# Increasing the Building Envelope Resilience to Moisture Damages

Final Research Report

## School of Architecture, Design and Planning

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# Executive Summary

## Research Overview

The Victorian Building Authority (VBA) supported research conducted by the University of Sydney's School of Architecture, Design and Planning, through a research grant, to study the design and construction practices that improve moisture resilience in building envelopes. The research team included University of Sydney experts in hygrothermal assessment, building technology, and sustainability, alongside industry advisors from the Mott MacDonald façade team. The project aimed to enhance protection against moisture penetration and water-related damages in residential buildings across Victoria.

This report provides an in-depth analysis and investigation of the hygrothermal performance [1] of typical construction systems identified in Victoria, where unique climatic conditions and building practices pose specific challenges. This research explores how these systems respond to variations in standard conditions, assessing their resilience to mould growth risk. The research comprised of three main phases:

- **Phase 1**: Analysed the hygrothermal performance of typical residential wall and roof assemblies under standard code-compliant conditions [2] .
- **Phase 2**: Conducted further tests on the hygrothermal performance of Phase 1 assemblies under non-standard conditions, which may either intensify or mitigate moisture levels.
- **Phase 3**: Examined the hygrothermal performance of 2D geometries, including critical areas like building junctions, to identify and address potential vulnerabilities related to heat and moisture movement.

The hygrothermal performance of the selected construction systems was tested through virtual simulations. Phase 1 and Phase 2 employed 1D simulations, analysing the movement of heat and moisture through different materials, conducted along a single axis, in this case through the cross section of external walls and roofs. WUFI Pro was selected as a simulation tool due to its reliability for conducting hygrothermal assessments in building components [1]. Phase 3 analysis was performed in WUFI 2D [2], focusing on specific building components and providing a deeper understanding of how heat and moisture move through these systems. The performance evaluation followed the VTT mould growth model, as the foundation of the ASHRAE 160 Standard [3] and was identified as one of the most reliable models for predicting mould growth risk [4].

The research focused on identifying prevalent construction trends across Victoria. By analysing data from various sources on different building typologies, the study incorporated common variations and standard solutions endorsed by the regulatory systems for wall and roof assemblies

Therefore, the following assemblies were analysed:

a. Wall Types:
    - Weatherboard-clad, timber-framed wall, insulated internally (EW1)
    - Fibre cement clad, timber-framed wall, insulated internally (EW2)
    - Brick veneer masonry, insulated internally (EW3)
    - Cavity brick masonry (EW4)
    - Externally insulated brick masonry (EW5)
    - Autoclaved aerated concrete masonry, insulated internally (EW6)

b. Roof Types - Flat roof, skillion roof and cathedral ceiling, insulated:

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[1] Hygrothermal performance evaluates the risk of mould growth resulting from condensation and moisture accumulation in construction assemblies by studying heat and moisture movement in the assembly's cross-section (1D assessment) and in complex geometries such as building junctions (2D assessment).

[2] Compliance with the current National Construction Code, Volume Two 2022, Housing Provisions.

- Metal-clad with the ceiling lining under the rafter (RF1)
- Terracotta-clad [3] with the ceiling lining under the rafter (RF2)
- Metal-clad with exposed rafters (RF3)
- Terracotta-clad with exposed rafters (RF4)

The methodology used in this research was designed to respond to the following:

- To test the hygrothermal performance of different regulatory-compliant wall build-ups under standard conditions, which are often used in condensation assessment.
- Further test the selected regulatory-compliant construction systems under non-standard scenarios to assess their drying potential and resilience to moisture damage.
- To investigate complex geometries (construction details) with non-uniform heat and moisture sources to identify potential weak points that could compromise the hygrothermal performance of the construction systems evaluated in Phase 1 and Phase 2.

This research provides evidence-based insights to improve the moisture resilience of building envelopes. It is not intended as a design or construction guidance. Practitioners may use this information to enhance their understanding of moisture management and associated risks; however, they should refer to relevant standards, codes, and professional guidelines for specific design and construction requirements. Applying these findings to real-world projects requires professional judgment and expert consultation.

[3] Terracotta has been chosen to represent a tile made of porous materials. It can also serve as a proxy for concrete tiles.

## Key Findings

This project analysed typical construction assemblies under both standard conditions (as defined by ASHRAE 160, DA07 and the National Construction Code) and non-standard scenarios. By comparing their hygrothermal performance across different assumptions, it highlights a critical issue: assemblies deemed compliant under standard conditions may lack moisture resilience when assumptions deviate from the norm. The following section summarises these key findings and highlights critical areas within the construction assemblies prone to mould growth risk.

### Key finding 1: Granular climate zoning better captures the hygrothermal performance variations of wall assemblies across Victoria

The NCC divides Australia into eight general climate zones, with two relevant to Victoria. However, this division does not accurately represent the diverse climatic conditions across the state. In contrast, the NatHERS scheme divides Australia into 69 climate zones, including nine in Victoria, offering a more detailed classification that accounts for micro-climatic variabilities, such as temperature fluctuations and humidity, which can influence building performance. Therefore, this study included seven of the nine NatHERS zones (Zones 21, 22, 60, 62, 63, 64, and 66), focusing on the state's most representative and diverse climatic conditions. This selection allows for a more detailed and manageable analysis while still capturing the significant climatic variations that can impact the performance of external assemblies. Zones 27 and 61 were excluded as they are less populated, and their climatic conditions are similar to those already selected.

Table 1 shows the variations in hygrothermal performance of all assemblies assessed according to the results obtained in Phase 1. Climate Zones 63, 64, and 66 exhibit the highest temperature fluctuations according to the climatic data analysis, increasing the risk of mould growth in brick masonry (EW3 and EW4), aerated concrete assemblies (EW6), and terracotta tiled roofs (RF4). These fluctuations can significantly impact the hygric properties of these materials due to their porous composition, as thermal expansion and contraction can create micro-cracks or enlarge existing pores, facilitating increased moisture penetration. In addition, elevated temperatures increase vapor pressure, speeding up moisture absorption into the pores, while cooling can cause condensation within the material [5].

This research demonstrates that the general Victorian NCC zoning is insufficient to accurately capture the hygrothermal variations across the state. In contrast, the refined NatHERS zoning provides a more detailed categorization, offering a better representation of local climate conditions. This enhanced zoning framework enables more precise assessments of moisture risks and building performance, supporting the development of more resilient construction practices.

**Table 1:** Hygrothermal performance rank by climate zone, based on Phase 1 Results assessed at the interface of the insulation and the membrane, taking as an example assembly with insulation performance Type 1: R2.3 (walls) and R2.5 (Roofs).

| Construction Type | Performance evaluation based on mould growth risk by Climate Zone | | | | | | |
|---|---|---|---|---|---|---|---|
| | NCC Zone 6 | | | | | | NCC Zone 7 |
| | 21 | 22 | 60 | 62 | 63 | 64 | 66 |
| **EW1** | 0.00 | 0.00 | 0.00 | 0.00 | 2.36 | 0.00 | 0.00 |
| **EW2** | 0.00 | 0.00 | 0.02 | 0.04 | 0.73 | 0.02 | 0.18 |
| **EW3** | 0.02 | 1.92 | 1.71 | 2.15 | 2.80 | 2.15 | 2.48 |
| **EW4** | 2.96 | 3.13 | 3.28 | 3.34 | 3.13 | 3.22 | 3.37 |
| **EW5** | 0.35 | 0.10 | 0.34 | 0.10 | 0.02 | 0.09 | 0.12 |
| **EW6** | 0.01 | 1.89 | 2.31 | 2.68 | 3.04 | 2.55 | 2.85 |
| **RF1** | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| **RF2** | 0.12 | 0.08 | 2.52 | 0.20 | 2.95 | 0.22 | 2.00 |
| **RF3** | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.03 | 0.05 |
| **RF4** | 0.12 | 0.08 | 0.18 | 0.00 | 1.02 | 2.66 | 1.91 |

*Table 1 notes:*
**Performance assessed for interstitial mould growth risk in the interface of the insulation and membrane for all construction systems under standard conditions.*

*Results are presented based on NatHERS climate ones for Victoria (21,22,60,62,63,64 and 66), NCC climates are showed for reference only.*
**Colour legend: Green – low mould growth risk; Yellow – Medium mould growth risk; Red– High mould growth risk.*

**Key finding 2: Porous materials such as brick veneer systems are prone to mould growth risk and require further considerations during the design and construction phases.**

Masonry construction systems need special attention, as simulation results indicate they are prone to mould growth risk under standard conditions across 86% of the studied climate zones. This is particularly evident at the interface between the insulation and membrane (monitor position M4), and at the inner side of the masonry (monitor position M5), as seen in EW3, EW4 and EW6 (Table 2). These findings indicate that further design measures are necessary to enhance moisture control, as these layers are the most sensitive to moisture and prone to mould growth risk. They are also crucial in regulating temperature and humidity, driving the need for these construction systems to be further tested under non-standard scenarios in Phase 2. Therefore, the arrangement of construction layers and material selection also significantly influences moisture management within the assembly.

Similarly, due to the porous nature of terracotta and concrete tiles, roofs are susceptible to moisture absorption and transport. Under standard conditions, results indicate a medium risk of mould growth on the external side of the insulation (M4) and a high risk at the interface of the membrane and cavity (M5) across all climate zones, as shown in Table 3, demonstrating the important role of the vapour permanence of the membrane in controlling moisture transfer within the assembly. The upcoming NCC 2025 [6] acknowledges the sensitivity of vapour control layers to moisture and proposes stringent ventilation openings to address this issue. However, there are no changes to the permeance values for membranes, which remain at >1.14 µg/N.s.

**Table 2:** Phase 1 Simulation results snapshot for critical external wall assemblies: Brick veneer (EW3), cavity brick (EW4) and aerated concrete (EW6) across all climate zones.

| Construction Type | Phase 1 External Walls VTT - Monitor Position M4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| **EW3** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **EW4** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **EW6** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Construction Type | Phase 1 External Walls VTT - Monitor Position M5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| **EW3** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **EW4** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **EW6** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

*Table notes:*
**Green – no mould growth risk; Yellow – Medium mould growth risk; Red – High mould growth risk; Grey– Not under assessment.*

**Table 3:** Simulation results snapshot for critical roof assemblies: Terracotta-clad roof with ceiling lining under rafters (RF2) and terracotta-clad roof with exposed rafters (RF4) across all climate zones.

| Construction Type | Phase 1 Roofs VTT - Monitor Position M4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| RF2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Construction Type | Phase 1 Roofs VTT - Monitor Position M5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | | Insulation Type | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| RF2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

_Table notes:_
**Green – Low mould growth risk; Yellow – Medium mould growth risk; Red – High mould growth risk.*

Since standard conditions do not account for ventilation, Phase 2 findings demonstrate that incorporating ventilation significantly improves performance.

Results from Phase 2, as outlined in Table 4 and Appendix 4 (full set of results), confirms that masonry assemblies and tiled roofs are highly susceptible to capillary moisture transport, especially under high rain loads. Moisture retention, inadequate ventilation, and temperature fluctuations contribute to damp conditions, creating an environment conducive to mould development. The findings highlight that ensuring a constant rate of ventilation in the cavity consistently reduces the risk of mould growth, emphasising the importance of airflow in managing moisture levels. Additionally, water control membranes with higher vapour permeance are better suited for use with glass wool insulation; however, proper ventilation remains crucial for effective moisture management.

**Key findings 3: Climate change impacts will increase the mould growth risks.**

Phase 2 of the research examined environmental conditions that could impact the moisture resilience of building assemblies, highlighting key vulnerabilities in the context of climate change. Findings indicate that increased rain loads (S3.2) significantly heighten the risk of moisture-related damage, particularly in sub-climates with higher rainfall or in design configurations where walls are unprotected. This underscores the need for enhanced moisture management strategies to improve the durability of building envelopes. Additionally, simulations considering elevated indoor temperatures and relative humidity levels (S4.1 and S4.2) revealed a heightened risk of mould growth across all assemblies. These conditions are especially critical in wet areas and cooking spaces, where inadequate ventilation can exacerbate moisture retention. As climate change intensifies rainfall patterns and leads to warmer, more humid indoor environments, these results identify the need for climate resilience assessments to ensure minimal risks of mould growth even under future climates.

The previous section discussed the impact of temperature and humidity fluctuations on porous materials and highlighted how additional factors, such as the arrangement of construction layers and material selection, significantly influence moisture management within the assembly. Under increased environmental conditions, glass wool insulation with a higher R-value tends to underperform, presenting a higher risk of mould growth due to its density, reduced airflow, susceptibility to moisture retention [7] and thermal bridging caused by the heat transfer through the framing. These findings underscore the necessity for meticulous design and installation practices to enhance moisture control and mitigate mould growth risk.

**Table 4:** Simulation results snapshot for assemblies tested under non-standard scenarios related to increased environmental conditions: S3.1+S3.2 (Increased rain loads), S4.1 (increased indoor temperature and relative humidity), and S4.2 (increased air tightness). It is important to note that only non-standard scenarios for environmental conditions are highlighted. All scenarios' results are presented in Phase 2 results section.

| **Construction Type** | Non-standard Scenario | **Phase 2 External Walls: VTT - Non-standard scenarios results.** | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 66 | | | |
| | | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| **EW1** | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| **EW2** | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| **EW3** | **S3.2** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Red | Grey | Red |
| | **S4.1** | Yellow | Red | Grey | Red | Yellow | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| **EW4** | **S3.2** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| | **S4.1** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| | **S4.2** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| **EW5** | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Yellow | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S4.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| **EW6** | **S3.2** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Red |
| | **S4.1** | Red | Red | Grey | Red | Red | Red | Grey | Red | Yellow | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |

| **Construction Type** | Non-standard Scenario | Phase 2 Roofs: VTT - Non-standard scenarios results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Climate Zone 21 | | Climate Zone 22 | | Climate Zone 60 | | Climate Zone 62 | | Climate Zone 66 | |
| | | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 |
| **RF1** | **S3.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.1** | Green | Red | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.2** | Red | Red | Yellow | Yellow | Yellow | Yellow | Yellow | Yellow | Red | Red |
| **RF2** | **S3.2** | Yellow | Yellow | Green | Green | Green | Green | Green | Yellow | Green | Green |
| | **S4.1** | Red | Red | Yellow | Red | Yellow | Red | Red | Red | Yellow | Yellow |
| | **S4.2** | Red | Red | Yellow | Red | Red | Red | Red | Red | Red | Red |
| **RF3** | **S3.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.1** | Red | Red | Green | Green | Green | Green | Yellow | Yellow | Yellow | Yellow |
| | **S4.2** | Red | Red | Red | Red | Red | Red | Red | Red | Red | Red |
| **RF4** | **S3.2** | Yellow | Red | Green | Green | Yellow | Yellow | Green | Green | Green | Green |
| | **S4.1** | Red | Red | Yellow | Yellow | Yellow | Red | Red | Red | Red | Red |
| | **S4.2** | Red | Red | Red | Red | Red | Red | Red | Red | Red | Red |

_Table notes:_
**Green – Low mould growth risk; Yellow – Medium mould growth risk; Red – High mould growth risk; Grey – not under assessment.*

## Key Finding 4: Attention to detail during the construction process is paramount to reduce mould growth risks.

When hygrothermal performance is assessed in 2D, the results differ significantly from those obtained through cross-sectional analysis. Assemblies that initially demonstrated lower mould growth risk under standard conditions in Phase 1 and Phase 2 now exhibit vulnerabilities in specific construction details.

Table 5 shows the hygrothermal performance results of the most critical assemblies and details, tested under standard conditions. A full set of results is presented in Section 4.3. The 2D assessment evaluates two-dimensional heat and moisture flow at specific junctions, providing a detailed analysis of the various materials and components. Consequently, the results are categorised according to the materials' sensitivity classes, which influence the mould growth risk per the VTT mould growth model. These classes include:

- Very Sensitive Materials: Paper-faced gypsum board, organic materials, and untreated wood.

- Sensitive Materials: Wood baseboards.
- Medium Resistant Materials: Glass wool.

Construction detail for external walls, particularly brick veneer (EW3) and cavity brick veneer (EW4), exhibit the highest risk of mould growth, especially at critical points like window heads (D5), windowsills (D6), and wall bases (D4, D7), due to their tendency to trap moisture. Findings reveal that the window-wall interface is particularly susceptible to condensation, primarily due to air leakage resulting from inadequate sealing and flashing [8]. Additionally, wall base flashing is essential to prevent water infiltration and to facilitate effective water diversion.

Lightweight assemblies (EW1 and EW2) generally exhibit a lower risk of mould growth under standard conditions. However, if not properly designed and constructed, they can still be susceptible to condensation and moisture accumulation at specific details, such as window-wall interfaces and wall bases.

Failures in membranes (D1), such as perforations and discontinuities, can create voids that allow moisture to penetrate construction layers, thereby compromising vapor control properties. This moisture intrusion can lead to condensation, mould growth, and structural damage. The 2D assessment results indicate a significant risk for timber elements in masonry walls (EW3 and EW4), as these materials are particularly susceptible to moisture absorption and transport through points of membrane failure. Timber's hygroscopic nature exacerbates this issue, as it readily absorbs and retains moisture, which can then spread through capillary action.

Additionally, corner gaps (D2) are critical points for moisture accumulation, influenced by outdoor climate changes and indoor latent heat impacts, particularly in Climate Zone 66. Proper flashing, sealing, and moisture management are essential to prevent these issues and maintain the building's structural integrity. Table 5 shows a snapshot of the results of the critical assemblies.

**Table 5:** External walls and Roofs—Construction details simulation results for critical assemblies. Mould growth risk is assessed following the VTT mould growth model and reported according to the different material sensitivity classes: very sensitive (VS), sensitive (S), and medium resistant (MR)[9].

| Climate Zone 66 Results 2D Walls | | | |
|---|---|---|---|
| 2D Details | VTT | | |
| | VS | S | MR |
| EW3-D1 | Red | Yellow | Green |
| EW3-D2 | Red | Red | Yellow |
| EW3-D3 | Yellow | Green | Green |
| EW3-D4 | Red | Yellow | Green |
| EW3-D5 | Red | Yellow | Green |
| EW3-D6 | Red | Red | Green |
| EW3-D7 | Red | Yellow | Green |
| EW3-D8 | Red | Red | Green |
| EW4-D1 | Red | Red | Yellow |
| EW4-D2 | Red | Yellow | Green |
| EW4-D3 | Red | Yellow | Green |
| EW4-D4 | Red | Yellow | Green |
| EW4-D5 | Red | Yellow | Green |
| EW4-D6 | Red | Yellow | Green |
| EW4-D7 | Red | Red | Yellow |

| Climate Zone 66 Results 2D Roofs | | | |
|---|---|---|---|
| 2D Details | VTT | | |
| | VS | S | MR |
| RF1-D1 | Red | Red | Green |
| RF1-D2 | Green | Green | Green |
| RF1-D3 | Green | Green | Green |
| RF1-D4 | Green | Green | Green |
| RF1-D5 | Red | Red | Green |

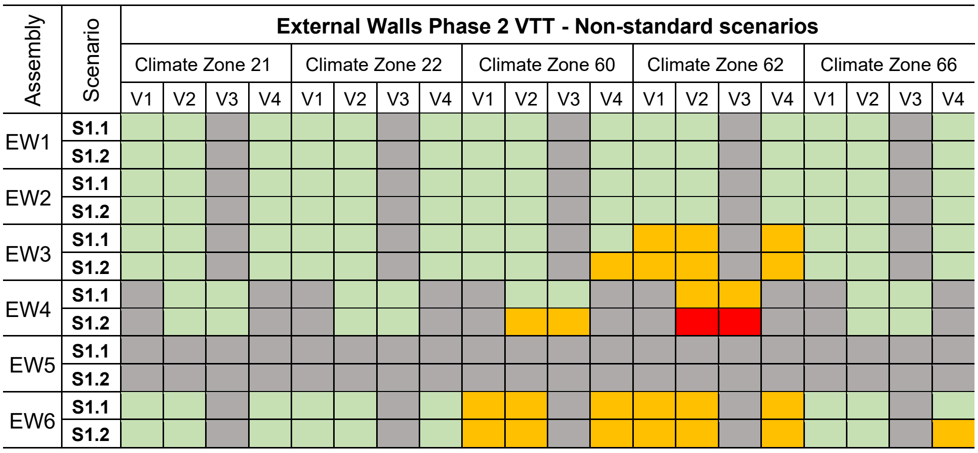
<u>*Table notes:*</u>
**Green – no mould growth risk; Yellow – Medium mould growth risk; Red – High mould growth risk*
**Very sensitive (VS) – Untreated wood*
**Sensitive (S) – paper-coated products, wood-based boards*
**Medium Resistant – Concrete, glass wool.*

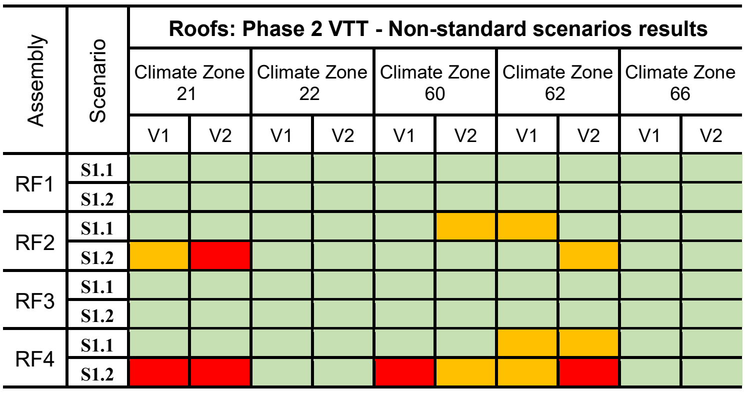
Similar to walls, roof details also contain critical points that require additional measures, particularly under Climate Zone 66 scenarios due to its higher temperature and humidity fluctuations. Details related to membrane sealing (D1) present a high risk of mould growth, requiring enhanced practices to ensure proper fixing and continuity. In addition, flashing and sealing are essential for moisture management in complex roof geometries, such as service penetrations and skylights (D5). Table 5 shows the construction details assessment results for climate zone 66, focusing on roof type 1 (metal clad). From this set of results, it can be seen that details involving water leaks through skylight (D5) necessitate additional measures, such as stringent waterproofing and flashing, particularly to control moisture content and absorption of materials like timber. While incorporating ventilation significantly reduced the risk of mould, it did not eliminate it entirely. Therefore, meticulous fixing and sealing is crucial.

**Key finding 5: A ventilated cavity can reduce the risk of mould growth in almost all scenarios.**
Ventilation across all Phases of analysis has demonstrated an efficient measure to support materials' drying capacity under increased moisture conditions. However, standards and NCC do not provide specific guidelines on optimal ventilation rate, a research gap identified early in this research.

Phase 2 involved testing the addition of ventilation in air cavities for walls and roof assemblies (S1.1) at a constant rate of 25 air changes per hour (ACH). The results showed a significant improvement in masonry walls and tiled roofs, with some cases achieving a total reduction in mould growth risk. Additional testing was conducted to understand the impact of cavity thickness alongside the addition of ventilation (Scenario 1.2), which proved less effective. This highlights the critical importance of maintaining adequate cavity thickness to ensure effective airflow.

**Table 6:** Phase 2 non-standard scenarios results for testing ventilation in air cavities.




Additional testing was conducted for the worst-performing Phase 3 details by incorporating ventilation into external wall masonry assemblies (EW3 and EW4). This involved adding weep holes into selected details to create the ventilation inlet, as required by the current NCC 2022 Housing provisions. Three different ventilation rates were modelled, as detailed in Table 7, and the results were compared against the standard scenario results (VTT version 1, which does not consider ventilation). The other two scenarios tested ventilation at rates of 50 ACH (Version 2) and 100 ACH (Version 3), as outlined in Table 7.

A comprehensive literature review was conducted to determine the appropriate ventilation rates. The selection criteria were based on the effectiveness of different rates in reducing mould growth risk. Notably, a significant reduction in mould growth was observed with a ventilation rate above 50 ACH.

**Table 7:** Additional ventilation rates are incorporated into selected construction details for external walls. The risk of mould growth is assessed using the VTT mould growth model and reported based on different material sensitivity classes and ventilation rates.

| 2D Details | VTT (Version 1) | | | VTT (Version 2) | | | VTT (Version 3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | VS | S | MR | VS | S | MR | VS | S | MR |
| EW3-D1 | Red | Yellow | Green | Red | Yellow | Green | Yellow | Green | Green |
| EW3-D2 | Red | Red | Yellow | Red | Yellow | Green | Yellow | Green | Green |
| EW3-D3 | Yellow | Green | Green | Yellow | Green | Green | Green | Green | Green |
| EW3-D4 | Red | Yellow | Green | Red | Green | Green | Green | Green | Green |
| EW3-D5 | Red | Yellow | Green | Red | Green | Green | Yellow | Green | Green |
| EW3-D6 | Red | Red | Green | Red | Yellow | Green | Red | Yellow | Green |
| EW3-D7 | Red | Yellow | Green | Red | Yellow | Green | Red | Yellow | Green |
| EW3-D8 | Red | Red | Green | Red | Yellow | Green | Red | Yellow | Green |
| EW4-D1 | Red | Red | Yellow | Yellow | Yellow | Green | Yellow | Green | Green |
| EW4-D2 | Red | Yellow | Green | Red | Red | Yellow | Red | Yellow | Green |
| EW4-D3 | Red | Yellow | Green | Yellow | Green | Green | Yellow | Green | Green |
| EW4-D4 | Red | Yellow | Green | Yellow | Yellow | Green | Yellow | Yellow | Green |
| EW4-D5 | Red | Yellow | Green | Red | Yellow | Green | Red | Yellow | Green |
| EW4-D6 | Red | Yellow | Green | Red | Yellow | Green | Yellow | Green | Green |
| EW4-D7 | Red | Red | Yellow | Red | Red | Yellow | Red | Red | Yellow |

*Table notes:*
**Green – Low mould growth risk; Yellow – Medium mould growth risk; Red – High mould growth risk; Grey – not under assessment.*
**Very sensitive (VS) – Untreated wood*
**Sensitive (S) – paper-coated products, wood-based boards*
**Medium Resistant – Concrete, glass wool.*
** VTT Version 1 – No ventilation; VTT Version 2 – ACH 50; VTT Version 3 – ACH 100*

The results indicate significant improvements with a high air change rate of 100 ACH. Most details showed reduced mould growth risk, except for the inner plasterboard lining at the windowsill-wall junction (D6) in the single masonry wall (EW3) and penetrations (D2), window head (D5) in double brick masonry (EW4), This is due to the sensitivity class assigned to the material (Very sensitive), represented as a paper-faced gypsum board. In these cases, using moisture-resistant plasterboard would be appropriate, as it typically contains core additives that repel water rather than absorb it. However, under flooding scenarios, the risk of moisture-related issues remained significant, demonstrating that high ventilation rates alone are insufficient. Therefore, additional measures, such as enhanced sealing, proper flashing, and the use of moisture-resistant materials, are essential for comprehensive moisture management.

