Ministry of Housing,
Communities &
Local Government

Research into resistance to moisture in buildings

Using calculation methods to assess surface and interstitial condensation

July 2019
PRP Architects LLP
Ministry of Housing, Communities and Local Government

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1. Background

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.*

The project was delivered in three main stages:

- **Stage One: Background research**
  Stage One covered all the background research activities required to inform the refinement of the analysis methodology and the parameters used for the analysis.

- **Stage Two: Detailed analysis of identified construction typologies**
  Stage Two involved the detailed analysis of the various construction types identified in Stage One for both new build and retrofit, including key thermal bridge junctions. In this stage, a number of software analysis packages and methodologies will be used to carry out a sensitivity analysis on each of the identified construction typologies:

  - Simplified Modelling based on *BS EN ISO 13788 (2012)* - the 'Glaser Method'
  - Standardised Modelling based on *BS EN 15026 (2007)* - with the use of a software package, WUFI (Wärme und Feuchte Instationär)
  - Multi-dimensional Thermal Modelling to *BS EN ISO 10211 (2007)* - with the use of THERM (for construction junctions only)

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

The outputs of this research are a series of eight reports, entitled:

- Research into resistance to moisture in buildings: Research Summary
- 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. Our Approach

2.1. Understanding the role of U-value backstops in preventing moisture in new buildings

This report is the **Using calculation methods to assess surface and interstitial condensation** report of the Research into resistance to moisture in buildings project.

The purpose of this stage of the research is to:

- Follow a typical path to Part C compliance
- Identify building fabric typologies that show no risk of surface and / or interstitial condensation
- Identify building fabric typologies that show risk of surface and / or interstitial condensation at different U-value backstops
- Rank building fabric typologies according to risk in order to identify the depth of further analysis required
- Indicate limitations of this level of analysis

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

It is assumed that where a construction typology is assessed as not presenting a condensation risk, no further analysis is needed and that the existing guidance in Approved Document C relating to ventilation and protection from moisture from the ground and precipitation is adequate.

2.2. Methodology

The method follows *BS 5250 Code of practice for control of condensation in buildings* and *BS EN ISO 13788 Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods standards,* and follows the guidance in BR 433 - *BRE Conventions for U-value calculations* (*2006 edition) by Brian Anderson*:

2.2.1. New Build Construction Typologies

The working set of the construction typologies was identified for New Build in the report Identification of common types of construction.

Typology Ref	Construction Type
Floors (Ground Floors)	
N1	Suspended timber floor - insulated
N2	Ground bearing concrete - insulated above
N3	Ground bearing concrete - insulated below
N4	Beam and block floor - insulated above
Floors (Exposed Upper Floors)	
N5	Timber joist with boards - insulated
N6	Concrete - insulated above
N7	Concrete - insulated below
Walls (Low Rise Buildings)	
N8	Solid - Internal insulated with a semi-porous finish
N9	Solid - External insulation with a non-porous finish
N10	Solid - External and internal insulation with a non-porous finish
N11	Cavity - Partial-fill with a semi-porous finish e.g. facing brickwork
N12	Cavity - Full-fill with a semi-porous finish e.g. facing brickwork
N13	Timber frame with air gap and a semi-porous finish e.g. facing brickwork
N14	Timber frame with no air gap and a non-porous finish e.g. render
N15	Light Gauge Steel Frame (LGSF) with air gap and a semi-porous finish e.g. facing brickwork
Walls (Medium / High Rise / Commercial Buildings)	
N16[1]	Curtain walling
Roofs (Pitched)	
N17	Cold roof (slates/concrete/clay tiles) - insulated

[1] Curtain walling will not be assessed at this stage of the study for three reasons:

- Curtain walling has many variations in structure and finish.
- Glaser methodology cannot reliably predict condensation risk for this construction type.
- The Part L backstop U-value for Curtain Walling of 2.0 W/m^2K is far greater than the Part C backstop U-value for walls.

More detailed analysis using WUFI will take place in the next stage of the analysis.

Typology Ref	Construction Type
Roofs (Pitched)	
N18	Warm roof (slates/concrete/clay tiles)
Roofs (Flat)	
N19	Warm roof - timber
N20	Cold roof - timber
N21	Warm roof - concrete
N22	Inverted roof - concrete

For each of the construction typologies listed above, typical build-ups and materials have been created. Each typology is considered individually for U-value, surface and interstitial condensation.

The calculation parameters which are used include the following backstops:

- The current U-value backstop in AD C for each element
- The highest of the Part L 2013 new-build element U-value backstops
- The relevant U-value from SAP 2013 Appendix R used to calculate the TER and TFEE

It should be noted that the Part C backstops only apply where Part L does not apply, such as unheated extensions.

	U-value backstops (W/m^{2}K)		
Construction Type	**AD C**	**AD L**	**SAP 2013**
Floors	0.70	0.25	0.13
Walls	0.70	0.35	0.18
Roofs	0.35	0.25	0.13

2.2.2. Retrofit Construction Typologies

The working set of the construction typologies was identified for Retrofit in the report Identification of common types of construction.

Typology Ref	Construction Type	Retrofit Measures Applied
Floors		
R1.1	Suspended timber ground floors	Insulation within joists
R1.2	Suspended timber ground floors	Insulation added above
R2	In situ ground bearing concrete floors	Insulation added
R4	Beam and block ground floors	Insulation added
R5.1	Exposed upper floors - timber joist with boards	Insulation between joists
Floors		
R5.2	Exposed upper floors - timber joist with boards	Insulation added below
R6	Exposed upper floors - concrete	Insulation added above
R7	Exposed upper floors - concrete	Insulation added below
Walls		

Typology Ref	Construction Type	Retrofit Measures Applied
R8	Solid masonry	IWI
R9	Solid masonry	EWI
R11.1	Cavity masonry with no insulation	Internal Wall Insulation (IWI)
R11.2	Partial-fill cavity masonry	IWI
R12.1	Cavity masonry with no insulation	External Wall Insulation (EWI) and Cavity Wall Insulation (CWI)
R12.2	Full-fill cavity masonry	IWI
R14.1	Framed building	EWI
R14.2	Framed building	IWI
Roofs		
R17	Cold (pitched) roof	Loft insulation
R18	Warm (pitched) roof	Sloping ceiling insulation
R19	Warm flat timber roof	Insulation
R20	Cold flat roof	Insulation below
R21	Warm Flat concrete roof	Insulation above
R22	Inverted flat concrete roof	Insulation above
R23[2]	Metal roof sheet	Insulation

For each of the construction typologies listed above, typical build-ups and materials have been created. Each typology is considered individually for surface and interstitial condensation.

The Approved Document C U-value backstops do not apply since if a wall is being retrofitted the target U-value is that stipulated in Approved Document L.

As the Approved Document L guidance is usually met in retrofit, lower U-value have not been analysed at this stage.

The U-value used for each construction typology is the highest of the Approved Document L 2013 retrofit element U-value backstops (excluding cavity wall fill as a single measure), as shown below:

	U-value backstops (W/m^2K)
Construction Type	**AD LB**
Floors	0.25
Walls	0.30
Cold Roofs	0.16
Warm roofs	0.18

[2] Metal roof sheet will be assessed at the next stage of the study for two reasons:

- Internal humidity conditions are likely to be non-standard.
- Part C indicates specific additional guidance (*MCRMA Technical Paper 14 Guidance for the design of metal roofing and cladding to comply with approved document L2:2001* (2002) is out of date.)

2.2.3. Adjustments and references to our methodology

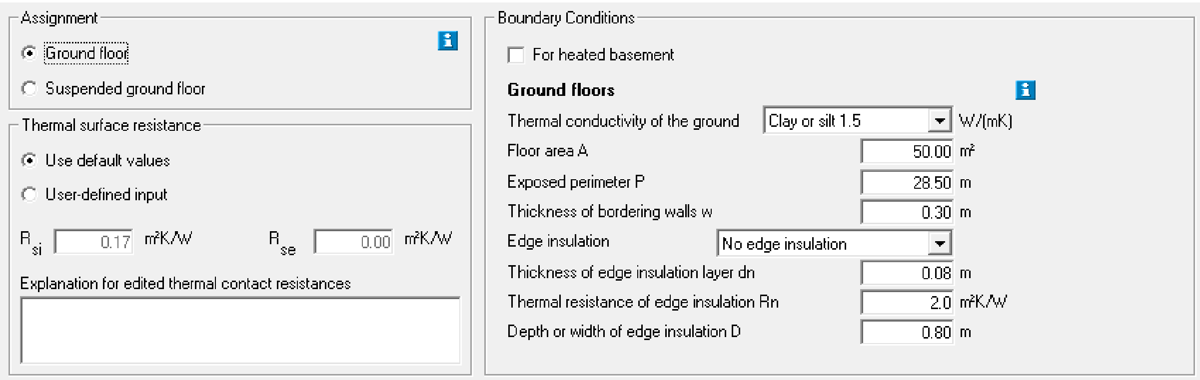
An adjustment (in $m^2/K/W$) is made to account for the thermal resistance of the air adjacent to the inner (R_{si}) or outer (R_{se}) surface of an element. This adjustment is different for different circumstances and the direction of heat flow.

The following default thermal resistance values for internal and external surfaces (R_{si} and R_{se}) are used in the modelling, as detailed in Table E5 of *BS5250:2011 Code of practice for control of condensation in buildings*:

		Thermal Resistance used for modelling (m^2K/W)	
Construction Type		**Internal surface (R_{si})**	**External surface (R_{se})**
Ground Floors	Suspended	0.17	0.17[3]
	Ground bearing	0.17	0.00
Exposed Upper Floors		0.17	0.04
Walls		0.13	0.04
Pitched Roofs	Cold	0.10	0.04
	Warm	0.10	0.10
Flat Roofs		0.10	0.04

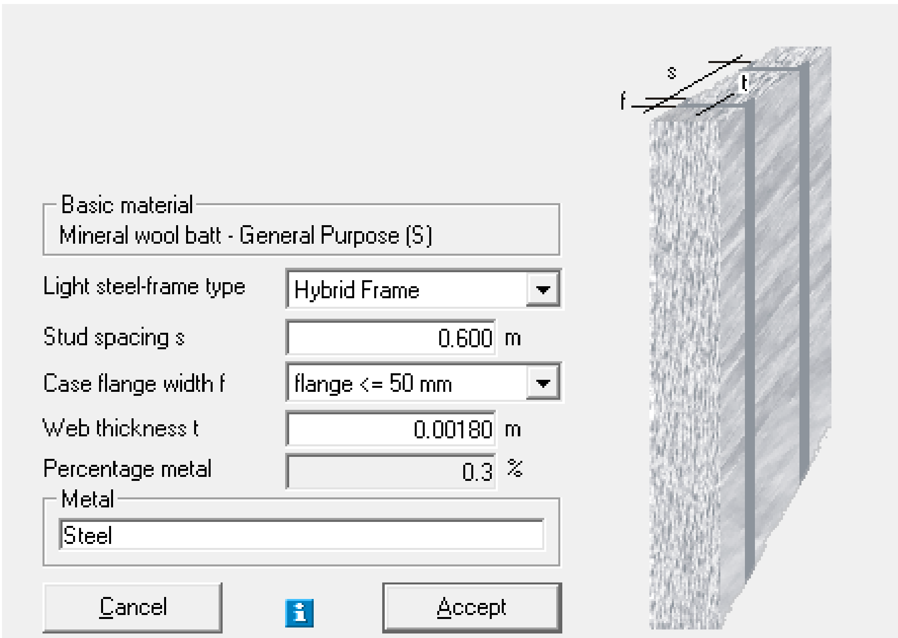
[3] This is the value given in *BR 443* Section 9.2 - The U-value of the floor deck can usually be calculated by the method of *BS EN ISO 6946*, allowing for any bridged layers and using surface resistance values of $0.17m^2K/W$ at both the upper and lower surfaces of the floor.

