Appendix D: WP5 – Desktop analysis of Hygrothermal modelling

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Section content

1. WP5: Desktop analysis of hygrothermal modelling

1.1 Scope of WP5

The scope of this work package is to provide a literature review of the state of the art of hygrothermal modelling.

The standardised method for hygrothermal modelling is described, and the limitations of existing hygrothermal modelling of cavities are highlighted. In particular, limitations associated with material properties, indoor and outdoor moisture loads and As-Built, In Service (ABIS) conditions are presented. Also the role of hygrothermal modelling in supporting moisture risk analysis is presented.

1.1.1 Overview

In the energy-efficient retrofit of existing buildings, hygrothermal simulations (described in Section 1.2) can support the selection of insulation systems, considering the context of the building being retrofitted. Designers can use them in moisture risk analyses for comparing different constructions and evaluating the impact of interventions, considering the effects of the external climate and occupants' behaviour on the moisture balance of the building fabric. However, an essential limitation to the use of hygrothermal simulations for moisture risk analysis lies in the difficulty of choosing suitable inputs. The uncertainty on the selection of input data is one of the main obstacles to the use of hygrothermal simulations in practice. Section 1.3 presents the limitations associated with the inputs required for hygrothermal simulations, with a focus on insulated cavity walls.

Moisture risk analysis provides an estimate of the extent of moisture accumulation - and the associated adverse consequences - within the building fabric. Several methods for moisture risk analysis were found in the literature; however, a worst-case scenario is suggested by the standard on hygrothermal modelling, BS EN 15026:2007 "Hygrothermal performance of building components and building elements — Assessment of moisture transfer by numerical simulation" [1]. Comparative studies considering both average and worst-case scenarios are the most common methods in research. In this way, probabilistic risk assessment has been recently investigated for complex problems. Section 1.4 presents a review of moisture risk analyses performed with hygrothermal simulations.

Finally, moisture risks in insulated cavity walls are associated largely with As Built-In Service (ABIS) conditions. In a study of insulated cavity walls in Wales, moisture issues were found in buildings where there was evidence of poor practice installation and inappropriate maintenance following the installation [2].

As hygrothermal simulations for moisture risk analysis should consider the phenomena leading to moisture ingress and accumulation in cavity walls, methods for including ABIS conditions in the simulations are sought, as presented in Section 1.5.

1.2 Hygrothermal simulations

Hygrothermal simulations consider the interaction of multiple moisture transfer mechanisms, which can occur simultaneously. The standard BS EN 15026:2007 [1] defines the practical application of hygrothermal simulation software and the phenomena that should be considered to comply with the standard, which are:

- Drying of construction moisture
- Moisture accumulation by interstitial condensation, due to vapour diffusion (occurring in wetting season[a])
- Condensation due to solar-driven vapour diffusion (occurring in drying season)
- Rainwater penetration, due to exposure to rainfall and wind driven rain

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a The wetting season roughly considers autumn and winter; the drying season considers spring and summer.

- External surface condensation, due to long-wave radiation exchange with the clear sky (in the evening)
- Moisture-related heat loss by transmission (moisture-dependent thermal conductivity) and evaporation (latent heat)

Hygrothermal simulation tools also consider the effect that heat transfer has on moisture transfer, and vice versa. For example, they consider the heat from solar radiation that is absorbed by the surface and its effect on increasing the material temperature and the evaporation of the water occurring in the material (solar-driven vapour diffusion).

Some of these mechanisms are likely to influence the performance of insulated cavity walls; others can be neglected. For example, interstitial condensation is not likely to affect insulated cavity walls, as (i) the vapour diffusion resistance of the inner leaf reduces the extent of diffusion and (ii) the surface where condensation is likely to occur is located on the outer leaf, which should withstand several moisture loads such as rainwater.

1.2.1 Standardised hygrothermal simulations

Hygrothermal simulations use building physics to simulate the combined heat and moisture transfer of a system subject to defined moisture loads, to estimate moisture levels within a building component.