## Regulatory Framework

This research evaluated the moisture resilience of typical construction assemblies that comply with the National Construction Code, Volume Two 2022, Housing provisions, specifically in relation to energy efficiency (Part 13.2) and condensation management (Part 10.8). The findings indicate that, although these systems meet regulatory requirements, certain assemblies may still develop mould over time, posing a long-term risk over a projected ten-year period.

The National Construction Code (NCC) introduced condensation management provisions for new residential buildings in 2019. These included exhaust systems and vapour-permeable membranes on the exterior side of the primary insulation layer of external assemblies for specific building classes and climate zones. The mandated vapour permeance values are based on a broad climate classification that considers only eight climate zones across Australia without accounting for sub-climatic conditions. However, this research highlights that hygrothermal performance is highly sensitive to variations in sub-climatic conditions, revealing significant limitations in the current climate zoning system. The existing zoning framework is too coarse to capture localized environmental differences, leading to an inadequate assessment of mould growth risk. A more refined and site-specific zoning system is needed to ensure that moisture-related vulnerabilities are thoroughly evaluated based on the specific climatic conditions of a given location.

Further, the 2022 update of the NCC [10] incorporated additional requirements to mitigate condensation in houses and apartments, these include increased vapour permeance for wall sarking, stricter roof ventilation, and additional indoor exhaust requirements which differ with the previous 2019 version, which provided only general guidance on wall construction without specific vapour requirements, roof ventilation without consideration of climate zones, and exhaust systems without the current 10-minute continuation or the mandate to discharge to the outside of the building. [11].

The 2022 NCC version does not mandate specific ventilation requirements for cavities, therefore ventilation is usually not accounted for in standard hygrothermal assessment. However, after extensive consultations with the industry, the latest draft of NCC 2025, published for public comment in May 2024, envisages minimum expectations regarding the use of ventilated and drained cavities (deemed to satisfy solution). These provisions mandate design requirements for cavities (with thicknesses conforming to this research's standard construction definition) and ventilation openings. However, minimum expected ventilation rates are not specified. This omission is significant, given that air change rates within wall cavities are governed by a complex interplay of environmental and construction-related factors. Key environmental influences include wind pressure, temperature fluctuations, and humidity levels, all of which can drive air movement within cavities and impact moisture behaviour. Construction-related factors, such as cavity depth, ventilation openings, material properties, and the presence of insulation, further contribute to variations in airflow. Additionally, unintended pathways created by construction defects or aging materials can alter expected ventilation rates.

The findings of this study revealed that the ventilation rate applied to air cavities has a significant impact on simulation results. This highlights the critical need for clear guidance on how to account for cavity ventilation during hygrothermal assessments, ensuring that models accurately capture all relevant variables.

This research demonstrates that the current approach—where assessments are performed based on a standard case—fails to capture the high variability of real-world conditions that assemblies may encounter. Therefore, it calls for a more comprehensive methodology that evaluates a range of environmental and construction scenarios to better account for this variability and ensure more reliable moisture risk assessments and more resilient construction systems.

# 1. Introduction

This report provides a comprehensive analysis of the hygrothermal performance of standard construction assemblies that comply with regulatory requirements for residential buildings in Victoria, Australia. This research examined how these systems perform under variations in standard conditions, meant as the combination of assumptions usually employed to test code compliance to the relevant provisions, evaluating their resilience to mould growth.

The investigation was undertaken by the University of Sydney, in collaboration with the Facade Team in Mott MacDonald, for the Victorian Building Authority (VBA) as part of the VBA's 2022 Research Grant Program, which aims to enhance the prevention of moisture penetration and water-related damage in buildings throughout Victoria.

The project was conducted in three phases:

- ***Phase 1 Standard Construction:*** This phase involved assessing the hygrothermal performance of typical residential building envelope assemblies, with a focus on Victoria's diverse climates and the current provisions outlined in the NCC 2022, Housing Provisions Deemed-to-Satisfy (DTS) guidelines relevant to condensation management [4]. The aim was to evaluate how well these construction systems perform in relation to moisture management under standard conditions.
- ***Phase 2 Non-Standard Scenarios:*** In this phase, all building assemblies assessed in Phase 1 were re-evaluated under a range of non-standard scenarios. The objective was to test the resilience of these systems to non-standard moisture conditions, providing a more comprehensive understanding of their performance under different environmental circumstances.
- ***Phase 3 Construction Details:*** This phase concentrated on analysing complex geometries with non-uniform heat and moisture sources to identify potential weak points that could compromise the hygrothermal performance of the construction systems evaluated in Phase 1 and Phase 2.

During the project, each phase was thoroughly discussed with the VBA through regular meetings with the core research team and the broader Research Advisory Group (RAG). Composition of the RAG included:

- Three members from the University of Sydney
- Four representatives from the Victorian Building Authority, including Building Surveyor, Principal Plumbing Specialist, Principal Structural Engineer and Research and Evaluation Manager
- Representative from the Department of Environment, Land, Water and Planning (Building Division, Planning), including the Director, Building Policy, Projects and Intergovernmental
- Representative(s) from the Australian Building Codes Board, including the Director, NCC Projects and Analysis and a Senior Project Officer, NCC Projects & Analysis
- One senior representative from the façade industry, Mott Macdonald Consulting Group.

The RAG role was to provide input, insights and comments to the research, ensuring that assumptions and results of each phase were relevant to the industry. Reports outlining assumptions, methodology and key findings of each phase were endorsed by the RAG on the following dates:

- Phase 1 Report – Issued in November 2023
- Phase 2 Report – Issued in January 2024
- Phase 3 Report – Issued in November 2024

Changes to the project scope after feedback from the RAG included:

- Changes in the performance definition for the assemblies due to the update of the NCC from the 2019 to the 2022 version in due course.

[4] NCC 2022, Housing Provisions, Part 10.8.

- Changes in the catalogue of construction assemblies to account for different variations within the assemblies.
- Inclusion of insulation variations for Phase 1 and Phase 2.
- Inclusion of additional 2D components and parameters, such as increased ventilation rates in the air cavities of selected assemblies.

## 1.1 Aims and Objectives

The overarching objective of this research was to evaluate the moisture resilience of regulatory-compliant external walls and roof assemblies under both standard and variable (non-standard) conditions. This evaluation also considered construction details where non-uniform sources of heat and moisture are present. Through this comprehensive assessment, the research aimed to provide an evidence-based overview of current design and construction practices, critically analysing their effectiveness in ensuring moisture resilience. Furthermore, it sought to produce insights that fill existing gaps in the Australian Construction Code and guide the formulation of future moisture safety regulations.

## 1.2 Research Scope

This research focused on the following scope:

- Building class 1, as defined by the NCC.
- Six wall and four roof assemblies. These systems have been selected to reflect typical building practices and materials currently employed in the Victorian residential sector.
- Seven climate zones across Victoria, aligned with NatHERS Climate Zoning, chosen to represent a range of climatic conditions and assess how different sub-climatic conditions impact building performance.
- Hygrothermal performances were assessed through virtual modelling only.
- The simulation methods followed the AIRAH DA07 and ASHRAE 160 standard.

## 1.3 Report Outline

- Section 1: Project introduction and objectives.
- Section 2: Research background.
- Section 3: Overall methods and approach for Phase 1, Phase 2, and Phase 3.
- Section 4: Hygrothermal performance results.
- Section 5: Key findings and conclusions.

# 2. Research Background

## 2.1 Mould globally

Indoor environment conditions and occupants' health are intrinsically correlated [14]. Research has shown that this correlation is influenced by a variety of factors, including thermal comfort, lighting, acoustic, and air quality, with mould and moisture issues being key factors that negatively affect occupants' health [15]. Consistent exposure to mouldy indoor environments can lead to a range of health issues, such as respiratory and allergic diseases, irritation symptoms (affecting eyes, nose and throat) and pro-inflammatory responses in the body (caused by mould compounds such as endotoxins) [16]. Beyond impacting occupants' health and wellbeing, mould is also responsible for increasing the risk of corrosion of metals, and biodeterioration of building materials, compromising the material's lifespan and anticipating remedial works [17].

Worldwide, 30% of homes were affected by mould in 2009 [13], with the latest projections reporting up to 47% [12]. With potentially millions of people negatively affected by mould, a transition to more resilient building practices is essential. This requires improved design strategies, enhanced moisture management techniques, and stricter regulatory measures to mitigate mould risks.

## 2.2 Mould in the Australian context

Research has identified that 40% of existing regulatory-compliant Australian housing presents moisture issues, such as condensation [18], and at least 27% of rental properties are declared to have mould problems [12]. This prevalence is due to a combination of climate, building practices, and occupant behaviour.

- Climate and Weather Conditions – Many parts of Australia experience high humidity, warm temperatures, and seasonal heavy rainfall, all of which create ideal conditions for mould growth [19–21]. Coastal regions, in particular, are prone to persistent moisture due to high atmospheric humidity and salt-laden air.
- Building Design and Materials – Traditional and modern construction practices in Australia often prioritize thermal efficiency without always considering moisture management. Lightweight construction materials, such as plasterboard and timber, are particularly susceptible to moisture retention, while inadequate ventilation in newer, airtight homes can trap humidity indoors [1].
- Condensation Issues – With increasing energy efficiency standards, buildings are being constructed to be more airtight, which can inadvertently lead to higher condensation risks if proper ventilation strategies are not implemented[20–22].
- Extreme Weather Events – Climate change is increasing the frequency and intensity of extreme weather events, including heavy rainfall, flooding, and cyclones, leading to prolonged damp conditions in homes. Water ingress from storms, combined with slow drying times, significantly increases mould risks [23].
- Occupant Behaviour – Everyday activities such as cooking, showering, and drying clothes indoors contribute to high indoor humidity levels. Without adequate ventilation or moisture control measures, this excess humidity encourages mould proliferation [24].

Water ingress, moisture accumulation, and the resulting damage consistently rank among the most common building defects, as reflected in complaints received by the VBA and in claims filed with the Victoria Managed Insurance Authority (VMIA). Research conducted by Victoria University, in partnership with the VBA and VMIA, found that 92% of the approximately 2,000 accepted domestic building insurance claims involved at least one water-related defect. A closer analysis of 54 selected claims highlighted the potential for these defects to contribute to mould growth, underscoring the significant risks associated with water damage in residential construction. Research has identified several improvement opportunities for building design, certification, construction, inspection, and waterproofing. These include the development of detailed construction drawings, the implementation of mandatory inspections prior to the issuance of occupancy certificates, and the encouragement of performance-based solutions for complex designs to ensure proper waterproofing [21].

Based on these results, the 2022 VBA's Research Grant Program targeted moisture penetration, condensation management and water damages in buildings.

## 2.3 Condensation and Mould – National Construction Code of Australia

Surface and interstitial condensation have been affecting Australian constructions for decades with documented concerns dating back to at least the early 2010s [25,26]. Further studies on the topic have demonstrated that enhancements in regulatory energy efficiency provisions in the Australian National Construction Code (NCC) Volume One and Volume Two 2019 [27] have exacerbated this issue [19] concluding that at least one-third of the Australian building stock presents moisture-related issues [28] due to the increment in airtightness and insulation requirements (R-values) [1], and poorly ventilated indoors with high thermal bridging [12].

The NCC only included condensation management provisions for new residential buildings in 2019, by mandating the use of 'exhaust systems' to reduce the moisture loads and by requiring the addition of a vapour permeable pliable membrane on the exterior side of the primary insulation layer of external assemblies for certain building classes and climate zones. The specified vapour permeance of the membrane varies according to the location of the construction. However, the code accounts only for eight climate zones, usually used for energy provisions, without acknowledging the differences in moisture pressure given by specific sub-climatic conditions. Hence, whether these provisions are suitable for all Australian construction types and climatic conditions is unclear. The NCC update of 2022 [10] incorporated additional requirements to mitigate condensation in houses and apartments, attributed to the reported appearance of moisture-related issues in construction [29], particularly evident in cold climate regions such as Victoria [30]. Some of the new requirements incorporated include increased vapour permeance to wall sarking, more stringent roof ventilation and sarking requirements and additional indoor exhausting requirements [11,30]. The latest draft of NCC 2025, published for public comment in May 2024, envisages some more detailed requirements with regards to vapour permeability of the sarking and minimum expectations with regards to the use of ventilated and drained cavities (deem to satisfy solution). However, it shares similar limitations to previous versions.

Therefore, further research and data are essential to assess whether the incremental implementation of current regulatory framework is effectively addressing moisture-related defects and mould risks, ensuring that building practices are moving in the right direction.

# 3. Methodology

This section outlines the methodology adopted for this study, which is designed to respond to the research aims, in particular:

- To test the hygrothermal performance of different regulatory-compliant construction systems (external walls and roofs) under standard conditions, meant as those conditions usually employed for condensation assessment (Research Phase 1);
- To conduct further testing of the selected regulatory-compliant construction systems under non-standard scenarios to test their drying potential and resilience to moisture damage (Research Phase 2); and,
- To investigate the hygrothermal performance of typical construction details (e.g., wall-to-roof section, wall corner) to detect weak points where non-uniform sources of heat and moisture occur (Research Phase 3).

This study employs virtual simulations to test the hygrothermal performance of the selected construction systems. The WUFI software suite is selected as a simulation tool due to its reliability for conducting hygrothermal assessments in building components [1]. This family of simulation tools allows for long-term assessment and the use of post-processors based on validated models for mould growth risk evaluation [9], as well as analysis of heat and moisture transport in two dimensions, which is essential for complex geometries such as window heads and sills and wall corners, among others.

The performance evaluation follows the VTT mould growth model, which is the foundation of the ASHRAE 160 Standard [3] and has been identified as one of the most reliable models for predicting mould growth [4] The VTT model has been successfully employed in several previous research projects, including the University of Tasmania Assessment of mould growth risk in regulatory compliant 6 and 7 star new homes in Victoria [31], also supported by the Victorian Building Authority through a research grant. The selection of this assessment method enables the two projects to adopt a consistent approach, increasing comparability and coherence across results.

Each research phase encompassed several stages, beginning with a literature review to define the scope of the assessment and establish parameter definitions. This was followed by stakeholder engagement through a Reference Advisory Group (RAG) to present research findings and obtain validation on the applicability of various constraints in real industry practices. Subsequently, simulation parameters were defined to accurately perform hygrothermal assessments. The final stages involved performance assessment, interpretation of results, and presentation of key findings to the RAG for validation.

## 3.1 Phase 1 – Standard Construction

### 3.1.1 Catalogue Phase 1 (Standard Construction)

This study examined wall and roof types typically used in Victoria, with data on their distribution and frequency sourced from various references, including the following:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australian database [32]
- Australian regulatory requirements [18,21,23]
- Australian grey literature and commercial publications [11,29,30,34,35]

The various sources enabled the evaluation of the most prevalent construction typologies in the building stock and expanded the catalogue of wall and roof types to include variations to reflect NCC-compliant solutions.

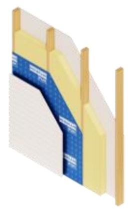
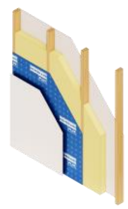
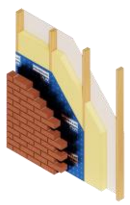
According to the sources consulted, brick veneer walls (EW3) are the most common construction method in Victoria, comprising 47% of single-dwelling housing stock. Clad weatherboard walls (EW1) followed at 22%, reflecting a trend toward cost-effective renovations. Less common systems, such as autoclaved aerated concrete masonry (5%), are considered to be emerging construction trends. In terms of roofing, mixed roofs ( a combination of tiled and metal) are the most prevalent, accounting for 46% of single-dwelling homes. Metal roofs follow at 30%, while tiled roofs make up 22%.

Based on this data, the catalogue of the most common construction assemblies in Victoria included six wall and four roof assemblies, both categorized by their cladding, in line with the CSIRO Australian Housing Database [32].

All air cavities were assumed to be unventilated due to the absence of specific ventilation rate requirements in Australian regulations. Consequently, unventilated cavities were used in the hygrothermal assessments to represent a worst-case scenario. Table 8 outlines Catalogue of Standard Construction used for Phase 1.

Lightweight wall systems (EW1 and EW2) are modelled with the inclusion of an unventilated air cavity. While the National Construction Code (NCC) does not currently mandate the use of an air cavity—allowing for direct-fix cladding systems—it is increasingly recognised that incorporating a cavity can significantly enhance the hygrothermal performance. Notably, upcoming NCC 2025 provisions will introduce mandatory ventilated cavities in certain climate zones (6, 7, and 8) to address condensation risks [36]. This research evaluates lightweight wall assemblies with the inclusion of a non-ventilated air cavity as a baseline for assessment.

**Table 8:** Common Victorian External Walls and Roofs Construction Systems.

| Code | Construction System | Detail | Build-ups | Specifications | | |
|---|---|---|---|---|---|---|
| | | | | Thickness (mm) | R value ($m^2 \cdot K/W$) | Density ($kg/m^3$) |
| **EW1** | Weatherboard lightweight-clad wall [5] |  | 1. Weatherboard cladding [40] | 19 | | 506 |
| | | | 2. Air cavity [6] | 35 | - | - |
| | | | 3. Water control membrane [7] | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/Ns) | | |
| | | | 4. Insulation in timber studs [8] | According to Table 9 | | |
| | | | 5. Plasterboard [41] | 13 | 0.170 | 880 |
| **EW2** | Fibre cement lightweight-clad wall |  | 1. Fibre-cement cladding [9] | 8 | 0.39 | 1580 |
| | | | 2. Air cavity | 35 | - | - |
| | | | 3. Water control membrane | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/Ns) | | |
| | | | 4. Insulation in timber studs | According to Table 8 | | |
| | | | 5. Plasterboard. | 13 | 0.170 | 880 |
| **EW3** | Brick veneer masonry |  | 1. Brick veneer [41] | 110 | 0.39 | 1430 |
| | | | 2. Air cavity | 50 | - | - |
| | | | 3. Water control membrane | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/N.) | | |
| | | | 4. Insulation in timber studs | According to Table 9 | | |
| | | | 5. Plasterboard. | 13 | 0.170 | 880 |
| **EW4** | Cavity brick masonry | | 1. External brick masonry | 110 | 0.39 | 1430 |
| | | | 2. Air cavity | 50 | - | - |
| | | | 3. Water control membrane | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/Ns) | | |
| | | | 4. Insulation | According to Table 9 | | |

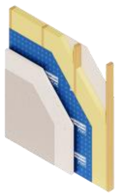
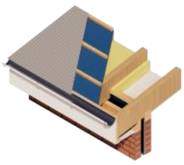
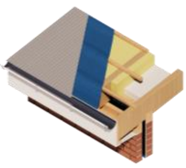
[5] Lightweight wall systems (EW1 and EW2) are represented with the inclusion of an unventilated air cavity, which represent best practices. NCC, do not mandate the inclusion of an air cavity, and suggests a direct-fix system.

[6] Air cavities are non-ventilated (ACH=0) as a baseline for assessment.

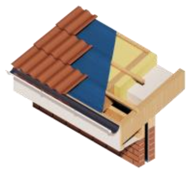
[7] Performance for membranes according to NCC 2022 Volume Two – P.10.8.1; for the scope of this research, Class 4 vapour control membranes located on the exterior side of the primary insulation layer have been specified (as a compliant solution).

[8] According to Table 9 (Insulation variations for external walls), expressed in ($m^2K$)/W.

[9] Fibre cement properties from manufacturer information 'Equitone Tectiva'

| Code | Construction System | Detail | Build-ups | Specifications | | |
|---|---|---|---|---|---|---|
| | | | | Thickness (mm) | R value (m²·K/W) | Density (kg/m³) |
| | |  | 5. Internal brick masonry | Same as external masonry | | |
| | | | 6. Plasterboard | 13 | 0.170 | 880 |
| EW5 | Externally insulated brick masonry |  | 1. Weatherboard cladding | 19 | 0.1 | 506 |
| | | | 2. Water control membrane | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/Ns) | | |
| | | | 3. Insulation | According to Table 9 | | |
| | | | 4. Air cavity | 50 | - | - |
| | | | 5. Brick veneer | 110 | 0.39 | 1430 |
| | | | 6. Plasterboard | 13 | 0.667 | 880 |
| EW6 | Autoclaved aerated concrete masonry |  | 1. Acrylic render [10] | 2 | 0.170 | 1900 |
| | | | 2. Autoclaved aerated concrete [11] | 50 | 0.150 | 510 |
| | | | 3. Air cavity | 24 | - | - |
| | | | 4. Water control membrane | Membrane class 4 (AS4200.1), vapour permeance of 1.1403 (µg/Ns) | | |
| | | | 5. Insulation [12] | According to Table 9 | | |
| | | | 6. Plasterboard | 13 | 0.667 | 880 |
| RF1 | Metal clad flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter |  | 1. Roof Cladding (metal) | 4 | - | 2680 |
| | | | 2. Air space + battens | 40 | 0.170 | - |
| | | | 3. Sarking / blanket | 1 | - | 260 |
| | | | 4. Rafter remaining roof space | 290 | 0.170 | - |
| | | | 5. Ceiling insulation (rafter allowance) | 290 | Insulation According to Table 10 | |
| | | | 6. Ceiling lining (Plasterboard) | | 0.059 | 850 |
| RF2 | Tiled flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter |  | 1. Roof Cladding (terracotta) | 26 | 0.032 | 1939 |
| | | | 2. Air space + battens | 40 | 0.170 | |
| | | | 3. Sarking / blanket | 1 | - | 260 |
| | | | 4. Rafter remaining roof space | 290 | 0.170 | - |
| | | | 5. Ceiling insulation (rafter allowance) | 290 | Insulation According to Table 10 | |
| | | | 6. Ceiling lining (Plasterboard) | | 0.059 | 850 |
| RF3 | Metal clad Flat roof, skillion roof and cathedral ceiling with exposed rafters |  | 1. Roof Cladding (metal) | 4 | - | 2680 |
| | | | 2. Air space + battens | 40 | - | - |
| | | | 3. Sarking / blanket | 1 | - | 260 |
| | | | 4. Rafter remaining roof space | 20 | 0.170 | - |
| | | | 5. Ceiling insulation (rafter allowance) | variable | Insulation According to Table 10 | |
| | | | 6. Ceiling lining (Plasterboard) | 10 | 0.059 | 850 |
| | | | 7. Rafter | 270 | - | - |
| RF4 | Tiled skillion roof and cathedral ceiling with exposed rafters | | 1. Roof Cladding (terracotta) | 48 | 0.032 | 1939 |
| | | | 2. Air space + battens | 40 | - | - |
| | | | 3. Sarking / blanket | 1 | - | 260 |
| | | | 4. Rafter remaining roof space | 20 | 0.170 | - |

[10] Acrylic render properties from manufacturer information 'Atlas acrylic render, thin coat'
[11] Aerated concrete properties from WUFI materials database.
[12] According to Table 10 (Insulation variations for roofs), expressed in (m$^2$K)/W.

| Code | Construction System | Detail | Build-ups | Specifications | | |
|---|---|---|---|---|---|---|
| | | | | Thickness (mm) | R value ($m^2 \cdot K/W$) | Density ($kg/m^3$) |
| | |  | 5. Ceiling insulation (rafter allowance) | variable | Insulation According to Table 10 | |
| | | | 6. Ceiling lining (Plasterboard) | 10 | 0.059 | 850 |
| | | | 7. Rafter | 270 | - | - |

Studies highlight insulation as one of the layers that significantly influence the thermal performance of buildings, leading to increased risks of condensation [23,37,38]. One major cause of interstitial condensation includes the temperature difference between the material and the air dew point [23], a condition that is particularly problematic in cold climates [20]. Therefore, the choice of insulation material is crucial to reduce condensation and mould growth risks [39]. Hence, this study included variations to the insulation, accounting for the broad variety of hygrothermal performance that this layer offers. According to the databases consulted during the identification of the most common wall types [32], glass wool insulation is the predominant type found in existing, renovated, and new dwelling stock. Reflective insulation and a combination of the two types are also considered predominant variations. Hence, three variations have been considered: bulk insulation, reflective insulation, and a combination of both, as outlined in Table 9 and Table 10 [32].

**Table 9:** Insulation Variation for External Walls – Parameters Review.

| **Scenario name** | **Insulation type** | **R-value** [40–42] | **Applicability** |
|---|---|---|---|
| V1 | Bulk insulation | 2.3 | All wall types except EW4 |
| V2 | Bulk insulation | 2.7 | All wall types except EW4 |
| V3[13] | Reflective insulation | 0.29 | All wall types |
| V4 | Bulk (V2) + reflective | 2.99 | All wall types except EW4 |
| V2[14] | Reflective | 0.2 | EW4 |
| V3[15] | Pliable composite insulation membrane | 0.45 | EW4 |

**Table 10:** Insulation Variation for Roofs – Parameters Review.

| **Scenario name** | **Insulation type** | **R-value** [43,44] | **Applicability** |
|---|---|---|---|
| V1 | Bulk insulation | 2.5 | All roof types |
| V2 | Bulk insulation | 4.1 | All roof types |
| V3 | Reflective insulation | 0.15 | All roof types |
| V4 | Bulk (V2) + reflective | 4.25 | All roof types |

Not all insulation variations have been applied to each wall or roof typologies, due to inherent constraints. The different insulation scenarios have been selected to match the wall typologies based on construction feasibility. The resulting matrix is the Phase 1 Walls Catalogue (Table 11), which include all walls and roofs variations considered to be commonly employed across Victoria.

**Table 11:** Phase 1 – Standard Construction Catalogue.

| **Code** | **Build-up Type** | **Variation Performance** ($m^2K$)/W[16,17] | | | |
|---|---|---|---|---|---|
| | | **V1** | **V2** | **V3** | **V4** |
| EW1 | Weatherboard lightweight-clad wall | 2.57 | 2.93 | 0.40 | 3.33 |
| EW2 | Fibre-cement lightweight-clad wall | 2.53 | 2.89 | 0.36 | 3.25 |
| EW3 | Brick veneer | 2.39 | 3.03 | 0.5 | 3.53 |

13 Microperforated membrane with low vapour permeance of 0.001(μg/N.s) (Class 1)
14 Reflective insulation acting as a vapour barrier, thermal break and microperforated with a class 4 permeance.
15 Breathable membrane, manufactured with closed-cell structured and reflective foil surface.
16 Variation performance corresponds to the total system R-Value measured in ($m^2K$)/W.
17 Variants correspond to different insulation types with different performances as outlined in Table 2.

| Code | Build-up Type | Variation Performance ($m^2K$)/W [16,17] | | | |
|---|---|---|---|---|---|
| | | V1 | V2 | V3 | V4 |
| EW4 | Cavity brick masonry [18] | n/a | 0.71 | 0.95 | n/a |
| EW5 | Externally insulated brick masonry | 2.51 | 3.15 | 0.62 | 3.77 |
| EW6 | Autoclaved aerated concrete masonry | 2.84 | 3.20 | 0.67 | 3.87 |
| RF1 | Metal clad roof with ceiling lining under rafter | 3.15 | 4.53 | 0.68 | 5.21 |
| RF2 | Tiled roof, with ceiling lining under rafter | 3.16 | 4.54 | 0.69 | 5.23 |
| RF3 | Metal clad roof, with exposed rafters | 2.98 | 4.36 | 0.16 | 4.52 |
| RF4 | Tiled clad roof, with exposed rafters | 2.99 | 4.37 | 0.17 | 4.54 |

The configurations of the construction assemblies were developed to reflect NCC-compliant solutions. However, due to the inherent constraints of one-dimensional hygrothermal simulation—where heat and moisture transport are modelled solely through the thickness of the assembly—certain two-dimensional or detail-specific features mandated by the NCC, such as weep holes in brick veneer systems, could not be represented in this phase. Consequently, the simulation results from Phase 1 should be interpreted as indicative of general performance trends rather than as a comprehensive evaluation of full NCC compliance.