Additional parameters are required for U-value calculations for ground floors (N1 and N4). These parameters are shown below:



For wall ties within cavity walls (N11 and N12), the number of fixings used is 2.5/m^2 and equivalent diameter is 10.1mm (vertical twist stainless steel fixing is used).

Additional parameters are required for U-value calculations for N15 Light Gauge Steel Frame (LGSF). These parameters are shown below:



Both the porosity of the material and the type of insulation have been taken into account, to ensure a full understanding of the parameters that could affect the behaviour of the construction typologies.

Following a comparison between different locations in the UK, the worst case scenarios location where both low temperatures and high humidity occur in winter months, has been identified as Wattisham, Suffolk. This location has been used in production of Glaser diagrams and in condensation risk calculations.

A database of construction typologies using typical materials and the thermal properties has been created. This database includes additional information relating to moisture for use in the next stage of the analysis.

A Glaser analysis cannot be considered a wholly accurate predicator of surface or interstitial condensation risk in two cases:

- Construction types where a layer within the construction contains more than a single material
- Construction types that are in contact with the ground

In order to compare any typology with the three different U-value backstops whilst retaining the same fundamental structure the difference in U-value is created by making changes to insulation only within a structure. This is by either:

- Making changes to the thickness of the insulation
- Making changes to the type of insulation

The below table shows the thermal conductivity of the insulation types used in the analysis.

Insulation Type	Thermal Conductivity (W/m^2K)
Mineral wool	0.038
EPS	0.040
XPS	0.027
Generic Phenolic / Polyurethane	0.025
High performance Phenolic	0.022

Where a typology does not achieve a backstop U-value with no insulation the lowest attainable U-value will be reported and used as the backstop for that typology.

Similarly, where the modelling did not allow testing for the U-value assigned, the typology has been tested for the closest U-value achievable; i.e. typology ref N11 (Cavity - Partial-fill with a semi-porous finish) could not be tested for U=13 W/m^2K as per the SAP TER as the minimum value achievable for partial filled cavity is 0.27 W/m^2K. For the same reason, typology ref N12 (Cavity - Full-fill with a semi-porous finish) cannot be tested for a U-value lower than 0.43 W/m2K even considering the lowest insulation performances.

In some scenarios interstitial condensation occurs but the condensate is predicted to evaporate during the summer months. This will be investigated further in the next stage of the project.

The vapour pressure distribution is calculated according to BS EN ISO 13788.

Key findings of each construction typologies can be found in Section 4 (for New Build) and Section 6 (for Retrofit).

For each construction typology there are two tables, the first table includes detailed information of the baseline build-up for each construction typology whereas the second one shows the variations to the baseline build-up for comparison with the three different U-value backstops.

As a reference point, please see below the list of data sources for the material for the baseline build-up.

1. Fraunhofer IBP database in WUFI
2. Other Database in WUFI
3. Manufacturer information
4. Adapted from manufacturer literature
5. Estimate based on industry literature

The following two sections (Section 3 and Section 4) provides an overall summary and key findings of each construction typologies for New Build.

3. Overall Summary of Key Findings - New Build

The construction typologies listed below are those that show a risk of surface and/or interstitial condensation; these typologies will be tested using WUFI with the aim of identify more precisely where condensation risks occurs.

The construction typologies not listed below will also be analysed using WUFI, this will be done primarily to verify the results of no-risk of surface and/or interstitial condensation, and sensitivity to wind driven rain.

Type	Ref	Typology	Backstop analysed	U-value	Surface condensation occurred	Interstitial condensation occurred
Ground Floors	N1	Suspended timber floor - insulated	C	0.70	Y	N
	N2	Ground bearing concrete - insulated above	C	0.62	Y	Y
			2A	0.25	N	Y[3]
			TER	0.13	N	Y
	N3	Ground bearing concrete - insulated below	C	0.62	Y	Y
			2A	0.25	N	Y[3]
			TER	0.13	N	Y
	N4	Beam and block floor - insulated above	C	0.61	Y[1]	N
Exposed Upper Floors	N5	Timber joist with boards - insulated	All	-	N	Y[2]
	N6	Concrete - insulated above	All	-	N	Y[2]
	N7	Concrete - insulated below	All	-	N	Y[2]
Walls	N11	Cavity - Partial-fill with a semi-porous finish e.g. facing brickwork	C	0.70	N	Y[4]
	N12	Cavity - Full-fill with a semi-porous finish e.g. facing brickwork	C	0.70	N	Y[4]
	N15	Light Gauge Steel Frame (LGSF) with air gap and a semi-porous finish e.g. facing brickwork	C	0.51	Y[1]	N
Roofs	N17	Cold pitched roof (slates/concrete/clay tiles) - insulated	All	-	N	Y[3]
	N19	Warm flat roof - timber	All	-	N	Y
	N21	Warm flat roof - concrete	All	-	N	Y[3]

Note:
Y[1]: only indicates a risk of condensation in uninsulated section of a bridged layer - to be analysed further in WUFI modelling.
Y[2]: only in conjunction with ceiling hangers
Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.
Y[4]: only if there is wet plaster.

3.1. Conclusions - New Build

The results of the Glaser modelling indicate that:

- Ground bearing floors indicate a risk of interstitial condensation at all backstop U-values.
- Ground bearing floors indicate a risk of surface condensation at the AD C backstop U-value.
- The wall construction types that indicate a risk of condensation are N11 and N15; N15 likely due to the thermal bridge across the steel frame.
- For exposed upper floors a risk of interstitial condensation is indicated where there is a suspended ceiling.
- All roof types except N20 indicate a risk of interstitial condensation at all backstop U-values.

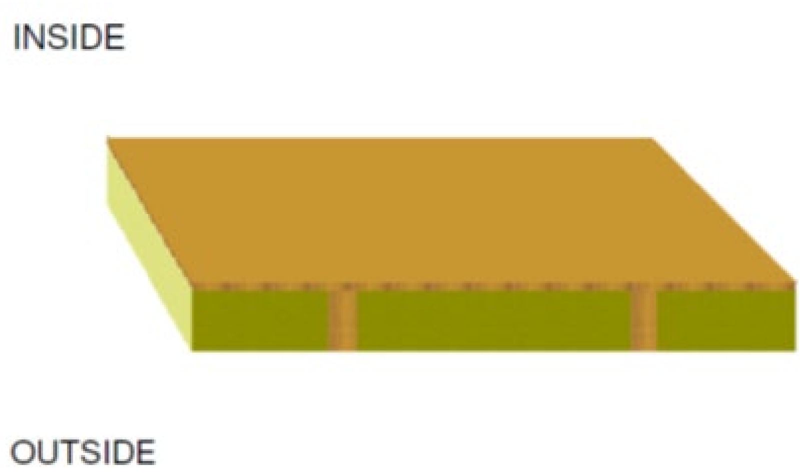
These typologies will have thorough investigation and analysis using WUFI in the next stage of the project across a greater range of boundary conditions than those with no indication of surface and / or interstitial condensation risks.

4. Key Findings of each Construction Typologies - New Build

Floors (Ground Floors)

4.1. N1 Suspended timber floor - insulated

4.1.1. Baseline build-up



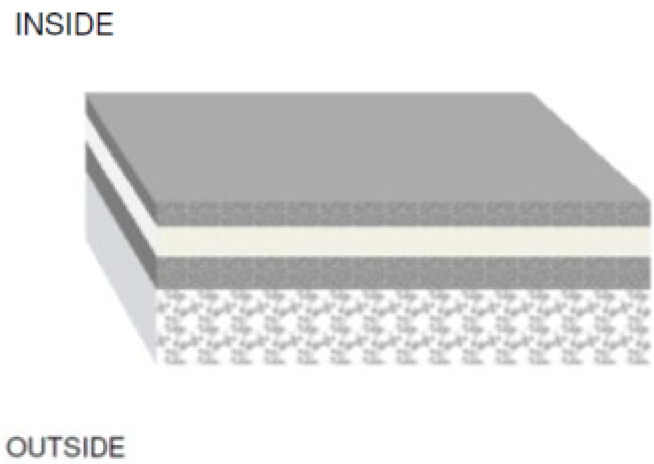
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	Mineral wool	91	5	120	25	0.038	1
b+	Timber joists	9	5		500	0.13	20

4.1.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	3mm of mineral wool insulation	Y	N
Part L U=0.25 W/m^{2}K	120mm of mineral wool insulation	N	N
TER U=0.13 W/m^{2}K	150mm of mineral wool between joists plus 100mm below joists	N	N

4.2. N2 Ground bearing concrete - insulated above

4.2.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Stainless steel mesh	13	5	1	7900	17	999999
b+	Concrete screed	87	5		1200	1.15	60
c	EPS insulation	100	5	87.5	15	0.04	60
d	Concrete slab	100	5	150	2000	1.35	60
e	DPM	100	5	0.3	920	0.17	400000
f	Sand	100	5	75	1700	2	50
g	Gravel	100	5	150			

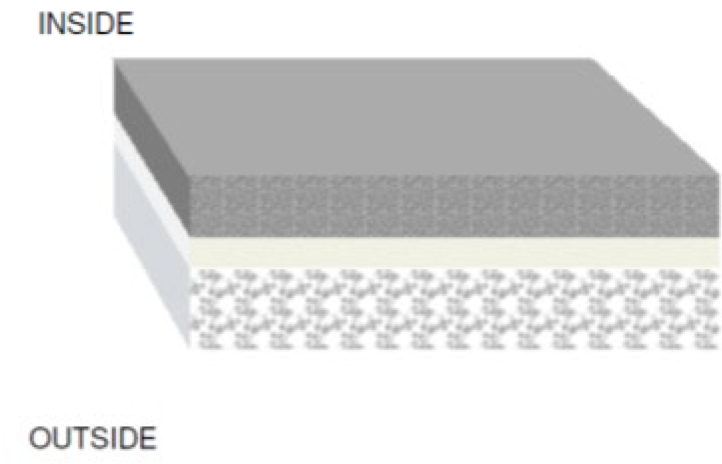
4.2.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.62 W/m^{2}K	No insulation	Y	Y
Part L U=0.25 W/m^{2}K	87.5 mm of EPS insulation	N	Y[3]
TER U=0.13 W/m^{2}K	155mm of XPS insulation	N	Y

Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.

