Retrofit of Historic Timber-Framed Buildings in the UK:

monitoring replacement infill panels

Dr Chris Whitman WhitmanCJ@Cardiff.ac.uk
Course Leader MSc Sustainable Building Conservation
Welsh School of Architecture

Prof Oriel Prizeman (Cardiff University)
Prof Pete Walker (University of Bath)
Iain McCaig & Soki Rhee-Duverne (Historic England)
Nigel Gervis (Ty Mawr Lime Ltd)

Tŷ-Mawr
sustainable building materials for healthier homes
deunyddiau adeiladu cynaliadwy ar gyfer cartrefi iachach

Historic England

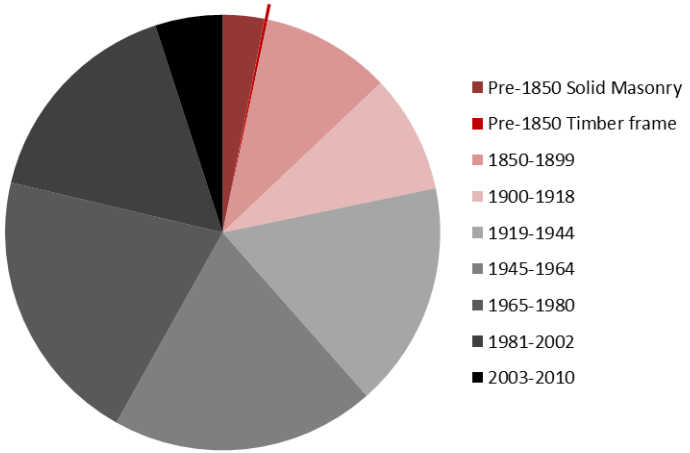
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

UNIVERSITY OF BATH

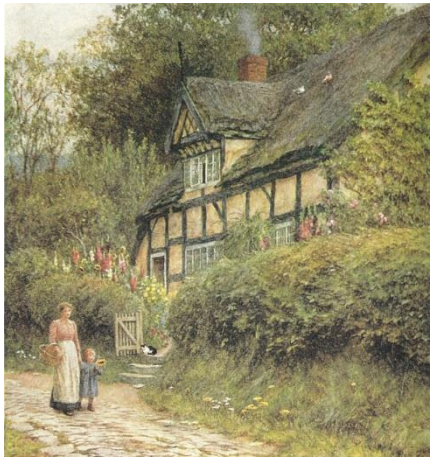
Retrofit of Historic Timber-Framed Buildings

To date, research into the retrofitting of historic and traditional buildings has focused on the retrofitting of solid walled masonry construction
(Scott & Rye, 2014; COTT & RYE, 2014; Mohammadpourkarbasi & Sharples, 2013; Gandhi et al., 2012) .

Historic timber-Frame Dwellings account 8% of the pre-1850 Housing Stock, with approximately 68,000 pre-1850 timber-framed buildings surviving in the UK
(NICOL et al., 2014; Whitman C.J. 2017).



English Housing Stock by Age *Source*: NICOL et al. 2014

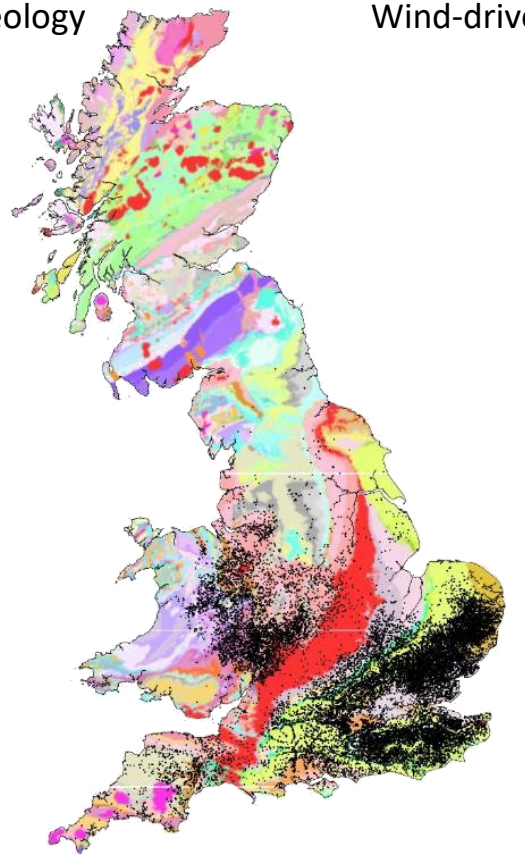


"Cottage Homes of England " *Source*: Allingham 1909

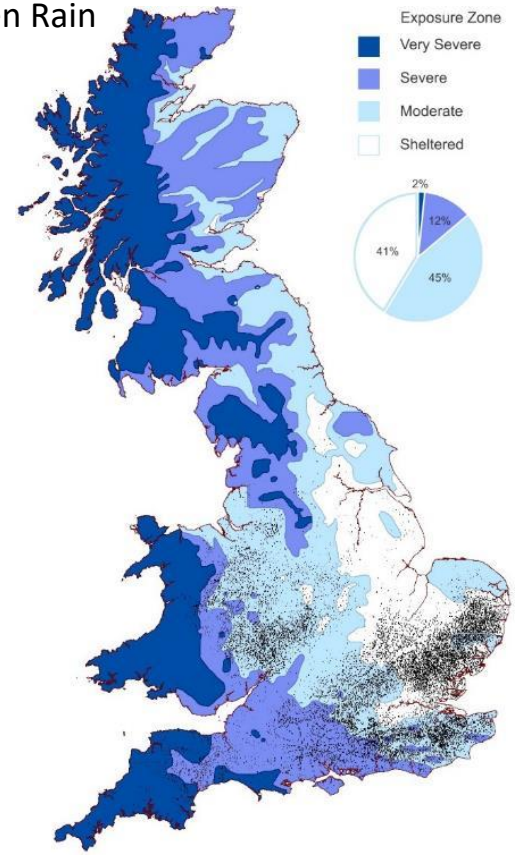
York, from "The Fairy Land of England" *Source*: Hussey 1924

The Distribution of Historic Timber-framed Buildings in The UK and influencing factors.

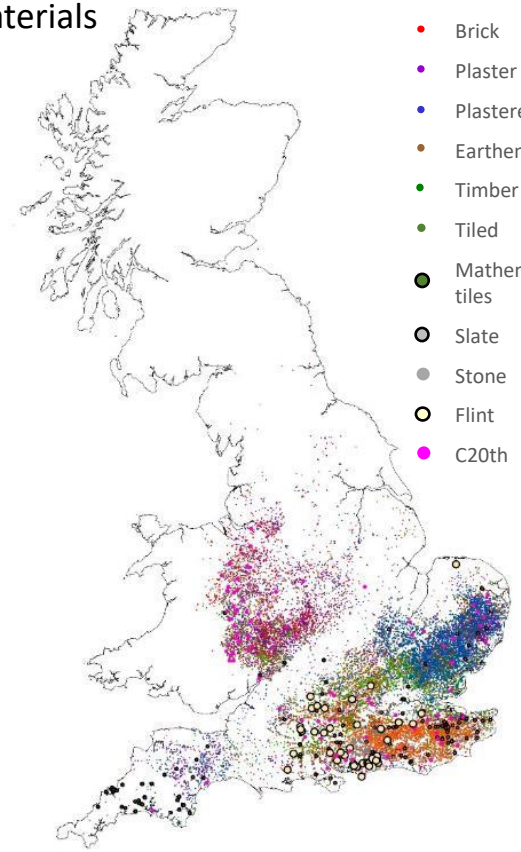
Geology



Wind-driven Rain



Infill Materials



Distribution of surviving pre-1850 timber-frame buildings.

Source: Author's own. Data from (Historic England 2014 & RCAHMW 2014, British Geological Survey, 2010 & HM Government, 2013)

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Infill Panels




Traditional Infill materials: Wattle and daub, lathe and plaster- pargetting and fired brick.

Where historic infill panels exist, all possible efforts should be made to retain and conserve these. However, where these are beyond repair or have already been replaced with unsuitable 20th century materials, replacement is an option.




Potential Retrofit Infill materials: Wood-fibre board, sheep's wool, expanded cork and hempcrete.