## 3.1.2 Indoor and Outdoor Climate

### 3.1.2.1 Indoor boundary conditions

Studies have shown the influence of indoor climate selection and modelling in hygrothermal simulations [1]. Factors such as HVAC profiles, occupancy, and activities performed impact the temperature and hourly profiles set in the hygrothermal simulation. Therefore, this research followed the ASHRAE 160 approach for determining the indoor design temperature and relative humidity profiles [3].

**Table 12**: Hourly indoor design temperature (T) and relative humidity (RH).

| **Hourly indoor design temperature (T)** | |
|---|---|
| **24 h Outdoor Running Mean** | **Indoor Temperature Design** (Heating Only) |
| $T_{o,24h} < 18.3^{0}C$ | $21.1^{0}C$ |
| $18.3^{0}C < T_{o,24h} < 21.1^{0}C$ | $T_{o,24h} + 2.8^{0}C$ |
| $T_{o,24h} > 21.1^{0}C$ | $T_{o,24h} + 2.8^{0}C$ |

| **Hourly indoor design relative humidity (RH)** | |
|---|---|
| **Daily Average Outdoor Temperature** | **Design Indoor Relative Humidity** |
| $T_{o,\,day} < 10\ ^{0}C$ | 40% |
| $-10\ ^{0}C \leq T_{o,day} < 20\ ^{0}C$ | 40% + ($T_{o,day}$ + 10) |
| $T_{o,\,day} > 20\ ^{0}C$ | 70% |

### 3.1.2.2 Outdoor boundary conditions

The NCC divides Australia into eight general climate zones, two of which are pertinent to the state of Victoria [45]. However, given the impact of sub-climatic conditions on moisture loads [46] , this division is not considered sufficiently accurate to represent the broad variety of climatic conditions found across the state. The Nationwide House Energy Rating Scheme (NatHERS) divides Australia into 69 climate zones, nine of which are found in Victoria [47]. Therefore, this study includes seven of the nine NatHERS zones (as listed in Table 13), focusing on the state's most representative and diverse climatic conditions. Zones 27 and 61 were excluded as they are less populated, and their climatic conditions are similar to those already selected.

This selection allows for a more detailed and manageable analysis while still capturing the significant climatic variations that can impact the performance of external assemblies. It is important to note that NatHERS climate data is a granular version of the broader NCC climatic classification based on climate data available [48].

[18] EW4, V1 and V4 (are not applicable), V2 (membrane only) and V3 (reflective insulation).

**Table 13**: Victorian NatHERS climate zones [47].

| NatHERS Climate Zone | Description (NCC) |
|---|---|
| 21, 22, 60,62,63,64 | Mild temperate |
| 66 | Cool temperate |

### 3.1.3 General Simulation Parameters

General simulation parameters include all those settings necessary to run the simulations. Appendix 1 shows different parameter inputs used and based on ASHRAE 160 [3], British Standards, BS 5250:2011 [49] and DA07 Criteria for Moisture Control Design Analysis [50]. Key parameters included south orientation, 90-degree wall inclination, and rain load calculation. The calculation period spanned ten years (30/06/2023 to 30/06/2033) 1-hour calculation step. Building data included an air exchange rate of 10 ACR @n50 / 0.5 ACH and a building volume of 500 m².

As simulations were conducted over a 10-year period, it is possible to understand the long-term hygrothermal performance of the different build-up systems and identify which construction layers or details are the most concerning for moisture safety.

## 3.2 Phase 2 - Non-Standard Scenarios

Non-standard scenarios encompass a variety of non-standard situations that could lead to increased moisture conditions in the wall construction system. These atypical situations can arise from construction or environmental factors. Various parameters were defined as scenarios and applied to the Phase 1 Standard Construction Catalogue to further evaluate their resilience to moisture and mould growth.

### 3.2.1 Catalogue Phase 2 (non-standard construction)

Non-standard construction scenarios involve variations to the standard wall and roof assemblies identified in Phase 1. These variations were designed to stress-test the moisture resilience at different assembly interfaces. They represent physical conditions within the construction system that could either increase or reduce moisture accumulation and transfer between different construction layers. It is important to note that not all scenarios were applied to all wall types. The criteria for inclusion or exclusion were primarily based on the mould growth risk assessment results from Phase 1.

Phase 2 Catalogue contains all construction variations that may impact the hygrothermal performance of the walls, as presented in Table 15. Refer to Appendix 3 for further details.

#### 3.2.1.1 Ventilated air cavity

Phase 1 Catalogue do not consider ventilation within the wall and roof cavities. Therefore, the objective of including ventilation rates for air cavities as a non-standard scenario was to test the drying potential benefits for the different construction layers within the wall and roof assemblies. Recent studies have highlighted that ventilation is crucial to maintaining moisture control within wall cavities [51], and found correlations between the thickness of the air cavities and the hygrothermal performance of the construction system [52–54]. For instance, thicker cavities can produce more space for air circulation, thereby reducing moisture accumulation [52]. Further, it has been demonstrated that openings of the air cavity, along with its thickness, have an impact on the drying potential of the wall system [52–54].

Therefore, for the purpose of this research, the cavity ventilation has been modelled as follows:

- S1.1 considered an ACH of 25 1/h, adopting a conservative ventilation rate based on similar studies [31]
- S1.2 examines the impact of reducing the air cavity thickness by half, while maintaining a constant air change rate (ACH) of 25 1/h. Cavity geometry—particularly thickness and the configuration of ventilation openings—can significantly influence ventilation rates [52–54]. For instance, increased cavity thickness can enhance air circulation, thereby reducing the risk of moisture accumulation [52]. To further investigate this relationship, the scenario is designed to

assess the potential adverse effects of reduced cavity thickness on moisture control and overall hygrothermal performance.

**Table 14:** Ventilated air cavity scenarios.

| Scenario name | Value | Applicability (wall typology) |
|---|---|---|
| S1.1 | Constant ventilation rate of 25 1/h | All walls except for EW5<br>All roofs |
| S1.2 | As above + reduced cavity thickness to half. | |

EW5 has been excluded from this scenario due to the similarity of the external assembly with EW1, which both cases did not present a risk of mould growth under standard conditions.

#### 3.2.1.2 Membrane

Water control membranes play an important role in controlling moisture within the building envelope. Studies have found correlations between vapour permanence of the membranes (or membrane class as classified in standards such as AS4200.1) and mould growth risks [55] suggesting that the type of membrane used within a wall assembly can directly influence its moisture management capabilities. Therefore, this study tested different water control membranes placed at the interface of the insulation and the cladding, as stated in the Australian NCC [19] (Table 15).

**Table 15:** Water control membrane scenarios

| Non-standard Scenario | AS4200.1 classification | Reflective | Vapour Permeance (µg/N.s) | Water vapour diffusion resistance factor | Applicability |
|---|---|---|---|---|---|
| 2.1 | Class 4 | No | 2.179 | 91.8 | All walls, except V3[20] |
| 2.2 | Class 1 | Yes | 0.001 | 200,000 | All walls V4 |
| 2.3 | Class 4 | No | 1.429 | 140 | All Roofs |

#### 3.2.1.3 Phase 2 Catalogue

Table 16 reports the Phase 2 catalogue as a combination of construction variants applied to the assemblies defined in the Phase 1 Catalogue.

**Table 16:** Phase 2 Wall Catalogue- Construction Scenarios.

| Wall type | Construction Scenarios | |
|---|---|---|
| | Ventilated air cavity | Membrane |
| EW1 | S1.1, S1.2 | S2.1, S2.2 |
| EW2 | S1.1, S1.2 | S2.1, S2.2 |
| EW3 | S1.1, S1.2 | S2.1, S2.2 |
| EW4 | S1.1, S1.2 | N/A |
| EW5 | N/A | S2.1, S2.2 |
| EW6 | S1.1, S1.2 | S2.1, S2.2 |
| RF1 | S1.1, S1.2 | S2.3 |
| RF2 | S1.1, S1.2 | S2.3 |
| RF3 | S1.1, S1.2 | S2.3 |
| RF4 | S1.1, S1.2 | S2.3 |

### 3.2.2 Indoor and Outdoor Climate

#### 3.2.2.1 Indoor Climate

The influence of indoor climate in hygrothermal simulations has been highlighted by several studies [1,38,56]. While the indoor climate conditions used in Phase 1 are defined based on ASHRAE 160 and

[19] NCC 2022, Housing Provisions, Part 10.8.1 States requirements of placing a membrane in compliance with AS 4200.1 located on the 'exterior side of the primary insulation layer of wall assemblies that form part of the external envelope of a building'.
[20] In non-standard scenarios, only V4 is considered as it combines reflective insulation (V3) and glass wool insulation (V2).

AIRAH DA07, Phase 2 considered indoor relative humidity (RH%) and temperature (0C) obtained through whole building simulations, performed using Design Builder software. This step allows to account for transient variations of indoor climates, posing further moisture loads on the external walls.

Assumptions used for the whole building simulations included:

- building layout from the Apartment Design Guidelines for Victoria [57], representing a 2-bedroom dwelling; total building volume of 192m3(considering a GFA of 80m2 and a ceiling height of 2.4 meters);
- 4 occupants (assuming two adults and two children);
- occupancy schedule adapted from NatHERS calculation method [58].

**Table 17**: Indoor RH and T scenarios.

| Scenario name | Value | Applicability |
|---|---|---|
| **S4.1** | Hourly relative humidity and temperature calculated through Design Builder | All wall and roof types |

### 3.2.2.2 Outdoor climate

Outdoor climate conditions for Phase 2 were kept unchanged. It must be noted that Zones 63 and 64 were not included in Phase 2, due to the similarity of the hygrothermal performance of the wall and roof types tested under standard conditions.

## 3.2.3 General simulation parameters

Most general simulation parameters were kept unchanged from Phase 1, except for the rain penetration load. Under standard conditions, an initial moisture source is represented as a fraction of rain load at 1% (as per AIRAH DA07 [50]), applied to the outer side of the cladding. As Phase 2 of this study aims to understand the resilience of wall assemblies to increased moisture loads, the moisture load value has been adjusted to simulate additional moisture exposure. This adjustment was necessary due to the absence of specific full-scale test methods and data for the as-built exterior, as noted in the DA07 criteria. Therefore, two approaches were tested:

- S3.1 considered rain exposure factor of 1.4% (replacing the initial 1%).
- S3.2 considered an additional 5% moisture load to the inner side of the water control membrane.

**Table 18:** Rain penetration scenarios.

| Scenario name | Value | Applicability |
|---|---|---|
| **S3.1** | Fraction of rain load (1.4%) | All wall and roof types |
| **S3.2** | Fraction of rain load (1.4 + 0.5= 1.9%) | All wall and roof types |

Another parameter tested as a non-standard scenario was the Air Change Rate (ACR) within the building. The NCC [18] requires new buildings to be airtight based on a blower door test verification method, which allows to estimate the values of air infiltration and air leakage, based on air pressure difference [60]. Air leakage can’t be higher than 10 ACR @n50 (equivalent to 0.5 air exchange rate per hour) value that was considered as a baseline in Phase 1. Phase 2 further reduced this value to 5 ACR @n50 (or 0.25 air changes per hour), representing an airtight scenario aligned with similar studies [23].

**Table 19:** Air exchange rate scenarios.

| Scenario name | Value | Applicability |
|---|---|---|
| **4.2** | 5 ACR = 0.25 ACH | All wall and roof types |

# 3.3 Phase 3 - Construction Details Assessment

Phase 3 focused on investigating the hygrothermal performance of typical construction details (e.g., wall-to-roof section, wall corner) based on the bi-dimensional transient hygrothermal analysis performed in WUFI-2D simulation software. This 2D analysis expanded the scope of the standard WUFI Pro one-dimensional hygrothermal analysis (focused on the cross-section of the building envelope only), allowing the analysis of heat and moisture transport in two dimensions, useful to understand the resilience to moisture of complex geometries and critical connections such as thermal bridges.

## 3.3.1 Construction Details Scope Definition

A literature review was initially conducted to identify weak points in the various assemblies examined in Phases 1 and 2, focusing on areas where heat and moisture sources interact. The review the following sources:

- Proactive Inspections Program (PIP) Quarterly reports [59]
- ABCB materials, such as the 2023 Condensation Handbook [60]
- NCC Volume Two, Housing Provisions [33] parts:
  - 5.7. Weatherproofing of masonry (Parts 5.7.3 Damp-proof courses and flashing materials and 5.7.4 Damp-proof courses and flashings installation)
  - 7.2 Sheet Roofing (Parts 7.2.7 Flashing and cappings)
  - 7.3 Roof tiles and shingles (Parts 7.3.3 Flashing and 7.3.4 Sarking)
  - 7.5 Timber and composite wall cladding (Part 7.5.6 Flashing to wall openings)
- Master Builders Association waterproofing guides:
  - Guide to Internal Wet Area Waterproofing (Book 1) [61]
  - Guide to External Waterproofing - Balcony and Decks (Book 2) [62]
  - Waterproofing Guide to Flashings and Damp-Proof Courses (Book 4)[63]
- Research Advisory Group meeting notes (RAG), in particular:
  - RAG 6 (06.12.2023)
  - RAG 7 (15.05.2024)
  - RAG 8 (11.07.2024)
  - RAG 9 (18.10.2024)
  - RAG 10 (18.11.2024)
  - RAG 11 (14.03.2025).

Table 20 outlines the review's key findings, identifying the major factors contributing to moisture damage. This table directly informed the Phase 3 Catalogue of Construction Detail.

**Table 20:** Construction details scope key findings.

| Construction System | Factor | Component | Issue | Construction Details |
|---|---|---|---|---|
| External Walls | Building Sealing | Building wrap | Membrane not fixed to frame or discontinuous | Combined on a single detail (D1) |
| | | | Continuous corner gaps[21] | Represented in 2D detail D2 |
| | Water Leaks [22] | Services penetration[23] | Water vapour leakage through pipes, power outlets and wiring | Represented in 2D detail D3 |
| | | Flashing | Wall base flashing without a fall to prevent ponding | Represented in 2D detail D4 |
| | | | Cavity membrane does not overflash the upturn of the flashing.[24] | Represented in 2D detail D4 (EW4 only) |

[21] Represented as a gap between the internal plasterboard corner junction in order to assess the vapour and moisture transfer between indoor conditions into the construction layers.
[22] Representing general water damages.
[23] Water vapour can occur due to condensation or infiltration from cladding.
[24] Applicable to Cavity clay masonry wall type only (EW4).

| Construction System | Factor | Component | Issue | Construction Details |
|---|---|---|---|---|
| | | | Windows and door heads without or incorrect flashing | Window head flashing represented in 2D detail D5 |
| | | | Window or door sill without or incorrect flashing (i.e., without boxing edges to direct water, windowsill does not extend out and over the cladding) | Windowsill flashing represented in 2D detail D6 |
| | Water Ingress [25] | Floodings | Rising damp through walls | Represented in 2D detail D7 |
| | Thermal Bridge | Steel framing | Steel Frame/insulation | Represented in 2D detail D8 |
| Roofs | Building Sealing | Sarking | Discontinuous sarking | Represented in 2D detail RF -D1 |
| | | Unsealed Gaps | Continuous gaps behind wall/ceiling junctions | Represented in 2D detail RF -D3 |
| | Water Leaks | Roof-wall junction[26] | Ventilation opening | Represented in 2D detail RF -D2 |
| | | Ceiling services penetration | Water vapour leakage through roof/ceiling penetrations | Represented in 2D detail RF -D4 |
| | | Skylights | Water leakage due to improper flashing and installation. | Represented in 2D detail RF -D5 |
| | | | Condensation due to poor indoor ventilation. | |

## 3.3.2 Catalogue Phase 3 (construction details)

The construction details scope review (Table 20) directly informed the Phase 3 Catalogue.

Tables 21 and 22 present the catalogue iteration subsets for external walls and roofs, respectively. These iterations were tested against two different NatHERS climate zones: Zone 21, representing an urban scenario in Melbourne, and Zone 66, representing a suburban scenario in Ballarat. The first zone represents average conditions, while the second represents harsh environmental conditions.

**Table 21:** Construction Details Catalogue – External Walls.

| Construction Details Catalogue (2D) – External Walls | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Construction system** | **Building Sealing** | | **Water leaks** | | | | **Water Ingress** | **Thermal Bridge** |
| | | | | **Flashing** | | | | |
| | **D1** | **D2** | **D3** | **D4** | **D5** | **D6** | **D7** | **D8** |
| | Membrane | Corner gap | Services Penetrations | Wall base | Window head | Windowsill | Flooding | Steel frame |
| EW1 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| EW2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| EW3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| EW4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | x |
| EW5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| EW6 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Iteration #** | **6** | **6** | **6** | **6** | **6** | **6** | **6** | **5** |
| **Total** | **47** | | | | | | | |

[25] Water ingress due to environmental conditions such as flooding.
[26] Ventilation opening according to NCC 2022, Housing Provisions, Part 10.8.3.

**Table 22:** Construction Details Matrix – Roofs.

| Construction Details Catalogue (2D) – Roofs | | | | | |
|---|---|---|---|---|---|
| **Construction system** | **Building Sealing** | | **Water leaks** | | |
| | | | | **Flashing** | |
| | **D1** | **D2** | **D3** | **D4** | **D5** |
| | Membrane | Unsealed gap | Services Penetrations | Roof-wall junction | Skylight |
| RF1 | ✓ | ✓ | ✓ | ✓ | ✓ |
| RF2 | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Iteration #** | **2** | **2** | **2** | **2** | **2** |
| **Total** | **10** | | | | |

### 3.3.2.1 Construction Details – Additional testing

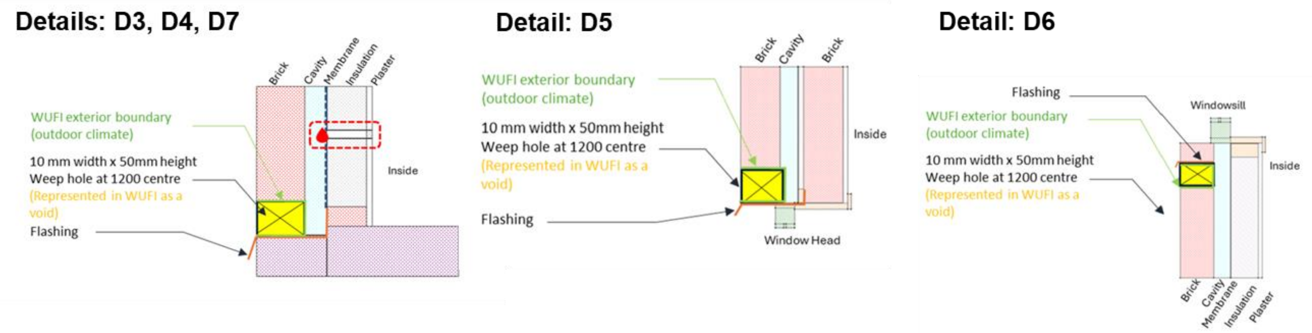
Following consultations with the VBA, construction details EW3 and EW4 were tested with enhanced cavity ventilation, as outlined in Section 4.3. These tests focused exclusively on Climate Zone 66, identified as the most critical for moisture-related risks. In this context, ventilation requirements under the current NCC 2022 and the upcoming NCC 2025 [36] were specifically examined. The 2D modelling was conducted as follows:

***Incorporation of weep holes:*** Weep holes were modelled according to the NCC 2022, Housing Provisions Section 5.7.5, which indicate location and sizing requirements.

Specific details included:

- Detail D3: Services penetration - Water vapour leakage through pipes, power outlets and wiring
- Detail D4: Flashing issues – Water leaks through base flashing
- Detail D7: Water ingress - Water ingress due to environmental conditions such as flooding
- Detail D5: Flashing issues - Windows and door head without or incorrect flashing
- Detail D6: Flashing issues - Window or door sill without or incorrect flashing

**Figure 1:** Applicability of weep holes in 2D details.




***Incorporation ventilation:*** In Phase 1, all air cavities were considered non ventilated, however anticipated modifications to the NCC (2025) NCC 2025—Draft, Section 10.8 Condensation Management [36] include design requirements for cavities and ventilation openings. Although specific ventilation rates are not specified, it is crucial to acknowledge that actual air change rates in wall cavities are highly variable and influenced by numerous environmental and construction factors. This research scope does not encompass a sensitivity analysis of ventilation rates. Consequently, a literature review has been conducted to identify current practices, drawing on findings from other studies [54,64]. In this assessment, construction details were evaluated with the air inlet applied at a specific point to simulate airflow from weep holes. Preliminary testing revealed significant variations in results when air exchange rates reached 50 air changes per hour (ACH) or higher. Based on these findings, air change rates of 50 and 100 ACH at a localized source were selected for further testing to better understand their impact on moisture management. The results from this additional testing are presented in Table 26. In summary, the following parameters were considered:

- Option 1 – No ventilation in cavities (standard conditions)
- Option 2 – 50 ACH
- Option 3 – 100 ACH

### 1.3.3 Indoor and Outdoor climate

The 2D hygrothermal assessment built upon and complemented the previous 1D assessment by providing a more detailed analysis of moisture behaviour across construction details. To ensure consistency and comparability, the input parameters for materials and boundary conditions—including indoor and outdoor climate conditions—were carried over from Phase 1 (Standard Construction Catalogue), as detailed in Appendix 1. This approach maintained alignment between the two assessment methods while allowing for a more comprehensive evaluation of moisture resilience. For a complete set of construction details used in the 2D analysis, refer to Appendix 5.

## 3.4 Hygrothermal Performance Evaluation Criteria

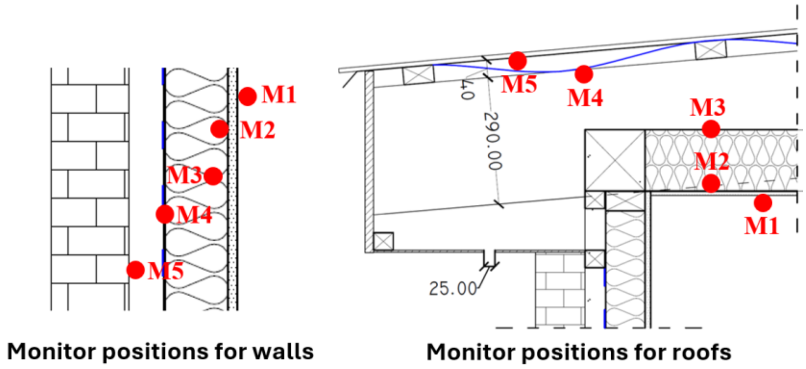
The hygrothermal performance assessment of all phases variations and iterations followed the VTT mould growth model [65], which is available in the WUFI Pro software platform. The simulation results were assessed according to the moisture performance evaluation criteria from ASHRAE 160 as outlined in Table 23.

**Table 23:** Hygrothermal performance criteria.

| Code | Mould risk level | VTT Mould growth index (MI) |
|---|---|---|
| Green | Low | MI < 1 |
| Yellow | Medium | 1< MI < 3 |
| Red | High | MI > 3 |

The 1D hygrothermal analysis has been conducted for all construction assemblies' interfaces at different layers (as shown in Figure 2).

**Figure 2:** Monitor positions for 1D hygrothermal performance assessment.



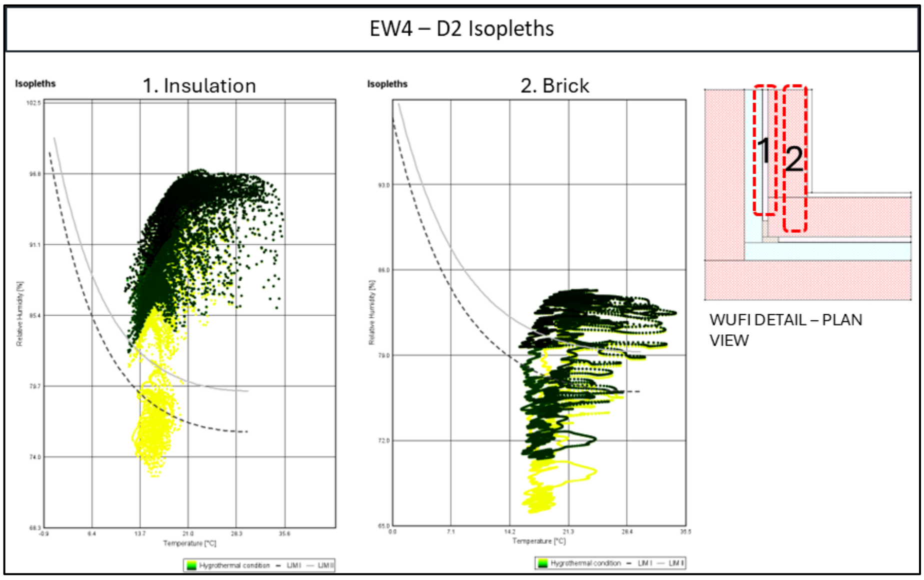

Bio-dimensional (2D) hygrothermal performance assessment results can be shown as two-dimensional fields of temperature, water content, relative humidity, vapour pressure, heat flux, capillary flux and diffusion flux at specific locations, as defined by the user [2]

Figure 3 shows an example of simulation output for EW4-D2 (cavity brick veneer, corner gaps issues), plotted as isopleth graphs at specific point of the construction details. Isopleths are graphs where relative humidity values are printed against the temperature for each simulation time step. This temperature-moisture diagram shows limiting curves (Lim 1 and Lim 2, defined below), which identify the range for mould growth conditions. If temperature and moisture conditions remain below these curves, no growth is expected. However, further assessment is required to estimate the total mould growth risk. In this example, the isopleths show risks for both the insulation and inner brick layers. Specific details of the location of these layers in the build-up are shown in the red details at the top-right corner of the image.

As defined by WUFI 2D, software [2]:

- LIM 1: Bio-utilizable substrates, such as wallpaper, plasterboard, building products made of biologically degradable materials, materials for permanently elastic joints, strongly contaminated surfaces, etc.
- LIM 2: Less bio-utilizable substrates with porous structure, such as plasters, mineral building materials, certain woods, and insulating materials not belonging to group I.

