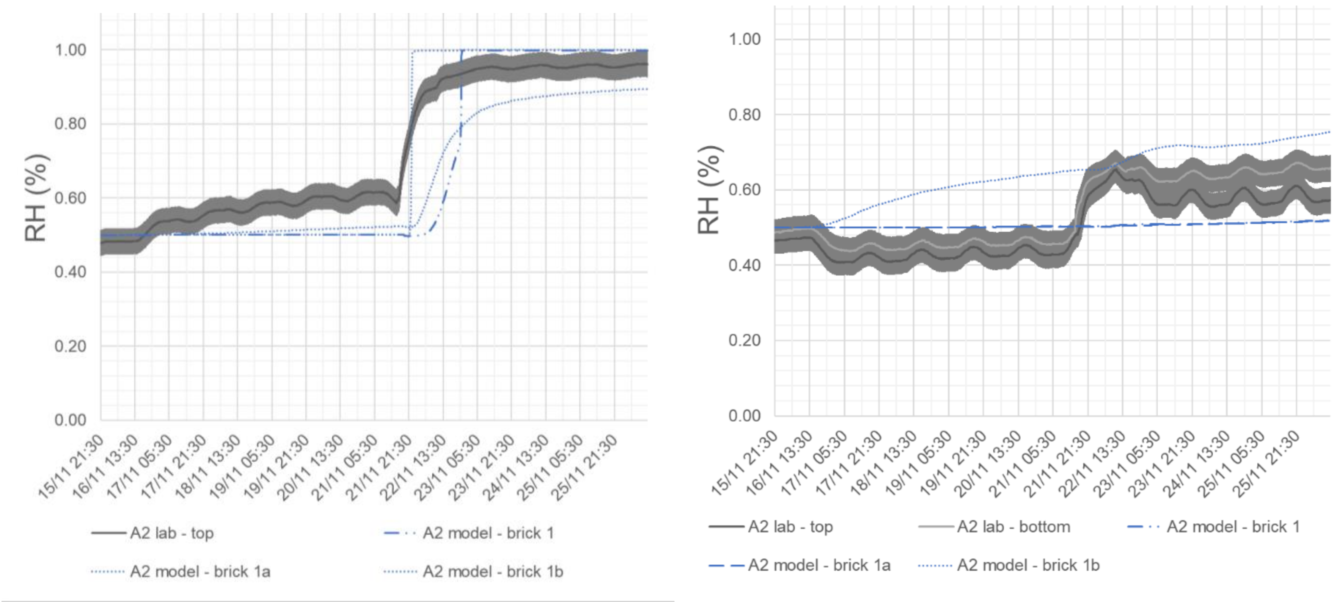


Figure 13 Sample A2 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error).

1.3.2.3 Comparisons of simulations and laboratory measurements, with the integration of measured material properties

Wall A, untreated

The results of the direct comparisons in untreated walls A were closely aligned with the results in 1.3.2.2. As shown in Figure 14 and Figure 15, the simulations predicted an increase of relative humidity up to 100% at the external leaf during wetting and no increase in relative humidity at the internal leaf. Considering the measured material properties allowed the three predictions of the hygrothermal behaviour to be more consistent, although not representative of the observed behaviour.

