Ministry of Housing,
Communities &
Local Government

Research into resistance to moisture in buildings

Research Summary

July 2019
PRP Architects LLP

Ministry of Housing, Communities and Local Government

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The document is prepared by Innovate at PRP Limited, part of PRP Architects LLP.

Contents

1. Introduction

It is a requirement of Part C of the Building Regulations that buildings, and people who use these buildings, are adequately protected from harmful effects of moisture. Approved Document C provides guidance on how to meet this requirement. However, much of this guidance was made before the energy performance requirements for buildings were improved in recent years and it is not certain that these recommendations are still appropriate. In addition, Approved Document C refers to a number of British Standards and other publications, but the usefulness and applicability of these documents, particularly in relation to retrofit works, required reviewing. It should be noted that this project focused specifically on moisture from precipitation, surface and interstitial condensation.

The Ministry of Housing, Communities and Local Government (MHCLG) commissioned PRP to carry out this research study, entitled Research into resistance to moisture in buildings.

There were two key aspects to the project:

- To verify the robustness of the guidance presented in Approved Document C (AD C) for new buildings in the light of changes to Part L and to identify gaps in the current guidance; and
- To develop a set of relevant guidance for situations where insulation is retrofitted to existing buildings.

This report is the **Research Summary** of the Ministry of Housing, Communities and Local Government's (MHCLG) *Research into resistance to moisture in buildings* project, it is written for a non-specialist readership. It is based upon information contained in the following detailed technical reports:

- Research into resistance to moisture in buildings: Identification of common types of construction.
- Research into resistance to moisture in buildings: Using calculation methods to assess surface and interstitial condensation
- Research into resistance to moisture in buildings: Using numerical simulation to assess moisture risk in new constructions
- Research into resistance to moisture in buildings: Using numerical simulation to assess moisture risk in retrofit constructions. Part 1
- Research into resistance to moisture in buildings: Using numerical simulation to assess moisture risk in retrofit constructions. Part 2
- Research into resistance to moisture in buildings: Assessment of current moisture guidance
- Research into resistance to moisture in buildings: Simplified rules for reducing the risk of moisture

2. Methodology

The project was been delivered in three main stages:

2.1. Stage One: Background research

Stage One covered all the background research required to refine the analysis methodology and the parameters used for the analysis.

A desktop research exercise was conducted in order to generate a list of the most commonly used construction typologies, for both new build and existing construction. A generic construction build-up was developed for each typical construction typology and formed part of the working set for Stage Two of the project.

A gap analysis identified thermal bridge junctions that had no Accredited Construction Details (ACDs) available and therefore cannot be used to comply with Approved Document C simply. Those thermal bridge junctions with the highest heat loss were shortlisted for the detailed analysis. Common thermal bridge junctions that are likely to be affected by retrofit insulation measure were also been identified for further detailed analysis.

2.2. Stage Two: Detailed analysis of identified construction typologies

Stage Two involved the detailed analysis of the various construction typologies identified in Stage One for both new build and retrofit, including key thermal bridge junctions. A number of software analysis packages and methodologies were used to carry out a sensitivity analysis on each of the identified typical construction typologies:

2.2.1. Simplified Modelling based on BS EN ISO 13788 (2012) - the 'Glaser Method'

The assessment method BS EN ISO 13788 (2012) is a one-dimensional steady-state assessment method predicting the risk of surface and interstitial condensation through a multi-layered structure occurring under specified environmental (monthly mean) conditions. This method only takes into account moisture transport via vapour diffusion alone.

The method has substantial limitations, such as the fact that it does not take into account any storage of moisture within the elements and assumes that materials transport properties are not affected by moisture content. This means that an accurate moisture risk assessment was limited to the build-ups where these aforementioned effects were considered negligible.

2.2.2. Standardised Modelling based on BS EN 15026 (2007) - with the use of an industry-standard software package, WUFI (Wärme und Feuchte Instationär)

The BS EN 15026 (2007) assessment method is a one-dimensional transient modelling of heat and moisture flows through a multi-layered structure with complex transport properties. This method takes into account the heat and moisture storage, the latent heat affect, and any liquid and convective transport under realistic boundary and initial conditions (i.e. non-steady climate conditions both internally and externally).

Similar to the BS EN ISO 13788 (2012) method, this method is limited to one-dimension assessment only and therefore junctions cannot be modelled. It also has some other limitations due to simplification around the modelling of air layers, as well as the lack of defined protocols and available data for materials, climate files, etc.

This assessment method is implemented in several software packages, including WUFI (Wärme und Feuchte Instationär), which is the software most commonly used in the industry, and the one used in our research study.

2.2.3. Multi-dimensional Thermal Modelling to BS EN ISO 10211 (2007) - with the use of THERM (for construction junctions only)

None of the hygrothermal assessment methods listed above is multi-dimensional and therefore none of them is able to assess moisture risks at junctions between different construction typologies. Surface condensation typically appears around junctions between materials due to low surface temperatures caused by any discontinuity of in the insulation layer. These moisture problems, mainly arising around junctions between different building elements, are called ‘connective effects’.

It is important to assess these junctions because surface condensation is also one of the main moisture risks that could lead to health issues for occupants and to fabric damage. The effect of extra heat losses appearing around junctions can also be analysed with multi-dimensional thermal calculations using the methods specified in BS EN ISO 10211 (2007): 'Thermal bridges in building construction - heat flows and surface temperatures - detailed calculations'.

BS EN ISO 10211 (2007) also refers to BS EN ISO 6946 (2007) Building components and building elements - Thermal resistance and thermal transmittance - Calculation method. The parameters used in the multi-dimensional thermal modelling work follow the parameters listed in this standard.

It should be noted that build quality was not considered, it was assumed that all construction is of a good quality.

2.3. Stage Three: Implications for Moisture Prevention and Key Findings

Stage Three involved the formulation of simplified rules and recommendations using the conclusions from the Stage Two work.

3. Key Findings from Moisture Assessment of Typical Construction Typologies

Twenty-one new build, and twenty-three retrofit construction build-ups were identified and modelled. The modelling identified four categories into which each construction typology can be placed. These categories are listed below; build-ups and associated categories can be found in Appendix C.

Retrofit full fill cavity wall insulation is not included in this study as there are established standards that, if followed, minimise the risk of moisture problems occurring.

It should be noted that the results of the analysis are based upon:

- good standards of workmanship
- adequate building ventilation
- normal occupant behaviour
- adequate building maintenance (e.g. gutters regularly cleaned and leaks fixed).

Since higher temperature air can hold higher levels of moisture, moisture risk is typically highest where high relative humidity (RH) levels coincide with colder surfaces such that the RH increases at that junction. The commonest scenario for interstitial condensation occurs at the junction between the outside (cold side) of the insulation and the next layer of the construction build-up.

We estimate that, for each wind-driven rain exposure zone (as stated in BS 8104), the location chosen for the transient hygrothermal modelling is representative of the wind-driven rain conditions experienced in diverse locations within this zone.

3.1. Category 1

Build-ups that are considered to be robust against moisture risk and therefore are of low risk of condensation and mould growth.

3.2. Category 2

Build-ups with conditions required for them to be considered reasonably robust against moisture risk.

These conditions are identified as follows.

3.2.1. Condition a

Needs adequate ventilation of the cold-side airspace

Any air layers present between the cold side of the structure (often, but not always demarked by the insulation layer), and any weatherproofing, or surface beyond the air layer, need to be adequately ventilated.

In particular for cold pitched roofs; current prescriptive guidance in BS 5250 (2011) (paragraph H.4.1) states that *‘there is a significant risk of interstitial condensation forming on the roof structure and on the underside of the underlay, from where it might run and drip onto the insulation and some risk of interstitial condensation in the batten space. Persistently high levels of humidity cause hygroscopic materials (such as timber and timber-based products) to absorb sufficient moisture to encourage the growth of moulds and the decay of structural members.'*

Paragraph 4.2.2 of BS 5250 (2011) also states that *'condensation on the coldest plane, usually on the underlay, should be removed by ventilation to outside air, assisted by wind action. The rate of ventilation is based on empirical experience.'*

3.2.2. Condition b

Build-up needs the presence of an air and vapour control layer (AVCL) on the warm side of the insulation

A continuous AVCL needs to be present on the warm side of the insulation.

3.2.3. Condition c

Build-up needs the use of rigid insulation without foil layers (or any vapour retarder / barrier) present on the faces of the insulation

Any rigid insulation installed should not of the type supplied with a foil vapour barrier. Installation of this type of insulation particularly on the external/cold side increases the likelihood of moisture becoming trapped within the structure.

3.2.4. Condition d

Build-up needs to be used / installed only in wind-driven rain exposure zones 1 to 3 (i.e. the build-up is entirely excluded from zone 4)

This build-up should be installed only in wind-driven rain exposure zones 1, 2 and 3 - it should not be used in very severe exposure zone 4.

3.2.5. Condition e

Build-up needs insulation which retains its thermal conductivity in conditions of high relative humidity (RH)

Insulation that retains its thermal conductivity in high relative humidity is needed, as although this construction is unlikely to present a mould growth risk, it could be detrimental to the performance of the insulation.

3.2.6. Condition f

Build-up needs the presence of continuous insulation below joists

Insulation should be present across the joists.

3.3. Category 3

This category covers commonly used typologies (ground bearing slabs and framed walls) where either; desktop analysis is unsuitable for the typology, or that results indicate a high moisture risk, but problems are not seen in practice. Until more research is carried out and a definitive moisture risk is established, a category 3 typology can continue to be used provided that it is a well-established construction for the circumstances (e.g. exposure zone) with no known moisture problems, or subject to specialist assessment.

3.4. Category 4

These build-ups are considered by definition “risky” build-ups and require specialist assessment, potentially with some transient hygrothermal modelling before they can be considered as robust against moisture risk.

Many of the category 4 typologies relate to internal wall insulation. The analysis examined the various factors which might affect the moisture risk and identified that the physical characteristics (including absorption) of the outer wall has the main effect. Differing amounts of insulation, wall orientation and exposure zone have little effect in comparison.

Where the absorbency of the outer wall is low, the use of moisture-permeable waterproofing, such as brick creams, can lower moisture risk to acceptable levels. However, where the absorbency is high, the moisture risk cannot be lowered enough to be declared “robust” against moisture risks.

As internal wall insulation is a valuable means of reducing heat demand, a ready means of identifying physical characteristics (including absorption) is needed in order to quickly identify the suitability of internal insulation, e.g. by establishing a "brick library" or developing new measuring techniques.

3.5. Other findings

Other general findings were:

- Guidance documents (Approved Document C and BS 5250) would benefit from being updated / being improved with additional details.

- Build-up and build-up “sub divisions” would benefit from additional detail in documents (Approved Document C and BS 5250).

  Some build-ups have been identified as having the potential to contain 'sub-divisions' in the insulation layers of their build-up. This typically occurs where the build-up contains structural cold bridging, such as timber structural members or an insulating installation method involving framing where insulation (which can be of different types) is present both between and across these.

  The single build-up format of Approved Document C and BS 5250 results in at least one of the scenarios (presence or absence of additional un-bridged insulation layer) being un-detailed.

- Current Part C U-value can be achieved with zero insulation. Some build-ups have been identified by the analysis as potentially meeting AD C U-value requirements in a build-up that contains no insulation.
- Increasing levels of insulation increases moisture risk. The analysis has identified some build-ups where an increase in thermal insulation has the effect of increasing moisture risk - typically by decreasing temperatures within the structure by isolating them from the heat inside the building. The implementation of these build-ups requires advanced knowledge to balance the requirement for thicker thermal insulation (to improve the building's energy efficiency) and thinner thermal insulation (to reduce or avoid moisture risk).
- Defect in the airtightness layer and as-built in-service (ABIS) conditions have not been tested. It is anticipated that, in build-ups which do not require an air and vapour control layer (AVCL) on the warm side of the insulation, such layer would still be beneficial to reduce moisture transfer via convection due to infiltration.
- Best practice when retrofitting insulation is to install insulation when the substrate is as dry as possible.
- There is a thermal bypass risk with non-compressible insulation, it should be considered good installation practice to ensure there are no gaps in the insulation.
- The characteristics of any external finishing layer need to be considered.