**Figure 3:** WUFI 2D simulation results sample – Isopleths and 2D Graphs for EW4- D2, showing potential mould risk on the insulation and brick layer. However, further assessment is required to understand the mould growth index under the VTT and ASHRAE 160 models.




Similar to Phases 1 and 2, the 2D hygrothermal assessment was conducted using the VTT model and evaluated according to ASHRAE 160 criteria, as detailed in Table 23.

# 4. Results and Discussion

To ensure the reliability of the results, an analysis of simulation convergence failures was conducted, revealing minimal failures (less than 2.0), consistent with similar studies on hygrothermal performance [37]. Convergence failures refer to the iterative method used by WUFI to solve its transport equations [66]. The following sections present the findings in detail.

## 4.1 Phase 1 - Construction Systems under Standard Conditions

Table 24 shows a snapshot of the hygrothermal performance of the different construction systems under standard conditions (Phase 1) plotted according to the different climate zones. Table 24 includes results for the monitor positions M4 and M5 only (as shown in Figure 2), found to be the most critical across all wall types. Refer to Appendix 2, for a complete set of results. A key observation from the analysis is that results vary significantly depending on the climate zone, emphasizing the need for a more detailed sub-climatic assessment. Given Victoria's diverse range of microclimates, a broad, generalized approach may overlook critical variations in moisture behaviour, temperature fluctuations, and rainfall exposure. This highlights the importance of refining climate zoning to ensure more accurate hygrothermal performance evaluations and better-informed construction practices tailored to specific regional conditions.

Each wall and roof system have been evaluated at different monitoring positions to assess the risk of condensation and mould growth at various wall build-up interfaces. The results in Table 24 presents the highest mould growth index (MI) recorded for monitor positions M4 and M5, representing failures primarily observed between the insulation and the membrane on the inner surfaces of the cladding respectively.

Results show that masonry wall assemblies (EW3, EW4 and EW6) and tiled roof assemblies are highly susceptible to mould growth in most climate zones, except for EW3 in climate zone 21. This exception can be due to Melbourne's lower rainfall and moderate humidity levels compared to the climate zones under assessment. The physical properties of masonry walls, such as porosity, can affect its moisture absorption [67,68] due to thermal expansion and contraction, which can create micro-cracks or enlarge existing pores, facilitating increased moisture penetration. Additionally, elevated temperatures increase vapor pressure, accelerating moisture absorption into the pores, while cooling can cause condensation within the material [5]. Under standard assessment conditions, these construction types do not account for ventilation within the air cavity. This lack of air movement hinders the drying process of these materials, leading to condensation and mould growth risk.

Testing different glass wool insulation performances helped determine if there is a correlation between higher thermal resistance and the risk of mould growth. The results showed an average increase of 15% in mould risk in insulated brick veneer systems with higher thermal resistance. Glass wool insulation with a higher R-value can be prone to mould growth due to its density, reduced airflow, and susceptibility to moisture retention [7] and thermal bridging caused by the heat transfer through the framing.

A reflective layer facing the cavity was included as an additional test sample (V3-R0.29). This reflective layer was tested in combination with insulation variation V2, resulting in a new scenario (V4: V2-R2.7 + V3-R0.29). The results for this combined insulation variation (V4) indicates an average increase of 27% in mould growth risk compared to insulation variation V1, which had lower thermal resistance. Additionally, V4 exhibited an average increase of 11% in comparison to insulation variation V2. This suggests that the reflective layer enhances radiant temperature by reflecting heat transferred from exterior surfaces back into the cavity, or vice versa from the interior, thereby causing an increase in the temperature differential, facilitating condensation.

**Table 24:** Hygrothermal performance results for typical external walls and roofs following the VTT Model under standard conditions. (Legend: Green: Acceptable; Yellow: Further assessment needed; Red: Not acceptable and; Grey: not under assessment).

| Wall Type | External Walls VTT - Monitor Position M4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| EW1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Wall Type | External Walls VTT - Monitor Position M5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| EW1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EW6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Build-Up | Roofs VTT - Monitor Position M4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| RF1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Build-Up | Roofs VTT - Monitor Position M5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 63 | | | | Climate Zone 64 | | | | Climate Zone 66 | | | |
| | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| RF1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RF4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Construction assemblies that showed no risk of mould growth under standard conditions included lightweight wall systems (EW1 and EW2), the externally insulated brick wall system (EW5), and metal-clad roof types (RF1 and RF3). With their current configuration, these assemblies are less prone to mould growth under standard condition [69] in mid-cold climates. In contrast, masonry wall systems have a higher risk of mould due to their porous nature, which allows for capillary moisture transport. This porosity leads to moisture being absorbed and retained within the masonry, creating conditions that are conducive to mould growth. Similarly, metal-clad roofs allow for better water runoff compared to terracotta tiles, resulting in less moisture accumulation. However, as this hygrothermal performance assessment only considers the cross-section of the wall and roof assemblies, these might still present condensation and mould growth risk at different junctions such as stud/insulation, where thermal bridging occurs.

Results show that construction systems that comply with regulatory requirements are not necessarily moisture resilient.

It is important to acknowledge that due to the inherent limitations of one-dimensional hygrothermal simulation, the results from Phase 1 should be interpreted as indicative of general performance trends rather than as a comprehensive evaluation of full NCC compliance. Key NCC-mandated construction details—such as weep holes—and broader environmental factors, including extreme climate events like flooding, cannot be accurately represented within this modelling framework. To address these limitations, subsequent phases incorporate non-standard scenarios and two-dimensional construction details, aiming to provide a more robust and holistic hygrothermal performance assessment under both regulatory and evolving climatic conditions.

## 4.2 Phase 2 - Non-Standard Scenarios

Table 25 and 26 present the results of the hygrothermal performance assessment for the non-standard scenarios tested across selected climate zones for monitor position M4, as the critical interface for mould growth identified in Phase 1 results.

Scenarios with cavity ventilation (S1.1) consistently demonstrate a significant reduction in the risk of mould growth across all climate zones, making this one of the most effective measures to prevent bio germination. For example, results for EW3, V1, V2, and V4 in climate zones 21, 22, 60, and 66 showed in almost all scenarios a 100% reduction of the mould growth risk over a 10-year period. The climate zone with the least improvement is Climate Zone 62, where the mould growth index (MI) was reduced by 51%. Although this reduction is lower than those observed in other climate zones, it is still significant, as it lowers the mould risk classification from high to medium.

Considering scenario 1.2, which included the same ventilation rate but with a reduced cavity thickness, does not yield the same effects. In this case, hygrothermal performances are improved by up to 20% and in some case no improvement is shown, which reinforce the need for further research aimed at determining the appropriate ventilation rates and strategies to reduce the risk of mould growth.

Evaluating water control membranes with different vapour permeance contributes to understanding their suitability for specific climate zones and construction types. Scenarios 2.1 and 2.3 evaluate the impact of a water control membrane with higher vapour permeance for walls and roofs, measuring 2.179 µg/N·s and 1.429 µg/N·s, respectively—both greater than the standard membrane's permeance of 1.1403 µg/N·s. In contrast, Scenario 2.2 examines the effect of a membrane with significantly lower vapour permeance, measured at 0.001 µg/N·s Across most climate zones, results show that a membrane with a lower vapour permeance (S2.2) traps moisture, leading to interstitial condensation at the interface of the insulation and the membrane. Conversely, the higher vapour permeance membrane (S2.1) facilitates moisture transfer within the assembly but does not reduce the mould growth risk at the same interface, meaning ventilation is crucial to effectively manage moisture and reduce mould growth risk.

Both external and internal environmental factors significantly impact the hygrothermal performance of wall assemblies. External factors, such as additional rain loads (Scenarios 3.1 and 3.2), particularly affect masonry (EW3 and EW4), aerated concrete assemblies (EW6) and terracotta tiled roofs (EW4) in climate zone 21. According to climate files data, climate zone 21 has less seasonal variation in temperature and relative humidity compared to other regions in Victoria. This stability means that, under standard conditions, certain wall assemblies do not pose a risk for mould growth. However, when these assemblies are exposed to additional moisture loads from rain, they exhibit a significant increase in moisture content. The porous nature of these materials makes them highly susceptible to capillary moisture transport, leading to higher moisture retention and increased risk of mould. These findings highlight the critical need for improved moisture management strategies to reduce the vulnerability of these assemblies to increased rain exposure. This is particularly important in sub-climates with higher rainfall loads, where excessive moisture infiltration can accelerate material deterioration and mould growth. Additionally, unprotected wall configurations, such as those lacking sufficient overhangs or drainage provisions, are especially susceptible to moisture-related issues. Internal conditions, such as air tightness and increased moisture loads (Scenarios S4.1 and S4.2), also significantly decrease hygrothermal performance, facilitating mould growth risks across most assemblies in all climate zones. Scenario S4.2 presents the highest mould growth risk, causing wall assemblies to underperform by an average of 10% compared to standard conditions across all climate zones, with some assemblies in climate zone 21 underperforming by over 100%. These results highlight the critical importance of considering both external and internal factors in the design and construction of resilient wall assemblies to ensure their performance and durability in harsh environments.

For a complete simulation set of results, refer to Appendix 3.

**Table 25:** Non-standard scenarios result for external walls. (Legend: Green: Acceptable; Yellow: Further assessment needed; Red: Not acceptable and; Grey: not under assessment).

| Assembly | Scenario | VTT - Non-standard scenarios | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 66 | | | |
| | | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| EW1 | **S1.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S1.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S2.1** | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green |
| | **S3.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| EW2 | **S1.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S1.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S2.1** | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green |
| | **S3.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| EW3 | **S1.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Yellow | Yellow | Grey | Yellow | Green | Green | Grey | Green |
| | **S1.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Green | Green | Grey | Green |
| | **S2.1** | Green | Green | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Green | Grey | Grey | Grey | Yellow | Grey | Grey | Grey | Red | Grey | Grey | Grey | Yellow | Grey | Grey | Grey | Yellow |
| | **S3.1** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Red |
| | **S3.2** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Red | Grey | Red |
| | **S4.1** | Yellow | Red | Grey | Red | Yellow | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| EW4 | **S1.1** | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Yellow | Yellow | Grey | Grey | Green | Green | Grey |
| | **S1.2** | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Yellow | Yellow | Grey | Grey | Red | Red | Grey | Grey | Green | Green | Grey |
| | **S2.1** | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey |
| | **S3.1** | Grey | Yellow | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| | **S3.2** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| | **S4.1** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| | **S4.2** | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey | Grey | Red | Red | Grey |
| EW5 | **S1.1** | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey |
| | **S1.2** | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey | Grey |
| | **S2.1** | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey | Green | Green | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green | Grey | Grey | Grey | Green |
| | **S3.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| | **S3.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Yellow | Green | Green | Grey | Green |
| | **S4.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |

| Assembly | Scenario | VTT - Non-standard scenarios | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Climate Zone 21 | | | | Climate Zone 22 | | | | Climate Zone 60 | | | | Climate Zone 62 | | | | Climate Zone 66 | | | |
| | | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 | V1 | V2 | V3 | V4 |
| | **S4.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green | Green | Green | Grey | Green |
| EW6 | **S1.1** | Green | Green | Grey | Green | Green | Green | Grey | Green | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Green | Green | Grey | Green |
| | **S1.2** | Green | Green | Grey | Green | Green | Green | Grey | Green | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Green | Green | Grey | Yellow |
| | **S2.1** | Green | Green | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey | Yellow | Yellow | Grey | Grey |
| | **S2.2** | Grey | Grey | Grey | Green | Grey | Grey | Grey | Yellow | Grey | Grey | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Grey | Grey | Grey | Yellow |
| | **S3.1** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow |
| | **S3.2** | Red | Red | Grey | Red | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Yellow | Yellow | Yellow | Grey | Red |
| | **S4.1** | Red | Red | Grey | Red | Red | Red | Grey | Red | Yellow | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |
| | **S4.2** | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red | Red | Red | Grey | Red |

**Table 26:** Non-standard scenarios results for roofs. (Legend: Green: Acceptable; Yellow: Further assessment needed; Red: Not acceptable and Grey: not under assessment).

| Construction | Scenario | Phase 2 Roofs: VTT - Non-standard scenarios results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Climate Zone 21 | | Climate Zone 22 | | Climate Zone 60 | | Climate Zone 62 | | Climate Zone 66 | |
| | | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 |
| RF1 | **S1.1** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S1.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S2.3** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S3.1** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S3.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.1** | Green | Red | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.2** | Red | Red | Yellow | Yellow | Yellow | Yellow | Yellow | Yellow | Red | Red |
| RF2 | **S1.1** | Green | Green | Green | Green | Green | Yellow | Yellow | Green | Green | Green |
| | **S1.2** | Yellow | Red | Green | Green | Green | Green | Green | Yellow | Green | Green |
| | **S2.3** | Green | Green | Green | Green | Green | Green | Yellow | Yellow | Yellow | Green |
| | **S3.1** | Yellow | Yellow | Green | Green | Green | Green | Green | Green | Green | Yellow |
| | **S3.2** | Yellow | Yellow | Green | Green | Green | Green | Green | Yellow | Green | Green |
| | **S4.1** | Red | Red | Yellow | Yellow | Yellow | Red | Yellow | Red | Yellow | Yellow |
| | **S4.2** | Red | Red | Red | Red | Red | Red | Red | Red | Red | Red |
| RF3 | **S1.1** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S1.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S2.3** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S3.1** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S3.2** | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| | **S4.1** | Red | Red | Green | Green | Green | Green | Yellow | Yellow | Yellow | Yellow |
| | **S4.2** | Red | Red | Red | Red | Red | Red | Red | Red | Red | Red |
| RF4 | **S1.1** | Green | Green | Green | Green | Green | Green | Yellow | Yellow | Green | Green |
| | **S1.2** | Red | Red | Green | Green | Red | Yellow | Yellow | Red | Green | Green |
| | **S2.3** | Green | Green | Green | Yellow | Green | Green | Green | Yellow | Green | Green |
| | **S3.1** | Yellow | Red | Green | Green | Green | Green | Green | Green | Yellow | Green |
| | **S3.2** | Yellow | Red | Green | Green | Yellow | Yellow | Green | Green | Green | Green |
| | **S4.1** | Red | Red | Yellow | Yellow | Yellow | Red | Red | Red | Red | Red |
| | **S4.2** | Red | Red | Red | Red | Yellow | Red | Red | Red | Red | Red |

# 4.3 Phase 3 - Construction Details Assessment

## 4.3.1 Key Findings – External Walls 2D Details under Standard Conditions

Consistent with Phases 1 and 2, construction details for external walls, specifically brick veneer (EW3) and cavity brick veneer (EW4), exhibit the highest risk of mould growth among all assessed construction details, as shown in Table 27.

Bricks can easily trap and accumulate moisture, significantly increasing the risk of mould growth at critical points such as window heads, windowsills, and wall bases. The interaction between aluminium framing and glass frequently results in condensation due to the high thermal conductivity of aluminium. When warm, moist indoor air comes into contact with the cooler surfaces of the aluminium frame and glass, condensation forms. This accumulated moisture can lead to the corrosion of metal components, further compromising the structural integrity of the window assembly. These areas are particularly vulnerable to water ingress due to environmental conditions, exacerbating moisture-related damages. Based on the modelling of 2D details, it is essential to verify that proper flashing and sealing are in place to ensure resilience to moisture.

Assemblies that previously exhibited lower mould growth risk under standard conditions in Phase 1 and Phase 2 now show vulnerabilities in specific construction details. Issues such as moisture accumulation at window heads (D5), water ingress at wall bases (D4), and thermal bridging (D8) highlight the limitations of assessing hygrothermal performance based solely on cross-sections. These findings underscore the necessity of detailed evaluations that consider construction detailing to accurately capture mould growth risks. Table 27 outlines the hygrothermal performance results for critical assemblies under Climate Zone 66 conditions.

Failures in membranes, such as perforations and discontinuities (D1), can allow moisture to penetrate directly into the assembly and impact the overall hygrothermal performance, leading to condensation, mould growth, and structural damages. Corner gaps (D2) have also been shown to be a critical point of moisture accumulation. Studies have attributed this issue to the sensitivity of these regions to outdoor climate changes [70], consistent with climate zone 66 temperature fluctuations. Furthermore, the impact of indoor latent heat on the internal lining of these assemblies presents an additional risk. This heightened humidity can lead to condensation and subsequent moisture damage, particularly in areas where the internal lining is less resistant to moisture. To mitigate this risk, watertight corner seals should be applied, particularly in wet areas where moisture exposure is higher.

Flashing plays a crucial role in moisture management by preventing water infiltration. In scenarios with increased moisture, such as flooding (D7), flashing at the base of the wall is vital for collecting moisture and redirecting it outside, thereby preventing rising dampness. However, in the water ingress scenario (D7), the flashing was found to lack a slope to direct water away, leading to a higher risk of mould growth, particularly in brick veneer systems (EW3 and EW4). Ensuring that flashing is properly designed and installed is essential for effective moisture control. Additionally, the membrane should cover the upturn of the flashing to provide comprehensive moisture protection. This detail is crucial for preventing water from bypassing the flashing and entering the wall assembly.

Joints such as corner gaps (D2), presents a significant risk for vapour transfer from indoor conditions, which can promote interstitial condensation. To mitigate this risk, watertight corner seals should be applied, particularly in wet areas where moisture exposure is higher. Proper sealing in these critical areas helps to prevent moisture ingress and maintain a dry and healthy indoor environment.

**Table 27:** 2D Hygrothermal performance results for external walls in Climate Zone 66 and 21.

| Climate Zone 66 2D Results - Walls | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| **EW1- D1** | 0.00 | 0.00 | 0.00 |
| **EW1- D2** | 0.00 | 0.00 | 0.00 |
| **EW1- D3** | 0.00 | 0.00 | 0.00 |
| **EW1- D4** | 0.00 | 0.00 | 0.00 |
| **EW1- D5** | 0.00 | 1.00 | 0.00 |
| **EW1- D6** | 0.00 | 0.00 | 0.00 |
| **EW1- D7** | 0.00 | 1.00 | 0.00 |
| **EW1- D8** | 3.36 | 0.00 | 0.00 |
| **EW2- D1** | 4.04 | 0.00 | 0.00 |
| **EW2- D2** | 2.40 | 1.40 | 0.00 |
| **EW2- D3** | 1.20 | 0.2 | 0.00 |
| **EW2- D4** | 0.00 | 0.00 | 0.00 |
| **EW2- D5** | 3.56 | 1.33 | 0.00 |

| Climate Zone 21 Results 2D - Walls | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| **EW1- D1** | 0.00 | 0.00 | 0.00 |
| **EW1- D2** | 0.00 | 0.00 | 0.00 |
| **EW1- D3** | 0.00 | 0.00 | 0.00 |
| **EW1- D4** | 0.00 | 0.00 | 0.00 |
| **EW1- D5** | 0.00 | 0.00 | 0.00 |
| **EW1- D6** | 0.00 | 0.00 | 0.00 |
| **EW1- D7** | 0.00 | 0.00 | 0.00 |
| **EW1- D8** | 0.00 | 0.00 | 0.00 |
| **EW2- D1** | 0.00 | 0.00 | 0.00 |
| **EW2- D2** | 3.72 | 2.70 | 0.67 |
| **EW2- D3** | 0.00 | 0.00 | 0.00 |
| **EW2- D4** | 0.00 | 0.00 | 0.67 |
| **EW2- D5** | 0.00 | 0.00 | 0.00 |

| Climate Zone 66 2D Results - Walls | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| **EW2- D6** | 2.35 | 0.83 | 0.00 |
| **EW2- D7** | 4.48 | 1.92 | 0.00 |
| **EW2- D8** | 4.24 | 1.18 | 0.00 |
| **EW3-D1** | 3.74 | 2.46 | 0.00 |
| **EW3-D2** | 4.75 | 3.70 | 1.96 |
| **EW3-D3** | 1.91 | 0.47 | 0.47 |
| **EW3-D4** | 3.58 | 2.24 | 0.10 |
| **EW3-D5** | 3.88 | 2.59 | 0.13 |
| **EW3-D6** | 4.69 | 3.46 | 0.78 |
| **EW3-D7** | 3.87 | 1.91 | 0.13 |
| **EW3-D8** | 4.92 | 3.33 | 0.66 |
| **EW4-D1** | 4.66 | 3.62 | 1.83 |
| **EW4-D2** | 3.47 | 2.29 | 0.11 |
| **EW4-D3** | 3.81 | 2.17 | 0.17 |
| **EW4-D4** | 3.67 | 2.39 | 0.13 |
| **EW4-D5** | 4.08 | 2.93 | 0.03 |
| **EW4-D6** | 3.88 | 2.69 | 0.17 |
| **EW4-D7** | 4.91 | 3.87 | 2.23 |
| **EW5-D1** | 0.23 | 0.10 | 0.00 |
| **EW5-D2** | 0.00 | 0.00 | 0.00 |
| **EW5-D3** | 0.00 | 0.00 | 0.00 |
| **EW5-D4** | 0.11 | 0.00 | 0.00 |
| **EW5-D5** | 0.02 | 0.00 | 0.00 |
| **EW5-D6** | 0.00 | 0.00 | 0.00 |
| **EW5-D7** | 0.00 | 0.00 | 0.00 |
| **EW5-D8** | 0.00 | 0.00 | 0.00 |
| **EW6-D1** | 0.00 | 0.00 | 0.00 |
| **EW6-D2** | 0.00 | 0.00 | 0.00 |
| **EW6-D3** | 0.00 | 0.00 | 0.00 |
| **EW6-D4** | 0.00 | 0.00 | 0.00 |
| **EW6-D5** | 0.00 | 0.00 | 0.00 |
| **EW6-D6** | 0.00 | 0.00 | 0.00 |
| **EW6-D7** | 6.00 | 5.30 | 3.45 |
| **EW6-D8** | 4.95 | 3.86 | 1.83 |

| Climate Zone 21 Results 2D - Walls | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| **EW2- D6** | 0.00 | 0.00 | 0.00 |
| **EW2- D7** | 0.00 | 0.00 | 0.00 |
| **EW2- D8** | 0.00 | 0.00 | 0.00 |
| **EW3-D1** | 0.00 | 0.00 | 0.00 |
| **EW3-D2** | 0.00 | 0.00 | 0.00 |
| **EW3-D3** | 0.00 | 0.00 | 0.00 |
| **EW3-D4** | 0.00 | 0.00 | 0.00 |
| **EW3-D5** | 0.00 | 0.00 | 0.00 |
| **EW3-D6** | 0.00 | 0.00 | 0.00 |
| **EW3-D7** | 0.00 | 0.00 | 0.00 |
| **EW3-D8** | 0.00 | 0.00 | 0.00 |
| **EW4-D1** | 0.00 | 0.00 | 0.00 |
| **EW4-D2** | 0.00 | 0.00 | 0.00 |
| **EW4-D3** | 0.00 | 0.00 | 0.00 |
| **EW4-D4** | 0.00 | 0.00 | 0.00 |
| **EW4-D5** | 0.00 | 0.00 | 0.00 |
| **EW4-D6** | 0.00 | 0.00 | 0.00 |
| **EW4-D7** | 0.00 | 0.00 | 0.00 |
| **EW5-D1** | 0.00 | 0.00 | 0.00 |
| **EW5-D2** | 0.00 | 0.00 | 0.00 |
| **EW5-D3** | 0.00 | 0.00 | 0.00 |
| **EW5-D4** | 0.00 | 0.00 | 0.00 |
| **EW5-D5** | 0.00 | 0.00 | 0.00 |
| **EW5-D6** | 0.00 | 0.00 | 0.00 |
| **EW5-D7** | 0.00 | 0.00 | 0.00 |
| **EW5-D8** | 0.00 | 0.00 | 0.00 |
| **EW6-D1** | 0.00 | 0.00 | 0.00 |
| **EW6-D2** | 0.00 | 0.00 | 0.00 |
| **EW6-D3** | 0.00 | 0.00 | 0.00 |
| **EW6-D4** | 0.00 | 0.00 | 0.00 |
| **EW6-D5** | 0.00 | 0.00 | 0.00 |
| **EW6-D6** | 0.00 | 0.00 | 0.00 |
| **EW6-D7** | 3.05 | 0.00 | 0.00 |
| **EW6-D8** | 4.54 | 0.00 | 0.00 |

The additional testing conducted by incorporating ventilation into the details of critical assemblies (EW3 and EW4) demonstrated significant improvements when a high air change rate of 100 ACH (Air Changes per Hour) was applied. This high ventilation rate effectively enhanced the overall hygrothermal performance of the assemblies, reducing moisture accumulation and the associated risk of mould growth. The results consistently showed improvements across all details, with the exception of the sensitive layers, specifically the inner plasterboard lining at the windowsill-wall junction (D6) in the single masonry wall assembly (EW3) and penetrations (D2) and window head (D5) in double brick masonry (EW4). However, it is important to note that under flooding scenarios, the risk remains significant across all cases. This indicates that while high ventilation rates can mitigate moisture issues, they are not sufficient on their own to address all potential moisture-related problems. The persistent moisture accumulation in the sensitive layers suggests that additional measures, such as enhanced sealing, proper flashing, and the use of moisture-resistant materials, are necessary to ensure comprehensive moisture management and prevent long-term damage.

**Table 28:** Additional 2D Hygrothermal performance results for selected external walls in Climate Zone 66.

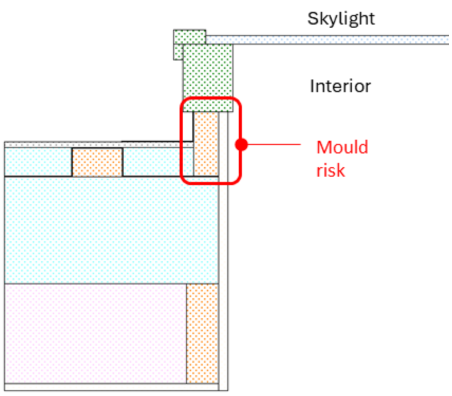
| 2D Details | VTT (no Ventilation) | | | VTT (ACH 50) | | | VTT (ACH 100) | | |
|---|---|---|---|---|---|---|---|---|---|
| | VS | S | MR | VS | S | MR | VS | S | MR |
| EW3-D1 CZ66 | | | | | | | | | |
| EW3-D2 CZ66 | | | | | | | | | |
| EW3-D3 CZ66 | | | | | | | | | |
| EW3-D4 CZ66 | | | | | | | | | |
| EW3-D5 CZ66 | | | | | | | | | |
| EW3-D6 CZ66 | | | | | | | | | |
| EW3-D7 CZ66 | | | | | | | | | |
| EW3-D8 CZ66 | | | | | | | | | |
| EW4-D1 CZ66 | | | | | | | | | |
| EW4-D2 CZ66 | | | | | | | | | |
| EW4-D3 CZ66 | | | | | | | | | |
| EW4-D4 CZ66 | | | | | | | | | |
| EW4-D5 CZ66 | | | | | | | | | |
| EW4-D6 CZ66 | | | | | | | | | |
| EW4-D7 CZ66 | | | | | | | | | |

## 4.3.2 Key Findings – Roof 2D Details under Standard Conditions

Similar to walls, roof details also contain critical points that require additional measures, especially under Climate Zone 66 scenarios. As previously discussed, this zone experiences harsh climatic conditions, necessitating enhanced protective strategies. Metal-clad roofs are particularly susceptible to higher mould risk due to the high thermal conductivity of the metal, which increases the temperature difference between indoor and outdoor conditions, leading to condensation problems. Table 27 shows the results for roof construction details in climate zones 21 and 66, plotted according to the mould growth index based on the ASHRAE 160 and VTT models.

