

GBEC1319 – The Old Stables, Tottenham House Marlborough

| Hygrothermal Risk Assessment Report

RIBA Stage 5
May 2026

Audit Sheet

Rev	Date	Description	Author	Reviewed
	5/05/2026	Hygrothermal Risk Assessment	TC	MV
1	12/05/2026	Hygrothermal Risk Assessment	TC	MV
2	15/05/2026	Hygrothermal Risk Assessment	TC	MV
3	20/05/2026	Hygrothermal Risk Assessment	TC	MV
4	21/05/2026	Hygrothermal Risk Assessment	TC	MV

Contents

Audit Sheet 1

Contents 2

1. Executive Summary 3

1.1 Project Overview 3

1.2 Objectives and Purpose of this Report 3

1.3 Summary and Recommendations 3

2. Introduction 4

2.1 Background 4

3. Materials Testing 5

3.1 Method 5

3.2 Results 5

3.3 Representative Materials 6

4. Hygrothermal Risk Assessment 7

4.1 Model Setup 7

4.2 Preliminary Assessment 9

4.3 Main Assessment 10

5 Conclusions and Recommendations 12

5.1 Conclusions 12

5.2 Recommendations 12

References 13

Appendix A Sample Collection Record 14

1. Executive Summary

1.1 Project Overview

Tottenham House is a Grade I listed Palladian country house in the parish of Great Bedwyn, Wiltshire, on the southern edge of Savernake Forest. The Old Stables, which form the subject of this assessment, are a Grade II* listed structure designed by Thomas Cundy and constructed in 1818–19. The external walls comprise ashlar stone to the outer face over a solid brick inner leaf, approximately 500–600 mm in combined thickness.

As part of a wider estate refurbishment, the ground floor construction of the Old Stables has been lifted in its entirety. Historic England require the original York stone and cobble floor finish to be reinstated; the client additionally requires a modern stone finish appropriate to the intended use as high-quality accommodation. These constraints produce the relatively complex floor stratigraphy that is the subject of this assessment, in which the re-laid historic finish is incorporated within a new build-up comprising a layer of Glapor foamed glass aggregate sub-base, separating membrane, Screed Replacement Tile system, and a further stone finish layer above. A 50 mm perimeter void has been proposed at the slab edge to provide a vapour-permeable interface between the floor build-up and the base of the external walls.

Historic England have required the design team to demonstrate, by means of building-specific calculations, that the proposed floor construction will not result in harm to the historic fabric, and specifically that the perimeter gap at the slab edge functions as an effective vapour pathway. Greengauge were appointed by Corrigan Gore to address this requirement through two-dimensional dynamic hygrothermal simulation of the ground floor-to-wall junction, which was undertaken using Delphin 6.1.7.

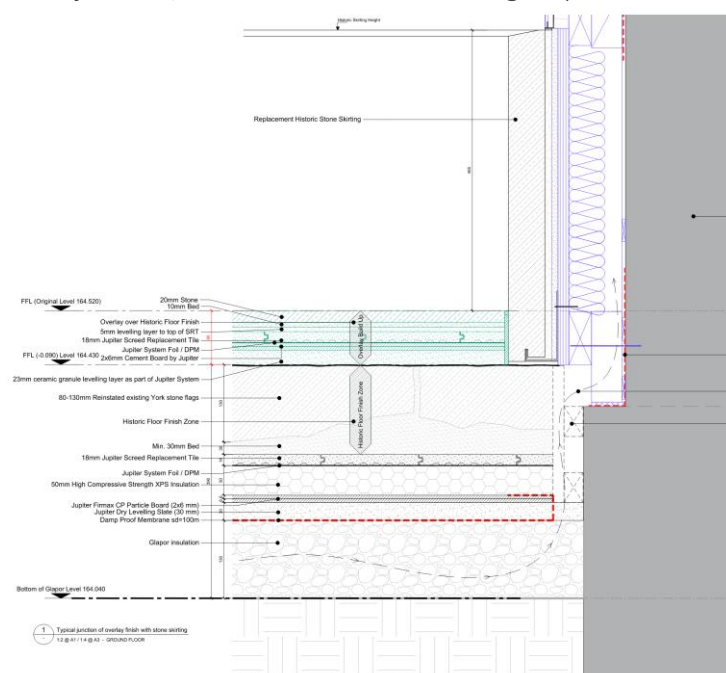


Figure 1. Proposed floor buildup in relation to existing wall

1.2 Objectives and Purpose of this Report

The most significant mechanism for harm to the historic fabric potentially exacerbated by the floor design is thought to be damage to, and loss of material from, the historic stone façade as a result of freeze-thaw action. This report has therefore focussed on this risk.

The key objectives of this assessment were to:

- Assess the risk of freeze-thaw damage to the external ashlar and masonry under the proposed floor construction.
- Determine the key moisture transport properties of the existing masonry materials through laboratory testing of samples retrieved from the building;
- Assess whether the proposed floor construction is likely to increase the moisture content of the base of the external walls relative to the pre-intervention condition;
- Assess the role of the perimeter strip at the slab edge in providing a vapour pathway between the sub-floor ground and the wall void;

1.3 Summary and Recommendations

This risk assessment evaluated the moisture risk associated with replacing the historic floor with a system incorporating new insulation under reinstated York stone flags, and contemporary stone finish. The proposed construction was modelled in Delphin 6.1.7, a dynamic hygrothermal simulation software validated against BS EN 15026:2007.



Figure 2. Stables Entrance circa 2016 (Marlborough.news).

As part of the risk assessment, samples of the existing brick and stone were characterised to inform the selection of representative material properties for the simulations. A preliminary sensitivity study (2D simulation of the wall in plan) investigated the influence of material properties from which worst-case materials were carried forwards. Three full two-dimensional simulations were run: one representing the historic floor condition, one representing the proposed build-up as designed, and one representing the proposed build-up without the perimeter strip, to assess its contribution.

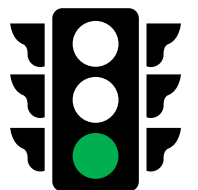
The risk assessment was based on conservative assumptions throughout, including adoption of the lowest critical degree of saturation reported in the literature for limestone (58%, from Prick (1997)).

The primary conclusion is that the proposed floor construction does not increase the risk of freeze-thaw damage to the historic masonry facade.

While the proposed floor increases moisture flux into the base of the wall by approximately 25% relative to the historic floor, this increase is from a low baseline and the absolute moisture levels remain low. No critical freeze-thaw cycles were recorded in any simulation. The presence or absence of the perimeter void/strip makes a negligible difference to this outcome. These findings address Historic England's requirement to demonstrate that the proposed works will not result in harm to the historic fabric.

Key Findings

- The proposed floor does increase the uptake of moisture from the ground into the existing masonry wall, but this increase is from a low baseline, and small in absolute terms.
- Despite the slightly increased moisture levels, the surface of the wall is not subjected to any critical freeze-thaw cycles, i.e. frost events where the moisture content is above a threshold of 58% (a value found in the academic literature)



2. Introduction

2.1 Background

British and International Standards

Hygrothermal risk in buildings is a complex topic that requires careful assessment by an experienced assessor. Guidance for this is given in a number of documents and standards, with the most notable being:

- BS EN ISO 15026:2007 Hygrothermal performance of building components and building elements – Assessment of Moisture Transfer by Numerical Simulation
- BS EN ISO 13788:2012 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods
- BS 5250:2021 Management of Moisture in Buildings

Delphin

The software used for the hygrothermal risk assessments here is called Delphin 6.1.7, a two-dimensional hygrothermal simulation tool based on principles outlined in BS 15026:2007.

Key Risk Factors

For this exercise, the risk assessment has focussed on the deterioration of the historic stone façade via the mechanism of freeze-thaw induced spalling.

Moisture Accumulation

Moisture accumulation in and of itself is not necessarily a problem, depending on the location, timing and amount. Most porous materials can safely hold some amount of water within their pore structure with no adverse effects. Moisture is therefore often considered to be an agent of deterioration, rather than problematic in and of itself. Hygrothermal simulations output temperature and humidity (or moisture content) and the results must therefore be interpreted, often with the help of secondary tools and calculations, to arrive at a judgement in terms of moisture risk.

Frost Damage / Spalling

Porous materials can be damaged when subjected to freezing and thawing conditions due to the accumulation of ice within their pore structure. When water within a pore freezes, it expands by approximately 9% in volume; where pore geometry constrains this expansion, hydraulic pressure is generated in the surrounding material.

If the induced stress exceeds the tensile strength of the material, cracking and spalling can result. Repeated freeze-thaw cycling may cause progressive, cumulative damage through successive crack propagation, even where individual cycles are insufficient to cause immediate failure. This is analogous to, but mechanistically distinct from, fatigue in metals: rather than sub-critical cyclic loading acting on a crystalline microstructure, the damage mechanism here is the incremental extension of pre-existing microcracks under thermally-driven hydraulic pressure. Frost damage risk is a complex function of several interacting parameters, each carrying significant uncertainty:

- *Degree of pore saturation.* Ice formation becomes damaging above a critical degree of saturation, below which sufficient unfilled pore volume exists to accommodate expanding ice without generating destructive pressures. Values reported in the literature vary considerably. Prick (1997) tested ten limestone types and found critical saturation (Cs) values ranging from 58% to over 95%, with eight of the ten samples exhibiting Cs above 80%. For the purposes of this assessment, 58% has been adopted for all simulations, in order to ensure that the results are not contingent on a more generous assumption.
- *Freezing point.* The effective freezing point of pore water is depressed by dissolved salts and by pore diameter: water in very fine pores can freeze at temperatures substantially below 0°C. Historic masonry frequently contains soluble salts, and the actual freezing point of pore water in the subject materials is unknown. This assessment assumes freezing occurs at 0°C, which may overestimate the number of effective freeze-thaw cycles.
- *Material vulnerability.* Susceptibility to frost damage is determined by pore size distribution, tensile strength, and elastic modulus, none of which are directly measured as part of this assessment. These properties vary considerably between brick types, stone types, and mortar mixes, and the assessment cannot differentiate between materials of differing frost resistance.

The methodology counts the number of critical freeze-thaw cycles at the external surface over the simulation period: an instance in which the degree of saturation exceeds the critical threshold whilst material temperature simultaneously falls below 0°C. This is a relative, comparative metric rather than an absolute measure of damage. There is no established threshold above which damage is certain, nor can simulation determine whether a single critical cycle is sufficient to initiate cracking in a given material. The frost damage assessment should therefore be interpreted as an indicator of relative risk — specifically, whether the proposed works are likely to increase or decrease the vulnerability of the historic masonry to freeze-thaw damage compared to the pre-intervention condition — rather than as a prediction of whether damage will or will not occur.

