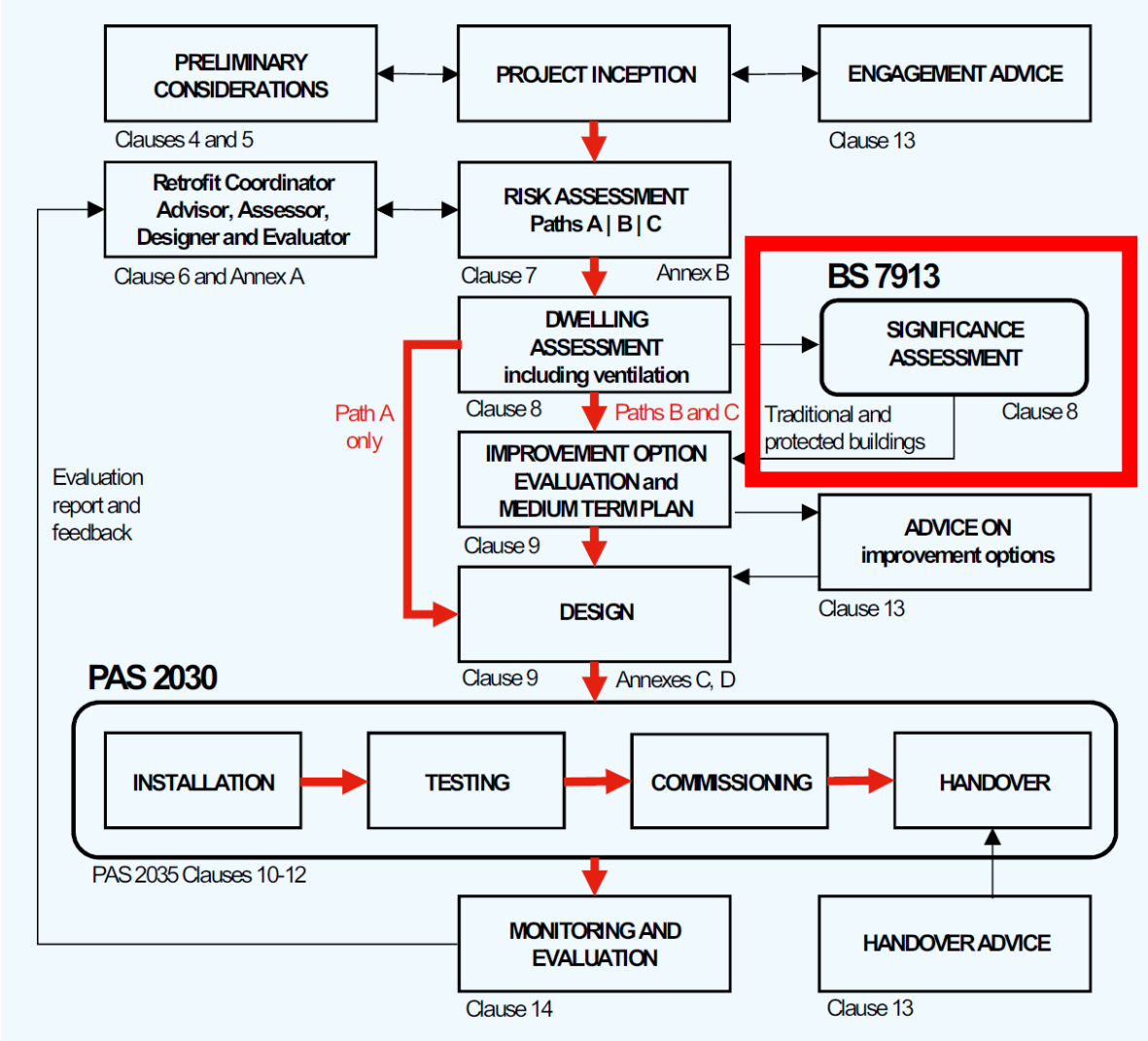
BUILDING LIMES FORUM
CONFERENCE & ANNUAL GATHERING 2025

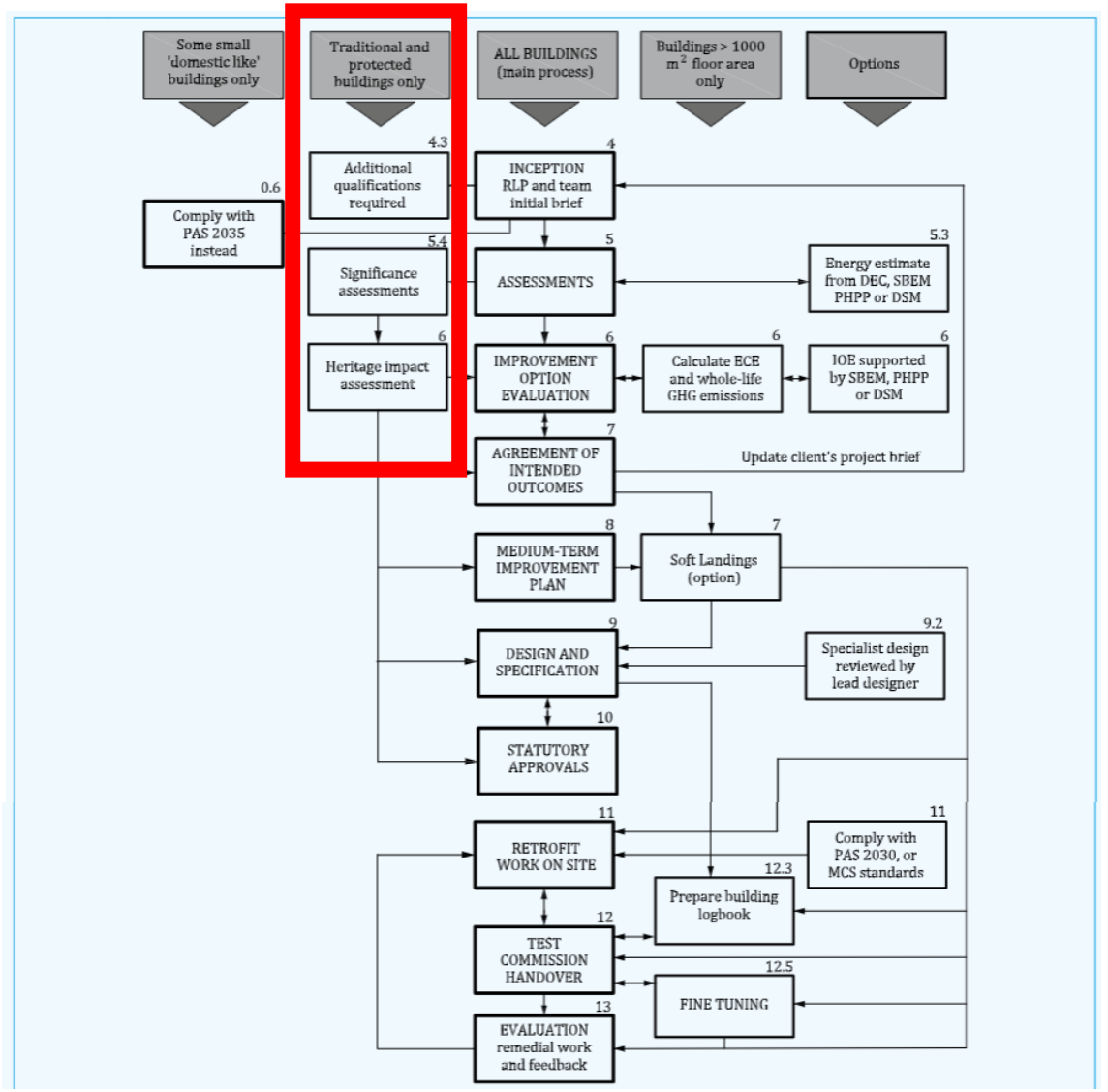
Lime in Retrofit:
Monitoring Performance

Dr Chris Whitman

Welsh School of Architecture, Cardiff University,
WhitmanCJ@Cardiff.ac.uk



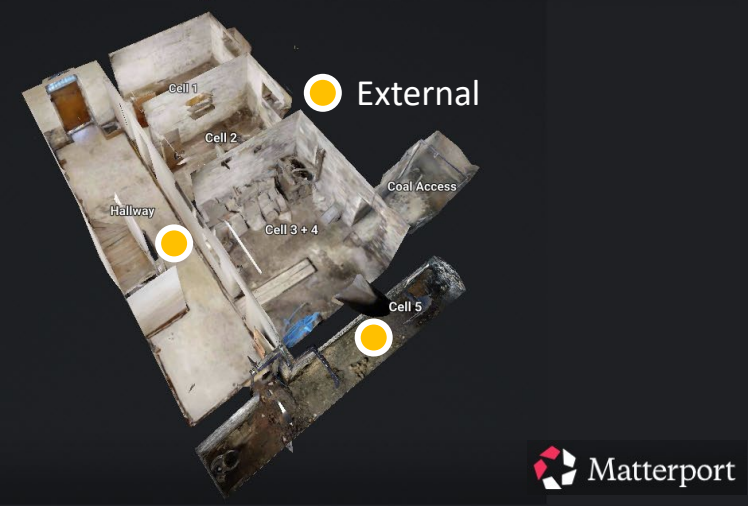
Workflow diagram for retrofit of domestic properties PAS 2030 & PAS 2035. (BSI 2020)



Workflow diagram for retrofit of non-domestic properties PAS 2038. (BSI 2021)

PAS 2030, PAS 2025 & PAS 2038 highlight that traditional buildings require special considerations when considering energy retrofits, as unintended consequences may arise. Understanding changes to moisture movement through the building fabric is especially critical. (BSI, 2020; BSI, 2021)