Potential risks of retrofitting: increased moisture content leading to insect infestation and fungal decay

Beetles and their larvae

Fungi

Powderpost
Lycus linearis Goeze & Lyctus brunneus

8-25%
26˚C

House Longhorn
Hylotrupesw bajulus

15-25%
20-30˚C

Woodworm
Anobium punctatum

>12%
22˚C

Deathwatch
Xestobium rufovillosum

>15%
>10˚C

Dry Rot
Serpula lacrymans

>25%
17-23˚C

Oak Rot
Coniophora puteana

>28%
5-40˚C

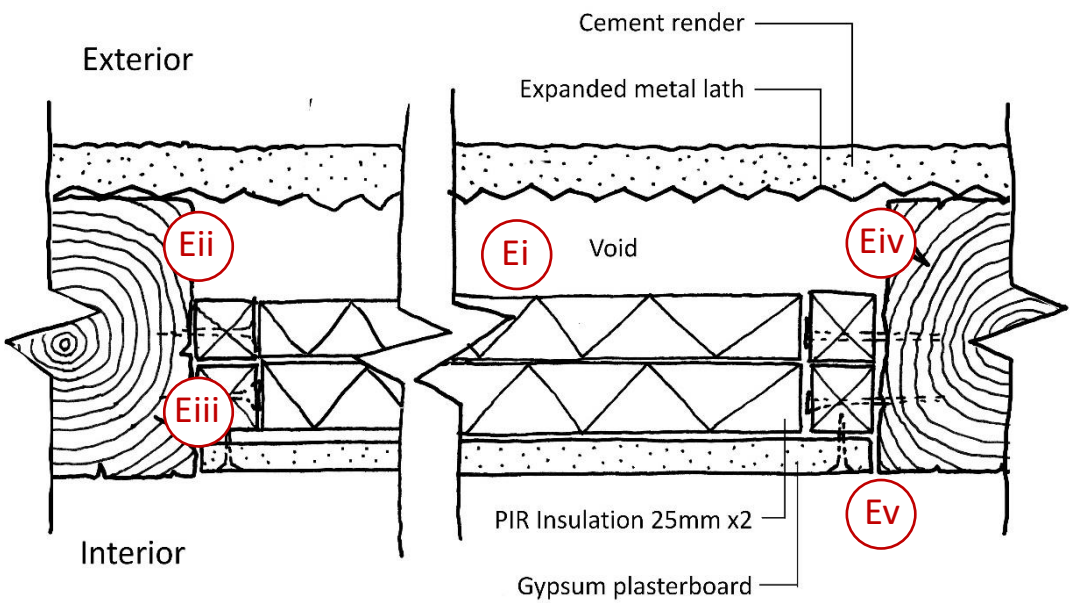
Cellar Rot
Coniophora puteana

>25%
20-32˚C

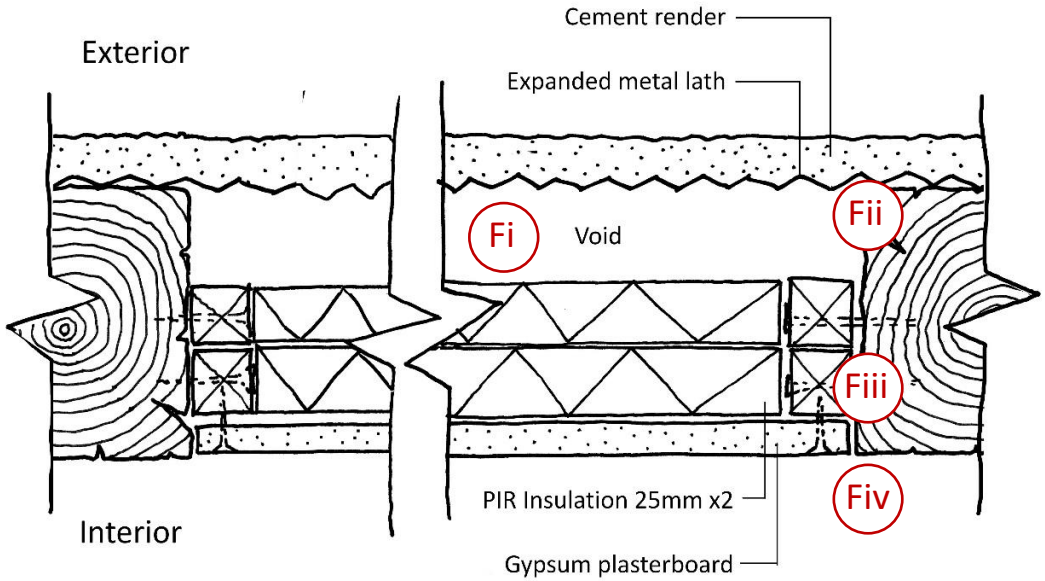
Source: (McCaig & Ridout, 2012)

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Drawing room
North Wall



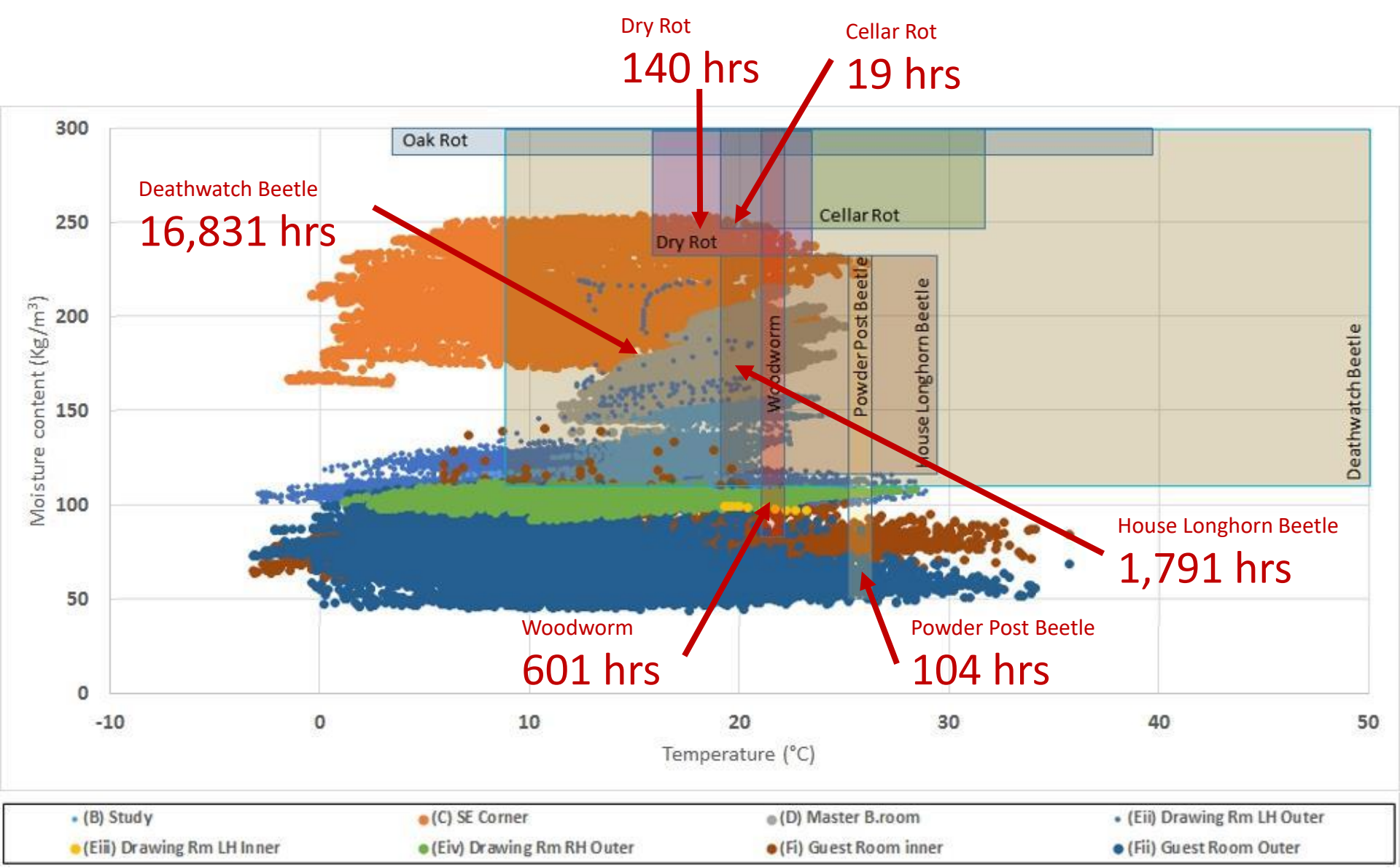
Guest bedroom
South Wall



In Situ Interstitial Hygrothermal Monitoring

Whitman, C., et al. The impact of modernization of a 16th century timber-framed farmhouse, Suffolk, UK. in EEHB2018, Visby, Sweden, September 26th to 27th, 2018. 2018. Uppsala University.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



Hygrothermal measurements overlaid with principal Biological Threats.

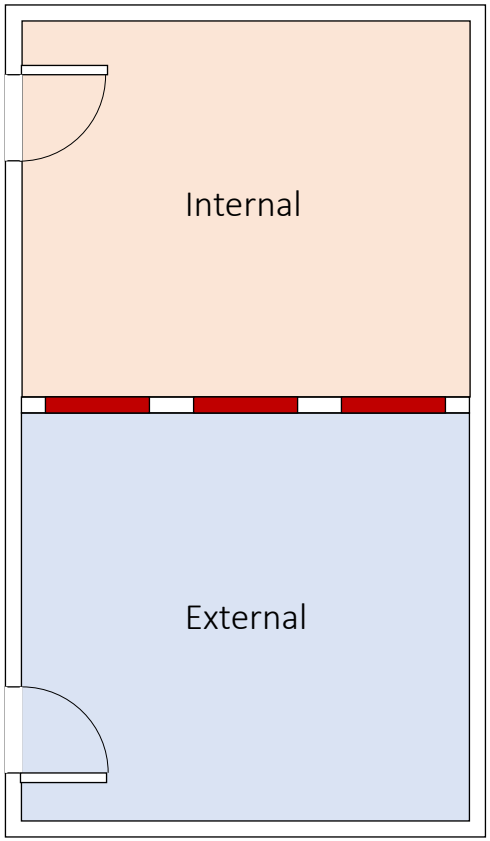
In Situ Interstitial Hygrothermal Monitoring (Aug 16- Aug 18)

Whitman, C., et al. The impact of modernization of a 16th century timber-framed farmhouse, Suffolk, UK. in EEHB2018, Visby, Sweden, September 26th to 27th, 2018. 2018. Uppsala University.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Physical Monitoring of Replacement Infill Panels:

Comparing hygrothermal simulations and dual climate chamber testing



Dual climate chamber testing: University of Bath, Building Research Park, Swindon