4.3. N3 Ground bearing concrete - insulated below

4.3.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Concrete slab	100	5	150	2000	1.35	60
c	Stainless steel mesh	13	5	1	7900	17	999999
c+	Concrete screed	87	5		1200	1.15	60
d	EPS insulation	100	5	87.5	15	0.04	60
e	DPM	100	5	0.3	920	0.17	400000
f	Sand	100	5	75	1700	2	50
g	Gravel	100	5	150			

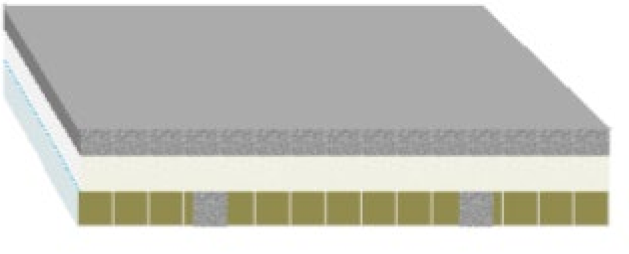
4.3.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.62 W/m^{2}K	No insulation	Y	Y
Part L U=0.25 W/m^{2}K	87.5 mm of EPS insulation	N	Y[3]
TER U=0.13 W/m^{2}K	155mm of XPS insulation	N	Y

Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.

4.4. N4 Beam and block floor - insulated above

4.4.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor µ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Stainless steel mesh	13	5	1	7900	17	999999
b+	Concrete screed	87	5		1200	1.15	60
c	EPS insulation	100	5	95	15	0.04	60
d	DPM	100	5	0.3	920	0.17	400000
e	Floor blocks 440x215	87	5	100	660	0.16	6
e+	Reinforced concrete	13	5		2400	2.5	80

4.4.2. Results table

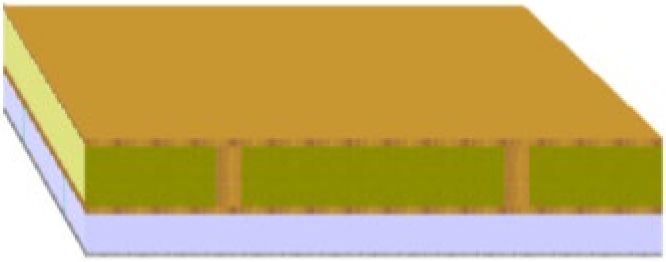
U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.61 W/m²K	No insulation	Y[1]	N
Part L U=0.25 W/m²K	95mm of EPS insulation	N	N
TER U=0.13 W/m²K	155mm of XPS insulation	N	N

Y[1]: only indicates a risk of condensation in uninsulated section of a bridged layer - to be analysed further in WUFI modelling.

Floors (Exposed Upper Floors)

4.5. N5 Timber joist with boards - insulated

4.5.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	Mineral wool	91	5	155	25	0.038	1
b+	Timber joists	9	5		500	0.13	20
c	Chip board	100	5	18	600	0.14	15
d	Air layer	98	5	100	1.2	0.9	1
d+	Stainless steel	2	5		7900	17	999999
e	Timber cladding	100	5	18	700	0.18	50

4.5.2. Results table

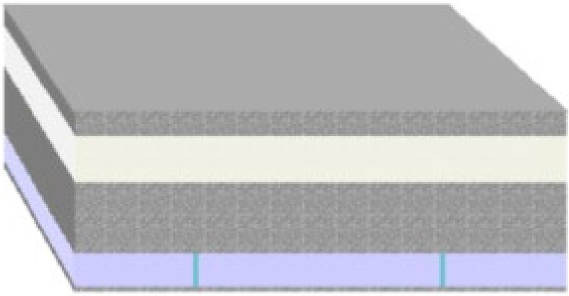
U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	22mm of mineral wool insulation	N	Y[2]
Part L U=0.25 W/m^{2}K	155mm of mineral wool insulation	N	Y[2]
TER U=0.13 W/m^{2}K	245mm of phenolic insulation	N	Y[2]

Y[2]: only in conjunction with ceiling hangers

4.6. N6 Concrete - insulated above

4.6.1. Baseline build-up

INSIDE



OUTSIDE

Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Stainless steel mesh	13	5	1	7900	17	999999
b+	Concrete screed	87	5		1200	1.15	60
c	EPS insulation	100	5	135	15	0.04	60
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	PVC cladding	100	5	18	1390	0.17	50000

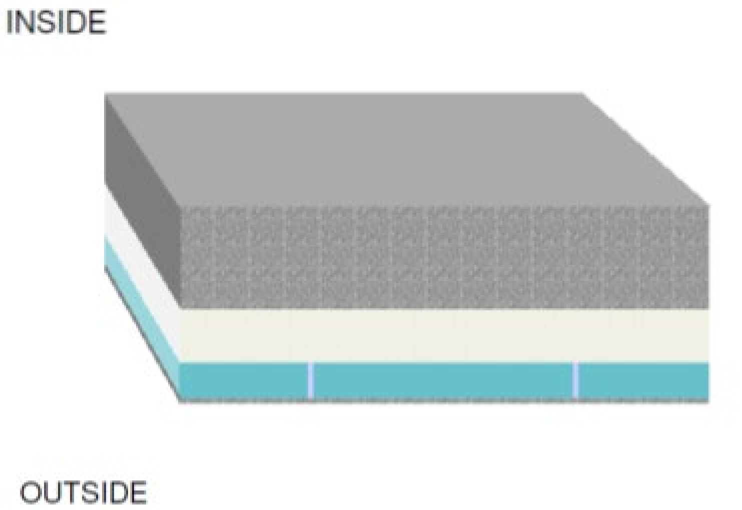
4.6.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	31mm of EPS insulation	N	Y^2
Part L U=0.25 W/m^{2}K	135mm of EPS insulation	N	Y^2
TER U=0.13 W/m^{2}K	190mm of XPS insulation	N	Y^2

Y^2: only in conjunction with ceiling hangers

4.7. N7 Concrete - insulated below

4.7.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Concrete slab	100	5	215	2000	1.35	60
c	EPS insulation	100	5	150	15	0.04	60
d	Air layer	98	5	100	1.2	0.9	1
d+	Stainless steel	2	5		7900	17	999999
e	PVC cladding	100	5	18	1390	0.17	50000

4.7.2. Results table

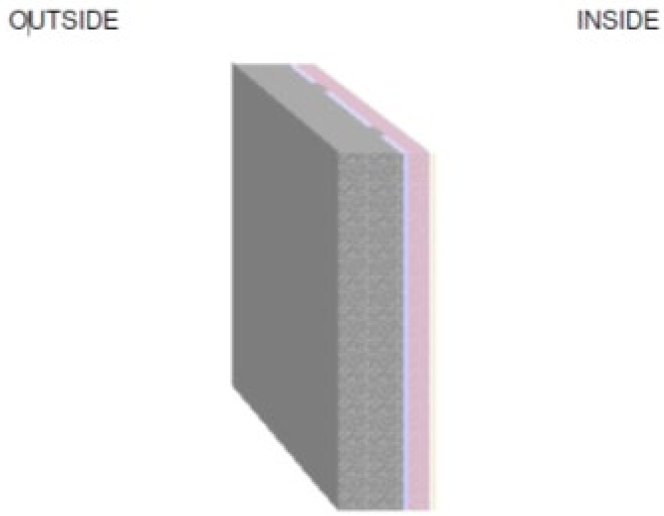
U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^2K	40mm of EPS insulation	N	Y[2]
Part L U=0.25 W/m^2K	150mm of EPS insulation	N	Y[2]
TER U=0.13 W/m^2K	220mm of XPS insulation	N	Y[2]

Y[2]: only in conjunction with ceiling hangers

Walls (Low Rise Buildings)

4.8. N8 Solid - Internal Insulated with a semi-porous finish

4.8.1. Baseline build-up



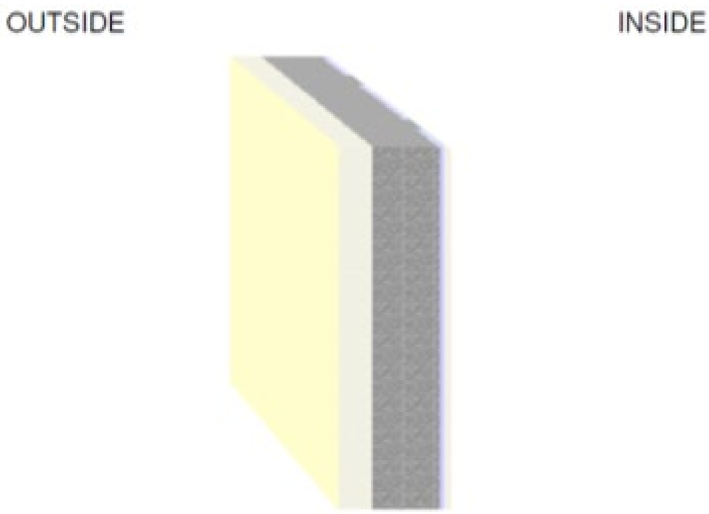
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete	100	5	215	2400	2.5	80
b	Air layer	80	5	15	1.2	0.088	1
b+	Gypsum plaster dabs	20	5		1200	0.43	4
c	Phenolic	100	5	70	30	0.025	60
d	Foil paper facing	100	3 // 1	0.05	1100	200	999999
e	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

4.8.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	29mm of phenolic insulation	N	N
Part L U=0.35 W/m^{2}K	70mm of phenolic insulation	N	N
TER U=0.18 W/m^{2}K	150mm of phenolic insulation	N	N