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



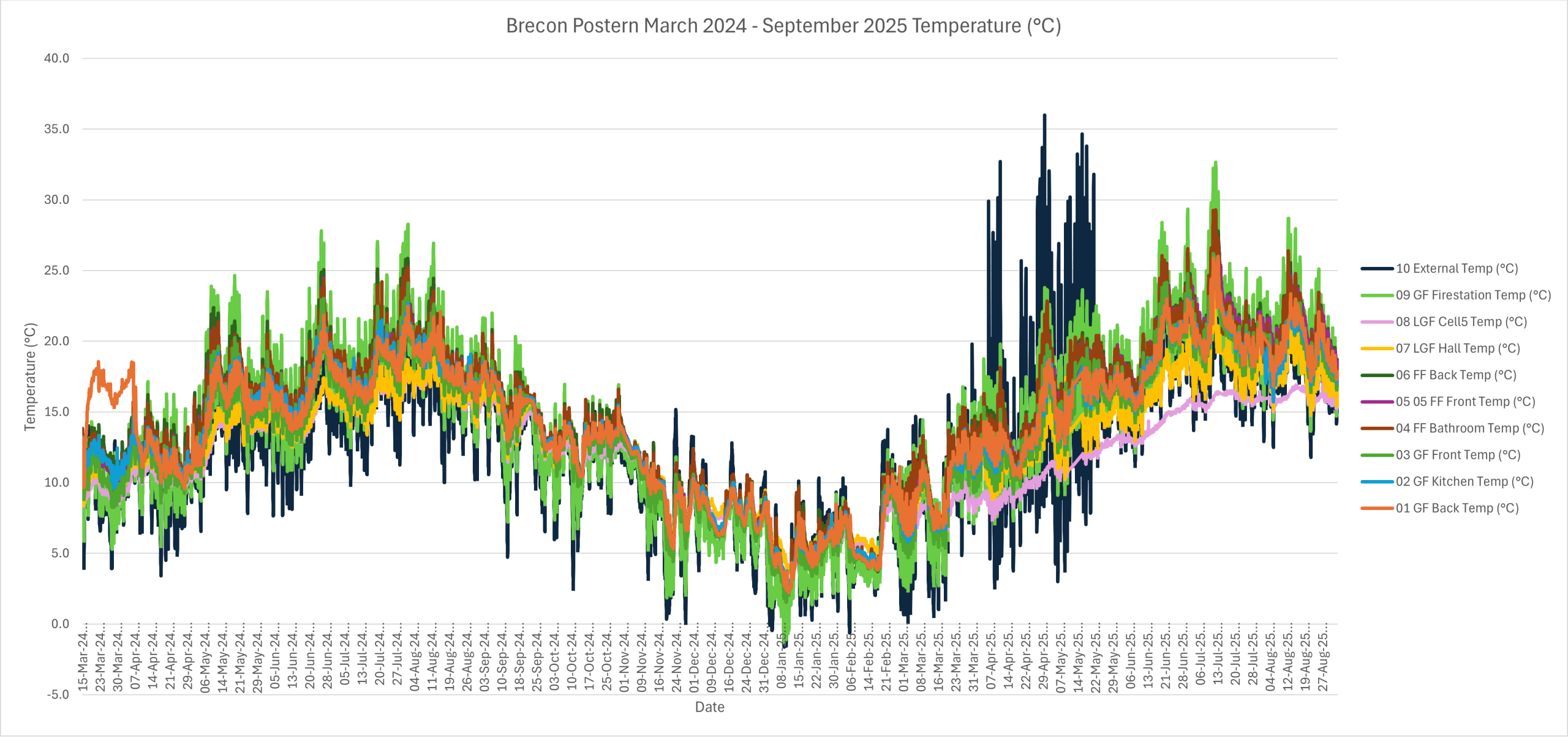
Brecon Postern Monitoring – Internal Hygrothermal Conditions

Temperature (°C) and Relative Humidity (RH%)
9 Internal Monitoring Positions + 1 external

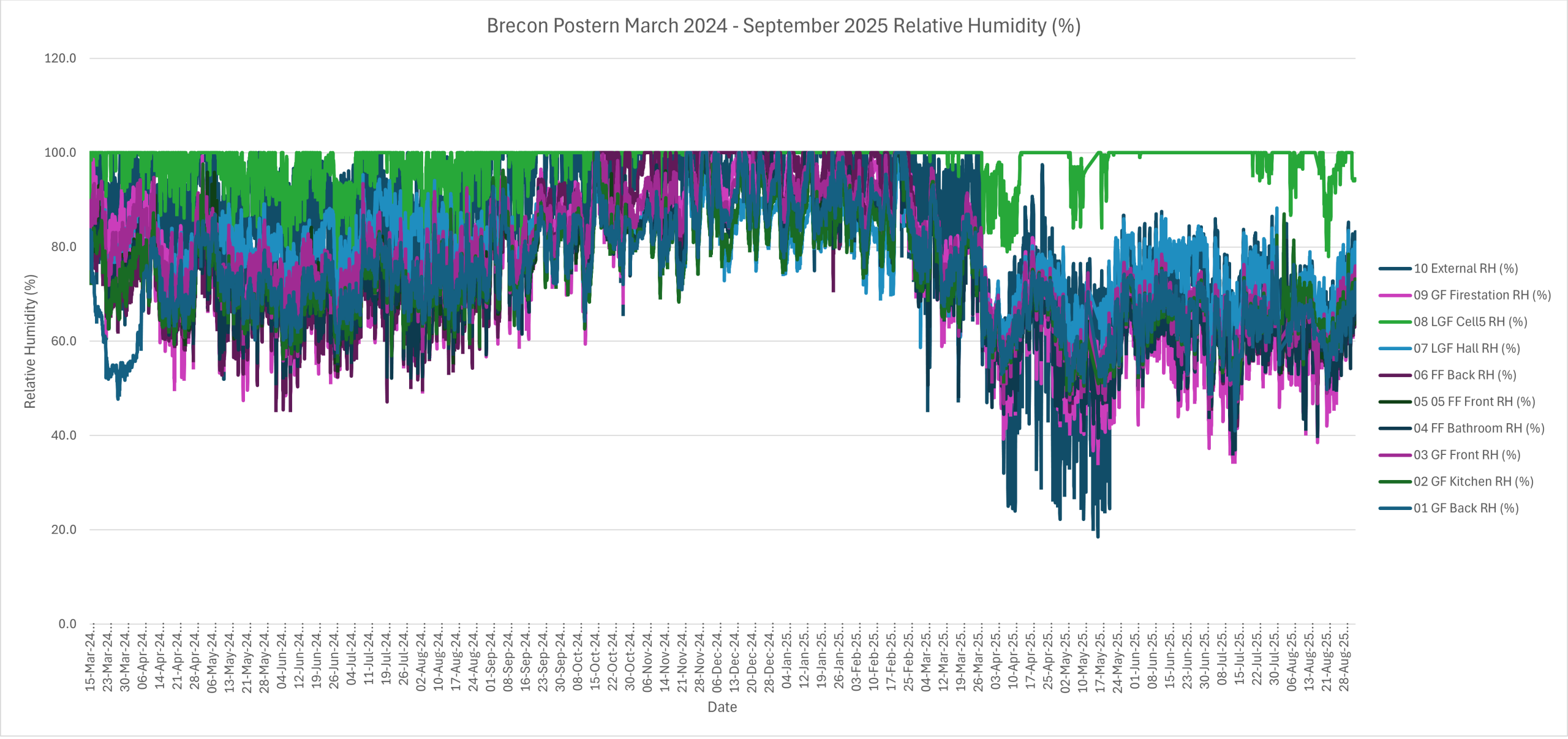
15/03/2024 – 28/03/2025
TinyTag Ultra 2
-25°C to +85°C (±0.6°C)
0% to 95% RH (±3%)
Manual download
Issues at 100% RH

28/03/2025 – to date
Milesight LoRaWAN EM300-TH
-30°C to +70°C (±0.3°C)
0% to 100% RH (±3%)
Remote Access
Required LoRaWAN Hub

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



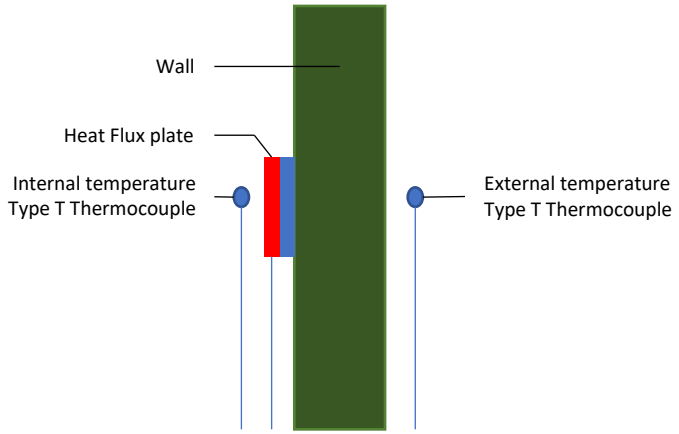
Brecon Postern Monitoring – Results - Temperature



Brecon Postern Monitoring – Results – Relative Humidity

Brecon Postern Monitoring – In-Situ U-Value Measurements

Measured in 4 locations (only 3 successful)



Methodology for in-situ u-value monitoring *Source*: BS ISO 9869-1

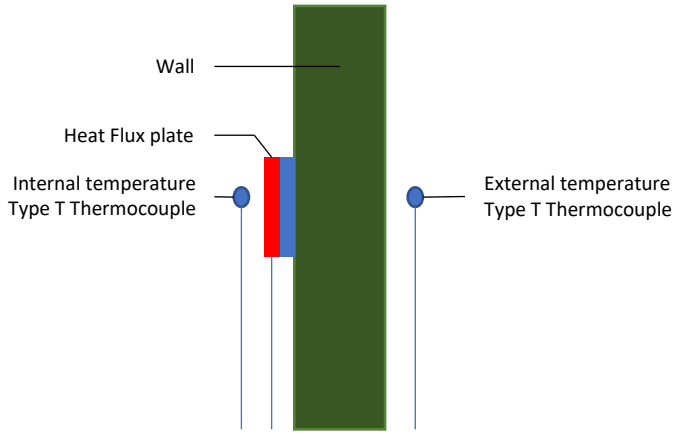
Heat flux Plate Hukseflux HFP01

Campbell Scientific® CR1000 datalogger

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Brecon Postern Monitoring – In-Situ U-Value Measurements

Measured in 4 locations (only 3 successful)