Caveats and Context

All assessments were undertaken based on information received from the client. The calculations in this report have been completed using Delphin 6.1.7. It is important to understand that these 2D simulations are a simplification of the real-life processes occurring in the buildup, but when used correctly, can give useful guidance.

Although the majority of materials within the Delphin database have been tested and analysed by research bodies such as TUDresden, only a small percentage of these are UK building materials and as such most are not directly equivalent to materials used within the UK. The most closely matching materials within these databases have been selected to represent the actual proposed materials and generate meaningful results.

The climate file used has been generated externally and reflects weather data for the project location. Although it is accurate for present-day simulations, due to the nature of the fluctuating climate along with climate change, it cannot be used to accurately predict future climate.

Assumptions about the occupancy and occupant behaviour based on the provided information have been used to inform the simulation. It is possible that the actual in-use conditions differ from these assumptions.

Limitations

This report is for the exclusive use of the client and should not be used in whole or in part by any other third parties without the express permission of Greengauge in writing. This report should not be solely relied on by the client to inform decisions but should be used in conjunction with other documents such as architectural plans. Hygrothermal simulations are based on assumptions such as material properties, internal and external climates, construction quality, workmanship and usage, all of which contain uncertainties. Taking these uncertainties into account, our best efforts have been made to give accurate and informative results and analysis, and a reasonable assessment of the risks identified.

3. Materials Testing

3.1 Method

Background
Hygrothermal simulation requires a number of inputs; of these, an important subset is the material properties, of which several are necessary. A pragmatic approach is to measure a selection of parameters that can be undertaken relatively quickly and inexpensively, and use these to inform selection of materials from the database. The following parameters have therefore been measured:

- Desnsity – closely related to porosity, which is an important factor.
- Absorption coefficient, A_w – how quickly a material takes up water.
- Saturation water content, W_{sat} – the total amount of moisture a material can hold.

Test Method
The sample is suspended from an analytical balance positioned above a water bath of large surface area, as shown in Figure 3. The water level is slowly increased until it reaches the bottom face of the sample. The sample mass is recorded at regular intervals. Analysis specified in BS EN ISO 15148 is undertaken to calculate the absorption coefficient.

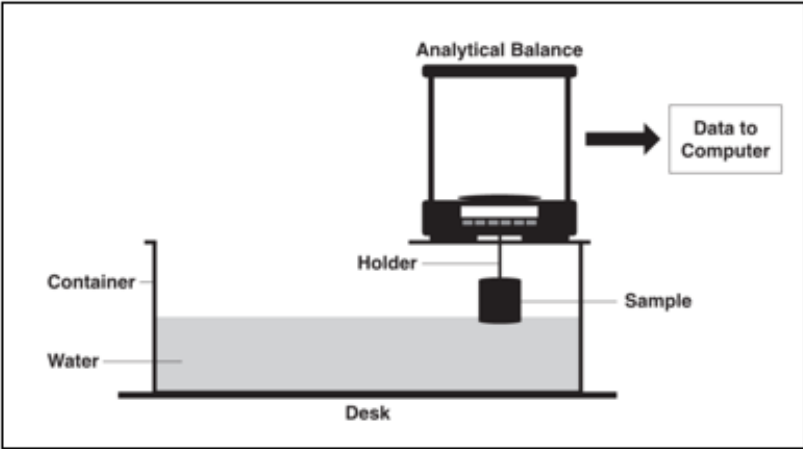


Figure 3. Diagram indicating the measurement apparatus setup

Sample Collection and Preparation
Brick and stone cores as well as loose samples were extracted by Greengauge during a site visit on 08/04/2026. To provide a good representation of the materials used across the building, a variety of masonry samples were collected, including:

- 6 Stone (50mm cores from standing masonry)
- 3 Brick (50mm cores from standing masonry)
- 3 whole, original bricks from a demolished section of wall
- 2 new Matthews Bricks
- 1 blue stable block
- 1 clay paving brick
- 1 piece of York flagstone

3.2 Results

Figure 5 presents the results of the absorption testing of the brick samples and Table 1 summarises the measured properties. The results show:

- There is variability in the colour and texture of the brick samples. This reflects the difficulty of core drilling on site and sawing of the whole bricks collected; some bricks were very hard to cut, with others being much easier. In order to reflect this variability, we have undertaken K-means clustering of the samples into two groups that will be used to select representative materials from the database (see below).
- There is also some variability in the properties of ashlar stone, which appears to be an Oolitic limestone, possibly a dense Cotswold limestone. The stones have similar density (within ~5% of the group average) but a larger variation in absorption and saturation water content.

Table 1. Material properties obtained for stone samples from The Old Stables

Test Sample #	Location	Int / Ext	Density (kg/m³)	Absorption Coefficient (kg/m²s¹/²)	Saturation Water Content (kg/m³)
1	GH2	Int	2130	0.040	120
2	GH1	Int	1970	0.10	220
3	GH1	Int	2050	0.090	190
4	Party Rm	Int	1740	0.13	230
5	G28 Corridor	Int	1950	0.070	170
6	Party Rm	Int	2100	0.060	130
Avg. of 1-6	All stone representative of facade		1990 ± 103 (5%)	0.082 ± 0.023 (29%)	177 ± 33 (19%)

Table 2. Material properties obtained for brick samples from The Old Stables

Test Sample #	Location/description	Int / Ext	Density (kg/m³)	Absorption Coefficient (kg/m²s¹/²)	Saturation Water Content (kg/m³)
7	GH2a	Int	1890	0.040	900
8	GH2b	Int	1440	0.032	290
9	GH1	Int	1620	0.19	240
10	Old Brick A	Loose	1796	0.26	280
11	Old Brick B	Loose	1749	0.32	430
12	Old Brick C	Loose	1909	0.030	340
Avg. of 1-6	All Brick		1932 ± 147 (8%)	0.084 ± 0.056 (67%)	170 ± 43 (25%)

Table 3. Material properties obtained for flooring masonry samples from The Old Stables

Test Sample #	Location	Int / Ext	Density (kg/m³)	Absorption Coefficient (kg/m²s¹/²)	Saturation Water Content (kg/m³)
7	Clay Paver	Loose	1761	0.18	350
8	Stable Block	Loose	2322	0.005	370
9	York Flagstone	Loose	1960	0.013	-

3. Materials Testing

3.3 Representative Materials

The results from the material testing were used to select the closest representative materials from the material database within the Delphin software. Table 3 outlines the database materials which were selected to represent the characterised samples, indicating the percentage difference between the database parameters and the average measured values (in Table 2).

All representative material selections overestimate the density of the actual bricks. This is not expected to have a significant impact on the assessment accuracy, and the selection was based on similarity with the measured moisture transport characteristics, saturation water content and absorption coefficient.

All representative material selections slightly overestimate the saturation water content of the actual bricks. This is expected to be a conservative assumption.

Table 4. Clustering summary of the 6 bricks into 2 groups

Sample ID	Density	Aw	Cs	Group
Old Brick A	1796	0.259	278	1
Old Brick B	1749	0.312	425	1
Old Brick C	1909	0.030	340	2
GH2	2130	0.040	120	2
GH1a	1970	0.100	220	2
GH1b	2050	0.090	190	2

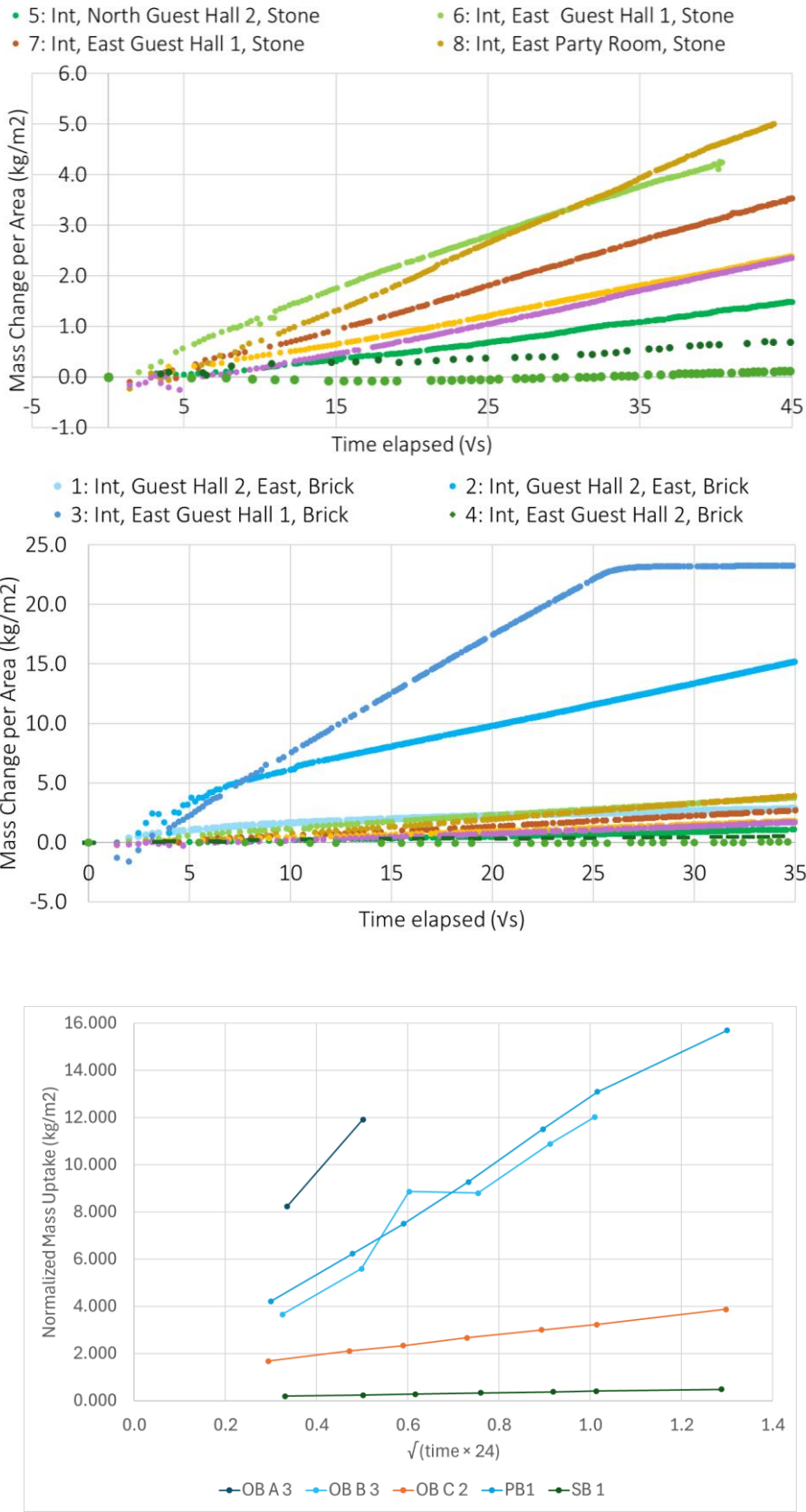
Table 5. Representative material properties for the 2 groups