Hygrothermal simulations are standardised, according to BS EN 15026:2007[1]. The standard describes the moisture transfer mechanisms and the necessary parameters to be considered in hygrothermal simulations. The mechanisms considered are:

- Liquid transfer
- Vapour diffusion
- Moisture storage
- Latent heat transfer by vapour diffusion
- Heat storage (in building materials and water)
- Heat conduction (moisture-dependent)

The standard also provides a benchmark example for validating hygrothermal simulation tools. The standard only deals with one-dimensional tools. However, some simulation tools also have 2D capability.

The most common simulation tools that are compliant with BS EN 15026 are WUFI®[3] and Delphin[4], developed by Fraunhofer IBP and TU Dresden, respectively. Although both compliant with the standard, these tools deal with liquid transfer considering different mechanisms. Delphin considers a liquid transfer equation based on capillary pressure, which is the actual driving force for liquid transfer, whereas WUFI® considers a simplified equation based on moisture content as the driving force[5].

1.2.2 Hygrothermal simulations for moisture risk assessment

In moisture risk assessment, the possible risks are identified (risk identification), the extent of the adverse consequences related to these risks is estimated (risk analysis), and the estimated levels of risk are compared with suitable risk acceptance criteria (risk evaluation).

Hygrothermal simulations help to support risk analysis, by allowing the estimation of moisture levels in the building fabric, when subject to defined moisture loads. Post-processing of hygrothermal simulation results can indicate the occurrence of adverse consequences associated with moisture accumulation within the building fabric, such as mould growth and corrosion. However, it is important to bear in mind that simulation tools are inherently deterministic, as the outcome of each simulation depends uniquely on the inputs and initial conditions provided. Hence, the outcome of the analysis is mostly affected by the validity of relevant inputs, such as material properties and climate data, as described in the next section.

1.3 Input data for hygrothermal simulations: required data and limitations

1.3.1 Inputs required for hygrothermal simulations

Material properties and moisture loads are required for the hygrothermal simulation of the heat and moisture transfer mechanisms described above.

- Material properties describe the resistance of a material to liquid transfer, vapour diffusion and heat conduction but also the ability to store heat and moisture;
- Indoor moisture loads represent the water vapour levels in the indoor environment (for vapour diffusion) and the indoor ambient temperature (for heat transfer);
- Outdoor moisture loads describe (a) outdoor air properties, (b) the extent of wind-driven rain and (c) the extent of radiation exchange from the sun and to the sky. For this purpose, three types of climate parameters are identified, as shown in Table 1.

Table 1 Complete set of climate parameters for hygrothermal simulations [1]. Parameters are used to describe (a) outdoor air properties, (b) the extent of wind-driven rain and (c) the extent of radiation exchange from the Sun and to the sky.

Climate parameter	
(a)	Dry bulb temperature
	Relative humidity (or other parameters describing humidity)
	Total atmospheric pressure
(b)	Wind speed
	Wind direction
	Rainfall intensity (through a horizontal plane)
(c)	Global horizontal irradiance
	Diffuse horizontal irradiance
	Sky temperature

Several are the sources of input data that can be used for hygrothermal simulations, from databases to measured data. Often, it is possible to combine data sources.

1.3.2 Material properties

Hygrothermal simulations require several material properties to describe the hygrothermal behaviour of the building materials. Cavity wall construction has been the most prominent construction method in the UK since 1919. The composition of bricks has changed considerably in this period, leading to the high variability of their hygrothermal properties.

To run hygrothermal simulations, proprietary databases of hygrothermal simulation software contain information on the necessary material properties of the most common building materials. The majority of entries in the database are associated to modern building materials. Although there is research around the properties of materials found in existing buildings, there is a minimal amount of measured data that can be used for hygrothermal simulations of existing buildings. Worldwide, some efforts have been made recently in the heritage field, such as measuring properties for lime plaster [3,4] and historic bricks [5]. However, there is no clear picture of the clay bricks and stones used in UK construction.