Methodology for in-situ u-value monitoring *Source*: BS ISO 9869-1

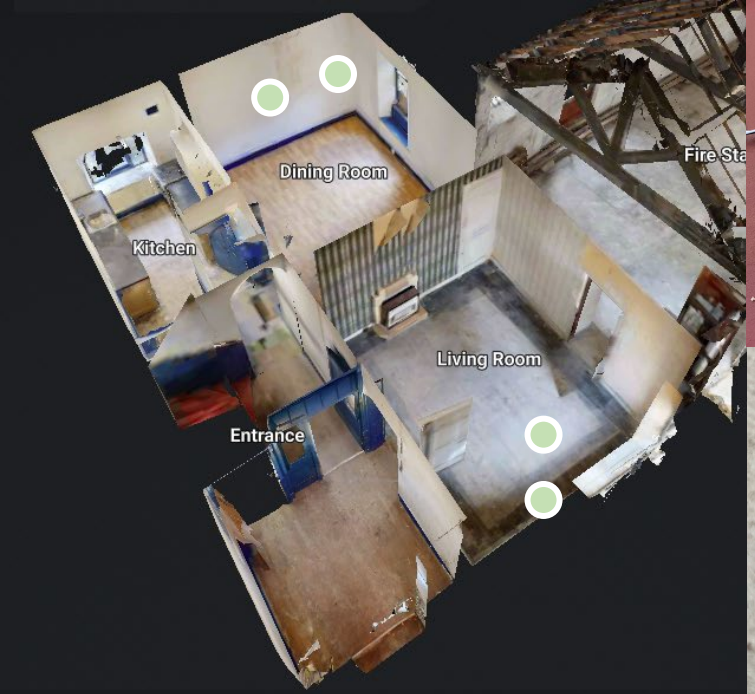
Heat flux Plate Hukseflux HFP01

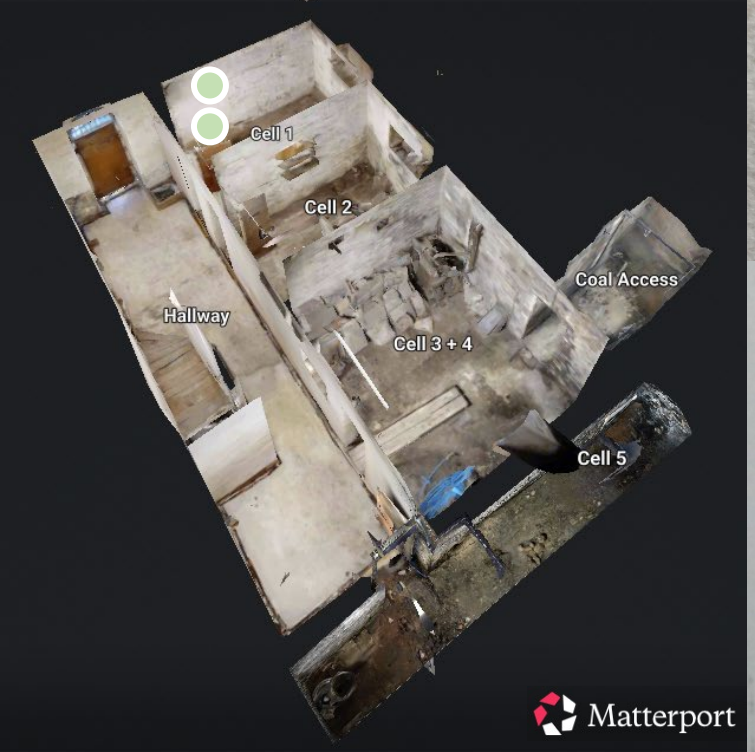
Campbell Scientific® CR1000 datalogger

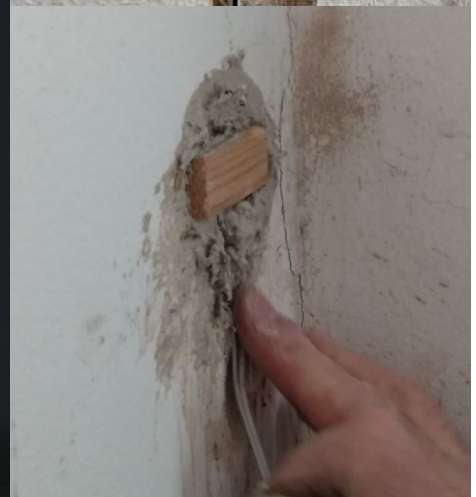
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Brecon Postern Monitoring – Thermography

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

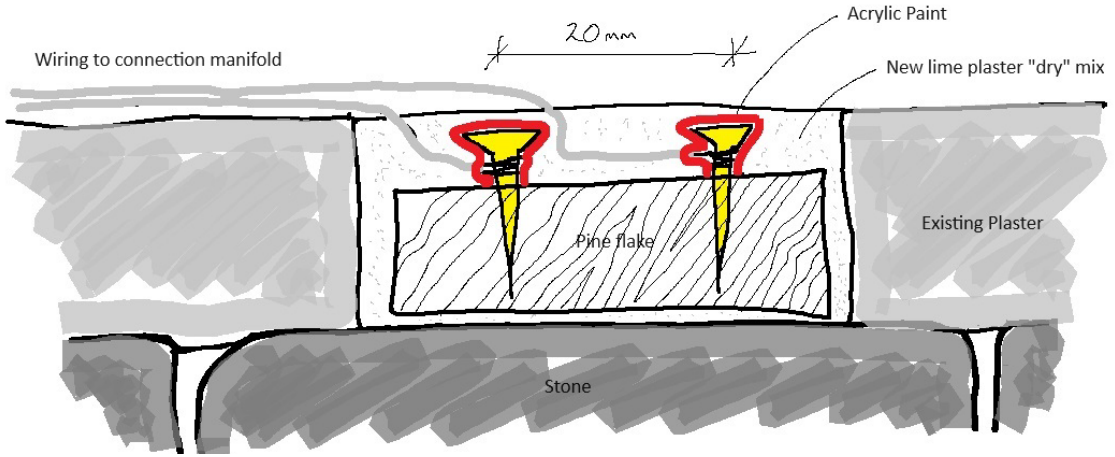






Brecon Postern Monitoring – Interstitial Moisture and Temp

6 installed so far – intention of 2 per room

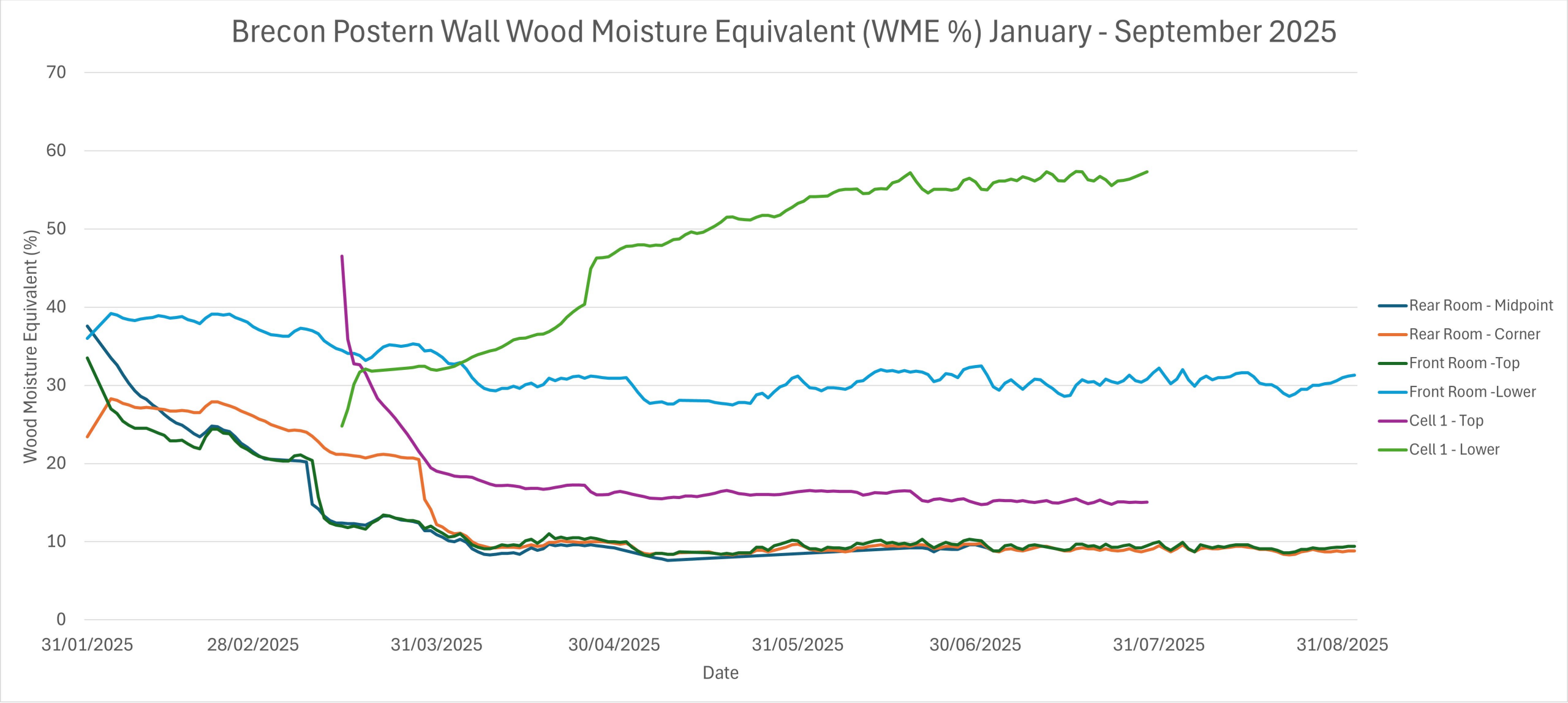


Omnisense S-4 Wireless Dual Channel and Gateway

Campbell Scientific® CR1000 datalogger

Initially using Omnisense S-4 wireless sensors but access to online data cost US$20 per month, therefore looking to hardwire to Campbell® CR1000. Also investigating LoRaWAN option…