Group	Count	Density	Aw	Cs
1	2	1772	0.286	352
2	4	2015	0.065	218

Six unique bricks are represented in the range of specimens, including three taken by core drilling and three by collection of loose bricks from a dismantled section of wall. Of the core samples, two were considerably harder than the third as observed during extraction. Of the loose bricks, two were relatively soft, while one was visibly over-burned and harder to cut. The harder specimens are consistently more dense, with lower absorption coefficients. There is less pronounced difference in the capillary saturation. This suggests the samples should be grouped; we used K-means clustering to confirm the grouping and find a representative average of the 2 groups. These average values were then used to select similar bricks from the material database.

Table 6. Representative entries from the database for use in simulation

Sample #	Material Label	Delphin Database Material	Density (kg/m³)	Absorption Coefficient (kg/m²s¹/²)	Saturation Water Content (kg/m³)	Reference Water Content (kg/m³)	Vapour Resistance Factor μ (-)	Thermal Conductivity λdry (W/m·K)
Limestone Facing	Sa	Sander Sandstone*	2032 (+2%)	0.064 (-22%)	193 (+10%)	27.1	25.9	1.41
	Sb	Cotta Sandstone	1940 (-3%)	0.07 (-14%)	230 (+30%)	8.5	19.0	2.4
	Sc	Reinhardsdorft Sandstone	1988 (+23%)	0.072 (+32%)	212 (+10%)	3.1	23	0.80
Brick group 1	B1a	Historical Brick Cluster 4	1710 (3%)	0.280 (2%)	319 (10%)	4.8	8.3	0.8
	B1b	Brick ZL	1677 (5%)	0.36 (25%)	343 (2%)	4.7	13.3	0.52
Brick Group 2	B2a	Reithalle Brick	1905 (5%)	0.057 (12%)	220 (1%)	3.8	38	0.73
	B2b	Sander Sandstone	2032 (1%)	0.064 (-2%)	193 (+11%)	27.1	25.9	1.41



4. Hygrothermal Risk Assessment

4.1 Model Setup

Software
The proposed wall buildup was modelled using Delphin 6.1.7, a dynamic hygrothermal simulation software following and validated against BS EN 15026:2023. Initially, simulations were run of the floor in 1D, and horizontal (in-plan) section of wall, in order to check numerical stability, understand the behaviour of each element in isolation and confirm materials to carry forwards to the more complex 2D simulation.

Wall Buildup and Materials
The existing wall is reported to vary between approximately 500 – 600mm. As thicker walls tend to result in lower moisture risk, a model based on a two-brick thick english bond (assuming imperial dimensions), plus 100mm facing stone was developed.

All models assume a SW facing wall, which is worst-case due to the exposure to rain driven by the prevailing wind.

Simulation methodology:

Preliminary Assessment — Methodology
Initially, the wall was simulated in isolation: the floor in one dimension, and the wall in two dimensions. Moisture flux through the floor construction is expected to be negligible due to the vapour control layers present within the build-up. The wall construction, by contrast, contains materials whose properties are likely to be significant to the results, and a 2D simulation was adopted from the outset to capture lateral moisture transport at the junction detail.
The preliminary assessment addressed the following questions:

- Which combinations of stone, brick, and mortar produce worst-case hygrothermal conditions at the external stone surface (in terms of freeze-thaw risk)
- Does the proposed floor design influence the risk of surface damage to the external masonry?

To address these questions, three simulation stages were undertaken:

Stage 1 — Uninsulated wall. The existing wall construction, without internal insulation, was modelled in 2D in plan using the closest matching brick selection and three candidate stone types. The overall moisture content of the wall and the number of critical freeze-thaw cycles at the external face were calculated for each stone type to identify the most appropriate selection to carry forward into the full 2D junction simulation. A single mortar type was assumed at this stage.

Stage 2 — Insulated wall. Using the stone type selected in Stage 1, the proposed insulated wall construction was simulated with four representative brick types to assess the sensitivity of freeze-thaw risk to brick material properties. This validates the material selection for use in the subsequent full 2D simulation.

Stage 3 — Floor influence on wall condition. The material selections and simulation parameters established in Stages 1 and 2 were used to inform a comparative assessment of the proposed floor design. Two floor configurations were simulated: the proposed build-up as designed, and an approximation of the previously existing condition comprising York stone flags laid in mortar directly on the ground. Wall moisture content was evaluated in both cases, and the critical freeze-thaw cycle count was used as an indicative metric for the relative risk of surface deterioration. The inherent limitations of this metric, as discussed above, apply equally here: the cycle count is interpreted as a comparative indicator rather than an absolute measure of damage risk.

Stage 4 — Influence of perimeter ventilation strip. To assess the benefit of the open void specified at the slab edge between the proposed floor build-up and the base of the external walls, a further simulation was run using the proposed floor configuration but with the perimeter strip omitted, replacing it with a fully infilled condition. This allowed direct comparison of the moisture flux through the base of the wall and the surface saturation of the facing stone, with and without the ventilation strip, under otherwise identical conditions.

Table 3. Key properties of materials selected from the Delphin database

Delphin Database Material		Density (kg/m³)	Absorption Coefficient (kg/m²·s ^{1/2})	Reference Water Content (kg/m³)	Saturation Water Content (kg/m³)	Vapour Resistance Factor μ (–)	Thermal Conductivity λ _{dry} (W/m·K)
	Historical Brick Cluster 4	1710	0.28	4.8	319	8.3	0.8
	Old Building Brick Dresden ZL	1677	0.36	4.7	344	13.3	0.521
	Old Brick Reithalle Potsdam	1906	0.06	3.8	220	37.8	0.73
	Sander Sandstone	2032	0.06	27.1	194	25.9	1.41
	Cotta Sandstone	1940	0.07	8.5	230	19	2.43
	Reinhardsdorft	1989	0.14	4.8	203	16.5	2.4
	Lime Cement Mortar (low cement ratio)	1739	0.49	39	258	28.3	1.05
	Mineral wool	67	0	0.1	900	1	0.035
	Wood wool cement board	180	0.01	25.8	340	4.9	0.06
	Lime Plaster (fine)	1520	0.07	57.9	380	51	0.8

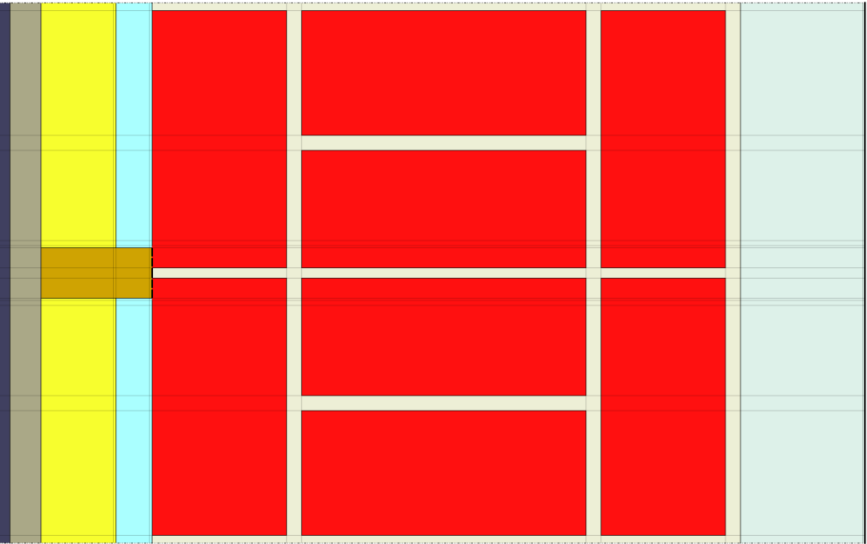


Figure 5. 2D plan model of insulated external walls

4. Hygrothermal Risk Assessment

4.1 Model Setup

Simulation design

The full 2D model was designed to capture the behaviour of the wall-floor junction in sufficient detail to understand the influence of the floor on surface damage risk.

The geometry and specification of materials was based upon drawing 240.4 “Ground Floor Finishes Typical junction of overlay finish with stone skirting” (19/03/2026) by BLDA architects.

Materials

Materials other than the existing masonry were based upon the notes in the drawing, and datasheets where relevant and available. With regards to the floor, an initial 1D simulation exercise indicated that very little moisture flux and storage was occurring in the floor due to the DPMs present, which makes the precise selection of materials less critical.

The soil was assumed to be “Medium Clayey Silt”, which has moderate moisture storage and transport properties. The ground was represented as a homogenous block of soil extending 2m deep, 2m from the external surface of the wall and 2m from the internal surface of the wall. The exposed ground surface was allocated an external weather boundary condition, with full rain (this assumes no surface water is drained away, which is a worst-case scenario). The bottom surface of the block of soil was assigned a condition of 11.22 C (the annual average of the climate file) and 99% RH. The sides of the block of soil were assigned adiabatic conditions.

To represent the Glapor aggregate, a modified version of Foamglas board was used. As the rigid board material has very high vapour resistance this would overestimate the resistance of the compacted aggregate material; the macro pores create relatively easy paths for diffusion. A measured vapour resistance was not available for the aggregate product, so we estimated a mu-value of 10.

Delphin contact conditions were used to represent the DPM’s; a condition with zero liquid transport and an Sd value of 100m as per the drawings was specified immediately below both layers of SRT tile. “Pure sand” was used to represent the ceramic granule levelling layer: this has a degree of liquid transport and storage but being located close to a DPM means very little moisture will be present in or moving through that layer. “Lime Cement Mortar (low cement ratio)” was assumed for mortar in the floor and wall. While the original mortar predates Portland cement, where visible it appears to be quite hard suggesting a hydraulic set. The SRT were represented with a ceramic engineering brick.