4.9. N9 Solid - External insulation with a non-porous finish

4.9.1. Baseline build-up



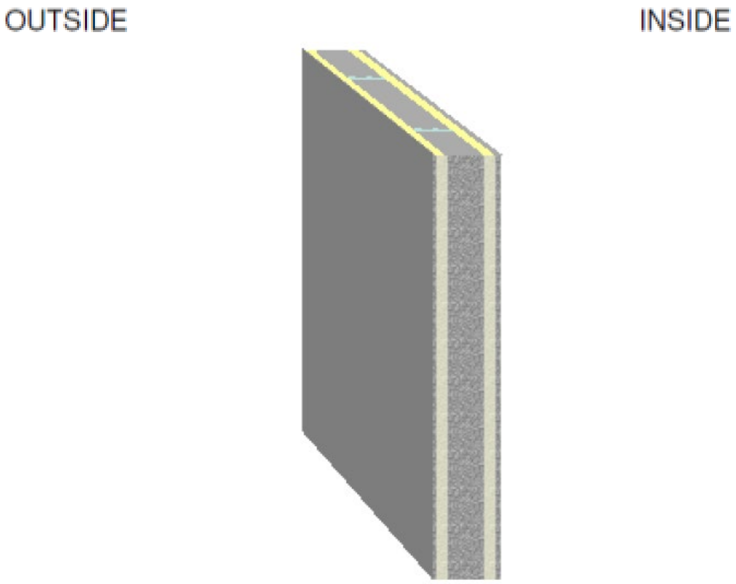
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Silicone render	100	5	15	1250	0.3	9.8
b	Expanded polystyrene (EPS) - with fixings	100	5	100	15	0.04	60
c	Concrete	100	5	215	2400	2.5	80
d	Air layer	80	5	15	1.2	0.088	1
d+	Gypsum plaster dabs	20	5		1200	0.43	4
e	Foil paper facing	100	3 // 1	0.05	1100	200	999999
f	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

4.9.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	43mm of EPS insulation	N	N
Part L U=0.35 W/m^{2}K	100mm of EPS insulation	N	N
TER U=0.18 W/m^{2}K	220mm of EPS insulation	N	N

4.10. N10 Solid - External and internal insulation with a non-porous finish

4.10.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Gypsum Plasterboard	100	4 // 1	15	700	0.21	4
b	Polyurethane	100	5	30	30	0.025	50
c	Concrete	95	5	102	1800	1.15	60
c+	Stainless steel ties	5	1		7900	17	999999
d	Polyurethane	100	5	30	30	0.025	50
e	Gypsum Plasterboard	100	4 // 1	15	700	0.21	4

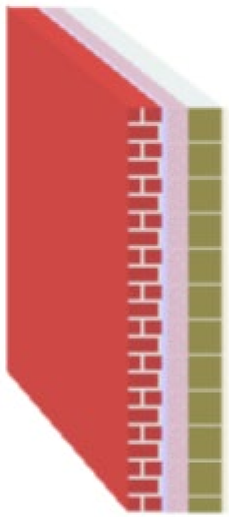
4.10.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	13.5mm of polyurethane on each side*	N	N
Part L U=0.35 W/m^{2}K	30mm of polyurethane on each side*	N	N
TER U=0.18 W/m^{2}K	65mm of polyurethane on each side*	N	N

* the thickness required to achieve this U-value may not be available on the market

4.11. N11 Cavity - Partial-fill with a semi-porous finish e.g. facing brickwork

4.11.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Air layer	100	5	50	1.2	0.088	1
c	Phenolic partial cavity foam	100	5	60	30	0.025	60
d	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
e	Gypsum plaster	100	4 // 1	12.5	700	0.21	4

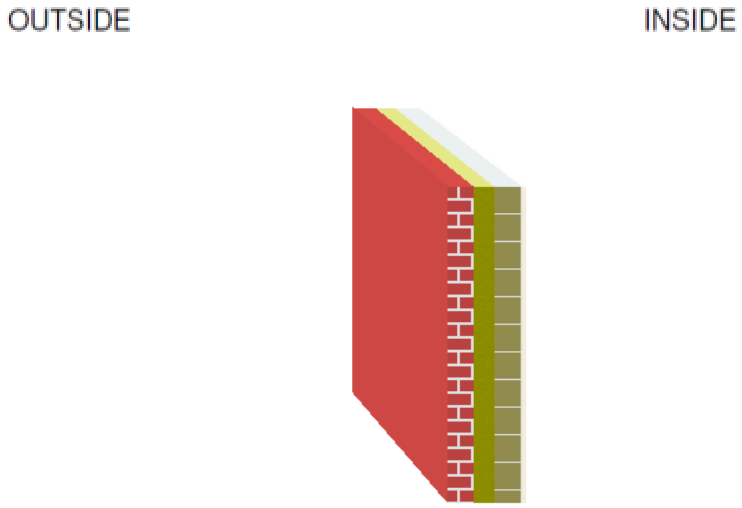
4.11.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.70 W/m^{2}K	30mm of mineral wool insulation	N	Y[4]
Part L U=0.35 W/m^{2}K	60mm of phenolic insulation	N	N
TER U=0.27 W/m^{2}K	80mm of phenolic insulation	N	N

Y[4]: only if there is wet plaster

4.12. N12 Cavity - Full-fill with a semi-porous finish e.g. facing brickwork

4.12.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Mineral wool insulation	100	5	90	25	0.038	1
c	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
d	Air layer	80	5	15	1.2	0.088	1
d+	Gypsum plaster dabs	20	5		1200	0.43	4
e	Gypsum plasterboard	100	4 // 1	12.5	700	0.21	4

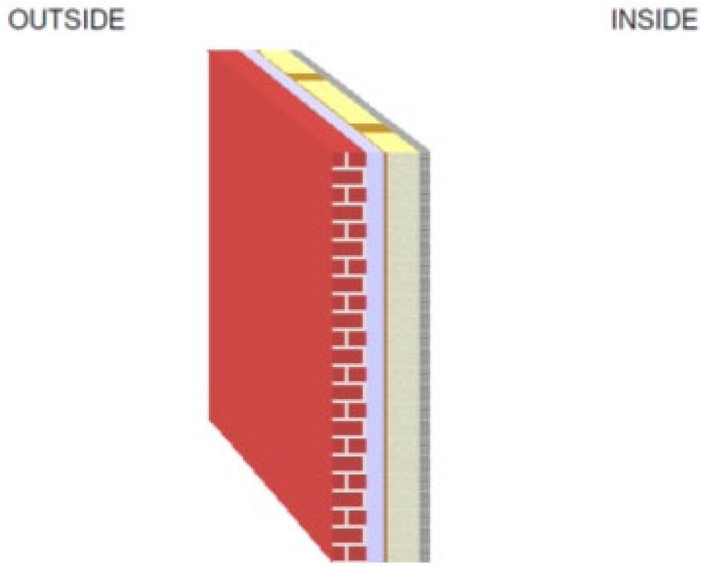
4.12.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.55 W/m²K	50mm of mineral wool insulation	N	Y[4]
Part L U=0.35 W/m²K	90mm of mineral wool insulation	N	N
TER U=0.23 W/m²K	150mm of mineral wool insulation	N	N

Y[4]: only if there is wet plaster

4.13. N13 Timber frame with air gap and a semi-porous finish e.g. facing brickwork

4.13.1. Baseline build-up



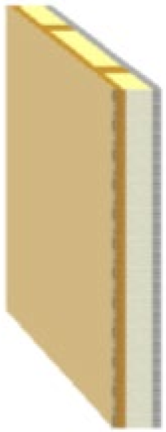
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Air layer	100	5	50	1.2	0.278	1
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Plywood	100	5	9	500	0.13	70
e	Timber studs	9	5	90	500	0.13	20
e+	Polyurethane	91	5		30	0.025	50
f	Polyethylene	100	5	0.2	920	0.17	300000
g	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
h	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

4.13.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.42 W/m^{2}K	90mm of mineral wool between timber studs	N	N
Part L U=0.35 W/m^{2}K	90mm of polyurethane between timber studs	N	N
TER U=0.18 W/m^{2}K	90mm of mineral wool between timber studs and 100mm polyurethane insulation	N	N

4.14. N14 Timber frame with no air gap and a non-porous finish e.g. render

4.14.1. Baseline build-up



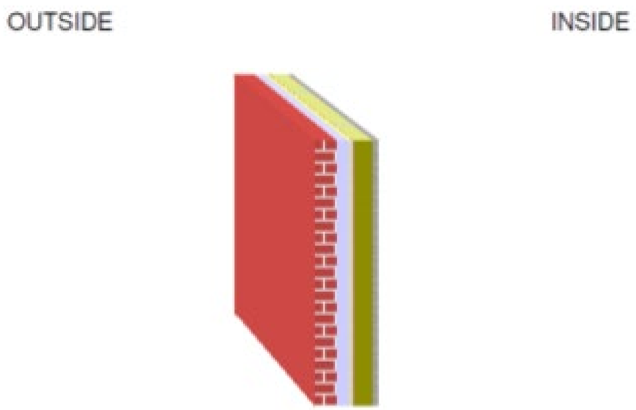
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Render, cement and sand	100	5	15	1600	0.8	6
b	Cement particle board	100	5	25	1200	0.23	30
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Timber studs	9	5	95	500	0.13	20
d+	Polyurethane	91	5		30	0.025	50
e	Polyethylene	100	5	0.2	920	0.17	300000
f	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
g	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

4.14.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.53 W/m²K	75mm of mineral wool insulation between timber studs	N	N
Part L U=0.35 W/m²K	95mm of polyurethane insulation between timber studs	N	N
TER U=0.18 W/m²K	90mm of polyurethane insulation between timber studs and 65mm over timber studs	N	N

4.15. N15 Light Gauge Steel Frame (LGSF) with air gap and a semi-porous finish e.g. facing brickwork

4.15.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Air layer	100	5	50	1.2	0.278	1
c	Polyurethane	100	5	12	30	0.025	50
d	Breathable membrane	100	5	0.1	350	0.17	2000
e	OSB	100	5	9	650	0.13	30
f	Steel studs	0.3	5	100	7900	17	999999
f+	Mineral wool	99.7	5		25	0.038	1
g	Polyethylene	100	5	0.2	920	0.17	300000
h	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
i	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

4.15.2. Results table

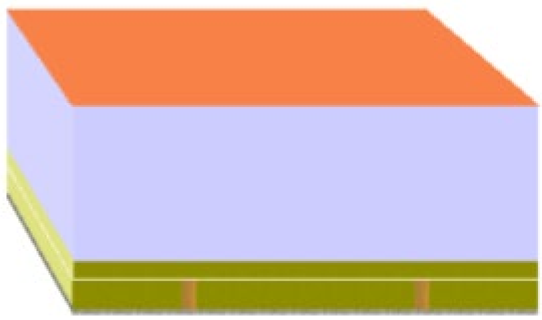
U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.51 W/m^2K	100mm of mineral wool between steel studs	Y[1]	N
Part L U=0.37 W/m^2K	100mm of mineral wool between steel studs and 12mm of polyurethane insulation	N	N
TER U=0.18 W/m^2K	100mm of mineral wool between steel studs and 80mm of polyurethane insulation	N	N

Y[1]: only indicates a risk of condensation in uninsulated section of a bridged layer - to be analysed further in WUFI modelling.