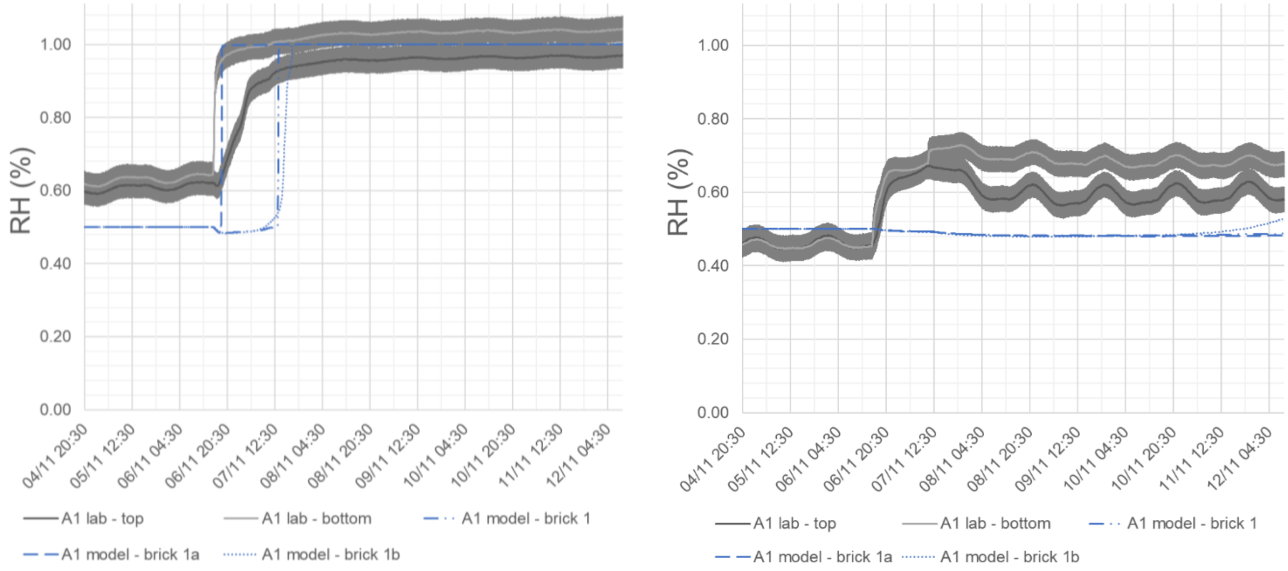


Figure 14 Sample A1 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

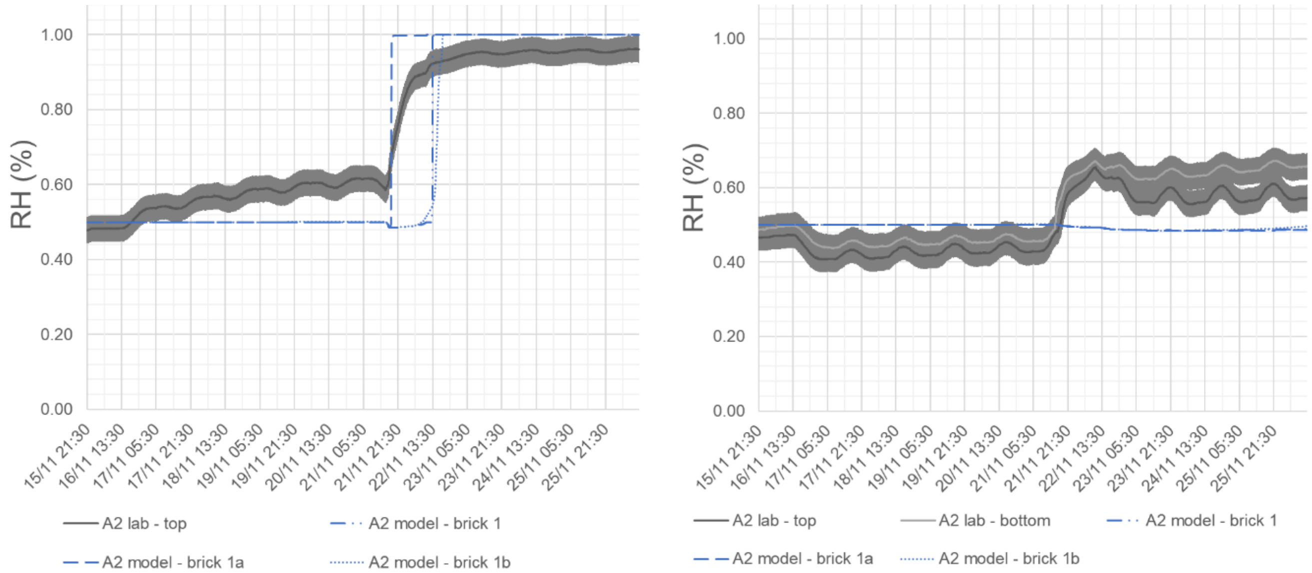


Figure 15 Sample A2 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

Wall B

Figure 16 shows that the simulations were not able to adequately represent the levels of relative humidity observed in the laboratory experiment for the treated walls B for the insulated case, too. Behind the external leaf, the experimental results showed an increase of relative humidity during wetting, which was not found in the model predictions. On the other hand, the observed relative humidity behind the internal leaf showed limited increase; here, the model predictions are more in agreement with the experimental results.