Project team:
Dr Chris Whitman
Prof Oriel Prizeman
Prof Pete Walker (Bath)
Dr Andy Shea (Bath)

UNIVERSITY OF BATH

Tŷ-Mawr
sustainable building materials for healthier homes
deunyddiau adeiladu cynaliadwy ar gyfer cartrefi iachach

RoystonDavies
Conservation Builders

Martin Weaver Scholarship 2015

APT INTERNATIONAL
The Association for Preservation Technology International
Association Internationale pour la preservation et ses techniques

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Interstitial hygrothermal monitoring

Monitoring positions for moisture content and temperature

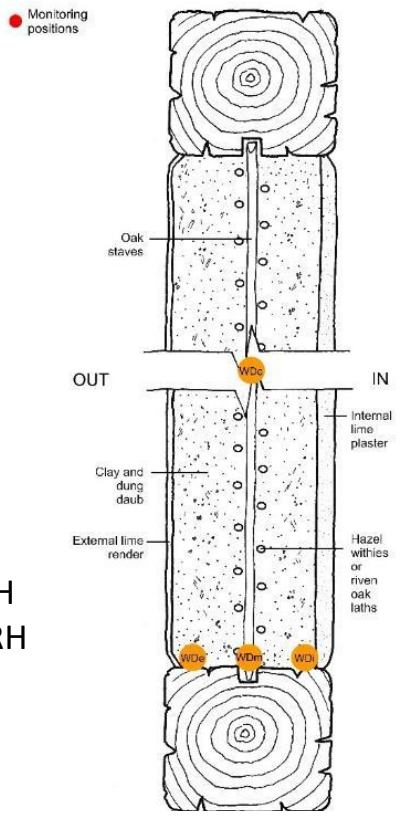
Electrical resistance readings for moisture content (%)

Thermistors type-T for temperature (°C)

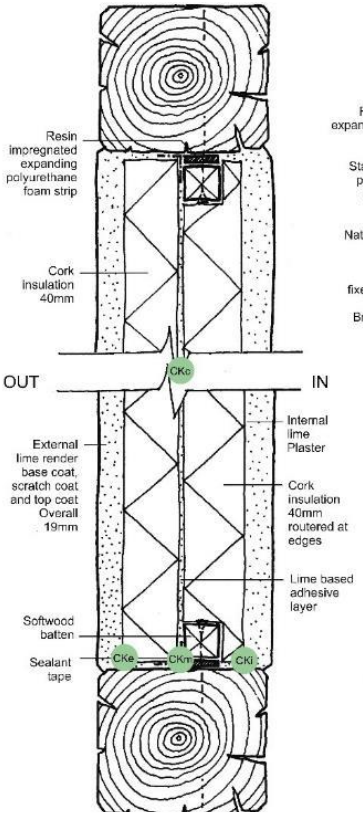
3 weeks at steady state conditions

External conditions: 5°C and 80% RH
Internal conditions: 21°C and 70% RH

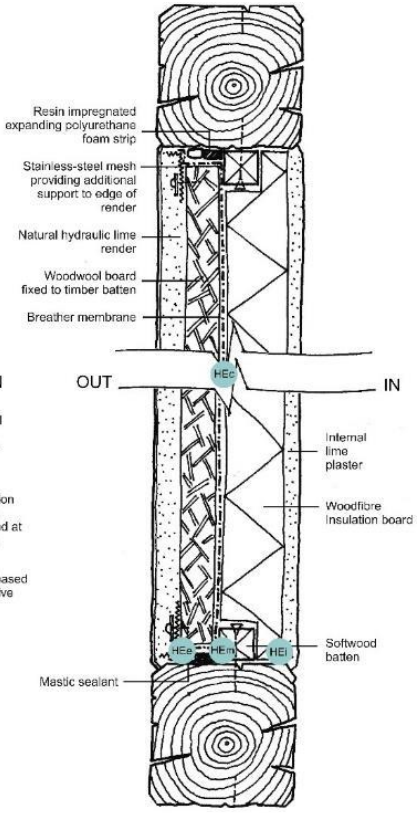
2 weeks cyclical conditions



Wattle-and-daub



Cork



Wood fibre and wood wool

Martin Weaver Scholarship 2015

The Association for Preservation Technology International
Association Internationale pour la preservation et ses techniques

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Moisture content – Monitoring v Simulation

Whitman, C.J., et al., Energy retrofit infill panels for historic timber-framed buildings in the UK: physical test panel monitoring versus hygrothermal simulation. Architectural Science Review, 2020: p. 1-12.

Panel Infill Type		Glaser calculation	WUFI® Pro5.3	WUFI® 2D 3.3	Physical monitoring	Agreement
Wattle-and-Daub	Exterior	→	↓	↓	↑	✗
	Centre	→	↗	↗	→	✓
	Interior	↑	↑	↑	↗	✓
Cork	Exterior	→	↗	↓	↑	✗
	Centre	→	→	→	→	✓
	Interior	→	↘	↑	→	✗
Wood wool and woodfibre	Exterior	→	↗	↓	↑	✗
	Centre	↑	↑	↑	↑	✓
	Interior	→	↓	↑	↓	✗

Comparison of results from simulation and monitoring: Steady →, Decrease ↓, Increase ↑

Hygrothermal Monitoring of Timber-Frame Replacement Infill Panels

Test cell at Cardiff University, Cathays Campus.

Dr Chris Whitman WhitmanCJ@Cardiff.ac.uk

Prof Oriel Prizeman (Cardiff University)
Prof Pete Walker (University of Bath)
Iain McCaig (HE) & Soki Rhee-Duverne (HE)
Nigel Gervis (Ty Mawr Lime Ltd)

UK HEMPCRETE

RoystonDavies Conservation Builders

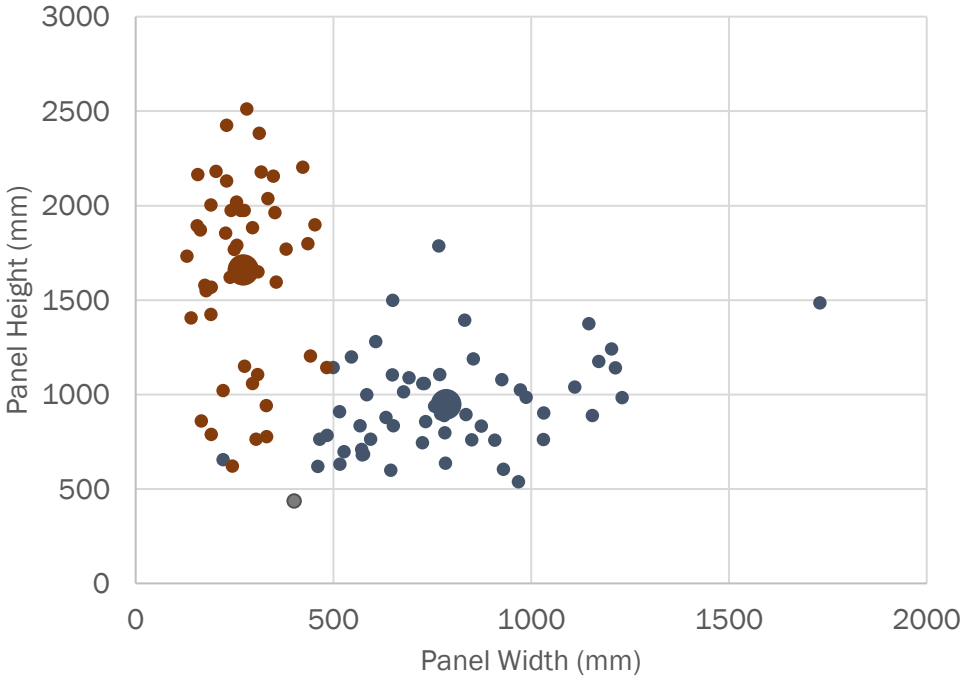
Tŷ-Mawr
sustainable building materials for healthier homes
deunyddiau adeiladu cynaliadwy ar gyfer cartrefi iachach