Moreover, hygric properties of building materials can show significant variability, given by the different geometry of the pore system, which for example, affects the vapour diffusion resistance of the material. Roels et al. (2002)[6] found a wide range of vapour diffusion resistance factors in modern handmade bricks coming from the same batch, as shown in Figure 1. This indicates that the variability of some material properties remains high, even for modern bricks, which are fired at controlled temperatures. Using an average value for properties such as the vapour diffusion resistance has an effect on the simulations, as risk can be underestimated.

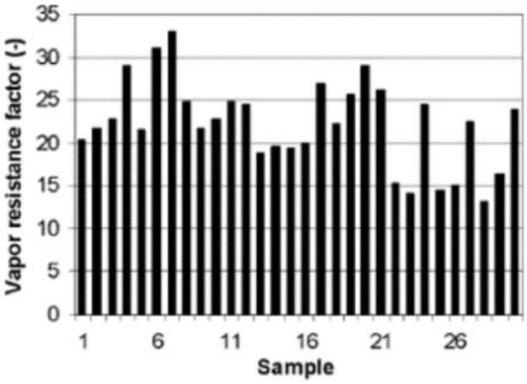

Figure 1 Water vapour diffusion resistance coefficient for 30 handmade bricks from the same batch (from Roels et al. 2002)

Therefore, even within the same building, there might be considerable differences in the hygrothermal properties of bricks and mortar. As it is impossible to measure hygrothermal properties for each brick, statistical techniques can contribute to a meaningful description of material properties. For example, clustering methods have been used to describe hygrothermal properties of similar bricks[7]. Identifying the clusters of existing bricks in the UK existing buildings stock would allow a more informed moisture risk assessment.

Moreover, the influence of waterproofing treatments on hygrothermal properties is rarely available. So far, the influence of waterproofing is considered in hygrothermal simulations by (i) reducing the fraction of rain that is available for absorption[8–10], or by (ii) reducing the water absorption coefficient and at the same time slightly increasing the vapour diffusion resistance factor[11], based on standardised laboratory measurements for building materials[12,13]. Laboratory measurement procedures specific for waterproofing treatments have not been developed yet. However, the effectiveness of waterproofing treatments depends on several characteristics of the substrate that are not considered during laboratory measurements. For example, there is evidence on the negative influence of contaminants adsorbed in bricks due to air pollution, on the effectiveness of some waterproofing treatments[14].

The effectiveness of waterproofing treatments might also be influenced by the moisture content of building materials during its application, the workmanship, or the conditions of the wall. It is known that these products have a limited lifetime, but the change in overall hygrothermal performance over time has not been studied. Moreover, the hygrothermal performance associated with these products has usually been evaluated for bricks. However, the mortar used in walls could play an essential role on the effectiveness of waterproofing treatments, especially in the case of micro-cracks due to differential movements of the brick and mortar in case of structural movements. Finally, there are unintended consequences associated with waterproofing treatments, such as the additional runoff from the wall, which can lead to higher rainwater penetration through defects.

1.3.3 Outdoor moisture loads

The outdoor moisture loads considerably affect the hygrothermal performance of an insulated cavity wall. In particular, the main failure mechanisms for cavity walls, highlighted in WP2, are all associated with rainwater penetration through the building fabric.

The climate parameters describing the outdoor moisture loads are several and interconnected. The climate parameters affect the wall in different ways, being the cause for both moisture accumulation and drying.

Climate parameters are collected in climate files that can be used for the analysis. Reference years can be used for the analysis, and are constructed to represent weather conditions found at a location over a long period. Reference years can represent typical weather conditions and are called *typical years*, or represent worst-case conditions occurring every few years (*near-extreme years*).