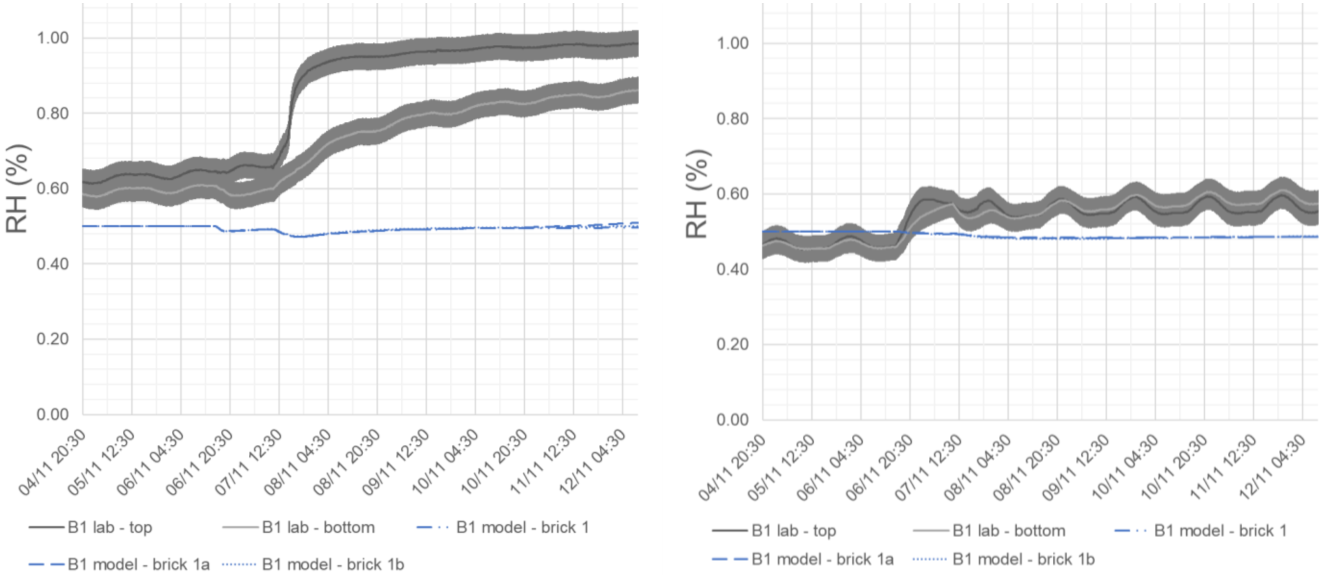


Figure 16 Sample B1 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

Wall C

Similar to walls B, the simulations were not able to adequately represent the levels of relative humidity observed in the laboratory experiment for the treated and insulated walls C, as shown in Figure 17. Behind the external leaf, the experimental results showed an increase of relative humidity, which was not found in the model predictions. On the other hand, the observed relative humidity behind the internal leaf showed limited increase; here, the model predictions are more in agreement with the experimental results.