Several critical areas require careful consideration to ensure effective moisture management and prevent mould growth. Details related to membrane sealing (D1) present a high risk of mould growth (>5), requiring enhanced practices to ensure proper fixing and continuity. Membrane fixing and continuity are essential for controlling vapour diffusion and preventing interstitial condensation within the construction layers. Similarly, Flashing and sealing are essential for moisture management in complex roof geometries, such as skylights (D5). Skylights also report a mould growth index >5 at the roof-wall and skylight framing junction, as shown in Figure 4. This risk is likely due to condensation occurring in the skylight framing where it contacts the upper vertical envelope system, a situation exacerbated by poor indoor ventilation.

**Figure 4:** Skylight construction detail (D5), highlighting area with mould growth risk.




Ventilation of roof spaces is important as it impacts the drying potential of the materials; therefore, ventilation opening following NCC 2022 housing provisions has been applied to a selected construction detail (D2), and no mould growth risk was observed. However, as this detail is focused on a specific section, it is not representative of the hygrothermal performance of the whole roof system. Besides construction detail D2, simulation boundary conditions do not consider ventilation within the roof cavity.

**Table 27:** 2D Hygrothermal performance results for roofs in Climate Zone 21 and Climate Zone 66.

| Climate Zone 66 Results - 2D Roofs | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| RF1-D1 | 5.07 | 3.73 | 0.03 |
| RF1-D2 | 0.00 | 0.00 | 0.00 |
| RF1-D3 | 0.00 | 0.00 | 0.00 |
| RF1-D4 | 0.00 | 0.00 | 0.00 |
| RF1-D5 | 5.05 | 3.73 | 0.03 |
| RF2-D1 | 0.00 | 0.00 | 0.00 |
| RF2-D2 | 0.15 | 0.07 | 0.01 |
| RF2-D3 | 0.00 | 0.00 | 0.00 |
| RF2-D4 | 0.00 | 0.00 | 0.00 |
| RF2-D5 | 0.15 | 0.07 | 0.01 |

| Climate Zone 21 Results - 2D Roofs | | | |
|---|---|---|---|
| 2D Details | VTT (Version 1) | | |
| | VS | S | MR |
| RF1-D1 | 0.00 | 0.00 | 0.00 |
| RF1-D2 | 0.00 | 0.00 | 0.00 |
| RF1-D3 | 0.00 | 0.00 | 0.00 |
| RF1-D4 | 0.00 | 0.00 | 0.00 |
| RF1-D5 | 0.00 | 0.00 | 0.00 |
| RF2-D1 | 0.00 | 0.00 | 0.00 |
| RF2-D2 | 0.00 | 0.00 | 0.00 |
| RF2-D3 | 0.00 | 0.00 | 0.00 |
| RF2-D4 | 0.00 | 0.00 | 0.00 |
| RF2-D5 | 0.00 | 0.00 | 0.00 |

## 4.4 Limitations

The prediction and mitigation of condensation and mould growth are areas of scientific research and development today. The methods (ASHRAE 160, AIRAH DA07) and software (WUFI Pro) used for this analysis are internationally accepted as state-of-the-art tools for these types of analysis. However, the results of these investigations are not definitive, and must be considered as qualitative in nature. The results of the analysis are expressed in categories according to the likelihood of mould growth and severity of the risks. Therefore, even a Mould Index below 1, which corresponds to “acceptable risk”, does not completely exclude the eventuality of mould growth.

Amongst other factors, the accuracy of the analysis and results is limited by the following factors:

- This method assumes limited rainwater intrusion (1% + 0.5% of external rain). Substantial rainwater intrusion due to installation defects, plumbing leaks, groundwater, and water damage caused by natural disasters, such as floods and cyclones, are not considered.
- The method assesses the risk of interstitial condensation considering the hygrothermal flux as mono-directional. The one-dimensional calculation allows the hygrothermal behaviour of the building component to be modelled only as perpendicular to its surface. The method overlooks the contribution of air movement through the envelope. Consequently, the accuracy of the results is generally higher for airtight envelopes.
- For better accuracy, the analysis should employ ‘Moisture Design Weather Data’ files, as outdoor climate conditions play a significant role in hygrothermal simulations [71]. Current practices often rely on climate files developed for energy performance [72], which may not capture precipitation data accurately [25]. This research incorporates detailed weather data, including precipitation, to enhance the accuracy of moisture control analysis. By considering precipitation levels, the study provides a more comprehensive understanding of environmental moisture dynamics, crucial for assessing building performance and mitigating potential moisture-related issues.
- Simulation parameters and assumptions can impact results, as these can derive to miscalculations in moisture transport [73].Therefore, it is recommended to conduct a sensitivity analysis of the relevant parameters to ensure the reliability of the simulations results. These research parameters were carefully considered and based on previous studies and relevant scientific literature.
- In this study, all materials except for timber, plasterboard (sensitive) and metal (resistant) were classified as medium-resistant

The results presented in this report should be interpreted within the specific context and scope of the analysis. All findings are based on the assumptions, boundary conditions, and methodologies defined in this study. While the results provide valuable insights into the hygrothermal performance of the assessed construction systems, they are not universally applicable to all cases beyond the parameters of this research. Variations in climate, materials, construction techniques, and usage patterns may lead to different outcomes, and further studies would be required to validate these findings in broader contexts.

# 5. Conclusion

This study employed transient hygrothermal analysis to test the most common Victorian code-compliant residential build-ups under standard and non-standard scenarios and evaluate their ability to provide mould-free resilient indoors to the building occupants. This approach offers a comprehensive assessment of moisture resilience by testing various scenarios beyond the standard one-case evaluation.

This research highlights a fundamental limitation of the current assessment approach, which relies on standardized conditions to evaluate moisture risk in building assemblies. While this method provides a baseline for compliance, it fails to capture the significant variability in real-world conditions, including differences in local climate, construction practices, material properties, and occupant behaviour. As a result, assemblies that perform well under standard conditions may still be vulnerable to moisture accumulation, interstitial condensation, and mould growth in actual building environments. For instance, lightweight systems (EW1 and EW2), which perform well under standard conditions, exhibit a significant increase in mould growth risk under non-standard scenarios such as increased temperature, relative humidity, and air tightness. To address this shortcoming, a more comprehensive assessment methodology is needed—one that considers a broader range of environmental and construction scenarios. By testing assemblies under diverse conditions, including variations in humidity levels, ventilation rates, and exposure to rain and temperature fluctuations, a more accurate evaluation of moisture resilience can be achieved.

Generally, results confirmed that when mould growth risk is present, the highest mould index and growth levels occur at two critical interface points: between the insulation and membrane (monitor position M4) and between the cladding and membrane (monitor position M5). These areas are particularly susceptible to interstitial condensation, driven by vapour migrating outward from the warm, humid indoor environment. This pattern is characteristic of the climate zones examined in this study and occurs regardless of the specific wall or roof typology analysed.

A key factor influencing the simulation results is the ventilation rate within the air cavities, as it plays a crucial role in the drying potential of materials. The findings reveal a strong correlation between cavity design, ventilation rate, and moisture management. Specifically, a shallow or fully obstructed cavity depth can significantly hinder drying, especially when moisture is present across the entire surface. This limited airflow creates conditions that promote mould germination, emphasising the importance of proper cavity design and ventilation strategies, as well as maintenance, as a way to mitigate moisture-related risks. The importance of ventilated and drained cavities in building construction cannot be overstated, especially when comparing different air change rates (ACH) from 0 to 25. Ventilated cavities help manage moisture by allowing air to circulate, which aids in drying out any accumulated moisture and reducing the risk of mould growth. Drained cavities ensure that any water that enters the cavity can be effectively drained away, preventing water damage and mould. Although the upcoming NCC 2025 acknowledges the importance of ventilation in cavities, it does not clearly define ventilation rates or require verification methods.

Overall, the findings highlight potential limitations in the current regulatory requirements for addressing condensation and mould growth in buildings. The assessment indicates that existing practices may not fully support the achievement of moisture-resilient construction. If unaddressed, these challenges could impact efforts toward enhancing moisture resilience in the built environment. This highlights the importance of considering updates to policy and providing clearer, more practical guidance for designers and builders in this area.

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# Appendix

## Appendix 1: Simulation parameters

WUFI simulations parameters for standard conditions.

| WUFI Parameter | Details |
|---|---|
| **Orientation** | South |
| **Wall Inclination** | 90 degrees |
| **Rain Load** | Calculation method [3] |
| **Rain Exposure** | 1.0, Building height <10m, Medium (referring to a low rise building in a semiurban environment). |
| **Rain depositing factor** | Wall with eaves |
| **Exterior surface air film resistance** | 0.040 [49] |
| **Exterior surface Sd value:** | Weatherboard: 0.3<br>Fibrecement: 0.3<br>Metal: N/A<br>Brick: N/A<br>Concrete AAC: N/A |
| **Short-wave radiation value** | Weatherboard: DIN4108 medium (0.6)<br>Fibrecement: DIN4108 medium (0.6)<br>Metal: DIN4108 medium (0.6)<br>Brick: Brick red<br>Concrete AAC: DIN4108 medium (0.6) |
| **Ground reflectivity** | 0.26 (green grass) |
| **Rain adhering factor:** | 0.7 (Absorption unpainted surfaces only) |
| **Fraction of Rain Load** | 1% |
| **Interior surface air film resistance** | 0.13 [49] |
| **Interior surface Sd value** | No coating assumed |
| **Initial moisture** | Constant |
| **Initial temperature** | Constant |
| **Initial RH** | 0.8 (80%) |
| **Initial temperature** | 20.0 (NatHERS min). |
| **Calculation period** | Ten years, 30/06/2023 to 30/06/2033 |
| **Calculation step** | 1 hour |
| **Air Exchange rate** | 10 ACR @n50 / 0.5 ACH |
| **Building Volume** | 500 $m^2$ |

# Appendix 2: Phase 1 Standard Construction Simulations Results

WUFI Simulations Results – Phase 1.

| Construction Assembly | Assembly Variation | Monitor Position | Climate Zone 21 | Climate Zone 22 | Climate Zone 60 | Climate Zone 62 | Climate Zone 63 | Climate Zone 64 | Climate Zone 66 |
|---|---|---|---|---|---|---|---|---|---|
| | | | VVT | VVT | VVT | VVT | VVT | VVT | VVT |
| | | | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI |
| EW1 | EW V1 (Insulation R2.3) | m5 | 0.00 | 0.00 | 0.00 | 0.00 | 2.36 | 0.00 | 0.00 |
| | | m4 | 0.00 | 0.02 | 0.07 | 0.01 | 0.09 | 0.07 | 0.00 |
| | EW V2 (Insulation R2.7) | m5 | 0.00 | 0.00 | 0.00 | 0.00 | 2.38 | 0.00 | 0.00 |
| | | m4 | 0.00 | 0.03 | 0.01 | 0.00 | 0.01 | 0.00 | 0.06 |
| | EW V3 (Insulation R0.29) | m4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | EW V4 (Insulation R2.99) | m4 | 0.00 | 0.08 | 0.00 | 0.00 | 2.42 | 2.59 | 0.55 |
| EW2 | EW2 V1 (Insulation R2.3) | m4 | 0.00 | 0.00 | 0.02 | 0.04 | 0.73 | 0.02 | 0.18 |
| | | m5 | 0.00 | 0.00 | 0.03 | 0.44 | 0.33 | 0.05 | 0.14 |
| | EW2 V2 (Insulation R2.7) | m4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.05 | 0.00 |
| | | m4 | 0.00 | 0.07 | 0.02 | 0.01 | 0.63 | 0.02 | 0.20 |
| | EW2 V3 (Insulation R0.29) | m4 | 0.00 | 0.00 | 0.10 | 0.00 | 0.03 | 0.00 | 0.00 |
| | EW2 V4 (Insulation R2.99) | m4 | 0.22 | 0.01 | 0.22 | 0.05 | 0.98 | 0.02 | 0.00 |
| | | m5 | 0.00 | 0.01 | 0.02 | 0.02 | 0.34 | 0.06 | 0.18 |
| EW3 | EW3 V1 (Insulation R2.3) | m4 | 0.02 | 1.92 | 1.71 | 2.15 | 2.80 | 2.15 | 2.48 |
| | | m5 | 0.18 | 3.37 | 3.50 | 3.50 | 3.50 | 3.50 | 3.49 |
| | EW3 V2 (Insulation R2.7) | m4 | 0.00 | 2.10 | 1.98 | 2.50 | 2.98 | 2.40 | 2.90 |
| | | m5 | 0.37 | 3.37 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |
| | EW3.V3 (Insulation R0.29) | m4 | 0.00 | 0.00 | 2.69 | 2.82 | 2.77 | 2.76 | 0.00 |
| | | m5 | 0.34 | 2.20 | 3.50 | 3.50 | 3.50 | 3.50 | 3.33 |
| | EW3 V4 (Insulation R2.99) | m4 | 0.02 | 2.56 | 2.53 | 2.60 | 2.92 | 2.66 | 2.77 |
| | | m5 | 0.33 | 3.37 | 3.50 | 3.50 | 3.50 | 3.50 | 3.49 |
| | EW4 (no Insulation) | m4 | 2.96 | 3.13 | 3.28 | 3.34 | 3.13 | 3.22 | 3.37 |
| | | m5 | 3.33 | 3.49 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |

| Construction Assembly | Assembly Variation | Monitor Position | Climate Zone 21 | Climate Zone 22 | Climate Zone 60 | Climate Zone 62 | Climate Zone 63 | Climate Zone 64 | Climate Zone 66 |
|---|---|---|---|---|---|---|---|---|---|
| | | | VVT | VVT | VVT | VVT | VVT | VVT | VVT |
| | | | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI |
| | EW4 V2 (Insulation R0.2) | m3 | 0.70 | 2.42 | 2.51 | 1.01 | 1.83 | 1.74 | 0.56 |
| | | m4 | 2.69 | 3.14 | 3.28 | 3.28 | 3.21 | 3.13 | 3.12 |
| | | m5 | 3.15 | 3.48 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |
| | EW4 V3 (Insulation R0.45) | m4 | 2.80 | 3.20 | 3.33 | 3.36 | 3.28 | 3.26 | 3.30 |
| | | m5 | 3.49 | 3.49 | 3.50 | 3.35 | 3.50 | 3.50 | 3.50 |
| EW5 | EW5 V1 (Insulation R2.3) | m5 | 0.35 | 0.10 | 0.34 | 0.10 | 0.02 | 0.09 | 0.12 |
| | EW5 V2 (Insulation R2.7) | m5 | 0.59 | 0.10 | 0.03 | 0.10 | 0.13 | 0.08 | 0.11 |
| | EW5 V3 (Insulation R0.29) | m5 | 0.21 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | EW5 V4 (Insulation R2.99) | m5 | 0.86 | 0.10 | 0.05 | 0.10 | 0.10 | 0.08 | 0.99 |
| EW6 | EW6 V1 (Insulation R2.3) | m4 | 0.01 | 1.89 | 2.31 | 2.68 | 3.04 | 2.55 | 2.85 |
| | | m5 | 2.30 | 3.04 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |
| | EW6 V2 (Insulation R2.7) | m4 | 0.01 | 1.94 | 2.32 | 2.70 | 3.06 | 2.63 | 2.78 |
| | | m5 | 2.34 | 3.09 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |
| | EW6 V3 (Insulation R0.29) | m4 | 0.05 | 0.00 | 0.08 | 2.36 | 2.45 | 1.37 | 0.00 |
| | | m5 | 0.32 | 2.32 | 3.50 | 3.50 | 3.50 | 3.50 | 2.86 |
| | EW6 V4 (Insulation R2.99) | m4 | 0.04 | 2.39 | 2.64 | 2.86 | 3.19 | 2.79 | 2.76 |
| | | m5 | 2.31 | 5.54 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 |
| **Roofs** | | | | | | | | | |
| RF1 | RF1 V1 (Insulation R2.5) | m4 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| | RF1 V2 (Insulation R4.1) | m4 | 0.11 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | RF1 V3 (Insulation R0.15) | m4 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| | RF1 V4 (Insulation R4.1+0.15) | m4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RF2 | RF2 V1 (Insulation R2.5) | m4 | 0.12 | 0.08 | 2.52 | 0.20 | 2.95 | 0.22 | 2.00 |
| | | m5 | 3.21 | 3.33 | 3.49 | 3.50 | 3.50 | 3.50 | 3.27 |
| | RF2 V2 (Insulation R4.1) | m4 | 0.01 | 0.12 | 0.24 | 0.70 | 3.05 | 0.85 | 0.21 |
| | | m5 | 3.23 | 3.35 | 3.49 | 3.50 | 3.50 | 3.50 | 3.30 |

| Construction Assembly | Assembly Variation | Monitor Position | Climate Zone 21 | Climate Zone 22 | Climate Zone 60 | Climate Zone 62 | Climate Zone 63 | Climate Zone 64 | Climate Zone 66 |
|---|---|---|---|---|---|---|---|---|---|
| | | | VVT | VVT | VVT | VVT | VVT | VVT | VVT |
| | | | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI | Yearly Mould Index MI |
| | RF2 V3 (Insulation R0.15) | m4 | 0.01 | 0.03 | 0.05 | 1.99 | 2.19 | 0.00 | 0.07 |
| | | m5 | 3.25 | 3.23 | 3.49 | 3.50 | 3.50 | 3.50 | 3.29 |
| | RF2 V4 (Insulation R4.1+0.15) | m4 | 0.41 | 1.91 | 2.58 | 1.52 | 3.01 | 3.80 | 2.25 |
| | | m5 | 3.29 | 3.40 | 3.49 | 3.50 | 3.50 | 3.50 | 3.36 |
| RF3 | RF3 V1 (Insulation R2.5) | m4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.03 | 0.05 |
| | RF3 V2 (Insulation R4.1) | m4 | 0.00 | 0.00 | 0.89 | 0.00 | 0.12 | 0.01 | 0.00 |
| | RF3 V3 (Insulation R0.15) | m4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| | RF3 V4 (Insulation R4.1+0.15) | m4 | 0.00 | 0.00 | 0.05 | 0.00 | 0.26 | 0.03 | 0.07 |
| RF4 | RF4 V1 (Insulation R2.5) | m4 | 0.12 | 0.08 | 0.18 | 0.00 | 1.02 | 2.66 | 1.91 |
| | | m5 | 3.21 | 3.13 | 3.49 | 2.76 | 3.50 | 3.50 | 3.26 |
| | RF4 V2 (Insulation R4.1) | m4 | 0.10 | 0.12 | 2.36 | 2.71 | 2.95 | 2.60 | 1.39 |
| | | m5 | 3.23 | 3.20 | 3.49 | 3.49 | 3.50 | 3.50 | 3.29 |
| | RF4 V3 (Insulation R0.15) | m4 | 0.20 | 0.01 | 0.02 | 0.02 | 2.90 | 3.34 | 0.21 |
| | | m5 | 3.22 | 3.11 | 1.15 | 3.50 | 3.50 | 3.50 | 3.29 |
| | RF4 V4 (Insulation R4.1+0.15) | m4 | 2.89 | 0.09 | 2.58 | 2.84 | 2.51 | 1.61 | 2.19 |
| | | m5 | 3.29 | 3.40 | 3.49 | 3.50 | 3.50 | 3.50 | 3.35 |

# Appendix 3: Phase 2 Non-Standard Scenarios Parameters

| Build Up | Description | Construction Scenarios | | Environmental Scenarios | | |
|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | |
| | | **Ventilated air cavity** (ACH) **and cavity thickness (m)** | **Membrane** | **Fraction of Rain Load** (%) | **Indoor climate (RH% and $T^0$)** | **Indoor ventilation (ACH) (1/h)** |
| **EW1** | **Clad Weatherboard** | | | | | |
| **V1** | As above + Insulation R2.3 | S 1.1 (25 1/h)<br>S1.1 + S1.2 (Thickness/2) | S 2.1 (2.179 µg/N/s ) | S3.1(1.4)<br>S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0C$) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |
| **EW2** | **Clad Fibre-cement sheet** | | | | | |
| **V1** | As above + Insulation R2.3 | S 1.1 (25 1/h)<br>S1.1 + S1.2 (Thickness/2) | S 2.1 (2.179 µg/N/s ) | S3.1(1.4)<br>S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0C$) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |
| **EW3** | **Clay masonry veneer** | | | | | |
| **V1** | As above + Insulation R2.3 | S 1.1 (25 1/h)<br>S1.1 + S1.2 (Thickness/2) | S 2.1 (2.179 µg/N/s ) | S3.1(1.4)<br>S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0C$) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |
| **EW4** | **Cavity clay masonry** | | | | | |
| **V1** | As above + Insulation R2.3 | S 1.1 (25 1/h)<br>S1.1 + S1.2 (Thickness/2) | S 2.1 (2.179 µg/N/s ) | S3.1(1.4)<br>S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0C$) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |
| **EW5** | **Externally insulated clay masonry** | | | | | |
| **V1** | As above + Insulation R2.3 | n/a | S 2.1 (2.179 µg/N/s ) | S3.1(1.4)<br>S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0C$) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |

| Build Up | Description | Construction Scenarios | | Environmental Scenarios | | |
|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | |
| | | **Ventilated air cavity** (ACH) **and cavity thickness (m)** | **Membrane** | **Fraction of Rain Load** (%) | **Indoor climate (RH% and $T^0$)** | **Indoor ventilation (ACH) (1/h)** |
| **EW6** | **Autoclaved aerated concrete masonry** | | | | | |
| **V1** | As above + Insulation R2.3 | S 1.1 (25 1/h) S1.1 + S1.2 (Thickness/2) | S 2.1 (2.179 µg/N/s ) | S3.1(1.4) S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0$C) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R2.7 | | | | | |
| **V4** | As above + Integrated (Insulation R2.7 + Reflective) | | S2.2 (0.001 µg/N/s.) | | | |
| **RF1** | **Metal clad flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter** | | | | | |
| **V1** | As above + Insulation R2.5 | S 1.1 (25 1/h) S1.1 + S1.2 (Thickness/2) | S2.3 (1.429 µg/N/s ) | S3.1(1.4) S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0$C) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R4.1 | | | | | |
| **V4** | As above + Integrated (Insulation R4.1 + Reflective) | | | | | |
| **RF2** | **Terracotta clad flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter** | | | | | |
| **V1** | As above + Insulation R2.5 | S 1.1 (25 1/h) S1.1 + S1.2 (Thickness/2) | S2.3 (1.429 µg/N/s ) | S3.1(1.4) S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0$C) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R4.1 | | | | | |
| **V4** | As above + Integrated (Insulation R4.1 + Reflective) | | | | | |
| **RF3** | **Metal clad flat roof, skillion roof and cathedral ceiling with exposed rafters** | | | | | |
| **V1** | As above + Insulation R2.5 | S 1.1 (25 1/h) S1.1 + S1.2 (Thickness/2) | S2.3 (1.429 µg/N/s ) | S3.1(1.4) S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0$C) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R4.1 | | | | | |
| **V4** | As above + Integrated (Insulation R4.1 + Reflective) | | | | | |
| **RF4** | **Terracotta clad flat roof, skillion roof and cathedral ceiling with exposed rafters** | | | | | |
| **V1** | As above + Insulation R2.5 | S 1.1 (25 1/h) S1.1 + S1.2 (Thickness/2) | S2.3 (1.429 µg/N/s ) | S3.1(1.4) S 3.1 + S3.2 (0.5) | S4.1 (60% and $17^0$C) | S4.2 (0.25 1/h) |
| **V2** | As above + Insulation R4.1 | | | | | |
| **V4** | As above + Integrated (Insulation R4.1 + Reflective) | | | | | |