4. Key Findings from Moisture Assessment of Junctions

4.1. Connective Effects in New Buildings using THERM junction modelling

A working set of the most common new build junctions currently not covered by Accredited Construction Details (ACDs) is shown in Appendix D. These junctions have been chosen on the basis of high value of heat loss as identified by a default value of linear thermal transmittance (Psi or Ψ-value), greater than or equal to 0.1 W/m.K.

When the junction is modelled using a 20°C internal temperature (T_i) and 0°C external temperature (T_e), all surface temperatures (T_{si}) should have a minimum temperature of 15°C and a minimum internal surface temperature factor (f_{RSi}) value of 0.75 in order to minimize the risk of mould growth.

The internal surface temperature factor (f_{Rsi}) is used as a risk indicator for mould growth. It is effectively a ratio of the internal surface temperature to the internal room temperature, both compared to the external air temperature and is calculated using:

$$f_{Rsi} = (T_{si} – T_e) / (T_i – T_e)$$

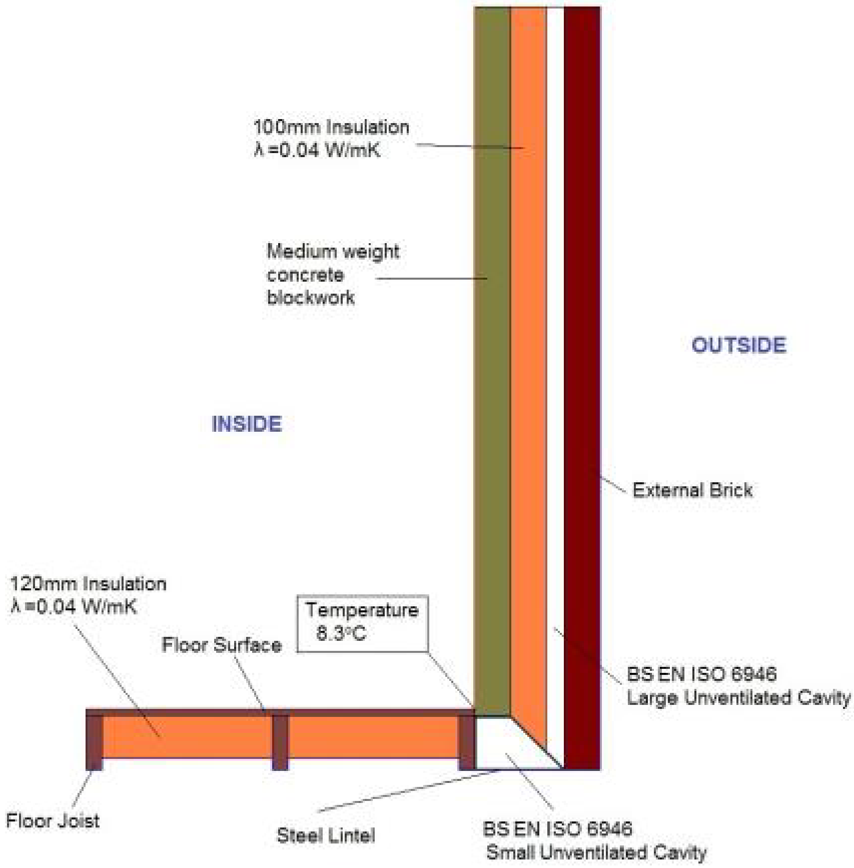
where:

- T_{si} = internal surface temperature (°C)
- T_i = internal temperature (°C)
- T_e = external temperature (°C)

Three commonly used junctions have been identified as being inherently likely to suffer from mould growth having a risk of moisture risks, as detailed below. There needs to be an ACD for each of them to include measures to minimize moisture risk.

SAP Ref E20- exposed floor (normal)

The E20 junction consists of an exposed timber floor and a typical partially filled cavity, both insulated to Approved Document L (2013) levels, often supported by a steel lintel.



The lowest calculated internal surface temperature (T_{si}) is 8.3°C. With an external temperature of 0°C, the resultant f_{Rsi} is 0.42, which indicates a risk of mould growth.

SAP Ref E21 *Exposed floor (inverted)*

This junction has insulation above the floor, which is exposed below (e.g. a roof over an external passageway). Mould growth could occur in colder / wetter conditions or with greater discontinuity of insulation at the junction. Where this junction is used, a bespoke calculation should be used to show that the risk of mould growth is acceptable.

SAP Ref E23 Balcony within or between dwellings

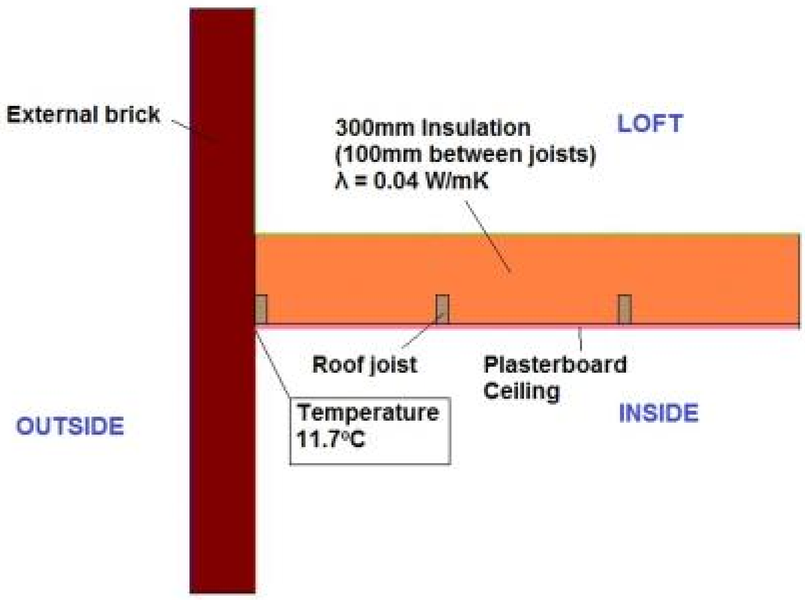
This junction is where a balcony support penetrates wall insulation. Mould growth could occur in colder / wetter conditions or if there is discontinuity of insulation at the junction. Where this junction is used, a bespoke calculation should be used to show that the risk of mould growth is acceptable. Cantilevered balconies with no thermal break are becoming rarer as a construction technique since the thermal bridging values associated with the construction are very high and detrimental to compliance with AD L (2013).

4.2. Connective Effects on Retrofit cases using THERM junction modelling

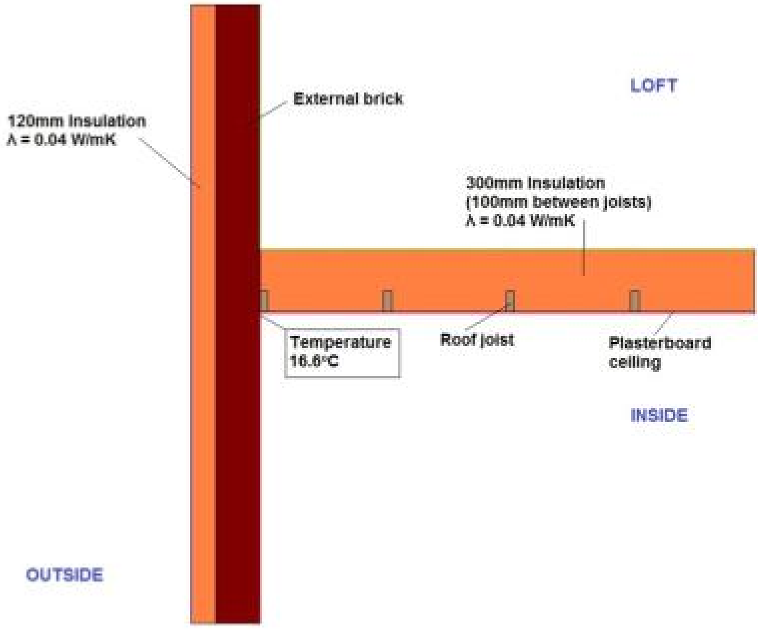
The mould growth risk of a working set of the most common retrofit junctions is shown Appendix E. Since there are no ACDs available for retrofit cases, these junctions have been chosen on the basis of the most common cases and critical scenarios.

In many cases it has been found that insulating only one element at a junction can result in a surface mould growth risk. In the majority of cases the risk can be eliminated by insulating the adjacent element.

The best example of this is where a loft is insulated and mould growth risk can occur at the junction between the ceiling and a gable wall.

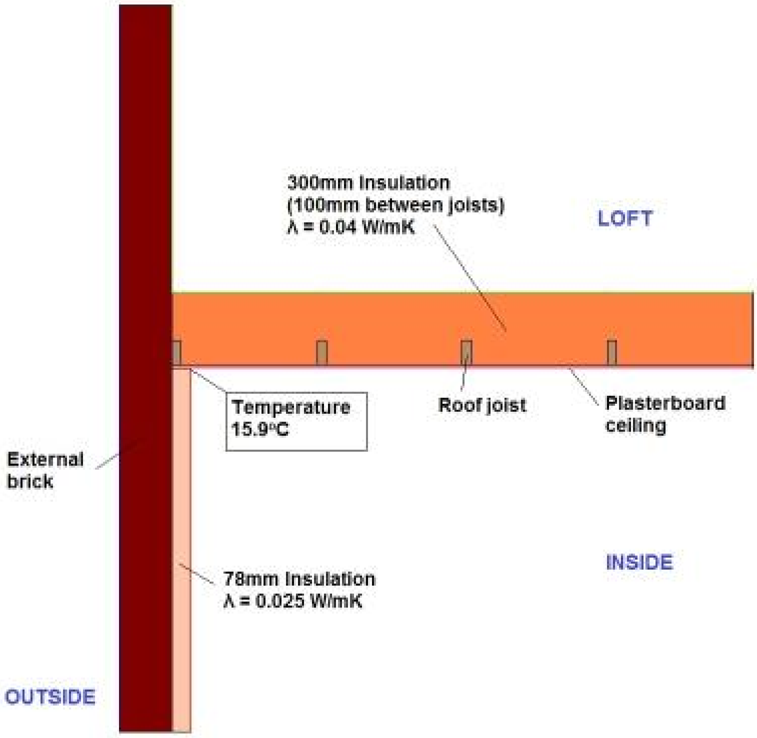


This risk can be mitigated by insulating the adjacent wall (either internally[1] or externally[2]).

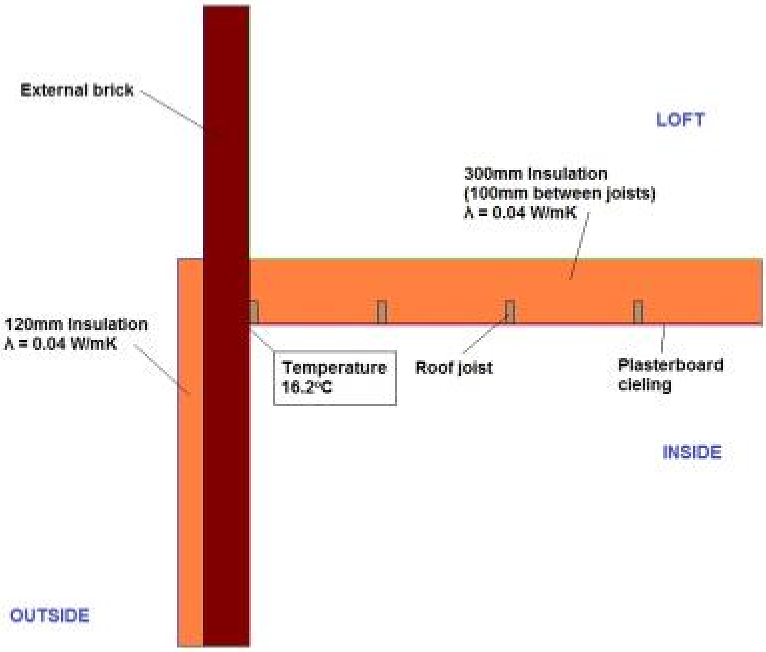


[1] Internal wall insulation should be subject to specialist assessment before installation.