Roofs (Pitched)

4.16. N17 Cold roof (slates/concrete/clay tiles) - insulated

4.16.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Tiled roof above	100	5	500	1.2	2.5	1
b	Mineral wool	100	5	55	12	0.038	1
c	Mineral wool	94.2	5	100	12	0.038	1
c+	Timber joists	5.8	5		500	0.13	20
d	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

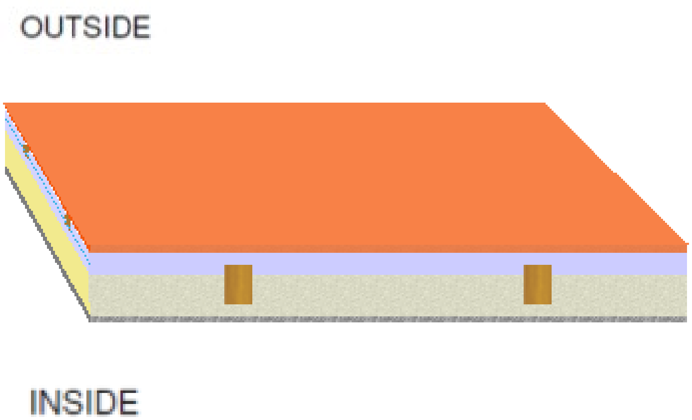
4.16.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.35 W/m²K	10mm of mineral wool over insulated timber joists (100+10)	N	Y[3]
Part L U=0.25 W/m²K	55mm of mineral wool over insulated timber joists (100+55)	N	Y[3]
TER U=0.13 W/m²K	220mm of mineral wool over insulated timber joists (100+220)	N	Y[3]

Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.

4.17. N18 Warm roof (slates/concrete/clay tiles)

4.17.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Clay tiles	100	5	20	2000	1	-
b	Ventilated air layer	90	5	30	1.2	0	-
b+	Softwood batts	10	5		500	0.13	20
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Ventilated air layer	90	5	25	1.2	0	-
d+	Softwood rafters	10	5		500	0.13	20
e	Polyurethane	90	5	75	30	0.025	50
e+	Softwood rafters	10	5		500	0.13	20
f	Polyurethane	100	5	32	30	0.025	50
g	Polyethylene	100	5	0.2	920	0.17	300000
h	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

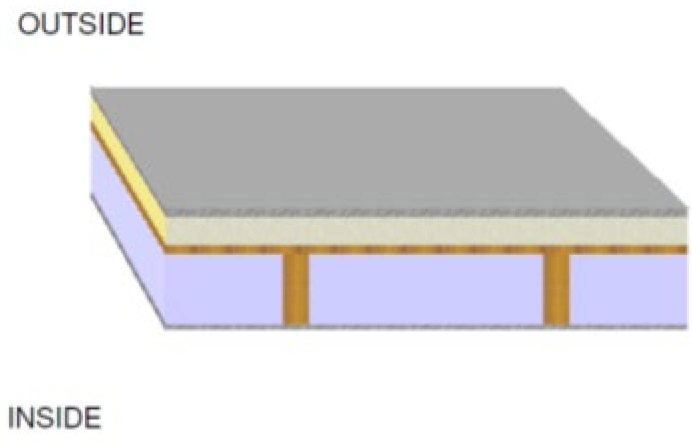
4.17.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.35 W/m^{2}K	83mm of polyurethane between rafters	N	N
Part L U=0.25 W/m^{2}K	75mm of polyurethane between rafters and 32mm below rafters	N	N
TER U=0.13 W/m^{2}K	75mm polyurethane between rafters and 130mm below rafters	N	N

Roofs (Flat)

4.18. N19 Warm roof - timber

4.18.1. Baseline build-up



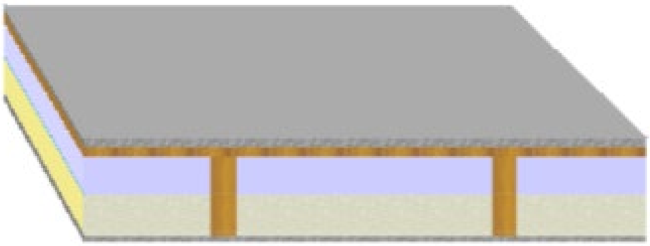
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Polyurethane	100	5	80	30	0.025	50
c	Polyethylene	100	5	0.2	920	0.17	300000
d	Plywood	100	5	25	700	0.17	90
e	Air layer	90	5	200	1.2	0.625	1
e+	Softwood batts	10	5		500	0.13	20
f	Gypsum plasterboard	100	4 // 1	12.5	900	0.25	4

4.18.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.35 W/m^{2}K	50mm of polyurethane	N	Y
Part L U=0.25 W/m^{2}K	80mm of polyurethane	N	Y
TER U=0.13 W/m^{2}K	180mm of polyurethane	N	Y

4.19. N20 Cold roof - timber

4.19.1. Baseline build-up



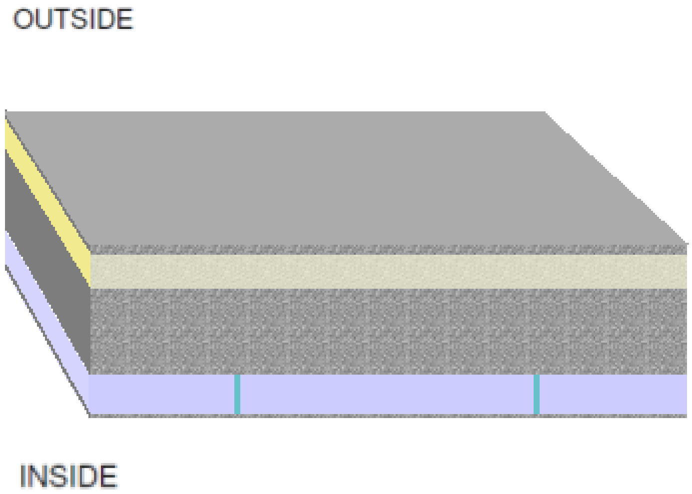
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Plywood	100	5	25	700	0.17	90
c	Air layer	91	5	100	1.2	0.625	1
c+	Softwood batts	9	5		500	0.13	20
d	Polyurethane	91	5	110	30	0.025	50
d+	Softwood batts	9	5		500	0.13	20
e	Polyethylene	100	5	0.2	920	0.17	300000
f	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

4.19.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.35 W/m²K	75mm of polyurethane	N	N
Part L U=0.25 W/m²K	110mm of polyurethane	N	N
TER U=0.13 W/m²K	100mm of polyurethane between joists and 100mm below joists	N	N

4.20. N21 Warm roof - concrete

4.20.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Polyurethane	100	5	85	30	0.025	50
c	Polyethylene	100	5	0.2	920	0.17	300000
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	Gypsum plasterboard	100	4 // 1	12.5	900	0.25	4

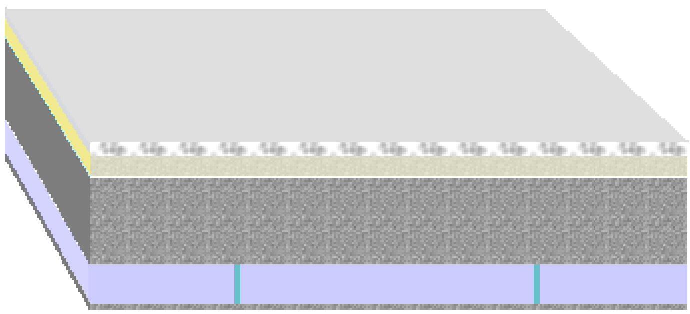
4.20.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.35 W/m^{2}K	55mm of polyurethane	N	Y[3]
Part L U=0.25 W/m^{2}K	85mm of polyurethane	N	Y[3]
TER U=0.13 W/m^{2}K	190mm of polyurethane	N	Y[3]

Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.

4.21. N22 Inverted roof - concrete

4.21.1. Baseline build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Gravel	100	5	150	1700	2	50
b	Phenolic insulation	100	5	85	29	0.023	8341
c	Vcl and water proofing	100	5	5	400	0.1	333333
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	Gypsum plasterboard	100	4 // 1	12.5	900	0.25	4

4.21.2. Results table

U-value backstops analysed	Variation to Baseline Build-up	Surface condensation	Interstitial condensation
Part C U=0.38 W/m^{2}K	50mm of phenolic insulation	N	N
Part L U=0.25 W/m^{2}K	85mm of phenolic insulation	N	N
TER U=0.13 W/m^{2}K	165mm of phenolic insulation	N	N

The following two sections (Section 5 and Section 6) provides an overall summary and key findings of each construction typologies for Retrofit.

5. Overall Summary of Key Findings - Retrofit

The construction typologies listed below are those that show a risk of surface and/or interstitial condensation; these typologies will be tested using WUFI with the aim of identify more precisely where condensation risks occurs.

The construction typologies not listed below will also be analysed using WUFI primarily to verify the results of no-risk of surface and/or interstitial condensation, and sensitivity to wind driven rain.

Type	**Ref**	**Typology**	**Backstop analysed**	**U-value**	**Surface condensation occurred**	**Interstitial condensation occurred**
Ground Floors	R2	Ground bearing concrete Retrofit measure: insulation added	B	0.25	N	Y
	R4	Beam and block floors Retrofit measure: insulated added	B	0.25	N	Y[5]
Exposed Upper Floors	R5.1	Exposed upper floors - timber joist with boards Retrofit measure: Insulation between joists	B	0.25	N	Y[2]
	R6	Exposed upper floors - concrete Retrofit measure: Insulation added above	B	0.25	N	Y
	R7	Exposed upper floors - concrete Retrofit measure: Insulation added below	B	0.25	N	Y[2]
Roofs	R19	Warm flat timber roof Retrofit measure: Insulation	B	0.18	N	Y
	R21	Warm Flat concrete roof Retrofit measure: Insulation	B	0.18	N	Y[3]

Note:

Y[1]: only indicates a risk of condensation in uninsulated section of a bridged layer - to be analysed further in WUFI modelling.
Y[2]: only in conjunction with ceiling hangers
Y[3]: only indicates a risk of condensation in an insulated section of a bridge layer - to be analysed further in WUFI modelling.
Y[4]: only if there is wet plaster.
Y[5]: indicates a risk of condensation in a bridge layer - to be analysed further in WUFI modelling.