# Appendix 4: Phase 2 Non-Standard Scenarios Results

| Climate Zone 21 - Non-standard Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Assembly** | **Assembly Variation** | **Construction Scenarios** | | | | | **Environmental conditions Scenarios** | | | |
| | | **S1** | | **S2** | | | **S3** | | **S4** | |
| | | **S1.1 Constant ventilation rate** | **S1.1 + S1.2 Air cavity Thickness** | **S2.1 Membrane (wall)** | **S2.2 Membrane (wall)** | **S2.3 Membrane (roof)** | **Fraction of Rain Load** | | **S4.1 Indoor climate** | **S4.1 + S4.2 Indoor Ventilation (ACH)** |
| | | | | | | | **S3.1** | **S3.1 + S3.2** | **Relative Humidity & Temperature** | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{o}$C | 0.25 (1/h) |
| **External Walls** | | | | | | | | | | |
| **EW1** | **EW1.1 (Insulation R2.3)** | 0.02 | 0.05 | 0.03 | | | 0.13 | 0.13 | 0.01 | 3.46 |
| | **EW1.2 (Insulation R2.7)** | 0.03 | 0.04 | 0.01 | | | 0.14 | 0.00 | 0.02 | 3.42 |
| | **EW1.4 (Insulation R2.99)** | 0.06 | 0.10 | | 0.10 | | 0.12 | 0.13 | 0.23 | 3.30 |
| **EW2** | **EW2.1 (Insulation R2.3)** | 0.01 | 0.16 | 0.02 | | | 0.24 | 0.23 | 0.04 | 3.46 |
| | **EW2.2 (Insulation R2.7)** | 0.07 | 0.12 | 0.01 | | | 0.22 | 0.25 | 0.26 | 3.41 |
| | **EW2.4 (Insulation R2.99)** | 0.07 | 0.09 | | 0.14 | | 0.23 | 0.26 | 0.03 | 3.25 |
| **EW3** | **EW3.1 (Insulation R2.3)** | 0.22 | 0.03 | 0.00 | | | 3.20 | 3.35 | 2.90 | 3.50 |
| | **EW3.2 (Insulation R2.7)** | 0.22 | 0.05 | 0.00 | | | 3.17 | 3.46 | 3.03 | 3.49 |
| | **EW3.4 (Insulation R2.99)** | 0.02 | 0.05 | | 0.03 | | 3.61 | 3.77 | 3.00 | 3.50 |
| **EW4** | **EW4.2 (Insulation R0.2)** | 0.00 | 0.00 | | | | 2.90 | 5.49 | 5.50 | 5.70 |
| | **EW4.3 (Insulation R0.45)** | 0.00 | 0.00 | | | | 3.00 | 5.59 | 5.53 | 5.71 |
| **EW5** | **EW5.1 (Insulation R2.0)**[2] | | | 0.04 | | | 2.13 | 2.25 | 0.59 | 0.59 |
| | **EW5.2 (Insulation R2.7)**[2] | | | 0.38 | | | 1.76 | 1.87 | 0.75 | 0.73 |
| | **EW5.4 (Insulation R2.99)**[2] | | | | 0.08 | | 1.76 | 3.55 | 0.75 | 0.34 |
| **EW6** | **EW6.1 (Insulation R2.0)** | 0.01 | 0.01 | 0.03 | | | 4.55 | 4.63 | 2.70 | 3.49 |

| Climate Zone 21 - Non-standard Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Assembly** | **Assembly Variation** | **Construction Scenarios** | | | | | **Environmental conditions Scenarios** | | | |
| | | **S1** | | **S2** | | | **S3** | | **S4** | |
| | | | | | | | **Fraction of Rain Load** | | **S4.1 Indoor climate** | **S4.1 + S4.2 Indoor Ventilation (ACH)** |
| | | **S1.1 Constant ventilation rate** | **S1.1 + S1.2 Air cavity Thickness** | **S2.1 Membrane (wall)** | **S2.2 Membrane (wall)** | **S2.3 Membrane (roof)** | **S3.1** | **S3.1 + S3.2** | **Relative Humidity & Temperature** | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| | **EW6.2 (Insulation R2.7)** | 0.26 | 0.00 | 0.05 | | | 4.45 | 4.54 | 2.77 | 3.02 |
| | **EW6.4 (Insulation R2.99)** | 0.01 | 0.00 | | 0.07 | | 4.81 | 4.94 | 2.81 | 3.98 |
| **Roofs** | | | | | | | | | | |
| **RF1** | **RF1.1 (Insulation R2.5)** | 0.00 | 0.00 | | | 0.01 | 0.01 | 0.01 | 0.00 | 5.25 |
| | **RF1.2 (Insulation R4.1)** | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.01 | 3.53 | 5.50 |
| **RF2** | **RF2.1 (Insulation R2.5)** | 0.16 | 2.61 | | | 0.03 | 2.36 | 2.44 | 4.52 | 5.53 |
| | **RF2.2 (Insulation R4.1)** | 0.21 | 3.07 | | | 0.02 | 2.84 | 2.88 | 4.60 | 3.01 |
| **RF3** | **RF3.1 (Insulation R2.5)** | 0.00 | 0.00 | | | 0.00 | 0.15 | 0.19 | 4.07 | 5.46 |
| | **RF3.2 (Insulation R4.1)** | 0.00 | 0.00 | | | 0.00 | 0.02 | 0.05 | 4.15 | 5.55 |
| **RF4** | **RF4.1 (Insulation R2.5)** | 0.04 | 5.53 | | | 0.02 | 2.54 | 2.60 | 4.68 | 4.43 |
| | **RF4.2 (Insulation R4.1)** | 0.09 | 4.01 | | | 0.03 | 4.30 | 4.33 | 4.90 | 5.75 |

**Notes**

- Results reported for monitor position m4 unless indicated otherwise
- Scenario 1.2 accounts for scenario 1.1 parameters
- Scenario 3.2 accounts for scenario 3.1 parameters
- Scenario 4.2 accounts for scenario 4.1 parameters
- Grey – Not on scope

| Climate Zone 22 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | Fraction of Rain Load S3.1 | Fraction of Rain Load S3.1 + S3.2 | S4.1 Indoor climate Relative Humidity & Temperature | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{o}$C | 0.25 (1/h) |
| **External Walls** | | | | | | | | | | |
| EW1 | EW1.1 (Insulation R2.3) | 0.00 | 0.00 | 0.00 | | | 0.00 | 0.00 | 3.44 | 3.50 |
| | EW1.2 (Insulation R2.7) | 0.00 | 0.00 | 0.00 | | | 0.03 | 0.04 | 3.28 | 3.49 |
| | EW1.4 (Insulation R2.99) | 0.01 | 0.01 | | 0.01 | | 0.08 | 0.08 | 3.19 | 3.49 |
| EW2 | EW2.1 (Insulation R2.3) | 0.00 | 0.01 | 0.00 | | | 0.00 | 0.02 | 3.46 | 3.50 |
| | EW2.2 (Insulation R2.7) | 0.00 | 0.00 | 0.00 | | | 0.01 | 0.01 | 3.45 | 3.50 |
| | EW2.4 (Insulation R2.99) | 0.01 | 0.01 | | 0.00 | | 0.02 | 0.02 | 3.46 | 3.50 |
| EW3 | EW3.1 (Insulation R2.3) | 0.00 | 0.04 | 1.93 | | | 2.01 | 2.15 | 1.17 | 3.50 |
| | EW3.2 (Insulation R2.7) | 0.00 | 0.04 | 2.37 | | | 2.28 | 2.13 | 3.49 | 3.50 |
| | EW3.4 (Insulation R2.99) | 0.00 | 0.01 | | 2.44 | | 2.61 | 2.68 | 3.43 | 3.50 |
| EW4 | EW4.2 (Insulation R0.2) | 0.00 | 0.00 | | | | 3.25 | 3.26 | 3.24 | 3.28 |
| | EW4.3 (Insulation R0.45) | 0.00 | 0.01 | | | | 3.27 | 3.33 | 3.33 | 3.34 |
| EW5 | EW5.1 (Insulation R2.0)[2] | | | 0.07 | | | 0.11 | 0.02 | 0.05 | 0.05 |
| | EW5.2 (Insulation R2.7)[2] | | | 0.06 | | | 0.10 | 0.10 | 0.06 | 0.06 |
| | EW5.4 (Insulation R2.99)[2] | | | | 0.13 | | 0.10 | 0.13 | 0.05 | 0.05 |
| EW6 | EW6.1 (Insulation R2.0) | 0.03 | 0.07 | 1.97 | | | 2.00 | 2.18 | 3.50 | 3.50 |
| | EW6.2 (Insulation R2.7) | 0.04 | 0.10 | 2.03 | | | 2.05 | 2.21 | 3.50 | 3.50 |
| | EW6.4 (Insulation R2.99) | 0.05 | 0.12 | | 2.38 | | 2.46 | 2.56 | 3.50 | 3.50 |
| **Roofs** | | | | | | | | | | |
| RF1 | RF1.1 (Insulation R2.5) | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.09 | 0.00 | 2.86 |
| | RF1.2 (Insulation R4.1) | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.00 | 0.00 | 2.51 |
| RF2 | RF2.1 (Insulation R2.5) | 0.01 | 0.03 | | | 0.10 | 0.08 | 0.09 | 2.79 | 3.18 |
| | RF2.2 (Insulation R4.1) | 0.02 | 0.04 | | | 0.14 | 0.12 | 0.13 | 2.45 | 3.14 |
| RF3 | RF3.1 (Insulation R2.5) | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.00 | 0.03 | 3.19 |
| | RF3.2 (Insulation R4.1) | 0.00 | 0.05 | | | 0.00 | 0.00 | 0.00 | 0.33 | 3.07 |
| RF4 | RF4.1 (Insulation R2.5) | 0.00 | 0.05 | | | 0.10 | 0.08 | 0.08 | 2.53 | 3.27 |

| Climate Zone 22 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | Fraction of Rain Load | | S4.1 Indoor climate | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | | | | | | S3.1 | S3.1 + S3.2 | Relative Humidity & Temperature | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| | RF4.2 (Insulation R4.1) | 0.01 | 0.06 | | | 1.94 | 0.13 | 0.13 | 2.84 | 3.34 |

**Notes**

- Results reported for monitor position m4 unless indicated otherwise
- Scenario 1.2 accounts for scenario 1.1 parameters
- Scenario 3.2 accounts for scenario 3.1 parameters
- Scenario 4.2 accounts for scenario 4.1 parameters
- Grey – Not on scope

| | Climate Zone 60 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Build-up** | **Build-up Variation** | **Construction Scenarios** | | | | | **Environmental conditions Scenarios** | | | |
| | | **S1** | | **S2** | | | **S3** | | **S4** | |
| | | **S1.1 Constant ventilation rate** | **S1.1 + S1.2 Air cavity Thickness** | **S2.1 Membrane (wall)** | **S2.2 Membrane (wall)** | **S2.3 Membrane (roof)** | **Fraction of Rain Load** | | **S4.1 Indoor climate** | **S4.1 + S4.2 Indoor Ventilation (ACH)** |
| | | | | | | | **S3.1** | **S3.1 + S3.2** | **Relative Humidity & Temperature** | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{o}$C | 0.25 (1/h) |
| **External Walls** | | | | | | | | | | |
| **EW1** | **EW1.1 (Insulation R2.3)** | 0.01 | 0.01 | 0.00 | | | 0.00 | 0.00 | 3.13 | 3.49 |
| | **EW1.2 (Insulation R2.7)** | 0.01 | 0.01 | 0.01 | | | 0.01 | 0.18 | 3.31 | 3.49 |
| | **EW1.4 (Insulation R2.99)** | 0.01 | 0.01 | | 0.01 | | 0.01 | 0.02 | 3.19 | 3.49 |
| **EW2** | **EW2.1 (Insulation R2.3)** | 0.01 | 0.01 | 0.02 | | | 0.03 | 0.05 | 3.36 | 3.50 |
| | **EW2.2 (Insulation R2.7)** | 0.01 | 0.01 | 0.02 | | | 0.03 | 0.05 | 3.39 | 3.50 |
| | **EW2.4 (Insulation R2.99)** | 0.01 | 0.01 | | 0.03 | | 0.04 | 0.06 | 3,27 | 3.49 |
| **EW3** | **EW3.1 (Insulation R2.3)** | 0.15 | 0.51 | 2.63 | | | 1.71 | 2.15 | 3.48 | 3.50 |
| | **EW3.2 (Insulation R2.7)** | 0.19 | 0.85 | 2.66 | | | 1.84 | 2.38 | 3.49 | 3.50 |
| | **EW3.4 (Insulation R2.99)** | 0.24 | 1.63 | | 3.16 | | 2.54 | 2.68 | 4.49 | 3.50 |
| **EW4** | **EW4.2 (Insulation R0.2)** | 0.09 | 2.75 | | | | 3.21 | 3.22 | 3.46 | 3.23 |
| | **EW4.3 (Insulation R0.45)** | 0.30 | 2.78 | | | | 3.34 | 3.30 | 3.49 | 3.36 |
| **EW5** | **EW5.1 (Insulation R2.0)[2]** | | | 0.06 | | | 0.10 | 0.12 | 0.03 | 0.03 |
| | **EW5.2 (Insulation R2.7)[2]** | | | 0.05 | | | 0.09 | 0.10 | 0.05 | 0.05 |
| | **EW5.4 (Insulation R2.99)[2]** | | | | 0.11 | | 0.09 | 0.13 | 0.03 | 0.03 |
| **EW6** | **EW6.1 (Insulation R2.0)** | 1.45 | 1.99 | 2.82 | | | 2.32 | 2.45 | 2.80 | 3.50 |
| | **EW6.2 (Insulation R2.7)** | 1.52 | 2.13 | 2.84 | | | 2.33 | 2.40 | 3.49 | 3.50 |
| | **EW6.4 (Insulation R2.99)** | 2.34 | 2.62 | | 2.40 | | 2.73 | 2.80 | 3.49 | 3.50 |
| **Roofs** | | | | | | | | | | |
| **RF1** | **RF1.1 (Insulation R2.5)** | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.00 | 0.00 | 2.10 |
| | **RF1.2 (Insulation R4.1)** | 0.00 | 0.01 | | | 0.00 | 0.01 | 0.00 | 0.00 | 2.49 |
| **RF2** | **RF2.1 (Insulation R2.5)** | 0.02 | 0.29 | | | 0.23 | 0.19 | 0.20 | 2.77 | 3.32 |
| | **RF2.2 (Insulation R4.1)** | 1.62 | 0.82 | | | 0.59 | 0.24 | 0.20 | 3.20 | 3.38 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **RF3** | **RF3.1 (Insulation R2.5)** | 0.01 | 0.01 | | | 0.00 | 0.02 | 0.04 | 0.78 | 3.09 |
| | **RF3.2 (Insulation R4.1)** | 0.00 | 0.01 | | | 0.00 | 0.04 | 0.02 | 0.72 | 3.13 |
| **RF4** | **RF4.1 (Insulation R2.5)** | 0.08 | 3.05 | | | 0.22 | 0.18 | 2.58 | 2.87 | 2.13 |
| | **RF4.2 (Insulation R4.1)** | 0.25 | 1.93 | | | 0.36 | 0.23 | 2.49 | 3.21 | 3.42 |

**Notes**

- Results reported for monitor position m4 unless indicated otherwise
- Scenario 1.2 accounts for scenario 1.1 parameters
- Scenario 3.2 accounts for scenario 3.1 parameters
- Scenario 4.2 accounts for scenario 4.1 parameters
- Grey – Not on scope

| Climate Zone 62 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | Fraction of Rain Load S3.1 | S3.1 + S3.2 | S4.1 Indoor climate Relative Humidity & Temperature | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| **External Walls** | | | | | | | | | | |
| EW1 | EW1.1 (Insulation R2.3) | 0.00 | 0.00 | 0.00 | | | 0.00 | 0.00 | 3.34 | 3.49 |
| | EW1.2 (Insulation R2.7) | 0.00 | 0.00 | 0.00 | | | 0.01 | 0.29 | 3.19 | 3.49 |
| | EW1.4 (Insulation R2.99) | 0.00 | 0.00 | | 0.00 | | 0.70 | 0.03 | 3.03 | 3.49 |
| EW2 | EW2.1 (Insulation R2.3) | 0.00 | 0.00 | 0.00 | | | 0.06 | 0.11 | 3.44 | 3.50 |
| | EW2.2 (Insulation R2.7) | 0.00 | 0.00 | 0.04 | | | 0.08 | 0.12 | 3.44 | 3.50 |
| | EW2.4 (Insulation R2.99) | 0.00 | 0.00 | | 0.06 | | 0.09 | 0.13 | 3.43 | 3.49 |
| EW3 | EW3.1 (Insulation R2.3) | 1.06 | 2.27 | 2.66 | | | 2.31 | 2.51 | 3.49 | 3.50 |
| | EW3.2 (Insulation R2.7) | 1.51 | 2.61 | 2.91 | | | 2.50 | 2.67 | 3.50 | 3.50 |
| | EW3.4 (Insulation R2.99) | 2.18 | 2.78 | | 2.50 | | 2.80 | 2.90 | 3.50 | 3.50 |
| EW4 | EW4.2 (Insulation R0.2) | 2.39 | 3.27 | | | | 3.35 | 3.37 | 3.49 | 3.24 |
| | EW4.3 (Insulation R0.45) | 2.49 | 3.26 | | | | 3.37 | 3.38 | 3.48 | 3.28 |
| EW5 | EW5.1 (Insulation R2.0)[2] | | | 0.06 | | | 0.12 | 0.14 | 0.04 | 0.04 |
| | EW5.2 (Insulation R2.7)[2] | | | 0.05 | | | 0.11 | 0.13 | 0.06 | 0.06 |
| | EW5.4 (Insulation R2.99)[2] | | | | 0.12 | | 0.11 | 2.90 | 0.04 | 0.04 |
| EW6 | EW6.1 (Insulation R2.0) | 2.61 | 2.63 | 2.92 | | | 2.68 | 2.79 | 3.49 | 3.50 |
| | EW6.2 (Insulation R2.7) | 2.52 | 2.60 | 2.90 | | | 2.60 | 2.81 | 3.50 | 3.50 |
| | EW6.4 (Insulation R2.99) | 2.81 | 2.92 | | 2.72 | | 2.93 | 2.93 | 3.49 | 3.49 |
| **Roofs** | | | | | | | | | | |
| RF1 | RF1.1 (Insulation R2.5) | 0.00 | 0.00 | | | 0.02 | 0.00 | 0.04 | 0.00 | 2.63 |
| | RF1.2 (Insulation R4.1) | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.03 | 0.00 | 2.25 |
| RF2 | RF2.1 (Insulation R2.5) | 2.78 | 0.89 | | | 2.83 | 0.20 | 0.23 | 2.98 | 3.33 |
| | RF2.2 (Insulation R4.1) | 0.46 | 1.79 | | | 1.88 | 0.74 | 1.02 | 3.03 | 3.32 |
| RF3 | RF3.1 (Insulation R2.5) | 0.00 | 0.00 | | | 0.00 | 0.03 | 0.13 | 1.14 | 3.16 |

| Climate Zone 62 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | Fraction of Rain Load | | S4.1 Indoor climate | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | | | | | | S3.1 | S3.1 + S3.2 | Relative Humidity & Temperature | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| | RF3.2 (Insulation R4.1) | 0.00 | 0.00 | | | 0.00 | 0.03 | 0.07 | 1.84 | 3.24 |
| RF4 | RF4.1 (Insulation R2.5) | 1.79 | 2.18 | | | 0.35 | 0.19 | 0.21 | 3.05 | 3.42 |
| | RF4.2 (Insulation R4.1) | 2.27 | 3.23 | | | 1.66 | 0.54 | 0.80 | 3.17 | 4.32 |

**Notes**

- Results reported for monitor position m4 unless indicated otherwise
- Scenario 1.2 accounts for scenario 1.1 parameters
- Scenario 3.2 accounts for scenario 3.1 parameters
- Scenario 4.2 accounts for scenario 4.1 parameters
- Grey – Not on scope

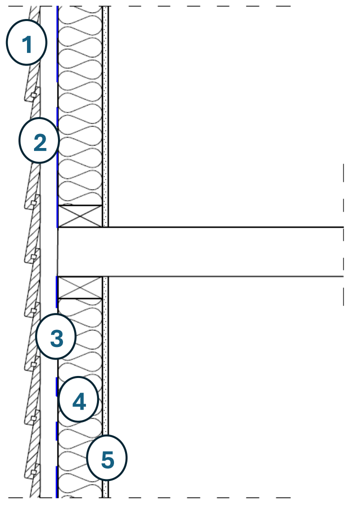
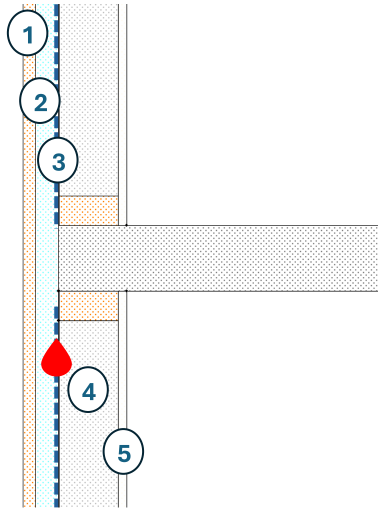
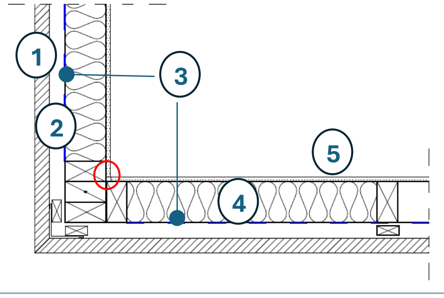
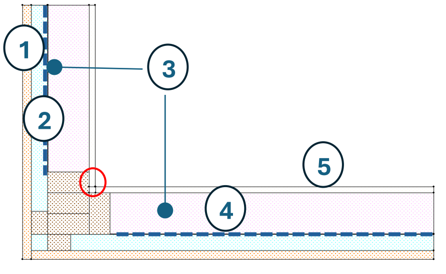
| Climate Zone 66 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | | | | | | Fraction of Rain Load | | S4.1 Indoor climate | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | S3.1 | S3.1 + S3.2 | Relative Humidity & Temperature | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| **External Walls** | | | | | | | | | | |
| **EW1** | **EW1.1 (Insulation R2.3)** | 0.01 | 0.02 | 0.00 | | | 0.00 | 0.00 | 3.49 | 3.50 |
| | **EW1.2 (Insulation R2.7)** | 0.02 | 0.04 | 0.04 | | | 0.08 | 0.11 | 3.48 | 3.50 |
| | **EW1.4 (Insulation R2.99)** | 0.02 | 0.03 | | 0.06 | | 0.04 | 0.10 | 3.47 | 3.50 |
| **EW2** | **EW2.1 (Insulation R2.3)** | 0.06 | 0.10 | 0.17 | | | 0.20 | 0.24 | 3.49 | 3.50 |
| | **EW2.2 (Insulation R2.7)** | 0.07 | 0.10 | 0.19 | | | 0.22 | 0.26 | 3.48 | 3.50 |
| | **EW2.4 (Insulation R2.99)** | 0.06 | 0.09 | | 0.21 | | 0.22 | 0.31 | 3.47 | 3.50 |
| **EW3** | **EW3.1 (Insulation R2.3)** | 0.03 | 0.11 | 2.79 | | | 2.75 | 2.99 | 3.46 | 3.50 |
| | **EW3.2 (Insulation R2.7)** | 0.05 | 0.13 | 2.93 | | | 2.92 | 3.02 | 3.46 | 3.46 |
| | **EW3.4 (Insulation R2.99)** | 0.05 | 0.14 | | **2.97** | | **3.02** | **3.10** | **3.50** | **3.49** |
| **EW4** | **EW4.2 (Insulation R0.2)** | 0.00 | 0.25 | | | | **3.13** | **3.29** | **3.44** | **3.02** |
| | **EW4.3 (Insulation R0.45)** | 0.00 | 0.06 | | | | 3.26 | 3.32 | 3.49 | 3.33 |
| **EW5** | **EW5.1 (Insulation R2.0)[2]** | | | 0.08 | | | 0.16 | 0.22 | 0.07 | 0.07 |
| | **EW5.2 (Insulation R2.7)[2]** | | | 0.07 | | | 0.15 | 0.20 | 0.08 | 0.08 |
| | **EW5.4 (Insulation R2.99)[2]** | | | | 0.14 | | 0.15 | 0.88 | 0.10 | 0.10 |
| **EW6** | **EW6.1 (Insulation R2.0)** | 0.16 | 0.52 | 2.88 | | | 2.86 | 2.94 | 3.46 | 3.50 |
| | **EW6.2 (Insulation R2.7)** | 0.18 | 0.61 | 2.95 | | | 2.88 | 2.96 | 3.50 | 3.50 |
| | **EW6.4 (Insulation R2.99)** | 0.32 | 1.25 | | 2.94 | | 2.99 | 3.06 | 3.50 | 3.50 |
| **Roofs** | | | | | | | | | | |
| **RF1** | **RF1.1 (Insulation R2.5)** | 0.00 | 0.00 | | | 0.00 | 0.04 | 0.07 | 0.00 | 3.33 |
| | **RF1.2 (Insulation R4.1)** | 0.00 | 0.00 | | | 0.00 | 0.06 | 0.09 | 0.00 | 3.14 |
| **RF2** | **RF2.1 (Insulation R2.5)** | 0.19 | 0.26 | | | 2.23 | 0.18 | 0.19 | 2.97 | 3.43 |

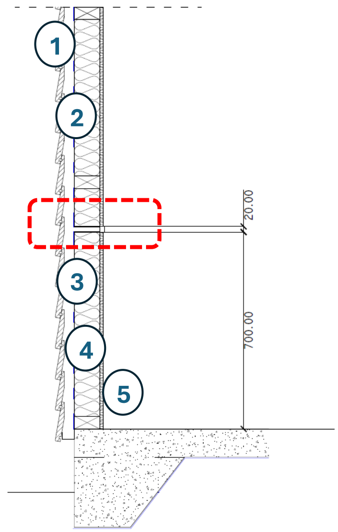
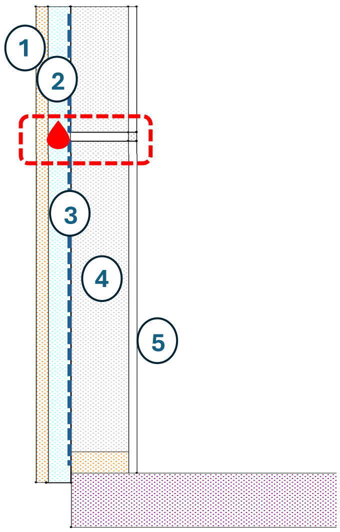
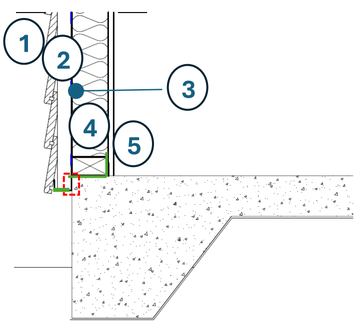
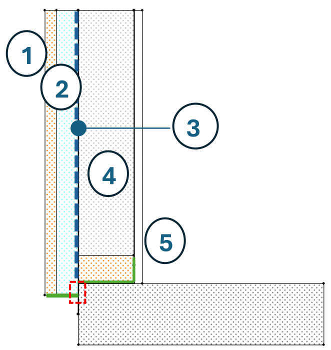
| Climate Zone 66 - High Stress Scenarios Performance - VVT Model Mould Index (MI) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Build-up | Build-up Variation | Construction Scenarios | | | | | Environmental conditions Scenarios | | | |
| | | S1 | | S2 | | | S3 | | S4 | |
| | | S1.1 Constant ventilation rate | S1.1 + S1.2 Air cavity Thickness | S2.1 Membrane (wall) | S2.2 Membrane (wall) | S2.3 Membrane (roof) | Fraction of Rain Load | | S4.1 Indoor climate | S4.1 + S4.2 Indoor Ventilation (ACH) |
| | | | | | | | S3.1 | S3.1 + S3.2 | Relative Humidity & Temperature | |
| | | ACH 25 1/h | (Thickness /2) wall 0.020m (roof) | 2.179 µg/N/s | 0.001 µg/N/s. | 1.429 µg/N/s | 1.40% | (1.4+0.5)=1.9% | 60%/ 17 $^{0}$C | 0.25 (1/h) |
| | **RF2.2 (Insulation R4.1)** | 0.21 | 0.28 | | | 0.26 | 2.45 | 0.23 | 2.96 | 3.38 |
| **RF3** | **RF3.1 (Insulation R2.5)** | 0.00 | 0.00 | | | 0.06 | 0.12 | 0.15 | 2.92 | 3.38 |
| | **RF3.2 (Insulation R4.1)** | 0.00 | 0.00 | | | 0.10 | 0.09 | 0.17 | 2.98 | 3.38 |
| **RF4** | **RF4.1 (Insulation R2.5)** | 0.14 | 0.30 | | | 0.20 | 1.95 | 0.19 | 3.14 | 3.47 |
| | **RF4.2 (Insulation R4.1)** | 0.17 | 0.34 | | | 0.25 | 0.21 | 0.23 | 3.20 | 3.47 |