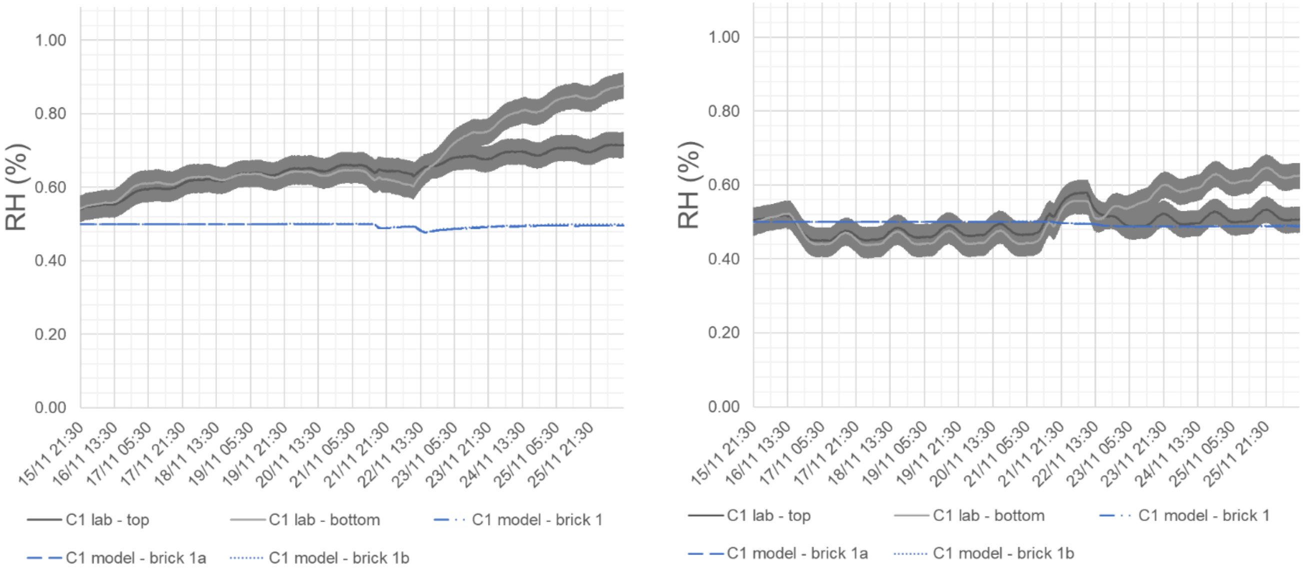


Figure 17 Sample C1 insulated. Relative Humidity behind external leaf (left) and internal leaf (right), model predictions (dashed lines) and observations (solid lines, with ±3.5% declared RH measurement error). The hygrothermal modelling considered measured material properties.

1.4 Conclusions and recommendations

1.4.1 How accurate are hygrothermal simulations for cavity walls?

For untreated walls we found similar results between modelling and monitoring, which shows that the hygrothermal simulation tool can represent the hygrothermal behaviour of cavity walls but it relies on the representativeness of the input data.

In the untreated case it was possible – knowing some basic properties of the brick – to perform hygrothermal simulations that were representative of the behaviour of the laboratory wall assemblies.

However, when materials were treated, the measured absorptivity of materials was not representative of the behaviour of the laboratory wall assemblies. The water absorption coefficients measured in bench tests for bricks, mortar and for the combination of brick and mortar were low; as a result, the simulations showed little/no increase in relative humidity, but water uptake was observed in the laboratory experiment. This may suggest that the moisture behaviour was not governed by the material properties themselves, but by the properties at the interface between building materials and by defects observed in the mortar joints of the wall (See Figure 18).

Figure 18 Sample of defects observed in the mortar joints of the walls tested (in the picture walls C1 and A2) .

1.4.2 How can hygrothermal simulations be improved?

Hygrothermal simulations can be improved in the following areas:

Material properties

The identification of appropriate hygric properties of building materials is key. In this work, we considered some easily-measurable material properties to reflect what had been tested in the laboratory and found it to be crucial for our analysis. Moreover, in-situ characterisation of the main hygric properties of cavity wall assemblies would be beneficial for the development of appropriate hygrothermal modelling methods for waterproofed cavity walls.