Typical years are designed to estimate the average building energy use, without considering their influence on the hygrothermal performance of building components. Some near-extreme years, on the other hand, were developed with a clear focus on moisture risk. For these years, the frequency of worst-case conditions can be decided depending on how severe the risk is. If the risk has a high impact (e.g. structural collapse), the worst-case conditions should occur very rarely; for less severe risk, the worst-case conditions are allowed to occur more often. Usually, for moisture risk assessment, the worst-case condition should not occur more than once in ten years.

Unsurprisingly, it was found that the typical reference years (e.g. Test Reference Years and Typical Meteorological Years) can be unrepresentative of long-term weather conditions from a moisture perspective. On the other hand, near-extreme years, such as considering 90th percentile of rainfall[1], can be more representative of the worst-case conditions found at a location over a long period of time[15].

Building near-extreme years requires long-term observations of several climate parameters (see Table 1) from weather stations and knowledge on the mechanisms leading to worst-case conditions. Long-term hourly weather data have been measured and collected by the Met Office, but they are not freely available. Also, most weather stations lack climate parameters associated with radiation, requiring the integration of weather data from different sources.

As this information is not available yet, typical years for energy use are used in practice for hygrothermal simulations, often leading to an underestimation of the moisture risk. Moreover, there is widespread use of synthetic climate files for the generation of typical reference years. However, there are limitations to their reliability[16], and comparisons with observed data are needed to evaluate the representativeness of synthetic climate files.

Generation of weather files is not only an issue for the construction of reference years. The influence of climate change on the hygrothermal performance of cavity walls could be significant, and the generation of future climates, considering the change in rainfall, could be useful for the assessment of long-term hygrothermal performance of walls[17].

Finally, the interactions between the weather and the wall present a spatial heterogeneity. At the building level, shading[18] and the dynamics of wind[19] affect radiation exchange and wind-driven rain respectively. At an urban level, factors such as topography and terrain roughness have an influence on the local climate. For this reason, areas in wind-driven rain exposure zone 4 might be in a sheltered local environment. Semi-empirical models such as BS 8104[20] or BS EN ISO 15927[21] are a practical solution for assessing the exposure of a building, although they underestimate extreme wind-driven rain events[22].

1.4 Moisture risk analysis methods

Risk analysis methods help evaluate the change in moisture balance leading to failure. To ensure that the risk is assessed for the majority of cases, the hygrothermal simulations for risk analysis must consider a worst-case scenario approach, the use of parametric studies or a probabilistic approach.

1.4.1 Worst-case scenario

The majority of moisture risk analyses use scenario analysis, where sets of scenarios (e.g. average, worst-case) are used to analyse potential adverse consequences. In the standard for hygrothermal simulations [1], a worst-case scenario analysis is the suggested approach. Here, input variables are selected to represent the worst-case scenario and then used within the deterministic hygrothermal simulations. The type of input files for indoor and outdoor moisture loads suggested by the standard are as follows:

Internal boundary conditions: Internal boundary conditions shall be appropriate to the most severe likely use of the building, as buildings can be subject to significant changes in occupancy. The suggested options for internal conditions are (i) measured values for similar buildings in a similar climate; (ii) results from building simulations, considering indoor environmental conditions (e.g. temperature and relative humidity); (iii) calculation of internal conditions based on specifications of moisture production and ventilation rates. For guidance on the calculation of internal humidity, the standard refers to BS EN ISO 13788 [23], where two methods are described. The first method, for maritime climates, is based on five humidity classes representing the use of the building (e.g. office, dwelling with unknown occupancy). Here it is suggested to use the upper limit of each category unless it is demonstrated that the conditions are less severe [23]. The second method, for continental climates, is based on occupancy levels (i.e. normal and high occupancy); levels are selected according to the expected occupancy of the building.

For indoor moisture loads, the WTA 6-2 guideline [24] suggests adding a safety margin of 5% to the indoor relative humidity considering normal occupancy level.