5.1. Conclusions - Retrofit

The results of the Glaser modelling indicate that:

- Ground bearing floor types R2 and R4 indicate a risk of interstitial condensation at the AD L backstop U-value.
- Upper floor types R5.1, R6 and R7 indicate a risk of interstitial condensation at the AD L backstop U-value.
- Roof types R19 and R21 indicate a risk of interstitial condensation at the AD L backstop U-value.

These typologies will have thorough investigation and analysis using WUFI in the next stage of the project across a greater range of boundary conditions than those with no indication of surface and / or interstitial condensation risks.

No walls indicate a risk of surface or interstitial condensation.

6. Key Findings of each Construction Typologies - Retrofit

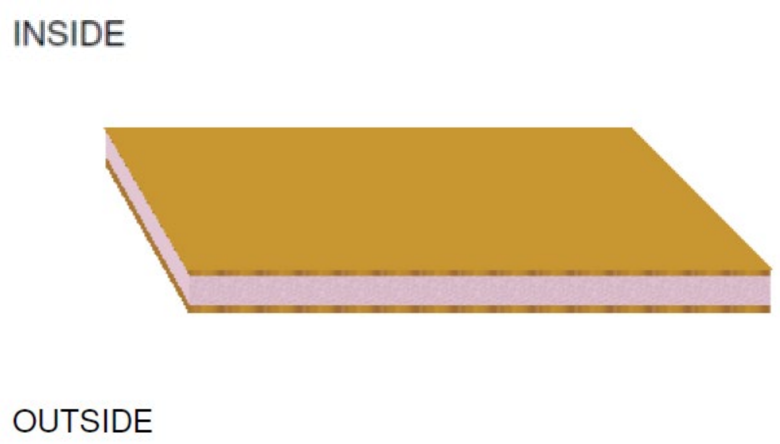
Floors

6.1. R1.1 Suspended timber ground floors Retrofit measure: Insulation within joists

See Section 4.1: *N1 Suspended timber floor - insulated* for build-up and results.

6.2. R1.2 Suspended timber ground floors Retrofit measure: Insulation added above

6.2.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	Phenolic	100	5	64	30	0.025	60
c	Chip board	100	5	18	600	0.14	15
d	Timber joists	100	5	150	500	0.13	20

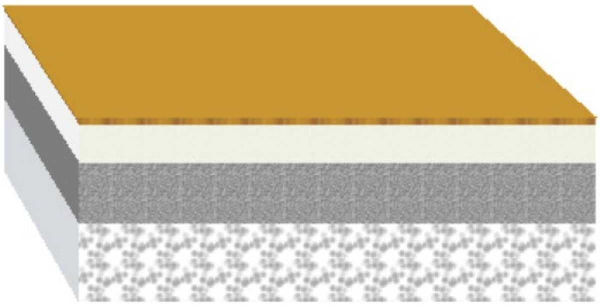
6.2.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.25 W/m²K	64mm of phenolic insulation	N	N

6.3. R2 In situ ground bearing concrete Retrofit measure: insulation added

6.3.1. Build-up

INSIDE



OUTSIDE

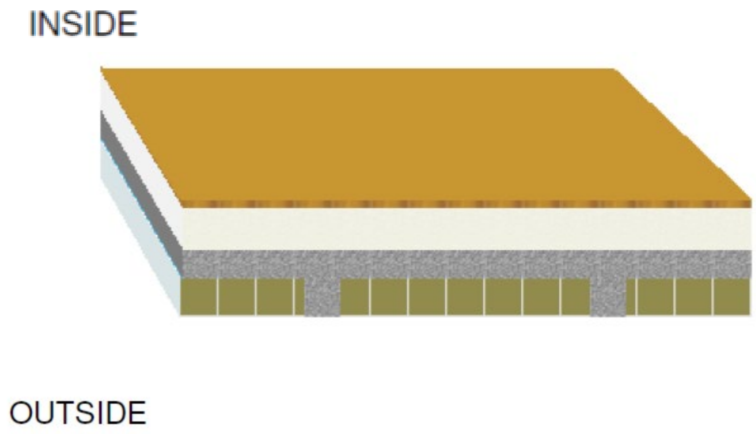
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	0	0.14	15
b	EPS Insulation	100	5	82	15	0.04	60
c	Concrete screed	100	5	75	1200	1.15	60
d	Concrete slab	100	5	150	2000	1.35	60
e	DPM	100	5	0.3	920	0.17	400000
f	Sand	100	5	75	1700	2	50
g	Gravel	100	5	150			

6.3.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.25 W/m²K	82mm of EPS added on top of concrete screed	N	Y

6.4. R4 Beam and block floors Retrofit measure: insulated added

6.4.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	EPS Insulation	100	5	90	15	0.04	60
c	Concrete screed	100	5	75	1200	1.15	60
d	DPM	100	5	0.3	920	0.17	400000
e	Floor blocks 440x215	87	5	100	660	0.16	6
e+	Reinforced concrete	13	5		2400	2.5	80

6.4.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.25 W/m^{2}K	90mm of EPS added on top of concrete screed	N	Y[5]

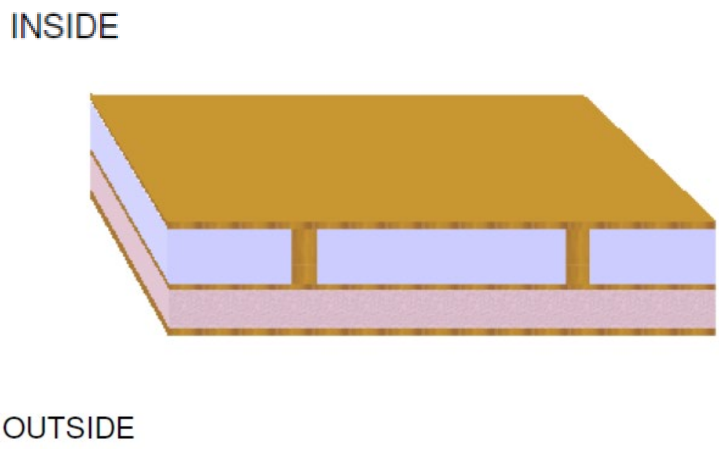
Y[5]: indicates a risk of condensation in a bridge layer - to be analysed further in WUFI modelling.

6.5. R5.1 Exposed upper floors - timber joist with boards Retrofit measure: Insulation between joists

See Section 4.5: N5 Timber joist with boards - insulated for build-up and results

6.6. R5.2 Exposed upper floors - timber joist with boards Retrofit measure: Insulation added below

6.6.1. Build-up



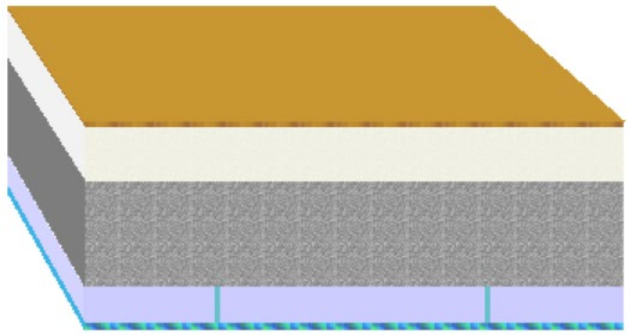
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	Air layer	91	5	150	1.2	0.9	1
b+	Timber joists	9	5		500	0.13	20
c	Chip board	100	5	18	600	0.14	15
d	Phenolic	100	5	90	30	0.025	60
e	Timber cladding	100	5	18	700	0.18	50

6.6.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.25 W/m^{2}K	90mm of phenolic insulation installed below	N	N

6.7. R6 Exposed upper floors - concrete
Retrofit measure: Insulation added above

6.7.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Chip board	100	5	18	600	0.14	15
b	EPS Insulation	100	5	130	15	0.04	60
c	Concrete screed	100	5	75	1200	1.15	60
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	PVC Cladding	100	5	18	1390	0.17	50000

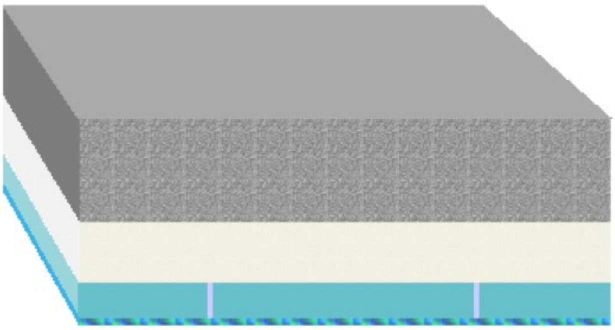
6.7.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.25 W/m²K	130mm of EPS above screed (false ceiling)	N	Y

6.8. R7 Exposed upper floors - concrete Retrofit measure: Insulation added below

6.8.1. Build-up

INSIDE



OUTSIDE

Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Concrete screed	100	5	75	1200	1.15	60
b	Concrete slab	100	5	215	2000	1.35	60
c	EPS Insulation	100	5	150	15	0.04	60
d	Air layer	98	5	100	1.2	0.9	1
d+	Stainless steel	2	5		7900	17	999999
e	PVC Cladding	100	5	18	1390	0.17	50000

6.8.2. Results table

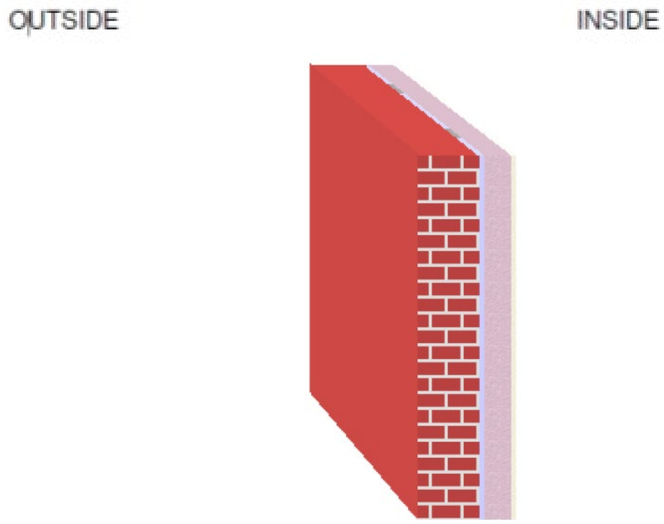
U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.25 W/m^{2}K	150mm of EPS above screed (false ceiling)	N	Y[2]