[2] Surface temperatures will rise despite the continued existence of a thermal bridge



In the case of external wall insulation although the risk is lessened, it is not necessary when considering surface mould growth risk, to insulate past the height of the loft insulation level.



Two types of junctions have been identified where mould growth risk will be made worse by insulating the adjacent element - in these cases the addition of floor insulation increases the mould growth risk. There is another case where a balance needs to be reached between the requirement for thicker thermal insulation (to improve the building's energy efficiency) and thinner thermal insulation (to reduce or avoid moisture risk). These two are:

- Where a wall is externally insulated with no below DPC edge insulation, adjoining a ground bearing floor.
- Where a wall is externally insulated (EWI), adjoining an exposed (upper) timber floor.

Some junctions have a surface mould growth risk that cannot be eliminated by insulating the adjacent element; but in many of these cases the risk is reduced. These are:

- Where a wall is externally insulated (EWI) - with or without below DPC edge insulation, adjoining a suspended timber ground floor, insulating the timber floor reduces surface mould growth risk.
- Where a wall is internally insulated (IWI) adjoining a window head / cill / jamb, internally insulating the window reveal reduces surface mould growth risk.
- Where a gable wall is externally insulated (EWI), adjoining a warm roof construction, insulating the roof reduces surface mould growth risk in some cases.
- Where a wall is internally insulated (IWI) and a balcony or walkway support penetrates the wall - In this case the effect of balcony insulation has not been assessed.

In all other cases even where no surface mould growth risk is identified, the addition of thermal bridge insulation will reduce risk further (see Appendix E).

Appendix A – References

BS 5250 (2011): Code of practice for control of condensation in buildings. BSI Standards Publication.

BS EN 15026 (2007): 'Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation'. BSI Standards Publication.

BS EN ISO 10211 (2007): Thermal bridges in building construction - heat flows and surface temperatures - detailed calculations. BSI Standards Publication.

BS EN ISO 13788 (2012): 'Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods'. BSI Standards Publication.

May, N. & Sanders, C. (2014). Moisture Risk Assessment and Guidance. Sustainable Traditional Building Alliance and Department of Energy & Climate Change.

Rirsch, E., Zhang, Z. (2012). Energy Saving from Water Repellents. Retrofit 2012. University of Salford.

Ward, T. I. (2006). Information Paper 1/06: Assessing the effects of thermal bridging at junctions and around openings. BRE.

Approved Document C Site preparation and resistance to contaminants and moisture. DCLG www.gov.uk

Approved Document L Conservation of fuel and power. DCLG www.gov.uk

Appendix B – Glossary

Accredited construction detail	Junction details developed to assist the construction industry achieve the performance standards required to demonstrate compliance with the energy efficiency requirements (Part L) of the Building Regulations. They focus on thermal bridging (i.e. avoiding extra heat loss at the junctions of insulted elements) and the consequential risk of surface condensation / mould growth. They are not designed to address interstitial condensation.
As-Built / In-Service (ABIS) conditions	ABIS conditions describe conditions to which a build-up is submitted, which occur in the real world and take into account the existing or likely-to-exist conditions in buildings, as opposed to a partial risk assessment “as designed” or “theoretical”(ADT), which excludes these ABIS conditions
Building fabric	Elements of the external building envelope (consisting of the building’s roofs, floors, walls, windows and doors), being the separation between the internal environment and the external conditions. It is a critical component of any building, since it both protects the building occupants and plays a major role in regulating the indoor environment.
Condensation	Process whereby water is deposited from air containing water vapour when its temperature drops to or below the dew point (or the vapour pressure rises above the saturated vapour pressure at a given temperature).
Connective effects	Moisture or thermal related effects that occur at interfaces/junctions between elements or materials
Convective transport	Collective motion of water molecules in a fluid (encompassing both diffusion and advection). Convective heat transfer is one of the major types of heat transfer, with convection being a major mode of mass transfer in fluids.
Diffusion	The net movement of water molecules from high concentration to low concentration

Glaser method	A simplified one-dimensional steady-state assessment method, described in BS EN ISO 13788, to calculate the amount of interstitial condensate formed during a cold winter period and the theoretical amount of evaporable water in a cold summer. If the amount of condensate does not exceed specified limits and, if it is lower than the evaporable amount of water, the building assembly is considered to be safe.
Hygrothermal	Relating to the movement of both heat and moisture
Internal Surface Temperature Factor (f_{Rsi})	The ratio of the total thermal resistance of the building envelope to the thermal resistance of the building envelope without the internal surface resistance as defined in EN ISO 10211. Depends on the indoor and outdoor air temperatures and on the temperature at the internal surface of the building envelope. Also referred to as the temperature ratio, temperature index, or condensation resistance factor. In this report, f_{Rsi} is used to indicate the risk of mould growth in indoor environments
Interstitial condensation	Condensation occurring within or between layers of construction elements that are part of a building's thermal envelope.
Porosity	The measure of the void (i.e. "empty") spaces in a material, and is a fraction of the volume of voids over the total volume. Value expressed as a ratio (between 0 and 1), or as a percentage (between 0 and 100%)
Precipitation	Any product of the condensation of atmospheric water vapour that falls under gravity (e.g. rain)
Ψ- value (psi)	In relation to a thermal bridge: A measure of linear thermal transmittance which describes how effective a junction between heat loss elements is as a heat insulator. The lower the ψ-value, the better the junction is. ψ-values are measured in watts per linear metre of junction length per degree Kelvin (W/m.K).
Surface condensation	Condensation occurring on interior surfaces of a building.
Thermal bypass	Where heat is transferred via convection in a building element due to air gaps within or between materials/components (including cavities). This air movement bypasses the normally expected heat transfer mechanisms (used to calculate U-values) and reduces the effective thermal performance of that building element.

Thermal conductivity	The property of a material that describes its ability to conduct heat. Measured in watts per meter kelvin (W/(m·K)). Used, along with a material's thickness, to calculate U-values
U-value	A measure of thermal transmittance, which describes how effective an element of building fabric is as a heat insulator. The lower the U-value, the better the construction is as an insulator. U-values are measured in watts per square metre of surface element per degree Kelvin (W/m^2K).
Vapour Control Layer (VCL)	A material with high vapour resistance (there are varying definitions of this) that reduces/prevents vapour diffusion through a building element.
Vapour diffusion	The physical process of water vapour (not liquid water) passing through porous building materials due to the difference in vapour pressures (water content of the air) on either side on that material.
Vapour resistance	A measure of a material's resistance to letting water vapour pass through. The vapour resistance takes into account the material's thickness, so can only be quoted for a particular thickness of material. It is usually measured in MNs/g ("MegaNewton seconds per gram").
WUFI (Wärme und Feuchte instationär - Transient Heat and Moisture)	Software developed by the Fraunhofer Institute of Building Physics (IBP) in Germany and implements the approach set out in BS EN 15026. It allows realistic calculation of the transient hygrothermal behaviour of multi-layer building components exposed to natural climate conditions and has been validated using data derived from outdoor and laboratory tests. WUFI is based on the newest findings regarding vapour diffusion and liquid transport in building materials. The modelling in this report was carried out with WUFI Pro 5.3, one-dimensional hygrothermal simulation software.

Appendix C – Key Findings from Moisture Assessment - Typical Construction Typologies

Key

Category 1

Build-ups that are considered to be robust against moisture risk and therefore are of low risk of condensation and mould growth.

Category 2

Build-ups with conditions required for them to be considered reasonably robust against moisture risk.

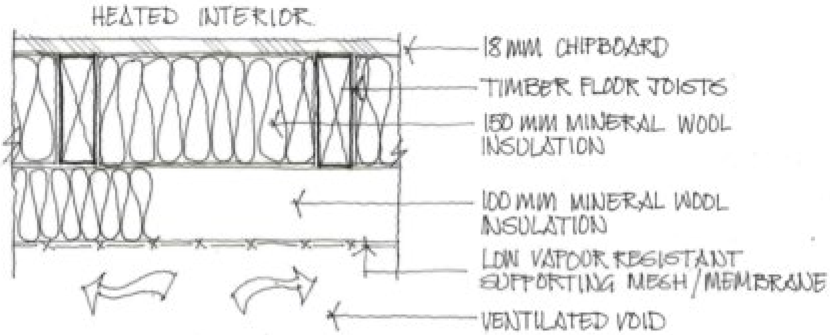
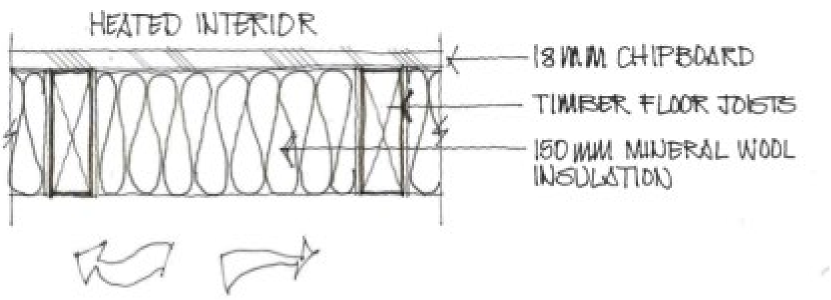
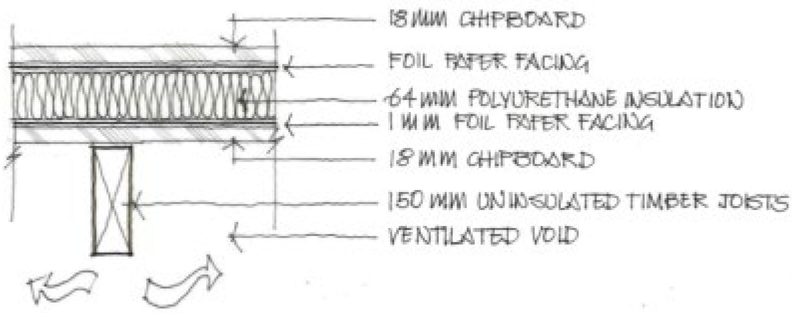
- Condition a - “requires adequate ventilation”
- Condition b - “presence of AVCL on the warm side of insulation”
- Condition c - “rigid insulation without foil layer”
- Condition d - “limited to zones 1 to 3”
- Condition e - "requires insulation that retains its thermal conductivity in high RH"
- Condition f - "presence of continuous insulation below joists"

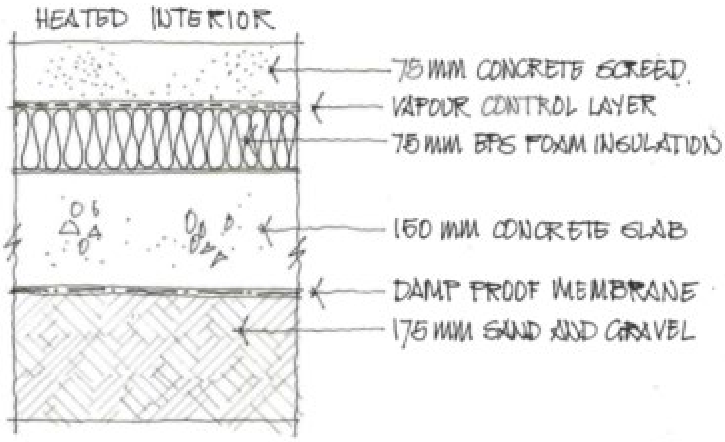
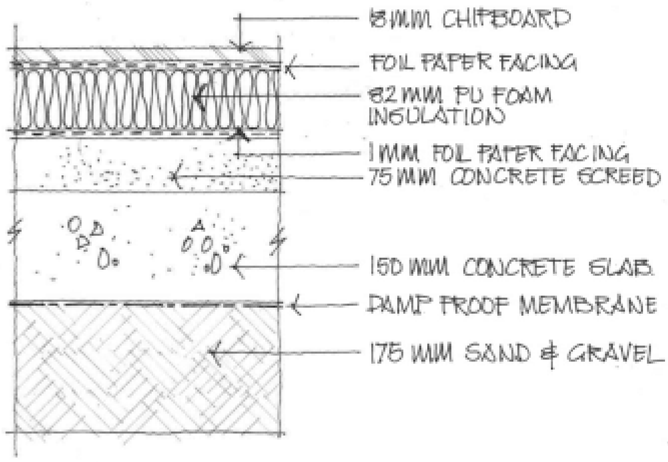
Category 3