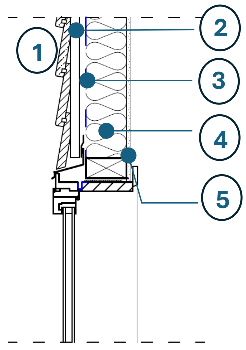
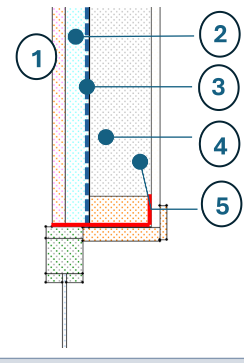
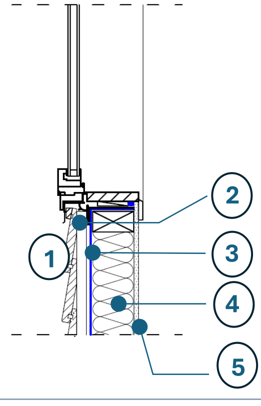
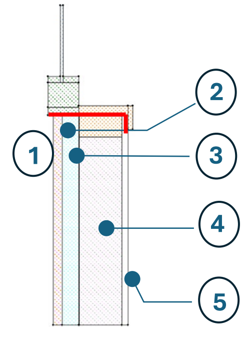
**Notes**

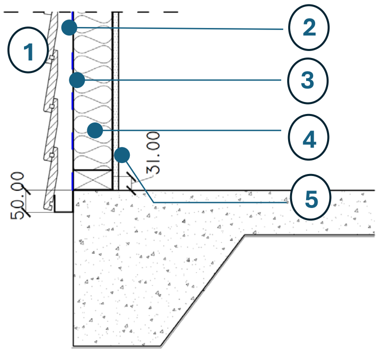
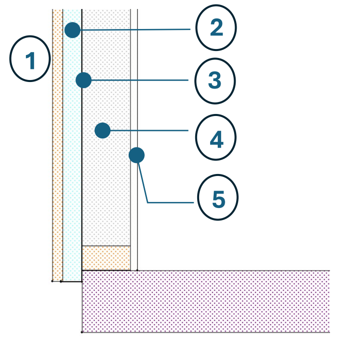
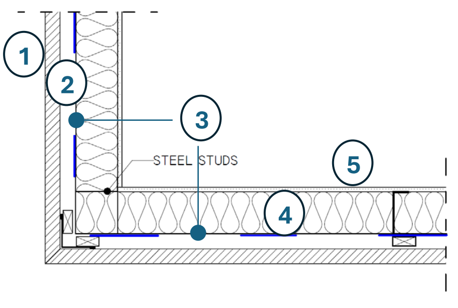
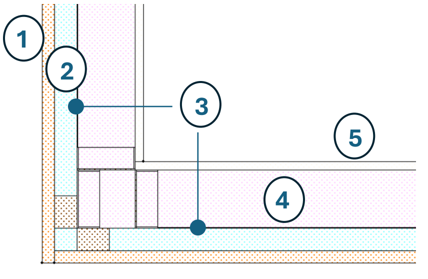
- Results reported for monitor position m4 unless indicated otherwise
- Scenario 1.2 accounts for scenario 1.1 parameters
- Scenario 3.2 accounts for scenario 3.1 parameters
- Scenario 4.2 accounts for scenario 4.1 parameters
- Grey – Not on scope

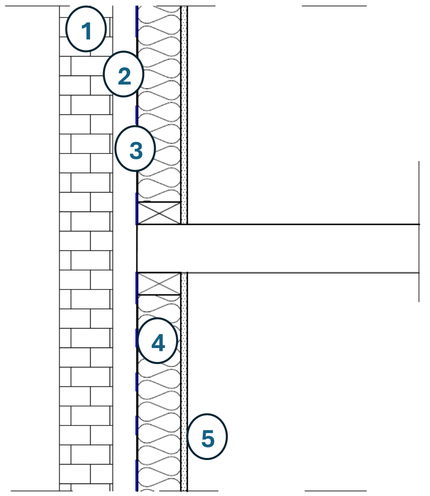
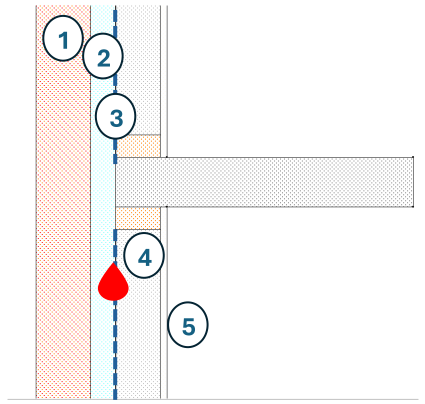
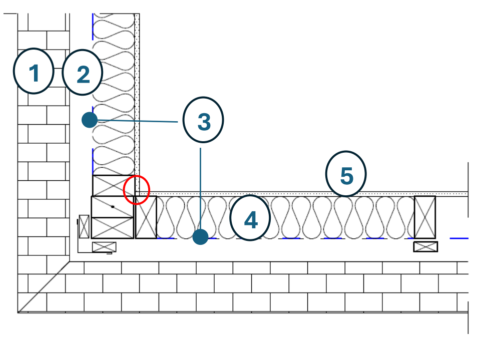
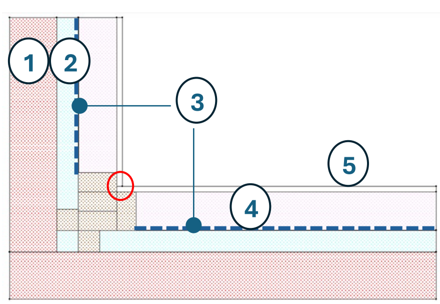
# Appendix 5: Phase 3 Construction details

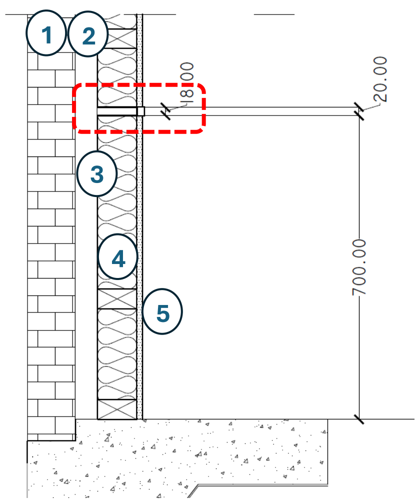
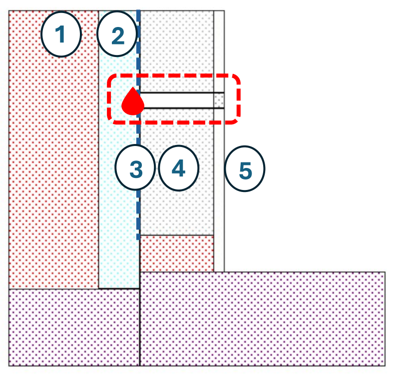
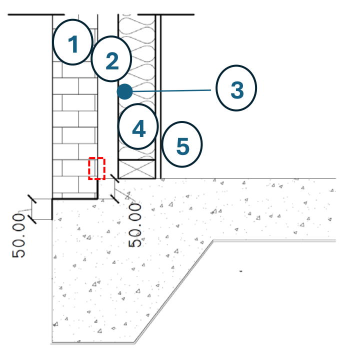
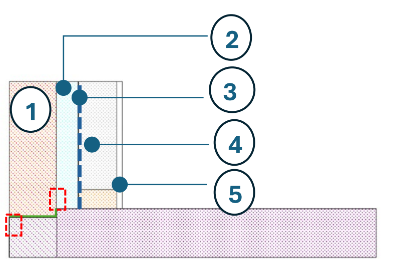
| EW1 EW2 | **Lightweight External wall systems (EW1, EW2):**<br>1. 19mm Weatherboard cladding (EW1) or 8mm Fibre cement (EW2).<br>2. 35mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard. | | |
|---|---|---|---|
| D1 | **Building Sealing - Membrane not fixed to frame or discontinuous.** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |   |   | • Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as indicated in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] |
| D2 | **Building Sealing - Continuous corner gaps** | | |
| | 2D CAD Details – Plan View | WUFI 2D Detail – Plan view | Comments |
| |   |   | The corner gap (highlighted in red) is represented as a gap between the internal plasterboard corner junction. |

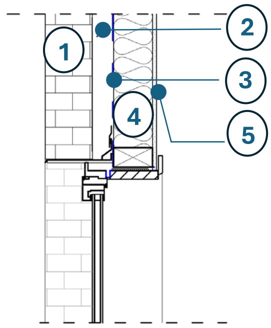
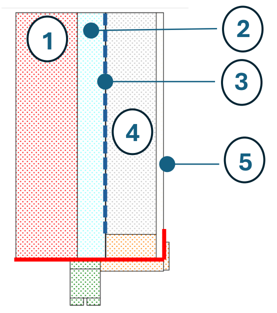
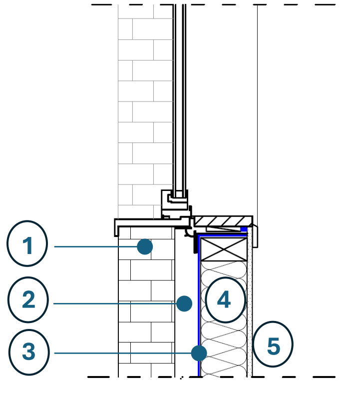
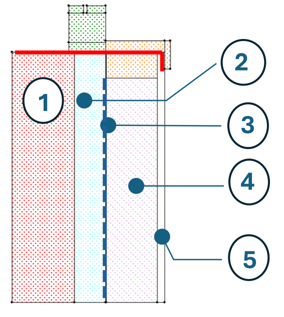
<table>
<tr><td rowspan="1">EW1<br>EW2</td><td colspan="3">Lightweight External wall systems (EW1, EW2):<br>1. 19mm Weatherboard cladding (EW1) or 8mm Fibre cement (EW2).<br>2. 35mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D3</td><td colspan="3">Services penetration - Water vapour leakage through pipes, power outlets and wirings</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>• Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as highlighted in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] to simulate moisture accumulation due to dripping of a pipe or moisture infiltration from the cladding.</td></tr>
<tr><td rowspan="3">D4</td><td colspan="3">Flashing issues - Wall base flashing without a fall to prevent ponding</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail – Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Flashing highlighted in green, does not consider a fall towards the bottom section of the wall (the missing section highlighted in red).</td></tr>
</table>

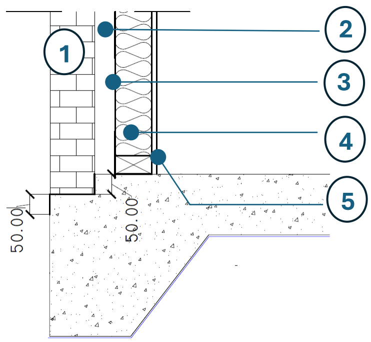
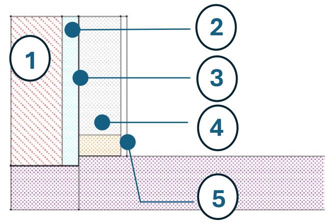
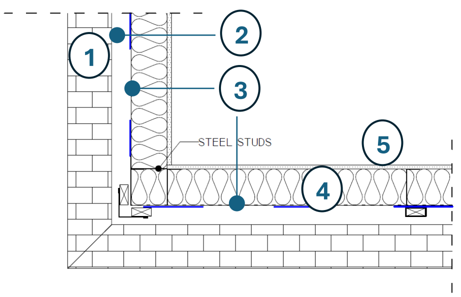
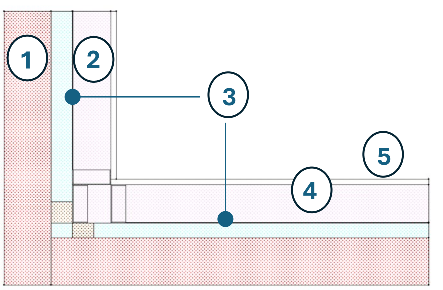
| | | | |
|---|---|---|---|
| **EW1 EW2** | **Lightweight External wall systems (EW1, EW2):**<br>1. 19mm Weatherboard cladding (EW1) or 8mm Fibre cement (EW2).<br>2. 35mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard. | | |
| **D5** | **Flashing issues - Windows and door head without or incorrect flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  |  | Represented by simulating the window head flashing is missing (missing flashing is highlighted in red) |
| **D6** | **Flashing issues - Window or door sill without or incorrect flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Represented by simulating the windowsill flashing is missing (missing flashing is highlighted in red) |

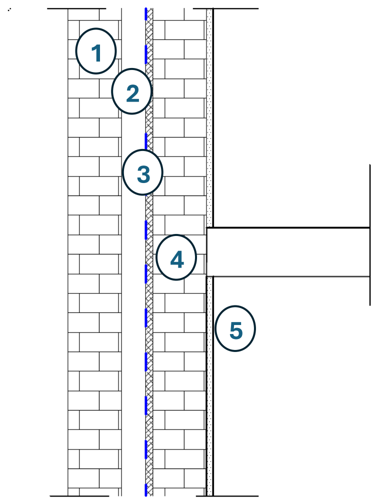
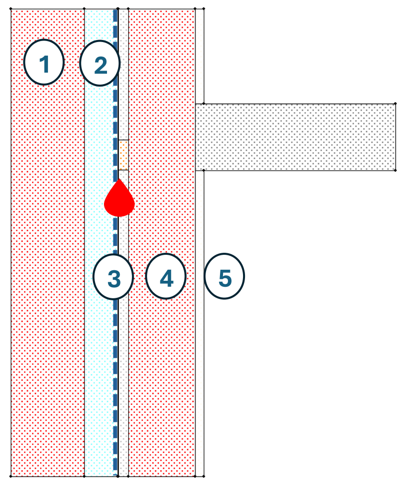
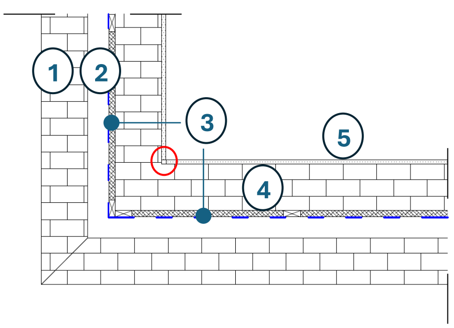
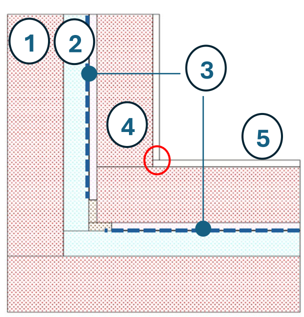
<table>
<tr><td rowspan="1">EW1<br>EW2</td><td colspan="3">Lightweight External wall systems (EW1, EW2):<br>1. 19mm Weatherboard cladding (EW1) or 8mm Fibre cement (EW2).<br>2. 35mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D7</td><td colspan="3">Water ingress - Water ingress due to environmental conditions such as flooding.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented as rising dampness through walls by increasing the external boundary conditions modifying the Driving Rain Coefficients as follows:<br>• Rain Exposure Factor [1.5] and<br>• Rain Deposition Factor [2].</td></tr>
<tr><td rowspan="3">D8</td><td colspan="3">Thermal bridge – Steel framing</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan view</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by replacing timber studs with steel.</td></tr>
</table>

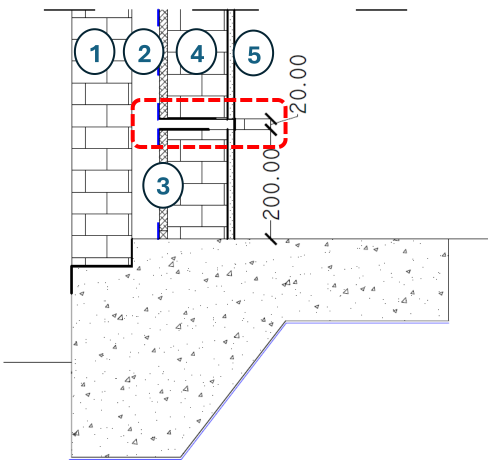
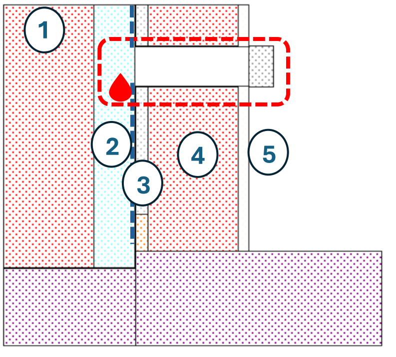
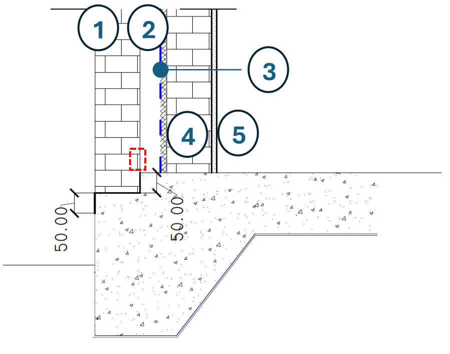
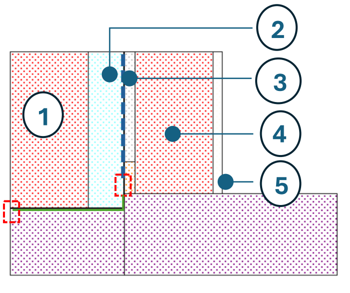
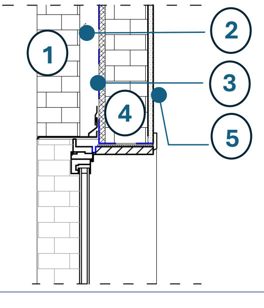
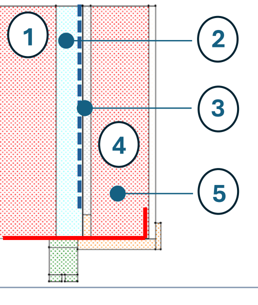
| | | | |
|---|---|---|---|
| **EW3** | **Heavyweight External wall system (EW3): Clay masonry veneer**<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard. | | |
| **D1** | **Building Sealing - Membrane not fixed to frame or discontinuous.** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  |  | • Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as indicated in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] |
| **D2** | **Building Sealing - Continuous corner gaps** | | |
| | 2D CAD Details – Plan View | WUFI 2D Detail – Plan view | Comments |
| |  |  | The corner gap (highlighted in red) is represented as a gap between the internal plasterboard corner junction. |

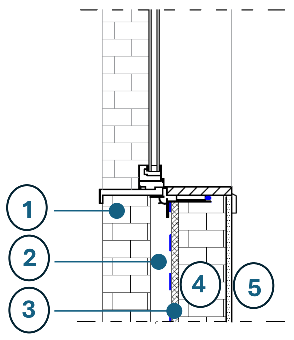
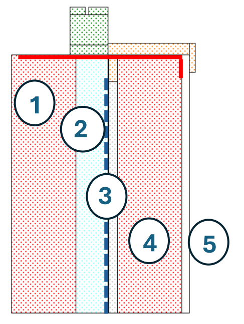
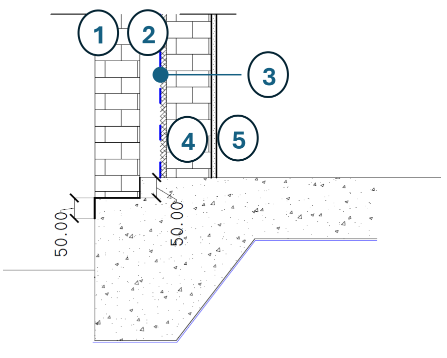
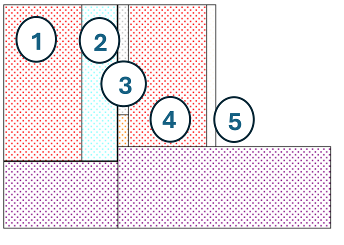
| | | | |
|---|---|---|---|
| **EW3** | **Heavyweight External wall system (EW3): Clay masonry veneer**<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard. | | |
| **D3** | **Services penetration - Water vapour leakage through pipes, power outlets and wirings** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  | * Penetration location was adjusted to 200mm height instead of 700mm, to reduce simplify the simulation processing.<br> | • Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as highlighted in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] to simulate moisture accumulation due to dripping of a pipe or moisture infiltration from the cladding. |
| **D4** | **Flashing issues – Water leaks through base flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | • Base flashing highlighted in green, do not have an upturn of 50mm (highlighted in red)<br>• Base flashing without a fall to prevent ponding |

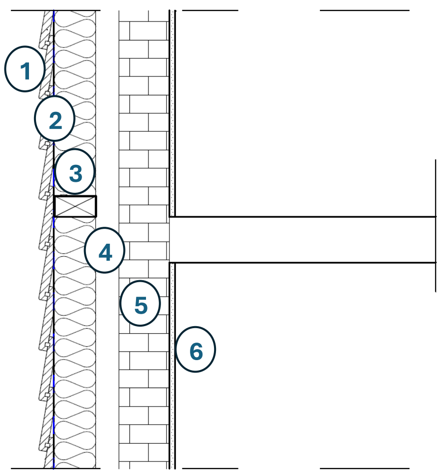
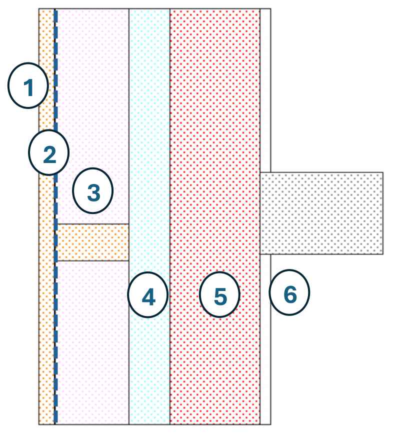
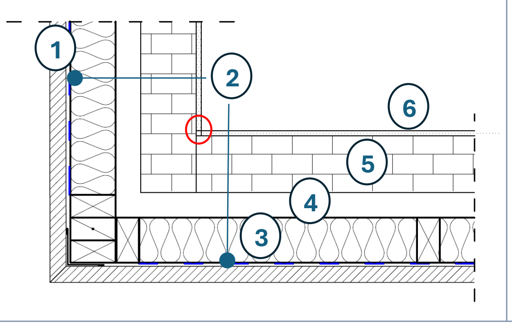
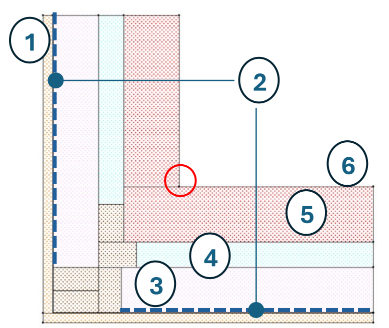
<table>
<tr><td>EW3</td><td colspan="3">Heavyweight External wall system (EW3): Clay masonry veneer<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D5</td><td colspan="3">Flashing issues - Windows and door head without or incorrect flashing</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by simulating the window head flashing is missing (missing flashing is highlighted in red)</td></tr>
<tr><td rowspan="3">D6</td><td colspan="3">Flashing issues - Window or door sill without or incorrect flashing</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail – Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by simulating the windowsill flashing is missing (missing flashing is highlighted in red)</td></tr>
</table>

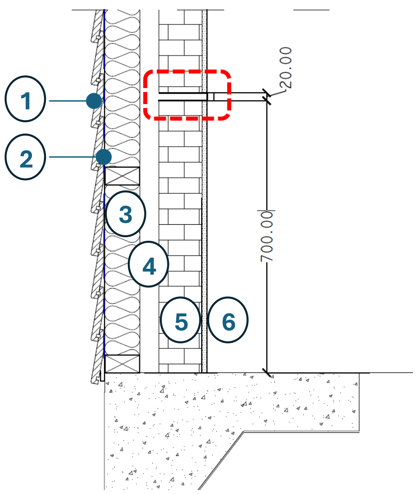
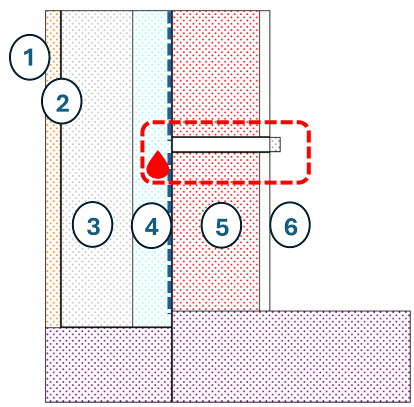
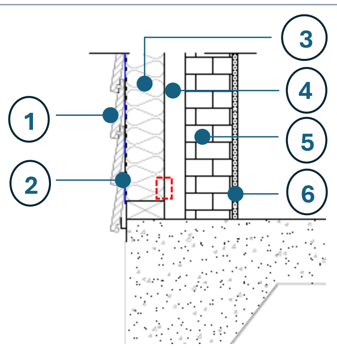
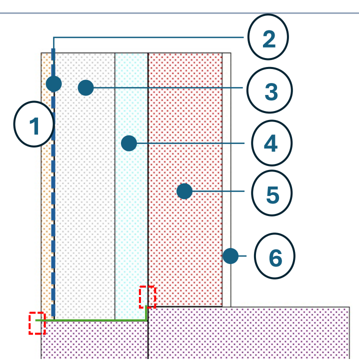
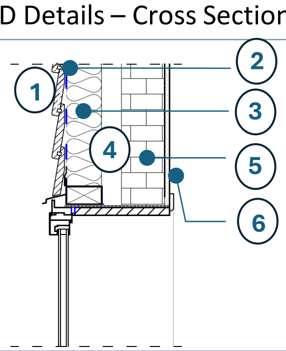
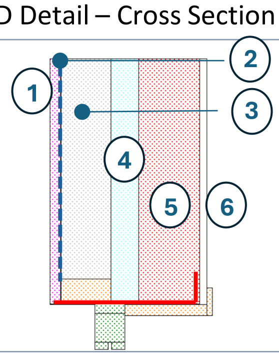
<table>
<tr><td>EW3</td><td colspan="3">Heavyweight External wall system (EW3): Clay masonry veneer<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D7</td><td colspan="3">Water ingress - Water ingress due to environmental conditions such as flooding.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented as rising dampness through walls by increasing the external boundary conditions modifying the Driving Rain Coefficients as follows:<br>• Rain Exposure Factor [1.5] and<br>• Rain Deposition Factor [2].</td></tr>
<tr><td rowspan="3">D8</td><td colspan="3">Thermal bridge – Steel framing</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by replacing timber studs with steel.</td></tr>
</table>