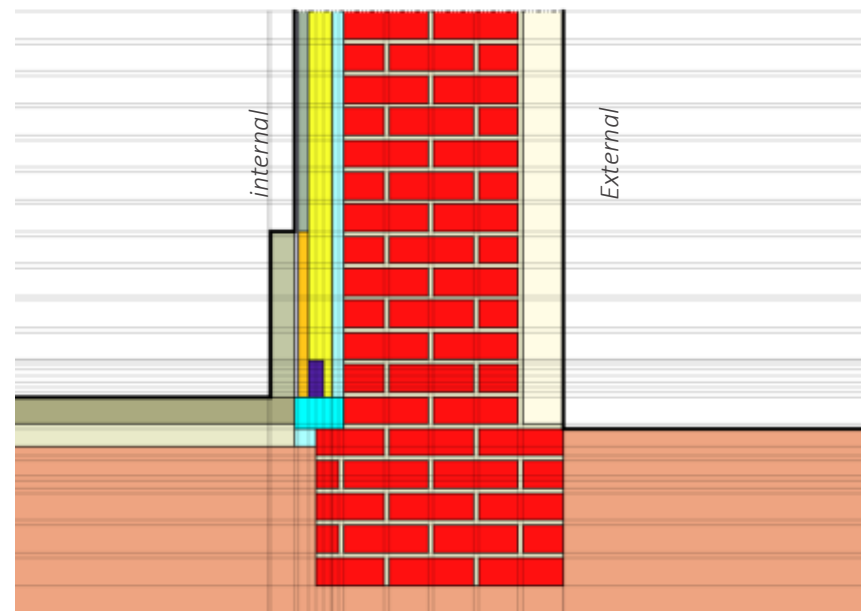


Figure 6: Detail of simulation geometry: Historic floor

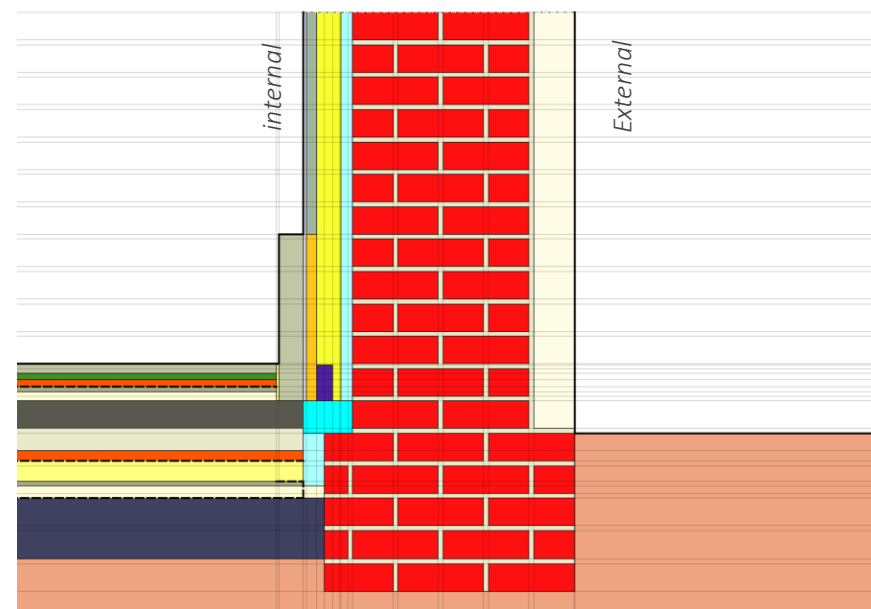


Figure 7: Detail of simulation geometry: proposed floor

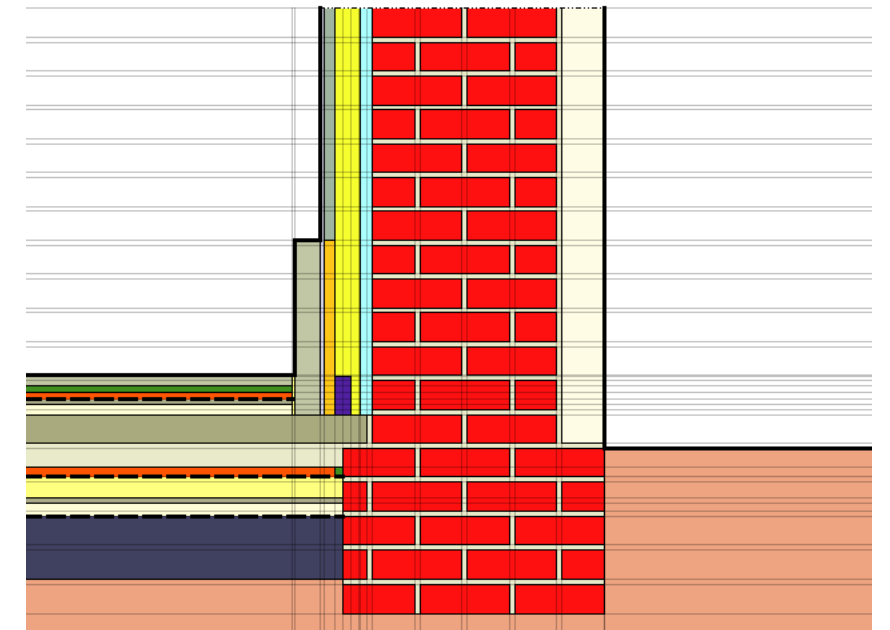


Figure 8: detail of simulation proposed floor, without perimeter zone

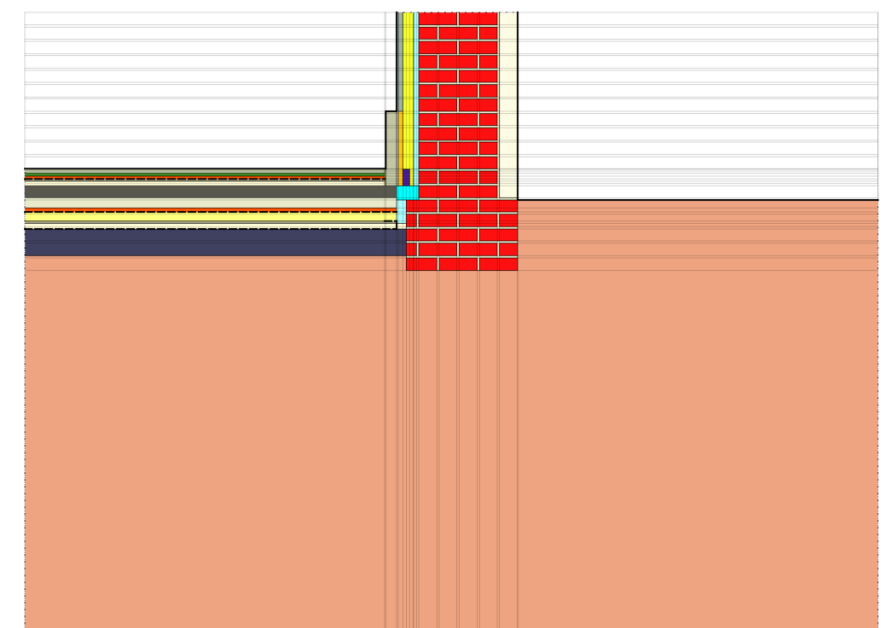


Figure 9: full size simulation showing geometry of soil block

4. Hygrothermal Risk Assessment

4.1 Model Setup

External Ground Surface

Ground water potentially impinging on the footings arrives from below ground (water from the water table being drawn upwards through the soil) and via rain falling on the ground and being transported laterally into the footing, directly or via the zone under the building. The surface finishes are therefore relevant. The courtyard area will be paved with predominantly impermeable flooring, with suitable surface water drainage. We understand that ground treatments on the external side will consist at least in part of soft landscaping which will not drain rain away. The rain load on the ground and footings on the courtyard side is therefore lower, and representing the ground surface as exposed soil in the simulations is a conservative/ worst-case scenario.

Climate

The hygrothermal risk assessment was based on a 'hygrothermal reference year' or 'HRY' weather file for Southampton, produced by the Fraunhofer Institute of Building Physics. Southampton is the closest of four UK HRY files currently available. These files are more accurate with respect to wind driven rain than Meteonorm, for which more local information is available, but gives a half to a quarter of the wind driven rain. It was therefore decided to use the more conservative, high WDR.

The HRY is a synthetic weather file constructed from historic weather data from the 2012-2020 period. The file has been constructed as a sequence of months from different years in the historic data, selected based on similarity to the average temperature, rainfall and relative humidity in the measured period. The HRY weather file is recommended by the Fraunhofer IBP for the evaluation of the long-term behaviour of constructions. Figure 9 illustrates the key climate parameters in this weather file.

A 'medium moisture load' as per BS EN 15026 representing an internal relative humidity range of 30% to 60% has been assumed as a baseline scenario. This is a conservative assumption for the building use type, assuming mechanical ventilation is provided as part of the refurbishment.

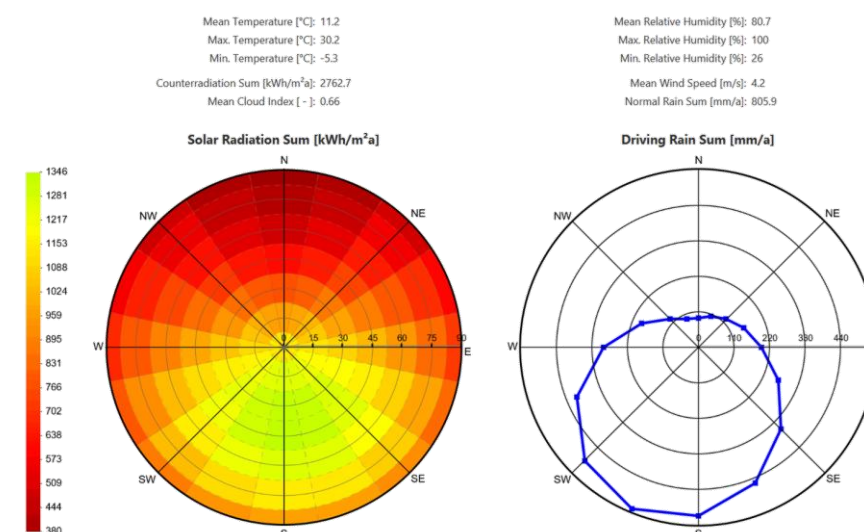


Figure 9. External climate data used in the assessment

4. Hygrothermal Risk Assessment

4.2 Preliminary Assessment

Impact of stone and brick properties

This section presents an initial analysis of the impact of material properties on the hygrothermal conditions within the **proposed, insulated and lined wall**, as well as showing a base case for the uninsulated wall for the materials to be carried forward to the more detailed analysis.