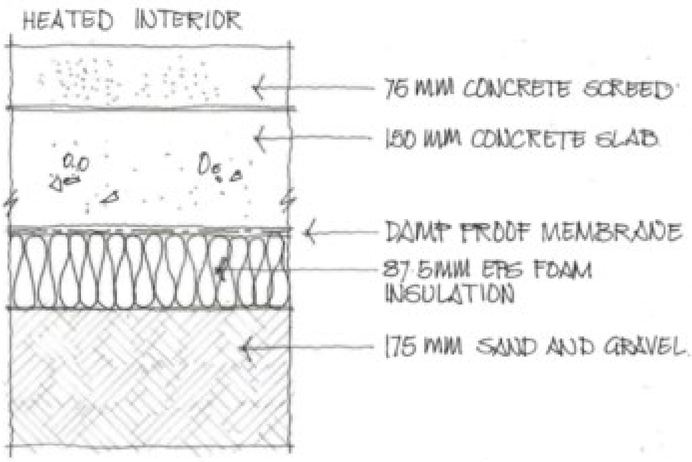
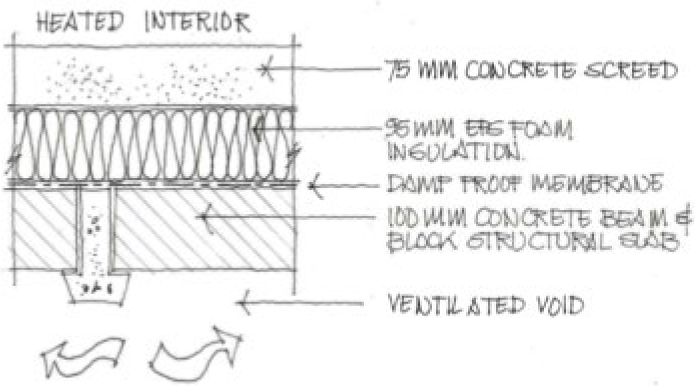
Examination of these build-ups has exposed complicated matters that cannot be solved by the application of the conditions listed above. Further research is needed, before being able to categorise these build-ups in categories 1, 2 and 4.

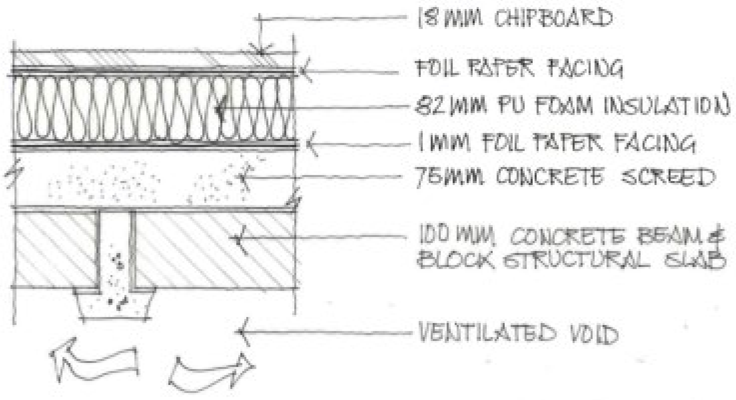
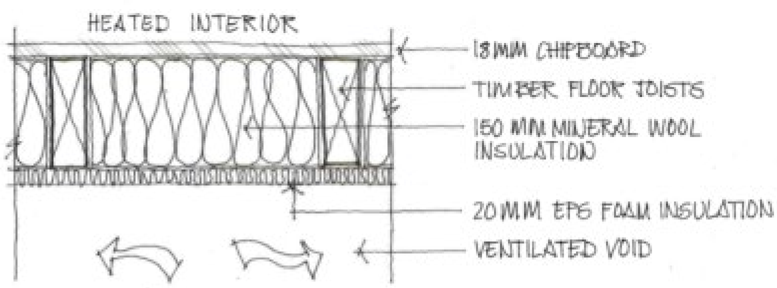
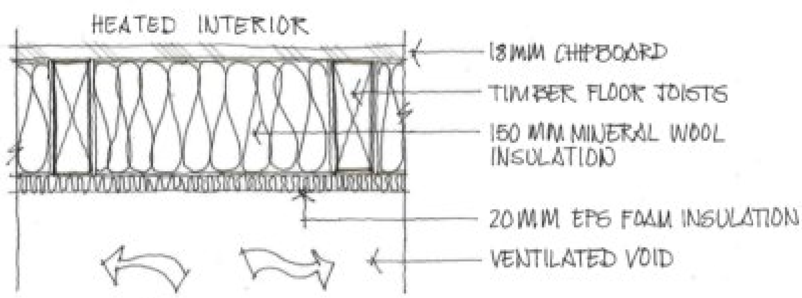
Category 4

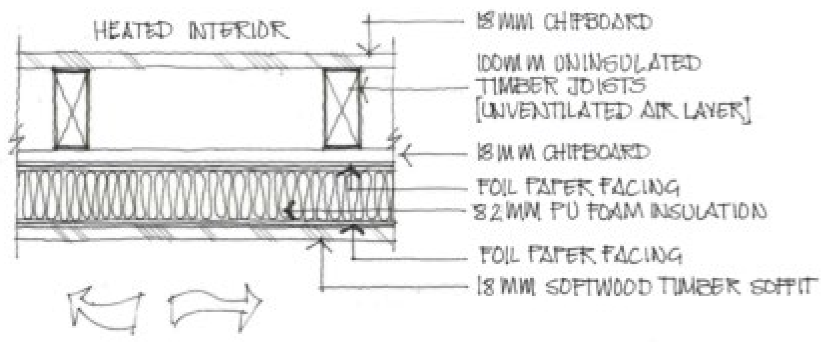
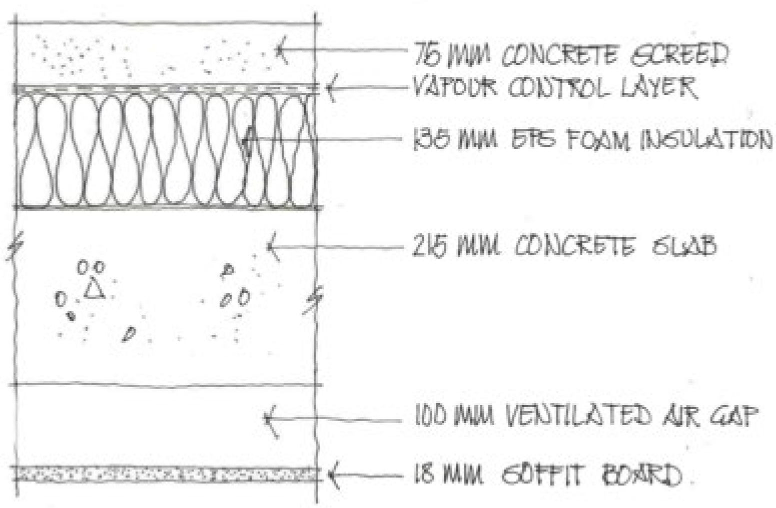
Build-ups require specialist assessment and potentially modelling before they can be considered as a robust build-up against moisture risk.

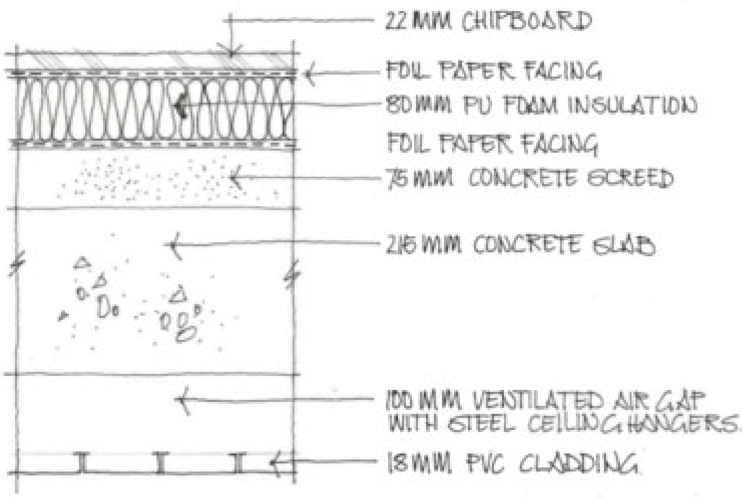
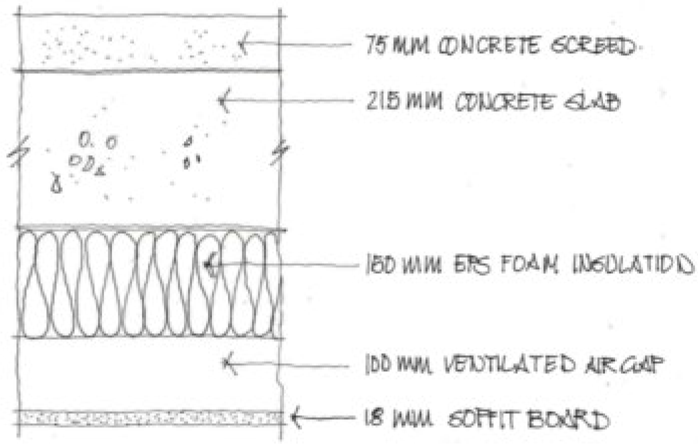
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N1 Suspended floor – insulated 	2	a
R1.1 - Suspended floor – retrofit = insulation between joists insulation 	2	a
R1.2 - Suspended floor – retrofit = insulation above joists insulation 	2	a, b, c, d

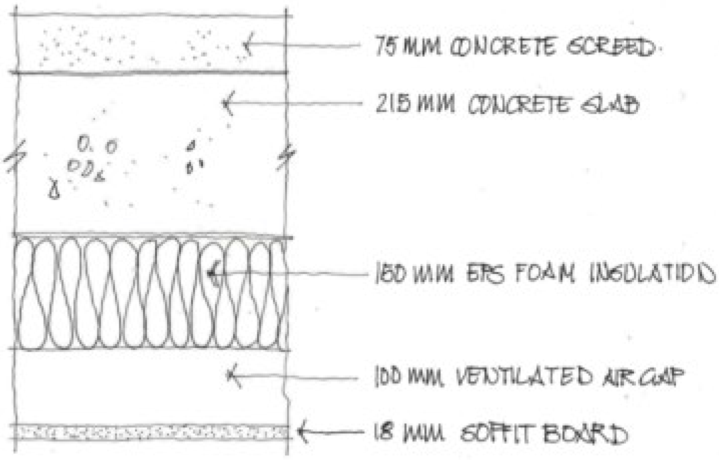
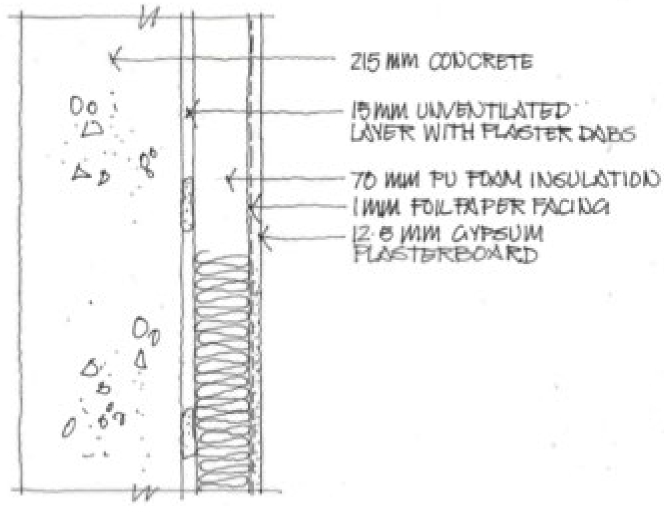
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N2 - Ground bearing concrete floor - insulated above  	3	n/a
R2 - In-situ ground bearing concrete floors (uninsulated)Retrofit Measure: insulation above  	3	n/a