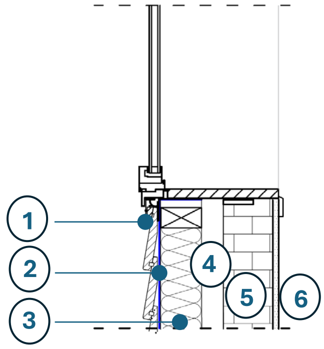
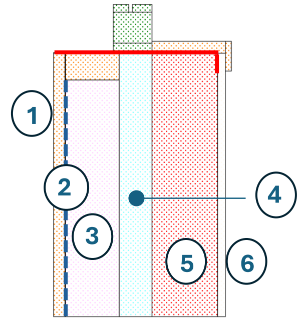
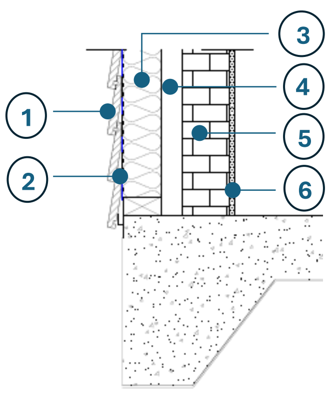
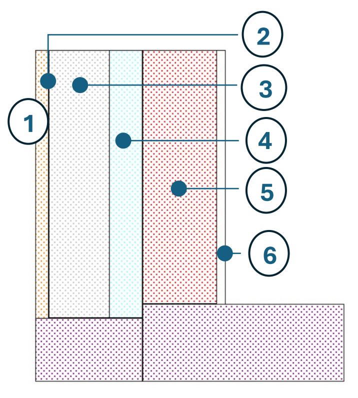
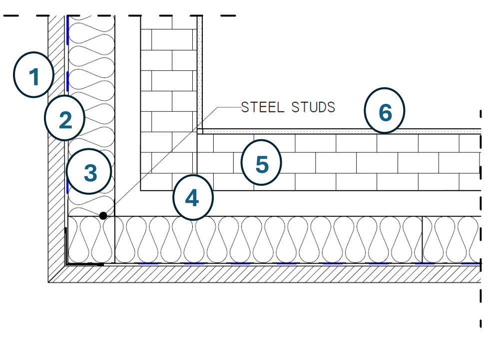
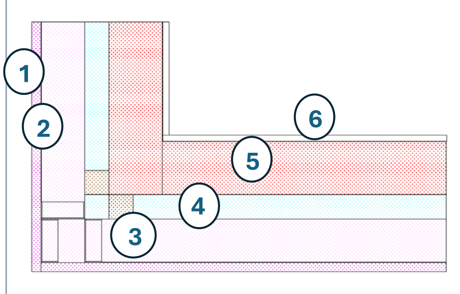
<table>
<tr><td>EW4</td><td colspan="3">Heavyweight External wall system (EW4): Cavity clay masonry<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane + 15mm cavity insulation<br>4. 110 mm Brick veneer<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D1</td><td colspan="3">Building Sealing - Membrane not fixed to frame or discontinuous.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>• Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as indicated in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction]</td></tr>
<tr><td rowspan="3">D2</td><td colspan="3">Building Sealing - Continuous corner gaps</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan view</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>The corner gap (highlighted in red) is represented as a gap between the internal plasterboard corner junction.</td></tr>
</table>

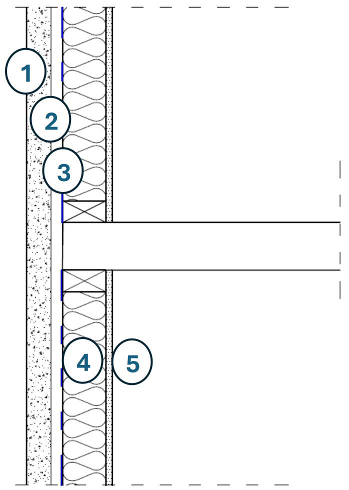
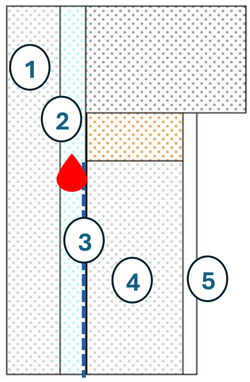
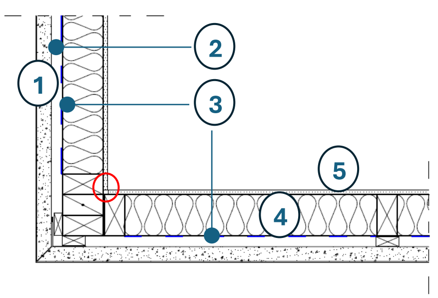
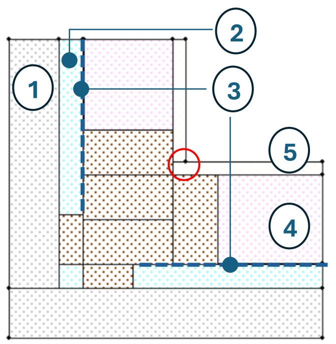
| | | | |
|---|---|---|---|
| **EW4** | **Heavyweight External wall system (EW4): Cavity clay masonry**<br>1. 110 mm Brick veneer<br>2. 50 mm non-ventilated cavity<br>3. Pliable membrane + 15mm cavity insulation<br>4. 110 mm Brick veneer<br>5. 13mm plasterboard. | | |
| **D3** | **Services penetration - Water vapour leakage through pipes, power outlets and wirings** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  |  | • Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as highlighted in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] to simulate moisture accumulation due to dripping of a pipe or moisture infiltration from the cladding. |
| **D4** | **Flashing issues – Water leaks through base flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Detail represented as follows:<br>• Base flashing highlighted in green, without an upturn of 50mm (highlighted in red)<br>• Base flashing without a fall to prevent ponding<br>• Membrane does not overflash the upturn of the flashing. |
| **D5** | **Flashing issues - Windows and door head without or incorrect flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Represented by simulating the window head flashing is missing (missing flashing is highlighted in red) |

| | | | |
|---|---|---|---|
| **EW4** | **Heavyweight External wall system (EW5): Externally insulated clay masonry**<br>1. 19 mm Weatherboard<br>2. Pliable membrane<br>3. 90mm insulation in timber frame<br>4. 50 mm non-ventilated cavity<br>5. 110 mm Brick veneer<br>6. 13mm plasterboard. | | |
| **D6** | **Flashing issues - Window or door sill without or incorrect flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  |  | Represented by simulating the windowsill flashing is missing (missing flashing is highlighted in red) |
| **D7** | **Water ingress - Water ingress due to environmental conditions such as flooding.** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Represented as rising dampness through walls by increasing the external boundary conditions modifying the Driving Rain Coefficients as follows:<br>• Rain Exposure Factor [1.5] and<br>• Rain Deposition Factor [2]. |

<table>
<tr><td>EW5</td><td colspan="3">Heavyweight External wall system (EW5): Externally insulated clay masonry<br>1. 19 mm Weatherboard<br>2. Pliable membrane<br>3. 90mm insulation in timber frame<br>4. 50 mm non-ventilated cavity<br>5. 110 mm Brick veneer<br>6. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D1</td><td colspan="3">Building Sealing - Membrane not fixed to frame or discontinuous.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>• Membrane (represented in blue)<br>• No additional moisture source considered</td></tr>
<tr><td rowspan="3">D2</td><td colspan="3">Building Sealing - Continuous corner gaps</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan view</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>The corner gap (highlighted in red) is represented as a gap between the internal plasterboard corner junction.</td></tr>
</table>

| | | | |
|---|---|---|---|
| **EW5** | **Heavyweight External wall system (EW5): Externally insulated clay masonry**<br>1. 19 mm Weatherboard<br>2. Pliable membrane<br>3. 90mm insulation in timber frame<br>4. 50 mm non-ventilated cavity<br>5. 110 mm Brick veneer<br>6. 13mm plasterboard. | | |
| **D3** | **Services penetration - Water vapour leakage through pipes, power outlets and wirings** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
| |  | * Penetration location was adjusted to 200mm height instead of 700mm, to reduce simplify the simulation processing.<br> | • Membrane (represented in blue)<br>• Included one additional moisture source to assess the moisture content of the different materials (as highlighted in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction] to simulate moisture accumulation due to dripping of a pipe or moisture infiltration from the cladding. |
| **D4** | **Flashing issues – Water leaks through base flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Base flashing highlighted in green, without an upturn of 50mm (highlighted in red)<br>• Base flashing without a fall to prevent ponding<br>• Membrane does not overflash the upturn of the flashing. |
| **D5** | **Flashing issues - Windows and door head without or incorrect flashing** | | |
| | 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
| |  |  | Represented by simulating the window head flashing is missing (missing flashing is highlighted in red) |

<table>
<tr><td>EW5</td><td colspan="3">Heavyweight External wall system (EW5): Externally insulated clay masonry<br>1. 19 mm Weatherboard<br>2. Pliable membrane<br>3. 90mm insulation in timber frame<br>4. 50 mm non-ventilated cavity<br>5. 110 mm Brick veneer<br>6. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D6</td><td colspan="3">Flashing issues - Window or door sill without or incorrect flashing</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by simulating the windowsill flashing is missing (missing flashing is highlighted in red)</td></tr>
<tr><td rowspan="3">D7</td><td colspan="3">Water ingress - Water ingress due to environmental conditions such as flooding.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail – Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented as rising dampness through walls by increasing the external boundary conditions modifying the Driving Rain Coefficients as follows:<br>• Rain Exposure Factor [1.5] and<br>• Rain Deposition Factor [2].</td></tr>
<tr><td rowspan="3">D8</td><td colspan="3">Thermal bridge – Steel framing</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan view</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>Represented by replacing timber studs with steel.</td></tr>
</table>

<table>
<tr><td rowspan="1">EW6</td><td colspan="3">Heavyweight External wall system (EW6): Autoclaved aerated concrete masonry<br>1. 2mm Acrylic membrane + 50mm Autoclaved aerated concrete<br>2. 24 mm non-ventilated cavity<br>3. Pliable membrane<br>4. 90mm insulation in timber frame<br>5. 13mm plasterboard.</td></tr>
<tr><td rowspan="3">D1</td><td colspan="3">Building Sealing - Membrane not fixed to frame or discontinuous.</td></tr>
<tr><td>2D CAD Details – Cross Section View</td><td>WUFI 2D Detail - Cross Section View</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>• Membrane (represented in blue) does not cover the stud section.<br>• Included one additional moisture source to assess the moisture content of the different materials (as indicated in red).<br>• Moisture source represented as an additional fraction of driving rain [1% fraction]</td></tr>
<tr><td rowspan="3">D2</td><td colspan="3">Building Sealing - Continuous corner gaps</td></tr>
<tr><td>2D CAD Details – Plan View</td><td>WUFI 2D Detail – Plan view</td><td>Comments</td></tr>
<tr><td>
</td><td>
</td><td>The corner gap (highlighted in red) is represented as a gap between the internal plasterboard corner junction.</td></tr>
</table>

**EW6**

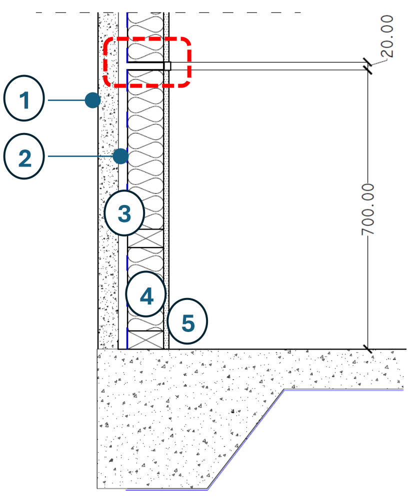
**Heavyweight External wall system (EW6): Autoclaved aerated concrete masonry**

1. 2mm Acrylic membrane + 50mm Autoclaved aerated concrete
2. 24 mm non-ventilated cavity
3. Pliable membrane
4. 90mm insulation in timber frame
5. 13mm plasterboard.

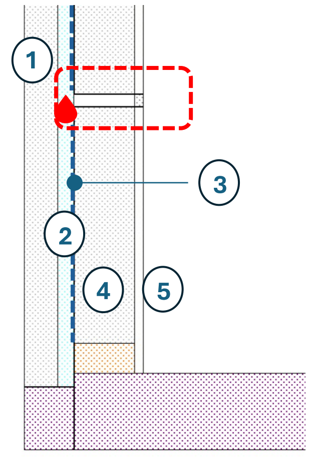
**D3**

**Services penetration - Water vapour leakage through pipes, power outlets and wirings**

2D CAD Details – Cross Section View




WUFI 2D Detail - Cross Section View



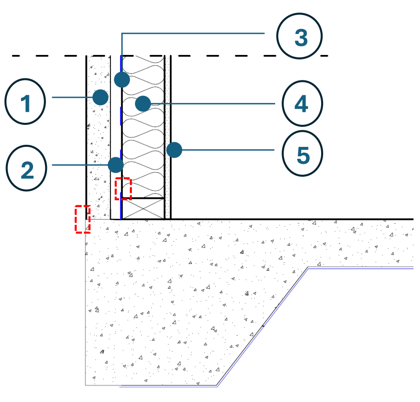

Comments

- Membrane (represented in blue)
- Included one additional moisture source to assess the moisture content of the different materials (as highlighted in red).
- Moisture source represented as an additional fraction of driving rain [1% fraction] to simulate moisture accumulation due to dripping of a pipe or moisture infiltration from the cladding.

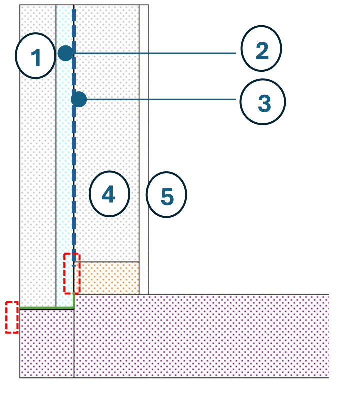
**D4**

**Flashing issues – Water leaks through base flashing**

2D CAD Details – Cross Section View




WUFI 2D Detail – Cross Section View




Comments

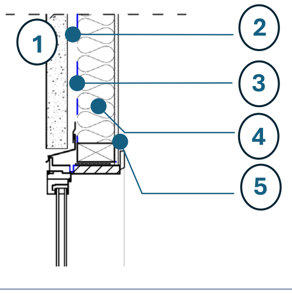
Detail represented as follows:

- Base flashing highlighted in green, without an upturn of 50mm (highlighted in red)
- Base flashing without a fall to prevent ponding
- Membrane does not overflash the upturn of the flashing.

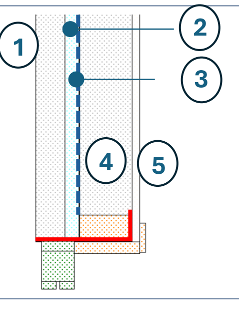
**D5**

**Flashing issues - Windows and door head without or incorrect flashing**

2D CAD Details – Cross Section View




WUFI 2D Detail – Cross Section View




Comments

Represented by simulating the window head flashing is missing (missing flashing is highlighted in red)

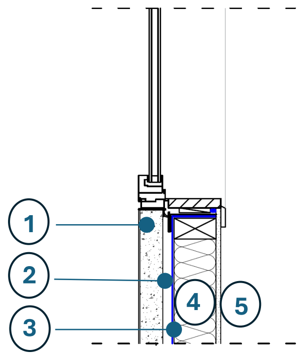
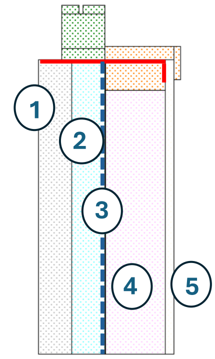
## EW6

**Heavyweight External wall system (EW6): Autoclaved aerated concrete masonry**

1. 2mm Acrylic membrane + 50mm Autoclaved aerated concrete
2. 24 mm non-ventilated cavity
3. Pliable membrane
4. 90mm insulation in timber frame
5. 13mm plasterboard.

## D6

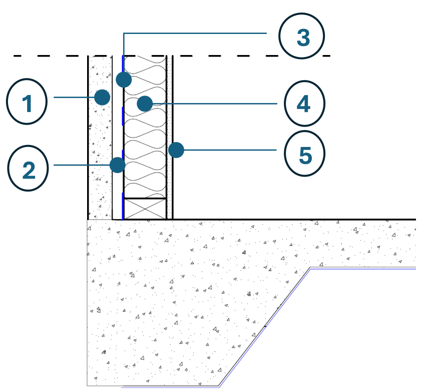
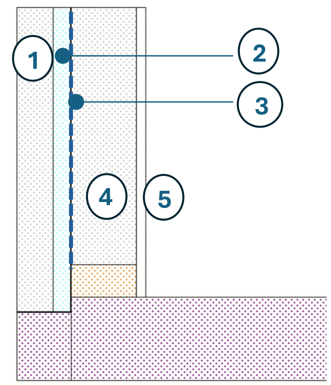
**Flashing issues - Window or door sill without or incorrect flashing**

| 2D CAD Details – Cross Section View | WUFI 2D Detail - Cross Section View | Comments |
|---|---|---|
|  |  | Represented by simulating the windowsill flashing is missing (missing flashing is highlighted in red) |



## D7

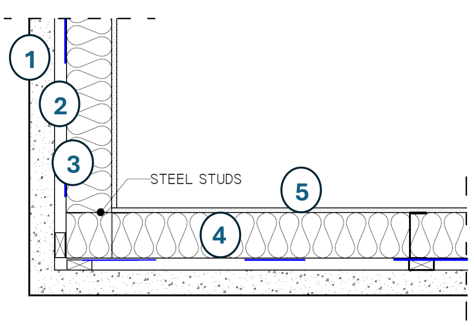
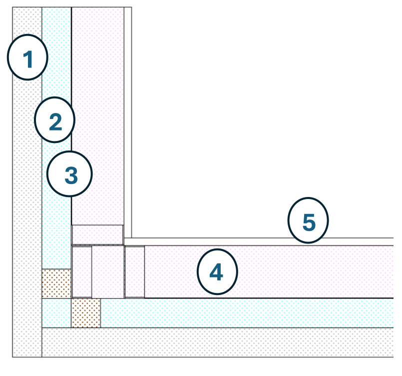
**Water ingress - Water ingress due to environmental conditions such as flooding.**

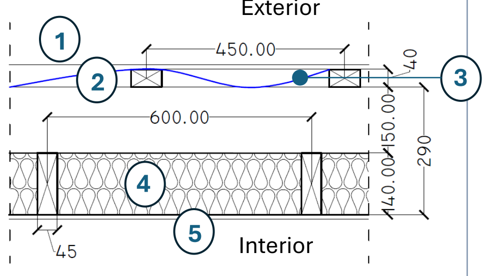
| 2D CAD Details – Cross Section View | WUFI 2D Detail – Cross Section View | Comments |
|---|---|---|
|  |  | Represented as rising dampness through walls by increasing the external boundary conditions modifying the Driving Rain Coefficients as follows:<br>• Rain Exposure Factor [1.5] and<br>• Rain Deposition Factor [2]. |



## D8

**Thermal bridge – Steel framing**

| 2D CAD Details – Plan View | WUFI 2D Detail – Plan view | Comments |
|---|---|---|
|  |  | Represented by replacing timber studs with steel. |

<table>
<tr>
<td>RF1<br>RF2</td>
<td colspan="2">Flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter (RF1):<br>1. 8mm Roof cladding (metal) or 26mm terracotta tiles<br>2. 40 mm non-ventilated cavity + battens<br>3. Pliable membrane<br>4. 140 mm insulation, rafters (290mm)<br>5. 10mm plasterboard.</td>
<td>Heavyweight External wall system (EW3): Clay masonry veneer<br>A. 110 mm Brick veneer<br>• 50 mm non-ventilated cavity<br>• Pliable membrane<br>• 90mm insulation in timber frame<br>• 13mm plasterboard.</td>
</tr>
<tr>
<td rowspan="3">D1</td>
<td colspan="3">Building sealing - Discontinuous sarking</td>
</tr>
<tr>
<td>2D CAD Details – Section View</td>
<td>WUFI 2D Detail - Section View</td>
<td>Comments</td>
</tr>
<tr>
<td>


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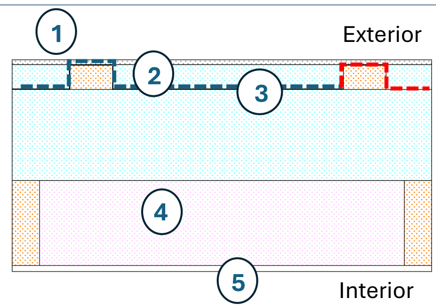

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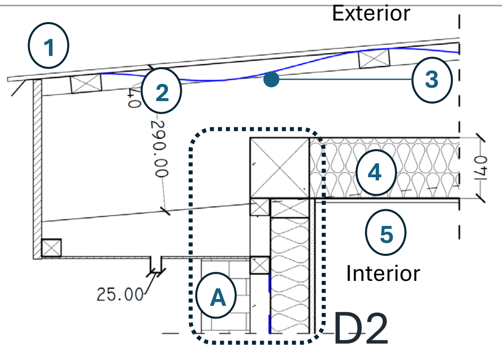
<td>Continuous Sarking is represented in blue, and the missing section is highlighted in red.</td>
</tr>
<tr>
<td rowspan="3">D2</td>
<td colspan="3">Building sealing – Continuous gap behind wall/ceiling junctions</td>
</tr>
<tr>
<td>2D CAD Details – Section View</td>
<td>WUFI 2D Detail – Section View</td>
<td>Comments</td>
</tr>
<tr>
<td>


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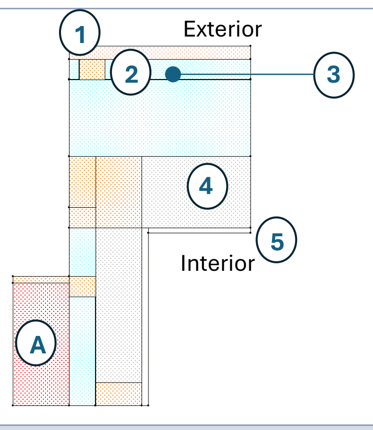
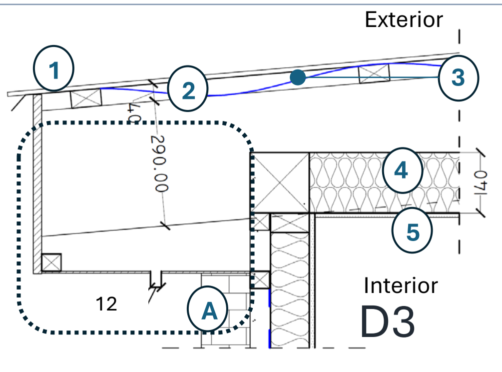


</td>
<td>Corner gaps between wall and ceiling lining</td>
</tr>
<tr>
<td rowspan="3">D3</td>
<td colspan="3">Water leaks – Ventilation opening</td>
</tr>
<tr>
<td>2D CAD Details – Section View</td>
<td>WUFI 2D Detail – Section View</td>
<td>Comments</td>
</tr>
<tr>
<td>


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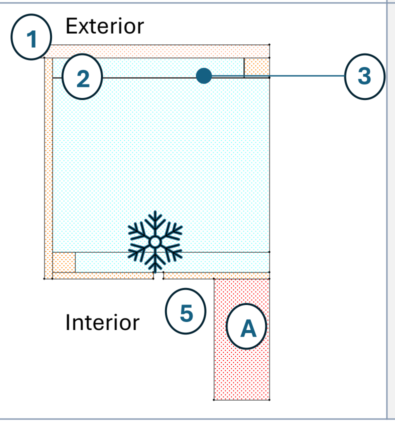
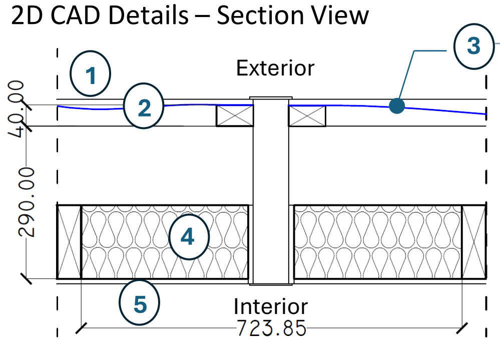
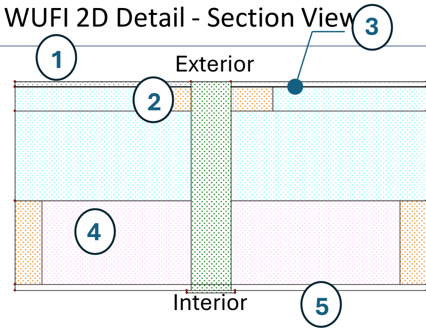
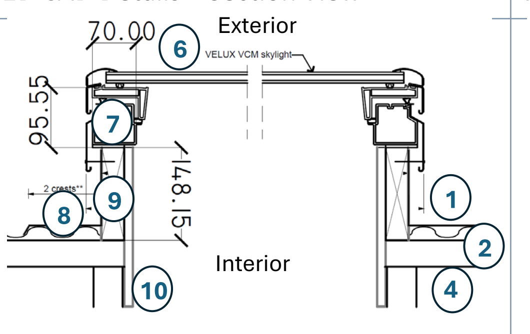
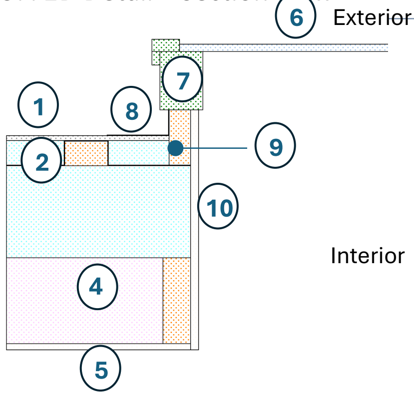


</td>
<td>Ventilation opening of 25,000 mm² according to NCC 2022 Housing Provisions, Part 10.8.3.<br><br>Applied an air change rate of 1 (1/h) highlighted in green.</td>
</tr>
</table>

| | | |
|---|---|---|
| RF1<br>RF2 | **Flat roof, skillion roof and cathedral ceiling with a ceiling lining under rafter (RF1):**<br>1. 8mm Roof cladding (metal) or 26mm terracotta tiles<br>2. 40 mm non-ventilated cavity + battens<br>3. Pliable membrane<br>4. 140 mm insulation, rafters (290mm)<br>5. 10mm plasterboard. | **Heavyweight External wall system (EW3): Clay masonry veneer**<br>**A.** 110 mm Brick veneer<br>• 50 mm non-ventilated cavity<br>• Pliable membrane<br>• 90mm insulation in timber frame<br>• 13mm plasterboard. |

| | | | |
|---|---|---|---|
| **D4** | **Building sealing - Discontinuous sarking** | | |
| | 2D CAD Details – Section View<br> | WUFI 2D Detail - Section View<br> | Comments<br>Services penetration is highlighted in green |
| **D5** | **Building sealing – Continuous gap behind wall/ceiling junctions** | | |
| | 2D CAD Details – Section View<br> | WUFI 2D Detail – Section View<br> | Comments<br>Skylight detail based on Velux manufacturer specifications as follows:<br>6. Glass<br>7. Sash<br>8. Flashing<br>9. Timber Base<br>10. Internal lining |