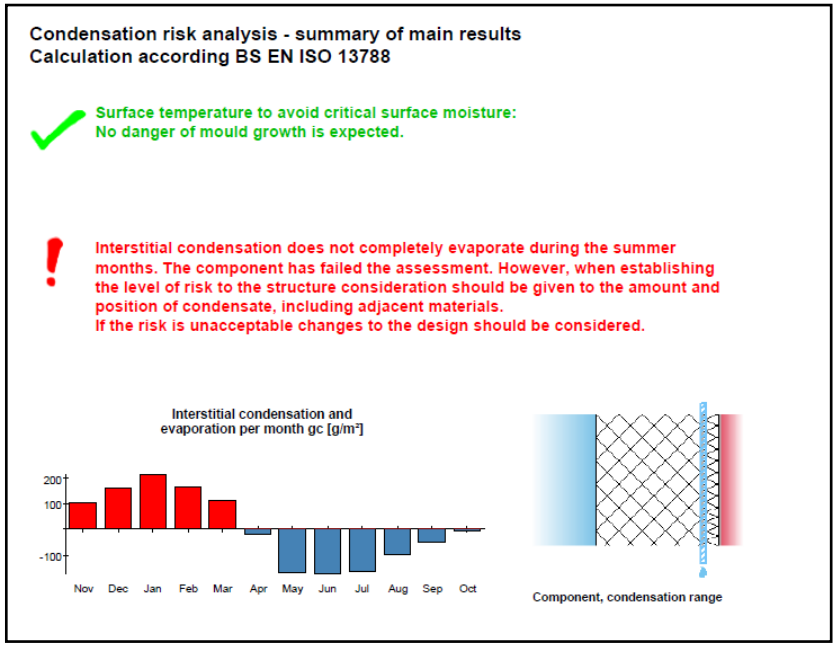
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



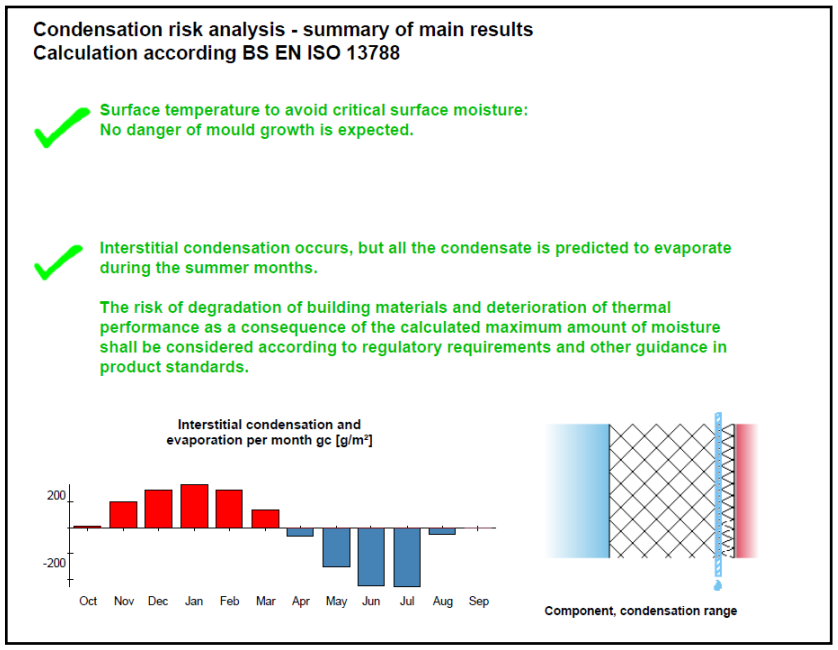
Brecon Postern Monitoring – Results – Wall WME %

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

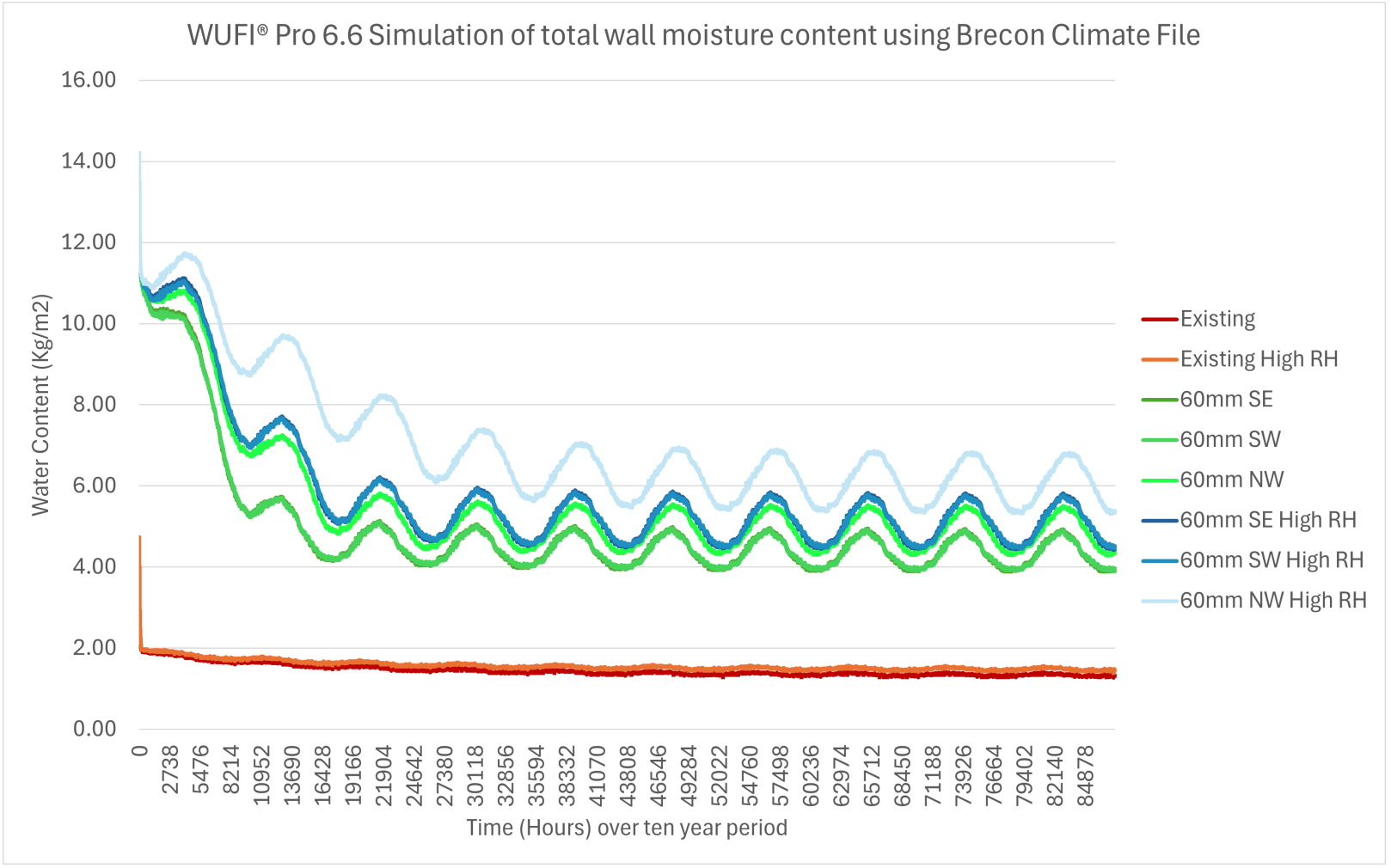
Brecon Postern Simulation
60mm Woodfibre Internal Wall Insulation



Ty Mawr BuildDesk Calculation – **West Wales**



Ty Mawr BuildDesk Calculation – **B’ham**



Simulation with WUFI® Pro 6.6

Brecon Postern Monitoring Conclusions

- Retrofit of traditionally constructed buildings is not without risk.
- Monitoring both before and after retrofit can help reduce these risks by informing both the design and learning from completed projects.
- The potential for low-cost embedded moisture monitoring in the future could increase knowledge and confidence in retrofit.

Hygrothermal Monitoring of Timber-Frame Replacement Infill Panels

Test cell at Cardiff University, Cathays Campus. *Source: (Whitman 2020)*

UK HEMPCRETE

RoystonDavies Conservation Builders

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

Funded by Historic England

UNIVERSITY OF BATH

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Historic Timber-Framed Buildings in the UK

C15 house, Lavenham, UK. (Whitman, 2022)

C17 buildings with C19 alterations, Newtown, Powys, Wales (Whitman, 2024).

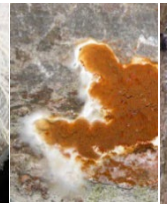
For the purpose of this research, historic timber-framed buildings refer to those built pre-1850 with an exposed timber structural timber frame, infilled with non-loadbearing panels. There exist approximately 68,000 surviving examples in the UK (Whitman, 2017).

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

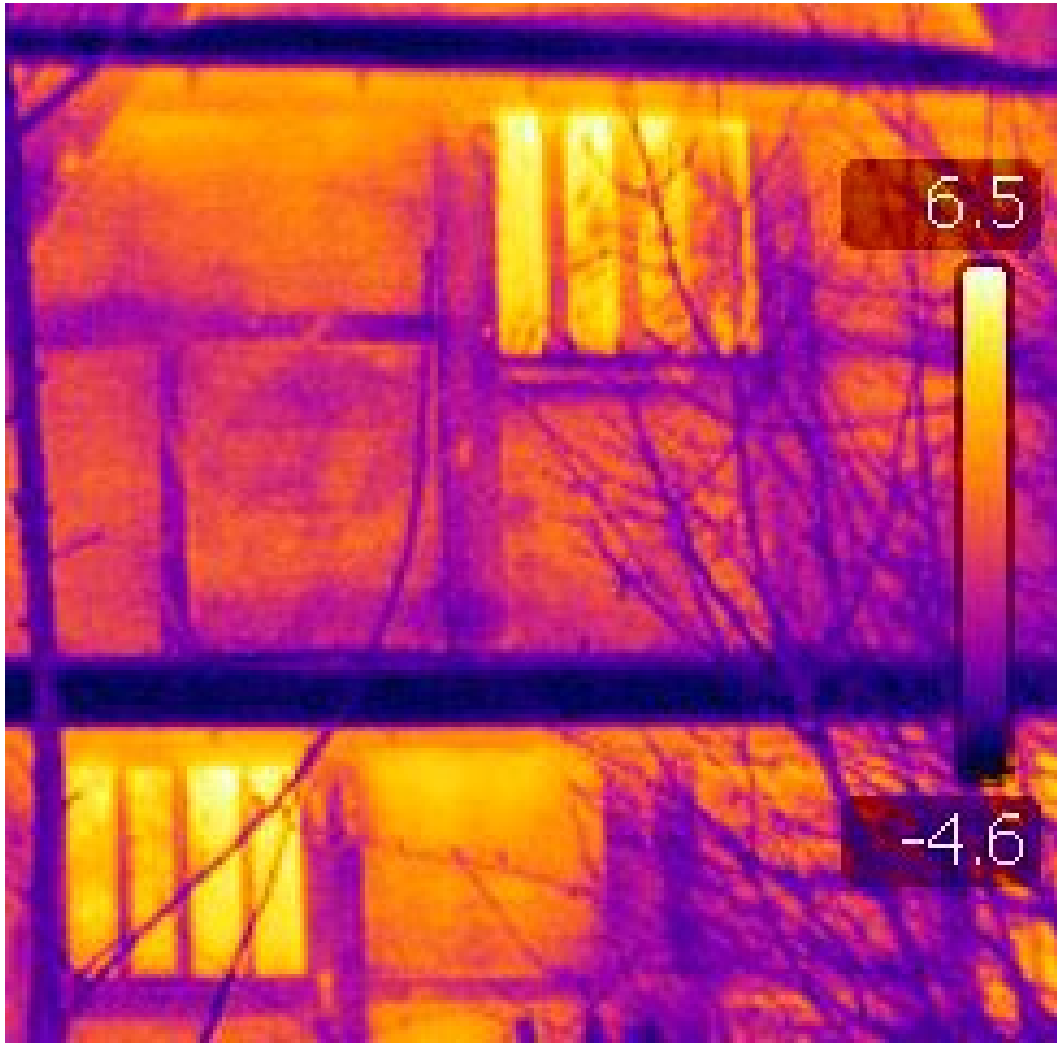
Low Energy Retrofit of historic timber-framed buildings