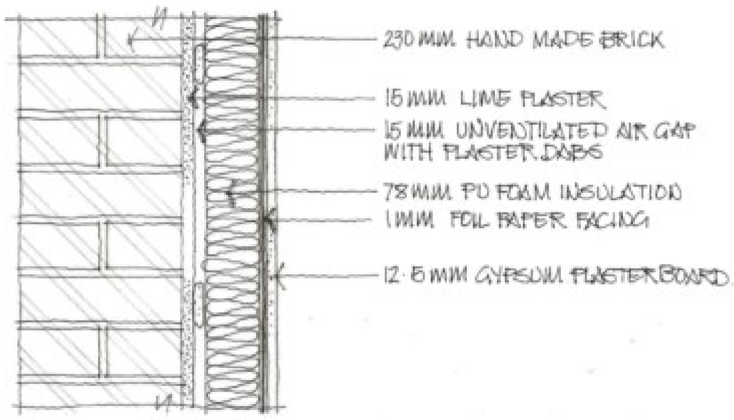
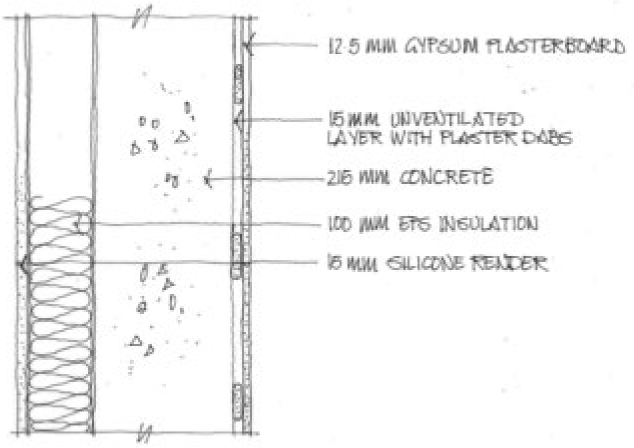
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N3 - Ground bearing concrete floor - insulated below 	3	n/a
N4 - Concrete beam & block floor – insulated above concrete blocks 	2	a, e

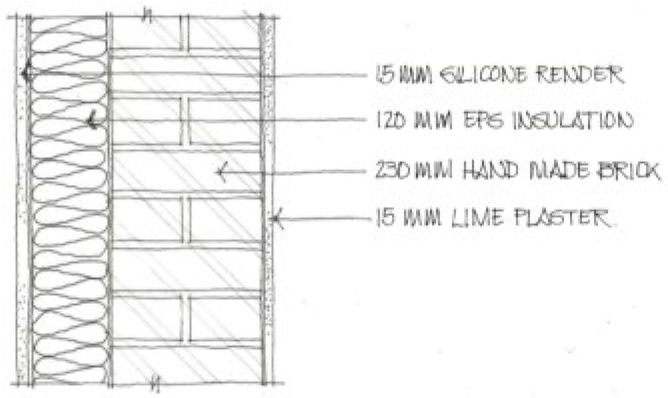
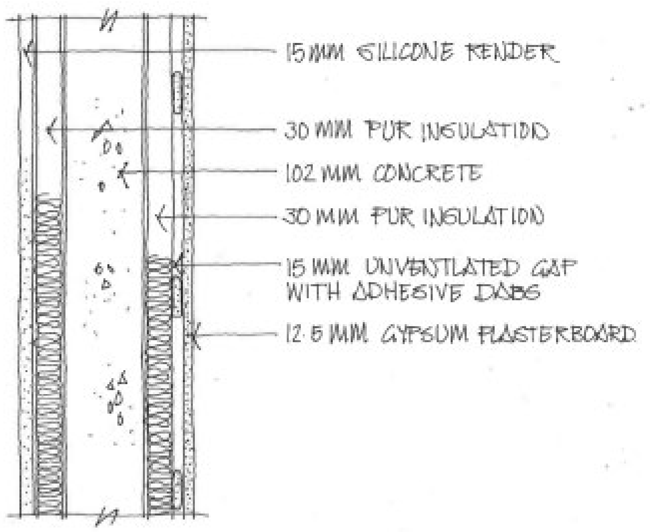
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R4 - Concrete beam & block floor – retrofit = insulated above concrete blocks + screed 	2	a, e
N5 - Exposed suspended timber floor – insulated between AND below joists 	2	a, c, f
R5.1 - Exposed suspended timber floor – retrofit = insulated between AND below joists 	2	a, c, f

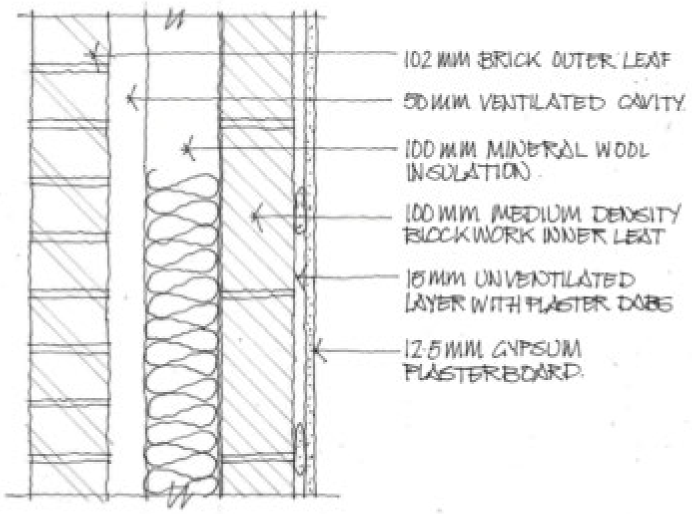
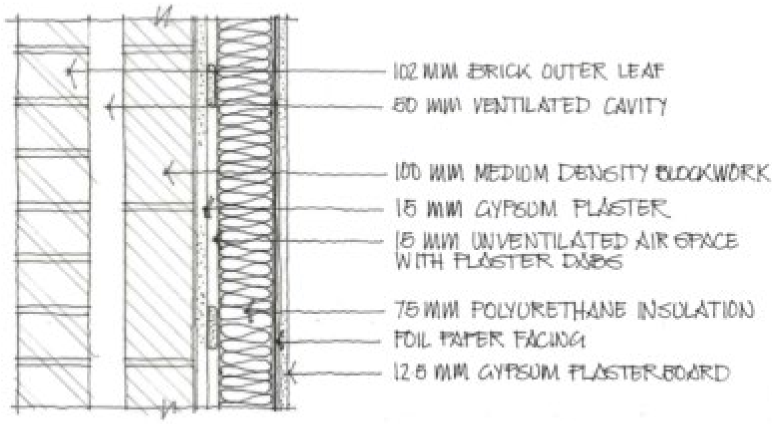
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R5.2 - Exposed suspended timber floor – retrofit = insulated below joists 	2	a
N6 - Exposed concrete floor – insulated above slab 	2	a, b

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R6 - Exposed concrete floor – retrofit = insulation above slab + screed  	2	a, b
N7 - Exposed concrete floor – insulated below slab  	2	a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R7 - Exposed concrete floor – retrofit = insulated below slab 	2	a
N8 – solid concrete wall with IWI 	4	n/a

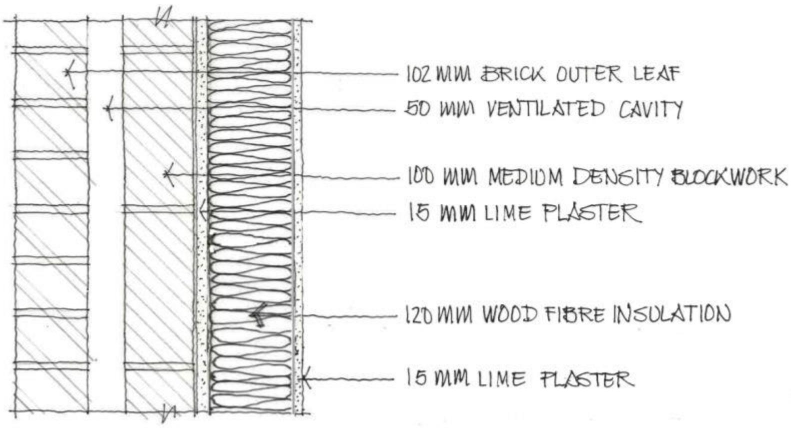
<table>
<tr><th>Construction Typology, with Build-up Illustration for Moisture Assessment</th><th>Category</th><th>Condition(s)</th></tr>
<tr><td>R8 – solid brick wall with rigid IWI

</td><td>4</td><td>n/a</td></tr>
<tr><td>Variation of R8 – solid brick wall with breathable IWI</td><td>3</td><td>n/a</td></tr>
<tr><td>N9 - Solid concrete wall with external insulation

</td><td>1</td><td>n/a</td></tr>
</table>

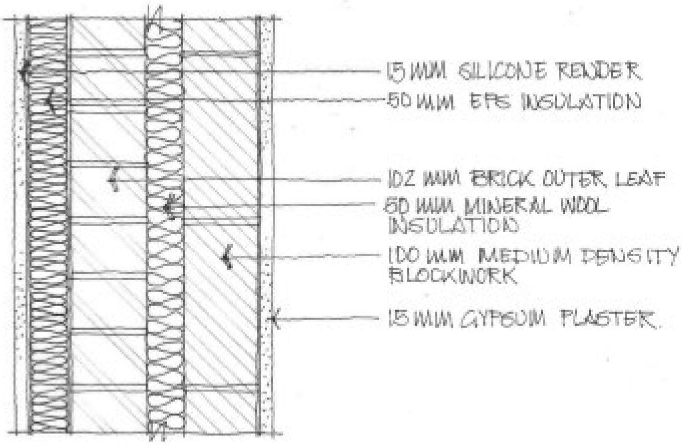
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R9 - Solid brick wall with external insulation 	1	n/a
N10 - Solid wall- external and internal insulation with a non-porous finish (Insulated concrete formwork) 	1	n/a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N11 - Cavity wall – partial fill with a semi-porous finish 	2	a
Variation of N11 – cavity wall (partial fill with rigid CWI)	4	n/a
R11.1 - Cavity masonry (uninsulated) – retrofit of IWI 	2[3]	a, d[4]

[3] Other inner leaf material (characteristics) could influence results.

[4] Less insulation would reduce thermal efficiency but also reduce moisture risks.