Y[2]: only in conjunction with ceiling hangers

Walls

6.9. R8 Solid Masonry
Retrofit measure: Internal Wall Insulation (IWI)

6.9.1. Build-up



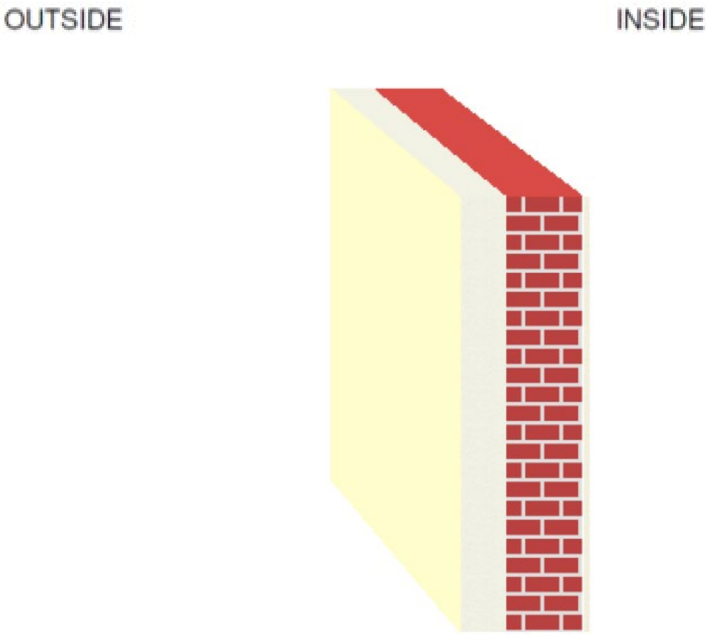
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Solid brick wall (outer leaf)	100	1	215	1700	0.77	45
b	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
c	Air layer	80	5	15	1.2	0.088	1
c+	Gypsum plaster dabs	20	5		1200	0.43	4
d	Phenolic	100	5	78	30	0.025	60
e	Foil paper facing	100	3 // 1	0.05	1100	200	999999
f	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

6.9.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.30 W/m²K	78mm of IWI (phenolic insulation)	N	N

6.10. R9 Solid Masonry Retrofit measure: External Wall Insulation (EWI)

6.10.1. Build-up



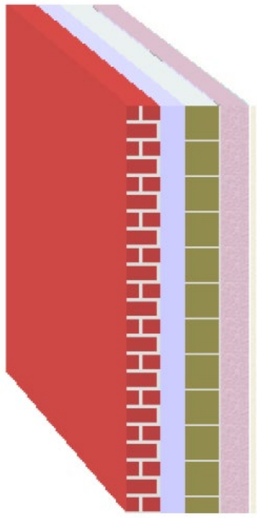
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Silicone render	100	5	15	1250	0.3	9.8
b	Expanded polystyrene (EPS) - with fixings	100	5	120	15	0.04	60
c	Solid brick wall (inner leaf)	100	1	215	1700	0.56	45
d	Gypsum Plaster	100	4 // 1	12.5	700	0.21	4

6.10.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.30 W/m^{2}K	120mm of EWI (EPS insulation)	N	N

6.11. R11.1 Cavity masonry with no insulation Retrofit measure: Internal Wall Insulation (IWI)

6.11.1. Build-up



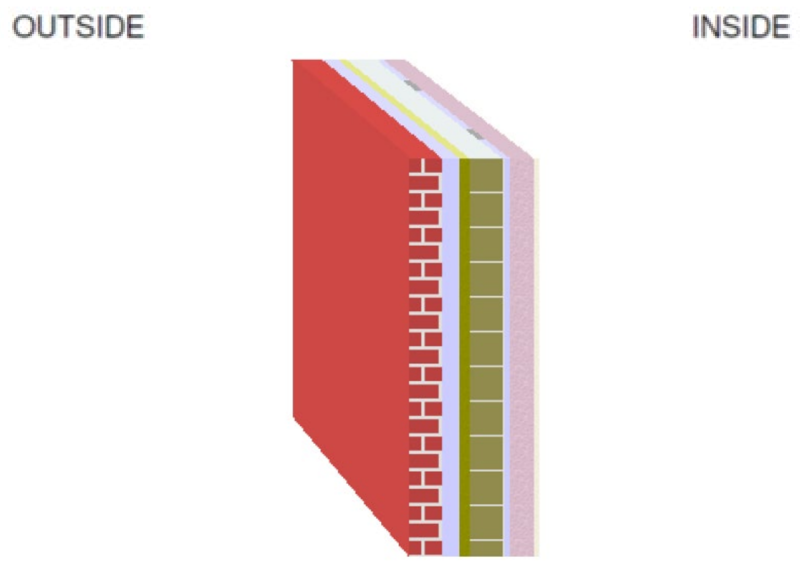
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Air layer	100	5	50	1.2	0.088	1
c	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
d	Air layer	80	5	15	1.2	0.088	1
d+	Gypsum plaster dabs	20	5		1200	0.43	4
e	Phenolic	100	5	75	30	0.025	60
f	Foil paper facing	100	3 // 1	0.05	1100	200	999999
g	Gypsum Plaster board	100	4 // 1	12.5	700	0.21	4

6.11.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-1 U=0.30 W/m^{2}K	75mm of IWI (phenolic insulation)	N	N

6.12. R11.2 Partial-fill cavity masonry
Retrofit measure: Internal Wall Insulation (IWI)

6.12.1. Build-up



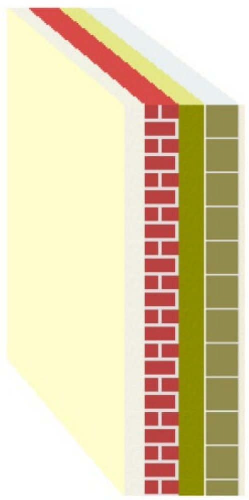
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Air layer	100	5	50	1.2	0.088	1
c	Mineral Wall CWI with fixings	100	5	30	25	0.038	1
d	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
e	Air layer	80	5	15	1.2	0.088	1
e+	Gypsum plaster dabs	20	5		1200	0.43	4
f	Phenolic	100	5	60	30	0.025	60
g	Foil paper facing	100	3 // 1	0.05	1100	200	999999
h	Gypsum Plaster board	100	4 // 1	12.5	700	0.21	4

6.12.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.30 W/m^{2}K	30mm of mineral wool in cavity and 60mm of IWI (phenolic insulation)	N	N

6.13. R12.1 Cavity masonry with no insulation Retrofit measure: External Wall Insulation (EWI) and Cavity Wall Insulation (CWI)

6.13.1. Build-up



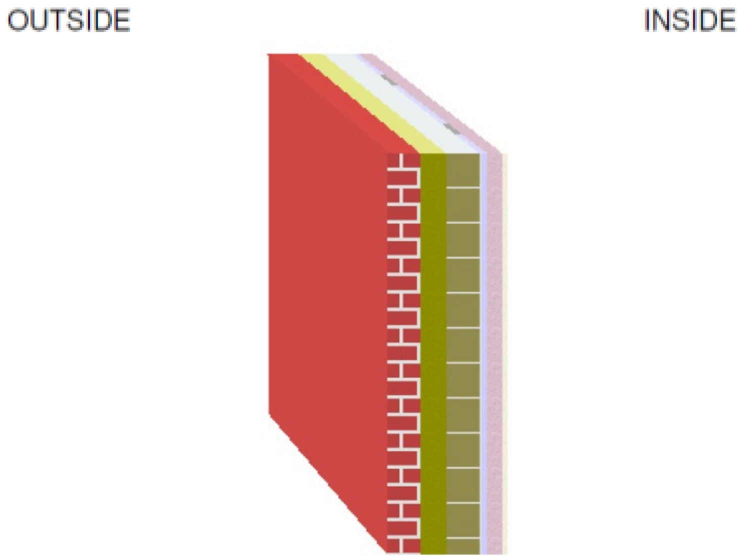
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Silicone render	100	5	15	1250	0.3	9.8
b	Expanded polystyrene (EPS) - with fixings	100	5	50	15	0.04	60
c	Brick inner leaf	100	1	102	1725	0.56	45
d	Mineral Wall CWI	100	5	75	25	0.038	1
e	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
f	Gypsum Plaster	100	4 // 1	12.5	700	0.21	4

6.13.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-1 U=0.30 W/m^{2}K	75mm of CWI and 50mm of EWI (EPS insulation)	N	N

6.14. R12.2 Full-fill cavity masonry Retrofit measure: Internal Wall Insulation (IWI)

6.14.1. Build-up



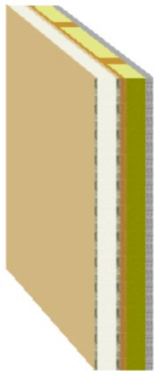
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Brick outer leaf	100	1	102	1725	0.77	45
b	Mineral Wall CWI with fixings	100	5	75	25	0.038	1
c	Blockwork - lightweight aggregate	100	5	100	1400	0.57	10
d	Air layer	80	5	15	1.2	0.088	1
d+	Gypsum plaster dabs	20	5		1200	0.43	4
e	Phenolic	100	5	30	30	0.025	60
f	Foil paper facing	100	3 // 1	0.05	1100	200	999999
g	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

6.14.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.30 W/m^{2}K	75mm of CWI and 30mm of IWI (phenolic insulation)	N	N

6.15. R14.1 Framed building
Retrofit measure: External Wall Insulation (EWI)

6.15.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Silicone render	100	5	15	1250	0.3	9.8
b	Expanded polystyrene (EPS) - with fixings	100	5	65	15	0.04	60
c	Render, cement and sand	100	5	15	1600	0.8	6
d	Cement particle board	100	5	25	1200	0.23	30
e	Breathable membrane	100	5	0.1	350	0.17	2000
f	Timber studs	9	5	75	500	0.13	20
f+	Mineral wool	91	5		25	0.038	1
g	Polyethylene	100	5	0.2	920	0.17	300000
h	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
i	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

6.15.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-1 U=0.30 W/m^{2}K	75mm of mineral wool between studs and 65mm of EWI (EPS insulation)	N	N

6.16. R14.2 Framed building Retrofit measure: Internal Wall Insulation (IWI)

6.16.1. Build-up

OUTSIDE INSIDE

Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Render, cement and sand	100	5	15	1600	0.8	6
b	Cement particle board	100	5	25	1200	0.23	30
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Timber studs	9	5	75	500	0.13	20
d+	Mineral wool	91	5		25	0.038	1
e	Polyethylene	100	5	0.2	920	0.17	300000
f	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
g	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4
h	Phenolic	100	5	40	30	0.025	60
i	Foil paper facing	100	3 // 1	0.05	1100	200	999999
j	Gypsum Plasterboard	100	4 // 1	12.5	700	0.21	4