Given that the exposed timber frame is a defining part of these building's aesthetic heritage value, the energy retrofit options for their walls are limited.

However, where the historic infill panels are beyond repair, or have already been replaced, an infill material with a higher thermal resistance may be retrofitted (HE 2010).

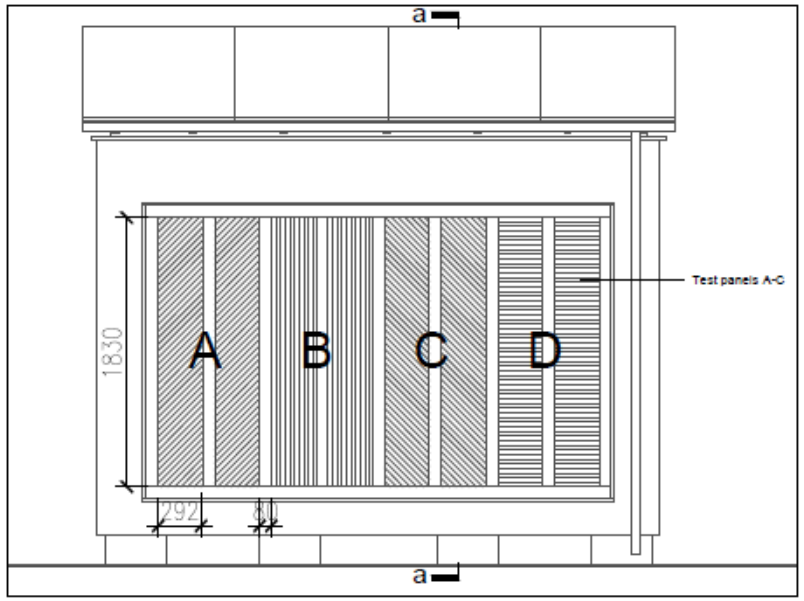
	Beetles and their larvae			Fungi		
						
Powderpost *Lycus linearis Goeze & Lyctus brunneus*	House Longhorn *Hylotrupesw bajulus*	Woodworm *Anobium punctatum*	Deathwatch *Xestobium rufovillosum*	Dry Rot *Serpula lacrymans*	Oak Rot *Donkioporia expansa*	Cellar Rot *Coniophora puteana*
8-25% 26˚C	15-25% 20-30˚C	>12% 22˚C	>15% >10˚C	>25% 17-23˚C	>28% 5-40˚C	>25% 20-32˚C

Optimum hygrothermal conditions for common UK biological threats (McCaig and Ridout 2012)

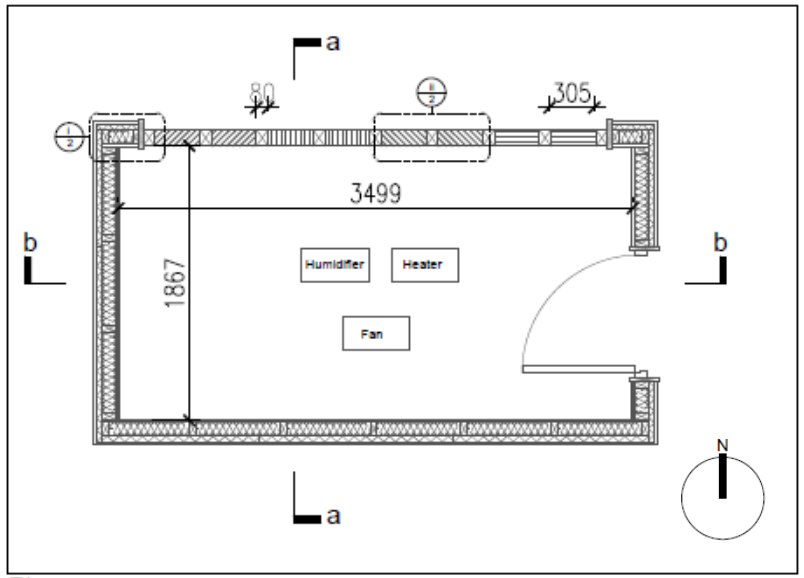


Thermographic image of Hacton Cruck Hall, Preston-on-Wye, (Whitman, 2015)

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



North Elevation



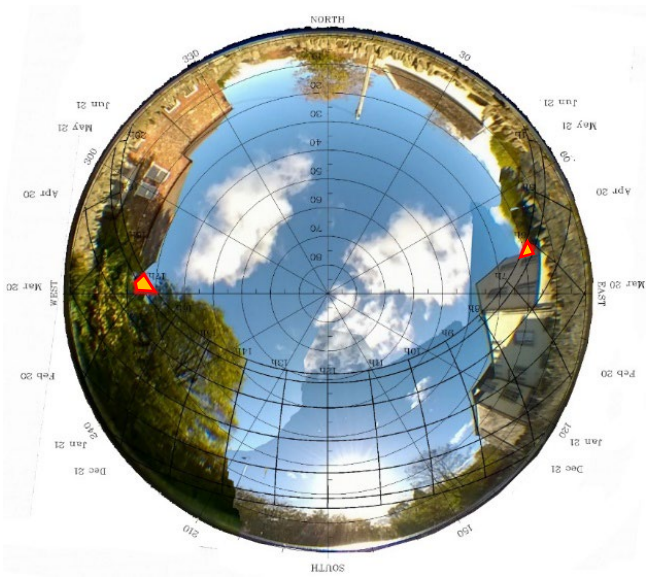
Plan

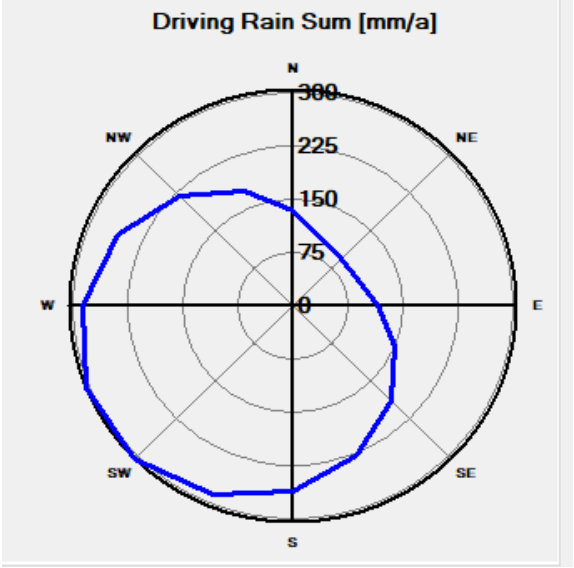
Test infill panels mounted in north façade

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

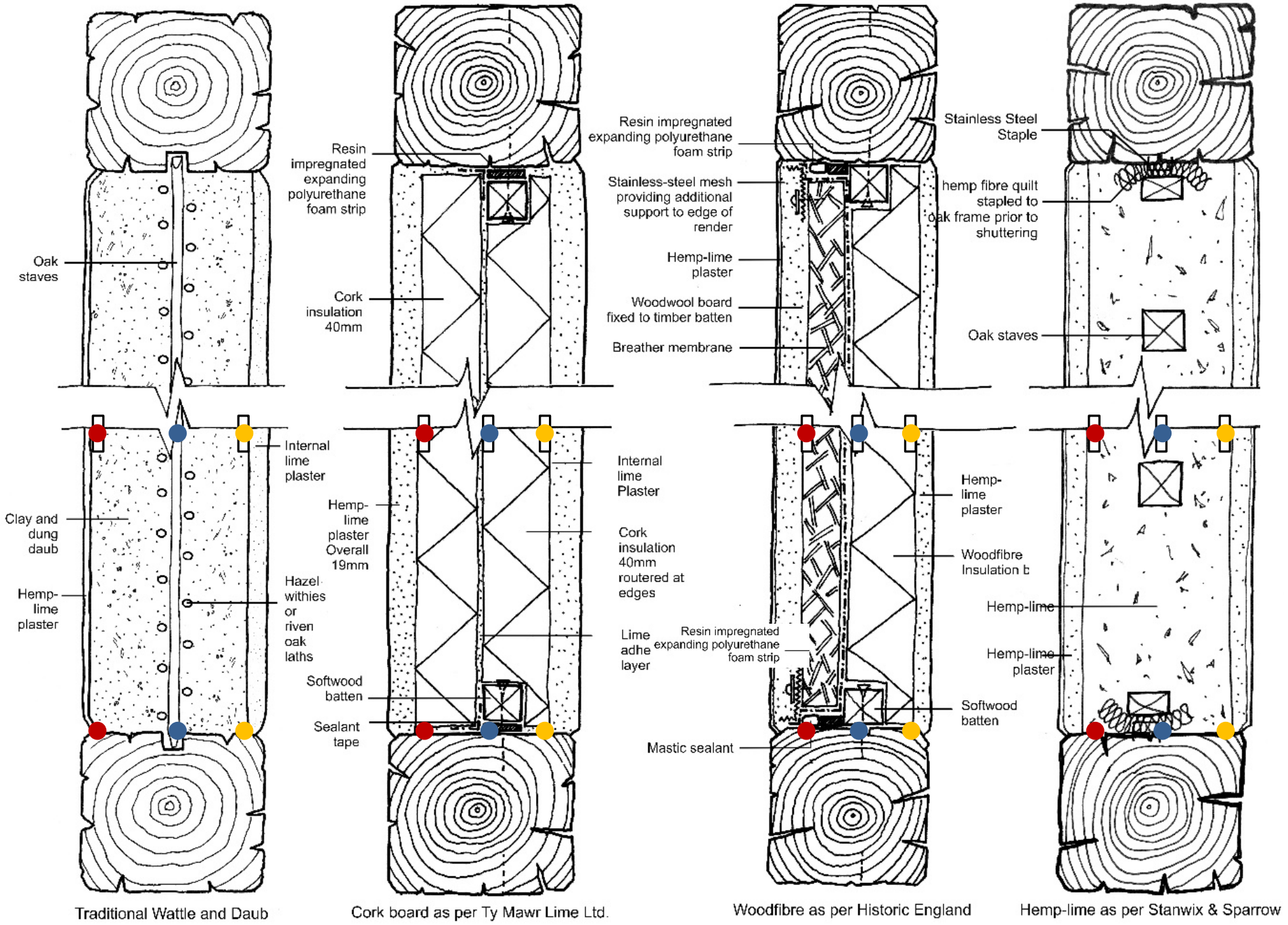
North façade chosen with aim to minimise climatic variables





Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



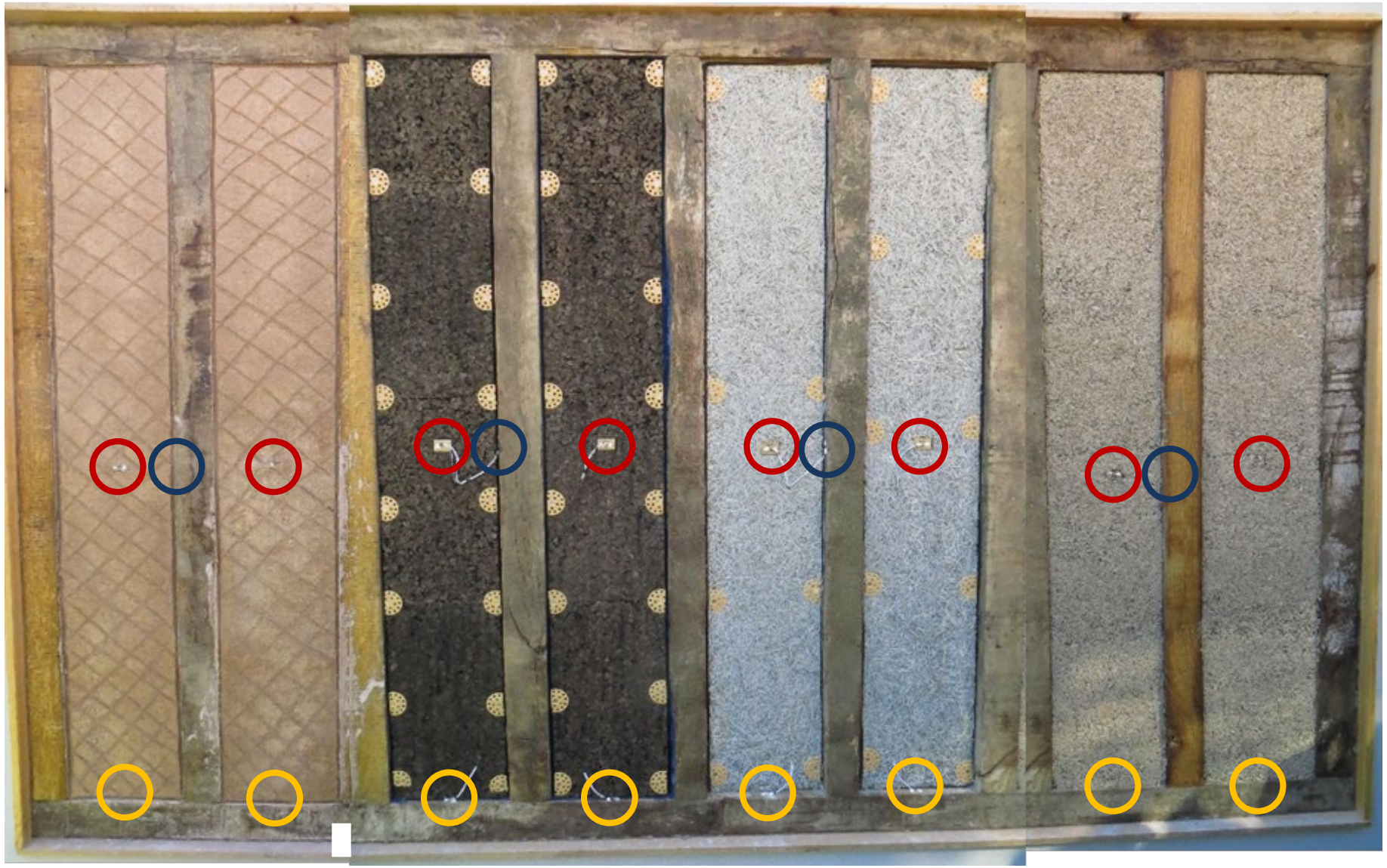
Sections showing panel infill details and monitoring locations.

Red- external

Blue- central

Yellow- Internal

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD



Left to right: Wattle and Daub, Expanded Cork Board, Wood Fibre and Wood Wool, and Hempcrete. *Source (Whitman 2019)*

Test panels prior to application of external render with monitoring locations highlighted.

Red- Mid Panel

Blue- Vertical Panel to Frame Junction

Yellow- Horizontal Panel to Frame Junction

Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Test panels :

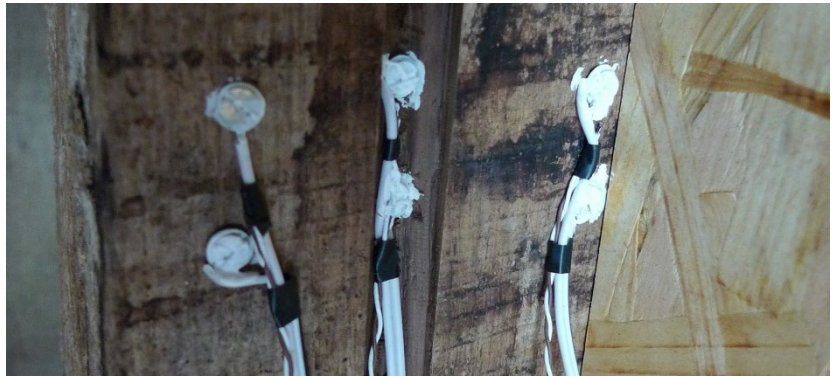
Lime-Hemp

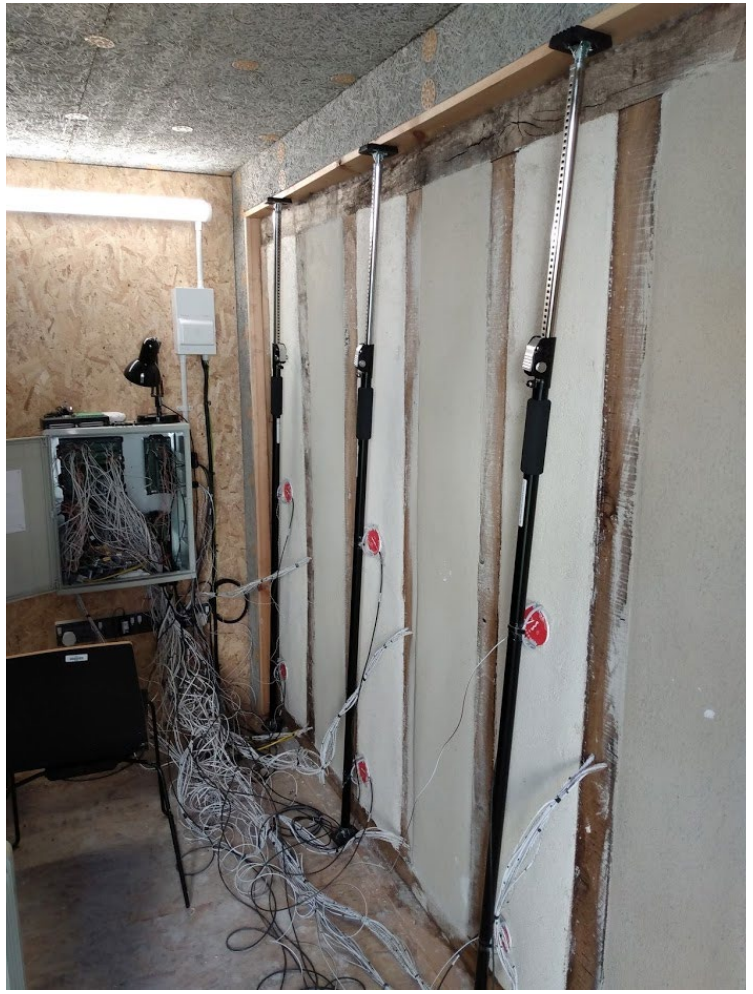
NHL 3.5

Left to right: Wattle and Daub, Expanded Cork Board, Wood Fibre and Wood Wool, and Hempcrete. *Source (Whitman 2019)*

Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD





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

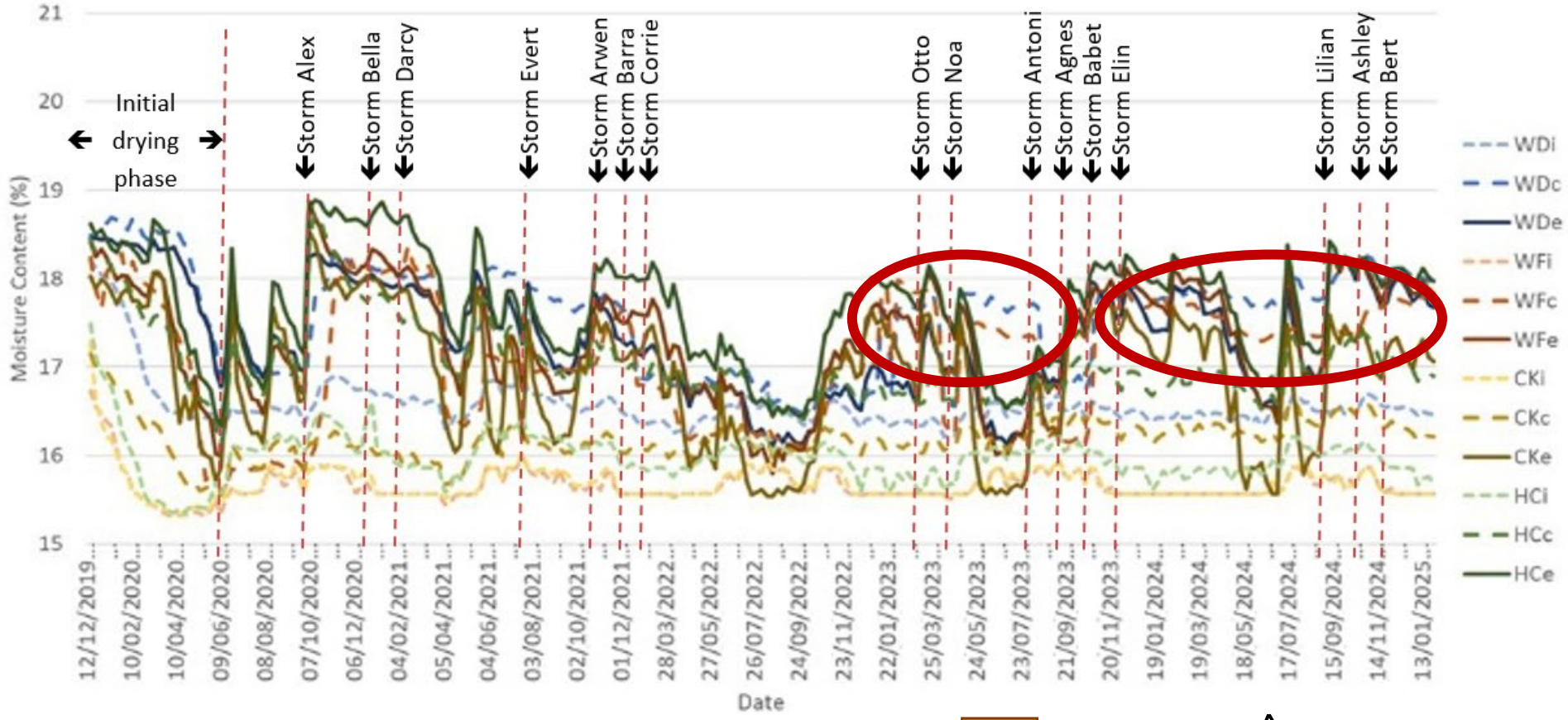
External Climatic Conditions-
Vaisala Weather Transmitter WXT520 Series and Kipp & Zonen CM5 pyrometer

Moisture content and temperature monitoring installed during construction. U-Value monitoring (Whitman, 2019)

Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Measured Moisture Content – Mid-Panel Location

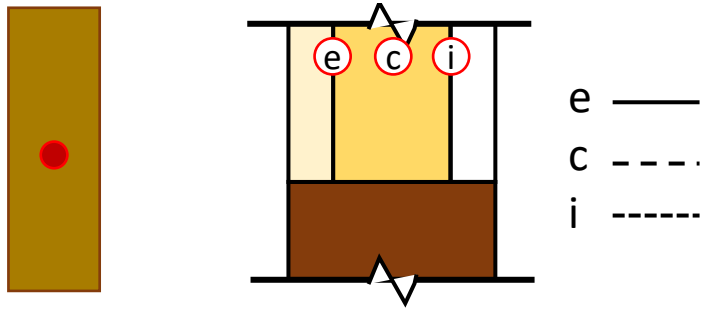


Wood Moisture Content at mid-point of **NHL 3.5 finished panels** 12/12/2019 – 05/02/2025. With UK named storm events overlaid.

WD-Wattle & Daub, WF-Wood Fibre

CK-Cork

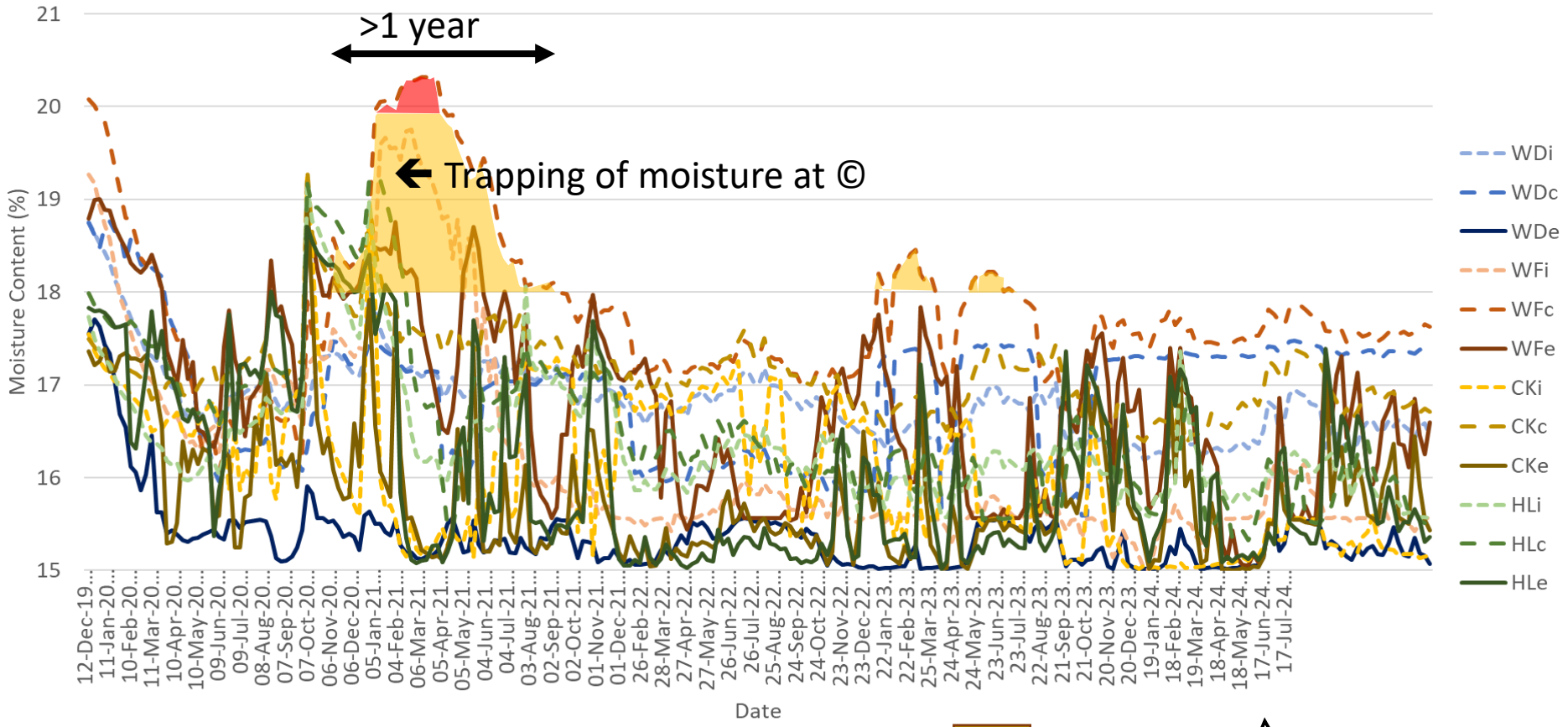
HC-Hempcrete



Funded by Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Measured Moisture Content – Horizontal Junction



Wood Moisture Content at horizontal junction between

NHL 3.5 finished panels and timber frame

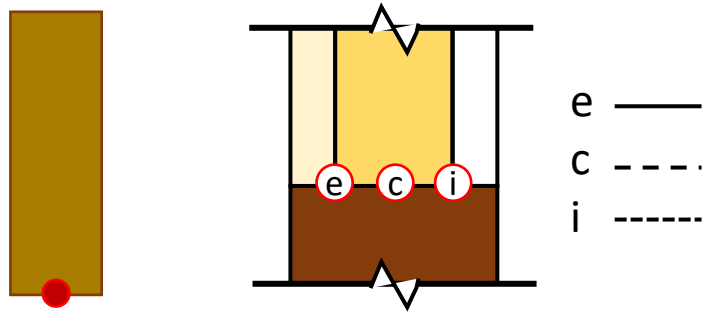
12/12/2019 – 05/02/2025.