External boundary conditions: the standard suggests (i) to assess the moisture risk for ten years, or (ii) to construct a reference year that considers the most severe conditions likely to occur once every ten years. Also, the standard states that "*in the absence of Reference Years, more severe conditions may be simulated by applying an annual temperature shift of ± 2 K to a mean of the whole data set, keeping the relative humidity unchanged, depending whether summer or winter condensation is likely to be the problem*" [1]. However, this is not relevant for the analysis of risks associated with wind-driven rain. For the specific assessment of moisture problems related to rainwater penetration, the standard suggests using the year with the 90th percentile of rainfall.

Another method of constructing near-extreme reference years is a method developed by Cornick et al.[25] for the assessment of moisture risk caused by rainwater penetration through porous materials, and based on a Moisture Index (MI). The moisture index is the ratio of a wetting index and a drying index. Wetting is represented by an annual or directional Driving-Rain Index (DRI), which is simply the product of average wind speed and the total rainfall of the year, sorted according to wind direction (when the DRI is directional). The drying index is the difference between the humidity ratios at saturation and the one of ambient air and is a measure of the ability of air to take up water vapour from the saturated surface of the assessed building component. Ranking the years according to the moisture index allows the identification of the year with the lowest, mean and highest moisture index. Other methods for the selection of near-extreme reference years are based on the hygrothermal response of a specific building component[26,27]. The disadvantage of these reference years lies in the fact that they cannot be used without considering the construction type, and are developed on a case-by-case basis.

1.4.1.1 Comparative and parametric studies based on scenario analysis

Most of the hygrothermal simulations of walls used for scenario analysis consider an average or a worst-case scenario and combine it with parametric analysis. In one of the first examples of simulation-based moisture risk analysis, the effect of internal wall insulation on the hygrothermal behaviour of exposed walls was analysed by Künzel [28] with one-dimensional boundary conditions and three insulation systems were compared. Other authors compared various insulation systems in a parametric study, considering an average scenario for boundary conditions [29,30] or combining this with some worst-case scenario parameters, e.g. occupancy levels [31]. Sometimes, the severity of the scenario is itself a parameter of the study [8,32–34].

Worst-case conditions have been considered in different ways. Often, the worst-case orientation (i.e. the orientation with the highest wind-driven rain load) is selected to evaluate the risk related to rainwater penetration [32,35–37].

To consider rainwater infiltration behind the layer providing rainwater protection, an additional 1% of wind-driven rain was introduced behind the rainwater protection layer, for the assessment of risk related to rainwater leakage in case of internal wall insulation [32,37,38] and external wall insulation[39]. This was one of the first approaches for the inclusion of As Built, In Service (ABIS) conditions in moisture risk analysis.

A comparative study was performed for the assessment of cavity wall insulation under ABIS conditions [40], where material properties were adjusted to reflect the results of laboratory studies and simulate the worst-case scenario. In particular, liquid transfer was allowed through the insulation material, and a point moisture source was added to the structure to represent rainwater penetration. The comparative analysis considered insulated and un-uninsulated cavities, five thicknesses for the cavity, four materials for the internal leaf, four types of external leaf, four external finishes and two levels of exposure to wind-driven rain. The inclusion of representative ABIS conditions will be further discussed in Section 1.5.

The benefits of the deterministic approach are its simplicity and relatively low computational effort, which usually are desired characteristics for decision-making.

1.4.2 Probabilistic moisture risk analysis

The probabilistic approach has been used for the analysis of the risks associated with internal wall insulation [41–43] and cavity wall insulation [44]. This approach, which is based on Monte Carlo simulations, considers the influence of the uncertainty and variability of various inputs on the moisture risk. In risk assessment, the outputs obtained from the Monte Carlo analysis can be compared against suitable failure criteria.

The probabilistic moisture risk analysis has been included in decision-making tools such as the risk management framework developed within the IEA Annex 55 on "Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance and Cost" [45] and the probabilistic approach to moisture risk assessment included in a conceptual reliability model for mould safety in buildings [46]. The use of a Monte Carlo-based probabilistic risk assessment has proven to be beneficial in assessing moisture risk considering the uncertainty and variability of inputs. However, one of its disadvantages is the time required for the risk assessment.

1.5 Considering the phenomena leading to moisture ingress and accumulation in cavity walls

The majority of the phenomena leading to moisture ingress and accumulation in cavity walls is associated with As Built, In Service (ABIS) conditions, as highlighted in WP2 and summarized in Table 2 (taken from WP2). As failure in cavity walls is associated with ABIS conditions, hygrothermal simulations should include known ABIS conditions in the analysis. However, in hygrothermal simulations, ABIS conditions are not commonly considered apart from the examples identified in section 1.4.1.1.

Table 2: Observed ABIS conditions in house surveys (2015, from WP2)

Primary ABIS	Failure mechanism (primary)	Secondary ABIS	Size of crack	Number of Occurrences
Damaged brick face	Water bypasses brickwork	No cavity closer	2-3 mm	71
		Saturation of mortar behind cement	1-2 mm	52
Saturation > 25% (common brick)	Water penetrates through brick	Weak render – high sand content	1.5-2 mm	67
Wall tie failure	Water penetrates gaps in mortar	Horizontal cracking	1-2 mm	52
Rubble in base of cavity	Water unable to escape cavity	Lack of overhang to sill	N/A	42
		Mastic failure around windows	1-2 mm	27
		Cold bridging	N/A	7
		Leaking gutters and downpipes	N/A	3
Pointing failure	Water penetrates gaps in mortar	Leaking gutters and downpipes	0.5-1 mm	21
Subsidence	Water penetrates gaps in mortar	N/A	7-10 mm	14
Saturation of mortar behind new pointing	Water penetrates through mortar	Mastic failure around windows	N/A	13
No cavity closer around windows	Water bypasses brickwork	Mastic failure around windows	1-2 mm	13
Cement pointing over lime: moisture trapped	Water penetrates through mortar	Mastic failure around windows	1-3 mm	8
Total occurrences				**390**

ABIS conditions are often included in moisture risk analyses through an “engineering” approach, considering a worst-case scenario. According to the ASHRAE standard 160 [47], adding 1% of the incident wind-driven rain load (by weight) could represent a best estimate for the rainwater infiltration behind the external cladding; this was developed for timber-frame buildings with brick as an outer leaf, but it is now applied to all construction types. However, it is not known if this value is conservative or if it is an underestimate. Therefore, further research was carried out to estimate the amount of rainwater infiltration through other types of wall assemblies, by means of laboratory experiments[48]. The amount of rainwater infiltration depends on several factors, including the construction type, the type of defect, the rain load, the air pressure difference and the pressure (and amount) of the run-off film[49].

An overview of the water tightness of masonry walls showed a wide range of measured rainwater infiltration in laboratory experiments through the outer brick leaf (between 0% and 20%), and a narrower range of rainwater infiltration in case of field test (between 0% and 3.4%)[50]. However, if low pressure differences were considered, the measured infiltration range in literature was between 0.0065% and 5.97%. Therefore, the use of 1% wind-driven rain as a simplified approach was considered reasonable for walls with an outer brick leaf. However, the sensitivity of the results to rainwater infiltration should be verified, considering infiltration rates between 0% and 10%.

Moreover, there is evidence of rainwater infiltration at the window-wall junctions of different wall constructions (>100 walls): rainwater infiltration was found in the majority of the junctions[51]. Moreover, other tests consider 29 window-wall interfaces and found that well performed and sealed joints around the windows in façades are usually not watertight, and point moisture sources should be considered in risk assessments[52]. The point moisture sources were estimated of the magnitude of 0,01-0,05 l/min, “in small invisible deficiencies”. This amount corresponds approximately to up to 2% of the wind-driven rain [53].