Section 3 discusses the shortlisting of materials used for simulation. The materials that could represent the Oolitic limestone facing are:

- Sander sandstone
- Cotta sandstone
- Reinhardsdorft sandstone

There are relatively few limestones available in the hygrothermal databases, perhaps due to the geology of Germany where the software derives from. However, Limestones have similarities in formation i.e. they are sedimentary but the most important factor for the purposes of simulation is that the hygrothermal properties are representative. We have analysed the properties measured statistically to arrive at the material selections used in these simulations.

Figure 10 shows the influence of stone type on the degree of saturation of the external stone facing. The Sander sandstone gives the highest water content at this surface, and hence the highest risk of surface damage due to freeze-thaw damage.

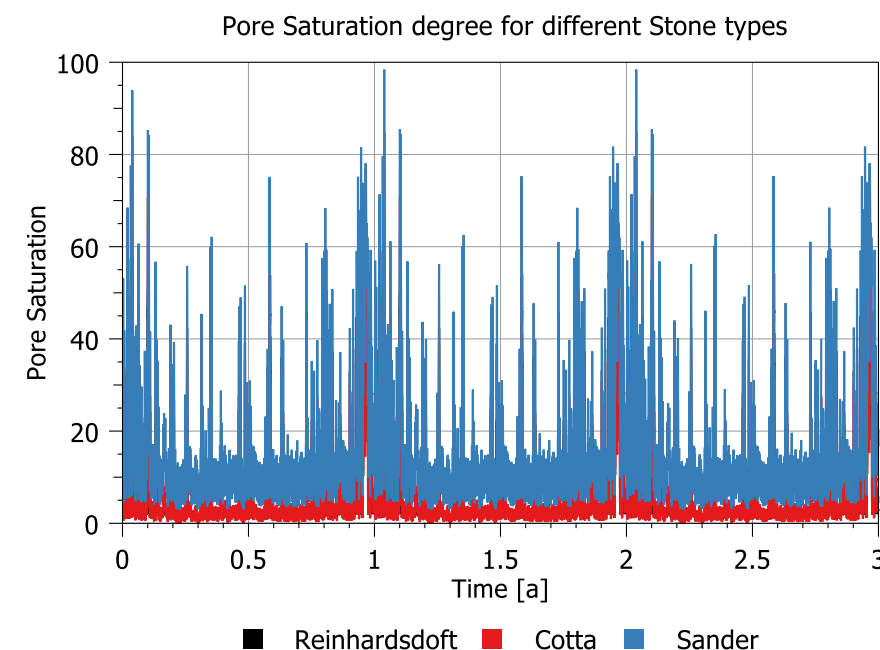


Figure 10. Pore saturation of the outer 1mm of facing stone, for a selection of stone types.

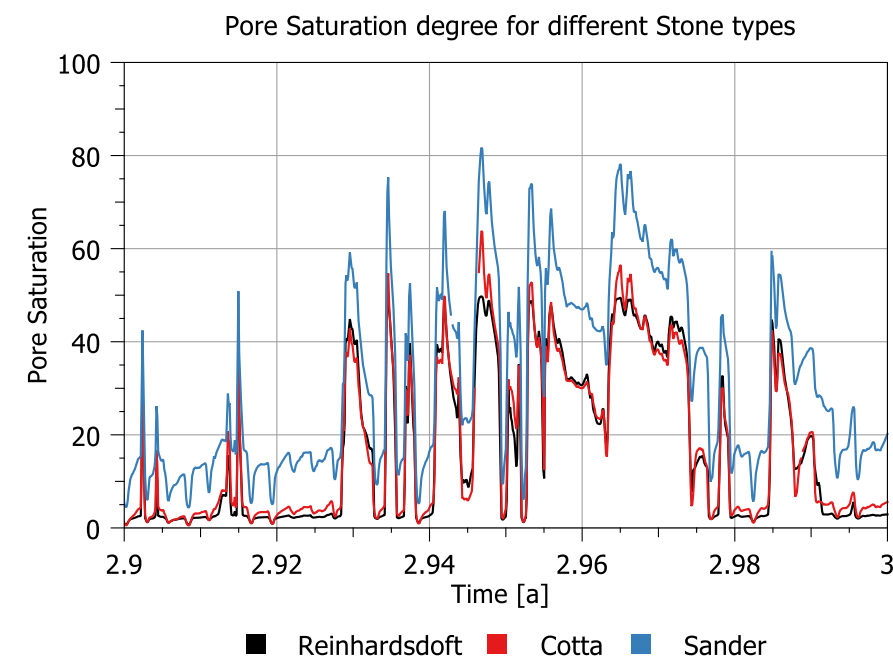


Figure 11. Pore saturation of the outer 1mm of facing stone, for a selection of stone types. (2 month period for clarity)

Figure 11 shows the same data for only 2 months at the end of the simulation to aid clarity (November and December).

Figure 12 shows the total moisture content of the simulation section of wall for the three different stone types. This does not agree with the results from the surface in that the Sander sandstone results in the driest overall wall. The difference between the behaviour at the surface and the overall is likely due to the liquid transport properties: The Sander sandstone is less able to transport rain on the surface deeper into the wall, which keeps the surface generally wetter but the core drier. Because the main risk of interest is decay of the historic stone surface, Sander sandstone was adopted for the remaining simulations.

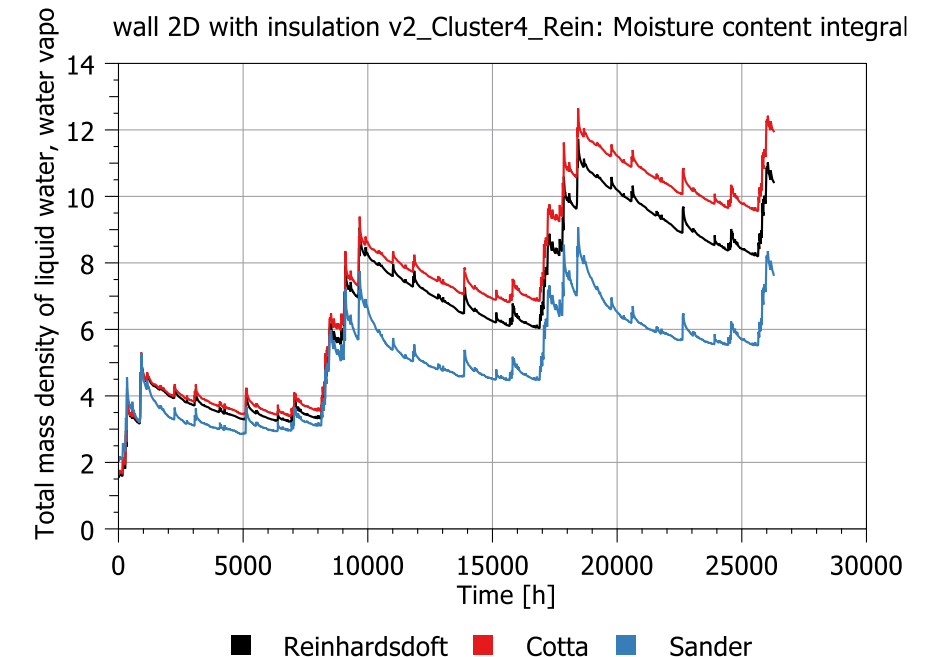


Figure 12. Total moisture content

Key Observations

- Sander Sandstone gives a worst-case material type for the facing stone, and hence will be used in all further simulations, to give a conservative risk assessment.

4. Hygrothermal Risk Assessment

4.3 Preliminary Assessment

Having identified the most suitable stone for the assessment, the most appropriate brick was assessed. Simulations were run using three different brick types that represent the bricks sampled as described in section 3.

Figure 14 shows the total moisture content for the simulated section of wall for the last year of a 3 year simulation. ZL and Reinhardsdorft bricks are shown, simulated with insulation and the Cluster 4 brick is simulated both with and without the insulation and lining. The total moisture content in the model is 1 – 1.5 kg more when insulated. (for the 1-brick width simulated). This could be due to the insulation reducing the ability of the wall to dry out. The type of brick also has an effect. The Reithalle behaves very similarly to the ZL brick, but the Cluster 4 brick results in the highest total moisture content.

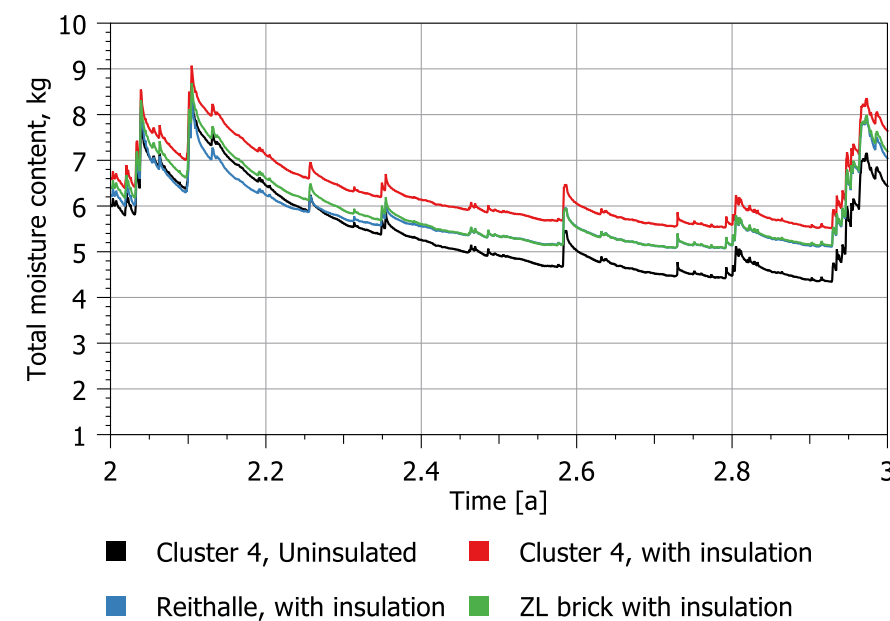


Figure 14. total moisture content for 3 different brick types.