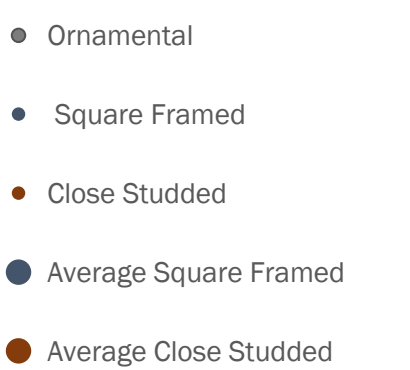
Historic England

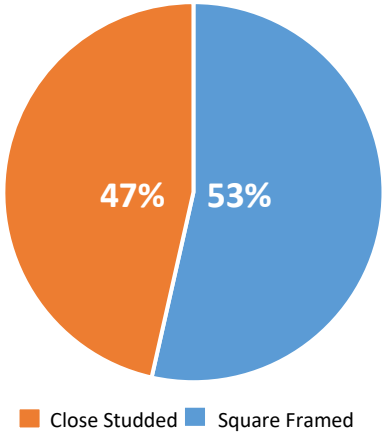
University of Bath

Cardiff University
Prifysgol Caerdydd

Definition of typical panel sizes





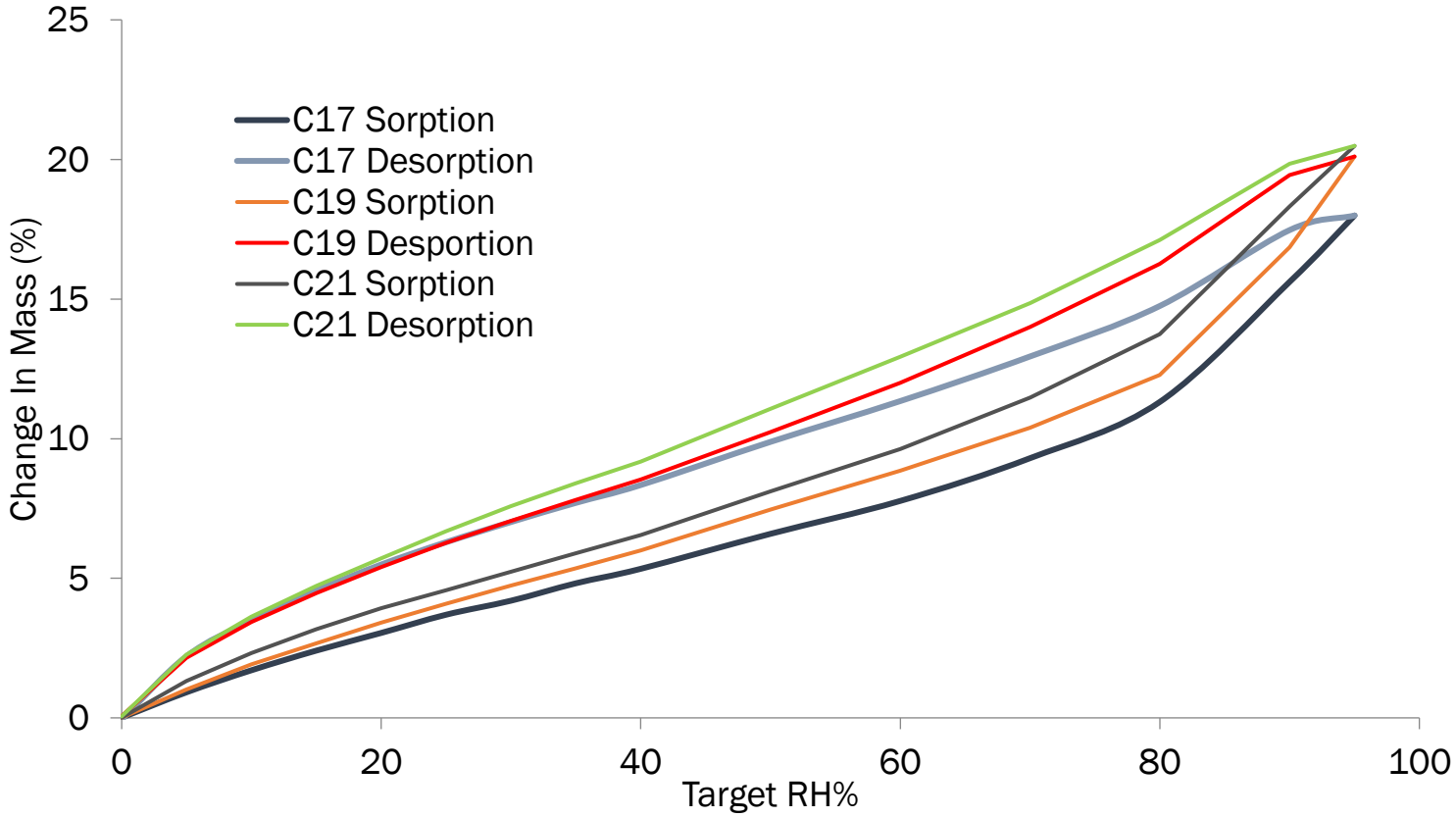


Average Close Studded= 950mm x 785mm (approx. 3'1½" x 5 ½')

Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

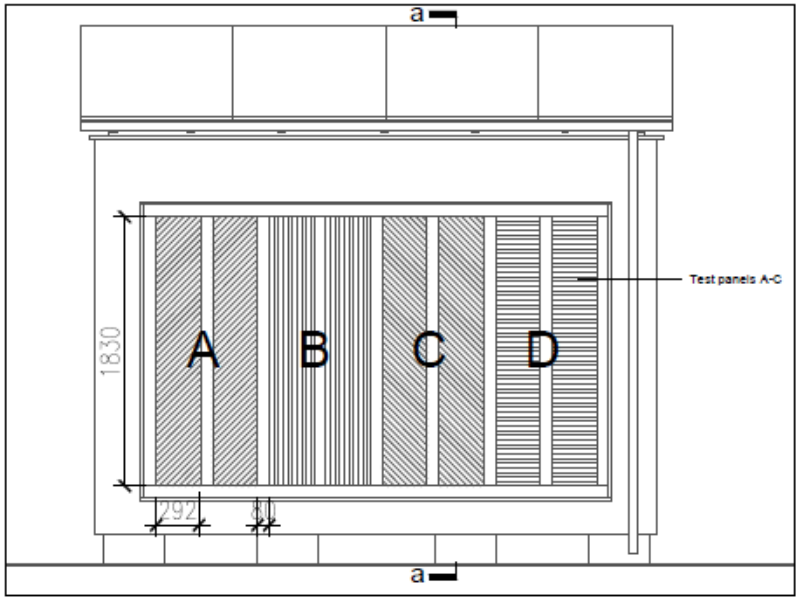
Evaluation of sorption properties of oak by age



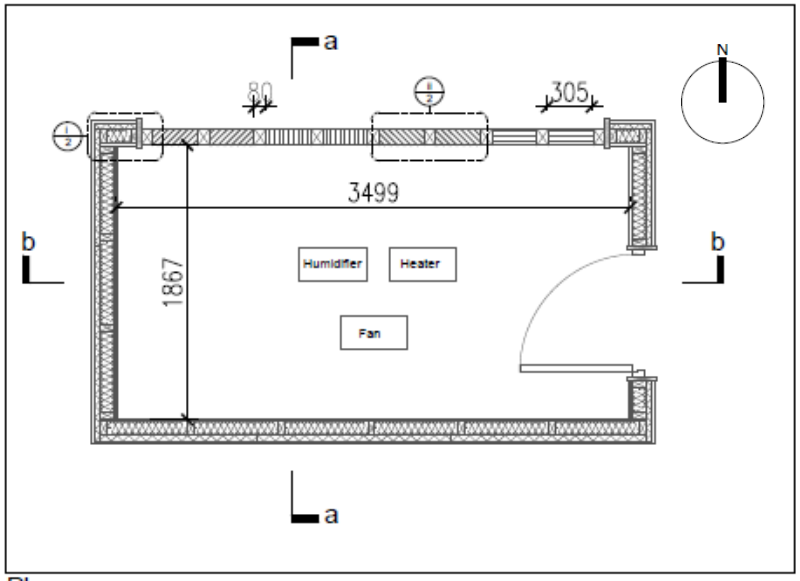
Dynamic Vapour Sorption (DVS) testing of three ages of timber

Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



North Elevation



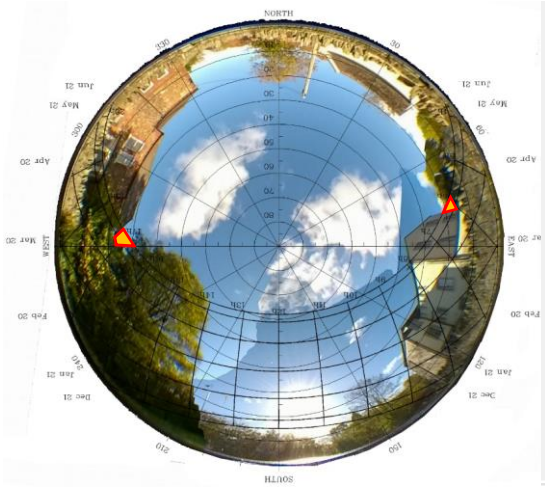
Plan

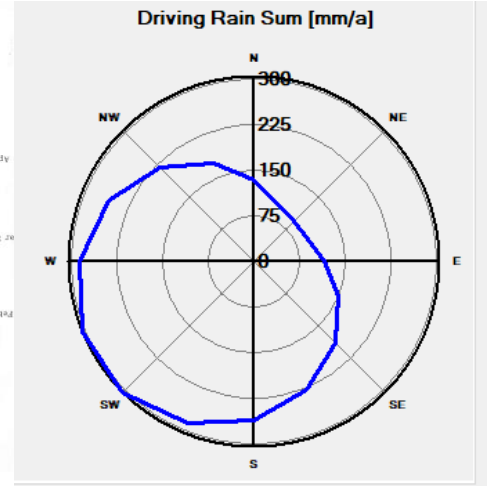
Test infill panels mounted in north façade

A – Wattle & Daub
B – Expanded Cork Board
C – Wood Fibre/ Wood Wool composite
D – Hempcrete

Each pair of panels finished one with lime-hemp plaster, the other with NHL 3.5

North façade chosen with aim to minimise climatic variables

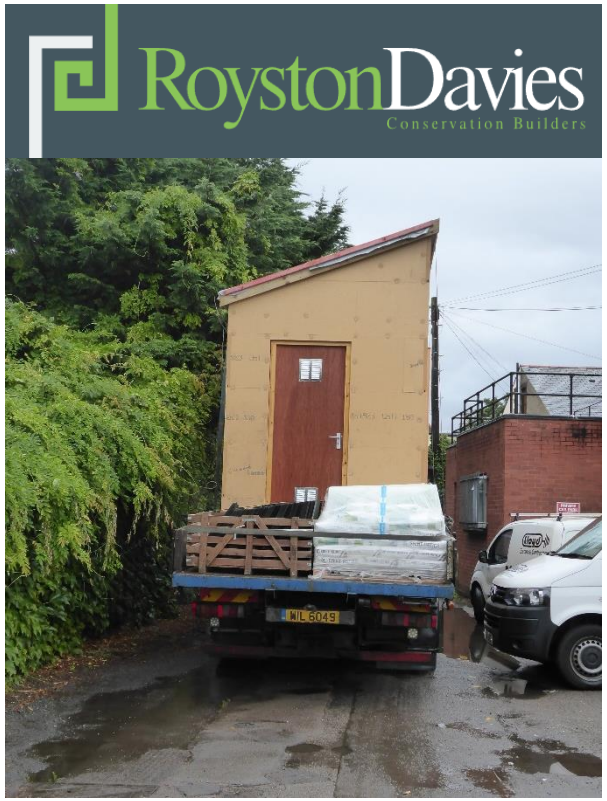




On-site weather station to measure micro climate

Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



Test cell constructed by Royston Davies Conservation Builders in Leominster, with materials from Ty Mawr Lime Ltd.

Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Test panels completed onsite by Royston Davies and UK Hempcrete.

Interstitial Moisture content-
Electrical resistance measured by Campbell Scientific CR1000

Interstitial Temperature-
Type T thermocouples

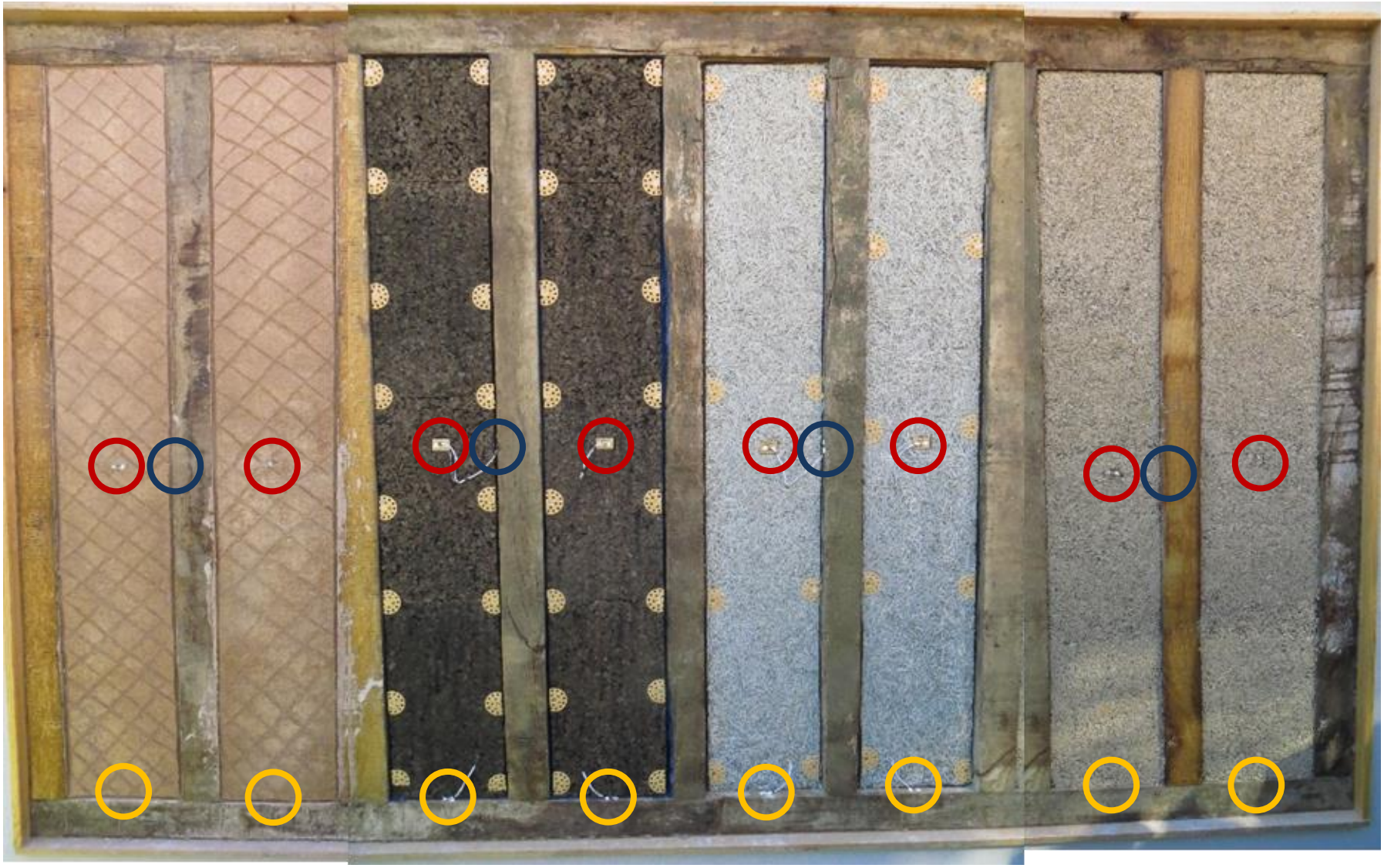
In situ u-value
Hukseflux heat flux plates and type T thermocouples

Internal Hygrothermal Conditions of test cell
Campbell CS215 probe

External Climatic Conditions
Vaisala Weather Transmitter WXT520 Series and Kipp & Zonen CM5 pyrometer

Historic England

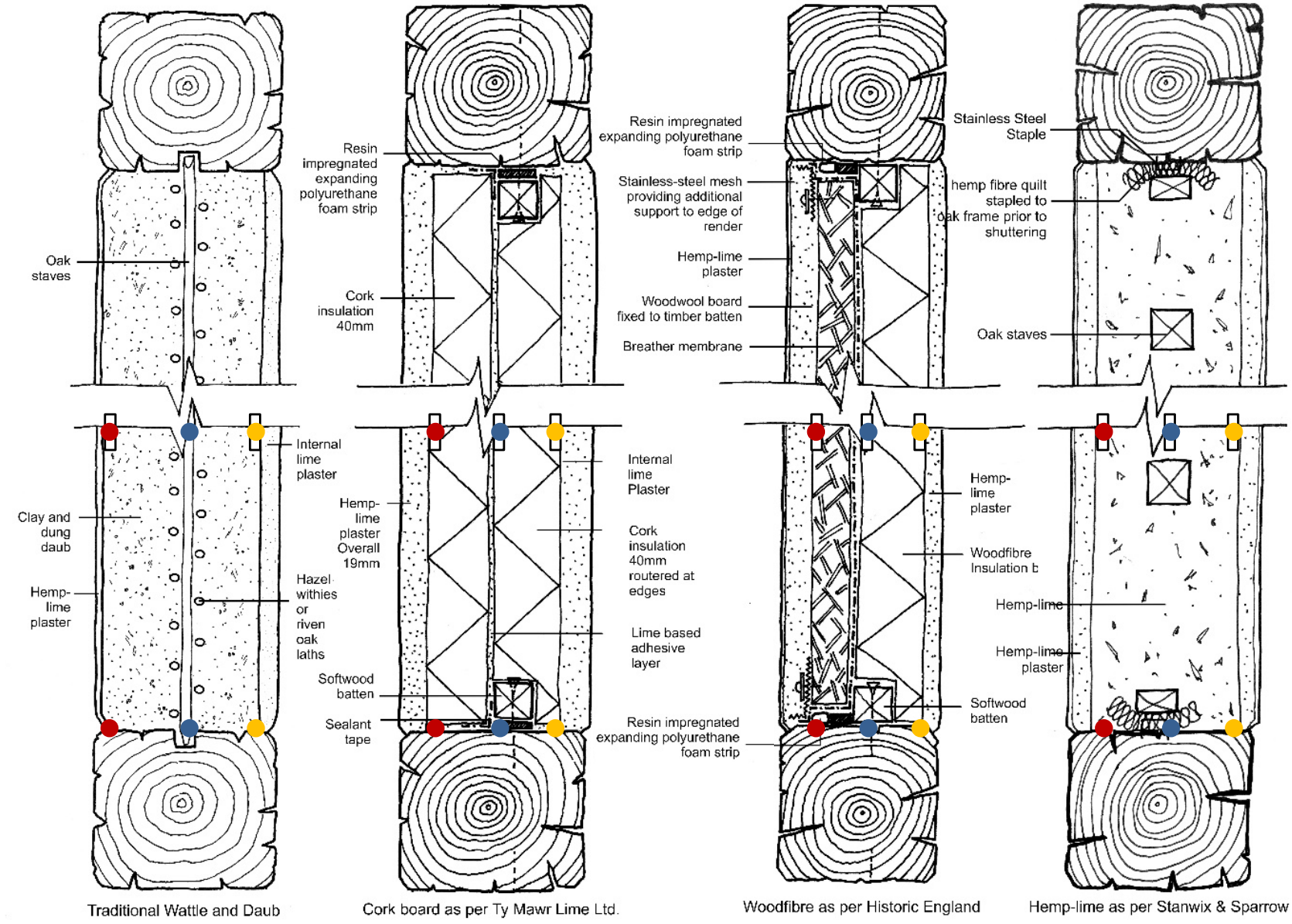
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



Test panels prior to application of external render with monitoring locations highlighted.
Red- Mid Panel, Blue- Vertical Panel to Frame Junction, and Yellow- Horizontal Panel to Frame Junction

Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



Sections showing panel infill details and monitoring locations. Red- external (e), Blue- central (c), and yellow- Internal (i)