Finally, there is evidence that water can transfer through some seemingly waterproof insulation, in case of workmanship defects in narrow cavities[54]. In this work, the performance of four non-insulated test samples, with different types of workmanship defects was compared to investigate the influence of workmanship on water tightness. Infiltration rates were found for each sample, as a function of the wetting regime and pressure difference. Subsequently, the non-insulated samples were compared to four insulated test samples considering two insulation materials, showing that samples insulated with PUR-foam almost eliminated water ingress, whereas liquid water transfer through insulation was found in samples with EPS beads.

1.6 Summary

Hygrothermal simulations can be used in moisture risk analysis to consider the effects of the external climate and occupant behaviour on the moisture balance of the building fabric. It is desirable to be able to rely on such modelling to assess the impact of energy efficiency retrofit interventions on existing constructions to avoid the potential for moisture accumulation and subsequent adverse consequences. However, as with all simulations, the outcome of each simulation largely depends on the representativeness of the input data used in the models.

Several methods for moisture risk analysis were identified and reviewed. Methods often consider average and worst-case scenarios. The accepted standard relating to hygrothermal simulations is BS EN 15026:2007. This relates to tools that consider one-dimensional moisture movements, with the most common being WUFI, developed by the Fraunhofer Institute, and Delphin, developed by the Dresden University of Technology. Simulations use building physics to model the combined heat and moisture transfer of a system subject to defined moisture loads, to estimate moisture levels within a building component. The standard describes the moisture transfer mechanisms and the necessary parameters to be considered in hygrothermal simulations.

Key inputs required include material properties along with indoor and outdoor moisture loads. There are currently limitations associated with each type of input parameter:

- There is little measured data relating to typical UK construction materials available for use in hygrothermal simulations. In particular, as was explored in the detailed wall analysis (Appendix A), the properties of bricks used in UK construction over time have varied considerably due to local availability of materials, enhancements in manufacturing techniques and quality control, which can vary their relative hygric properties. Research studies have identified that the porosity and thus water absorption of bricks are related to their strength and density, which is linked to the mineralogical composition of the brick and its firing temperature. Using average values can, therefore, lead to risks being over or underestimated in simulations.

- The influence of waterproofing treatments on hygrothermal properties is rarely available. In the literature, it has been considered in hygrothermal simulations by reducing the fraction of rain available for absorption or reducing the absorption coefficient while increasing the vapour diffusion resistance factor of building materials. Also, the effectiveness of waterproofing treatments depends on several characteristics of the substrate that are not considered during laboratory measurements, such as the potential influence of contaminants absorbed into bricks due to air pollution, and the moisture content of the substrate during the application of the treatments, amongst other potential ABIS conditions. It is also acknowledged in the manufacturer's literature that these products have a limited effective lifetime, but the change in overall hygrothermal performance over time has not been reported.

- Climate parameters used for analysis are typically for 'reference years' intended to represent weather conditions found at a location over a long period (either typical or worst-case scenarios) for the purposes of energy assessment. Not all-weather stations collect all potential parameters needed for hygrothermal simulation, requiring the integration of data from different sources. The conditions measured at the closest station to the site of interest can substantially differ from the microclimate conditions to which the building of interest is subjected to. This can again lead to an over or underestimation of moisture risk, and that is before the potential impacts of future climate change are considered.

- Buildings can be subject to significant changes in occupancy and use. Internal boundary conditions are therefore typically selected for the most severe likely use.

Evidence shows that moisture risks in insulated cavity walls are largely associated with ABIS conditions. It, therefore, follows that hygrothermal simulations for moisture risk analysis should consider these conditions. This is often done via an 'engineering' approach. According to the ASHRAE standard 160, 'Criteria for Moisture-Control Design Analysis in Buildings', adding 1% of the incident WDR load (by weight) could represent a 'best estimate' scenario for rainwater infiltration. Review of the available literature suggests this is a reasonable approach for walls with an outer brick leaf. Still, the sensitivity of the walls to rainwater infiltration should be verified considering rates between 0-10%.

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