The case for an engineering approach

In this work, we found that selecting bricks from a representative cluster allowed us to predict well the untreated case. However, this was not the case for treated bricks. One could think that the solution is to consider a combination of brick and mortar, but the results from bench testing showed an even lower water absorption coefficient for the combination mortar/brick. Also, the treated mortar showed a lower value than the treated brick.

The model was unable to replicate the tests in the climate chamber satisfactorily. The results suggest that the hygrothermal behaviour of the cavity wall is influenced by moisture transfer mechanisms other than the ones considered in the hygrothermal simulations. The simulations considered the mechanisms identified in BS EN

15026: 2007, which describe moisture transfer under As Designed - Theoretical (ADT) conditions. The mechanisms occurring in the case of As-Built, In-Service (ABIS) conditions were therefore neglected in the simulations. Among the neglected mechanisms is water infiltration through joints and cracks. These findings are in agreement with the literature and the modes of failure identified on-site, which showed that failure is not due to ADT conditions, but it is expected to be the result of ABIS factors. As a result, this analysis shows that the bench testing of hygric properties (e.g. water absorption) of material samples, even if combined, would not be sufficient for the description of the behaviour of walls treated with waterproofing agents.

Also, the findings show the lack of validity of methods currently used in first approximation for the hygrothermal modelling analysing the influence of waterproofing treatments.

Rather than considering a 2D simulation of perfect conditions, it is suggested that other methods be identified for characterising the effect of waterproofing. Engineering methods of allowing a certain percentage of wind-driven rain to penetrate the wall might be appropriate and are increasingly used (see Lacasse et al[5]).

Knowing the conditions prior to retrofit

Building inspections prior to retrofit are increasingly required (see PAS 2035:2019[6]) with the aim of improving the quality of energy efficient retrofit. An assessment of the condition of a cavity wall prior to retrofit would allow building professionals to decide whether the wall is ready to be insulated and/or waterproofed and what repairs are needed prior to insulation and/or waterproofing.

Some additional data could be collected prior to retrofit, to be used as inputs for hygrothermal simulations. This would lead to a better understanding of the possible moisture risks arising from insulating and/or waterproofing the cavity wall. The water absorption of the wall surface is one parameter that can identify the need for waterproofing. However, the in-situ measurements of the water absorption coefficient available to inform hygrothermal simulations are few and most of them unreliable.

1.5 Summary

In the untreated case, it was possible, knowing some basic properties of the brick, to perform hygrothermal simulations that were fairly representative of the behaviour of the laboratory wall assemblies. However, when bench testing samples were treated with waterproofing products, the measured absorptivity of materials was not representative of the behaviour of the laboratory wall assemblies.

The water absorption coefficients measured respectively for bricks, mortar and the combination of brick and mortar, reveal a value that is too low: the simulations suggest there should be little to no water uptake, but the laboratory results show some uptake. This suggests that the moisture behaviour is not governed by the material properties themselves in these cases, but by the properties at the interface between building materials and the hairline cracks formed within the actual walls.

The model was unable to replicate the tests in the climate chamber satisfactorily. The results suggest that the hygrothermal behaviour of the cavity wall might be influenced by moisture transfer mechanisms other than the ones considered in the hygrothermal simulations, i.e. the mechanisms related to As-Built, In-Service (ABIS) conditions. As a result, the bench testing of hygric properties (e.g. water absorption) of material samples (or combined materials), would not be sufficient for the description of the behaviour of walls treated with waterproofing agents.

‘Engineering approaches’ assuming a certain percentage of WDR will penetrate the wall might be an appropriate way for considering the influence of water infiltration and such techniques are increasingly used in the literature. However, there are no exact parameters for such techniques that can reliably simulate given ABIS conditions.

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