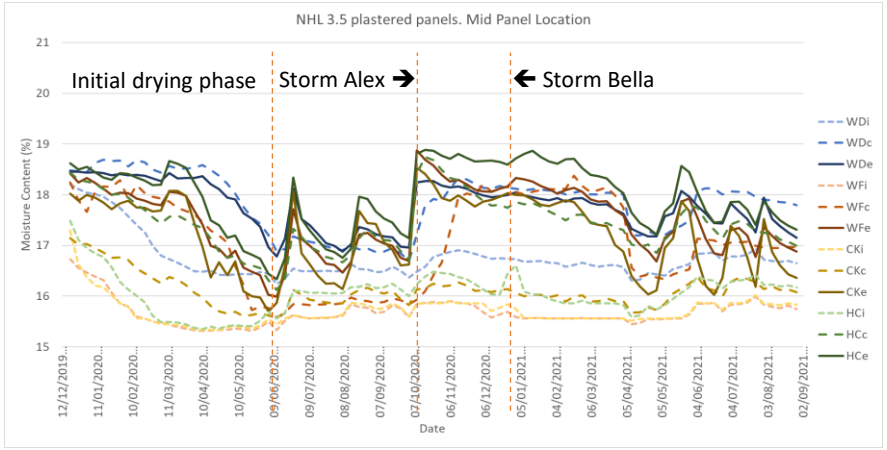
Historic England

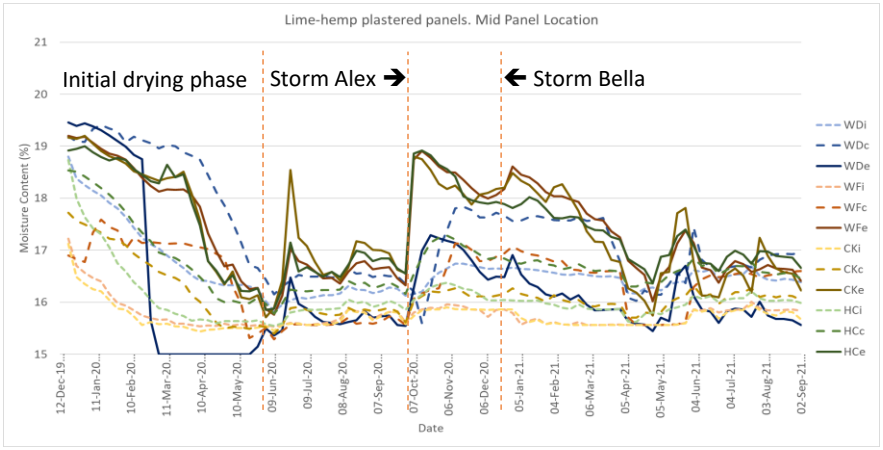
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Panels finished with NHL 3.5