<table>
<tr><th>Construction Typology, with Build-up Illustration for Moisture Assessment</th><th>Category</th><th>Condition(s)</th></tr>
<tr><td>Variation of R11.1 - Cavity masonry (uninsulated) – retrofit of breathable IWI


Breathable materials includes CaSi board and sheepswool insulation.</td><td>2</td><td>a</td></tr>
<tr><td>R11.2 - Cavity masonry (uninsulated) – retrofit of External Wall Insulation + Cavity Wall Insulation

</td><td>1</td><td>n/a</td></tr>
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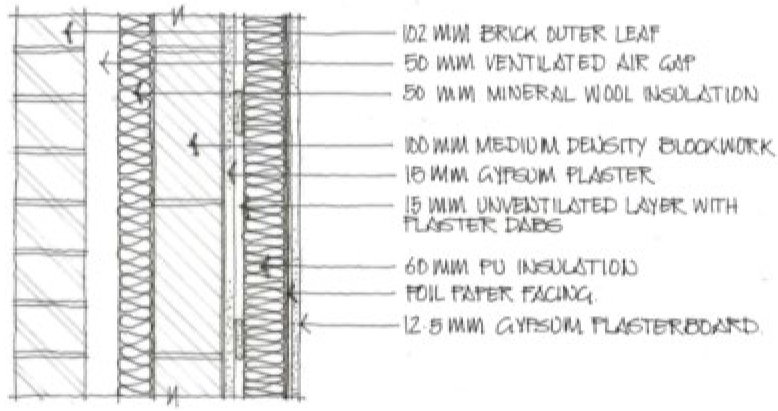
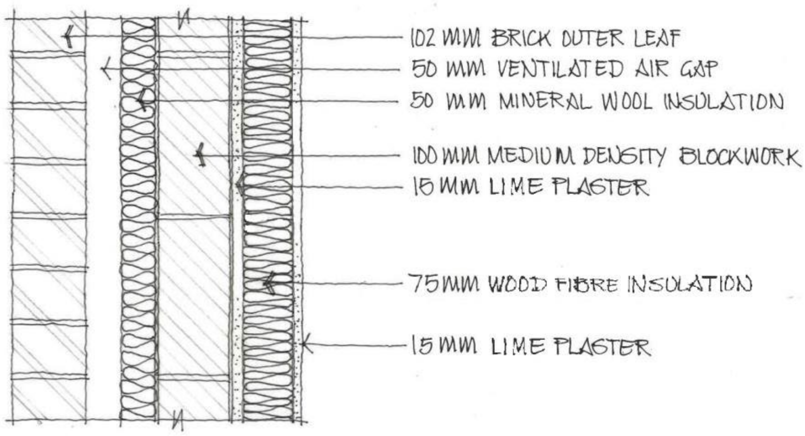
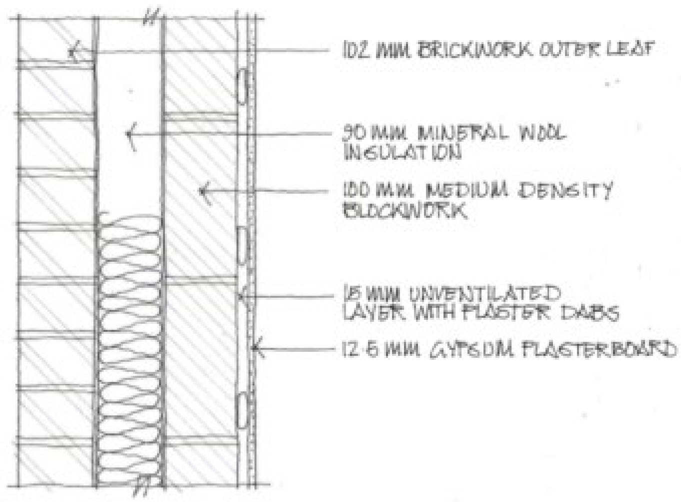
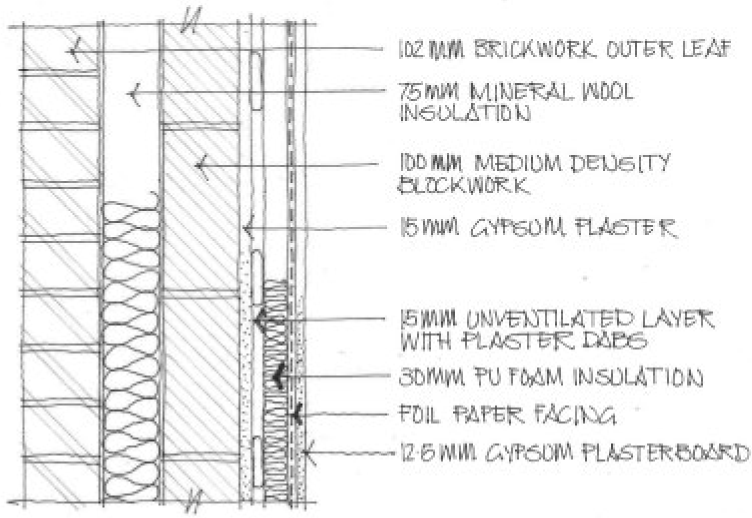
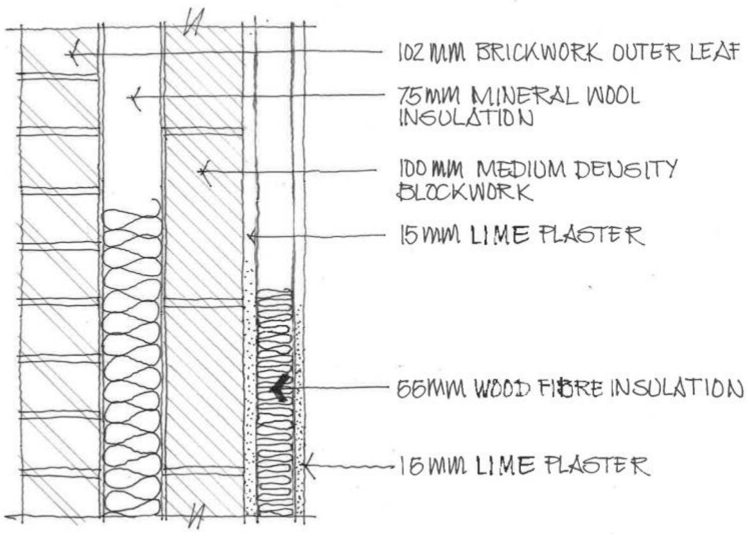
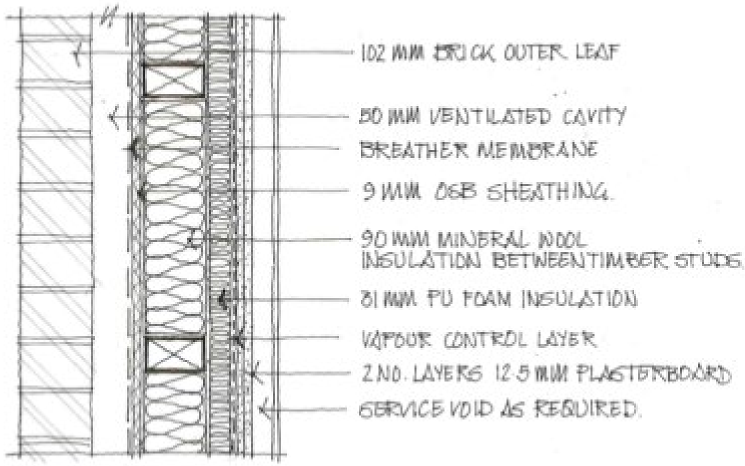
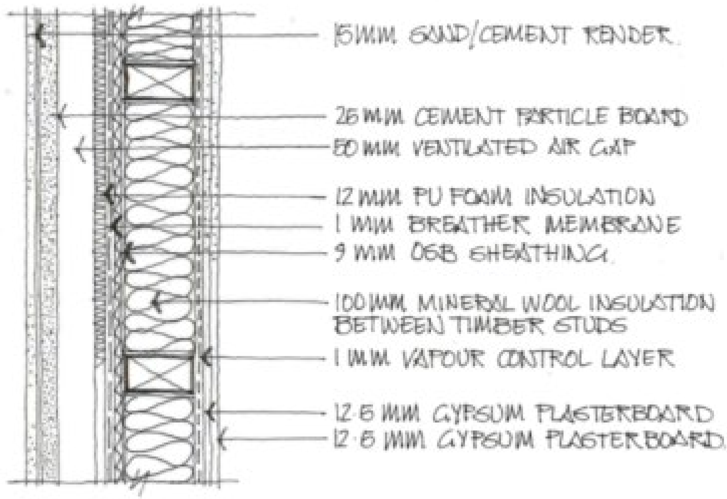
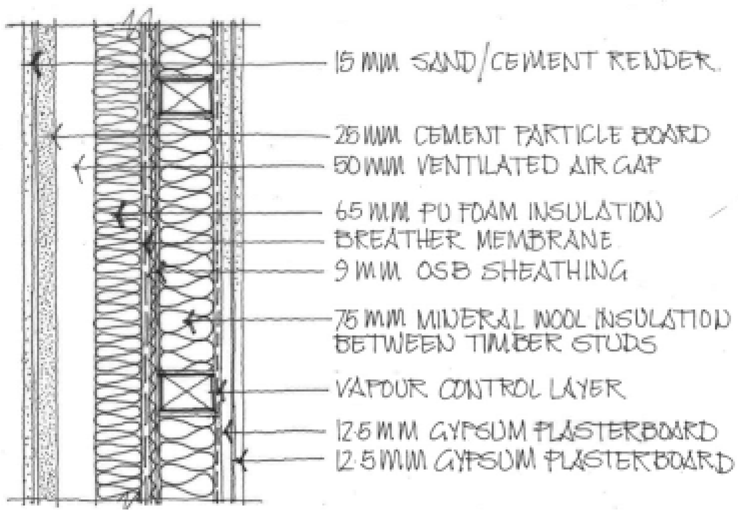
<table>
<tr><th>Construction Typology, with Build-up Illustration for Moisture Assessment</th><th>Category</th><th>Condition(s)</th></tr>
<tr><td>R11.3 - Cavity masonry (partial-fill) – retrofit of IWI

</td><td>2[5]</td><td>a</td></tr>
<tr><td>Variation of R11.3 - Cavity masonry (partial-fill) – retrofit of breathable IWI


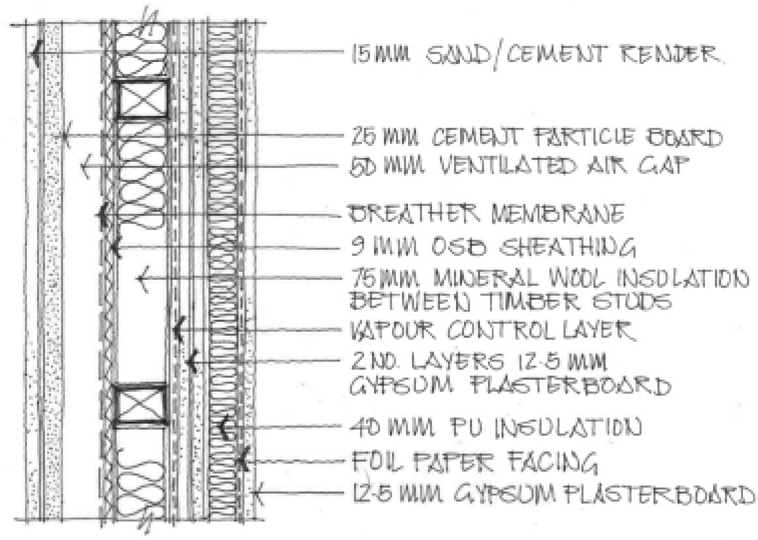
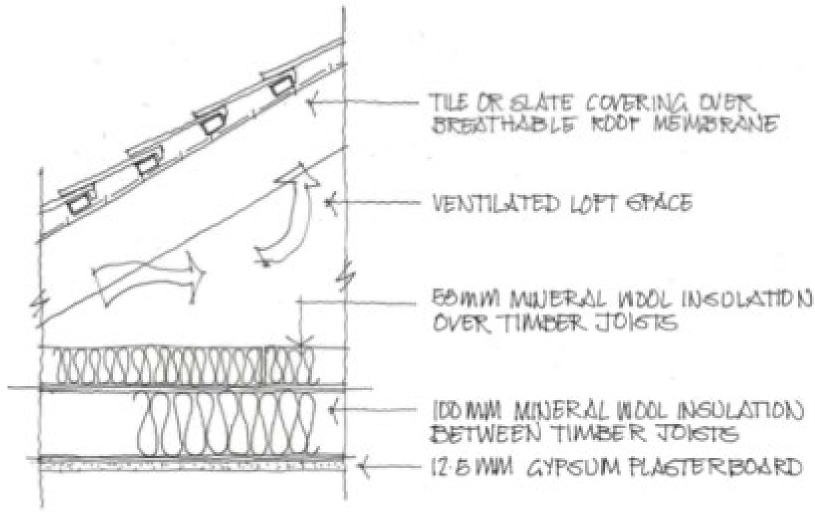
Breathable materials includes CaSi board and sheepswool insulation.</td><td>2</td><td>a</td></tr>
</table>