WD-Wattle & Daub,

WF-Wood Fibre

CK-Cork

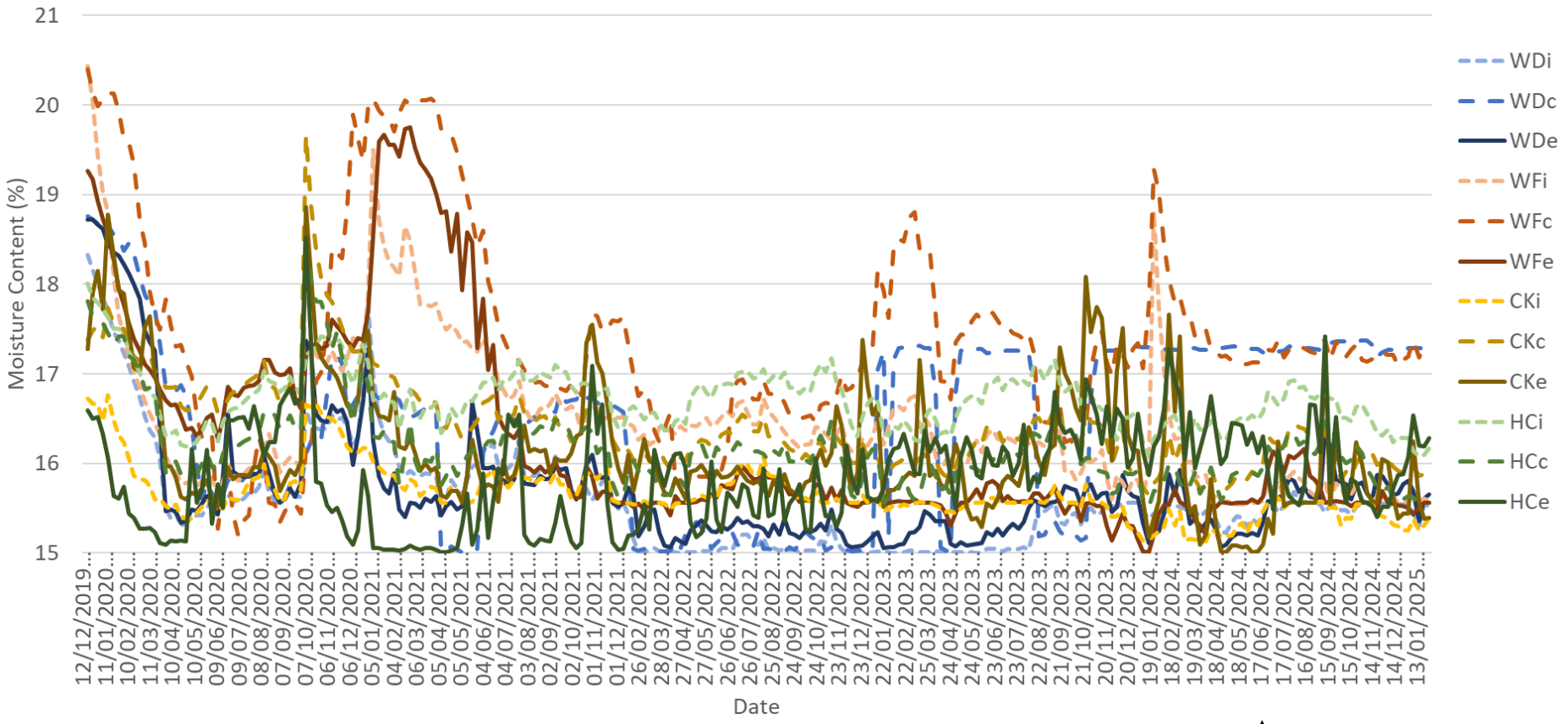
HC-Hempcrete



Funded by Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Measured Moisture Content – Horizontal Junction



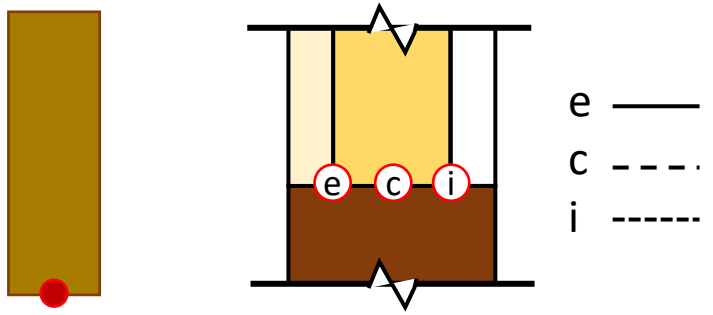
Wood Moisture Content at horizontal junction between **Lime-Hemp finished panels** and timber frame 12/12/2019 – 05/02/2025.

WD-Wattle & Daub,

WF-Wood Fibre

CK-Cork

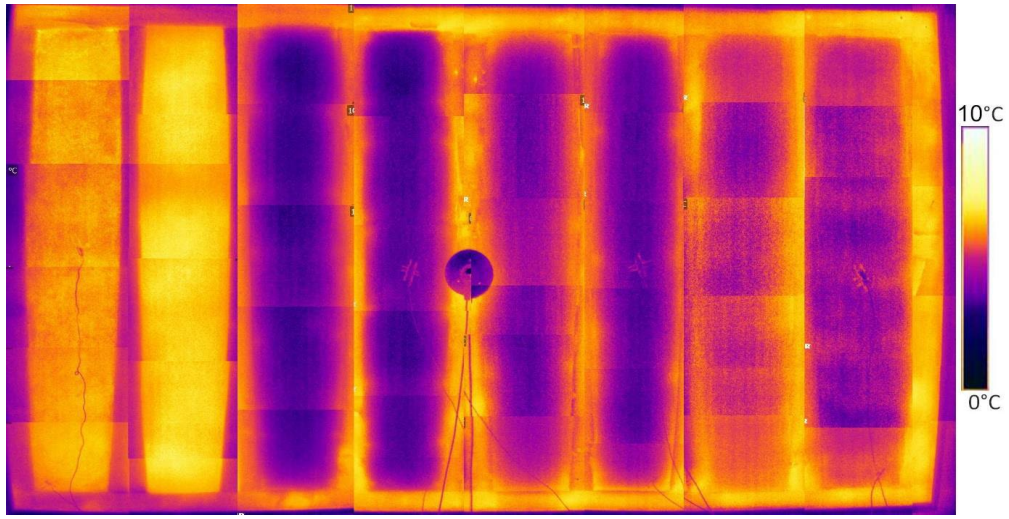
HC-Hempcrete



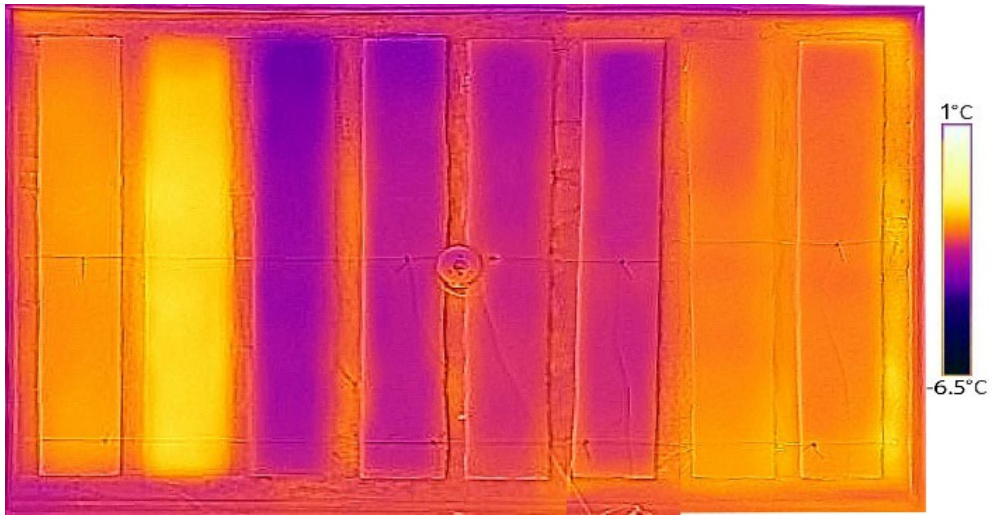
Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

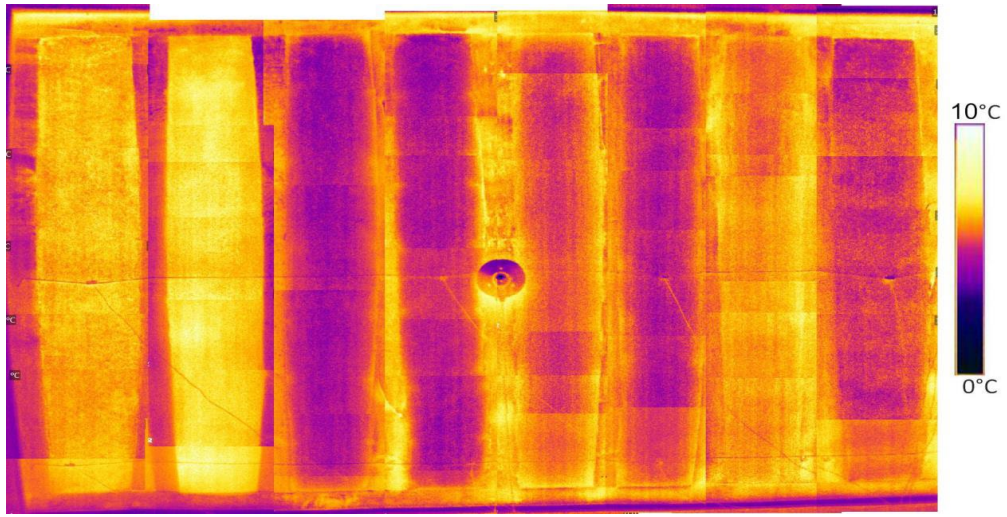
Thermal Performance



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



Right- External thermography
07:00, 06/02/25.
Internal temp. 20.5°C.
External temp. 1.4°C



Left- External thermography
07:00, 19/11/20.
Internal temp. 20.5°C.
External temp. 8.7°C

Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Airtightness

Comparison of diameters (mm) of holes equivalent to the open area around each panel as calculated from pressure testing BS EN ISO 9972:2015. Using a Minneapolis Blower Door, TEC® DG-1000 digital pressure and flow gauge, controlled by TEC® Auto Test™ software.

- No discernible difference was measured between those panels finished in the NHL 3.5 based render and the lime hemp render. Linear shrinkage measurements showed similar behaviour between the two renders.
- Expanding sealant tape at perimeter gives more consistent results
- Most airtight panel W&D has no sealant, proving **workmanship still key**.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Conclusions

- The more moisture permeable lime hemp render creates lower moisture contents, with reduced drying times when compared to those finished in the NHL 3.5 based renders.
- Evidence of Interstitial condensation has been identified in the wood fibre/wood wool detail and wattle & daub.
- Expanded cork boards achieve best thermal performance but can produce significant differences in surface temperature (up to 3°C) between timber frame and infill, as such potentially hempcrete which has a thermal performance similar to the timber frame may be more suitable.
- The use of perimeter, non-moisture permeable, sealants may potentially be trapping moisture at the junction between infill and historic timber-frame. They do however provide more consistency in achieving airtightness, however good workmanships is equally important.

Funded by
Historic England

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

BUILDING LIMES FORUM
CONFERENCE & ANNUAL GATHERING 2025

Thank You

Dr Chris Whitman

Welsh School of Architecture, Cardiff University,
WhitmanCJ@Cardiff.ac.uk

HERITAGE DECLARES

Climate & Ecological Emergency

Dr Chris Whitman

Course Leader MSc Sustainable Building Conservation

Welsh School of Architecture, Cardiff University

WhitmanCJ@Cardiff.ac.uk

Signatory and Coordinator of Heritage Declares

CARDIFF UNIVERSITY

PRIFYSGOL CAERDYDD