Role of Brick in surface conditions

Figure 15 shows the degree of pore saturation of the outermost 1mm of stone, assuming Sander sandstone, for the three different brick types. This graph shows the final two months of the simulation to aid clarity. The brick type (within the selection established) has only marginal influence on the moisture content at the surface of the facing stone.

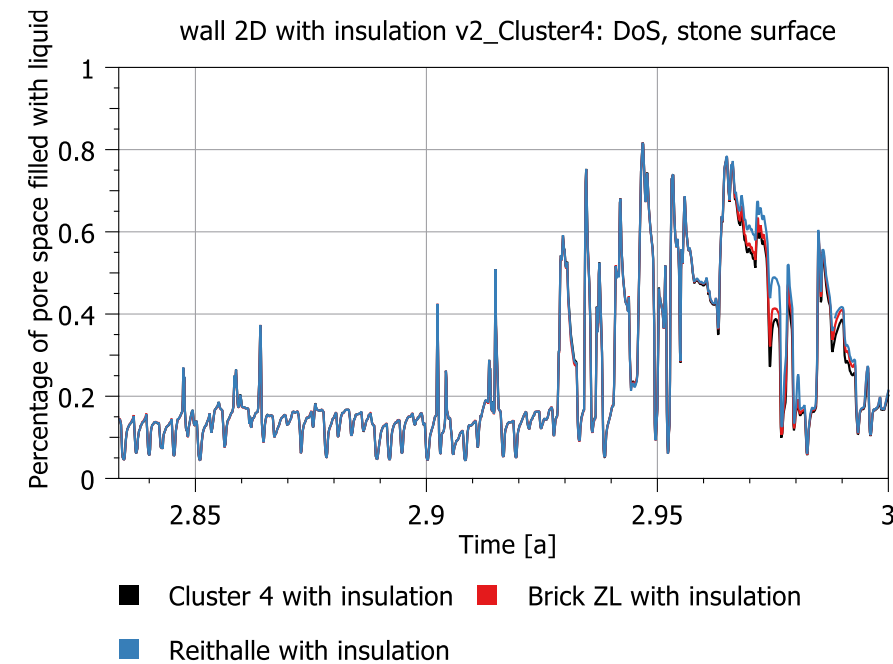


Figure 15. Degree of Saturation of the outer surface for a variety of brick types.

Role of Brick in interstitial conditions

Figure 16 shows the relative humidity at the external (cold) surface of the insulation over 3 years, for a variety of brick types. At the end of the 3 years, the RH is stabilised at 97 – 98% RH.

The simulations have assumed no ventilation in the cavity due to the difficulty (with respect to the heritage constraints, as well as technically) of introducing low and high level openings to provide ventilation.

Key Observations and recommendations

- Sander Sandstone and Cluster 4 brick give a worst-case combination of materials, and hence will be used in all further simulations, to give a conservative risk assessment.

4. Hygrothermal Risk Assessment

4.3 Main Assessment

Influence of floor design

A key area of performance of the proposals is the influence of the floor on the moisture content in the walls. There is an understanding that placing an impermeable floor build-up over a surface which previously allowed evaporation from the ground may cause more moisture to enter the walls via the foundations. One peer-reviewed paper did not find evidence to support this (Briggs et al 2022) however such mechanisms are often more complex and other factors may influence whether this mechanism causes a significant change in moisture in the walls. Until more comprehensive evidence has been established, each case must be carefully considered.

To achieve this, three simulations were performed, representing the wall, footings, floor (proposed and historic) and a block of soil 2m deep and 4.7m wide (~2m from the internal and external surfaces of the wall). For the proposed floor, a simulation was run with the proposed perimeter strip (proposed to be built by installing the sub-floor against a temporary timber formwork, creating a ~50mm void) and without this feature (floor layers abut the existing footings).

Figure 17 shows the overall moisture; in all 3 cases, the simulations are approaching a dynamic equilibrium after 5 years. The overall moisture content in the model with the proposed floor model contains approximately 200kg (per m of length of the foundation) more moisture than the model with the historic floor. This additional moisture will be spread across the masonry and the soil block so does not necessarily represent the state of the masonry.

The influence of the floor design was assessed in two ways: firstly by quantifying the total moisture flux into the existing wall from the ground, and secondly by counting the critical freeze-thaw cycles.

Figure 18 shows the moisture flux through a horizontal plane in the brickwork slightly above the external ground level, for the last year in a 5 year simulation. (The plane is roughly where a DPC might be found in relevant buildings). This captures the flux of both liquid and water vapour. This indicates that there is a slight increase in moisture flux through this plane associated with the proposed floor. There is negligible difference in moisture flux between the proposed floor with, versus without the perimeter void detail. Integrating these figures over the last year of simulation finds the annual flux is:

- 146 kg per m of wall per year with the historic floor
- 183 kg/m.a with the proposed floor with perimeter strip
- 172 kg/m.a with the proposed floor without the perimeter strip

The proposed floor creates a 25% increase in annual flux, or 18% increase without the perimeter strip. However, the absolute amounts of annual moisture in both cases is relatively small compared to the total moisture content (see Figure 17), and this does not dramatically change the moisture risk, as analysed further, below in this report.

The graph in Figure 18 runs January to December, hence it can be seen that the overall flux is lower in the summer, however the difference is more pronounced in the summer months.

The perimeter strip therefore does provide a marginal reduction in moisture flux from the ground into the wall, but this does not have a material benefit in terms of mitigating the risk of surface damage. However, good design practise would be to provide a means of separating the floor finishes and relevant elements of the sub-floor, from moisture ingress from the footings via a capillary break (i.e. a small gap) or waterproof component. A modest gap or strip of DPC or expansion foam or similar would therefore be a beneficial feature.

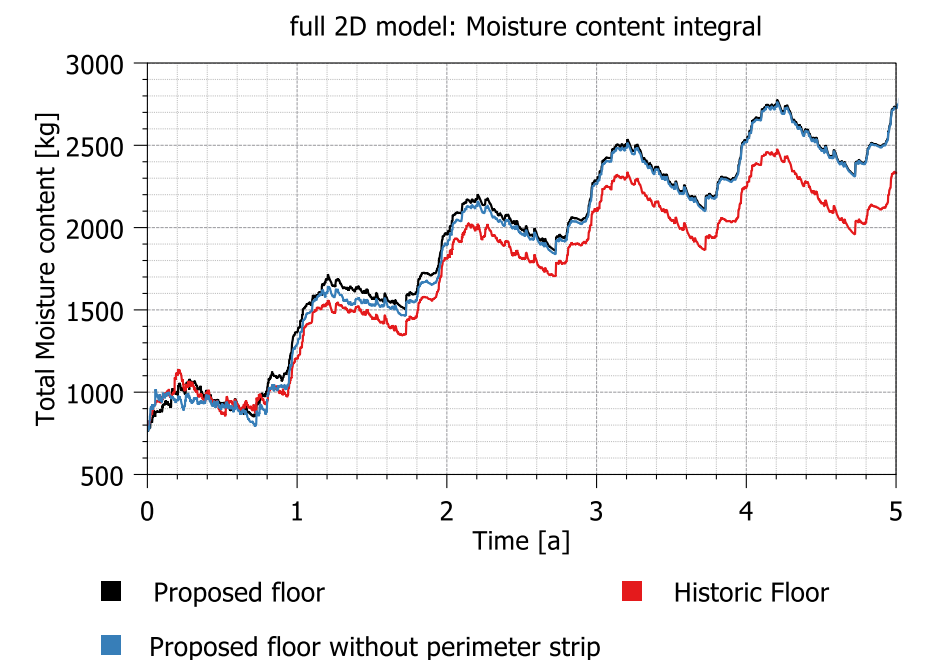


Figure 17. Total moisture content – comparison between the historic and proposed floors.

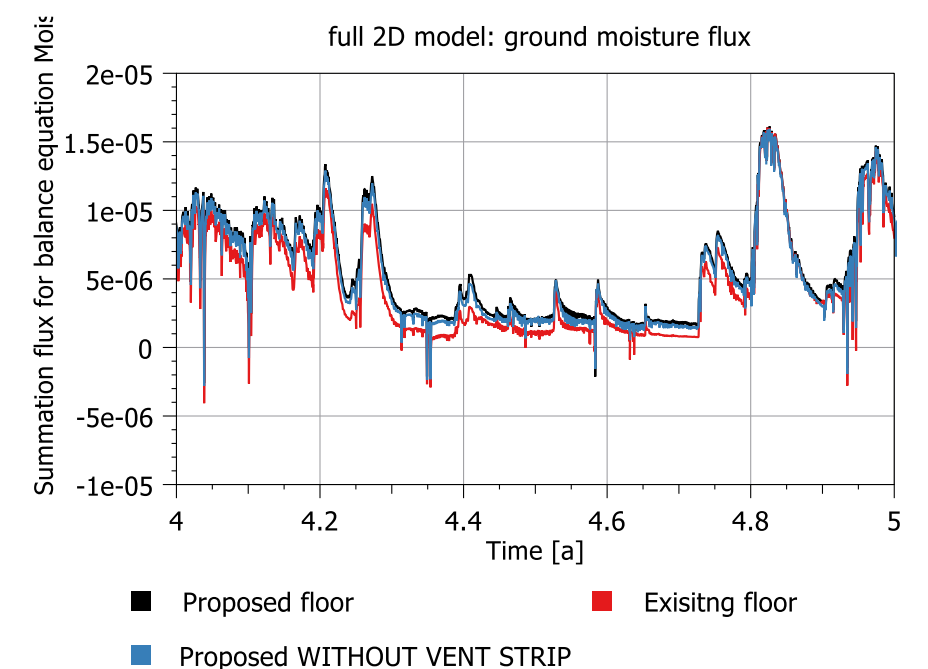


Figure 18. Moisture flux via the base of the wall, for 2 different floor constructions

4. Hygrothermal Risk Assessment

4.3 Main Assessment

Figures 19, 20 and 21 show a snapshot of the moisture content for the 3 scenarios during the spring of the final year of simulation. The role of the rain wetting the ground can be observed.

These images indicate that while the perimeter strip has no significant effect on the moisture content of most of the wall, there is an area behind the skirting which has higher moisture content. This is possibly due to the perimeter strip providing a greater area for evaporation from the footings; where the floor abuts the wall it creates more of a 'pinch point' for moisture leaving the wall into the lining void. This point is well protected and very unlikely to drop below zero degrees, hence we deem the risk of freeze-thaw damage to be very low, despite the higher moisture levels.

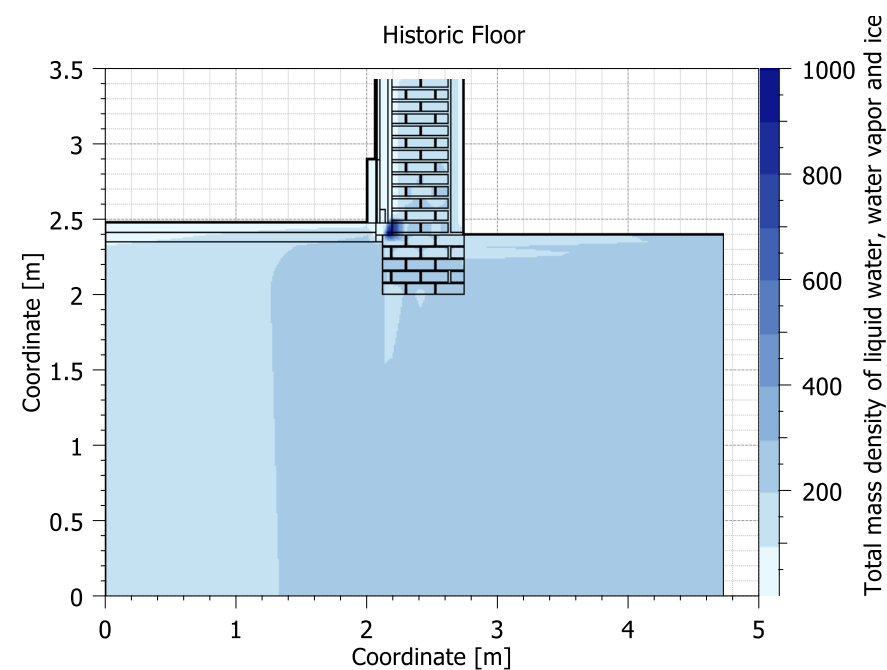


Figure 19: moisture profile of the historic floor model, spring time

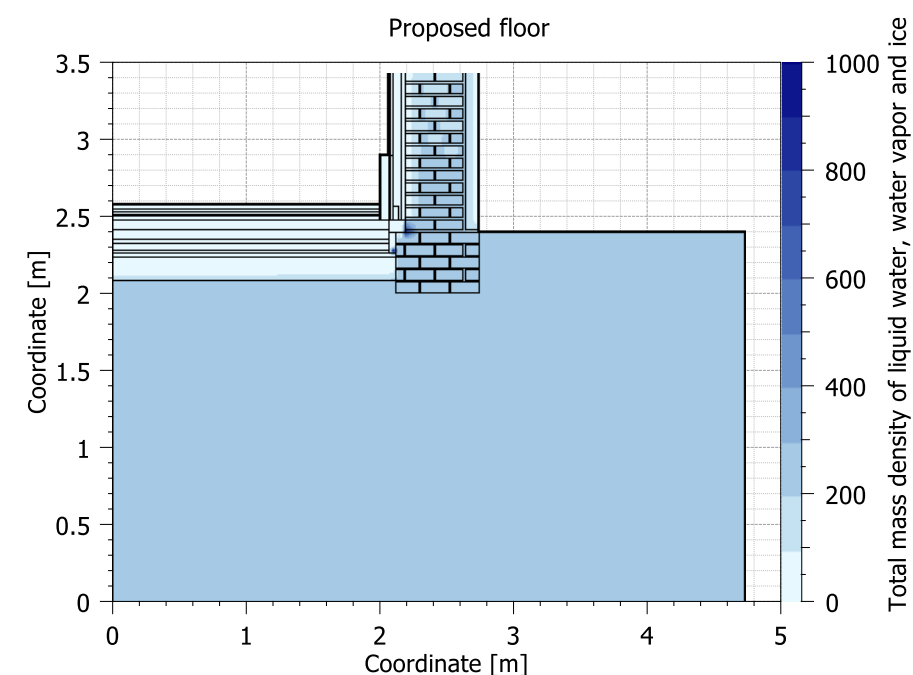


Figure 20 moisture content of the proposed floor model, spring time.

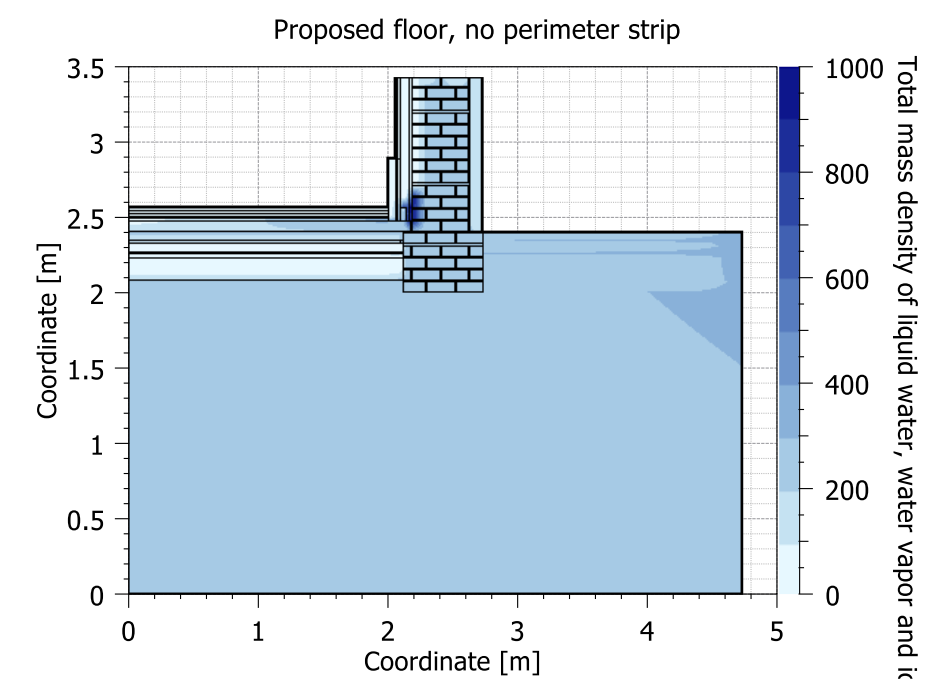


Figure 21 moisture content of the proposed floor model without perimeter strip, spring time.

4. Hygrothermal Risk Assessment

4.3 Main Assessment

Influence of floor design

Figures 22, 23 and 24 illustrate the moisture content of the surface of the facing stone. The vertical coordinate from the lowest point on the model is on the Y axis and these graphs have been cropped such that the y-axis represents the 200mm closest to the ground. All three graphs show that the lowest ~75mm of the surface does have generally higher moisture levels, however the difference between the two cases is small.

Degree of saturation, when combined with the temperature, can give a general indication of the risk of surface damage due to freeze-thaw action. A frost event occurs when the moisture content is high (for this exercise 58% has been selected based upon Prick (1997)) and the temperature drops below a threshold, usually 0° C. Figure 24 shows the temperature information in a similar format. The difference in the floor has negligible influence on the temperature at the surface of the wall.

These data were exported and post-processed as follows:

For each coordinate on the surface, for each hour, if the degree of saturation exceeded the critical threshold and the temperature fell below 0°C during that hour having been above 0°C in the previous hour, a frost cycle was recorded. Adopting the most conservative threshold identified in the literature — a critical degree of saturation of 58%, derived from the lowest value reported by Prick (1997) across ten limestone types — **zero critical frost cycles were recorded in all three simulations** (historic floor, proposed floor, and proposed floor without perimeter strip).

Key Observations

- **No critical frost events/cycles were predicted** by the simulation. This is possibly due to the relatively mild climate, as well as the nature of the simulated stone being such that it dries relatively quickly, such that the probability of it still being wet after rain when a frost occurs is small.
- The moisture flux from the ground does have an influence that is visible in simulation, but it is limited to ~75mm above ground, and the moisture content is not consistently, dramatically increased.

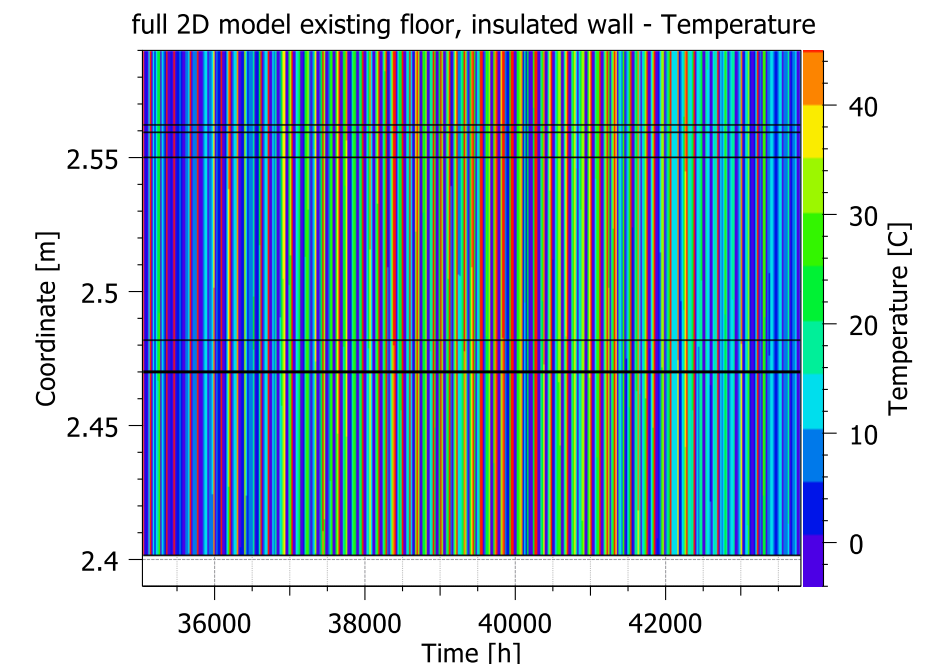


Figure 25 Temperature of the stone surface, varying height, last year of simulation