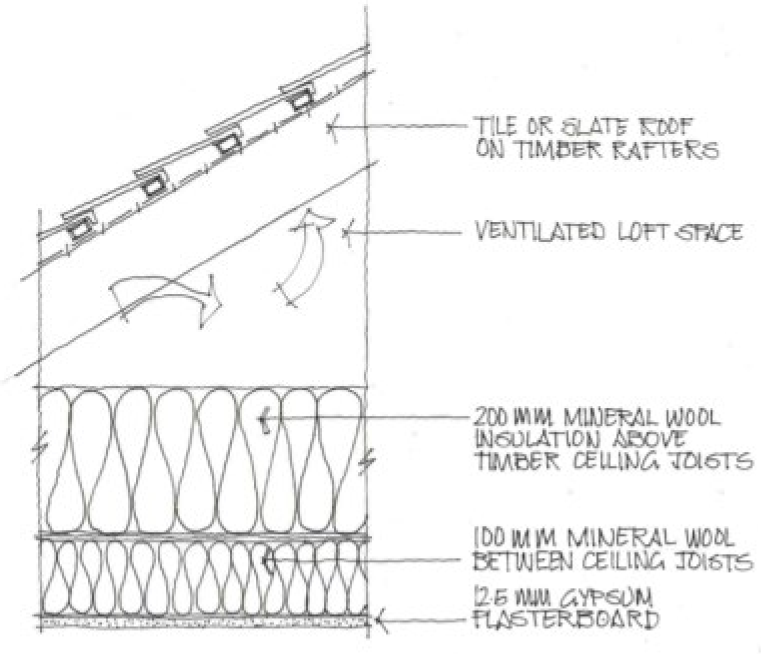
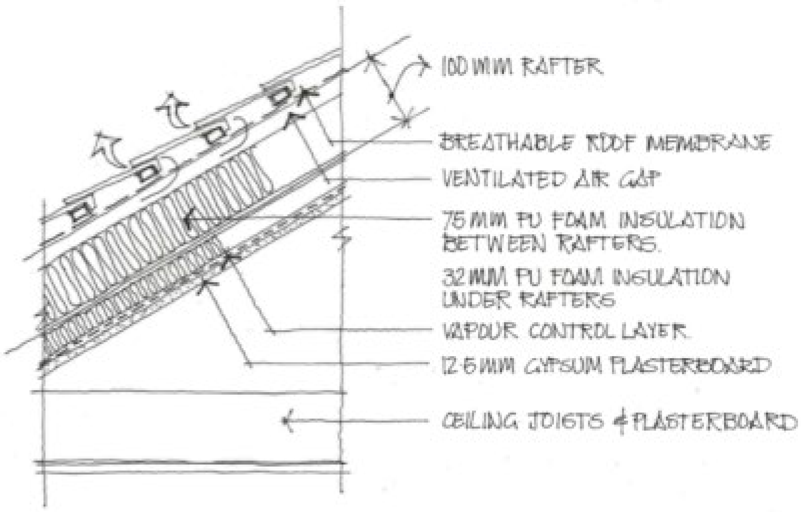
[5] Results depending on CWI/IWI insulation performance ratio. If thinner insulation, or poorer performing insulation in CWI, then moisture risk increases.

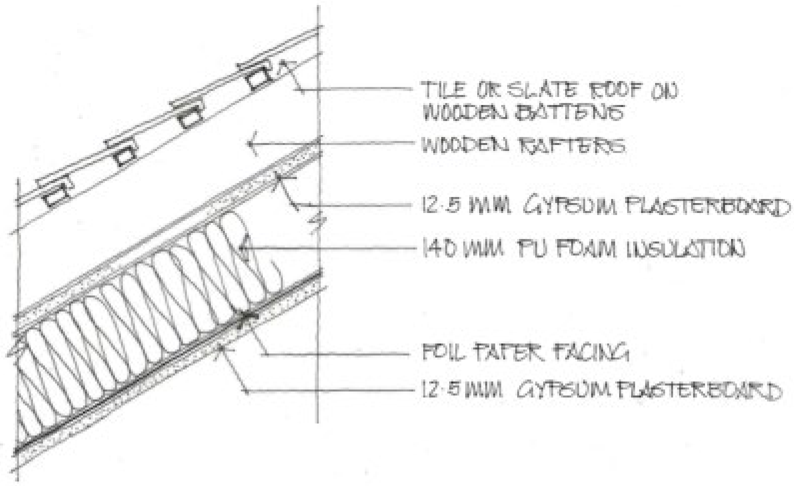
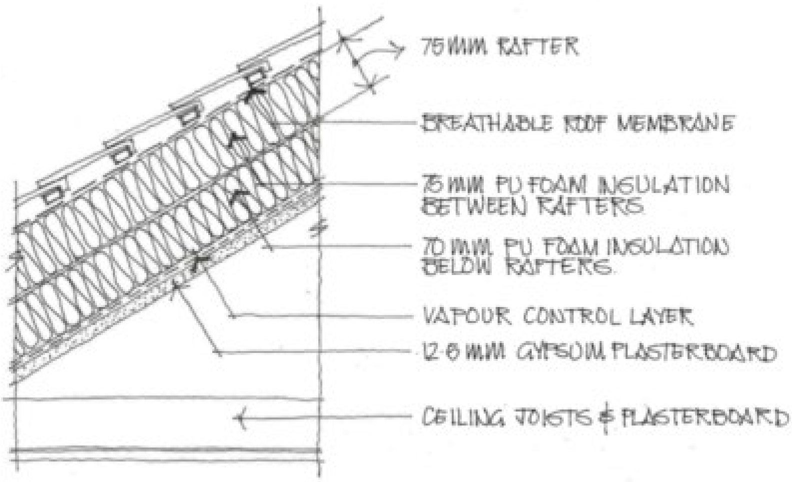
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N12 - Cavity wall- full fill with a semi-porous finish 	4	n/a
R12 – full-fill cavity masonry + retrofit of IWI 	4	n/a

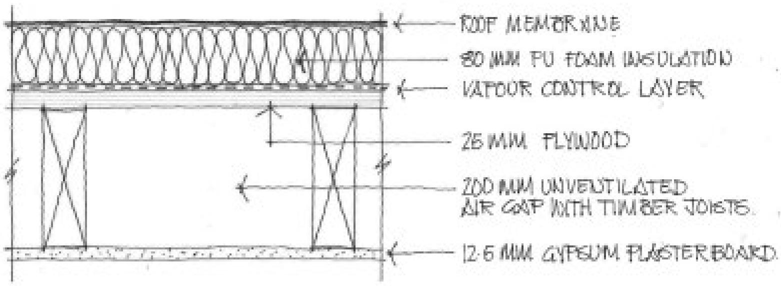
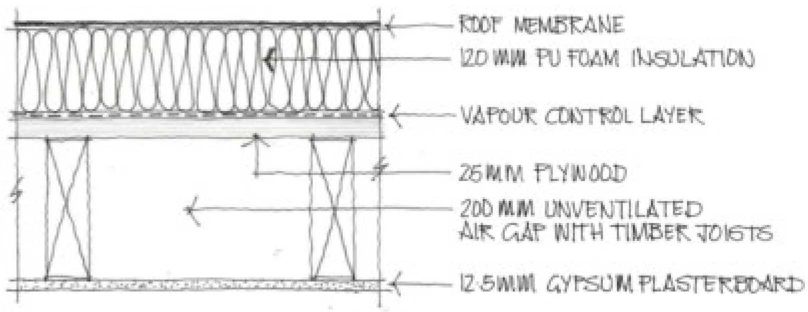
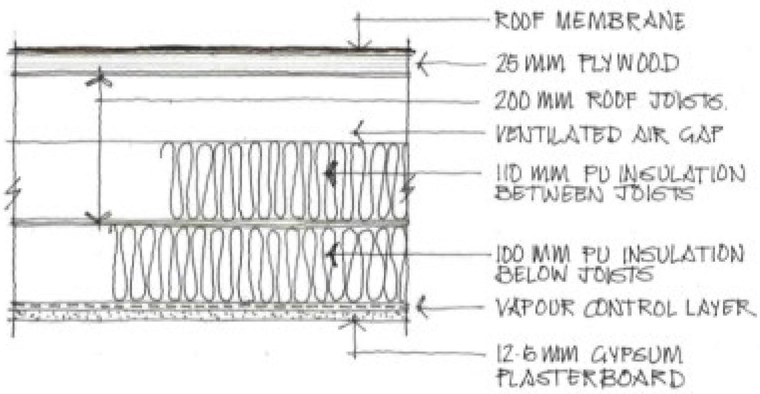
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
Variation of R12 – Full-fill cavity masonry – retrofit of breathable IWI  Breathable materials includes CaSi board and sheepswool insulation.	4	n/a
N13 - Timber frame wall – with air gap and a semi-porous finish 	3	n/a

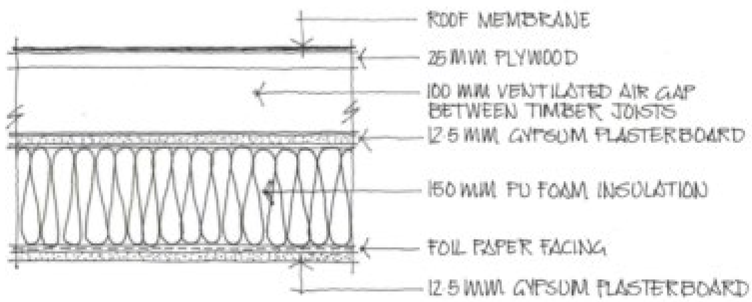
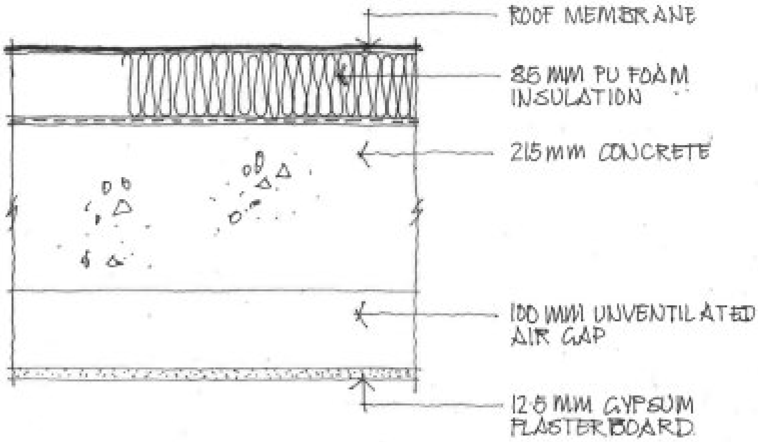
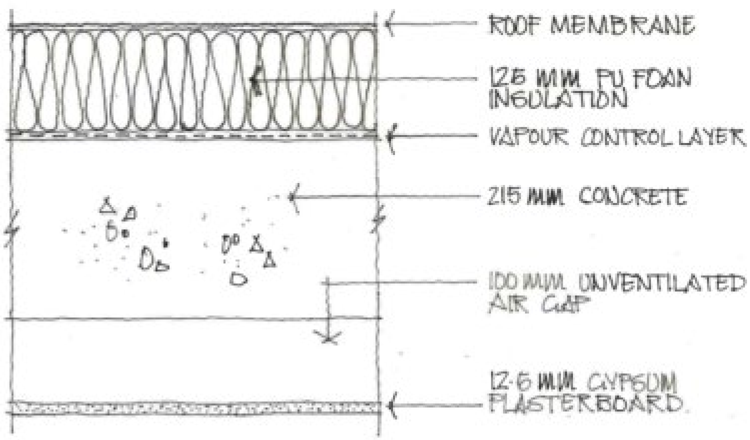
<table>
<tr><th>Construction Typology, with Build-up Illustration for Moisture Assessment</th><th>Category</th><th>Condition(s)</th></tr>
<tr><td>N14 - Timber frame wall (with air gap and a non-porous finish) – with Frame insulation + EWI