6.16.2. Results table

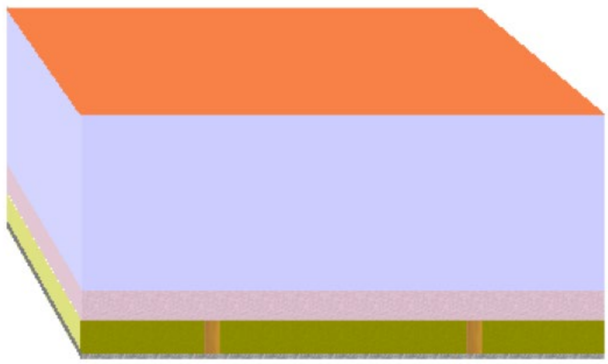
U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.30 W/m²K	75mm of mineral wool between studs and 40mm of IWI (Phenolic insulation)	N	N

Roofs

6.17. R17 Cold (pitched) roof
Retrofit measure: Loft insulation

6.17.1. Build-up

OUTSIDE



INSIDE

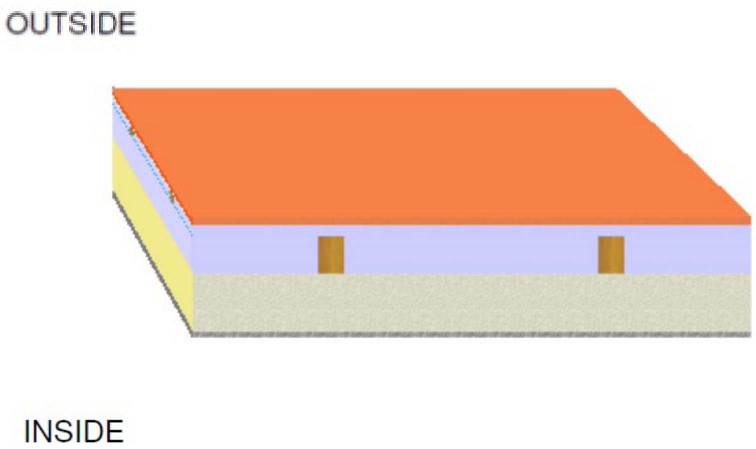
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Tiled roof above	100	5	500	1.2	2.5	1
b	Phenolic Insulation	100	5	85	30	0.025	60
c	Mineral wool	94.2	5	100	12	0.038	1
c+	Timber joists	5.8	5		500	0.13	20
d	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.17.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.16 W/m^{2}K	85mm of phenolic insulation above joists	N	N

6.18. R18 Warm (pitched) roof
Retrofit measure: Sloping ceiling insulation

6.18.1. Scenario 1 - Insulation added below uninsulated rafters - Build-up

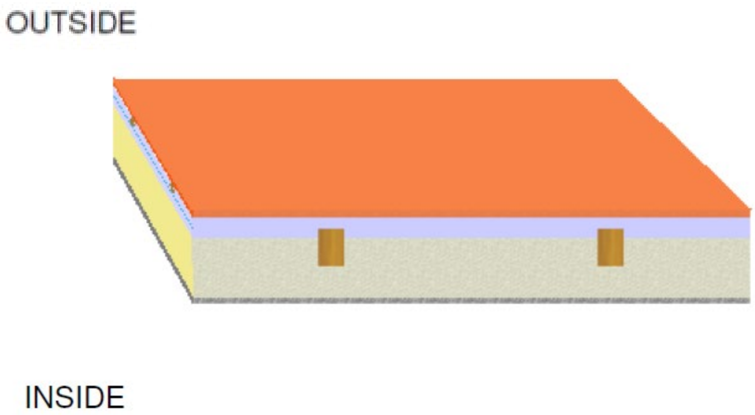


Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Clay tiles	100	5	20	2000	1	-
b	Ventilated air layer	90	5	30	1.2	0	-
b+	Softwood batts	10	5		500	0.13	20
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Ventilated air layer	90	5	100	1.2	0	-
d+	Softwood rafters	10	5		500	0.13	20
e	Polyurethane	100	5	140	30	0.025	50
f	Polyethylene	100	5	0.2	920	0.17	300000
g	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.18.2. Scenario 1 - Insulation added below uninsulated rafters - Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-1 U=0.18 W/m^{2}K	140mm of polyurethane insulation below uninsulated joists	N	N

6.18.3. Scenario 2 - Insulation between and below rafters - Build-up



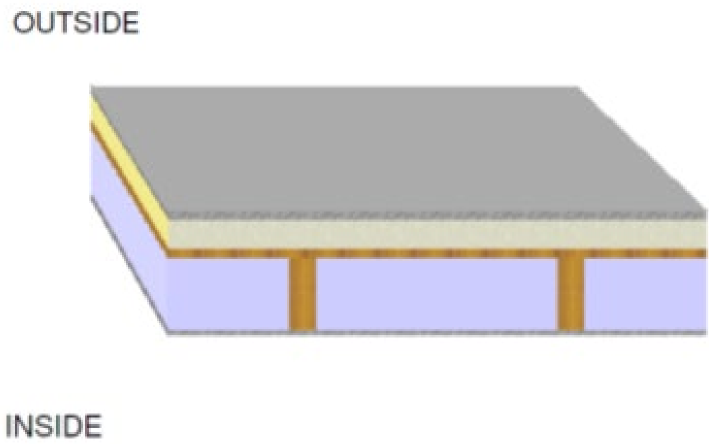
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Clay tiles	100	5	20	2000	1	-
b	Ventilated air layer	90	5	30	1.2	0	-
b+	Softwood batts	10	5		500	0.13	20
c	Breathable membrane	100	5	0.1	350	0.17	2000
d	Ventilated air layer	90	5	25	1.2	0	-
d+	Softwood rafters	10	5		500	0.13	20
e	Polyurethane	90	5	75	30	0.025	50
e+	Softwood rafters	10	5		500	0.13	20
f	Polyurethane	90	5	70	30	0.025	50
g	Polyethylene	100	5	0.2	920	0.17	300000
h	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.18.4. Scenario 2 - Insulation between and below rafters - Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B-2 U=0.18 W/m²K	70mm of polyurethane insulation below insulated joists (75mm of polyurethane)	N	N

6.19. R19 Warm flat timber roof
Retrofit measure: Insulation

6.19.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Polyurethane	100	5	120	30	0.025	50
c	Polyethylene	100	5	0.2	920	0.17	300000
d	Plywood	100	5	25	700	0.17	90
e	Air layer	90	5	200	1.2	0.625	1
e+	Softwood joists	10	5		500	0.13	20
f	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

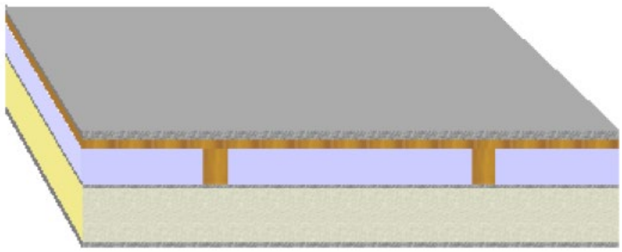
6.19.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.18 W/m^{2}K	120mm of polyurethane insulation above uninsulated joists	N	Y

6.20. R20 Cold flat roof
Retrofit measure: Insulation below

6.20.1. Build-up

OUTSIDE



INSIDE

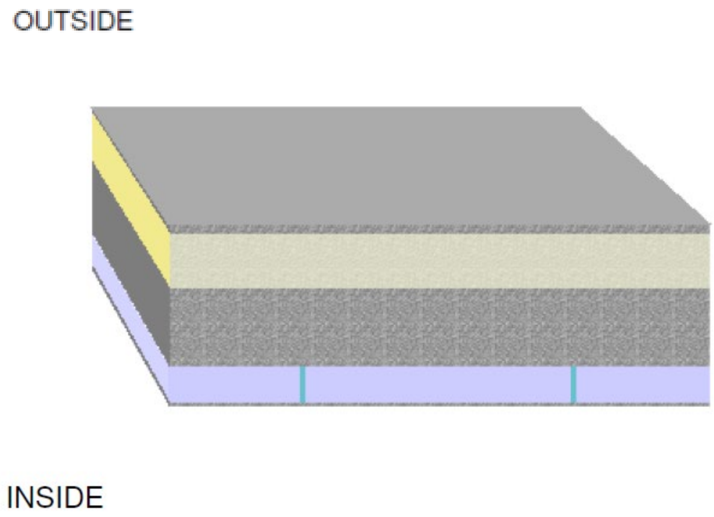
Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Plywood	100	5	25	700	0.17	90
c	Air layer	91	5	100	1.2	0.625	1
c+	Softwood joists	9	5		500	0.13	20
d	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4
e	Polyurethane	100	5	150	30	0.025	50
f	Polyethylene	100	5	0.2	920	0.17	300000
g	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.20.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.16 W/m^{2}K	150mm of polyurethane added below existing ceiling	N	N

6.21. R21 Warm Flat concrete roof Retrofit measure: Insulation above

6.21.1. Build-up



Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m³)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Bitumen	100	5	25	110	0.23	50000
b	Polyurethane	100	5	125	30	0.025	50
c	Polyethylene	100	5	0.2	920	0.17	300000
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.21.2. Results table

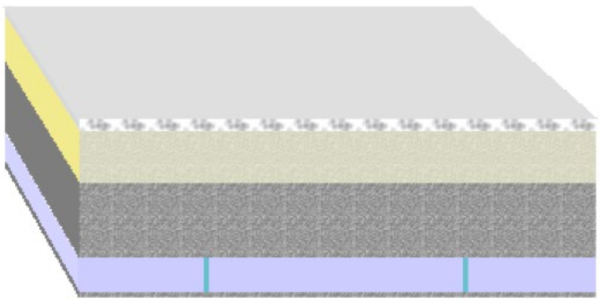
U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.18 W/m²K	125mm of polyurethane added above existing concrete slab	N	Y[3]

Y[3]: only experienced in a bridged layer - to be analysed further in WUFI modelling.

6.22. R22 Inverted flat concrete roof Retrofit measure: Insulation above

6.22.1. Build-up

OUTSIDE



INSIDE

Layers	Material	Proportion (%)	Data Source	Thickness t (mm)	Bulk Density ρ_{bulk} (kg/m^3)	Thermal Conductivity, Dry 10°C λ (W/m.K)	Water Vapour Diffusion Resistance Factor μ (-)
a	Gravel	100	5	150	1700	2	50
b	Phenolic insulation	100	5	125	29	0.023	8341
c	Vcl and water proofing	100	5	5	400	0.1	333333
d	Concrete slab	100	5	215	2000	1.35	60
e	Air layer	98	5	100	1.2	0.9	1
e+	Stainless steel	2	5		7900	17	999999
f	Gypsum Plasterboard	100	4 // 1	12.5	900	0.25	4

6.22.2. Results table

U-value backstops analysed	Retrofit measure	Surface condensation	Interstitial condensation
Part L1B U=0.18 W/m^{2}K	125mm of phenolic insulation added above existing concrete slab	N	N