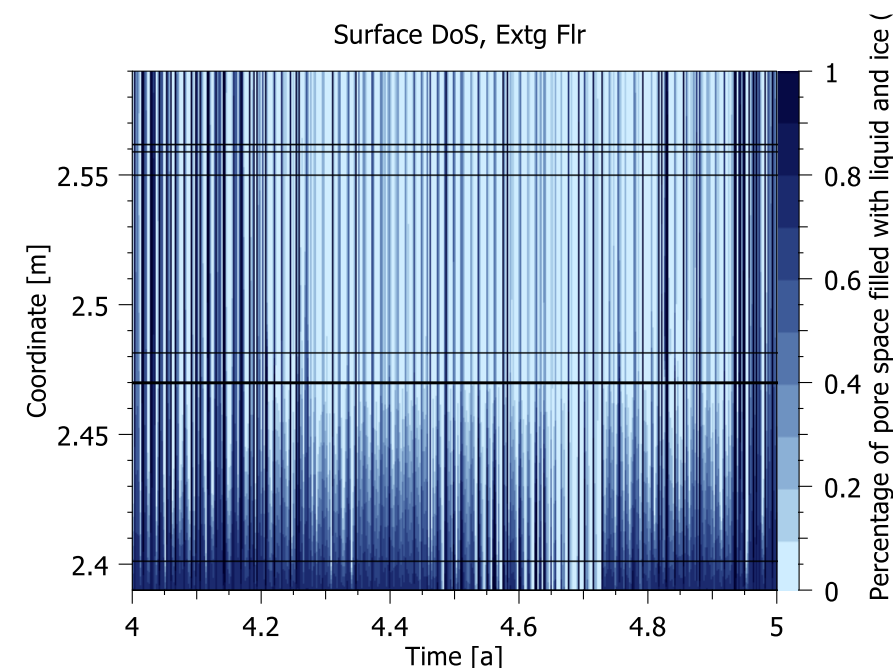


Figure 22: Degree of Saturation of the stone surface, varying height, last year of simulation. Historic floor

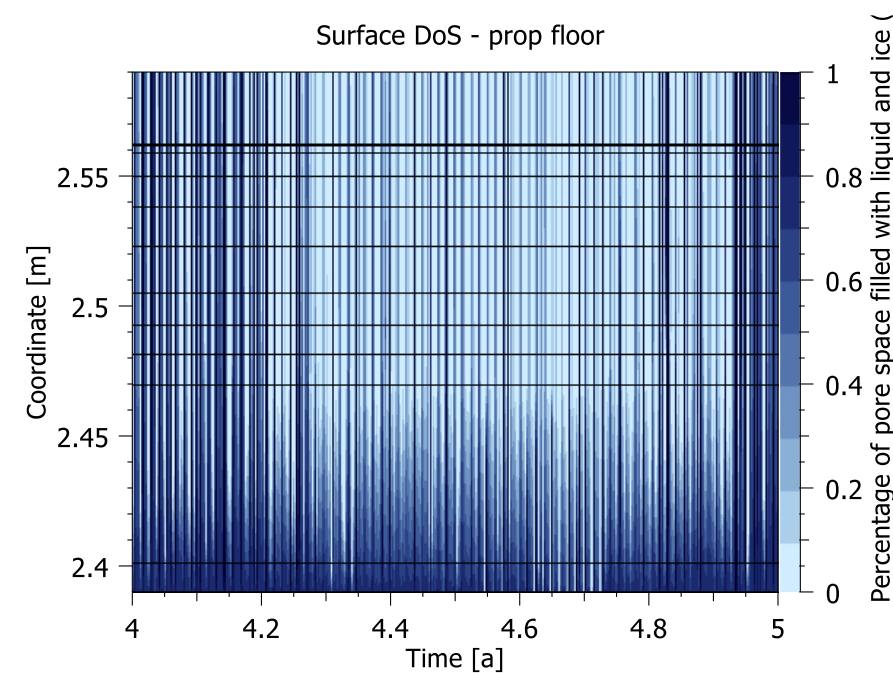


Figure 23: Degree of Saturation of the stone surface, varying height, last year of simulation. Proposed floor

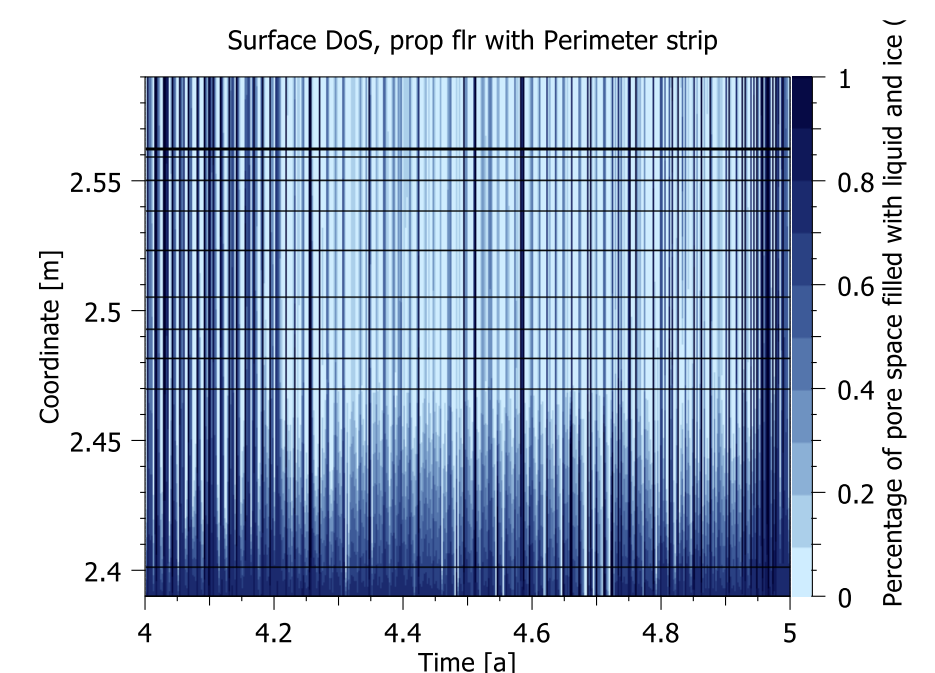


Figure 24: Degree of Saturation of the stone surface, varying height, last year of simulation. Proposed floor without perimeter strip

5. Conclusions and Recommendations

5.1 Conclusions

The hygrothermal risk assessment evaluated the moisture risk associated with providing the Old Stables, Tottenham House, with a new floor incorporating DPM's and other materials with low permeability. The proposed construction was modelled using Delphin 6.1.7, a dynamic hygrothermal simulation software following and validated against BS EN 15026:2007.

As part of the risk assessment, samples of the existing brick and stone were characterised to inform the selection of representative brick modelling assumptions. A preliminary sensitivity study investigated the impact of the exact material properties for the facing stone and the brick. The risk assessment was based on conservative assumptions for these and other parameters.

The central finding is that the proposed floor construction does not present a material risk of freeze-thaw damage to the historic masonry facade.

The floor does increase the flux of moisture into the base of the wall from the ground by approximately 25%, but this increase is from a low (historical) starting point and the absolute moisture levels remain small. No critical freeze-thaw cycles were predicted in any of the three simulations. This result based upon the most conservative saturation threshold identified in the literature and is unaffected by the presence or absence of the perimeter ventilation strip at the slab edge. The strip makes a negligible difference to the moisture flux through the base of the wall.

The moisture flux from the ground is limited in its influence to approximately 75 mm above ground level at the stone surface, and the degree of saturation in this zone is not consistently or dramatically elevated relative to the historic condition.

The absence of observed surface deterioration to date is consistent with the simulation findings.

5.2 Recommendations

We would recommend the following:

- Allow for repair of any defects in the existing masonry, openings and roof prior to installing new floors.
- Assess the façade for appropriate waterproofing details such as drip profiles, flashings etc. and improve where appropriate to minimise rain ingress (which could increase the risk of freeze-thaw damage). Ensure details around windows, penetrations and fabric junctions are robustly waterproofed.
- Ensure rainwater goods and drainage are functioning correctly during construction and ongoingly, to ensure that both direct and indirect (i.e. rain water from the roof percolating into the ground near to the building) moisture loading of the wall is minimised.
- Ensure a regular maintenance regime of the façade and rainwater drainage systems post-completion.

References

- Briggs, Ball, McCaig *In-situ measurements of wall moisture in a historic building in response to the installation of an impermeable floor* (2022) UCL Open : Environment [10.14324/111.444/ucloe.000046](https://open.ucl.ac.uk/10.14324/111.444/ucloe.000046)
- BS EN ISO 13788:2012 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods, BSI 2012
- BS EN ISO 15026:2023 Hygrothermal performance of building components and building elements – assessment of moisture transfer by numerical simulation, BSI 2023
- AHSRAE Standard 160-2016 Criteria for Moisture Control Design Analysis in Buildings, ASHRAE 2009
- WTA 6-2 Simulation of Heat and Moisture Transfer, 2002
- DIN 4108-2 Thermal protection and energy economy in buildings, German Institute for Standardisation, 2013
- WTA leaflet E 6-5-12: Interior insulation according to WTA II - verification of interior insulation systems using numerical calculation methods. 2012
- BS EN ISO 10456:2007 Building materials and products – Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values
- BS EN ISO 12571:2022 Hygrothermal performance of building material and products – Determination of hygroscopic sorption properties
- BS EN ISO 15148: 2002 (+A1:2016) Hygrothermal performance of building components and building elements – Determination of water absorption coefficient by partial immersion
- BR 497 Conventions for calculating linear thermal transmittance and temperature factors, BRE 2016.
- BS EN ISO 10211:2007, Thermal bridges in building construction - heat flows and surface temperatures - detailed calculations, BSI 2007
- IP1/06 Assessing the effects of thermal bridging at junctions and around openings, BRE 2006
- BS EN ISO 6946:2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation Method, BSI 2007
- Straube J, Building Science Digest 148 Simplified Prediction of Driving Rain on Buildings: ASHRAE 160P and WUFI 4.0, Building Science Press, 2010.
- Prick, A. (1997) Critical Degree of Saturation as a Threshold Moisture Level in Frost Weathering of Limestones. *Permafrost and Periglacial Processes*, 8(1), 83–99.

GBEC1311 – The Old Stables, Tottenham House Marlborough

Appendix A – Sample Collection Record

GREENGAUGE

The Old Brewery,
Newtown, Bradford-on-Avon, Wiltshire,
BA15 1NF

e: info@ggbec.co.uk
w: www.ggbec.co.uk
t: 01225 862605