</td><td>3</td><td>n/a</td></tr>
<tr><td>R14.1 - Framed building (timber framed) Retrofit Measure: External Wall Insulation (EWI)

</td><td>3</td><td>n/a</td></tr>
</table>

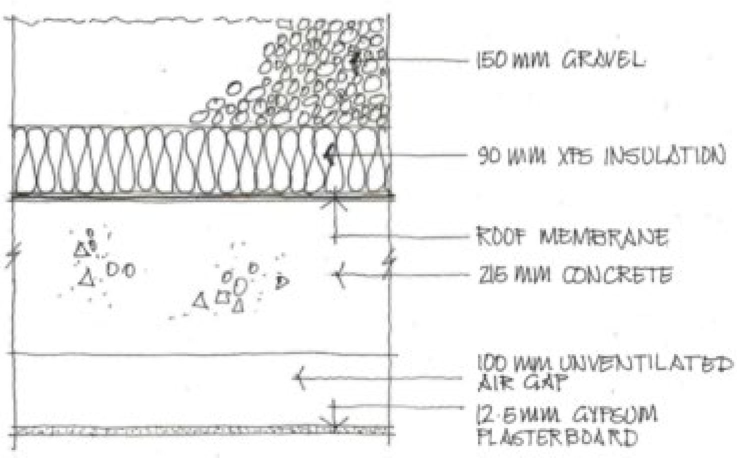
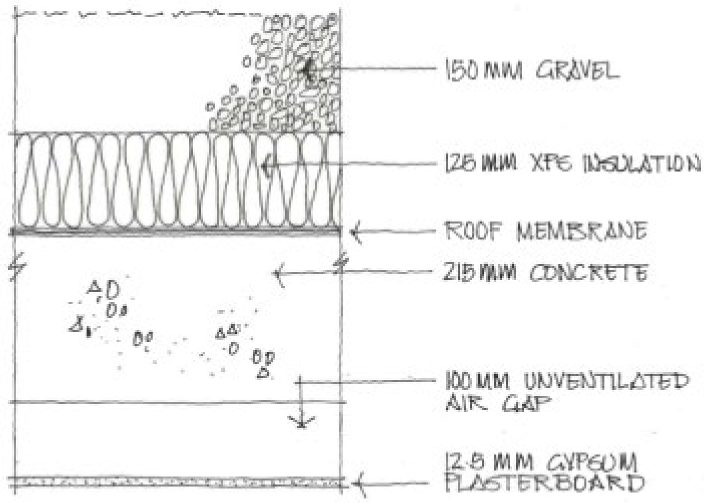
Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R14.2 - Framed building (timber framed) Retrofit Measure: Internal Wall Insulation (IWI)  	3	n/a
N15 - Light Gauge Steel Frame (with air gap and a semi-porous finish) – with Frame insulation	3	n/a
N17 - Cold pitched roof (slates/concrete/clay tiles)  	2	a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R17 - Cold pitched roof - insulated at ceiling level Retrofit Measure: Additional insulation above timber joists 	2	a
N18 - Warm roof – slates / concrete / clay tiles 	2	a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R18.1 - Warm pitched roof - uninsulated Retrofit Measure: Insulation below rafters 	4	n/a
R18.2 - Warm pitched roof - uninsulated Retrofit Measure: Insulation between and below 	2	a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N19 - Warm flat roof - timber 	2	b
R19 - Warm flat roof Retrofit Measure: insulation above 	2	b (Insulation must be dry at installation)
N20 - Cold roof – timber deck 	2	a

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
R20 - Cold flat roof Retrofit Measure: insulation below 	4	n/a
N21 - Warm roof - concrete 	2	b (AVCL at least as moisture resistant as roof water-proofing)
R21 - Warm flat concrete roof Retrofit Measure: insulation above 	2	b (AVCL at least as moisture resistant as roof water-proofing)

Construction Typology, with Build-up Illustration for Moisture Assessment	Category	Condition(s)
N22 - Inverted roof - concrete 	1	n/a
R22 - Inverted flat concrete roof Retrofit Measure: insulation above 	1	n/a

Appendix D – Key Findings from Connective Effects in New Buildings using THERM junction modelling

SAP Ref	Thermal Bridge Description - Junction between a partial fill cavity external wall	Risk Assessment
E20	Exposed suspended timber floor (normal)	A common construction solution for this junction type has a mould growth risk.
E21	Exposed concrete slab floor (inverted) with insulation above slab	Mould growth could occur in colder / wetter conditions or with greater discontinuity of insulation at the junction. Where this junction is used, a bespoke calculation should be used to show that the risk of mould growth is acceptable.
E21	Exposed concrete slab floor (inverted) with insulation below slab	Can be considered to be a robust junction against the risk of mould growth but still contains a considerable thermal bridge.
E23	Balcony within or between dwellings, balcony support penetrates wall insulation	Mould growth could occur in colder / wetter conditions or with greater discontinuity of insulation at the junction. Where this junction is used, a bespoke calculation should be used to show that the risk of mould growth is acceptable. Cantilevered balconies with no thermal break are becoming rarer as a construction technique since the thermal bridging values associated with the construction are very high and detrimental to compliance with AD L.
E24	Eaves (insulation at ceiling level - inverted)	This junction can be considered to be a robust junction against the risk of mould growth.
E25	Staggered party wall between dwellings	This junction can be considered to be a robust junction against moisture risk.

SAP Ref	Thermal Bridge Description - Junction between a fully filled cavity party wall	Risk Assessment

P1	Concrete beam and block floor ground floor - with insulation above	This junction can be considered to be a robust junction against moisture risk.
P7	Exposed concrete slab floor (normal) with insulation above slab	This junction can be considered to be a robust junction against moisture risk.
P7	Exposed concrete slab floor (normal) with insulation below slab	This junction can be considered to be a robust junction against moisture risk.
P8	Exposed concrete slab floor (inverted) with insulation below slab	This junction can be considered to be a robust junction against moisture risk.

Appendix E - Key Findings from Connective Effects on Retrofit cases using THERM junction modelling

Ground Floors	Risk Assessment
Uninsulated ground bearing floor / Solid wall - IWI	Mould growth risk
Insulated ground bearing floor / Solid wall - IWI	Robust against mould growth - insulation at floor level helps mitigate moisture risk
Uninsulated ground bearing floor / Solid wall - EWI	Mould growth risk
Insulated ground bearing floor / Solid wall - EWI	Mould growth risk - insulation at floor level does not mitigate the moisture risk and worsens the situation.
Uninsulated suspended Ground floor / Wall junction - IWI	Mould growth risk
Insulated suspended Ground floor / Wall junction - IWI	Robust against mould growth
Uninsulated suspended Ground floor / Wall junction - EWI	Mould growth risk
Insulated suspended Ground floor / Wall junction - EWI	Mould growth risk although insulation at floor level helps reduce moisture risk
Uninsulated ground bearing floor / Below DPC solid wall - EWI + Edge insulation	Robust against mould growth
Insulated ground bearing floor / Below DPC solid wall - EWI + Edge insulation	Robust against mould growth, although Insulation at floor level increases moisture risk
Uninsulated suspended Ground floor / Below DPC solid wall - EWI + Edge insulation	Mould growth risk

Insulated suspended Ground floor / Below DPC solid wall - EWI + Edge insulation	Mould growth risk although insulation at floor level helps reduce moisture risk
Insulated suspended Ground floor / Below DPC solid wall - Extended EWI + Edge insulation	mould growth risk although insulation at floor level helps reduce moisture risk
Windows	
Window head - cill - jamb / solid wall - EWI	Robust against mould growth
Window head - cill - jamb / solid wall - EWI and reveal	Robust against mould growth - external reveal insulation reduces risk
Window head - cill - jamb / solid wall - IWI	Mould growth risk
Window head - cill - jamb / solid wall - IWI and reveal	Mould growth risk - internal reveal insulation reduces risk
Upper Floors	
mid floor edge with solid wall - IWI no floor edge insulation	Robust against floor surface mould growth
mid floor edge with solid wall - IWI - floor edge insulation	Robust against floor surface mould growth
Stair string - IWI - no stair string insulation	Robust against mould growth
Stair string - IWI - stair string insulation	Robust against mould growth - Installing insulation over the stair string reduces risk of mould growth - equal amounts must be applied above and below stair tread to benefit.
Exposed Floors	
Uninsulated timber exposed floor - IWI	Mould growth risk
insulated timber exposed floor - IWI	Robust against floor surface mould growth

Uninsulated timber exposed floor - EWI	Mould growth risk
Insulated timber exposed floor - EWI	Mould growth risk
Uninsulated exposed timber floor (Inverted) - IWI	Robust against ceiling surface mould growth
Insulated (between joists) exposed timber floor (Inverted) - IWI	Robust against ceiling surface mould growth
Insulated (external) exposed timber floor (Inverted) - IWI	Robust against ceiling surface mould growth
Uninsulated exposed timber floor (Inverted) - EWI	Robust against ceiling surface mould growth
Insulated (between joists) exposed timber floor (Inverted) - EWI	Robust against ceiling surface mould growth
Insulated (external) exposed timber floor (Inverted) - EWI	Robust against ceiling surface mould growth
Balcony or walkway support penetrates wall - EWI	Mould growth risk
Balcony or walkway support penetrates wall - IWI	Robust against mould growth
Eaves	
Cold roof(insulation at flat ceiling level) - EWI - no wall plate insulation	Mould growth risk
Cold roof(insulation at flat ceiling level) - EWI - wall plate insulation	Robust against mould growth - Installing insulation around the eaves (without restricting loft ventilation) can eliminate a risk of mould growth when both loft insulation and EWI are installed.
Warm roof (sloping ceiling) - IWI and loft insulation with no sloping ceiling insulation	Mould growth risk
Warm roof (sloping ceiling) - IWI and loft insulation with sloping ceiling insulation between rafters	Robust against mould growth

Warm roof (sloping ceiling) - IWI and loft insulation with sloping ceiling insulation below rafters	Robust against mould growth
Warm roof (sloping ceiling) - IWI and loft insulation with sloping ceiling insulation between and below rafters	Robust against mould growth
Warm roof (sloping ceiling) - EWI and loft insulation with no sloping ceiling insulation	Mould growth risk
Warm roof (sloping ceiling) - EWI and loft insulation with sloping ceiling insulation between rafters and across wall plate junction	Robust against mould growth
Warm roof (sloping ceiling) - EWI and loft insulation with sloping ceiling insulation below rafters	Robust against mould growth
Warm roof (sloping ceiling) - EWI and loft insulation with sloping ceiling insulation between and below rafters, and across eaves junction	Robust against mould growth
Careful consideration is needed when designing retrofit insulation measures for a junction of this type.	
Gable at roof junction	
Gable (300mm insulation at ceiling level) - EWI	Robust against mould growth
Gable (300mm insulation at ceiling level) - IWI	Robust against mould growth
Installing either EWI or IWI wall insulation at a gable is low risk in terms of surface temperatures at the junction with a well-insulated loft.	
Uninsulated warm roof - EWI	Mould growth risk
Internally insulated (below rafters) warm roof - EWI	Mould growth risk
insulated (below and between rafters) warm roof - EWI	Mould growth risk
This junction is vulnerable to mould growth which is difficult to address	

Roof	
Cold roof insulation / external wall - 100mm Loft insulation	Mould growth risk
Cold roof insulation / external wall - 300mm Loft insulation	Mould growth risk
300mm Loft insulation - no loft hatch insulation	Robust against mould growth
300mm Loft insulation - 50mm loft hatch insulation	Robust against mould growth - loft hatch insulation greatly reduces risk
Other	
External Meter boxes - EWI no insulation behind meter box	Robust against mould growth
External Meter boxes - EWI insulation behind meter box	Robust against mould growth - behind meter box insulation greatly reduces risk