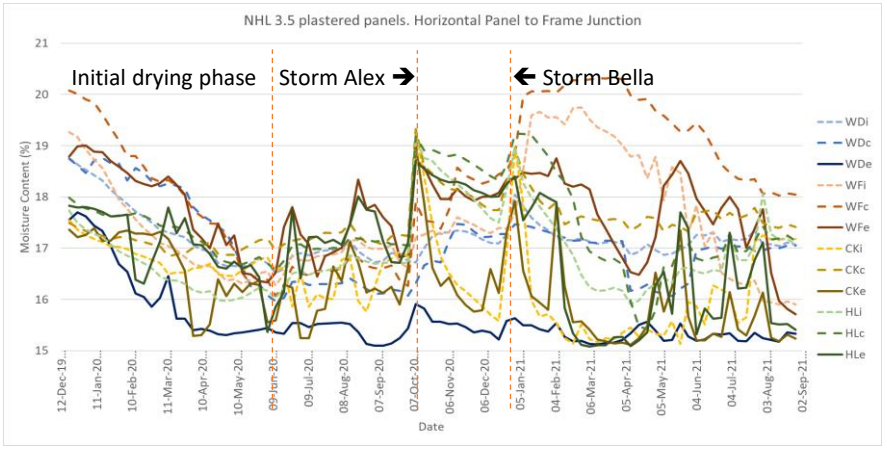
Panels finished with Lime-Hemp

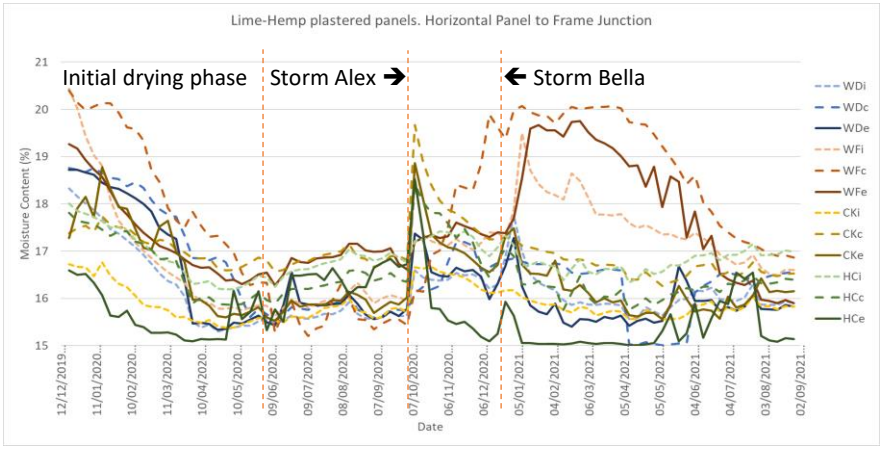
Mid point of panel



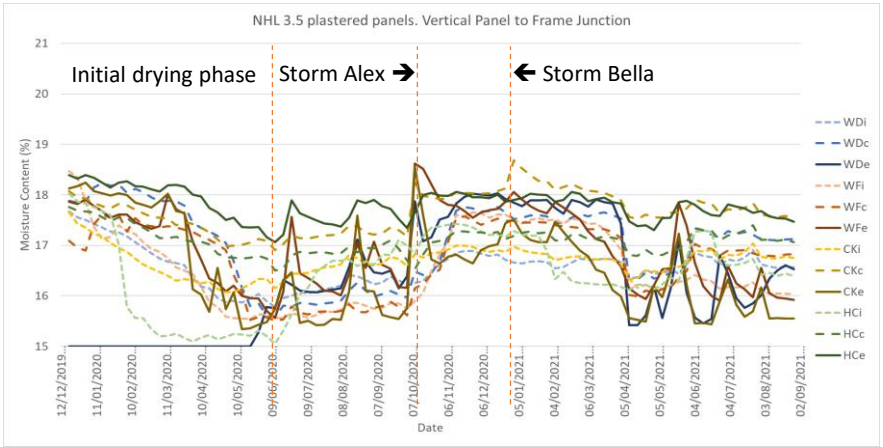


Horizontal Junction





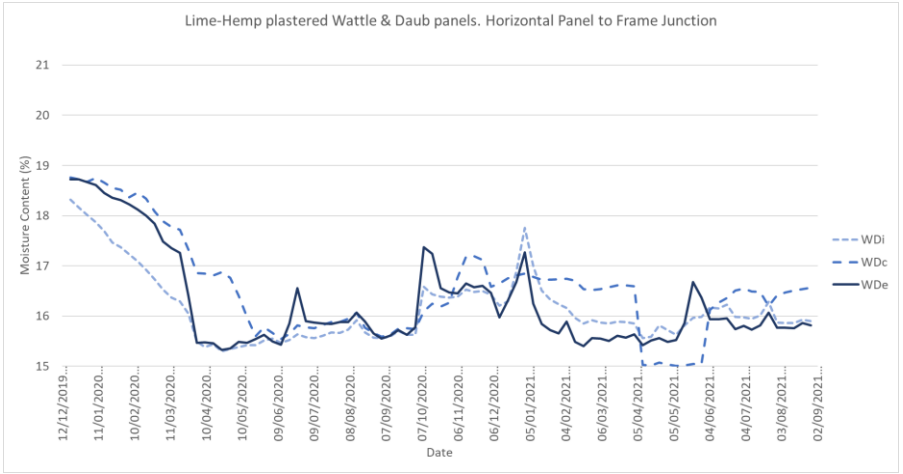
Vertical Junction



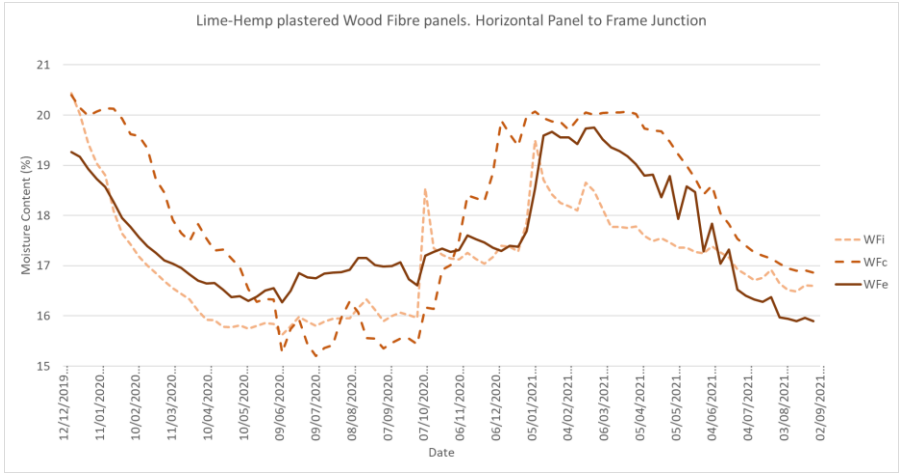
Latest results: Moisture content

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

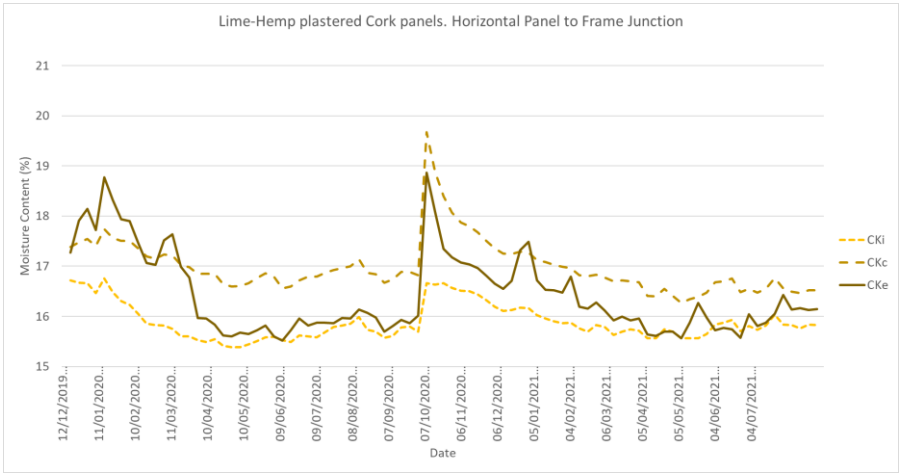
Wattle & Daub



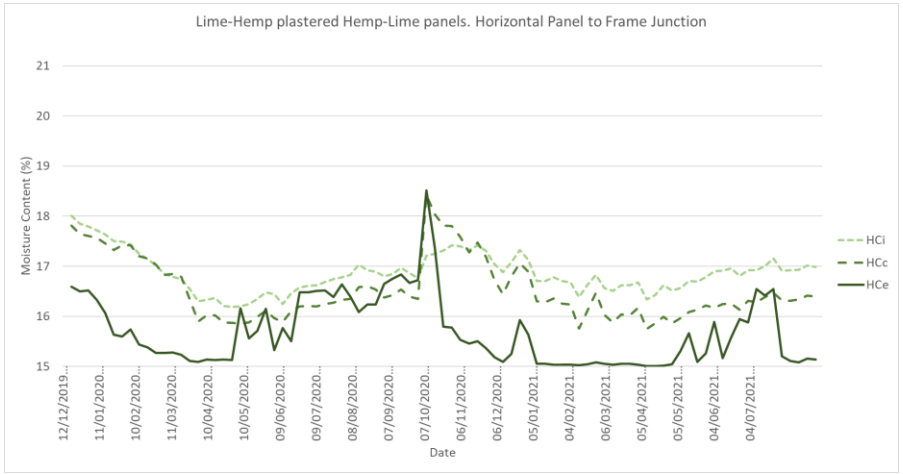
Woodwool - Woodfibre



Cork

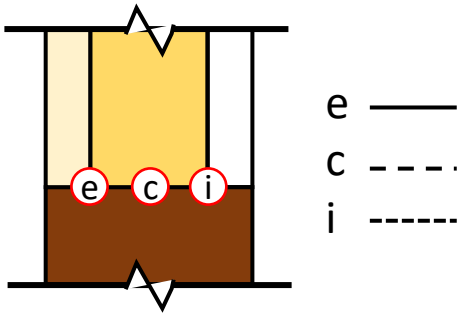


Hempcrete



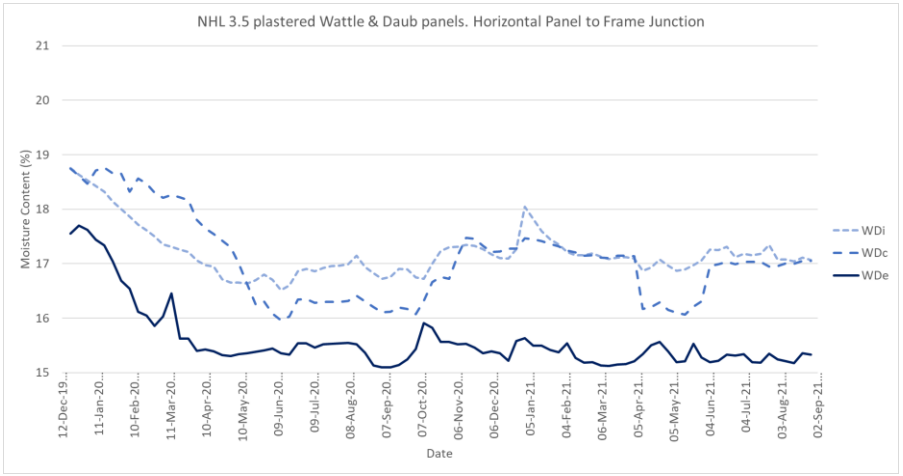
Latest results:

Moisture content Lime-hemp rendered panels.
Horizontal Panel to Frame Junction

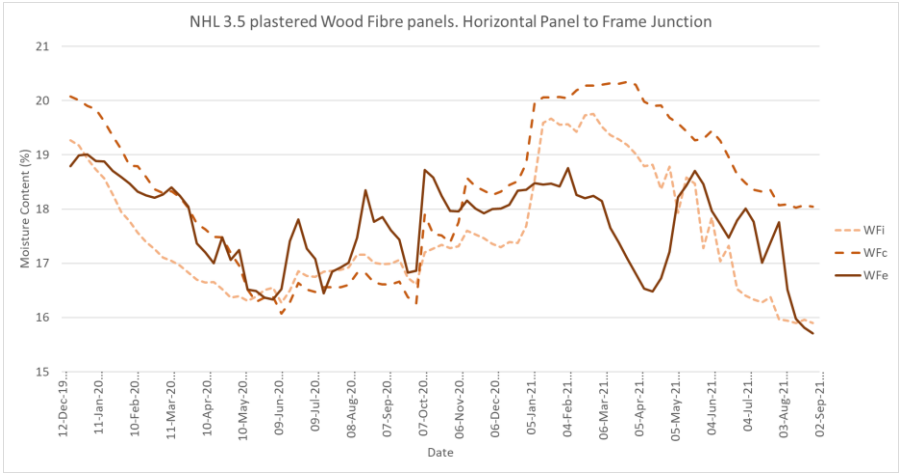


CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

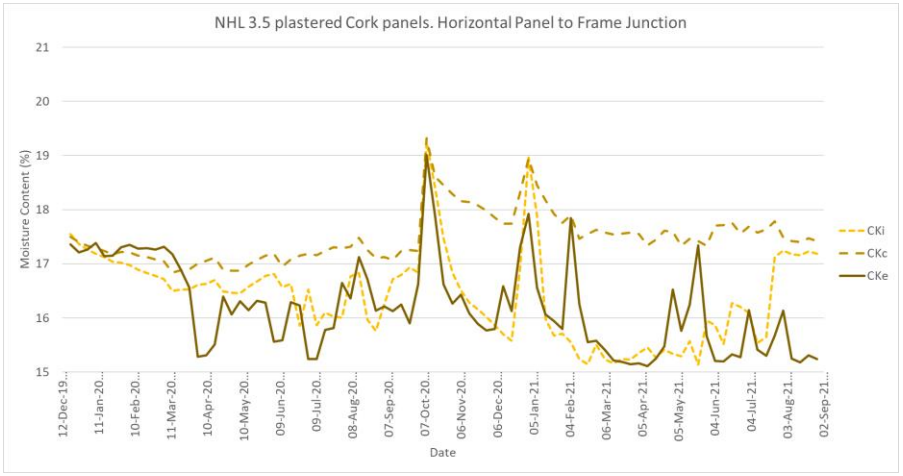
Wattle & Daub



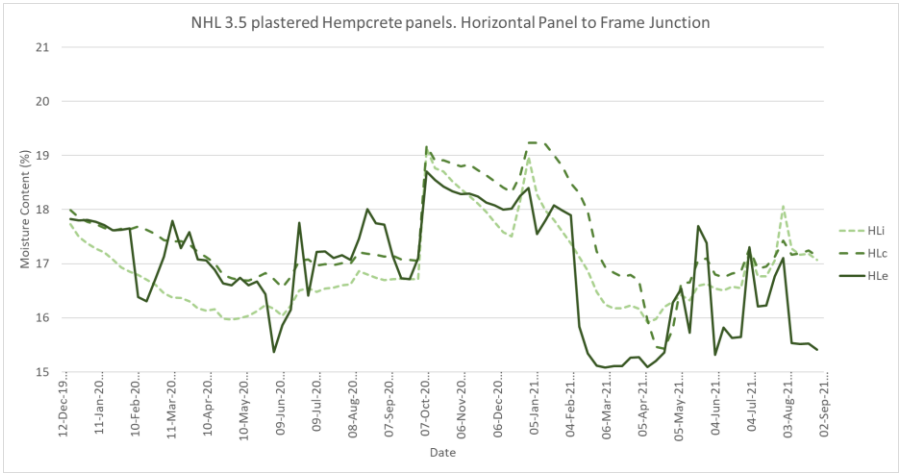
Woodwool - Woodfibre



Cork

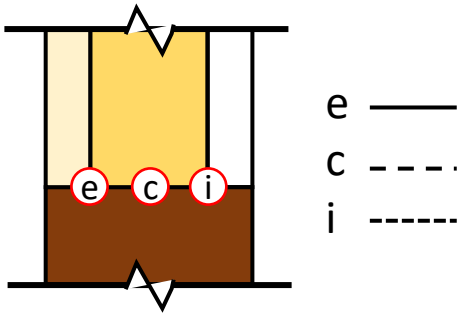


Hempcrete



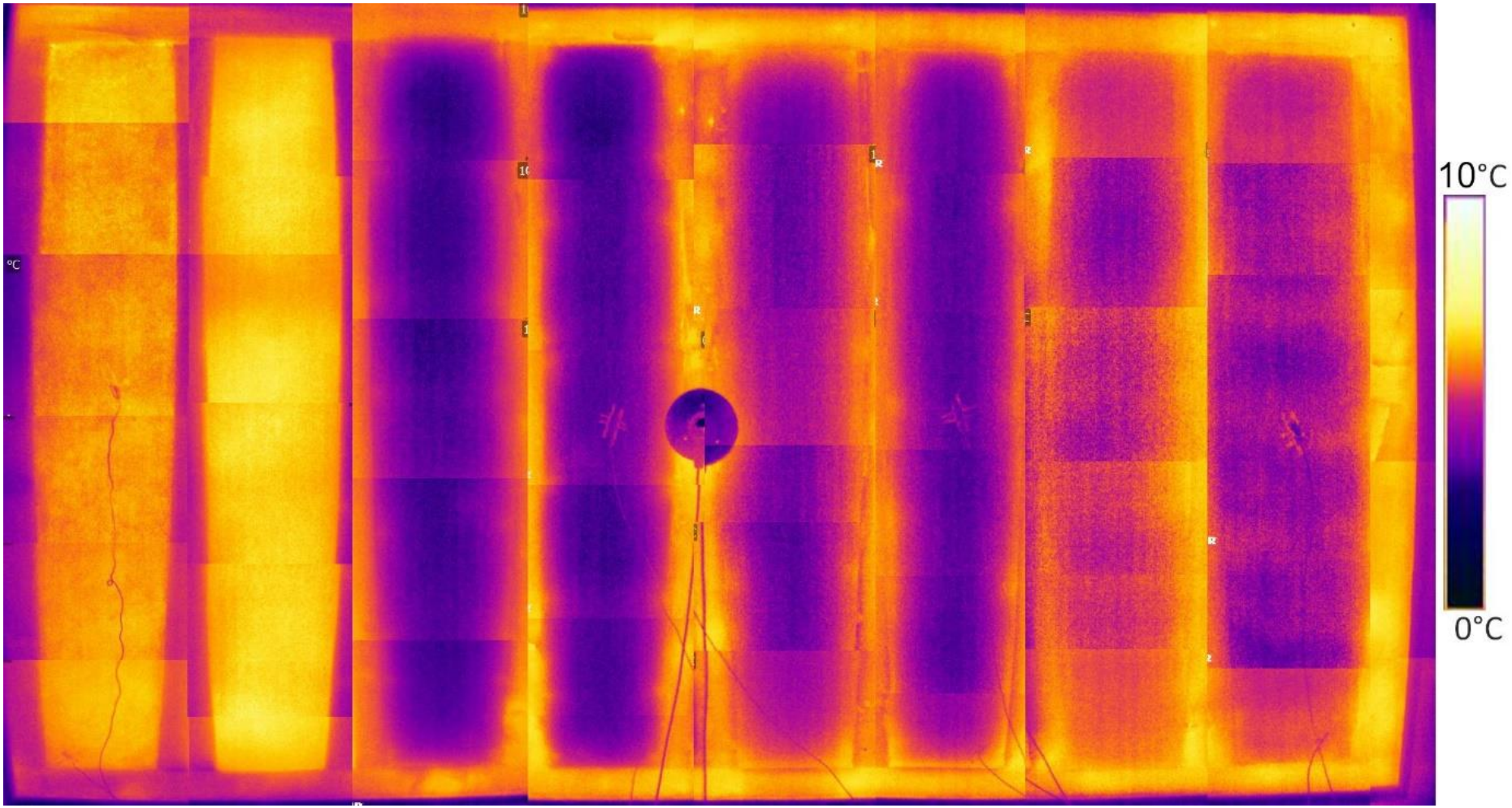
Latest results:

Moisture content NHL 3.5 rendered panels.
Horizontal Panel to Frame Junction



CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

External thermography 07:00, 19/02/20.
Internal temp. 20.6°C.
External temp. 3.7°C



Wattle & Daub Cork Wood Fibre Hempcrete

Thermal Performance- Thermography of external surface of test panels

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Results of in situ u-value monitoring showing thermal transmittance of test panels for the periods January-March 2020 and November 2020 -January 2021. Best thermal performance highlighted in green, worst in red.

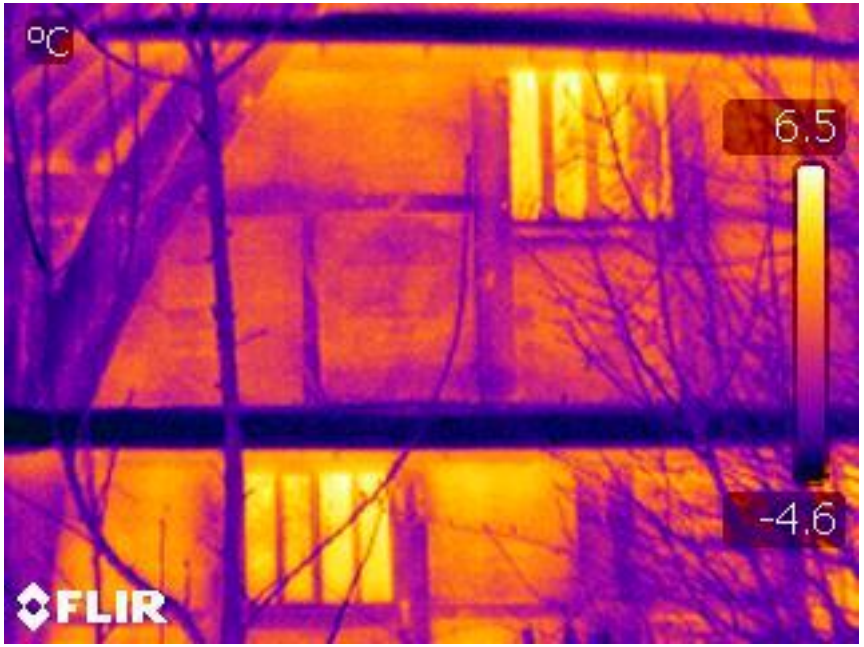
Infill Material	Internal and External finish	Position	No.	Measured Jan/March 2020 (W/m²K)	Measured Nov 2020/ Jan 2021 (W/m²K)	Change	Calculated (W/m²K)	Av. Moisture content Jan/March 2020 (%)	Av. Moisture content Nov 2020/ Jan 2021 (%)	Change
Wattle & Daub	NHL 3.5	Midpoint	1	2.92	2.95	**0.03**	2.65	18.2	17.6	**-0.6**
		Corner	2	2.18	2.08	**-0.10**		17.7	16.7	**-0.9**
	Lime-hemp	Midpoint	3	2.21	2.39	**0.18**	1.92	18.6	16.9	**-1.8**
		Corner	4	2.40	2.38	**-0.02**		18.0	16.3	**-1.7**
Cork	NHL 3.5	Midpoint	5	0.54	0.50	**-0.04**	0.45	16.8	16.6	**-0.2**
		Corner	6	0.68	0.79	**0.11**		17.2	17.1	**-0.1**
	Lime-hemp	Midpoint	7	0.46	0.47	**0.01**	0.43	17.2	16.6	**-0.6**
		Corner	8	0.53	0.53	**0.00**		17.2	16.5	**-0.7**
Wood Fibre	NHL 3.5	Midpoint	9	0.71	0.63	**-0.08**	0.58	17.3	17.3	**0.0**
		Corner	10	0.71	0.79	**0.08**		18.4	18.3	**-0.2**
	Lime-hemp	Midpoint	11	0.66	0.66	**0.00**	0.53	17.3	17.0	**-0.4**
		Corner	12	0.77	0.83	**0.06**		18.4	19.3	**1.0**
Hempcrete	NHL 3.5	Midpoint	13	1.56	0.94	**-0.62**	0.67	17.5	17.6	**0.1**
		Corner	14	1.54	1.30	**-0.24**		17.3	18.3	**1.0**
	Lime-hemp	Midpoint	15	1.22	1.00	**-0.22**	0.58	17.7	16.9	**-0.8**
		Corner	16	1.34	1.20	**-0.14**		16.8	16.1	**-0.7**

Thermal Performance In situ U-Value measurements

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Initial Conclusions

- As yet no evidence of interstitial condensation has been found, with wetting cycles correlating with climatic measurements of wind-driven rain.
- Infill materials with low moisture permeability are seen to produce higher moisture contents at the interface with the external.
- Those panels finished in the more moisture permeable lime hemp plaster, overall present lower moisture contents, with reduced drying times.
- The use of perimeter, non-moisture permeable, sealants would appear to potentially trap moisture. This requires further investigation.
- Monitoring is ongoing.
- Comparison with simulations using WUFI®Pro and WUFI 2D are in progress. Initial results generally corroborated the measured results. However, interstitial condensation in the wood fibre infill was predicted, and in all cases predicted drying times were considerably shorter than those measured.



Thank you!

Dr Chris Whitman

Course Leader MSc Sustainable Building Conservation

Welsh School of Architecture

WhitmanCJ@Cardiff.ac.uk

Signatory and Coordinator of Heritage Declares

HERITAGE DECLARES
Climate & Ecological Emergency

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD