Historic England

Building and Landscape Conservation

Energy efficiency and historic buildings: Assessing the thermal and hygrothermal performance of two refurbished dwellings

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Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 11/2023

Research Report Series 11/2023

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NGR:

ISSN 2059-4453 (Online)

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SUMMARY

This report presents key findings of research carried out by Historic England to assess the thermal performance and hygrothermal behaviour of two dwellings – one in Derbyshire and one in Cumbria – following fabric improvements to increase energy efficiency. Both houses were of traditional construction with solid masonry walls – one brick, the other stone. In each building, a variety of insulation materials and systems were added to the building envelope. In addition, measures to increase airtightness and enhance the thermal performance of windows and doors were carried out.

In both buildings, the U-values of elements of the building envelope were measured in situ. These measurements, together with co-heating and air-tightness tests, were carried out both before and after fabric improvements. The moisture content of building fabric in selected locations was then continuously monitored, with Building 1: New Bolsover monitored for seven years. The aim of this part of the study was to compare the long-term performance and behaviour of vapour-closed and vapour-open internal wall insulation systems. Whether the added insultation would result in moisture accumulation in walls, as had been predicted by numerical modelling, was a question of particular interest.

Fabric improvements in Building 1: New Bolsover resulted a reduction in thermal transmittance of the building envelope of nearly 40%. In contrast, the reduction following fabric improvements at Building 2: Appleby was about 10%. Moisture accumulation was not observed in walls at Building 1, except in one that was shaded by an adjacent building. This highlights the importance of solar radiation on the thermal performance and hygrothermal behaviour of the building envelope.

This report includes a critical review and evaluation of the methodologies adopted in each building, highlighting limitations. Both projects illustrate the challenges in analysing and interpreting data obtained from buildings in use. These include: the wide range of uncontrollable variables; uncertainties about materials and construction; the complex and dynamic interactions between building fabric and internal and external environments; changes in building ownership and occupation. Inevitably, data gathered are site-specific and the extent to which findings can be applied more widely is limited. However, data from long-term monitoring of building elements and assemblies are needed for the validation of numerical models, such as WUFI®. It is recommended that more controllable and repeatable assessment methodologies are devised for future work.

CONTRIBUTORS

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of the owners of the properties investigated and Soki Rhee-Duverne in producing this report.

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DATE OF RESEARCH

2022

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1.0 INTRODUCTION

The UK has the oldest housing stock in Europe. In England, about 20% of homes – nearly 5 million – were built before 1919. Some 2 million of these are in conservation areas, and at least 320,000 are listed buildings. For the most part, these older buildings have survived because they are durable, maintainable and adaptable, and they have an essential role to play in fighting climate change. Continuing to adapt, upgrade, repair and maintain them so they go on being useful and viable makes good social, economic and environmental sense. However, unsuitable improvements may not deliver the energy savings and carbon reductions predicted and may harm the building and the health and wellbeing of its occupants.

The two projects described in this report are part of an ongoing programme of research investigating the effects of retrofit measures on the performance of building elements of traditional construction. Of particular interest is the risk of moisture accumulation in building fabric. The aim of the research is to contribute to an evidence base that will enable better-informed decisions to be made about improving the energy and carbon performance of buildings of traditional construction.

2.0 BUILDING 1: NEW BOLSOVER, DERBYSHIRE

Figure 1 – Building 1: New Bolsover after fabric improvements.
(Historic England © Iain McCaig)

2.1 Description and construction before fabric improvements

Building 1 is a two-story, end of terrace house (listed Grade II) built c 1896. (Floor area: 86.7m^2). The construction of the building envelope before fabric improvements were carried out was as follows:

Building element	Construction
Roof	Slate (without underlay); softwood battens and rafters. Nominal 75mm glass fibre loft insulation at ceiling level; plaster ceilings.
External walls	Solid brickwork (230mm thick); dense, coal measures clay bricks laid in lime-based mortar containing ash and coal dust; external walls finished internally with plaster/plasterboard.
Windows	Single glazed timber windows (casement to front; sash to rear) with some double-glazed aluminium replacements.
Ground floor	Part suspended softwood; part concrete ground bearing slab (kitchen).

2.2 Summary of fabric improvements

Fabric improvements to enhance the thermal performance of the building envelope were carried in 2012 as follows:

Building element	Fabric improvements
Roof	300mm glass wool insulation at ceiling level (cold roof).
External walls (All existing plaster finishes and linings removed prior to improvements)	**Ground floor:** Internal wall insulation (IWI) **'Type A'** – 65mm foil-faced polyisocyanurate insulation (PIR) with bonded plasterboard and skim finish; **'Type B'** – 55mm foil-faced PIR with plasterboard and skim on battens to provide services zone. All joints in PIR taped to maintain airtightness. **First floor:** IWI '**Type C'** – 100mm wood fibre insulation bedded on lime plaster applied to brickwork. Lime plaster finish.
Windows	New single-glazed timber windows with low emissivity secondary glazing in metal frames. Secondary vacuum glazing applied to one window.
Suspended timber ground floor	100 mm wood fibre insulation between joists; airtightness membrane between joists and floorboards.
Ground bearing concrete slab:	No improvements.

See Appendix A1 for details of fabric improvements.

2.3 Assessment aims

There were three primary assessment aims:

- to quantify the level of improvement in thermal performance due to fabric improvements selected to minimise harm to the heritage significance of the building

- to compare the thermal performance and hygrothermal behaviour of two different IWI systems, one vapour-closed and non-hygroscopic (PIR), the other vapour-open and hygroscopic (wood fibre)

- to assess the risk of moisture accumulation in walls as a consequence of adding IWI.

2.4 Method of assessment

2.4.1 Thermal performance

U-value measurements were made in situ in representative locations following a thermal imaging survey within the house. These, along with co-heating and air tightness tests were performed before (2011) and after refurbishment (2012). In situ U-values and airtightness were measured again in 2017 to determine if any reduction in thermal performance had occurred. The procedures are described in Rhee-Duverne & Baker (2015).

2.4.2 Long-term monitoring of hygrothermal behaviour

Hygrothermal modelling had indicated that the risk of condensation/moisture accumulation would be at its greatest at the interface of the cold side of the insulation and the masonry walls. Therefore, combined relative humidity and temperature (RH/T) sensors were installed in this position in 32 locations. In addition, the electrical resistance of small wood blocks was monitored. These measurements were converted to moisture content to assess the potential risk of moisture damage. On the ground floor the sensors and wood blocks were mounted in the air gap between the brick and cold side of the PIR insulation; on the first floor they were installed in a recess within the plaster layer behind the wood fibre insulation.

Basic weather data were obtained throughout the monitoring period from weatherunderground.com. In addition, full weather data from Watnall, Nottinghamshire (about 20 miles from the site) were provided by the Met Office for the period 2015-2018. Measurements of internal room conditions were also recorded. Unfortunately, an equipment failure led to the loss of room data between 2012 and June 2014.

2.4.3 Numerical (WUFI®) Modelling

One dimensional numerical modelling of the hygrothermal behaviour of the two IWI systems was carried out using WUFI® Pro 5. An extensive sensitivity study was carried out to identify which brick in the WUFI® database gave the closest results to the monitored data (Baker & Rhee-Duverne, unpublished).

2.5 Key findings

The monitored data are shown in Appendices A2 (Indoor and outdoor conditions), A3 (Plots of interface measurements) and A4 (Tabulated interface measurements).

2.5.1 Thermal Performance

The in situ U-value measurements are summarised below.

Table 1: *Measured U-values before fabric improvements*

Building element	U-value W/m²K
Roof Ceiling insulated with c 75mm glass fibre (disturbed and incomplete).	0.17 – 0.45 ± 0.05
External walls Brick with plaster.	1.75 ± 0.20
External walls Brick with plasterboard on battens/studs.	1.21 ± 0.15
Windows Single glazed.	5.20 ± 0.50
Windows Double glazed.	2.70 ± 0.30
Suspended timber floor	1.19 ± 0.12

Table 2: *Measured U-values after fabric improvements*

Building element	U-value W/m²K
Roof Ceiling insulated with 300mm glass wool insulation.	0.15 ± 0.02
Walls Brick with Type A insulation (65mm PIR).	0.20 ± 0.02
Walls Brick with Type B insulation (55mm PIR with service void).	0.27 ± 0.03
Walls Brick with Type C insulation (100mm wood fibre).	0.33 ± 0.03
Windows Single glazing with low-e secondary glazing.	1.64 ± 0.08
Window Single glazing with vacuum secondary glazing.	0.81 ± 0.05
Suspended timber floor Insulated with 100mm wood fibre.	0.32 ± 0.03

Co-heating test

The co-heating tests indicated that the fabric improvements significantly reduced heat loss from the house. The more robust dynamic analysis method described in Rhee-Duverne & Baker (2015) estimated a saving of 43%. The whole house heat loss co-efficient dropped from 251 ± 44.3 W/K to 143 ± 16.2 W/K. The heat loss per unit floor area (otherwise referred to as the heat loss parameter) fell from 2.9 W/m^2K to 1.7 W/m^2K. These values represent the heat loss by conduction through the building envelope, including thermal bridges and the ventilation heat loss during the test period.

Air permeability tests

The air permeability value before improvements was $13m^3/(h.m^2)$ at 50 Pa. After improvements, this reduced to $10m^3/(h.m^2)$ at 50 Pa, thereby achieving the maximum permissible value given in the Building Regulations Approved Document Part L1A 2010 (HMG, 2010).

Conclusions

The fabric improvements carried out at Building 1 resulted in a significant increase in energy efficiency with predicted reductions, determined by SAP (2009), of 38% in total fuel consumption, 40% in primary energy use, 38% in CO_2 emissions, and an improvement in SAP band from E to D. This last result, however, does not reflect the degree of improvement achieved and highlights problems with SAP calculations.

Further U-value measurements of walls and an air pressurisation test were carried out in 2017, five years after the installation of the fabric improvements. No significant changes were observed. This suggests that there had been no appreciable deterioration in the IWI systems installed and no moisture accumulation had occurred in the locations measured.

2.5.2 Hygrothermal Monitoring

Both IWI systems showed similar trends in behaviour, with strong seasonal cycles. High winter RH in the critical range (>90%) fell to safe levels during summer. However, the sheltered and shaded measurement locations on the south gable wall showed persistently high RH throughout the year. The results indicated that conditions at the IWI/brick interface were generally slightly drier with the non-hygroscopic PIR insulation than the hygroscopic wood fibre system. First floor locations with wood fibre IWI remained at critical RH values for longer before recovering than equivalent ground floor locations insulated with PIR.

The more persistent high RHs were a consequence of the moisture buffering behaviour of the wood-fibre insulation. It can absorb large quantities of moisture but takes longer to dry out. The extent to which this might result in a decay is unclear and needs further investigation, including mould risk analysis using isopleth models. However, when small diameter cores were extracted from both IWI systems on the south gable wall in 2015, no evidence of mould or decay at the insulation/wall interface was observed.

Nevertheless, the gable wall results give cause for concern for both IWI systems, suggesting that individual solutions may be needed for different elevations and degrees of exposure. Orientation effects due to differing exposure to rain, wind and solar radiation are a determining factor in the performance of the walls. The more exposed front and rear elevations tend to be drier than the gable wall, which receives lower level of direct solar radiation. Possible mitigating measures to reduce moisture risk might include reducing the thickness of insulation and/or applying a render. Further investigations are underway using modelling.

2.5.3 WUFI® Modelling

For the wood-fibre system on the first floor, good correlation was found between the simulations and the measured data for the east and west walls. However, modelling of south gable wall was less successful. For the PIR on the ground floor, modelling of the west elevation was successful, the east elevation rather less so, while the gable wall results were generally unsatisfactory.

Contributory factors leading to the discrepancies between simulation and measurement included: the degree of shading of the gable wall; driving rain estimation; variability in the rain adherence factor. Inaccuracies in measurements obtained from sensors and wood blocks exposed to high RH (> 90%) are also likely to have contributed to discrepancies.

2.6 Limitations

There was no on-site weather station to record external environmental conditions for most of the hygrothermal monitoring period, apart from the times when thermal measurements were being made. In addition, failure of the indoor environmental monitoring system meant that room temperature and relative humidity data for the first 2½ years of monitoring were lost.

Although weather data obtained from nearby locations are considered satisfactory, there is some uncertainty about the rainfall data. In retrospect, it would have been better to have measured rainfall on site.

3.0 BUILDING 2: APPLEBY IN WESTMORLAND, CUMBRIA

Figure 2 – Building 2: Appleby before fabric improvements.
(Historic England © Rebecca Pullen)

3.1 Description and construction before fabric improvements

Building 2 is a three-storey dwelling (listed Grade II) built in the early- to mid- 19th century; it adjoins a neighbouring property of similar date. (Floor area: 77.1 m^2). The building, situated within a flood zone, was subject to flooding in 2015 and again in 2020. The construction of the building envelope prior to fabric improvements was as follows:

Building element	Construction
Roof	Slate (without underlay); timber battens, rafters and structure. Lath and lime plaster ceiling beneath attic and lower sections of rafters (second floor accommodation partially within roof).
External walls	Solid random stone rubble (c 550mm thick) with sandstone ashlar dressings, laid in lime-based mortar; rubble masonry finished externally in roughcast render; plaster finishes internally.
Windows	Single glazed timber sash windows.
Ground floor	Concrete ground bearing slab.

3.2 Summary of fabric improvements

Fabric improvements to enhance thermal performance and flood resilience of the building envelope were carried out in 2019 as follows:

Building element	Fabric improvements
Roof	Slating re-laid on new timber battens on vapour permeable membrane on 25mm wood fibre sarking board; 100mm wood fibre insulation between rafters; 50mm wood fibre below rafters; 2-coat lime plaster ceiling finish.
External walls (All existing render, plaster and linings removed prior to improvements).	Internally: All floors: Walls dubbed-out in lime putty mortar to eliminate surface irregularities prior to application of insulating plasters. Ground floor: From floor level to 1600mm high: 25mm hot-mixed haired lime plaster with 2mm finish coat. Above 1600mm: 22mm lime/hemp/perlite plaster with 5mm finish coat. First floor: 35mm 'Diathonite Evolution' proprietary hydraulic lime/cork insulating plaster with lime-putty skim coat finish. Second floor: 50mm natural hydraulic lime/hemp/perlite plaster with 5mm finish coat. Externally: Walls dubbed-out in lime putty mortar prior to rendering with 25mm hot-mixed haired lime render with clay pozzolan; rough cast finish. Render coated with hot mix limewash.
Windows	Existing single-glazed timber sash windows overhauled and repaired.
External doors	Draft sealed (including letter box).
Ground floor	Existing solid floor replaced with 100mm 'limecrete' ground bearing slab on 300mm foam glass aggregate on geotextile membrane. 25mm cork board incorporated around perimeter of slab.

3.3 Assessment aims

The primary assessment aims were as follows:

- to quantify the level of improvement in thermal performance of the building envelope due to fabric improvements selected to minimise harm to the heritage significance of the building

- to compare the thermal performance and hygrothermal behaviour of various lime-based insulating plasters

- to assess the risk of moisture accumulation in the building envelope as a consequence of the fabric improvements

- to obtain data on normal equilibrium moisture contents of building fabric to provide a baseline for assessing drying rates and resilience in case of future flooding.

3.4 Method of assessment

Figures referred to are in Appendix B1.

3.4.1 Thermal Performance

The thermal performance of the building envelope (heat loss coefficient) was assessed by co-heating tests, in situ U-value measurements of building elements, and air pressurisation tests before and after rehabilitation of the property. The procedures are described in Rhee-Duverne & Baker (2015).

3.4.2 Long-term monitoring of hygrothermal behaviour

The objective of the monitoring was to assess the hygrothermal behaviour of the fabric following improvements by measuring conditions within the walls while also monitoring weather and room conditions in the building.

Combined relative humidity and temperature sensors (RH/T) were installed in the masonry joints as flush as possible to the internal surface (figure B1.1), prior to applying the plaster coats. Two RH/T sensors were placed together in most locations to provide some redundancy if a sensor failed. The RH/T sensors measure the interface conditions between the masonry and the cold side of the insulation system. Hygrothermal modelling indicates that this is the region potentially most at risk from condensation/moisture accumulation.

Temperature sensors were also placed on the internal surface of the insulating plaster before the finishing coat was applied. These sensors enable the temperature gradient across the insulating plaster to be calculated. The locations of the sensors on each floor are shown in figures B1.2 – B1.4.

Moisture sensors were installed in selected areas of the sandstone walls before application of plaster to enable long-term monitoring of moisture profiles the thickness of the walls. The sensors consist of three 100mm lengths of wooden dowel (Figure B1.1), glued end-to-end with epoxy resin adhesive, each with electrical connections to measure resistance (Ridout & McCaig, 2016). The locations of the dowels are shown in figures B1.5 and B1.6. Sensor readings were recorded as 10 minute average values using Campbell Scientific data loggers. These data were processed as daily averages. The moisture sensor resistance values were converted to equivalent timber moisture contents.

Additional sensors were installed in the newly insulated roof, with RH/T sensors placed on cold surface of the insulated sarking, under membrane and temperature sensors under roof tiles (Figure B1.7). These were measured using the main indoor logging system.

3.4.3 Weather Monitoring

A weather station (ClimaVue50, campbellsci.com/climavue-50) was installed above the chimney on the east elevation of the building (Figure B1.8). The climate parameters measures are as follows:

- Temperature
- Relative Humidity
- Wind Speed and Direction
- Solar Radiation
- Rainfall
- Vapour Pressure
- Barometric Pressure

Hourly and daily data were recorded using a Campbell Scientific data logger. Additional measurements were made on the external wall surfaces of rainfall (each elevation) and solar radiation (south, east and west elevations) to determine effects of orientation and wind driven rain. Vertically mounted solarimeters (Apogee 200,) and rain gauges (Hydreon RG-11) were used (figure B1.9) and monitored using the main logging system. External surface temperatures of the wall were also measured using standalone Tinytag temperature sensors.

3.4.4 Soil Moisture

Two soil moisture sensors (Delta-T Devices SM150T) were installed under the new limecrete ground floor. These were measured using the main indoor logging system. It was also the intention to measure the soil moisture content externally, beyond the gable wall. However, access was unavailable due to ownership of the land by another party.

3.4.5 Indoor Environment

It was intended in the original project proposal to monitor indoor air temperature, relative humidity and air quality (CO_2) using sensors mounted permanently and accessible remotely. However, due to the Covid-19 restrictions it was not possible to install these. A temporary solution was to use standalone Tinytag RH and temperature sensors in some rooms.

3.5 Key findings

3.5.1 Thermal performance

The in situ U-value measurements are summarised below.

Table 3: *Measured U-values before and after fabric improvements*

	Before	After
Location	U-value W/m²K	U-value W/m²K
Ground Floor:		
Front Elevation	1.53 ± 0.26	1.41 ± 0.22
Gable	1.71 ± 0.25	1.19 ± 0.15
Rear (above fireplace)	1.18 ± 0.30	1.65 ± 0.17
Floor	0.39 ± 0.13	0.33 ± 0.09
First Floor:		
Front Elevation	1.57 ± 0.69	1.27 ± 0.42
Gable	1.49 ± 0.22	1.22 ± 0.19
Rear	1.46 ± 0.19	1.22 ± 0.17
Second Floor:		
Front Elevation	1.14 ± 0.20	1.13 ± 0.15
Gable	1.17 ± 0.22	*Logger Failed*
Rear	1.57 ± 0.29	1.44 ± 0.24
Ceiling	1.74 ± 0.26	0.31 ± 0.03
All Walls (average)*	1.46	1.27

* Excluding second floor gable results since no results were obtained post-improvements.

Co-heating test

The measured U-values are considered more indicative of the building envelope performance than the co-heating tests results. This is because it was difficult to estimate the heat loss/gain through the party wall with the adjoining property. Additionally, the post-intervention co-heating test was subject to equipment failure and a repeat test was not possible due to the Covid 19 restrictions. However, the pre-intervention Whole House Thermal Transmittance was 238 ± 27 W/K. The heat loss per unit floor area was 3.1 W/m^2K.

Air pressurisation test

Air pressurisation test results before and after improvements were similar with air permeability values of approximately 15 $m^3/(h.m^2)$ and 14 $m^3/(h.m^3)$, respectively at 50Pa. During the post-improvements test it was noted that there was significant air leakage around the front door. After sealing this, a result of 13 $m^3/(h.m^2)$ at 50Pa was obtained. This result exceeds maximum permissible value given in the Building Regulations Approved Document Part L1A 2010 (HMG, 2010). No improvements to the sliding sash windows were carried out other than joinery repairs. This could account for the high level of air leakage.

Conclusions

The pre-improvement results are consistent with U-values measured on plastered sandstone walls with a similar thickness of 550-600mm for Historic Scotland (Baker, 2011). In comparison, the post-improvement results showed only a slight increase in thermal performance. However, when the heat flux meters for these tests were being installed, it was observed that the internal plaster finishes were still not fully dry. Flooding had occurred in Appleby in early February, before the post-improvement tests which commenced on 28 February 2020. Water reached the front doorstep (Figure B1.10) and may have increased the moisture content of the ground floor wall. Residual construction moisture may have been a further contributory factor. But by mid-March 2022, dowel moisture contents near internal surfaces and interface relative humidities had fallen (or were decreasing) to safe levels in most locations. Therefore, it is recommended that the in situ U-values are re-measured during the next heating season (2022-23). In contrast, the results for the improved ceiling on the second floor showed a significant improvement using the wood fibre insulation.

3.5.2 Hygrothermal behaviour following fabric improvements

The monitored daily data are available from August 2020 until the final download in mid-March 2022. Weather station data are available from 28 February 2020 (see Appendix B2).

The available indoor conditions data indicate that the average temperature maintained in the house was about 15^{o}C during the heating season. Relative humidities were generally above 60%, and consistently exceeded 70% in the kitchen and bathroom, although there was no obvious evidence of mould. There are no data during the initial stages of drying following the completion of internal plastering during October 2019. Due to Covid restrictions, useful data were missed until the internal data logging systems were commissioned in August 2020.

The rain gauges mounted on each elevation showed that driving rain is highest on the south (gable) and west (front) elevations. These results were consistent with the wind direction distribution. Vertical solar radiation was higher on the south and west elevations than the east. It should be noted that the rain gauges and solarimeters were mounted about 500mm below the gutters on each elevation and are unobstructed. However, the gable and rear (east) elevations are partially obstructed by nearby buildings below second floor level.

The underfloor soil moisture contents showed small decreases over the monitoring period.

The trends in the interface relative humidity data and the dowel moisture contents vary with floor and elevation:

Ground floor walls

RH values at the interface between the sandstone and plaster on the north (return) and west (front) elevations appeared to be still decreasing in March 2022, after initially high levels at the start of monitoring in August 2020. The dowel moisture contents measured in the 100mm section nearest the internal surface of the sandstone in these elevations had fallen to safe levels below 20%. On the south (gable) the RH values remained high, although the dowel moisture contents had fallen to safe levels. No measurements were made on the east (rear) elevation due to presence of the old range and fireplace.

First floor walls

RH values in the north (return) and west (front) walls generally remained below 80%, with dowel moisture contents around 18%. The RH values in the south elevation generally remained above 80% until falling below 80% in November 2021. The dowel moisture content fell from around 20-21% to below 20% in autumn 2021. The RH values in the east (rear) wall near the chimney (Figure A3) remained high except for a brief period in summer 2021 and the dowel moisture content generally remains in the low to mid-20% range.

Second floor walls

North (return) wall RH values increased from 83% to 100% in December 2020 and fell to 92% in April 2021. Values rose sharply to 100% in early May 2021 and remained there. The inner dowel moisture remained below 20% until a sharp rise mirroring the rise in RH in early May 2021. Both the mid and outer dowel locations showed a similar rise in moisture beginning in late April/early May. The house owner discovered a leak in the roof at the same time as the sharp rises in dowel moisture contents and RH.

RH values in the west (front) wall increased from about 80% to above 90% in June 2021. Values decreased to below 80% by the end of July, then rose to around 90% in November 2021. RHs began to decrease by the end of monitoring in mid-March 2022. The trend in the front wall results followed that of the rainfall on the elevation. The inner dowel moisture contents rose from 20% to 23% between the start of monitoring and June 2021. Values then fell, finally stabilising at around 20%. The south (gable) wall results showed a similar trend to the west (front) elevation.

In the east (rear) wall one of the pair of RH sensors located near the chimney (Figure B1.4) remained at 100% throughout the monitoring period. The other stayed at 100% until June 2021 and then fell to a minimum of 94%, before rising again to 100% in October 2021. Values started to decrease in December, and reached 92% at the end of monitoring. Dowel moisture contents remained above 20%.

Comparison of results from walls on all three floors

In general, the first floor walls showed consistently lower interface humidity values than the ground floor and second floor walls, the latter having the highest values. Damp penetration down the chimney may be a cause of the high interface humidities on the east (rear) wall on both the first and second floors. Apart from the north (return) and east (rear) walls on the second floor, interface RHs generally showed a downward trend in 2022.

The inner dowel moisture contents showed a similar trend to the interface RHs, with only the dowel in the north (return) wall showing excessively high values following the roof leak in May 2021. In the other locations the dowels had all reached acceptable levels in 2022.

Roof

In autumn 2020, RH values between the external surface of the wood fibre sarking and the breather membrane beneath the slates rose to 100% on both north and south slopes and remained at this level over the winter (Figure B1.7). The south RH recovered in late February 2021 whilst the north RH recovered later in early April. A similar pattern was repeated in spring 2022. The south, with more exposure to solar radiation, dried out to lower humidities than the north during summer.

3.6 Limitations

It is difficult to compare the performance of the different insulated plaster systems since the height of each floor and shading/sheltering by adjacent buildings or obstructions affect the exposure to driving rain and solar radiation. The second floor is more exposed than the first floor and ground floors. To overcome this, more detailed rain and solar radiation measurements would be needed on each floor. Alternatively, sections of different insulating plasters could have been monitored on the south (gable) wall at second floor level.

Due to the phasing of the refurbishment works, it was not possible to set up the logging system when sensors were first installed prior to the application of the first plaster coat. It was the intention to set up and commission the logging system in March 2020 on completion of the thermal testing, however the Covid lockdown delayed this until August 2020.

Further in situ U-value measurements and hygrothermal monitoring are needed to understand better the performance of the fabric improvements, particularly if there were significant variations in weather conditions. However, uncertainties about the future ownership and occupation of the building may preclude this.

4.0 REVIEW AND EVALUATION OF METHODOLOGIES

4.1 How well did findings meet the aims of the studies?

Long term monitoring of Building 1 over a period of 7 years has produced an extremely large and useful data set for analysis. Despite the lack of indoor environmental data and some weather data during the first 2½ years, it has enabled a detailed performance assessment of two diverse insulation systems under a range of internal and external boundary conditions.

The U-value and air tightness testing in both buildings produced satisfactory results since well-defined procedures were used. However, in Building 2 the post-improvement U-values measurements were made before the building fabric had dried to normal equilibrium moisture contents. Further measurement is therefore recommended.

Long term monitoring of interface RHs and temperatures proved to be a suitable means of assessing the risk of moisture problems when coupled with moisture measurements using wood blocks or dowels. These act as a good proxy for assessing the risk of decay to organic timber-based materials. However, it may not now be possible to carry out long-term monitoring at Building 2 because of circumstances beyond the control of Historic England.

4.2 Flaws and problems in project design and methodology

4.2.1 Project design

The two projects presented in this report exemplify challenges in undertaking in situ measurements and monitoring in case study properties. These include:

- uncertainties about the materials, form and condition of the existing construction
- lack of direct control and supervision of fabric improvements. There were workmanship problems at Building 1, and it was not possible to check that all improvements had been carried out correctly
- the large number of uncontrollable variables. In particular, internal and external environmental parameters
- the complexity of dynamic interactions of building fabric with internal and external environmental boundary conditions
- changes in building ownership and occupancy during the planned monitoring period.

Statistically relevant correlations between monitored parameters can therefore be difficult to identify. Changing aspirations or circumstances of building owners/occupiers may complicate matters still further. Therefore, a larger sample of buildings would have been preferable to: a) separately trial the different insulation systems, and b) provide a range of occupancy behaviour.

An alternative and more economical approach would be to monitor small scale wall panels in a test cell exposed to the same climatic conditions and a controlled internal environment (Whitman *et al*, 2022).

4.2.2 Thermal performance measurements

In general, the in situ U-value and airtightness tests were satisfactory as they were carried out in accordance with well-defined measurement and analysis procedures, including the estimation of uncertainties. The co-heating tests were partially satisfactory in terms of the measurement procedures. But a number of factors can lead to errors in calculating the whole house heat loss coefficient. Firstly, estimates of heat loss through party walls based on heat flux measurements may be inaccurate, where the temperature regime in the adjacent house is unknown. Secondly, in general, it is not possible to directly measure the whole house heat loss coefficient because of the influence of solar radiation on heat transfer in the building. Thirdly, different methods of data analysis can produce different results. These problems are discussed in detail in Rhee-Duverne & Baker (2015).

4.2.3 Hygrothermal monitoring

As previously stated, the monitoring methods proved satisfactory. However, using different insulation systems on different floors in the same building is unsatisfactory because a) it is not known how well the insulation systems are separated, and b) the environmental conditions on each floor could be different (although the environmental conditions in both buildings proved to be similar in all rooms apart from the bathrooms).

At Building 1: New Bolsover, although the brickwork was in fair condition, there were many open joints and voids in the core of the walls. Repointing was therefore recommended as part of the fabric improvements. Unfortunately, this work was not carried out. Significant air infiltration through the brickwork was observed when the walls were stripped of plaster prior to the installation of IWI. This may have affected the hygrothermal behaviour of the ground floor walls, where PIR insulation was fixed on timber battens, leaving a small air gap between its cold side and the wall. Conversely, on the upper floor, a parge coat of lime plaster was applied to the walls before installing the wood fibre insulation. This prevented the ingress of air through gaps in the mortar joints. It is not clear from the data how the respective behaviour of the two systems may have been affected by these differences.

5.0 RECOMMENDATIONS FOR FUTURE WORK

Historic buildings may be harmed by climate change and associated adaptation. Numerical simulation programs such as WUFI® can be used to assess the potential risk. But long-term monitoring of hygrothermal behaviour of building elements and assemblies is necessary for model validation. Developing a reduced set of monitoring protocols augmented by periodic assessments using infrared thermography and microwave moisture surveys (Orr, 2021) would be of value. However, as the projects presented in this report demonstrate, there are challenges in analysing and interpreting data collected from case study buildings. Therefore, it is recommended that for future work more controllable and repeatable assessment methodologies are devised (Whitman, *et al* 2022).

It is also recommended that, if possible, U-value measurements at Building 2 are repeated during the 2022/23 heating season. At the same time, hygrothermal monitoring data should also be collected. This additional data will provide a better understanding of the performance of the building envelope, as its fabric should by then have dried down to normal equilibrium moisture contents. The findings should then be published as an addendum to this report.

6.0 REFERENCES

Baker, P and Rhee-Duverne, S *Sensitivity analysis of WUFI® simulations of a traditional brick building,* Historic England (unpublished)

HM Government Approved Document L1A 2010 *Conservation of fuel and power in new dwellings. The Building Regulations*, ISBN 978 1 85946 324 6

Orr, S. A 2021 *Moisture Measurement in the Historic Environment*, Technical Paper 35, Historic Environment Scotland

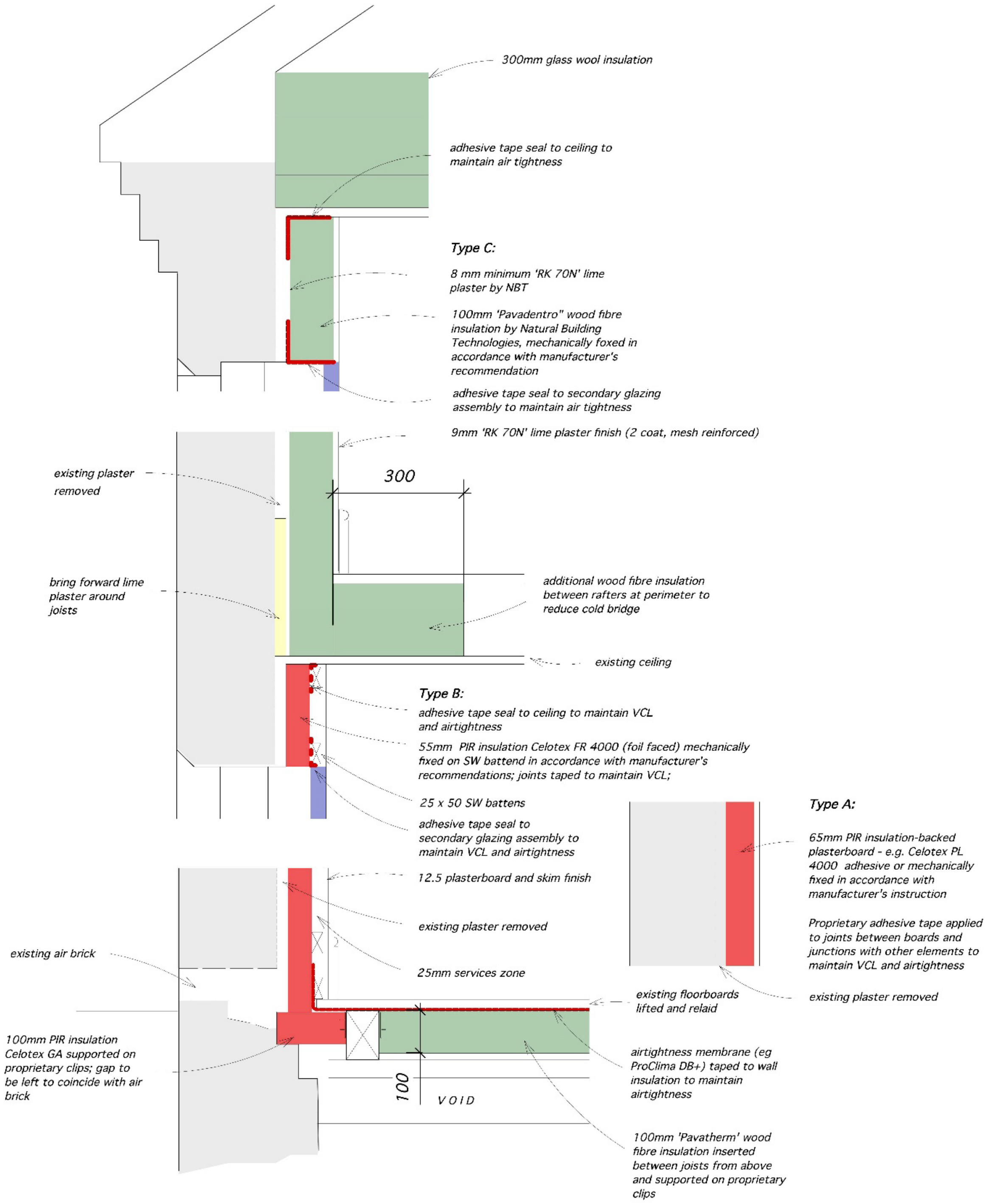
Rhee-Duverne, S and Baker, P 2015 *A Retrofit of a Victorian Terrace House in New Bolsover: A Whole House Thermal Performance Assessment*, Historic England

Ridout, B and McCaig, I 2016 *Measuring Moisture Content in Historic Building Materials,* Historic England

Whitman, C; Prizeman, O; Walker, P; Rhee-Duverne, S; McCaig, I 2022 *Hygrothermal Monitoring of Replacement Infill Panels for Historic Timber-Frame Buildings: Initial Findings*, UCL Open: Environment Preprint

APPENDIX A1

Building 1: New Bolsover
Details of fabric improvements



APPENDIX A2

Building 1: New Bolsover
Indoor and outdoor conditions

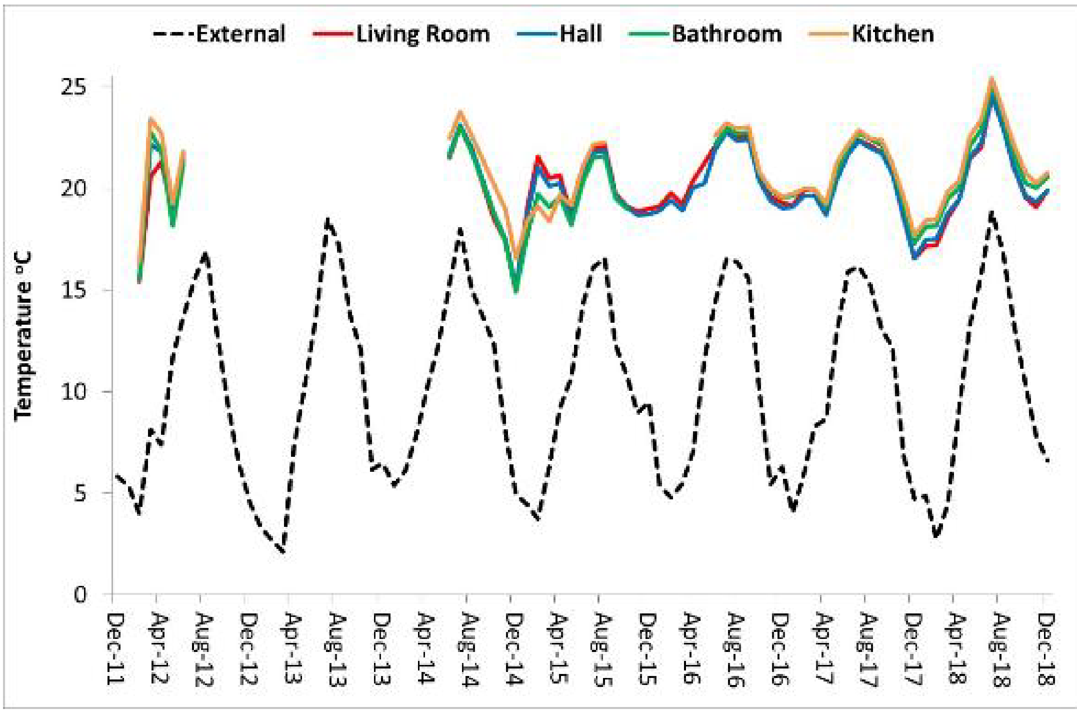


Figure A1.1: Ground floor room and external temperatures.

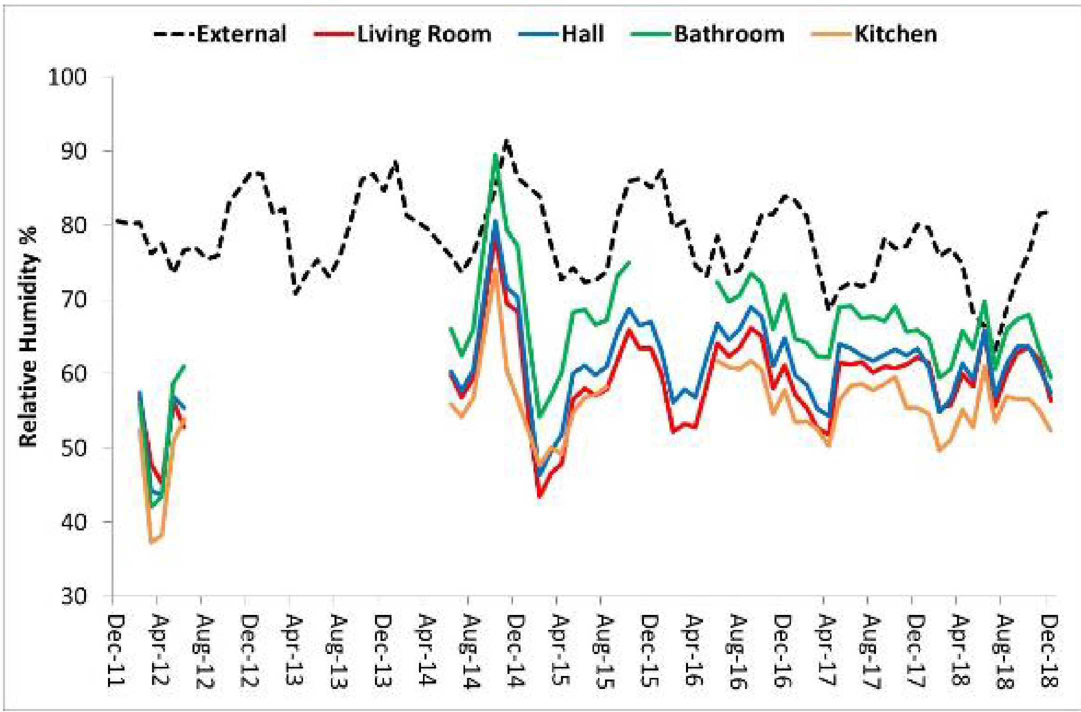


Figure A2.2: Ground floor room and external RHs.

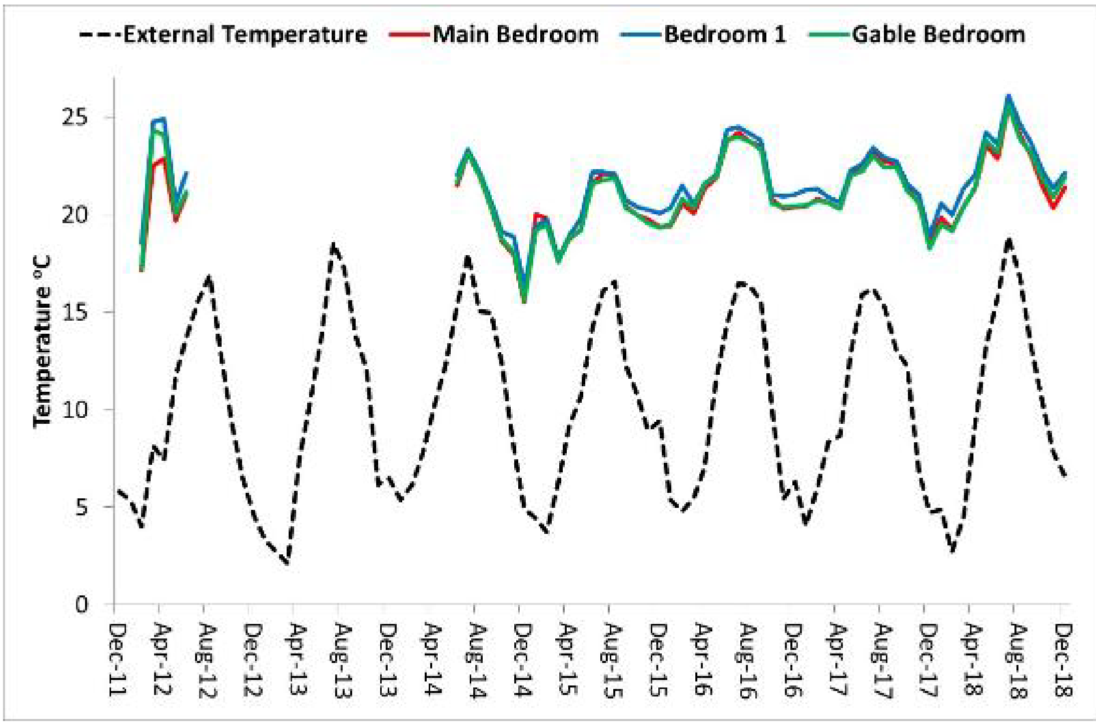


Figure A2.3: First floor room and external temperatures.

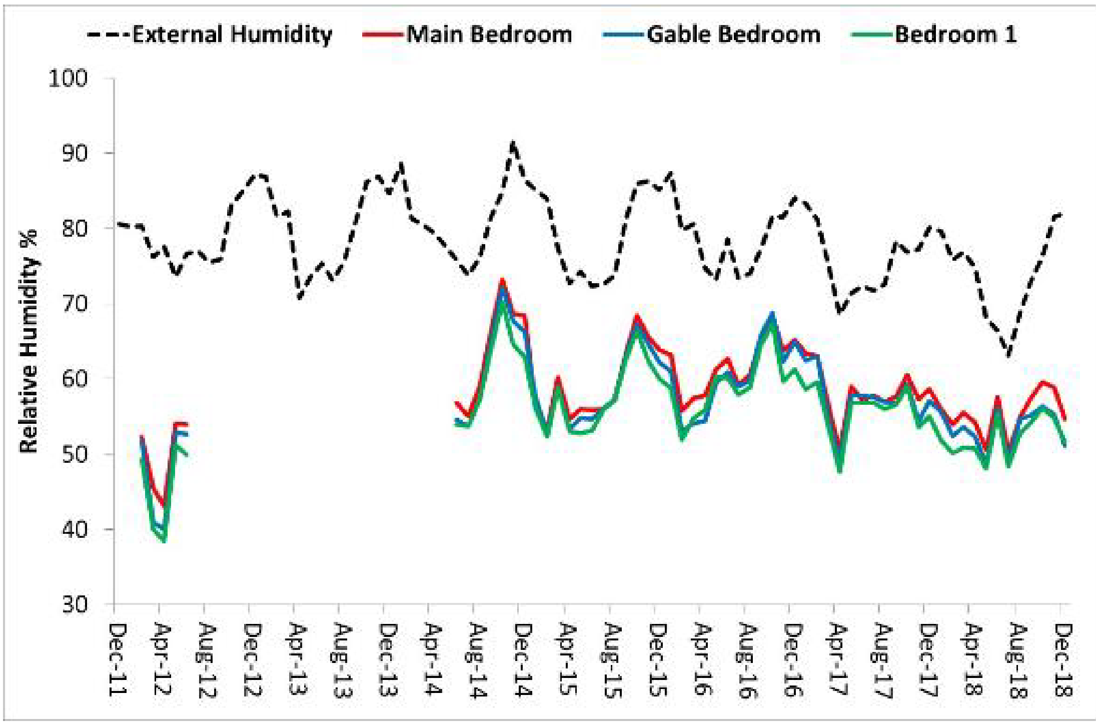


Figure A2.4: First floor room and external RHs.

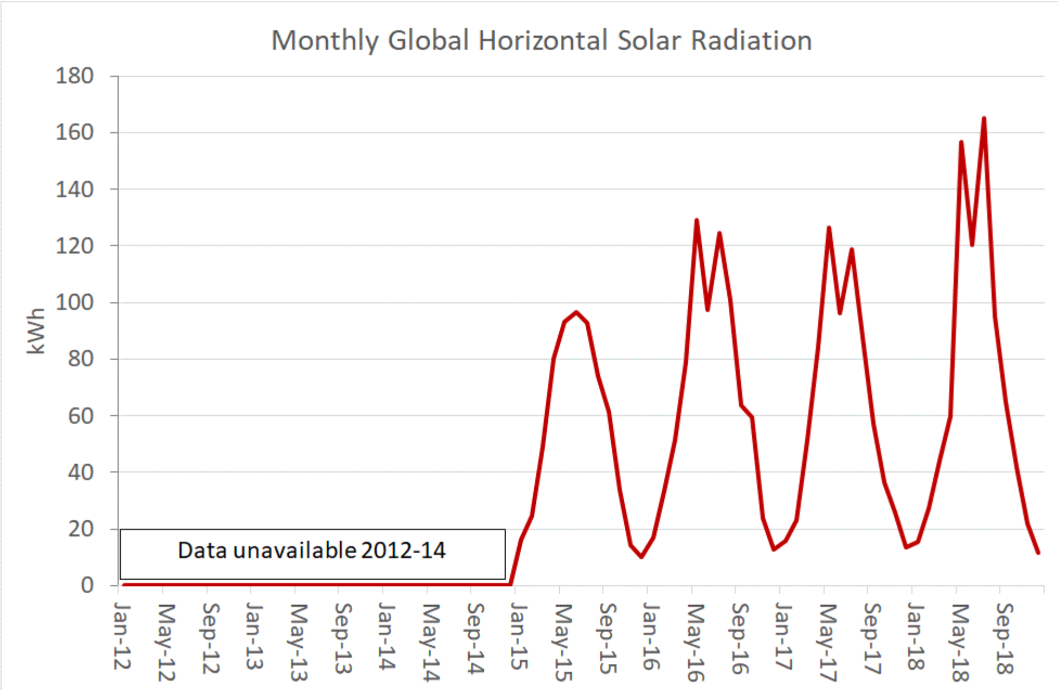


Figure A2.5: Monthly global horizontal solar radiation data from Watnall.

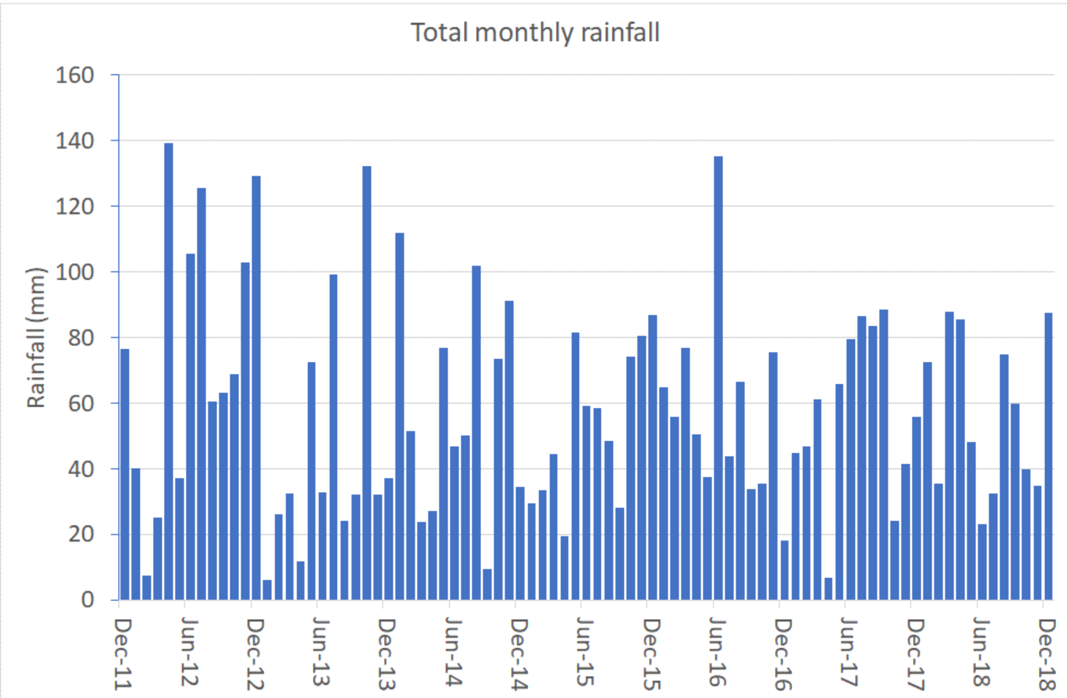


Figure A2.6: Total monthly rainfall data from Watnall.

APPENDIX A3

Building 1: New Bolsover

Plots of Interface, Room & External Conditions by Measurement Location

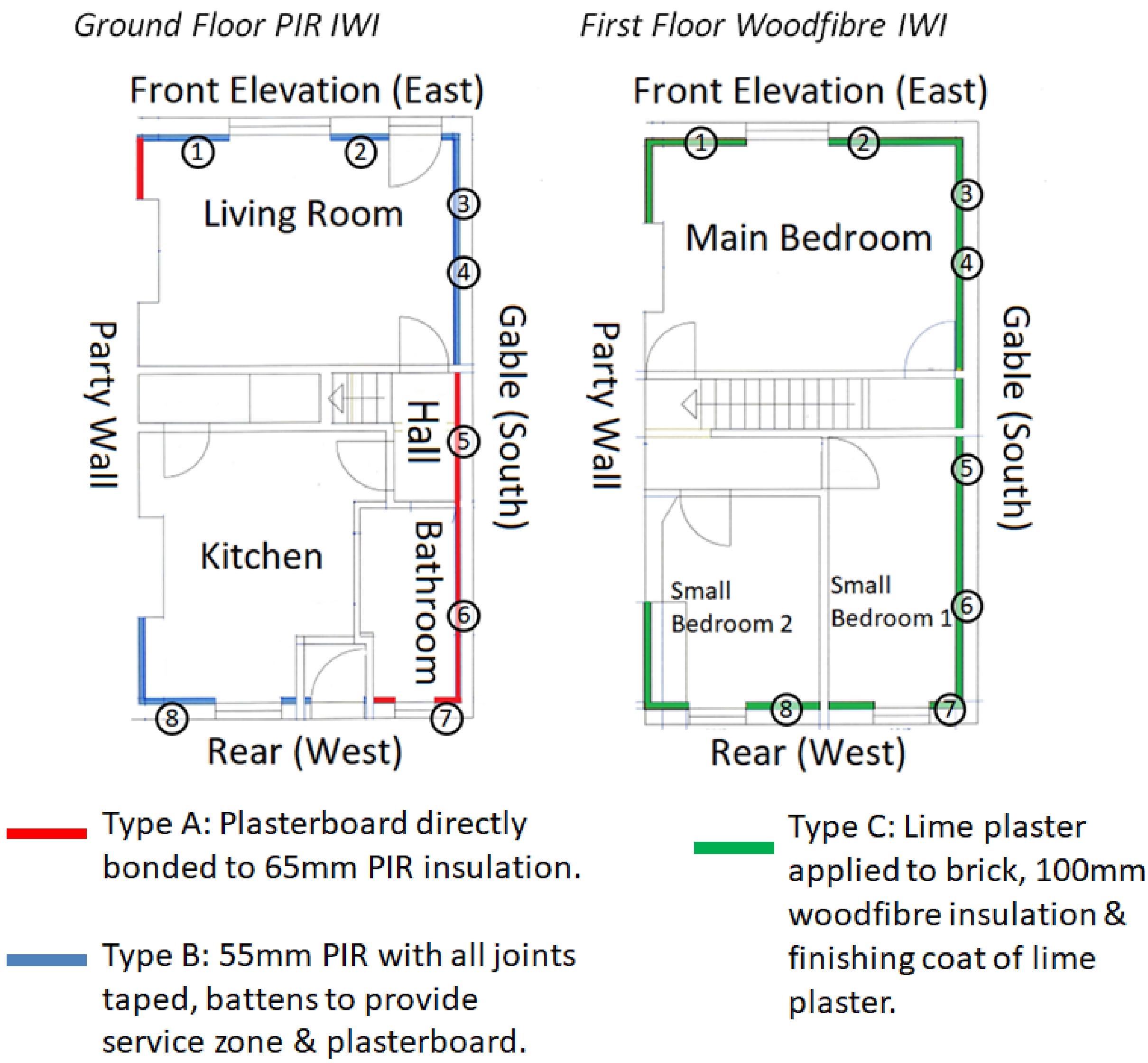
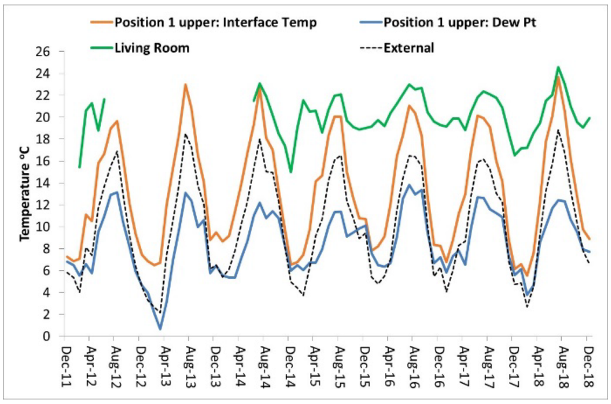
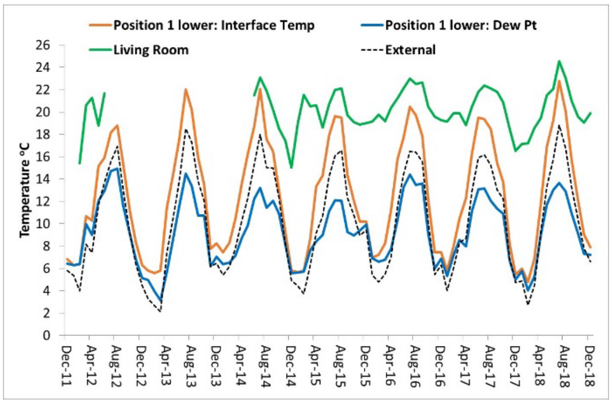


Figure A3.1: Locations of the internal wall insulation systems and the monitoring positions. Left: ground floor with PIR; right: first floor with wood fibre system.

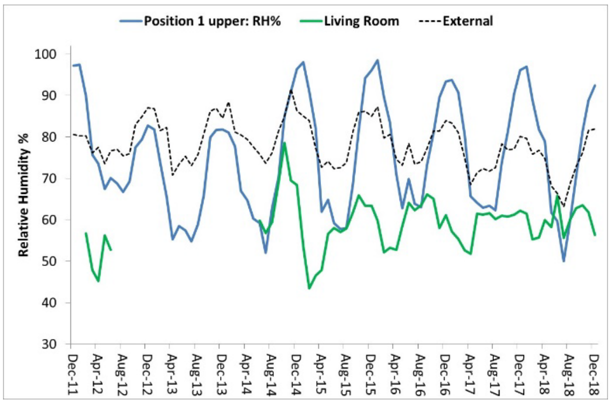
Figure A3.2: Ground Floor Position 1 - Living Room Front Elevation with PIR IWI.



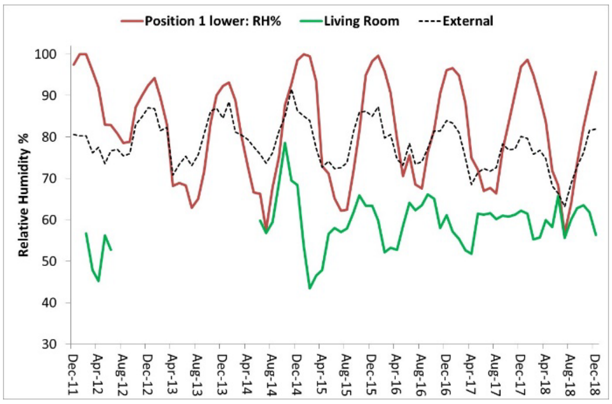
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



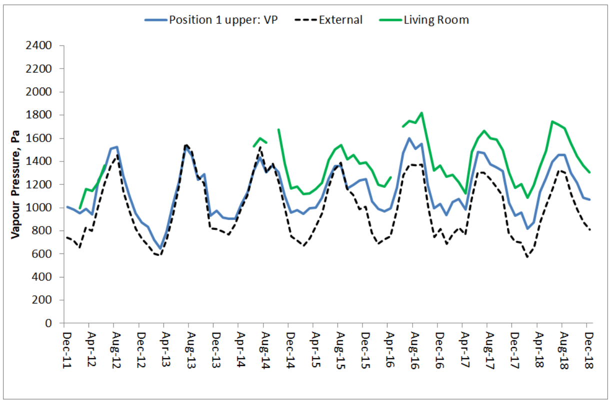
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



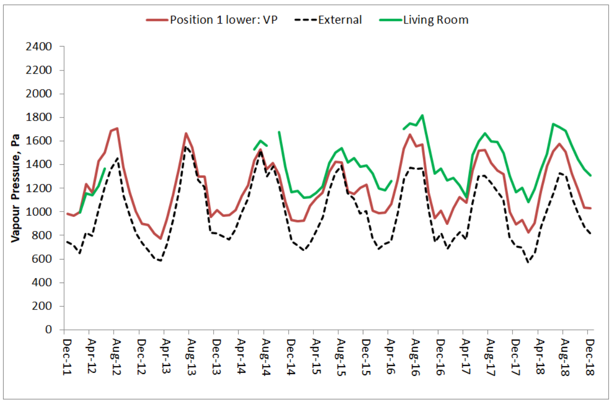
(c) Upper sensor: measured interface, room and external RHs.



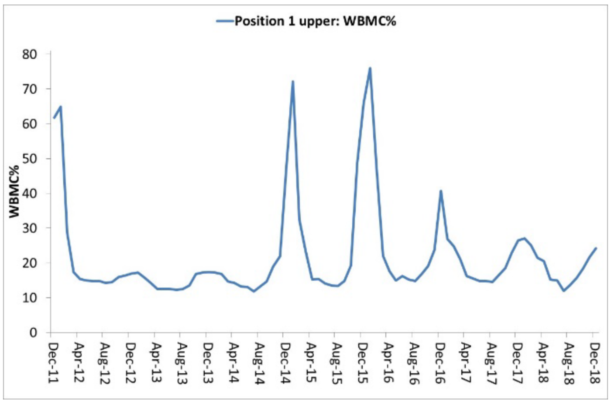
(d) Lower sensor: measured interface, room and external RHs.



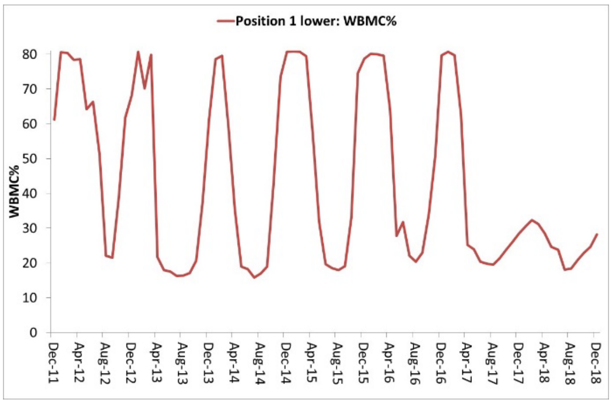
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

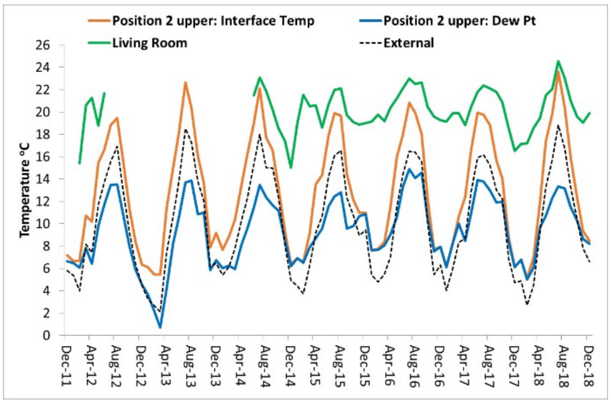


(g) Upper position: wood block moisture contents at the interface.

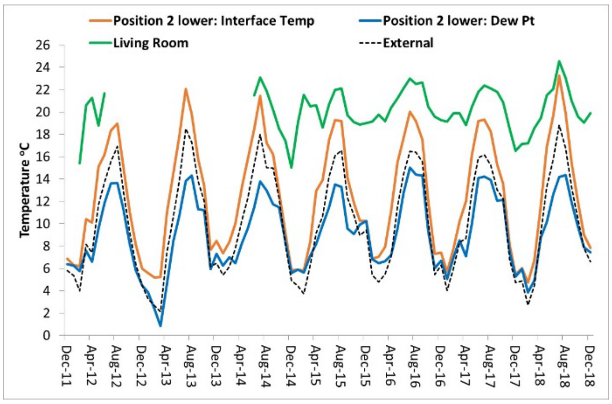


(h) Lower position: wood block moisture contents at the interface.

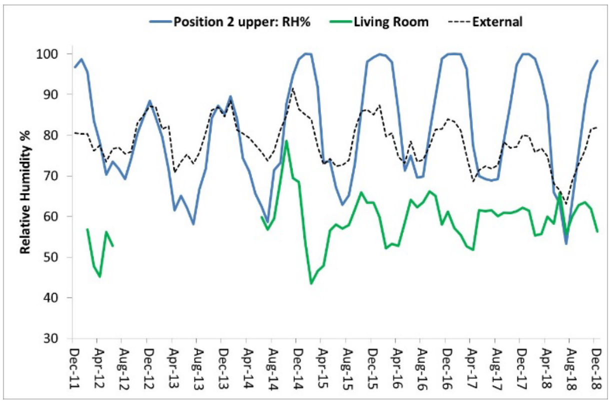
Figure A3.3: Ground Floor Position 2 - Living Room Front Elevation with PIR IWI.



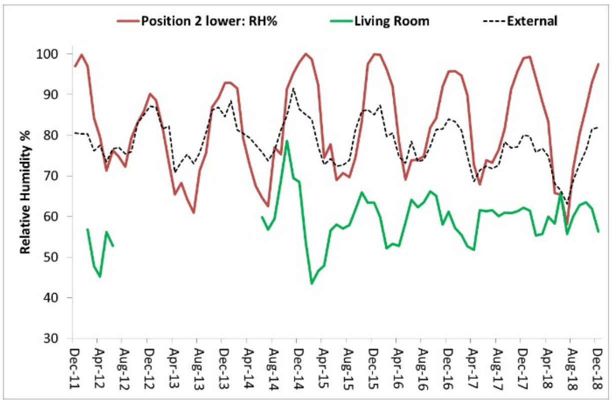
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



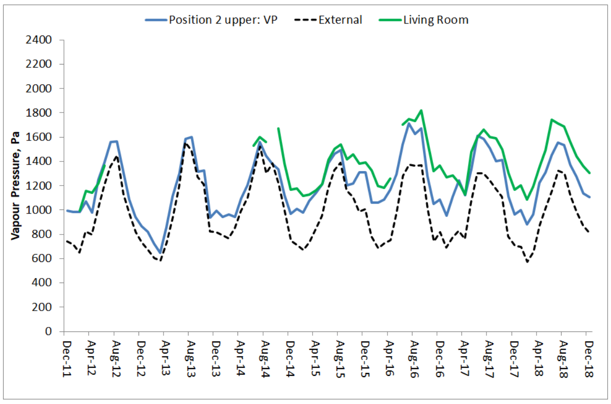
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



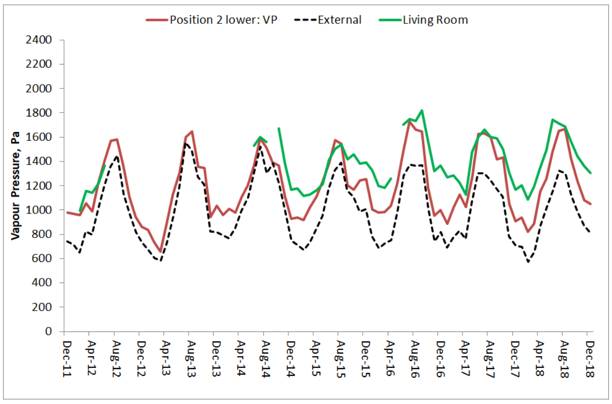
(c) Upper sensor: measured interface, room and external RHs.



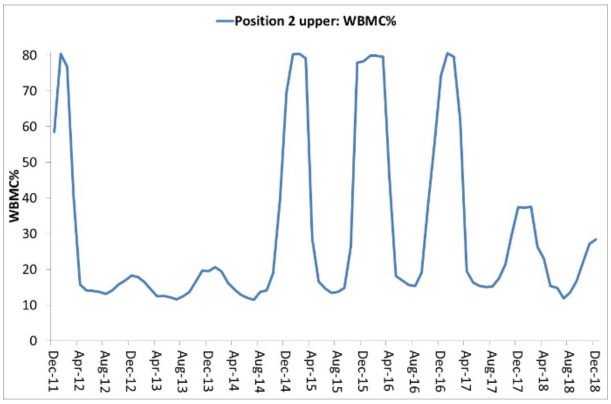
(d) Lower sensor: measured interface, room and external RHs.



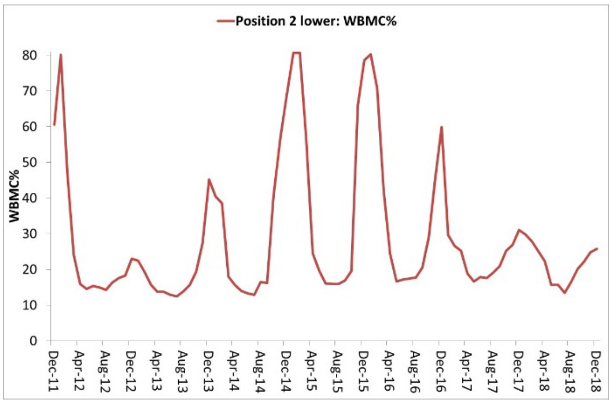
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

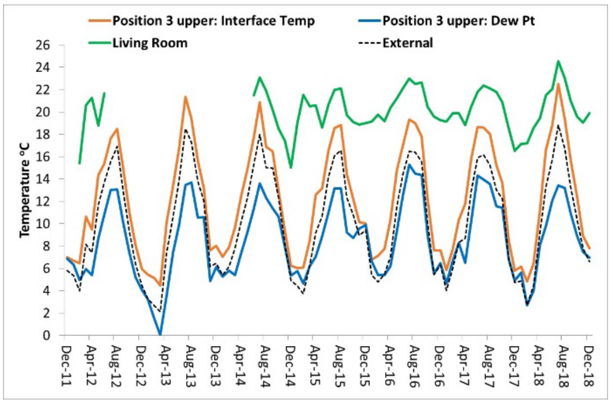


(g) Upper position: wood block moisture contents at the interface.

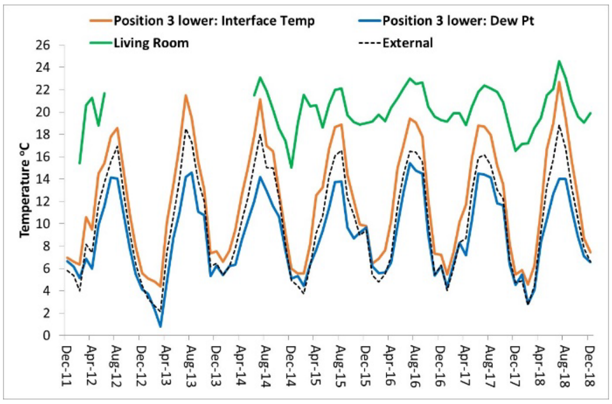


(h) Lower position: wood block moisture contents at the interface.

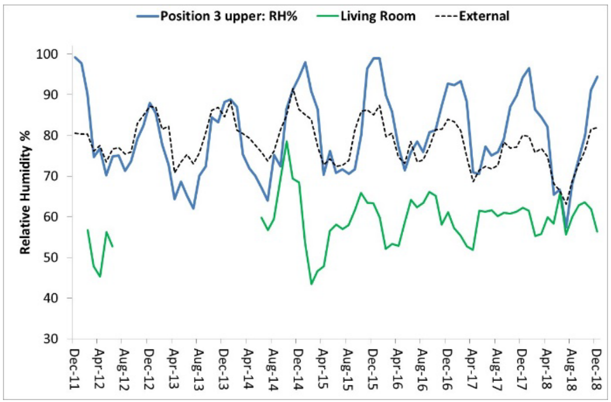
Figure A3.4: Ground Floor Position 3 - Living Room Gable Wall with PIR IWI.



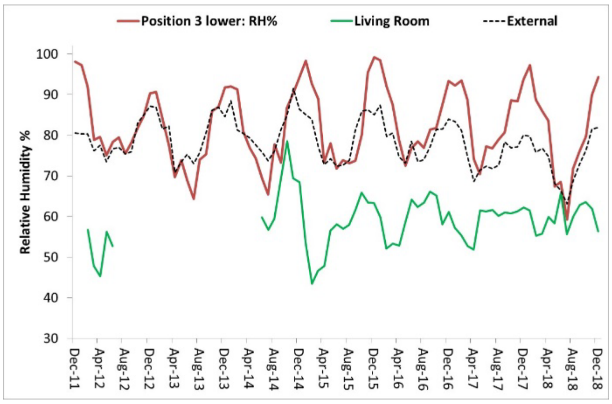
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



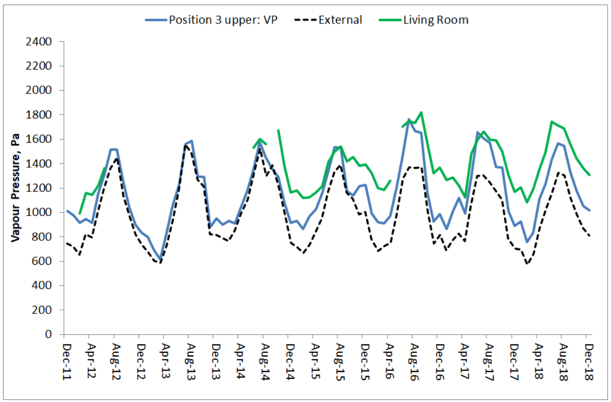
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



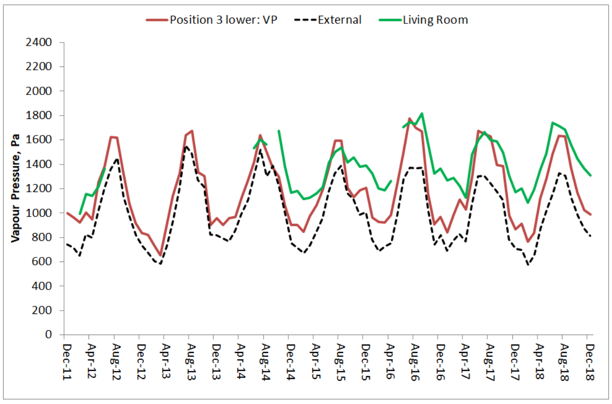
(c) Upper sensor: measured interface, room and external RHs.



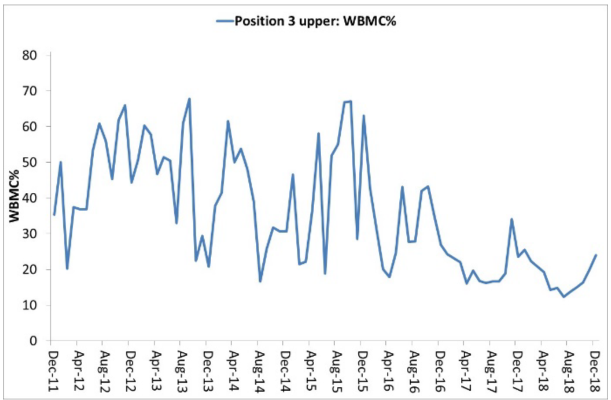
(d) Lower sensor: measured interface, room and external RHs.



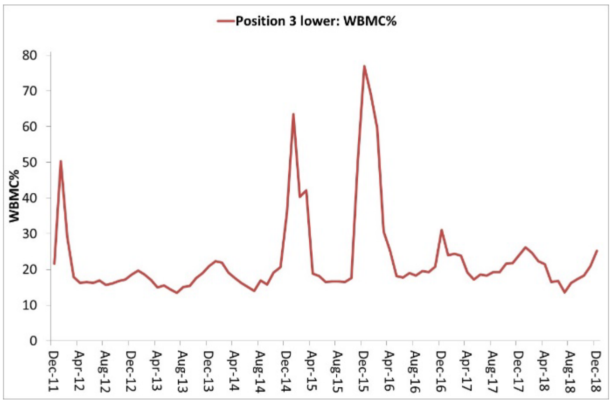
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

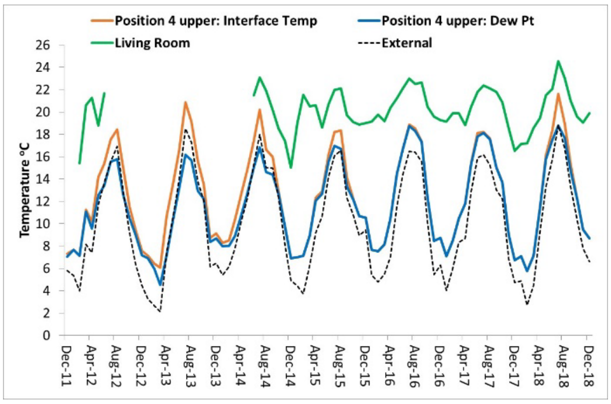


(g) Upper position: wood block moisture contents at the interface.

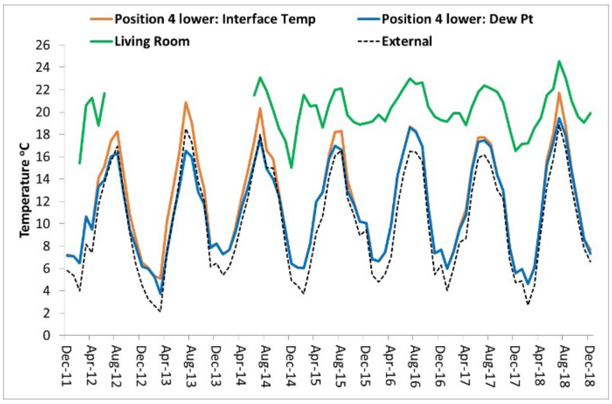


(h) Lower position: wood block moisture contents at the interface.

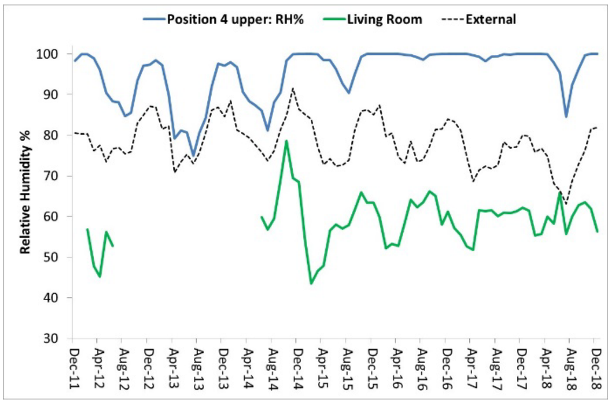
Figure A3.5: Ground Floor Position 4 - Living Room Gable Wall with PIR IWI



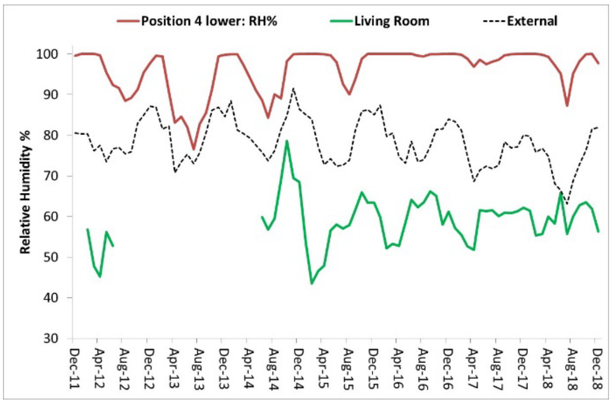
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



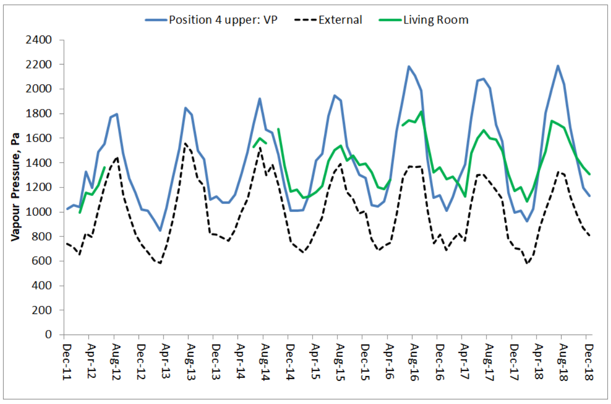
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



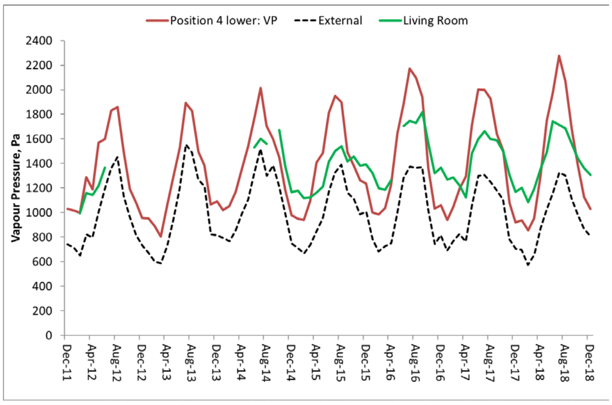
(c) Upper sensor: measured interface, room and external RHs.



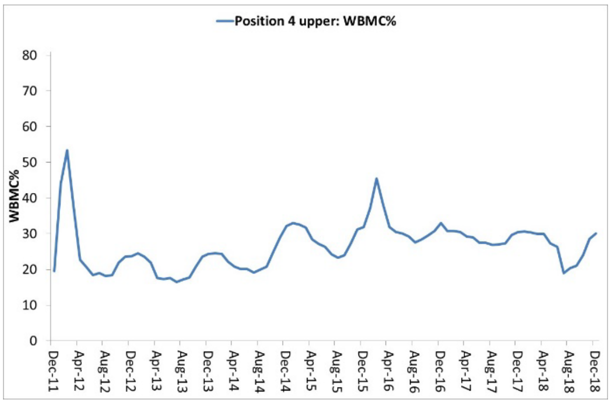
(d) Lower sensor: measured interface, room and external RHs.



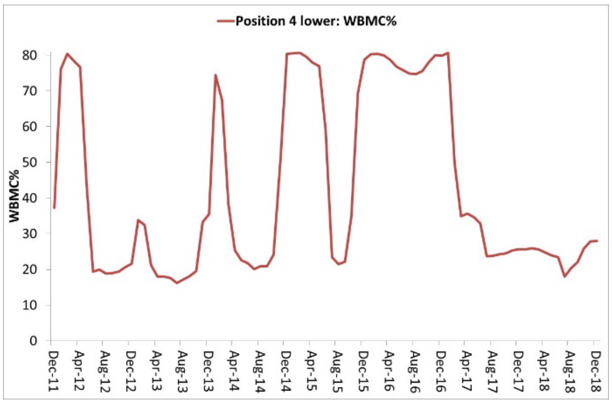
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

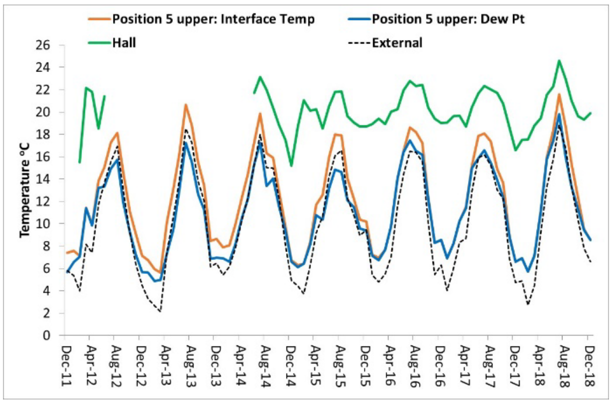


(g) Upper position: wood block moisture contents at the interface.

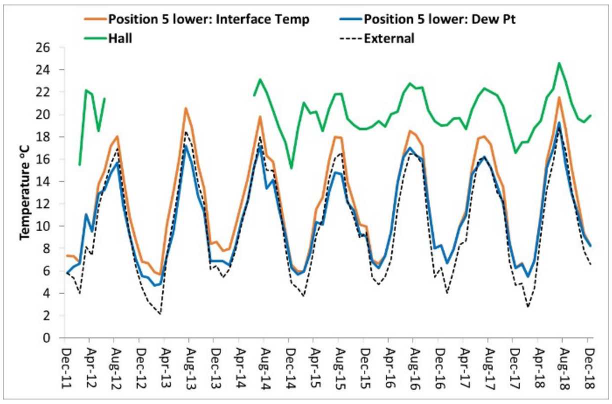


(h) Lower position: wood block moisture contents at the interface.

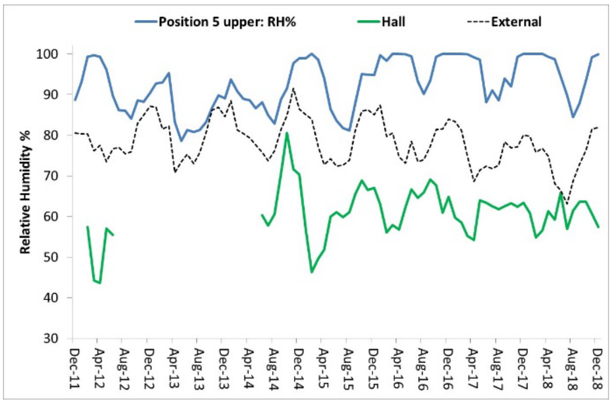
Figure A3.6: Ground Floor Position 5 - Hall Gable Wall with PIR IWI



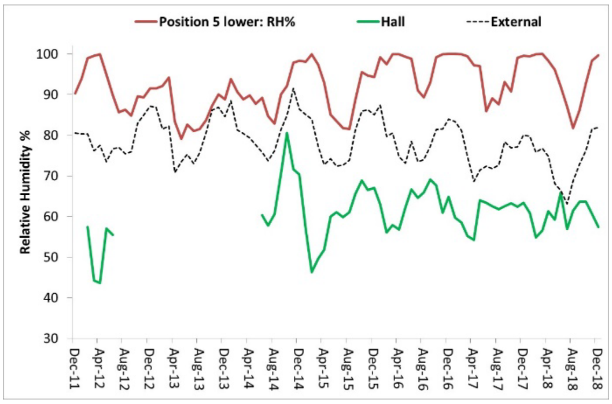
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



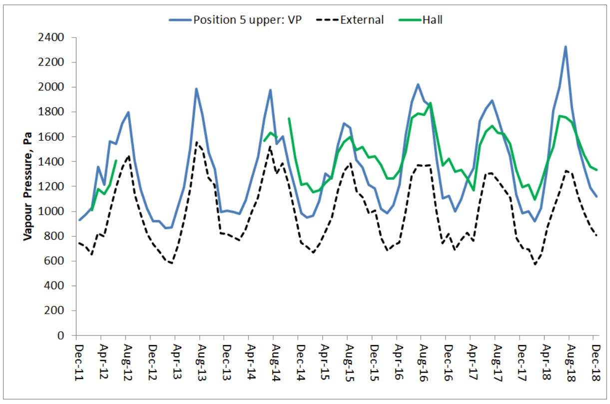
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



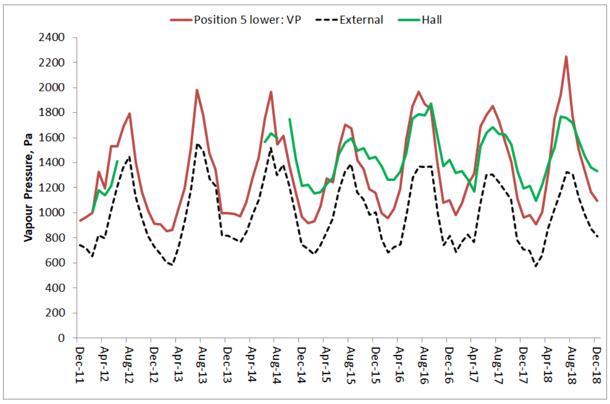
(c) Upper sensor: measured interface, room and external RHs.



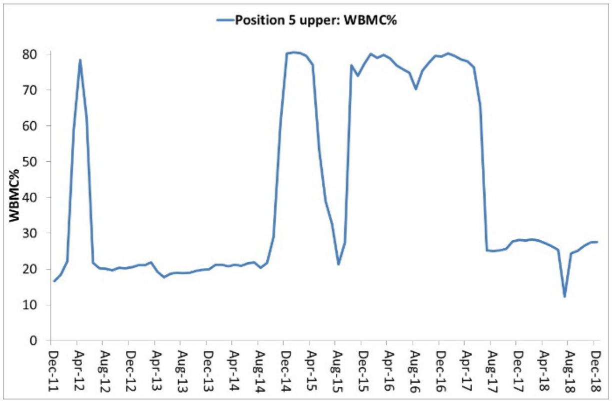
(d) Lower sensor: measured interface, room and external RHs.



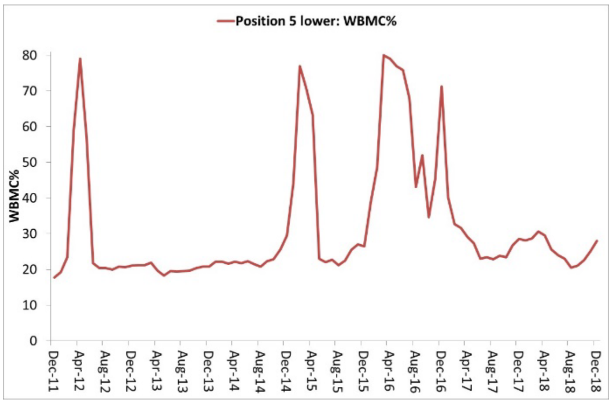
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

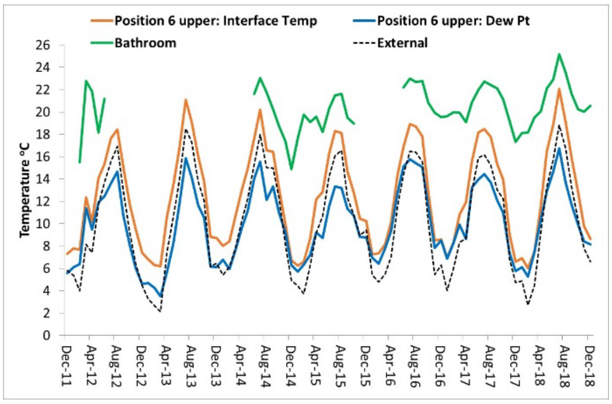


(g) Upper position: wood block moisture contents at the interface.

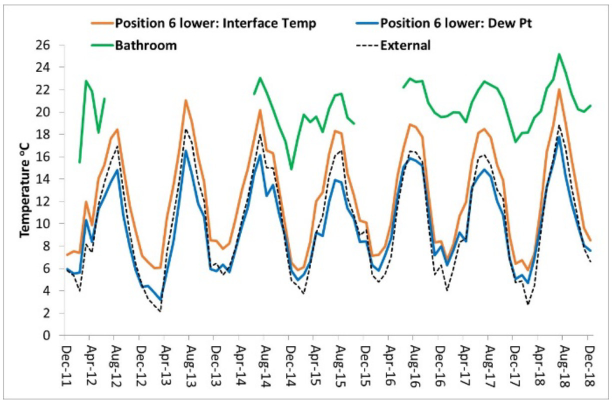


(h) Lower position: wood block moisture contents at the interface.

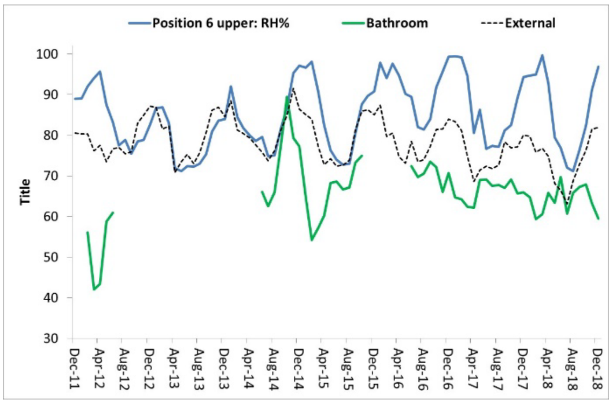
Figure A3.7: Ground Floor Position 6 - Bathroom Gable Wall with PIR IWI.



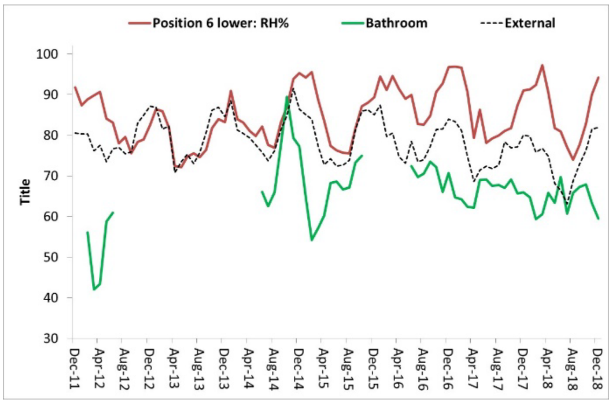
(c) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



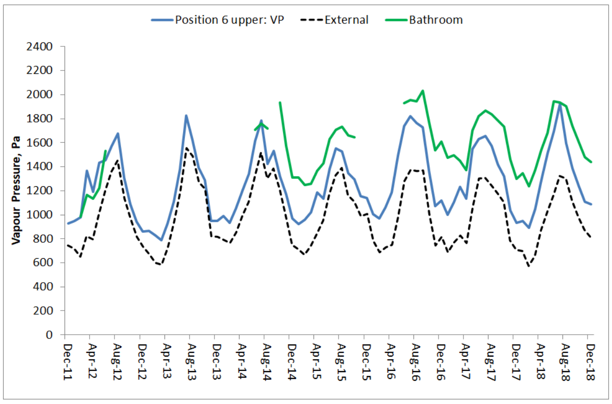
(d) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



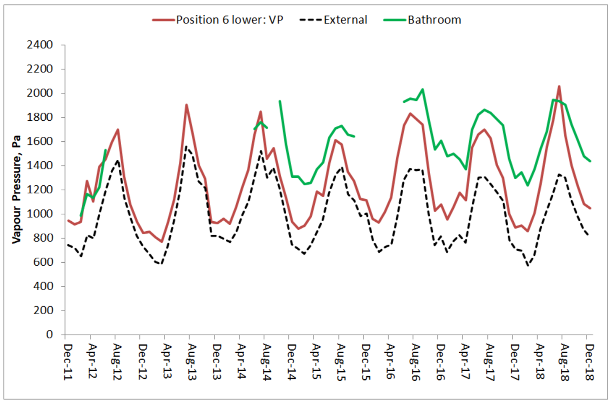
(c) Upper sensor: measured interface, room and external RHs.



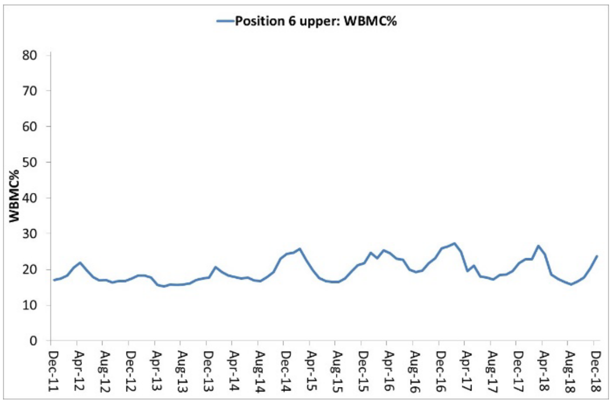
(d) Lower sensor: measured interface, room and external RHs.



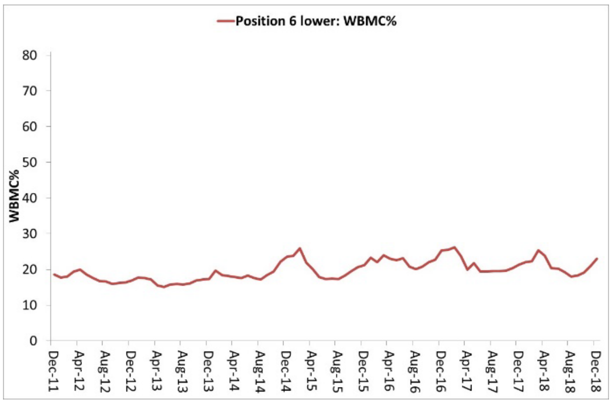
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

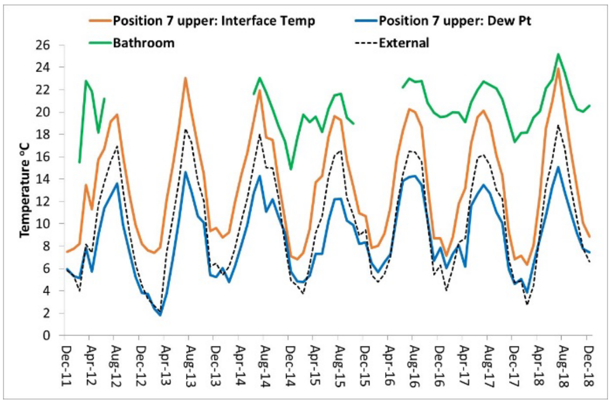


(g) Upper position: wood block moisture contents at the interface.

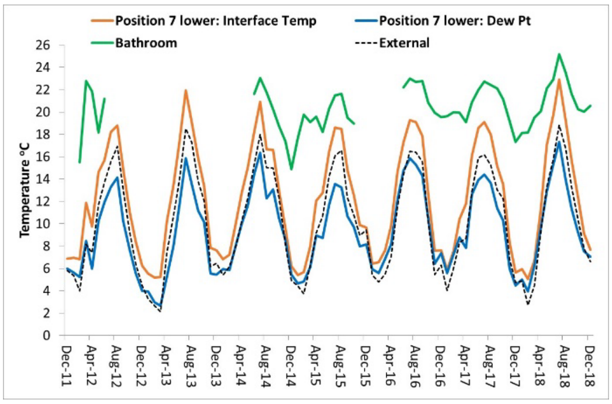


(h) Lower position: wood block moisture contents at the interface.

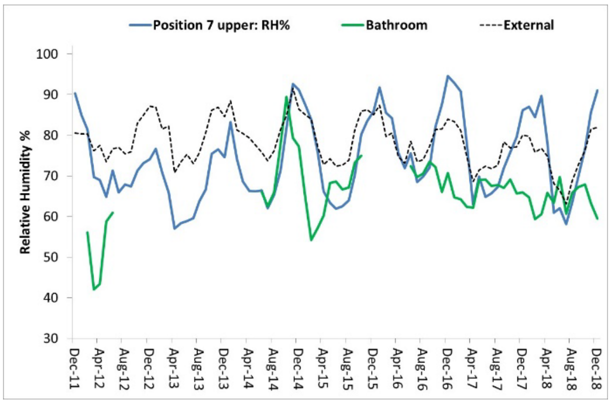
Figure A3.8: Ground Floor Position 7 - Bathroom Rear Elevation with PIR IWI.



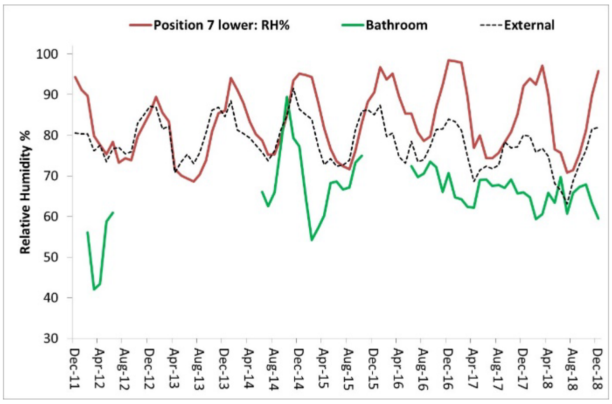
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



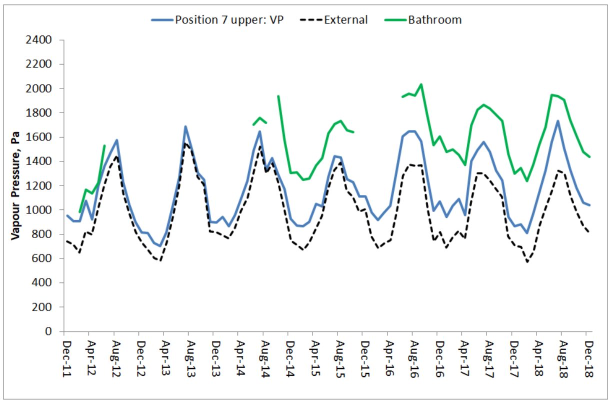
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



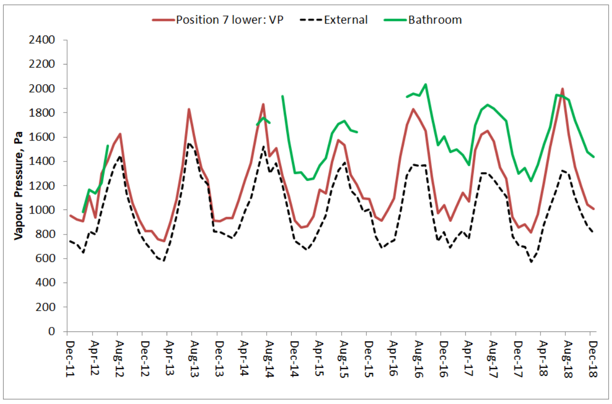
(c) Upper sensor: measured interface, room and external RHs.



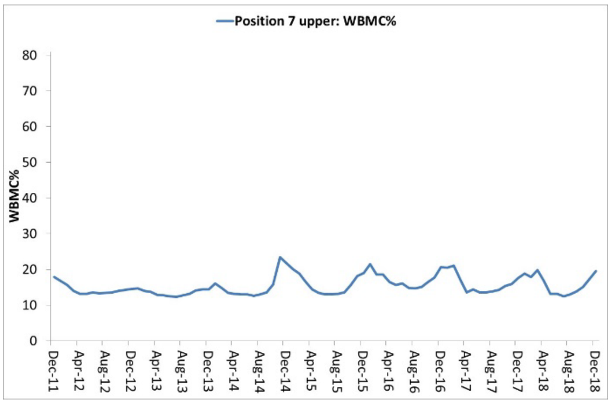
(d) Lower sensor: measured interface, room and external RHs.



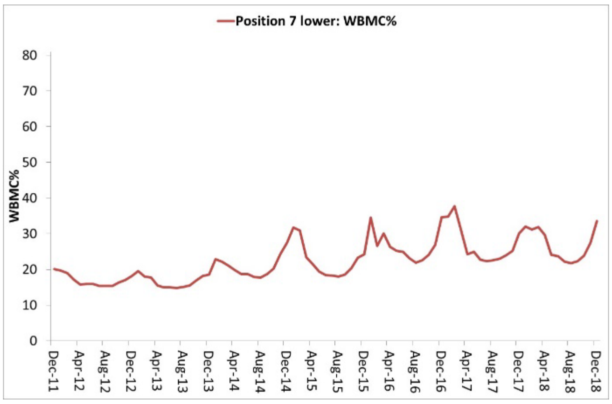
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

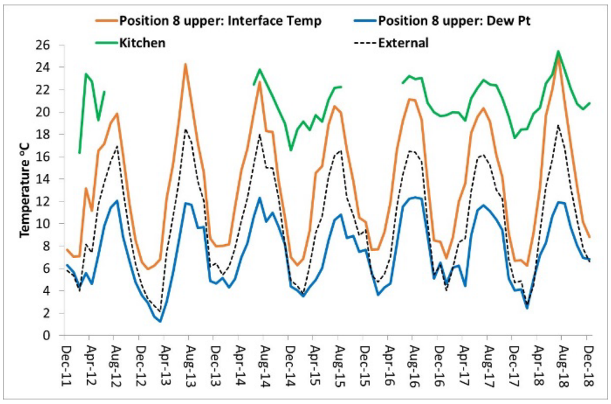


(g) Upper position: wood block moisture contents at the interface.

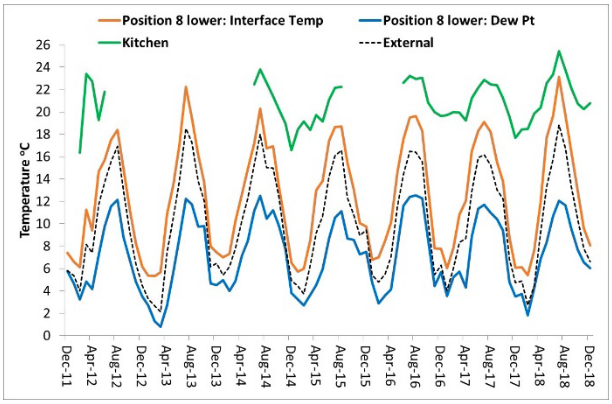


(h) Lower position: wood block moisture contents at the interface.

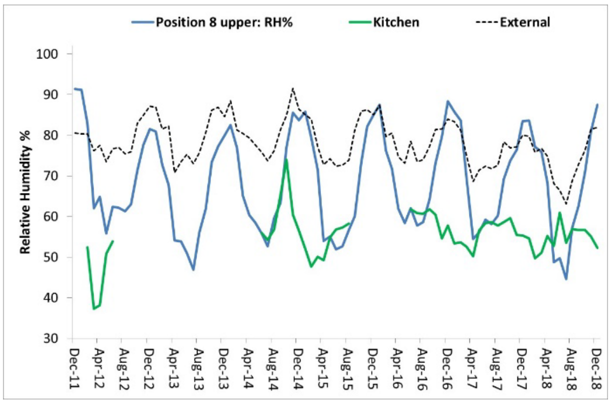
Figure A3.9: Ground Floor Position 8 - Kitchen Rear Elevation with PIR IWI.



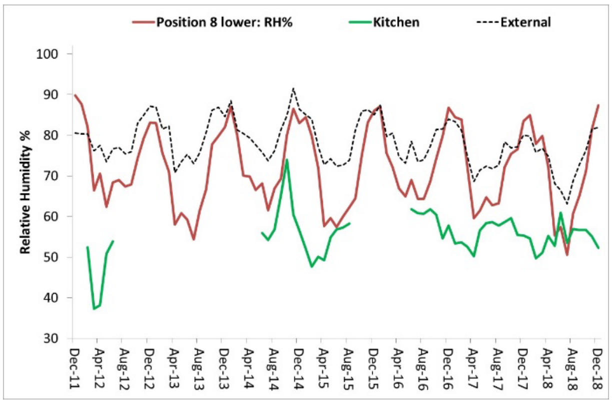
(b) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



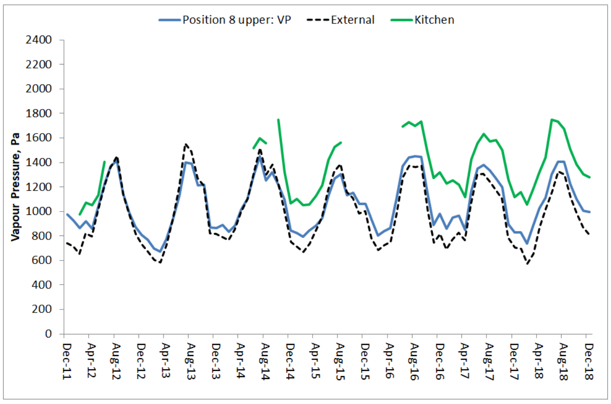
(c) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



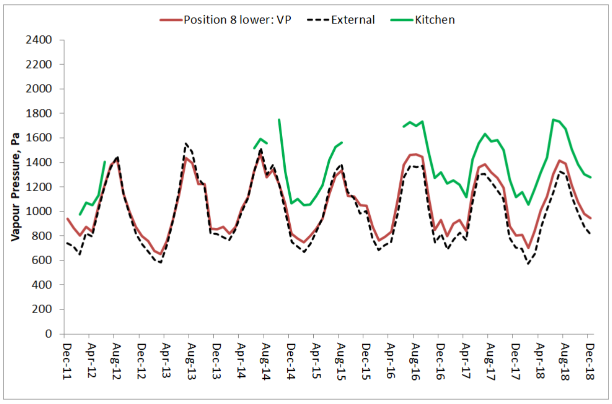
(c) Upper sensor: measured interface, room and external RHs.



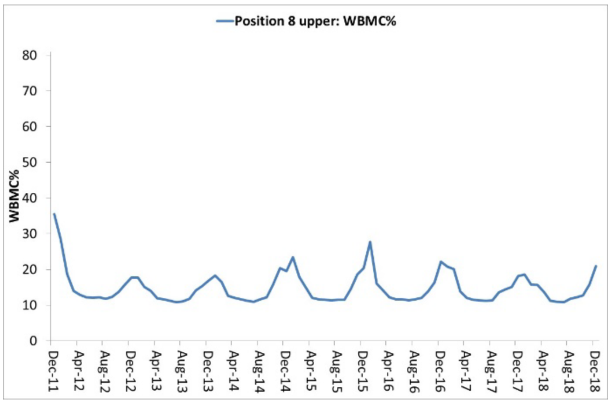
(d) Lower sensor: measured interface, room and external RHs.



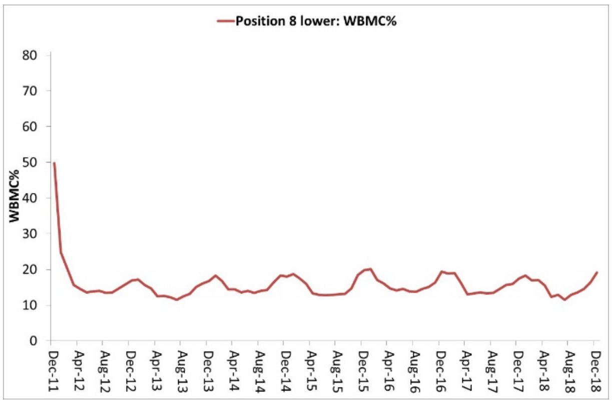
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

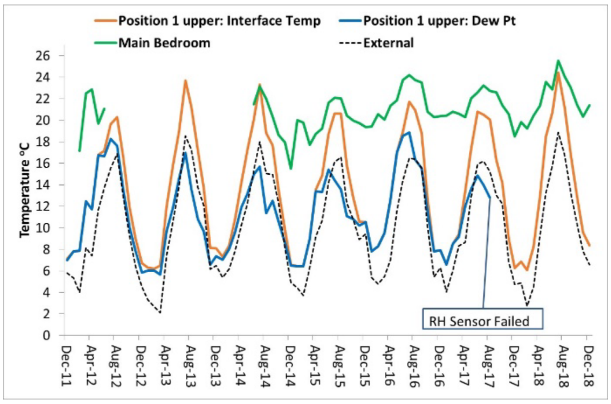


(g) Upper position: wood block moisture contents at the interface.

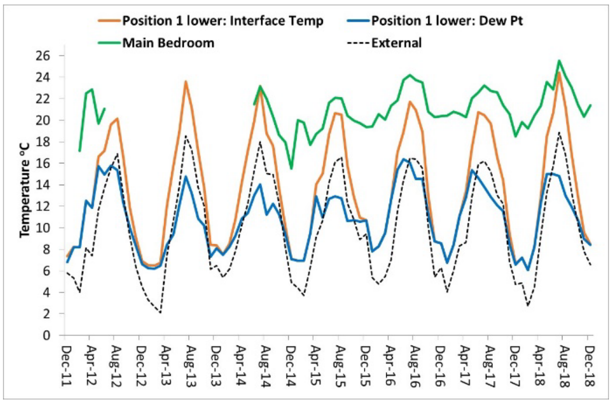


(h) Lower position: wood block moisture contents at the interface.

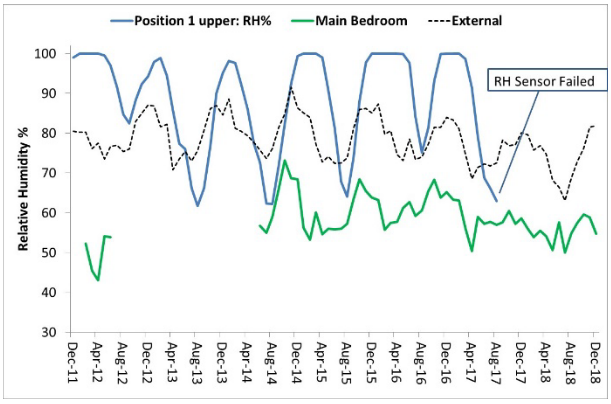
Figure A3.10: First Floor Position 1 - Main Bedroom Front Elevation with Woodfibre IWI.



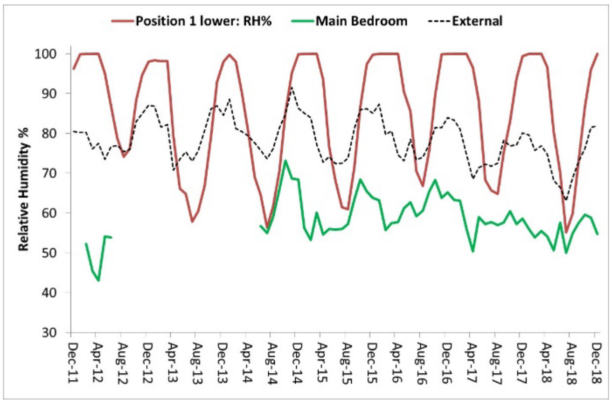
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



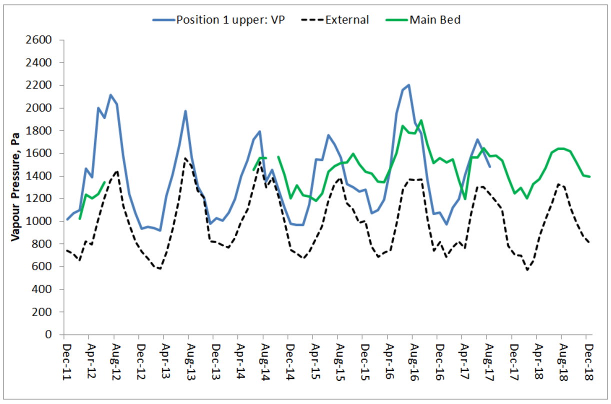
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



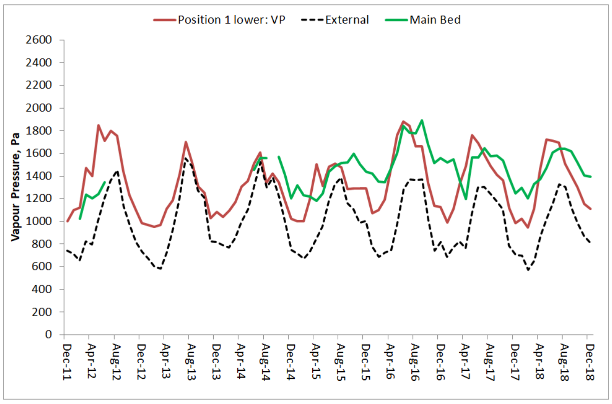
(c) Upper sensor: measured interface, room and external RHs.



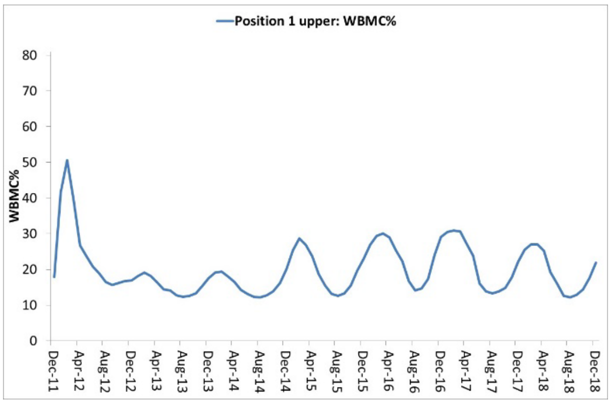
(d) Lower sensor: measured interface, room and external RHs.



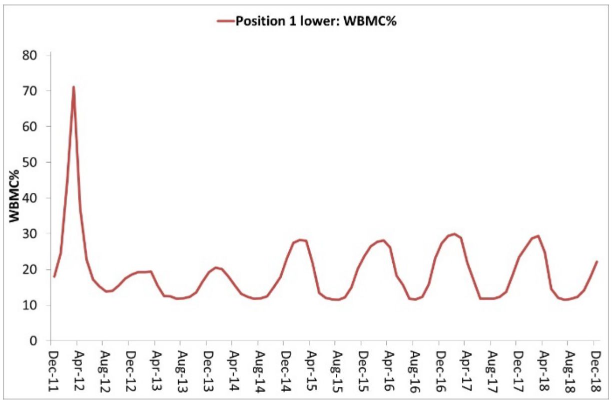
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

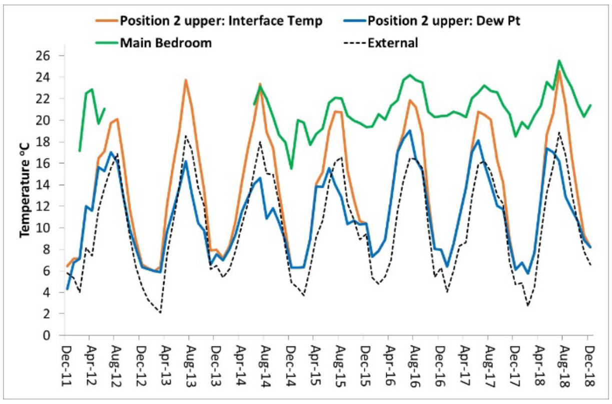


(g) Upper position: wood block moisture contents at the interface.

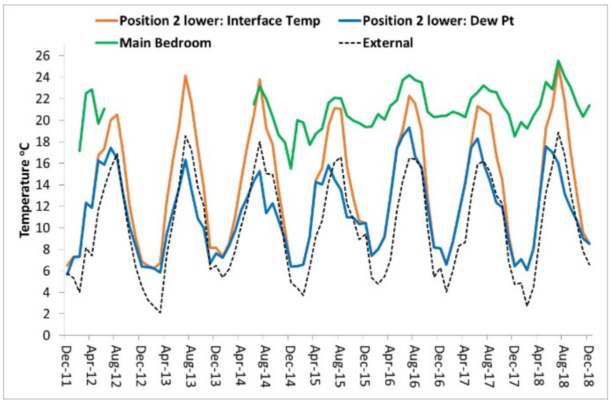


(h) Lower position: wood block moisture contents at the interface.

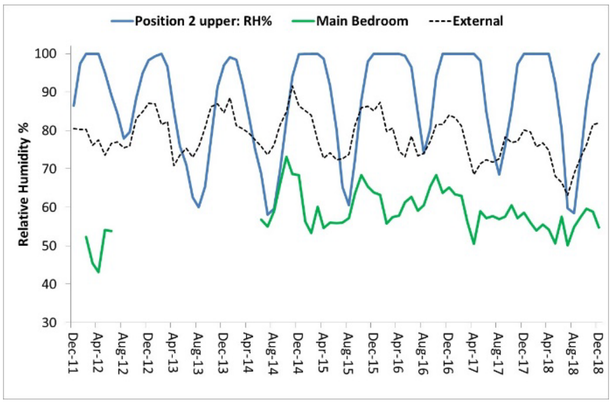
Figure A3.11: First Floor Position 2 - Main Bedroom Front Elevation with Woodfibre IWI



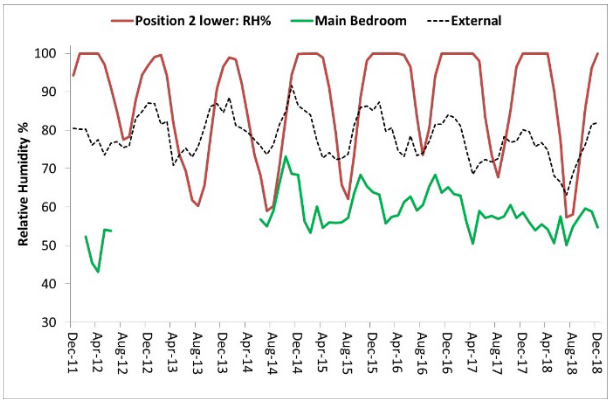
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



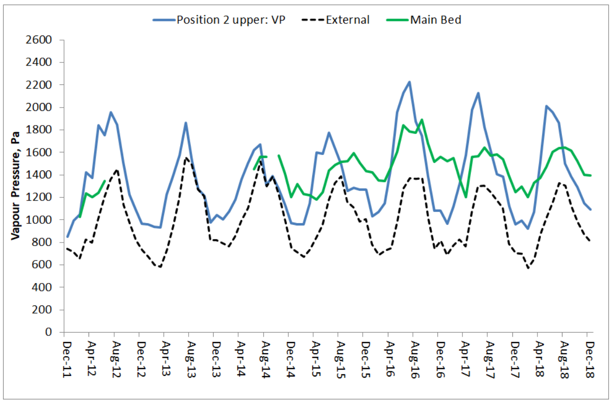
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



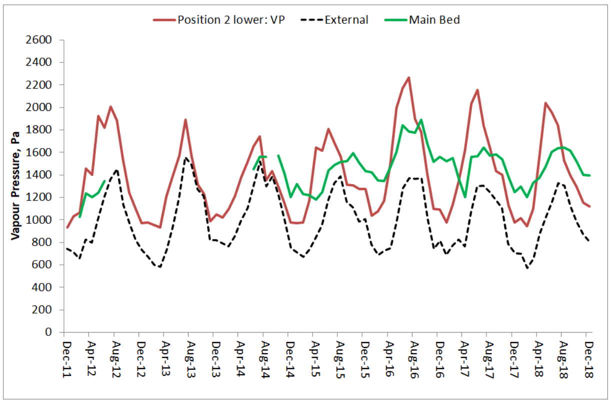
(c) Upper sensor: measured interface, room and external RHs.



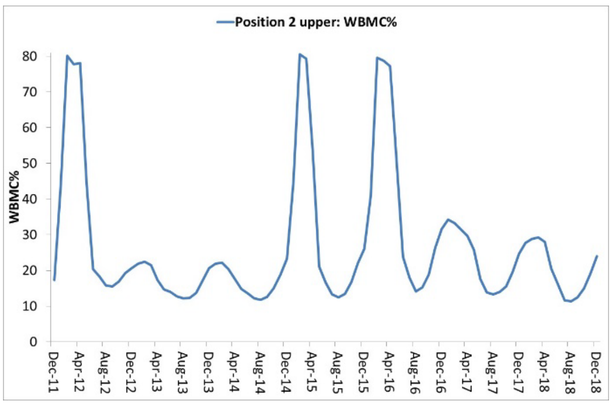
(d) Lower sensor: measured interface, room and external RHs.



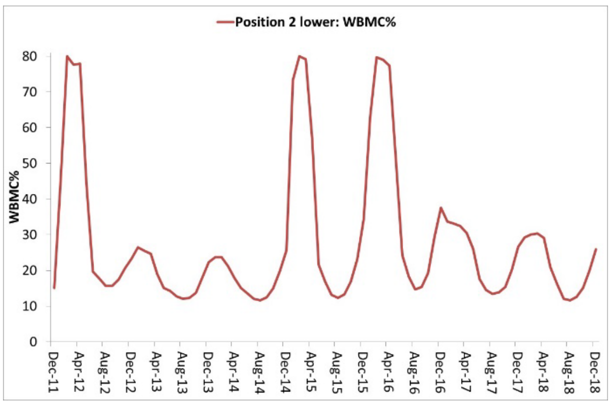
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

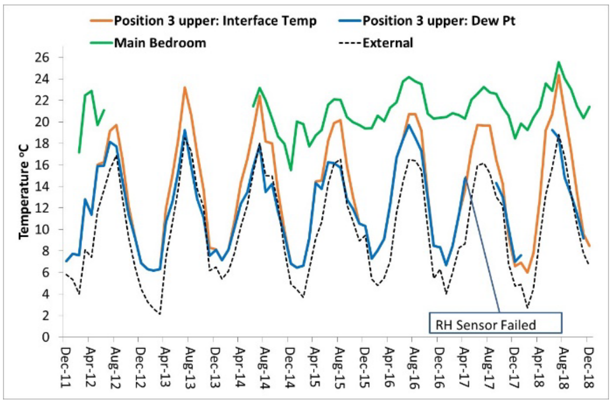


(g) Upper position: wood block moisture contents at the interface.

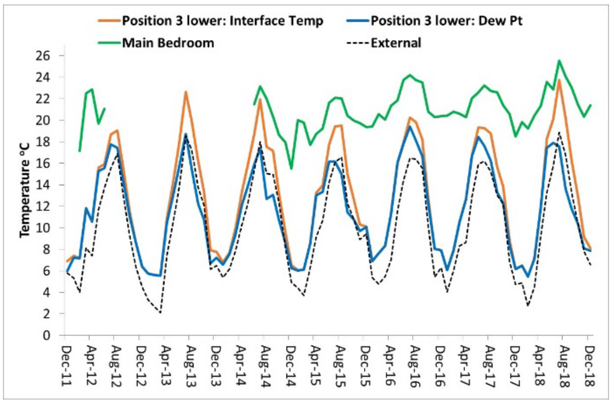


(h) Lower position: wood block moisture contents at the interface.

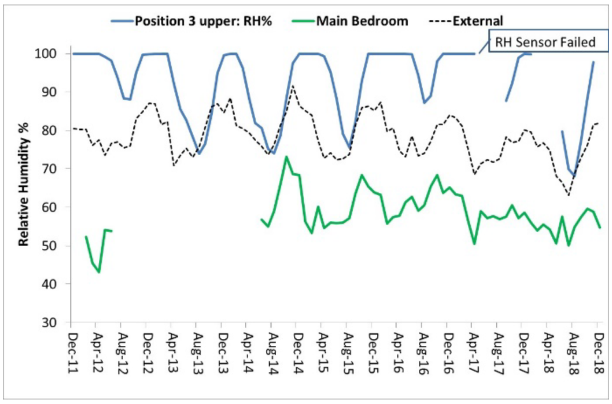
Figure A3.12: First Floor Position 3 - Main Bedroom Gable Wall with Woodfibre IWI.



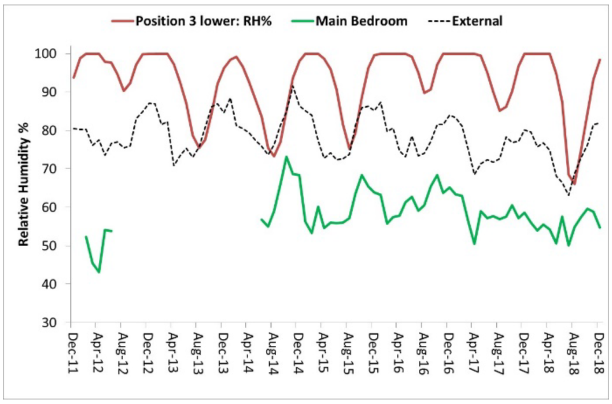
(e) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



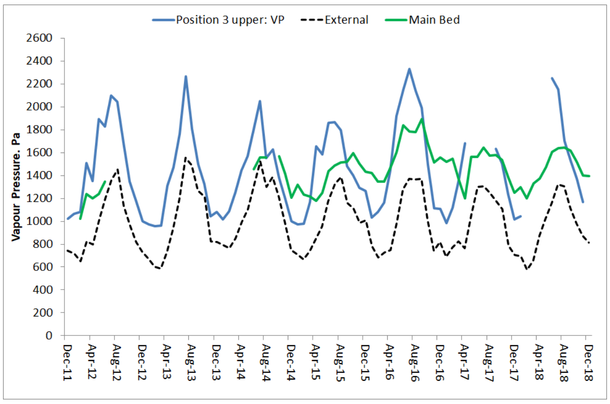
(f) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



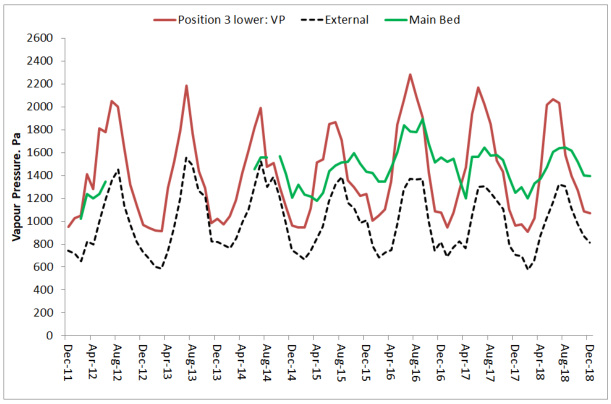
(c) Upper sensor: measured interface, room and external RHs.



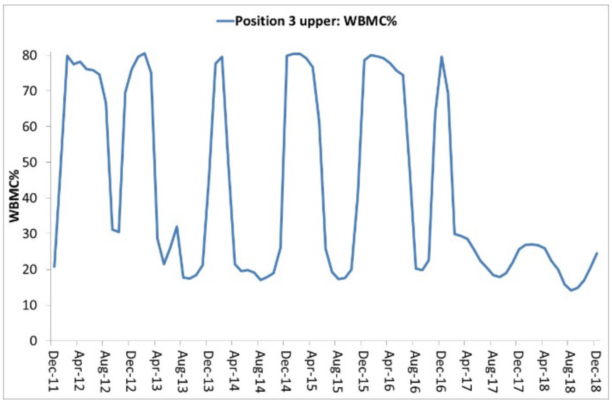
(d) Lower sensor: measured interface, room and external RHs.



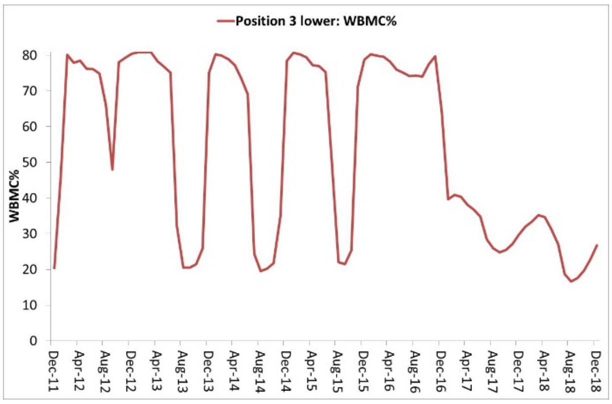
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

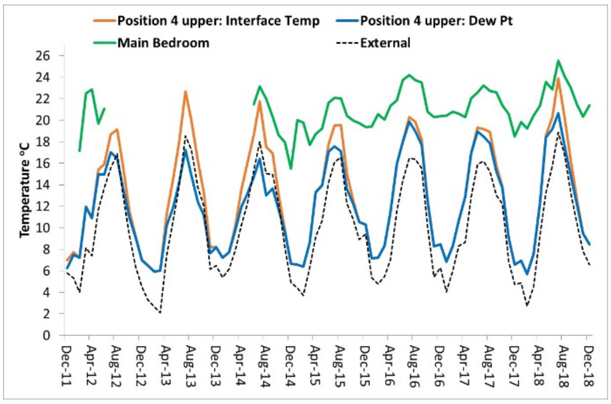


(g) Upper position: wood block moisture contents at the interface.

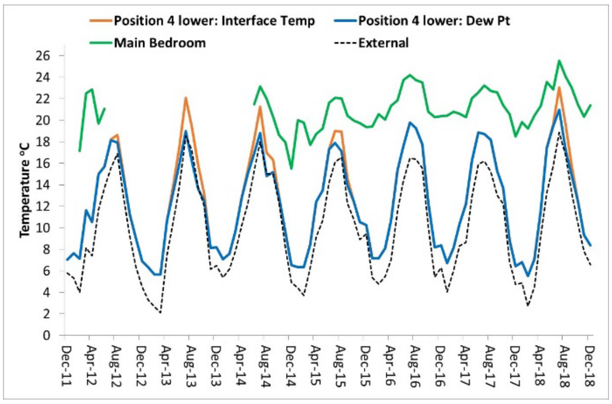


(h) Lower position: wood block moisture contents at the interface.

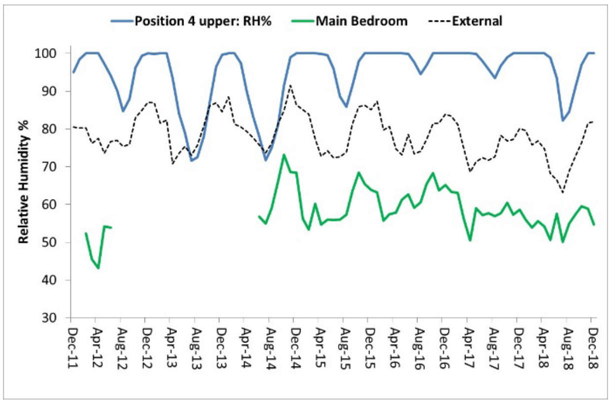
Figure A3.13: First Floor Position 4 - Main Bedroom Gable Wall with Woodfibre IWI.



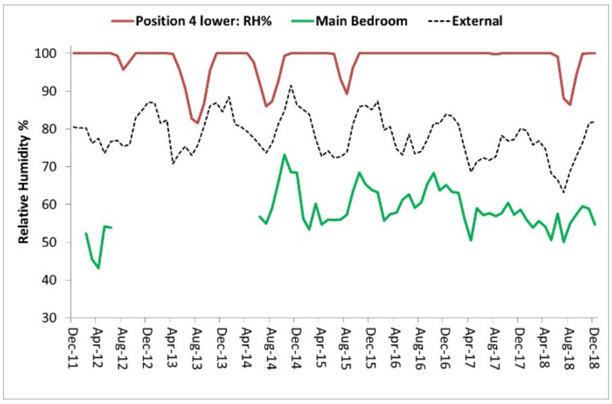
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



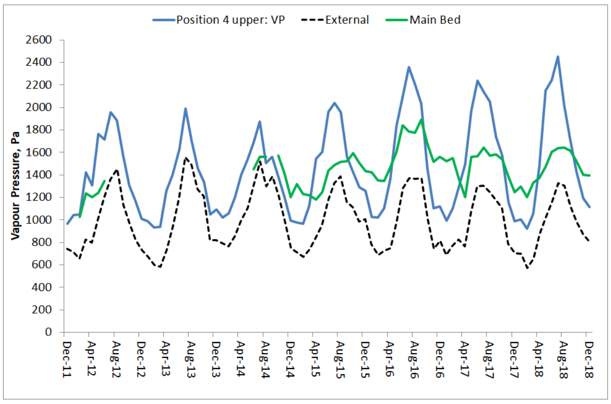
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



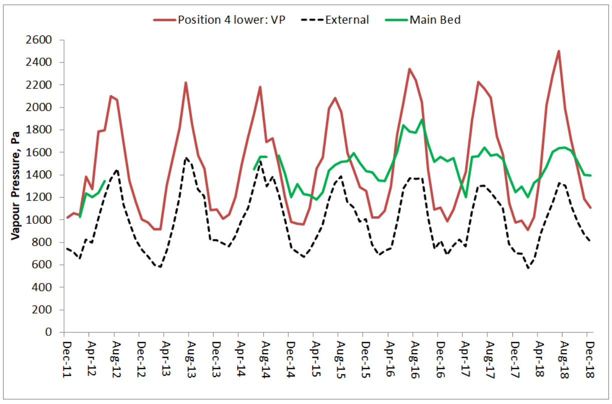
(c) Upper sensor: measured interface, room and external RHs.



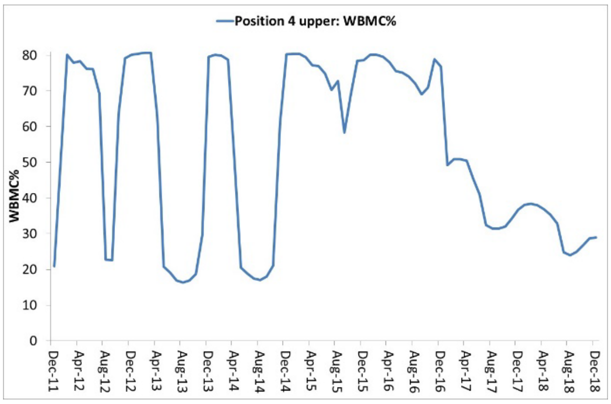
(d) Lower sensor: measured interface, room and external RHs.



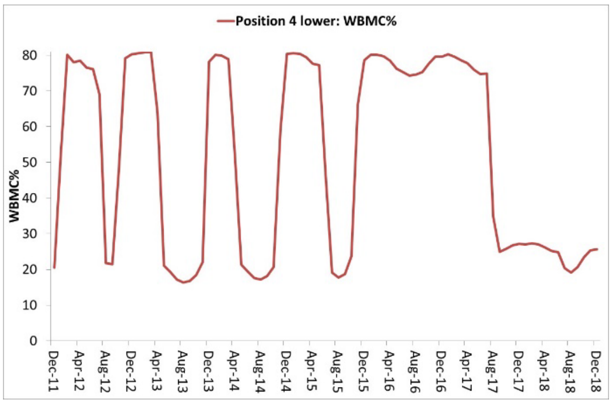
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

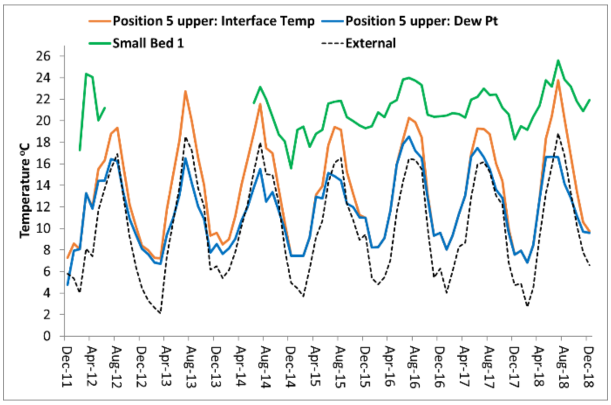


(g) Upper position: wood block moisture contents at the interface.

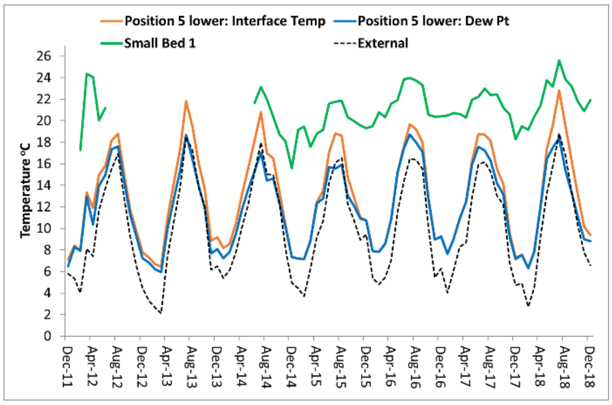


(h) Lower position: wood block moisture contents at the interface.

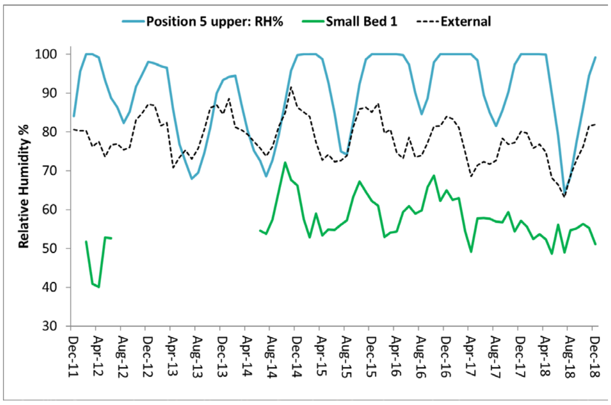
Figure A3.14: First Floor Position 5 - Small Bedroom 1 Gable Wall with Woodfibre IWI.



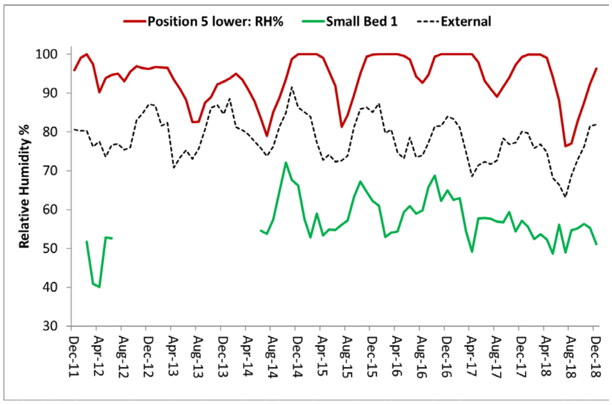
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



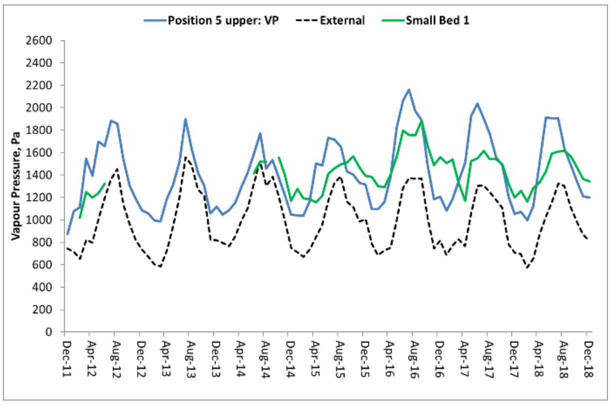
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



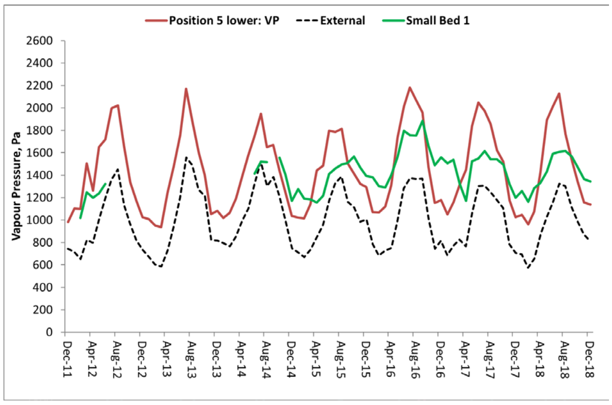
(c) Upper sensor: measured interface, room and external RHs.



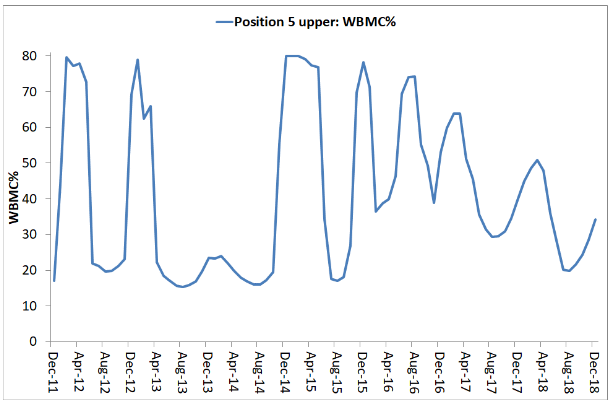
(d) Lower sensor: measured interface, room and external RHs.



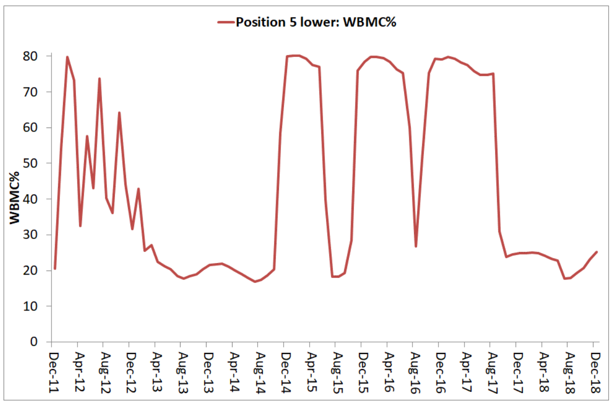
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

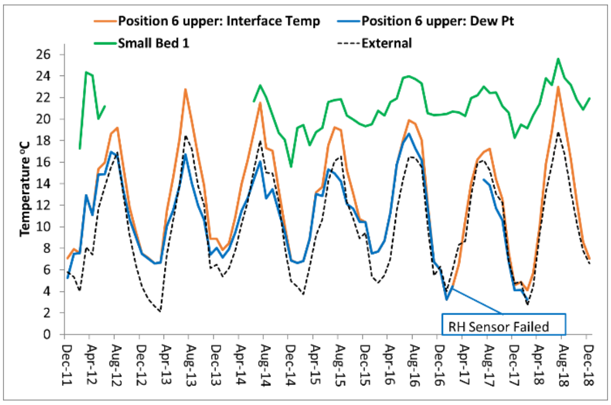


(g) Upper position: wood block moisture contents at the interface.

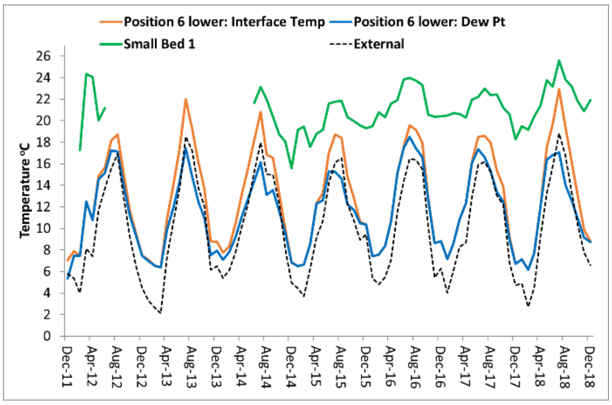


(h) Lower position: wood block moisture contents at the interface.

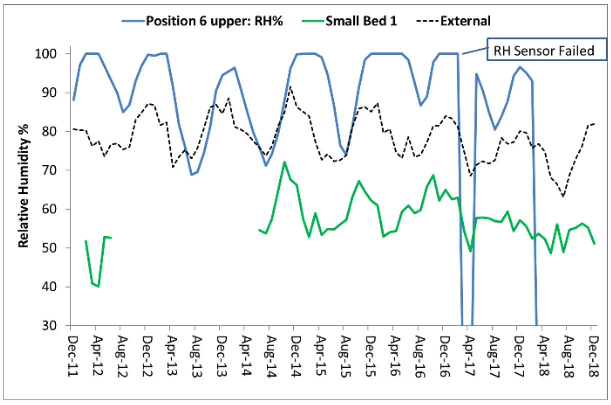
Figure A3.15: First Floor Position 6 - Gable Bedroom Gable Wall with Woodfibre IWI.



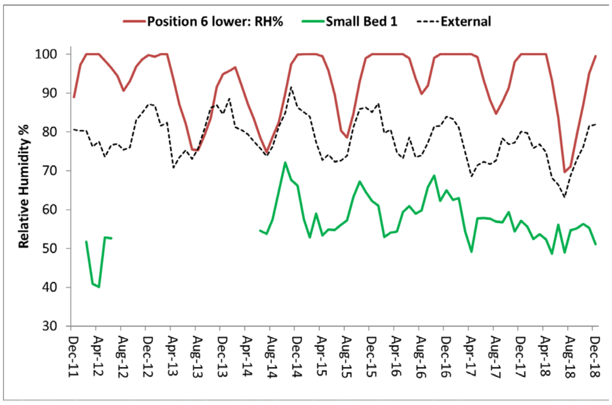
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



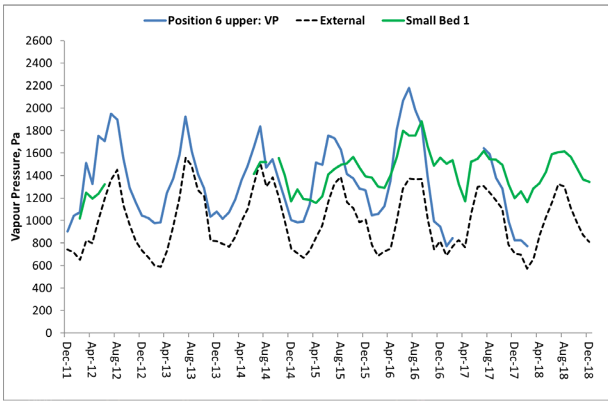
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



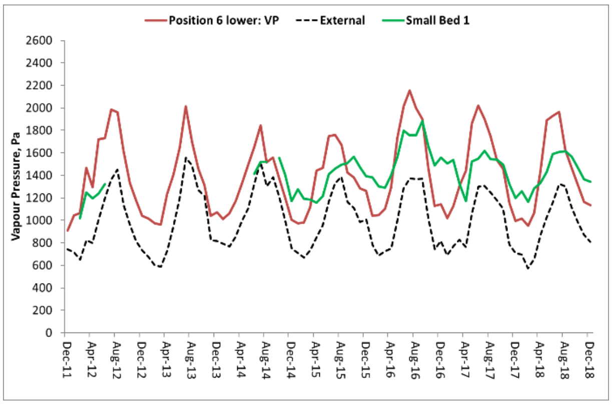
(c) Upper sensor: measured interface, room and external RHs.



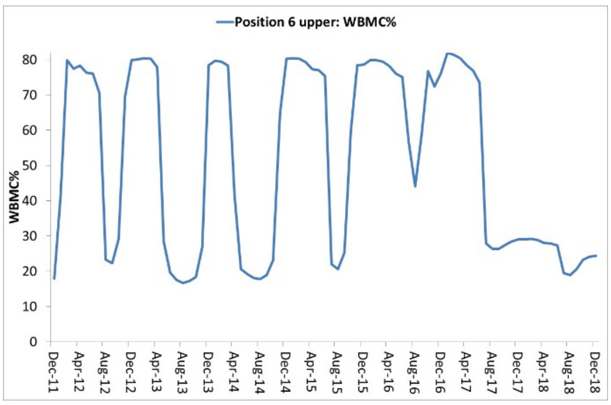
(d) Lower sensor: measured interface, room and external RHs.



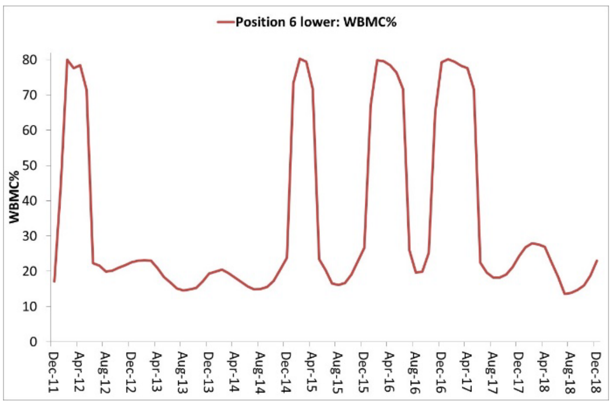
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

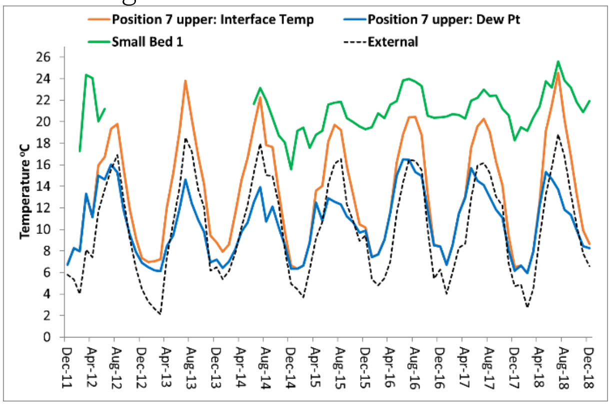


(g) Upper position: wood block moisture contents at the interface.

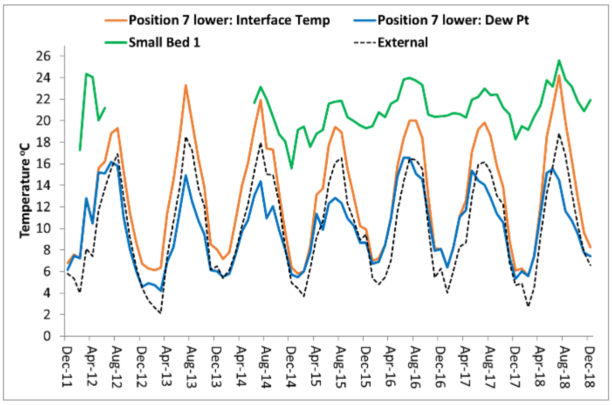


(h) Lower position: wood block moisture contents at the interface.

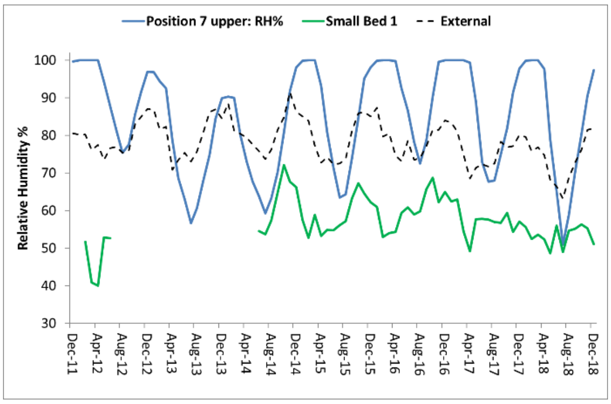
Figure A3.16: First Floor Position 7 - Gable Bedroom Rear Elevation with Woodfibre IWI.



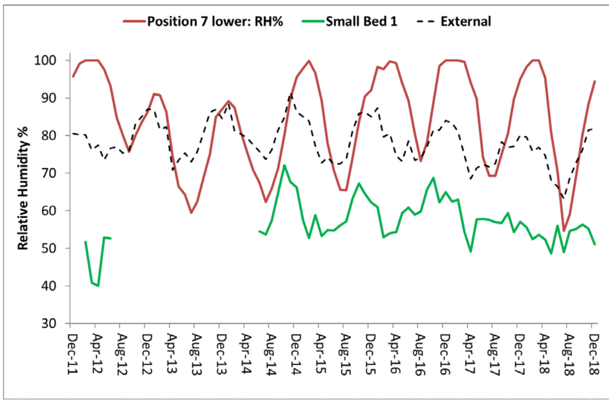
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



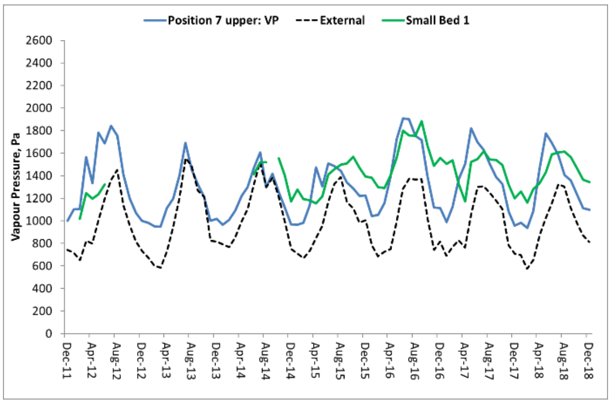
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



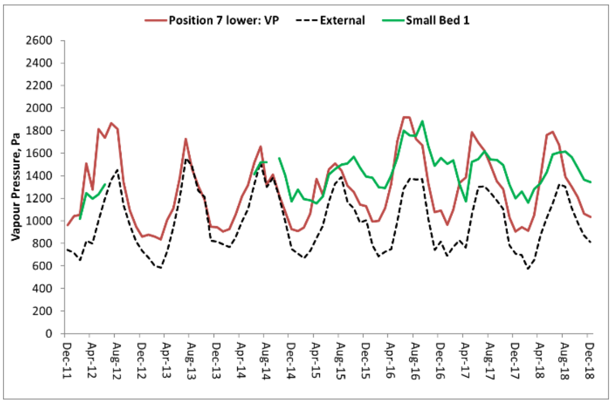
(c) Upper sensor: measured interface, room and external RHs.



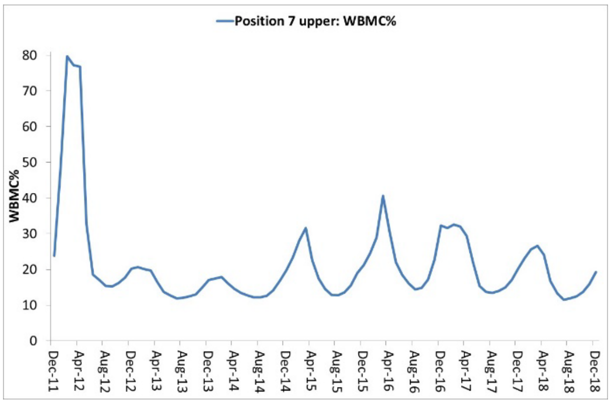
(d) Lower sensor: measured interface, room and external RHs.



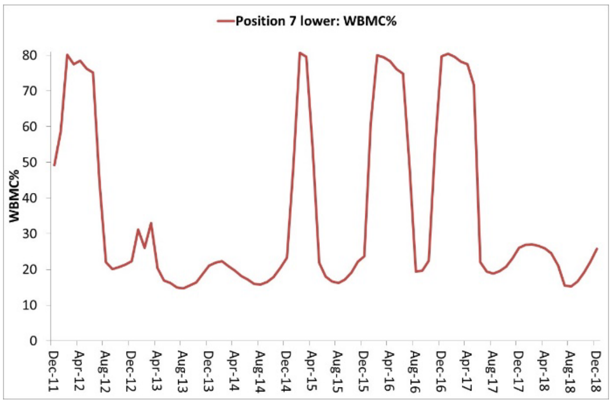
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.

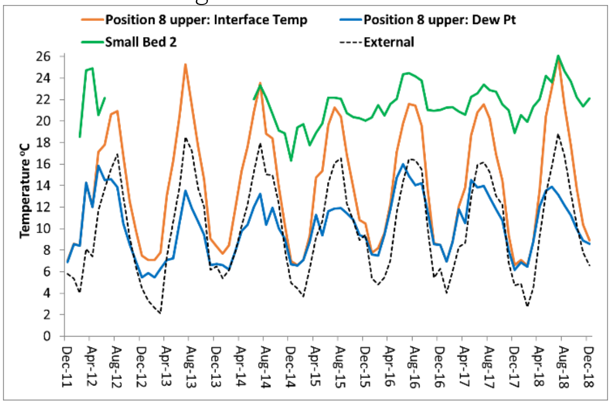


(g) Upper position: wood block moisture contents at the interface.

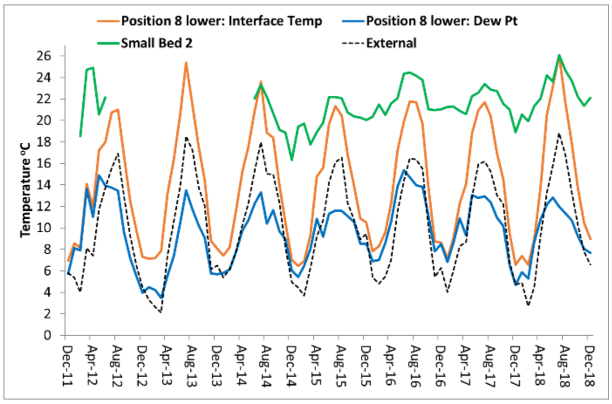


(h) Lower position: wood block moisture contents at the interface.

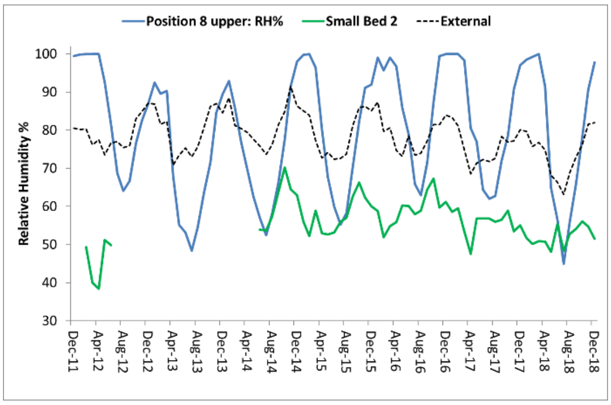
Figure A2.17: First Floor Position 8 - Bedroom 1 Rear Elevation with Woodfibre IWI.



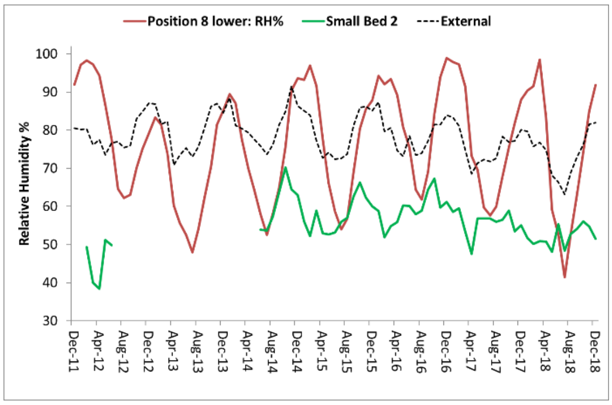
(a) Upper sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



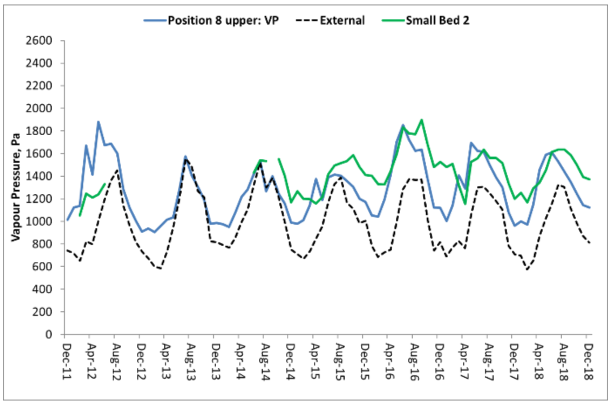
(b) Lower sensor: measured interface, room and external temperatures and calculated interface dew point temperature.



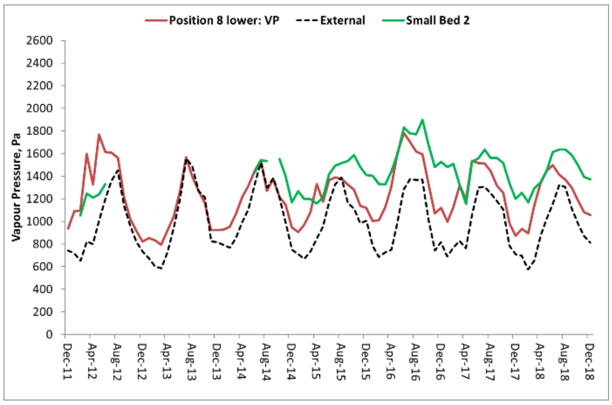
(c) Upper sensor: measured interface, room and external RHs.



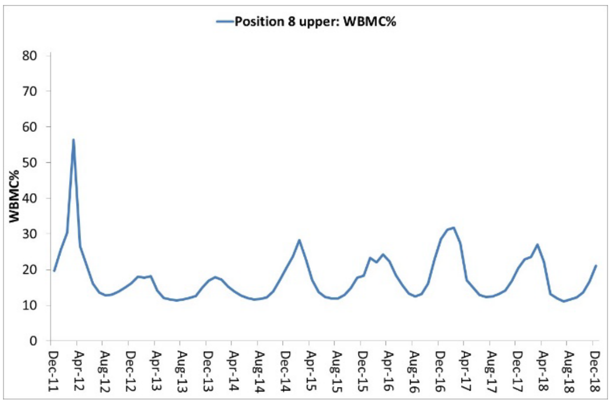
(d) Lower sensor: measured interface, room and external RHs.



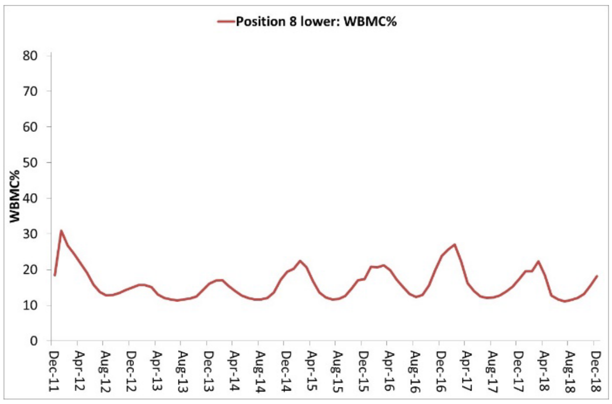
(e) Upper position: interface, room and external Vapour Pressures.



(f) Lower position: interface, room and external Vapour Pressures.



(g) Upper position: wood block moisture contents at the interface.



(h) Lower position: wood block moisture contents at the interface.

APPENDIX A4

Building 1: New Bolsover

Tabulated Interface Conditions

The monthly average measured wall data are presented in Tables C1-6. An Excel conditional formatting feature was used which applied a colour gradient to the range of interface temperature data in Tables C1-6: blue represents the minimum value in the data table, red the maximum value, and amber the mid-range value. Note: from October 2016 the sensor in measurement position 6 upper gave unreliable readings compared to the consistent trends in the adjacent measurements.

Conditional formatting was also applied to the RH and WBMC by colour to indicate levels of risk as follows:

Key to RH and WBMC Tables

Relative Humidity	
<80%	
80%-90%	
>90%	
RH sensor readings judged as unreliable	?

WBMC	
<16%	
16%-20%	
20%-30%	
>30%	

As a guide to interpreting the tables, high RHs are over 90% whilst safe levels are probably below 80%, which corresponds to an equilibrium wood block moisture content of about 16%. The level of risk due to high humidity is probably not the same as for internal room surfaces where surface RH>70% for prolonged periods at room temperatures would be likely to result in mould. With its high pH, lime plaster also acts as a fungicide.

Note that WBMCs above about 30% indicate higher moisture contents above the hygroscopic region; however, the magnitude of the value above 30% is probably not significant or meaningful. A very high value (70+%) may indicate that the wood block is the subject of irreversible change due to wetting, or to shorting out by surface moisture between the electrical connections. Since the wood blocks usually recovered from high values, shorting out is the most probable cause.

WBMCs about 16% and below indicate safe conditions and represent conditions found in dry buildings. Levels between 16-20% are satisfactory. WBMCs may lag changes in the RH at the interface as the timber absorbs moisture, and while it dries out.

Table A4.1: Ground Floor Monthly Average Interface Temperatures °C

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	7.3	6.8	7.2	6.8	7.0	6.9	7.3	7.2	7.4	7.3	7.3	7.2	7.5	6.9	7.6	7.4
Jan-12	6.9	6.3	6.6	6.3	6.7	6.6	7.7	7.1	7.6	7.3	7.8	7.5	7.7	7.0	7.0	6.6
Feb-12	7.1	6.4	6.7	6.2	6.5	6.3	7.1	6.5	7.1	6.8	7.6	7.4	8.2	6.8	7.1	6.1
Mar-12	11.1	10.7	10.7	10.4	10.6	10.6	11.3	10.6	11.4	11.1	12.3	12.0	13.5	11.9	13.2	11.2
Apr-12	10.5	10.3	10.2	10.1	9.5	9.5	10.2	9.5	9.9	9.6	10.2	9.9	11.3	9.7	11.1	9.4
May-12	15.8	15.1	15.5	15.1	14.3	14.5	14.2	14.1	13.8	13.7	14.1	14.0	15.7	14.6	16.5	14.7
Jun-12	16.6	15.9	16.6	16.2	15.4	15.4	15.4	15.1	15.0	14.9	15.3	15.3	16.7	15.7	17.2	15.7
Jul-12	19.0	18.2	18.8	18.3	17.6	17.8	17.5	17.4	17.3	17.2	17.6	17.6	19.1	18.2	19.0	17.5
Aug-12	19.7	18.8	19.4	19.0	18.5	18.6	18.4	18.3	18.1	18.0	18.4	18.4	19.8	18.8	19.8	18.4
Sep-12	16.2	15.3	15.7	15.1	15.0	14.9	15.1	14.6	14.6	14.4	15.1	15.1	16.0	14.9	16.1	15.0
Oct-12	12.1	11.2	11.3	11.0	10.9	10.9	11.5	10.9	11.1	10.8	11.7	11.6	12.6	11.0	11.7	11.2
Nov-12	9.4	8.4	8.4	8.2	8.1	7.9	9.5	8.7	9.1	8.8	9.5	9.3	9.9	8.4	8.5	8.3
Dec-12	7.4	6.3	6.3	6.0	5.9	5.6	7.6	6.5	7.1	6.8	7.4	7.1	8.2	6.2	6.5	6.1
Jan-13	6.9	5.8	6.1	5.6	5.5	5.1	7.1	6.1	6.7	6.7	6.8	6.6	7.6	5.6	6.0	5.4
Feb-13	6.5	5.6	5.5	5.2	5.1	4.8	6.4	5.3	5.9	5.9	6.3	6.0	7.4	5.2	6.3	5.3
Mar-13	6.7	5.8	5.4	5.2	4.5	4.4	6.0	5.1	5.6	5.7	6.2	6.1	7.9	5.2	6.8	5.7
Apr-13	12.0	11.5	11.4	11.0	10.1	10.2	10.7	10.2	10.1	10.1	10.6	10.5	12.2	10.2	12.3	10.9
May-13	15.4	14.5	15.0	14.5	13.4	13.5	13.6	13.3	13.1	13.1	13.5	13.4	15.3	13.4	15.3	13.6
Jun-13	18.5	17.6	18.2	17.8	16.7	16.9	16.5	16.4	16.2	16.1	16.7	16.6	18.7	17.3	19.3	17.0
Jul-13	23.0	22.0	22.6	22.1	21.4	21.5	20.9	20.9	20.7	20.6	21.1	21.0	23.0	21.9	24.3	22.2
Aug-13	20.8	20.2	20.4	19.8	19.4	19.4	19.1	19.0	18.8	18.9	19.1	19.1	20.0	19.1	20.9	19.5
Sep-13	16.5	15.9	16.1	15.8	15.6	15.6	15.6	15.3	15.4	15.4	16.0	15.9	17.0	15.8	17.2	16.1
Oct-13	14.1	13.5	13.7	13.4	13.2	13.1	13.5	13.1	13.4	13.4	13.8	13.7	14.5	13.4	14.6	13.7
Nov-13	8.8	7.7	7.9	7.6	7.6	7.4	8.7	7.9	8.5	8.4	8.8	8.5	9.4	7.9	8.7	8.0
Dec-13	9.5	8.2	9.2	8.4	8.0	7.5	9.1	8.2	8.6	8.6	8.7	8.5	9.6	7.6	8.0	7.4
Jan-14	8.7	7.4	7.6	7.3	7.0	6.6	8.3	7.2	7.9	7.8	8.0	7.8	8.8	6.8	8.0	7.0
Feb-14	9.1	8.3	8.9	8.4	7.9	7.6	8.5	7.7	8.0	8.0	8.4	8.3	9.2	7.2	8.2	7.3
Mar-14	11.4	10.4	10.4	10.0	9.7	9.5	10.4	9.6	9.9	9.9	10.6	10.4	11.9	9.8	11.5	10.2
Apr-14	13.9	13.6	13.4	13.2	12.6	12.6	12.7	12.4	12.3	12.2	13.0	13.0	14.4	12.8	14.8	12.6
May-14	16.7	16.2	16.2	15.8	14.8	14.9	14.8	14.7	14.4	14.3	14.9	14.9	16.3	15.0	16.7	14.9
Jun-14	19.3	18.7	18.9	18.5	17.7	17.8	17.4	17.4	17.3	17.2	17.6	17.6	19.2	18.2	19.9	17.2

Jul-14	22.7	22.1	22.1	21.5	20.9	21.1	20.2	20.3	19.9	19.8	20.2	20.2	21.9	20.9	22.7	20.3
Aug-14	18.1	17.5	17.7	17.2	16.9	17.0	16.6	16.6	16.3	16.3	16.6	16.6	17.7	16.7	18.3	16.7
Sep-14	17.0	16.5	16.6	16.2	16.5	16.5	16.0	15.8	15.9	15.8	16.4	16.3	17.5	16.6	18.2	16.9
Oct-14	13.3	12.9	13.2	12.9	12.9	12.9	12.9	12.7	12.9	12.8	13.2	13.1	13.8	13.0	13.9	13.2
Nov-14	9.7	9.2	9.3	9.1	9.3	9.1	9.7	9.4	9.7	9.5	9.9	9.7	10.4	9.6	10.5	9.9
Dec-14	6.5	5.8	6.4	5.9	6.3	6.0	6.9	6.4	6.7	6.6	6.7	6.5	7.1	6.2	7.0	6.5
Jan-15	6.8	5.7	6.9	5.9	6.0	5.5	7.0	6.1	6.3	5.9	6.2	5.9	6.8	5.4	6.3	5.7
Feb-15	7.4	5.8	6.5	5.8	6.1	5.5	7.1	6.0	6.4	5.9	6.6	6.1	7.4	5.7	6.9	6.0
Mar-15	9.7	8.6	9.2	8.4	8.5	8.2	9.0	8.3	8.4	8.0	8.7	8.4	9.5	8.0	9.4	8.5
Apr-15	14.1	13.3	13.5	12.9	12.6	12.5	12.3	12.0	11.7	11.5	12.2	12.0	13.7	12.0	14.5	13.0
May-15	14.7	14.3	14.4	13.9	13.2	13.2	12.9	12.9	12.6	12.6	12.8	12.8	14.3	12.8	15.2	13.8
Jun-15	18.3	17.9	17.9	17.5	16.6	16.7	16.1	16.2	15.9	15.9	16.3	16.2	17.8	16.4	18.9	17.4
Jul-15	20.1	19.6	19.9	19.3	18.6	18.7	18.2	18.2	18.0	18.0	18.3	18.3	19.6	18.6	20.5	18.7
Aug-15	20.1	19.5	19.7	19.2	18.8	18.9	18.3	18.3	17.9	17.9	18.1	18.1	19.3	18.5	19.9	18.7
Sep-15	15.0	14.3	14.5	14.1	14.4	14.3	14.1	13.9	14.1	13.9	14.7	14.5	15.7	14.8	16.6	15.5
Oct-15	12.6	12.1	12.2	11.9	12.2	12.0	12.2	11.9	12.2	12.1	12.8	12.5	13.3	12.5	13.8	13.0
Nov-15	10.8	10.2	11.0	10.3	10.1	9.9	10.7	10.2	10.4	10.1	10.5	10.3	10.9	9.9	10.5	10.1
Dec-15	10.7	10.2	11.0	10.2	10.0	9.8	10.5	10.0	10.2	10.0	10.2	10.1	10.7	9.6	10.1	9.8
Jan-16	7.8	7.0	7.6	6.9	6.8	6.4	7.7	6.8	7.2	7.0	7.3	7.1	7.8	6.4	7.7	6.8
Feb-16	8.2	7.2	7.7	7.0	7.1	6.9	7.5	6.6	7.0	6.6	7.4	7.2	8.0	6.6	7.7	7.0
Mar-16	9.1	8.3	8.4	7.9	7.7	7.6	8.1	7.5	7.7	7.4	8.2	8.0	9.1	7.6	9.3	8.5
Apr-16	12.1	11.3	11.5	11.1	10.3	10.2	10.4	9.9	9.8	9.5	10.2	10.0	11.4	9.8	11.9	10.1
May-16	16.4	15.8	16.0	15.5	14.8	15.0	14.5	14.3	14.0	13.9	14.3	14.3	15.9	14.6	16.6	14.6
Jun-16	18.3	17.7	17.9	17.6	17.0	17.0	16.7	16.4	16.5	16.3	16.9	16.8	18.3	17.3	19.2	17.5
Jul-16	21.1	20.5	20.8	20.0	19.3	19.4	18.9	18.7	18.6	18.5	18.9	18.9	20.2	19.3	21.1	19.5
Aug-16	20.4	19.7	19.9	19.2	19.0	19.0	18.5	18.3	18.2	18.2	18.7	18.7	20.0	19.1	21.0	19.6
Sep-16	18.3	17.9	18.0	17.5	17.8	17.8	17.4	16.9	17.2	17.2	17.8	17.8	18.7	17.9	19.3	18.3
Oct-16	12.7	12.2	12.2	12.0	12.2	12.1	12.3	11.5	12.3	12.1	12.9	12.7	13.4	12.6	13.8	13.1
Nov-16	8.4	7.4	7.7	7.3	7.6	7.3	8.5	7.4	8.3	8.0	8.5	8.3	8.7	7.6	8.5	7.8
Dec-16	8.2	7.4	7.9	7.4	7.6	7.2	8.7	7.7	8.6	8.3	8.6	8.4	8.7	7.6	8.4	7.8
Jan-17	6.8	5.8	6.1	5.7	5.8	5.5	7.1	6.0	6.9	6.7	7.0	6.7	7.1	5.8	6.9	6.0
Feb-17	8.7	8.0	8.3	7.8	7.7	7.4	8.5	7.5	8.2	7.9	8.4	8.2	8.8	7.6	8.8	7.9
Mar-17	11.2	10.5	10.6	10.2	10.3	10.2	10.4	9.7	10.2	10.0	10.8	10.7	11.8	10.4	12.0	10.8
Apr-17	12.9	12.3	12.4	12.0	11.8	11.7	11.8	11.2	11.5	11.4	11.9	11.9	13.2	11.8	13.6	12.1

May-17	17.0	16.3	16.6	16.2	15.8	15.9	15.4	15.0	15.2	15.1	15.6	15.6	17.2	16.1	18.1	16.5
Jun-17	20.2	19.5	19.9	19.2	18.6	18.8	18.1	17.7	17.9	17.9	18.2	18.1	19.5	18.6	19.6	18.3
Jul-17	19.9	19.4	19.8	19.3	18.6	18.7	18.2	17.7	18.1	18.0	18.5	18.5	20.1	19.1	20.3	19.1
Aug-17	19.1	18.5	18.8	18.2	18.0	17.9	17.6	17.1	17.4	17.3	17.8	17.7	19.0	18.0	19.2	18.2
Sep-17	16.0	15.4	15.7	15.3	15.3	15.2	15.0	14.4	14.9	14.7	15.3	15.2	16.1	15.1	16.1	15.5
Oct-17	14.1	13.7	14.0	13.6	13.6	13.5	13.7	13.0	13.7	13.5	13.9	13.9	14.3	13.5	14.2	13.8
Nov-17	8.9	8.2	8.7	8.2	8.5	8.2	9.0	7.9	8.9	8.6	9.0	8.9	9.3	8.3	9.1	8.8
Dec-17	6.2	5.4	6.1	5.4	5.8	5.4	6.7	5.6	6.6	6.3	6.6	6.4	6.8	5.6	6.7	6.1
Jan-18	6.6	6.0	6.8	6.0	6.2	5.8	7.1	5.9	6.9	6.7	6.9	6.7	7.1	5.9	6.7	6.1
Feb-18	5.5	4.8	5.2	4.8	4.8	4.6	5.8	4.6	5.7	5.5	6.0	5.8	6.3	5.0	6.3	5.4
Mar-18	7.6	6.9	7.0	6.8	6.4	6.2	7.1	6.1	7.1	6.9	7.5	7.3	8.1	6.7	9.2	7.6
Apr-18	12.3	11.8	11.9	11.7	11.2	11.1	11.4	10.6	11.2	11.1	11.6	11.5	12.6	11.3	13.2	12.0
May-18	17.8	16.9	17.4	16.9	16.6	16.7	16.1	15.7	16.0	15.9	16.5	16.4	18.5	17.1	19.7	17.7
Jun-18	20.1	19.2	19.9	19.7	18.8	18.9	18.3	18.0	18.3	18.3	18.9	18.8	21.0	19.7	22.0	19.6
Jul-18	23.7	22.8	23.6	23.2	22.5	22.7	21.6	21.7	21.6	21.5	22.1	22.0	23.9	22.9	25.1	23.1
Aug-18	20.6	20.1	20.4	19.9	19.4	19.4	19.0	18.7	18.7	18.7	19.1	19.0	20.1	19.3	20.9	19.7
Sep-18	16.2	15.7	15.9	15.5	15.7	15.7	15.3	14.9	15.3	15.2	15.9	15.8	16.6	15.7	17.1	16.4
Oct-18	12.7	12.1	12.3	11.9	12.4	12.3	12.3	11.6	12.3	12.2	12.8	12.6	13.2	12.4	13.3	12.9
Nov-18	9.7	9.0	9.3	9.0	8.9	8.7	9.5	8.6	9.5	9.4	9.8	9.6	10.1	9.1	10.1	9.6
Dec-18	8.9	7.9	8.5	7.8	7.8	7.4	8.7	7.7	8.6	8.3	8.6	8.5	8.9	7.7	8.8	8.0

Table A4.2: Ground Floor Monthly Average Interface Relative Humidities %

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	97	98	97	97	99	98	98	100	89	90	89	92	90	94	91	90
Jan-12	97	100	99	100	98	97	100	100	93	94	89	87	85	91	91	88
Feb-12	90	100	95	97	90	92	100	100	99	99	92	89	81	90	83	82
Mar-12	76	96	84	84	75	79	99	100	100	100	94	90	70	80	62	66
Apr-12	74	92	78	80	77	80	96	100	99	100	96	91	69	78	65	71
May-12	67	83	70	71	70	75	90	95	96	95	88	84	65	75	56	62
Jun-12	70	83	73	76	75	78	88	92	90	90	83	83	71	78	62	68
Jul-12	69	81	72	75	75	79	88	92	86	86	77	78	66	73	62	69
Aug-12	67	79	69	72	71	75	85	88	86	86	79	80	68	74	61	67
Sep-12	69	79	74	79	74	78	86	89	84	85	75	76	67	74	63	68
Oct-12	77	87	80	83	79	82	93	91	89	90	78	78	71	80	71	74
Nov-12	79	90	84	86	82	85	97	95	88	89	79	79	73	83	78	79
Dec-12	83	92	88	90	88	90	97	98	90	92	83	83	74	86	82	83
Jan-13	82	94	84	89	85	91	99	100	93	92	87	86	77	89	81	83
Feb-13	74	89	80	82	78	84	97	99	93	92	87	86	71	86	73	76
Mar-13	66	83	72	73	73	77	90	91	95	94	83	82	66	83	68	71
Apr-13	55	68	62	65	64	70	79	83	83	83	72	72	57	72	54	58
May-13	58	69	65	68	69	74	81	85	79	79	71	72	58	70	54	61
Jun-13	57	68	62	64	65	69	81	82	81	83	72	75	59	69	51	59
Jul-13	55	63	58	61	62	64	75	77	81	81	72	76	60	69	47	54
Aug-13	59	65	67	71	70	74	81	83	81	81	73	75	64	70	56	61
Sep-13	66	72	72	76	72	75	84	85	83	84	75	76	67	74	62	67
Oct-13	80	83	84	87	85	86	92	91	87	87	81	82	75	81	73	78
Nov-13	82	90	87	89	83	87	98	99	90	90	84	84	77	85	77	80
Dec-13	82	92	85	93	88	92	97	100	89	89	84	83	75	86	80	82
Jan-14	81	93	90	93	89	92	98	100	94	94	92	91	83	94	83	87
Feb-14	78	89	84	91	87	91	97	100	91	91	84	84	74	91	77	80
Mar-14	67	80	74	79	75	81	91	97	89	89	82	83	69	88	65	70
Apr-14	65	73	71	73	72	77	88	94	89	90	80	81	66	83	60	70
May-14	60	67	66	68	70	74	87	91	87	88	79	80	66	80	59	67
Jun-14	59	66	62	65	67	69	86	89	88	89	80	82	66	79	56	68
Jul-14	52	58	59	63	64	65	81	84	85	85	75	78	62	75	53	62
Aug-14	63	68	71	77	75	78	88	90	83	83	75	77	65	75	60	67
Sep-14	70	75	73	75	72	73	91	89	89	90	82	83	71	80	63	69
Oct-14	85	88	88	91	86	87	98	98	92	92	87	87	82	85	77	80
Nov-14	91	93	95	95	91	90	100	100	98	98	95	94	93	93	86	87
Dec-14	96	99	99	98	94	94	100	100	99	98	97	95	91	95	84	83
Jan-15	98	100	100	100	98	98	100	100	99	98	97	94	87	95	86	84
Feb-15	91	99	100	99	91	93	100	100	100	100	98	96	84	94	79	80
Mar-15	82	93	92	92	86	89	100	100	99	97	91	89	76	88	71	72
Apr-15	62	73	73	75	70	73	98	100	94	93	82	84	66	82	54	58
May-15	65	71	74	78	76	78	98	100	86	85	76	77	63	77	55	60
Jun-15	59	65	67	69	71	72	96	98	84	83	74	76	62	74	52	57

Jul-15	58	62	63	71	72	74	93	93	82	82	73	76	62	72	53	60
Aug-15	58	62	65	70	71	73	90	90	81	81	73	76	64	72	57	62
Sep-15	68	72	73	74	72	74	95	94	88	89	80	82	70	76	60	64
Oct-15	82	81	86	83	80	80	99	99	95	96	88	87	80	83	73	75
Nov-15	94	95	98	98	96	95	100	100	95	95	90	88	83	88	82	83
Dec-15	96	98	99	100	99	99	100	100	95	94	91	89	86	91	85	86
Jan-16	99	100	100	100	99	98	100	100	100	99	98	94	92	97	87	87
Feb-16	90	96	100	96	90	92	100	100	98	98	94	91	86	94	76	76
Mar-16	83	91	98	92	86	88	100	100	100	100	98	95	84	95	72	72
Apr-16	71	80	86	78	77	79	100	100	100	100	95	91	76	90	62	67
May-16	63	71	71	69	71	72	100	100	100	99	90	89	72	85	58	65
Jun-16	70	76	75	74	76	77	100	100	99	99	89	90	76	85	62	69
Jul-16	64	69	70	74	79	79	99	100	93	91	82	83	68	81	58	64
Aug-16	63	68	70	75	76	77	99	99	90	89	81	83	70	79	59	64
Sep-16	73	76	81	82	81	81	100	100	93	93	84	85	72	80	64	69
Oct-16	81	82	89	84	81	82	100	100	99	99	92	91	82	87	73	74
Nov-16	90	91	99	92	87	88	100	100	100	100	96	93	88	92	80	80
Dec-16	93	96	100	96	93	93	100	100	100	100	99	97	95	98	88	87
Jan-17	94	97	100	96	92	92	100	100	100	100	99	97	93	98	86	84
Feb-17	91	95	100	95	93	93	100	100	100	100	99	97	91	98	84	84
Mar-17	80	88	96	90	88	89	100	99	100	99	95	91	78	90	69	72
Apr-17	66	75	77	73	71	74	100	97	99	97	81	79	63	77	55	60
May-17	64	72	70	68	71	70	99	99	99	97	86	86	70	80	56	61
Jun-17	63	67	69	74	77	77	98	97	88	86	77	78	65	74	59	65
Jul-17	63	68	69	73	75	77	99	98	91	89	77	79	66	74	58	63
Aug-17	62	66	69	76	76	79	99	99	89	88	77	80	67	76	60	63
Sep-17	74	77	79	82	79	81	100	100	94	93	81	81	72	78	69	72
Oct-17	81	83	87	91	87	89	100	100	92	91	82	82	76	81	74	75
Nov-17	91	91	97	96	90	88	100	100	99	99	89	87	80	85	76	76
Dec-17	96	97	100	99	94	94	100	100	100	100	94	91	86	92	83	84
Jan-18	97	99	100	99	97	97	100	100	100	99	95	91	87	94	84	85
Feb-18	89	95	99	94	86	89	100	100	100	100	95	92	84	93	77	78
Mar-18	82	89	94	88	84	86	100	100	100	100	100	97	90	97	76	80
Apr-18	79	84	87	83	82	84	100	99	99	98	93	91	78	90	68	72
May-18	62	72	66	66	65	67	98	97	99	96	79	82	61	77	49	55
Jun-18	60	68	63	65	67	68	95	95	94	92	77	81	62	76	50	57
Jul-18	50	57	53	58	57	59	85	87	90	87	72	77	58	71	45	51
Aug-18	60	64	64	72	68	72	92	95	84	82	71	74	63	71	57	61
Sep-18	70	74	76	80	74	76	96	98	88	86	76	78	70	75	63	65
Oct-18	81	82	88	87	80	80	100	100	93	93	82	83	77	81	71	71
Nov-18	89	89	96	93	91	90	100	100	99	98	91	90	86	90	81	82
Dec-18	92	96	98	97	94	94	100	98	100	100	97	94	91	96	87	87

Table A4.3: Ground Floor Monthly Average Interface Wood Block Moisture Contents %

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	62	61	59	61	35	22	20	37	17	18	17	19	18	20	35	50
Jan-12	65	81	80	80	50	50	44	76	18	19	17	18	17	20	28	25
Feb-12	29	80	77	47	20	29	53	80	22	23	18	18	16	19	19	20
Mar-12	17	78	40	24	37	18	38	78	59	59	21	19	14	17	14	16
Apr-12	15	79	16	16	37	16	23	77	78	79	22	20	13	16	13	14
May-12	15	64	14	14	37	16	21	44	62	57	20	19	13	16	12	14
Jun-12	15	66	14	15	53	16	18	19	22	22	18	18	14	16	12	14
Jul-12	15	51	14	15	61	17	19	20	20	20	17	17	13	15	12	14
Aug-12	14	22	13	14	56	16	18	19	20	20	17	17	13	15	12	13
Sep-12	15	22	14	16	45	16	18	19	20	20	16	16	14	15	12	14
Oct-12	16	39	16	18	62	17	22	19	20	21	17	16	14	16	14	15
Nov-12	16	62	17	18	66	17	23	21	20	21	17	16	14	17	16	16
Dec-12	17	68	18	23	44	19	24	22	20	21	17	17	14	18	18	17
Jan-13	17	81	18	22	51	20	25	34	21	21	18	18	15	20	18	17
Feb-13	16	70	16	19	60	19	24	32	21	21	18	18	14	18	15	16
Mar-13	14	80	14	16	58	17	22	21	22	22	18	17	14	18	14	15
Apr-13	12	22	13	14	47	15	18	18	19	20	16	15	13	16	12	12
May-13	13	18	13	14	51	15	17	18	18	18	15	15	13	15	12	13
Jun-13	12	17	12	13	50	14	18	18	19	19	16	16	12	15	11	12
Jul-13	12	16	12	13	33	13	17	16	19	19	16	16	12	15	11	12
Aug-13	13	16	12	14	61	15	17	17	19	19	16	16	13	15	11	12
Sep-13	13	17	14	16	68	15	18	18	19	20	16	16	13	16	12	13
Oct-13	17	21	17	19	22	18	21	19	20	20	17	17	14	17	14	15
Nov-13	17	38	20	27	29	19	24	33	20	21	17	17	14	18	15	16
Dec-13	17	61	20	45	21	21	24	35	20	21	18	17	14	19	17	17
Jan-14	17	79	21	40	38	22	25	74	21	22	21	20	16	23	18	18
Feb-14	17	80	19	38	41	22	24	68	21	22	19	18	15	22	17	17
Mar-14	15	59	16	18	62	19	22	38	21	22	18	18	13	21	13	14
Apr-14	14	35	14	16	50	18	21	25	21	22	18	18	13	20	12	14
May-14	13	19	13	14	54	16	20	23	21	22	17	18	13	19	12	14
Jun-14	13	18	12	13	48	15	20	22	22	22	18	18	13	19	11	14
Jul-14	12	16	12	13	39	14	19	20	22	21	17	18	13	18	11	13
Aug-14	13	17	14	17	17	17	20	21	20	21	17	17	13	18	12	14
Sep-14	15	19	14	16	26	16	21	21	22	22	18	18	14	19	12	14
Oct-14	19	43	19	41	32	19	25	24	29	23	19	19	16	20	16	16
Nov-14	22	73	40	57	31	21	29	51	61	26	23	22	23	24	20	18
Dec-14	48	81	70	69	31	36	32	80	80	29	24	24	22	27	20	18
Jan-15	72	81	80	81	47	63	33	81	80	44	25	24	20	32	23	19
Feb-15	32	81	80	81	21	40	33	81	80	77	26	26	19	31	18	17
Mar-15	23	79	79	56	22	42	32	80	80	71	23	22	16	23	15	16
Apr-15	15	57	29	25	36	19	28	78	77	63	20	20	14	22	12	13
May-15	15	32	17	20	58	18	27	77	53	23	18	18	13	19	12	13

Jun-15	14	20	15	16	19	16	26	59	39	22	17	17	13	18	11	13
Jul-15	13	18	13	16	52	17	24	23	33	23	17	17	13	18	11	13
Aug-15	13	18	14	16	55	17	23	21	21	21	16	17	13	18	12	13
Sep-15	15	19	15	17	67	16	24	22	27	22	17	18	14	19	12	13
Oct-15	19	33	26	19	67	18	27	35	77	26	19	20	16	20	15	15
Nov-15	49	75	78	66	29	51	31	69	74	27	21	21	18	23	19	18
Dec-15	66	79	78	79	63	77	32	79	77	26	22	21	19	24	20	20
Jan-16	76	80	80	80	43	69	37	80	80	39	25	23	22	35	28	20
Feb-16	47	80	80	71	31	60	46	80	79	49	23	22	19	27	16	17
Mar-16	22	80	80	42	20	31	38	80	80	80	25	24	19	30	14	16
Apr-16	18	64	46	24	18	25	32	79	79	79	24	23	17	26	12	15
May-16	15	28	18	17	25	18	30	77	77	77	23	23	16	25	12	14
Jun-16	16	32	17	17	43	18	30	76	76	76	23	23	16	25	12	14
Jul-16	15	22	16	17	28	19	29	75	75	68	20	21	15	23	11	14
Aug-16	15	20	15	18	28	18	28	75	70	43	19	20	15	22	12	14
Sep-16	17	23	19	21	42	19	28	76	75	52	20	21	15	23	12	14
Oct-16	19	34	38	29	43	19	30	78	78	35	22	22	17	24	14	15
Nov-16	24	51	55	45	35	21	31	80	80	45	23	23	18	27	16	16
Dec-16	41	80	74	60	27	31	33	80	79	71	26	25	21	35	22	19
Jan-17	27	81	81	30	24	24	31	81	80	40	26	25	21	35	21	19
Feb-17	25	80	80	27	23	24	31	50	80	33	27	26	21	38	20	19
Mar-17	21	63	62	25	22	24	30	35	79	32	25	24	17	31	14	16
Apr-17	16	25	20	19	16	19	29	36	78	29	20	20	14	24	12	13
May-17	16	24	16	17	20	17	29	35	76	27	21	22	14	25	12	13
Jun-17	15	20	15	18	17	19	27	33	65	23	18	19	14	23	11	14
Jul-17	15	20	15	18	16	18	27	24	25	23	18	19	14	22	11	13
Aug-17	15	20	15	19	17	19	27	24	25	23	17	19	14	23	11	13
Sep-17	16	21	17	21	17	19	27	24	25	24	18	20	14	23	14	15
Oct-17	19	24	21	25	19	22	27	24	26	23	19	20	15	24	14	16
Nov-17	23	26	30	27	34	22	30	25	28	27	19	20	16	25	15	16
Dec-17	26	28	37	31	24	24	30	26	28	28	22	21	18	30	18	17
Jan-18	27	30	37	30	26	26	31	26	28	28	23	22	19	32	19	18
Feb-18	25	32	38	28	22	25	30	26	28	29	23	22	18	31	16	17
Mar-18	22	31	26	25	21	22	30	26	28	31	27	25	20	32	16	17
Apr-18	21	28	23	22	19	22	30	25	27	29	24	24	17	30	14	15
May-18	15	25	15	16	14	17	27	24	26	26	19	20	13	24	11	12
Jun-18	15	24	15	16	15	17	26	23	25	24	17	20	13	24	11	13
Jul-18	12	18	12	13	12	14	19	18	12	23	16	19	12	22	11	11
Aug-18	14	18	14	16	14	16	20	20	24	20	16	18	13	22	12	13
Sep-18	16	21	17	20	15	17	21	22	25	21	17	18	14	22	12	14
Oct-18	18	23	22	22	16	18	24	26	26	23	18	19	15	24	13	15
Nov-18	22	25	27	25	20	21	29	28	27	25	20	21	17	27	16	16
Dec-18	24	28	28	26	24	25	30	28	28	28	24	23	20	34	21	19

Table A4.4: First Floor Monthly Average Interface Temperatures °C

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	7.1	7.4	6.4	6.5	7.1	6.9	7.0	7.0	7.3	7.1	7.1	7.1	6.8	6.8	7.0	7.0
Jan-12	7.8	8.2	7.1	7.3	7.8	7.4	7.7	7.7	8.6	8.4	7.9	7.9	8.3	7.6	8.6	8.6
Feb-12	7.9	8.2	7.1	7.3	7.6	7.2	7.2	7.1	8.1	7.9	7.6	7.5	8.0	7.2	8.4	8.2
Mar-12	12.4	12.5	12.0	12.3	12.8	11.8	12.0	11.6	13.3	13.3	12.9	12.5	13.3	12.8	14.3	14.1
Apr-12	11.7	11.9	11.6	11.9	11.4	10.6	10.9	10.5	12.0	11.9	11.1	10.8	11.1	10.5	12.0	11.9
May-12	16.8	16.6	16.5	16.7	16.0	15.6	15.4	15.0	15.5	15.0	15.4	14.8	16.0	15.6	17.2	17.2
Jun-12	17.1	17.1	17.1	17.3	16.3	15.9	15.9	15.7	16.3	15.8	16.0	15.7	16.7	16.2	17.8	18.0
Jul-12	19.7	19.6	19.7	20.0	19.1	18.7	18.7	18.2	18.8	18.2	18.6	18.2	19.3	18.8	20.6	20.7
Aug-12	20.3	20.1	20.1	20.5	19.7	19.1	19.1	18.6	19.4	18.8	19.2	18.7	19.8	19.3	20.9	21.0
Sep-12	16.7	16.6	16.5	17.0	16.6	15.6	15.7	15.1	15.8	15.2	15.6	15.2	15.8	15.4	16.8	16.8
Oct-12	11.9	11.9	11.8	12.1	12.1	11.5	11.5	11.3	12.2	11.7	11.8	11.7	11.9	11.5	12.6	12.5
Nov-12	9.0	9.2	8.9	9.2	9.2	8.7	9.3	9.1	10.2	9.7	9.5	9.5	9.2	8.7	9.8	9.7
Dec-12	6.7	6.9	6.6	6.9	6.9	6.4	7.0	6.9	8.4	7.8	7.5	7.5	7.3	6.7	7.5	7.3
Jan-13	6.3	6.5	6.3	6.5	6.3	5.8	6.5	6.4	8.0	7.3	7.1	7.1	7.0	6.3	7.1	7.1
Feb-13	6.2	6.5	6.0	6.3	6.2	5.6	5.9	5.7	7.3	6.7	6.6	6.5	7.0	6.1	7.1	7.2
Mar-13	6.5	6.8	6.4	6.7	6.3	5.5	6.0	5.7	7.2	6.5	6.7	6.4	7.2	6.3	7.8	7.9
Apr-13	12.0	12.1	12.1	12.4	11.9	10.9	11.3	10.6	11.8	11.0	11.4	10.9	12.1	11.4	13.1	13.2
May-13	15.9	15.7	15.9	16.4	15.0	14.3	14.5	14.0	15.0	14.2	14.6	14.1	15.2	14.5	16.3	16.4
Jun-13	19.0	18.9	19.1	19.4	18.4	17.9	17.9	17.5	18.2	17.4	18.1	17.5	19.1	18.5	20.5	20.5
Jul-13	23.7	23.6	23.8	24.2	23.2	22.6	22.7	22.1	22.7	21.8	22.8	22.0	23.8	23.3	25.3	25.4
Aug-13	21.2	21.2	21.3	21.6	20.6	19.9	20.0	19.5	20.0	19.5	19.8	19.3	20.3	19.9	21.5	21.5
Sep-13	17.2	17.1	17.0	17.4	17.0	16.2	16.3	15.8	16.6	16.0	16.6	16.1	16.9	16.5	17.6	17.5
Oct-13	13.6	13.8	13.5	13.7	13.7	13.3	13.3	13.2	14.1	13.7	13.8	13.7	14.2	13.8	14.6	14.4
Nov-13	8.1	8.4	7.9	8.2	8.3	7.9	8.2	8.1	9.3	8.9	8.9	8.8	9.4	8.5	9.1	8.8
Dec-13	8.1	8.4	8.0	8.1	8.2	7.8	8.2	8.2	9.6	9.2	8.9	8.7	8.8	8.1	8.4	8.0
Jan-14	7.3	7.5	7.2	7.4	7.2	6.8	7.2	7.1	8.5	8.2	7.8	7.7	7.9	7.2	7.7	7.4
Feb-14	8.3	8.5	8.3	8.6	8.1	7.7	7.7	7.6	9.0	8.6	8.5	8.3	8.6	7.8	8.4	8.2
Mar-14	10.8	10.8	10.6	10.9	10.7	9.9	10.0	9.6	11.1	10.5	10.9	10.5	11.5	10.8	11.9	11.6
Apr-14	14.2	14.2	14.2	14.5	14.3	13.3	13.6	12.8	14.1	13.3	14.0	13.3	14.6	14.0	15.4	15.2
May-14	17.2	17.1	17.3	17.7	16.5	15.8	16.0	15.4	16.4	15.6	16.1	15.5	16.6	16.1	17.6	17.5
Jun-14	20.0	19.9	20.0	20.4	19.2	18.7	18.6	18.2	18.9	18.2	18.8	18.2	19.6	19.2	20.9	20.9

Jul-14	23.3	23.2	23.4	23.8	22.4	21.9	21.8	21.3	21.6	20.8	21.5	20.8	22.3	21.9	23.5	23.6
Aug-14	18.8	18.8	18.9	19.3	18.2	17.5	17.5	17.0	17.5	17.0	17.3	16.9	17.8	17.4	18.8	18.9
Sep-14	17.6	17.6	17.5	17.8	18.0	17.1	16.9	16.3	17.0	16.5	17.1	16.6	17.7	17.3	18.4	18.4
Oct-14	13.5	13.7	13.4	13.5	13.6	13.2	13.1	12.9	13.6	13.3	13.4	13.2	13.4	13.2	13.9	13.9
Nov-14	9.8	10.1	9.7	9.8	9.9	9.6	9.7	9.6	10.5	10.3	10.1	10.0	9.9	9.7	10.4	10.5
Dec-14	6.6	7.1	6.3	6.4	6.8	6.5	6.7	6.5	7.5	7.3	6.9	6.9	6.6	6.4	7.0	7.0
Jan-15	6.4	6.9	6.3	6.4	6.5	6.0	6.6	6.3	7.5	7.2	6.6	6.5	6.4	5.8	6.6	6.5
Feb-15	6.4	6.9	6.3	6.6	6.6	6.1	6.4	6.4	7.5	7.2	6.8	6.6	6.7	6.0	7.1	6.9
Mar-15	9.0	9.5	9.0	9.2	9.2	8.5	8.6	8.5	9.2	8.9	8.9	8.6	8.8	8.3	9.3	9.3
Apr-15	13.5	14.0	14.1	14.4	14.5	13.2	13.3	12.4	13.1	12.5	13.2	12.4	13.6	13.1	14.8	14.8
May-15	14.9	15.1	15.2	15.5	14.5	14.0	14.0	13.5	13.9	13.5	13.7	13.3	14.0	13.7	15.4	15.6
Jun-15	18.7	18.7	19.0	19.5	18.2	17.7	17.8	17.3	17.7	17.1	17.6	17.0	18.1	17.8	19.6	19.7
Jul-15	20.6	20.6	20.8	21.1	19.9	19.4	19.5	19.0	19.4	18.8	19.2	18.7	19.7	19.4	21.2	21.3
Aug-15	20.6	20.5	20.8	21.1	20.2	19.5	19.5	18.9	19.2	18.6	19.0	18.4	19.2	19.0	20.4	20.4
Sep-15	15.8	15.8	15.4	15.8	15.9	15.0	15.0	14.6	15.3	14.8	15.3	14.8	15.9	15.5	16.8	16.8
Oct-15	12.8	12.9	12.7	12.8	13.1	12.6	12.5	12.4	13.2	12.9	13.1	12.8	13.2	13.0	13.9	13.9
Nov-15	10.6	11.0	10.6	10.6	10.6	10.3	10.5	10.5	11.2	11.0	10.7	10.6	10.5	10.2	10.8	10.9
Dec-15	10.5	10.7	10.4	10.4	10.3	10.1	10.3	10.3	11.0	10.7	10.4	10.4	10.2	9.9	10.5	10.5
Jan-16	7.8	7.8	7.3	7.4	7.3	6.9	7.2	7.2	8.2	7.9	7.5	7.4	7.4	7.0	7.8	7.8
Feb-16	8.3	8.3	7.9	8.0	8.1	7.6	7.2	7.2	8.2	7.8	7.7	7.6	7.7	7.2	8.2	8.3
Mar-16	9.5	9.5	8.9	9.1	9.1	8.3	8.3	8.1	9.1	8.6	8.7	8.4	9.0	8.5	9.6	9.6
Apr-16	12.6	12.6	12.6	12.9	12.3	11.3	11.5	10.7	11.7	10.9	11.3	10.7	11.6	11.1	12.3	12.4
May-16	17.0	17.0	17.1	17.4	16.7	16.1	16.0	15.4	16.0	15.2	15.8	15.1	16.2	15.8	17.1	17.2
Jun-16	18.9	18.9	18.8	19.1	18.4	17.9	18.0	17.6	18.3	17.7	18.1	17.6	18.8	18.4	19.8	19.9
Jul-16	21.7	21.7	21.8	22.3	20.7	20.2	20.3	19.8	20.3	19.7	19.9	19.6	20.4	20.0	21.6	21.8
Aug-16	20.9	20.9	21.2	21.5	20.7	19.8	19.9	19.3	19.9	19.2	19.6	19.2	20.4	20.0	21.4	21.7
Sep-16	18.8	19.0	18.8	19.0	19.2	18.2	18.2	17.7	18.5	18.0	18.0	18.0	18.8	18.4	19.6	19.7
Oct-16	12.7	13.0	12.7	12.8	13.2	12.7	12.5	12.4	13.2	12.8	12.2	12.8	13.4	13.0	13.7	13.8
Nov-16	7.8	8.8	8.0	8.2	8.5	8.0	8.3	8.2	9.3	9.0	6.7	8.6	8.6	8.2	8.6	8.8
Dec-16	7.9	8.5	7.9	8.1	8.4	7.9	8.5	8.4	9.6	9.3	6.0	8.8	8.4	8.1	8.5	8.7
Jan-17	6.6	6.8	6.4	6.6	6.7	6.1	6.8	6.7	8.1	7.7	3.3	7.2	6.7	6.4	6.9	7.1
Feb-17	8.5	8.4	8.5	8.7	8.5	7.9	8.3	8.2	9.3	9.0	4.4	8.6	8.5	8.2	8.8	9.0
Mar-17	9.4	11.1	11.0	11.3	11.4	10.5	10.7	10.3	11.3	10.9	6.5	10.8	11.5	11.1	12.1	12.3

Apr-17	13.4	13.4	13.7	14.2	13.6	12.6	12.9	12.2	13.1	12.5	10.5	12.4	13.1	12.6	13.8	14.1
May-17	17.4	17.4	17.3	17.8	17.4	16.7	17.0	16.3	16.9	16.3	14.0	16.2	17.6	17.1	18.7	18.8
Jun-17	20.8	20.7	20.8	21.3	19.7	19.3	19.3	18.9	19.3	18.7	16.3	18.5	19.6	19.2	20.8	21.0
Jul-17	20.5	20.5	20.5	20.9	19.7	19.3	19.2	18.7	19.2	18.7	16.9	18.6	20.3	19.8	21.6	21.7
Aug-17	20.1	19.7	20.1	20.5	19.6	18.8	18.9	18.2	18.8	18.1	17.2	18.0	19.0	18.6	20.2	20.4
Sep-17	16.3	16.5	16.3	16.7	16.5	15.6	15.8	15.3	16.0	15.6	14.4	15.4	16.3	15.8	16.9	17.0
Oct-17	14.2	14.4	14.2	14.4	14.3	13.9	13.8	13.7	14.4	14.1	12.6	13.9	14.1	13.8	14.5	14.5
Nov-17	9.0	9.4	9.0	9.2	9.3	8.9	9.0	8.8	10.0	9.6	7.6	9.2	9.4	8.9	9.4	9.5
Dec-17	6.2	6.6	6.1	6.4	6.6	6.2	6.6	6.4	7.6	7.3	4.6	6.7	6.5	6.1	6.6	6.6
Jan-18	6.8	7.2	6.8	7.1	6.9	6.5	7.0	6.8	7.9	7.6	4.9	7.1	6.6	6.3	7.1	7.4
Feb-18	6.1	6.1	5.7	6.1	6.0	5.5	5.7	5.5	6.8	6.3	4.1	6.2	5.9	5.6	6.6	6.6
Mar-18	8.3	8.3	7.7	8.1	7.8	7.1	7.5	7.1	8.5	7.8	5.7	7.7	7.9	7.4	8.8	8.9
Apr-18	12.9	12.9	12.6	13.1	12.8	12.0	12.3	11.7	12.7	12.1	10.0	12.0	12.5	12.1	13.5	13.7
May-18	18.5	18.5	18.7	19.3	19.2	18.3	18.6	17.4	18.4	17.4	15.8	17.5	19.2	18.5	20.4	20.5
Jun-18	20.7	20.7	20.7	21.2	20.7	20.1	20.3	19.6	20.5	19.6	18.8	19.7	21.5	21.1	23.1	23.1
Jul-18	24.4	24.4	24.6	25.1	24.3	23.8	23.9	23.1	23.8	22.8	23.0	22.9	24.5	24.2	26.0	26.1
Aug-18	21.2	21.2	21.4	21.8	20.9	20.2	20.2	19.6	20.2	19.5	19.7	19.4	20.2	19.9	21.4	21.6
Sep-18	16.9	16.9	16.7	17.1	17.2	16.3	16.3	15.8	16.7	16.2	16.3	16.1	16.8	16.4	17.8	17.9
Oct-18	12.9	12.9	12.7	13.0	13.4	12.9	12.6	12.4	13.5	13.2	12.3	13.0	13.2	12.9	13.7	13.8
Nov-18	9.6	9.6	9.3	9.6	9.6	9.2	9.5	9.3	10.6	10.2	8.6	9.9	9.9	9.6	10.4	10.5
Dec-18	8.4	8.4	8.2	8.5	8.5	8.1	8.5	8.4	9.7	9.4	7.1	8.8	8.7	8.3	8.9	9.0

Table A4.5: First Floor Monthly Average Interface Relative Humidities %

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	99	96	86	94	100	94	95	100	84	96	88	89	100	96	99	92
Jan-12	100	100	97	100	100	99	98	100	96	99	97	97	100	99	100	97
Feb-12	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	98
Mar-12	100	100	100	100	100	100	100	100	100	97	100	100	100	100	100	97
Apr-12	100	100	100	100	100	100	100	100	99	90	100	100	100	100	100	94
May-12	100	95	95	97	99	98	97	100	93	94	97	98	94	98	93	87
Jun-12	97	87	89	91	98	98	94	100	89	95	93	97	88	93	81	78
Jul-12	92	79	85	85	94	95	90	99	86	95	90	94	81	85	69	65
Aug-12	85	74	78	78	88	90	85	96	82	93	85	91	75	80	64	62
Sep-12	83	76	80	78	88	92	88	98	85	95	87	93	78	76	67	63
Oct-12	88	88	88	88	95	97	96	100	92	97	93	97	86	80	77	70
Nov-12	92	95	95	94	100	100	99	100	95	96	97	99	92	83	82	75
Dec-12	94	98	98	97	100	100	100	100	98	96	100	100	97	86	87	79
Jan-13	98	98	99	99	100	100	100	100	98	97	99	99	97	91	92	83
Feb-13	99	98	100	100	100	100	100	100	97	97	100	100	94	91	90	81
Mar-13	94	98	97	94	100	100	100	100	97	96	100	100	93	86	90	74
Apr-13	86	79	85	82	92	97	93	100	86	93	91	94	79	74	68	60
May-13	77	66	76	74	86	92	84	96	77	91	82	87	69	66	55	56
Jun-13	76	65	71	69	83	87	79	91	72	88	76	82	63	64	53	53
Jul-13	66	58	63	62	78	79	72	83	68	83	69	75	57	59	48	48
Aug-13	62	60	60	60	74	76	72	82	69	83	70	75	61	62	55	54
Sep-13	66	67	65	66	76	77	78	87	75	88	74	79	68	69	64	63
Oct-13	77	79	78	78	84	84	87	96	81	89	81	84	75	75	71	70
Nov-13	90	93	91	91	95	92	96	100	90	92	91	92	84	85	85	81
Dec-13	95	98	97	97	100	96	100	100	93	93	94	95	90	87	89	85
Jan-14	98	100	99	99	100	98	100	100	94	94	95	96	90	89	93	89
Feb-14	98	98	98	98	100	99	100	100	94	95	96	97	90	87	86	87
Mar-14	92	90	92	92	96	97	97	100	87	93	91	92	80	81	77	77
Apr-14	86	80	84	83	88	92	90	100	80	91	85	87	73	76	69	70
May-14	77	69	75	73	82	88	83	98	75	88	80	83	68	71	63	64
Jun-14	73	65	69	68	81	84	78	92	73	83	76	79	64	67	57	58
Jul-14	62	56	58	59	75	76	72	86	69	79	71	75	59	62	52	53
Aug-14	62	62	60	60	74	73	75	87	73	85	74	79	63	66	58	58
Sep-14	72	71	70	70	79	77	81	93	79	89	80	83	70	71	66	65
Oct-14	82	85	83	83	88	85	92	99	88	94	88	90	81	80	78	76
Nov-14	93	95	94	94	97	94	99	100	96	99	96	97	92	90	92	90
Dec-14	99	100	100	100	100	98	100	100	100	100	100	100	98	96	98	94
Jan-15	100	100	100	100	100	100	100	100	100	100	100	100	100	98	100	93
Feb-15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	97
Mar-15	100	100	100	100	100	100	100	100	100	100	100	100	100	97	96	92
Apr-15	99	94	99	99	99	99	100	100	99	99	99	100	93	89	80	78
May-15	91	77	92	91	95	96	100	100	93	96	95	96	81	78	68	66
Jun-15	81	68	80	79	88	91	96	100	85	92	87	90	72	71	60	59

Jul-15	68	61	65	66	79	82	89	93	75	81	76	80	63	66	55	54
Aug-15	64	61	61	62	76	75	86	89	74	84	74	79	64	66	58	57
Sep-15	74	72	72	73	82	79	91	96	83	89	82	85	74	74	70	69
Oct-15	88	87	88	88	93	89	98	100	92	95	91	93	85	84	82	80
Nov-15	98	97	98	98	100	96	100	100	99	99	98	99	95	90	91	86
Dec-15	100	100	100	100	100	100	100	100	100	100	100	100	98	92	92	88
Jan-16	100	100	100	100	100	100	100	100	100	100	100	100	100	98	99	94
Feb-16	100	100	100	100	100	100	100	100	100	100	100	100	100	98	96	92
Mar-16	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	93
Apr-16	100	100	100	100	100	100	100	100	100	100	100	100	100	99	97	89
May-16	100	90	99	100	100	100	100	100	100	100	100	100	93	94	86	81
Jun-16	98	86	96	96	100	99	100	100	97	99	99	99	87	89	79	75
Jul-16	84	71	84	83	94	95	98	100	90	94	93	94	78	81	66	64
Aug-16	75	67	74	74	87	90	95	100	85	93	87	90	73	73	63	62
Sep-16	81	76	81	81	89	91	97	100	89	95	89	92	79	78	71	69
Oct-16	93	90	94	94	98	97	100	100	98	99	98	99	90	89	87	84
Nov-16	100	100	100	100	100	100	100	100	100	100	100	100	100	98	99	94
Dec-16	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99
Jan-17	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	98
Feb-17	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	97
Mar-17	99	100	100	100	100	100	100	100	100	100	?	100	100	100	98	91
Apr-17	91	97	100	100	100	100	100	100	100	100	?	100	99	94	80	73
May-17	79	88	98	98	?	99	100	100	98	98	95	99	89	90	77	70
Jun-17	69	68	85	83	?	95	98	100	89	93	91	93	73	74	64	60
Jul-17	66	66	75	74	?	90	96	100	85	91	85	88	68	69	62	58
Aug-17	63	65	68	68	?	85	93	100	81	89	81	85	68	69	63	60
Sep-17	?	75	76	76	88	86	97	100	86	92	84	88	75	75	72	68
Oct-17	?	83	85	85	92	90	99	100	90	94	88	91	82	81	79	75
Nov-17	?	94	97	96	99	97	100	100	97	97	94	98	91	90	91	82
Dec-17	?	99	100	100	100	100	100	100	100	99	97	100	98	95	97	88
Jan-18	?	100	100	100	100	100	100	100	100	100	95	100	100	98	98	90
Feb-18	?	100	100	100	?	100	100	100	100	100	93	100	100	100	99	92
Mar-18	?	100	100	100	?	100	100	100	100	100	?	100	100	100	100	99
Apr-18	?	97	100	100	?	100	100	100	100	99	?	100	98	95	91	83
May-18	?	80	92	90	?	95	99	100	90	94	?	93	79	81	65	59
Jun-18	?	70	80	77	80	87	93	99	79	88	?	84	65	71	57	53
Jul-18	?	55	60	57	70	68	82	88	64	76	?	70	51	55	45	41
Aug-18	?	60	58	58	68	66	85	86	68	77	?	71	59	59	56	53
Sep-18	?	73	73	72	77	75	91	94	78	83	?	79	70	69	66	63
Oct-18	?	87	87	86	88	85	97	100	86	87	?	87	80	80	78	74
Nov-18	?	96	97	96	98	93	100	100	94	92	?	95	91	88	91	85
Dec-18	?	100	100	100	?	98	100	100	99	96	?	99	97	94	98	92

Table A4.6: First Floor Monthly Average Interface Wood Block Moisture Contents %

	Posn 1 upper	Posn 1 lower	Posn 2 upper	Posn 2 lower	Posn 3 upper	Posn 3 lower	Posn 4 upper	Posn 4 lower	Posn 5 upper	Posn 5 lower	Posn 6 upper	Posn 6 lower	Posn 7 upper	Posn 7 lower	Posn 8 upper	Posn 8 lower
Dec-11	18	18	17	15	21	20	21	20	17	21	18	17	24	49	20	18
Jan-12	42	25	44	46	49	46	51	52	44	54	42	44	49	59	25	31
Feb-12	51	45	80	80	80	80	80	80	80	80	80	80	80	80	30	27
Mar-12	40	71	78	78	77	78	78	78	77	73	77	78	77	77	56	24
Apr-12	27	37	78	78	78	78	78	78	78	32	78	78	77	79	27	22
May-12	24	23	44	44	76	76	76	76	73	58	76	71	33	76	21	19
Jun-12	21	17	20	20	76	76	76	76	22	43	76	22	19	75	16	16
Jul-12	19	15	18	18	75	75	69	69	21	74	71	22	17	45	14	14
Aug-12	16	14	16	16	67	66	23	22	20	40	23	20	15	22	13	13
Sep-12	16	14	16	16	31	48	23	21	20	36	22	20	15	20	13	13
Oct-12	16	16	17	17	30	78	64	48	21	64	29	21	16	21	14	13
Nov-12	17	17	19	21	70	79	79	79	23	44	70	22	18	21	15	14
Dec-12	17	18	21	23	76	80	80	80	69	32	80	23	20	22	16	15
Jan-13	18	19	22	26	80	81	80	80	79	43	80	23	21	31	18	16
Feb-13	19	19	22	25	81	81	81	81	62	26	80	23	20	26	18	16
Mar-13	18	19	21	25	75	81	81	81	66	27	80	23	20	33	18	15
Apr-13	16	15	17	19	28	78	63	64	22	22	78	21	17	20	14	13
May-13	14	13	15	15	22	77	21	21	18	21	28	18	14	17	12	12
Jun-13	14	12	14	14	26	75	19	19	17	20	20	17	13	16	12	12
Jul-13	13	12	13	13	32	32	17	17	16	18	17	15	12	15	11	11
Aug-13	12	12	12	12	18	21	16	16	15	18	17	15	12	15	12	12
Sep-13	13	12	12	12	17	20	17	17	16	18	17	15	12	15	12	12
Oct-13	13	14	14	14	18	21	19	18	17	19	18	15	13	16	13	12
Nov-13	15	17	17	18	21	26	30	22	20	20	27	17	15	19	15	14
Dec-13	18	19	21	22	46	75	80	78	24	22	79	19	17	21	17	16
Jan-14	19	21	22	24	78	80	80	80	23	22	80	20	17	22	18	17
Feb-14	19	20	22	24	80	80	80	80	24	22	79	20	18	22	17	17
Mar-14	18	18	20	21	49	79	79	79	22	21	78	19	16	21	15	15
Apr-14	16	16	18	18	22	77	50	52	20	20	42	18	15	20	14	14
May-14	14	13	15	15	19	73	21	21	18	19	21	17	13	18	13	13
Jun-14	13	12	14	14	20	69	19	19	17	18	19	16	13	17	12	12
Jul-14	12	12	12	12	19	24	17	18	16	17	18	15	12	16	12	12
Aug-14	12	12	12	12	17	20	17	17	16	17	18	15	12	16	12	12
Sep-14	13	12	13	12	18	20	18	18	17	19	19	16	13	16	12	12
Oct-14	14	15	15	15	19	22	21	21	19	20	23	17	14	18	14	14
Nov-14	16	18	19	20	26	35	61	59	55	58	65	21	17	21	17	17
Dec-14	20	23	23	26	80	78	80	80	80	80	80	24	20	23	20	19
Jan-15	25	27	45	73	80	81	80	80	80	80	80	73	23	49	24	20
Feb-15	29	28	80	80	80	80	80	80	80	80	80	80	28	81	28	22
Mar-15	27	28	79	79	79	79	79	79	79	79	79	79	32	80	23	21
Apr-15	24	22	53	57	77	77	77	78	77	78	77	72	23	54	17	17

May-15	19	13	21	22	61	77	77	77	77	77	77	23	17	22	14	14
Jun-15	15	12	17	17	26	75	75	46	34	40	75	20	15	18	12	12
Jul-15	13	12	13	13	19	49	70	19	18	18	22	17	13	17	12	12
Aug-15	13	11	12	12	17	22	73	18	17	18	21	16	13	16	12	12
Sep-15	13	12	13	13	18	21	58	19	18	19	25	17	14	17	13	13
Oct-15	15	15	17	17	20	25	69	24	27	29	60	19	15	19	15	15
Nov-15	20	20	22	23	41	71	79	66	70	76	78	23	19	22	18	17
Dec-15	23	24	26	34	79	79	79	79	78	78	79	27	21	24	18	17
Jan-16	27	27	41	63	80	80	80	80	71	80	80	67	25	61	23	21
Feb-16	29	28	80	80	80	80	80	80	37	80	80	80	29	80	22	21
Mar-16	30	28	79	79	79	80	80	80	39	79	79	80	41	79	24	21
Apr-16	29	26	77	77	78	78	78	78	40	78	78	78	31	78	22	20
May-16	25	18	51	51	76	76	76	76	46	76	76	76	22	76	18	17
Jun-16	22	16	24	24	74	75	75	75	69	75	75	72	18	75	16	15
Jul-16	17	12	18	18	49	74	74	74	74	60	57	26	16	49	13	13
Aug-16	14	12	14	15	20	74	72	75	74	27	44	20	14	19	12	12
Sep-16	15	12	15	15	20	74	69	75	55	51	59	20	15	20	13	13
Oct-16	17	16	19	19	23	78	71	78	49	75	77	25	17	22	16	16
Nov-16	24	23	26	29	64	80	79	80	39	79	72	65	23	55	23	20
Dec-16	29	27	32	38	80	64	77	80	53	79	76	79	32	80	29	24
Jan-17	30	29	34	34	69	40	49	80	60	80	82	80	32	80	31	26
Feb-17	31	30	33	33	30	41	51	80	64	79	81	79	33	80	32	27
Mar-17	31	29	32	32	29	40	51	79	64	78	80	78	32	78	27	22
Apr-17	27	22	30	30	28	38	50	78	51	78	78	78	29	78	17	16
May-17	24	17	26	26	26	37	46	76	46	76	77	72	22	72	15	14
Jun-17	16	12	18	18	22	35	41	75	36	75	74	22	15	22	13	12
Jul-17	14	12	14	15	21	28	32	75	31	75	28	20	14	19	12	12
Aug-17	13	12	13	13	18	26	31	35	29	75	26	18	13	19	12	12
Sep-17	14	12	14	14	18	25	31	25	29	31	26	18	14	20	13	13
Oct-17	15	14	15	15	19	25	32	26	31	24	28	19	15	21	14	14
Nov-17	18	18	20	20	22	27	34	27	35	25	28	21	17	23	17	15
Dec-17	22	23	25	27	26	30	37	27	40	25	29	24	20	26	20	17
Jan-18	25	26	28	29	27	32	38	27	45	25	29	27	23	27	23	19
Feb-18	27	29	29	30	27	33	38	27	49	25	29	28	26	27	24	19
Mar-18	27	29	29	30	27	35	38	27	51	25	29	28	27	27	27	22
Apr-18	25	25	28	29	26	35	37	26	48	24	28	27	24	26	22	18
May-18	19	15	20	21	22	31	35	25	36	23	28	23	17	24	13	13
Jun-18	16	12	16	16	20	27	33	25	28	23	27	18	13	21	12	12
Jul-18	13	11	12	12	16	19	25	20	20	18	19	14	11	16	11	11
Aug-18	12	12	11	12	14	17	24	19	20	18	19	14	12	15	12	12
Sep-18	13	12	12	13	15	18	25	21	21	19	21	15	13	17	12	12
Oct-18	14	14	15	15	17	20	27	23	24	21	23	16	14	19	14	13
Nov-18	18	18	19	20	20	23	29	25	28	23	24	19	16	22	17	15
Dec-18	22	22	24	26	24	27	29	26	34	25	24	23	19	26	21	18

APPENDIX B1

Building 2: Appleby

Sensor Locations

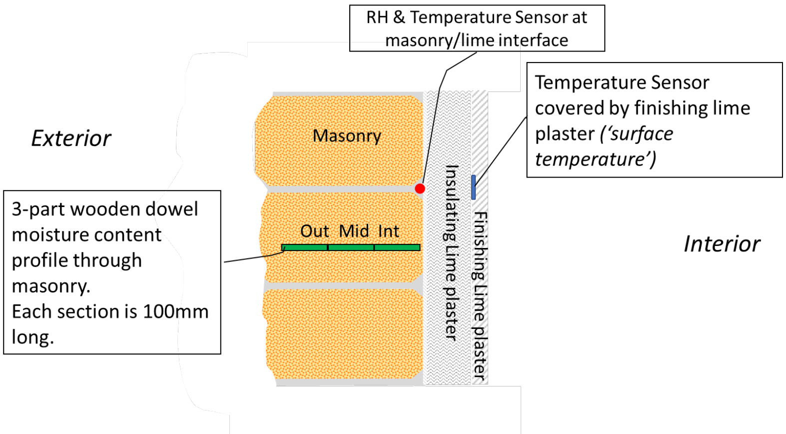


Figure B1.1: Schematic diagram of the positioning of sensors.

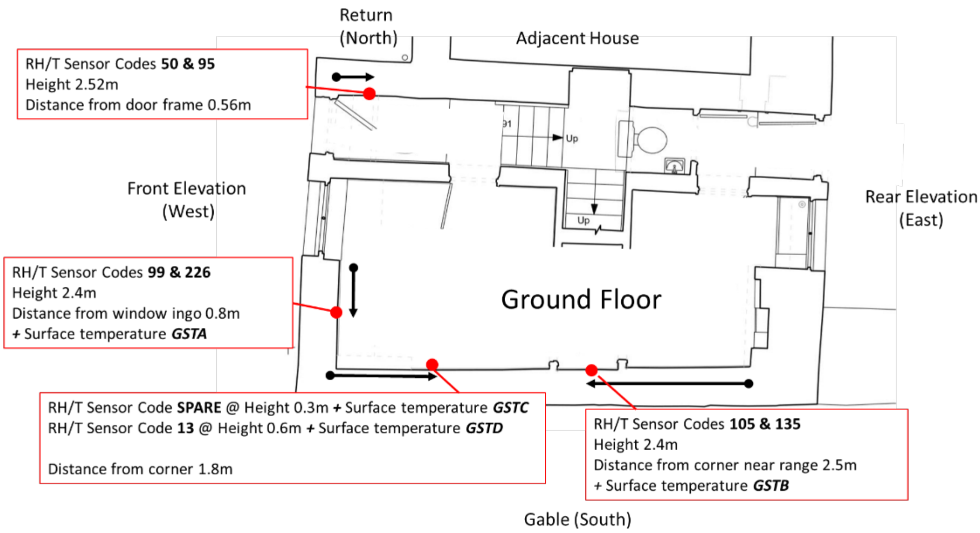


Figure B1.2: Ground floor plans – locations of temperature and humidity sensors.

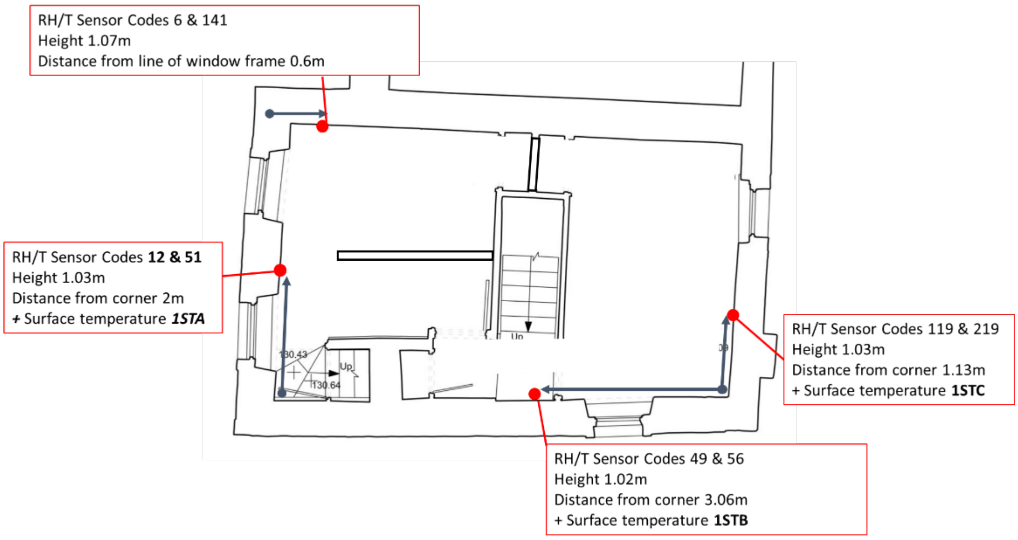


Figure B1.3: First floor plans – locations of temperature and humidity sensors.

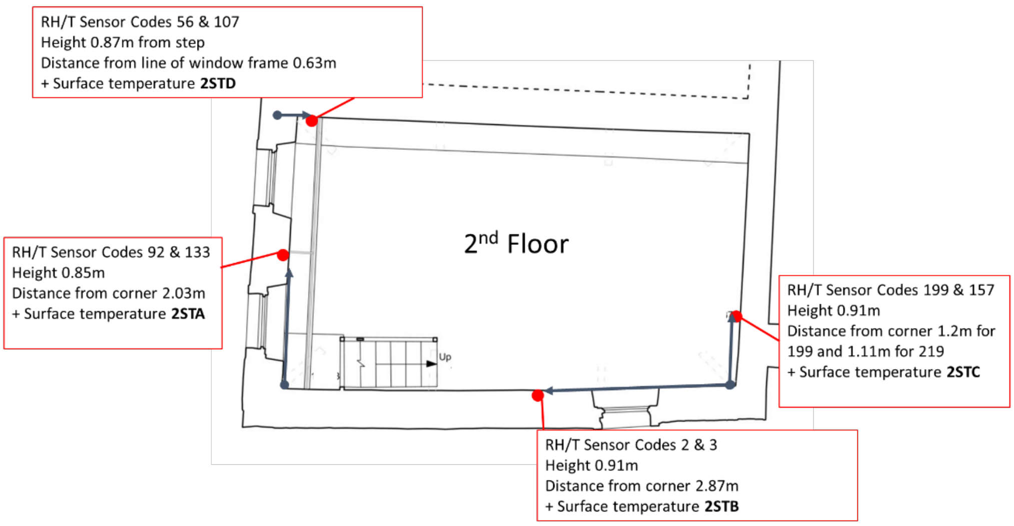


Figure B1.4: Second floor plans – locations of temperature and humidity sensors.

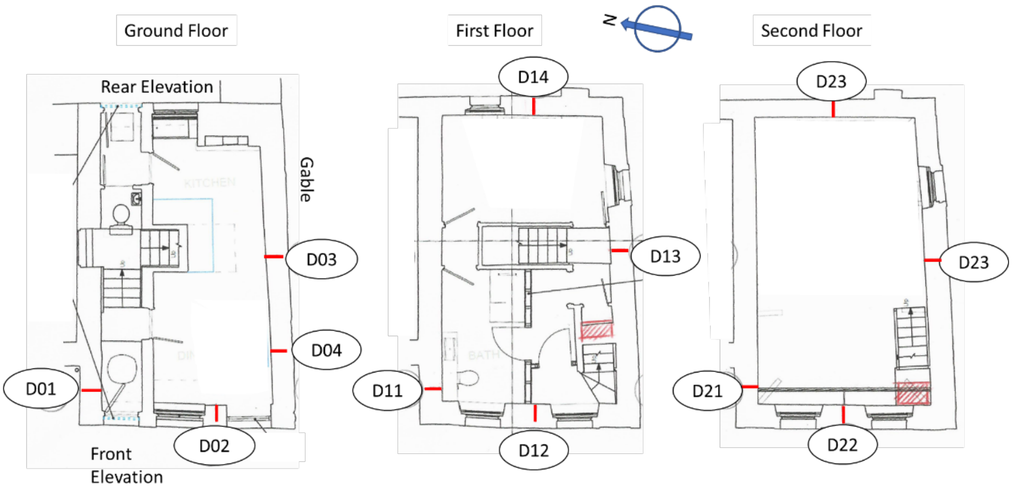


Figure B1.5: Floor plans – location of moisture sensors profiles.

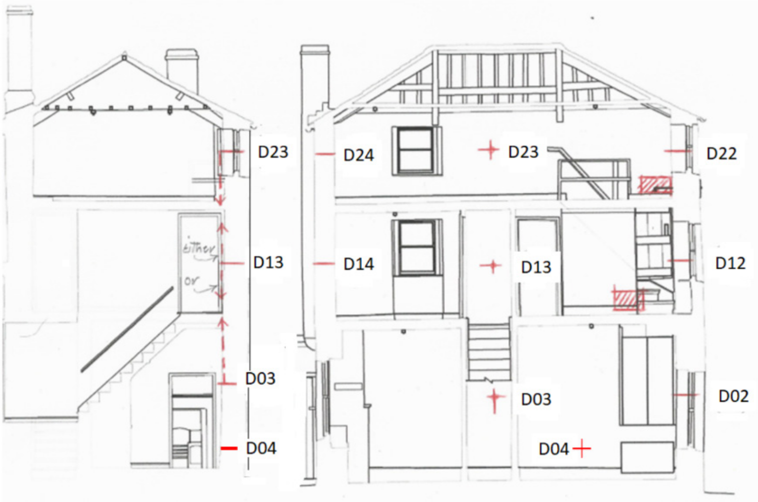


Figure B1.6: Sections – location of moisture sensors profiles.

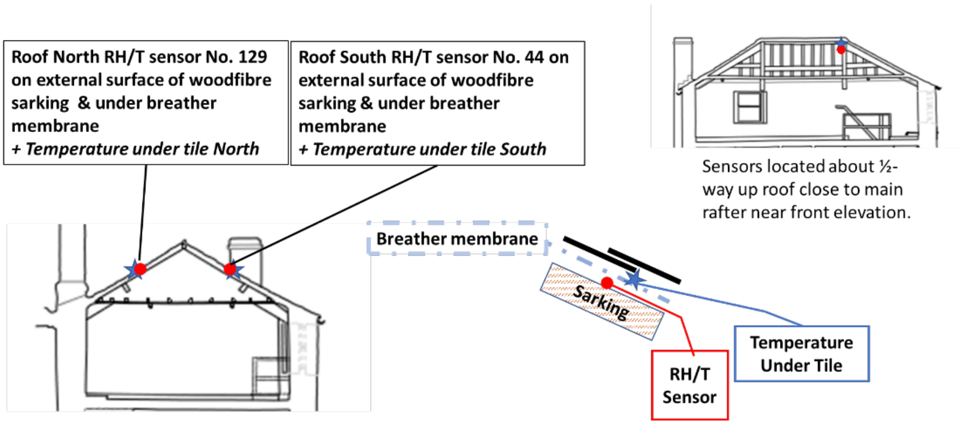


Figure B1.7: Location of roof sensors.

Outdoor sensors

Figure B1.8: Weather station.

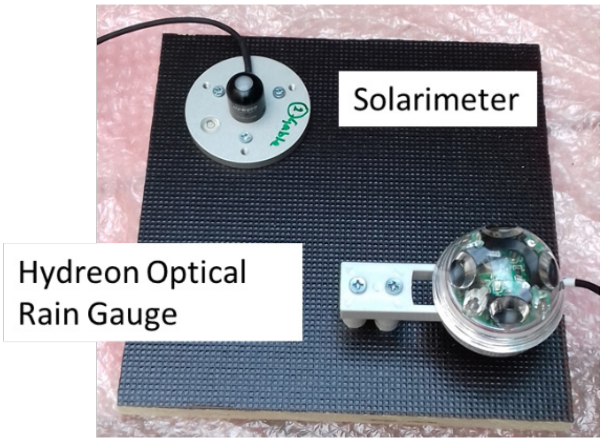


Figure B1.9: Vertically mounted sensors.

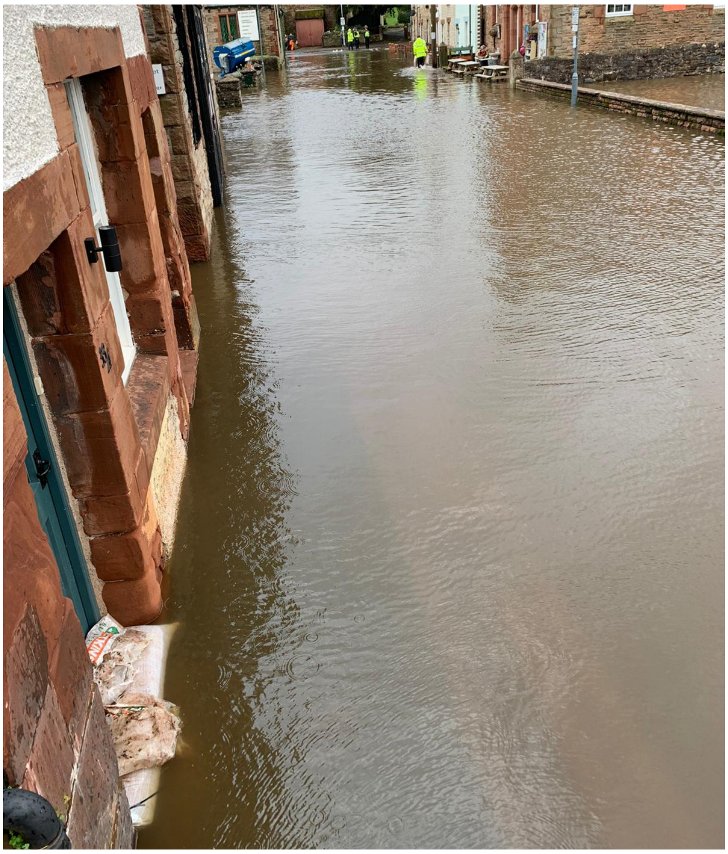


Figure B1.10: Flooding of Chapel Street, Appleby on 7 February 2020. © Chris Morphet.

APPENDIX B2

Building 2: Appleby
Monitored data

Weather Data

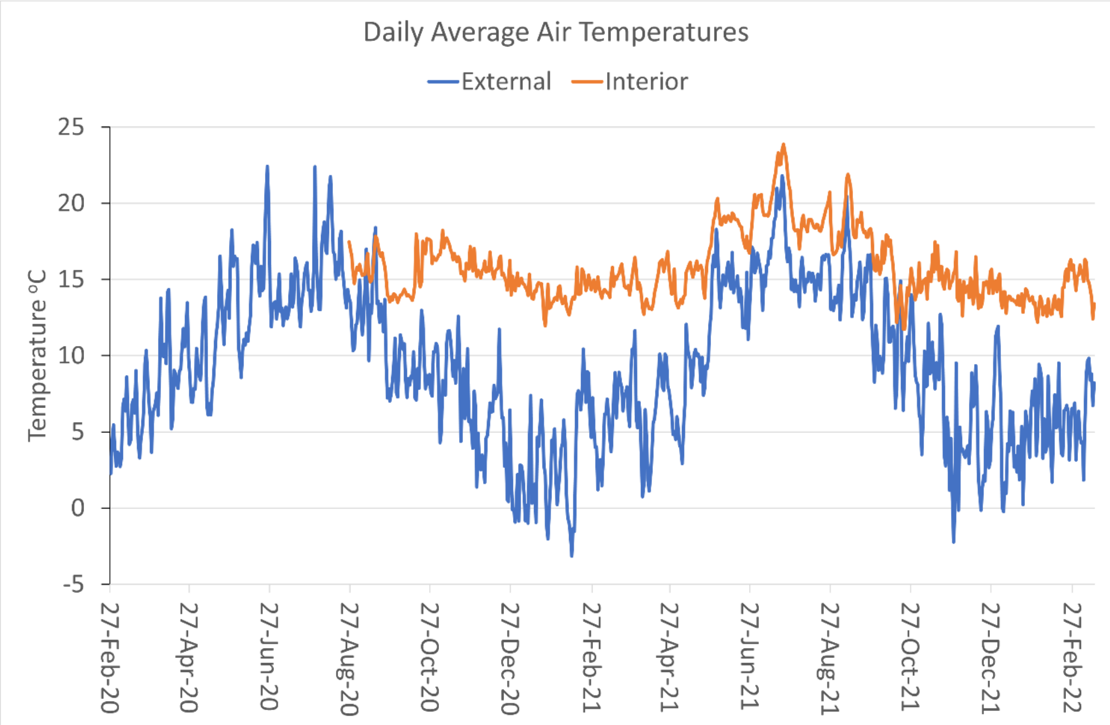


Figure B2.1: External and internal air temperatures

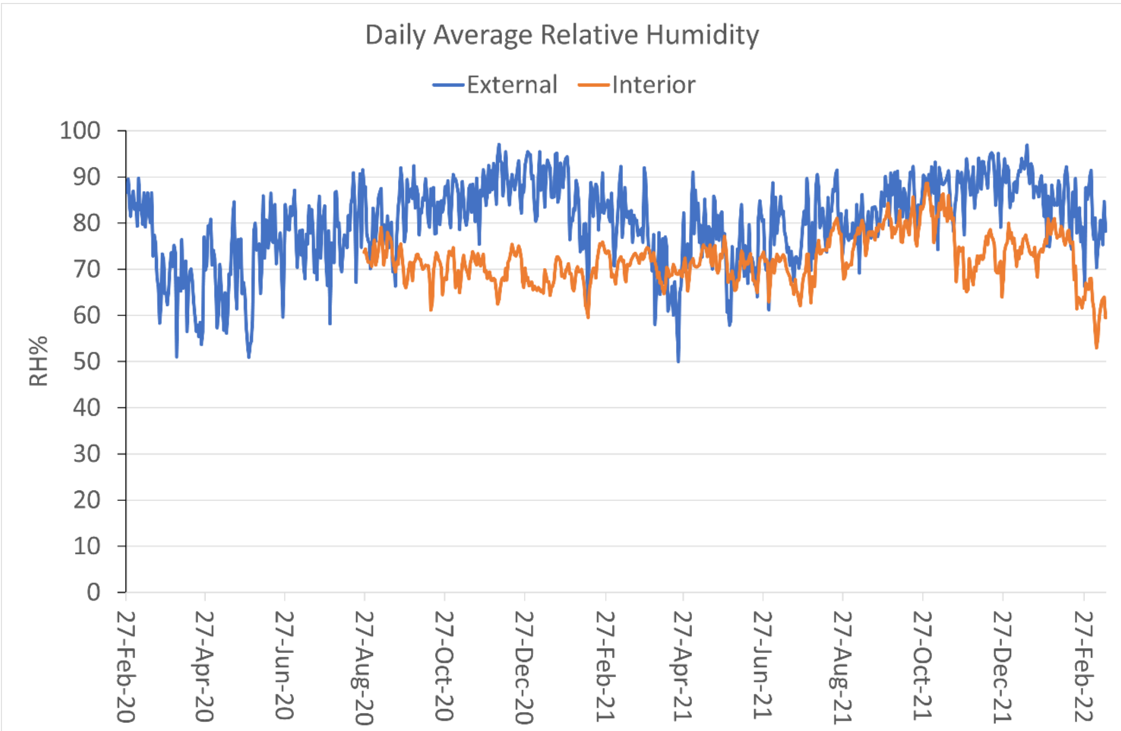


Figure B2.2: External and internal relative humidities

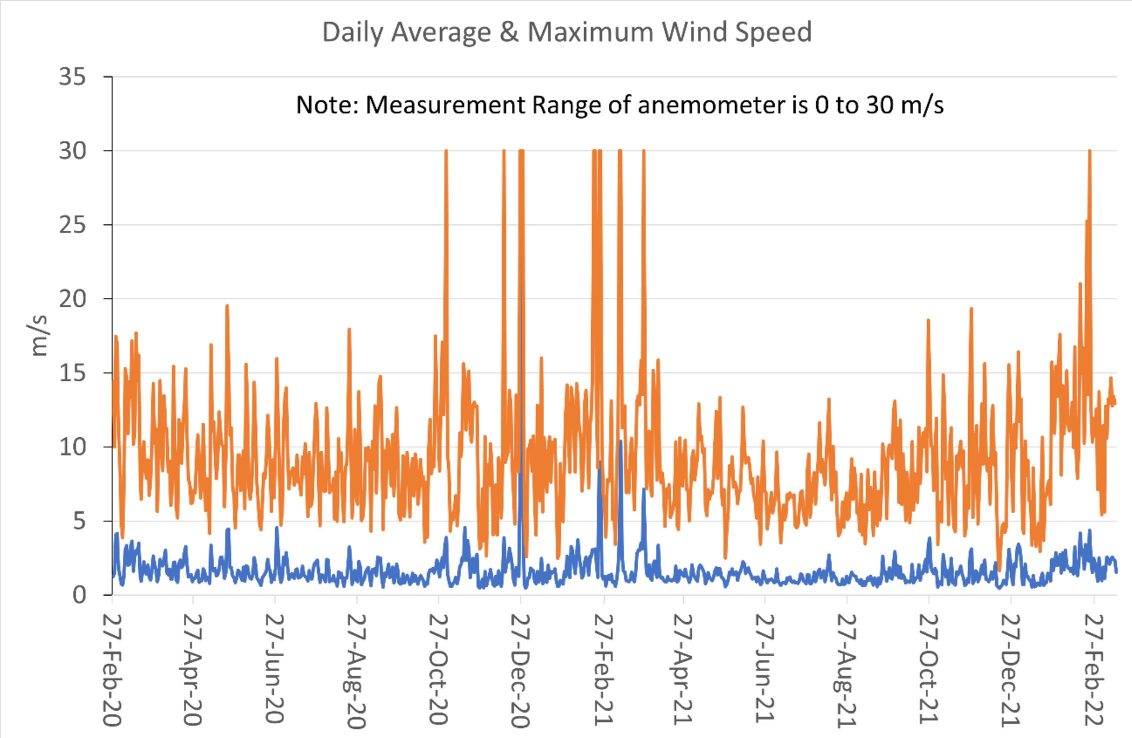


Figure B2.3: Daily average and maximum wind speed

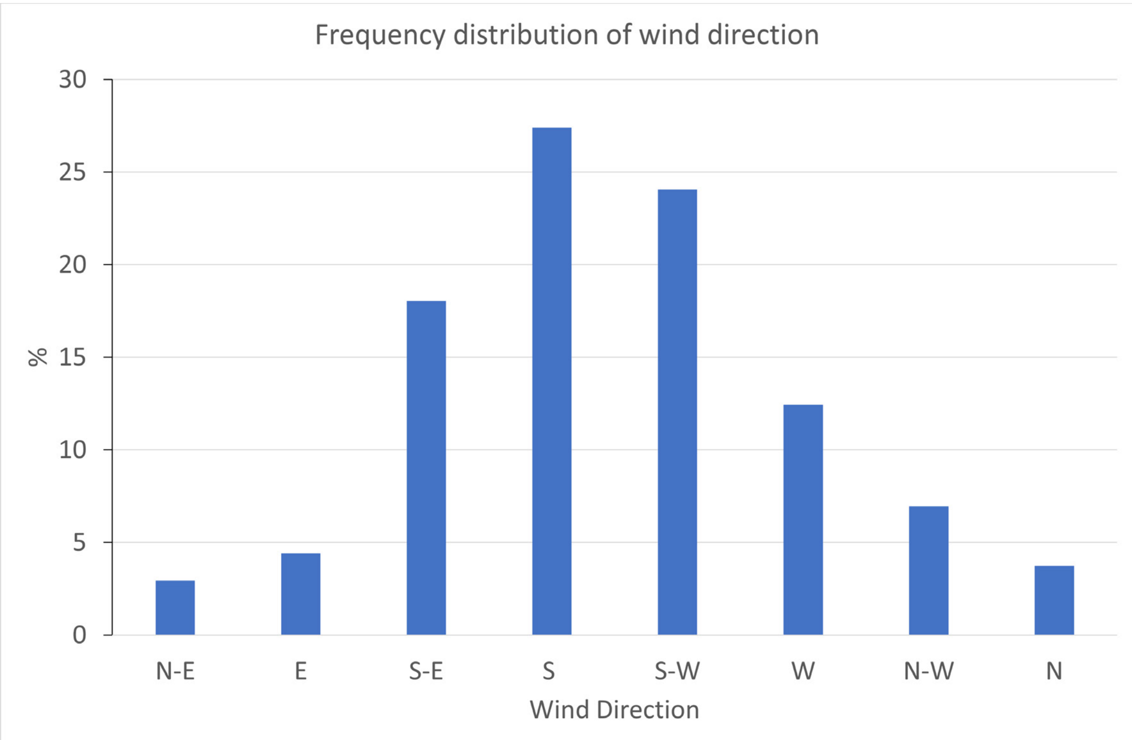


Figure B2.4: Distribution of wind direction

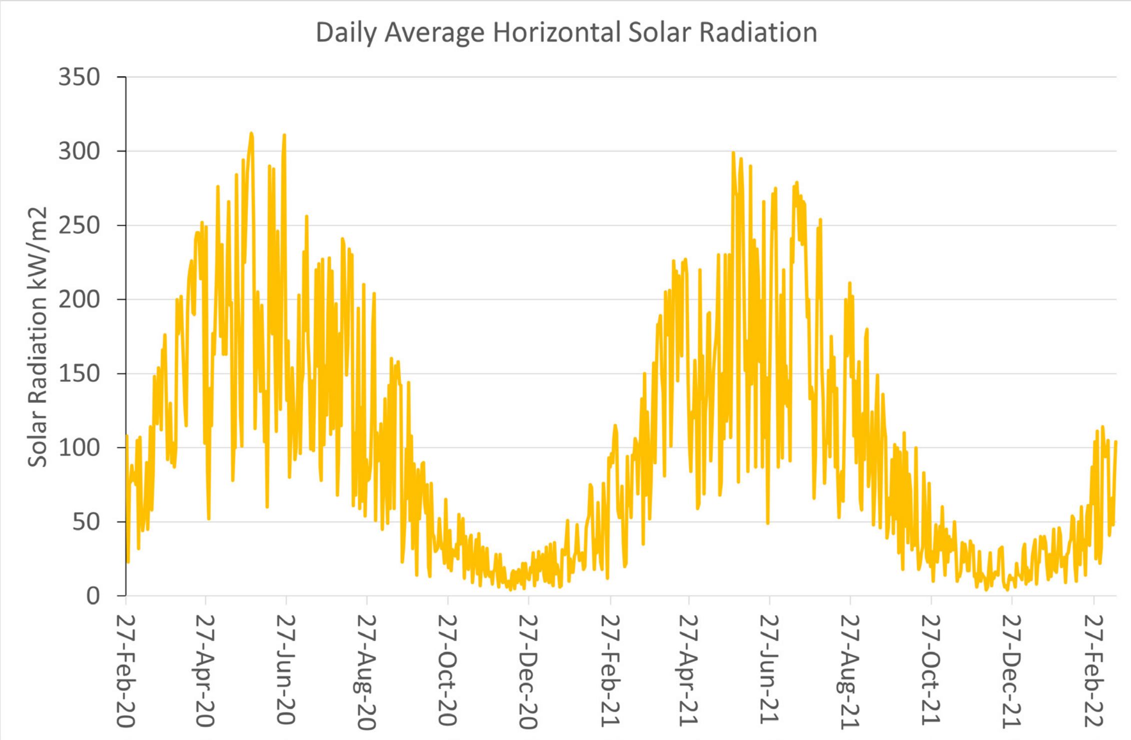


Figure B2.5: Daily average horizontal solar radiation (weather station)

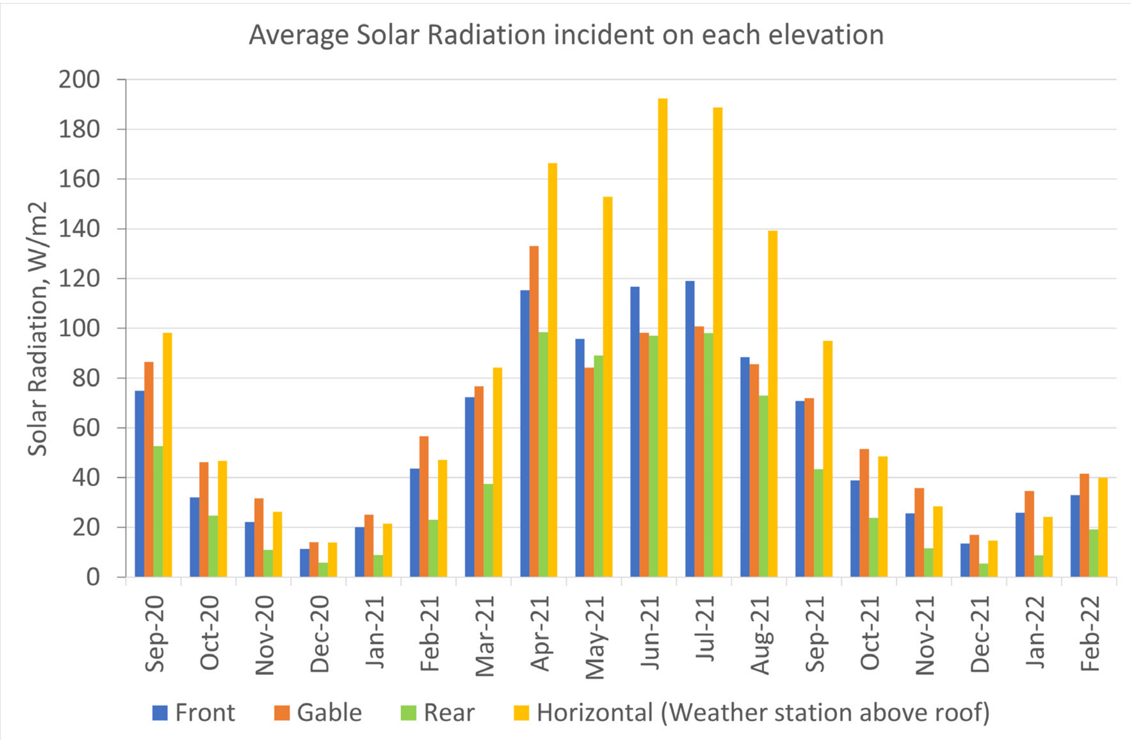


Figure B2.6: Monthly average solar radiation incident on each elevation

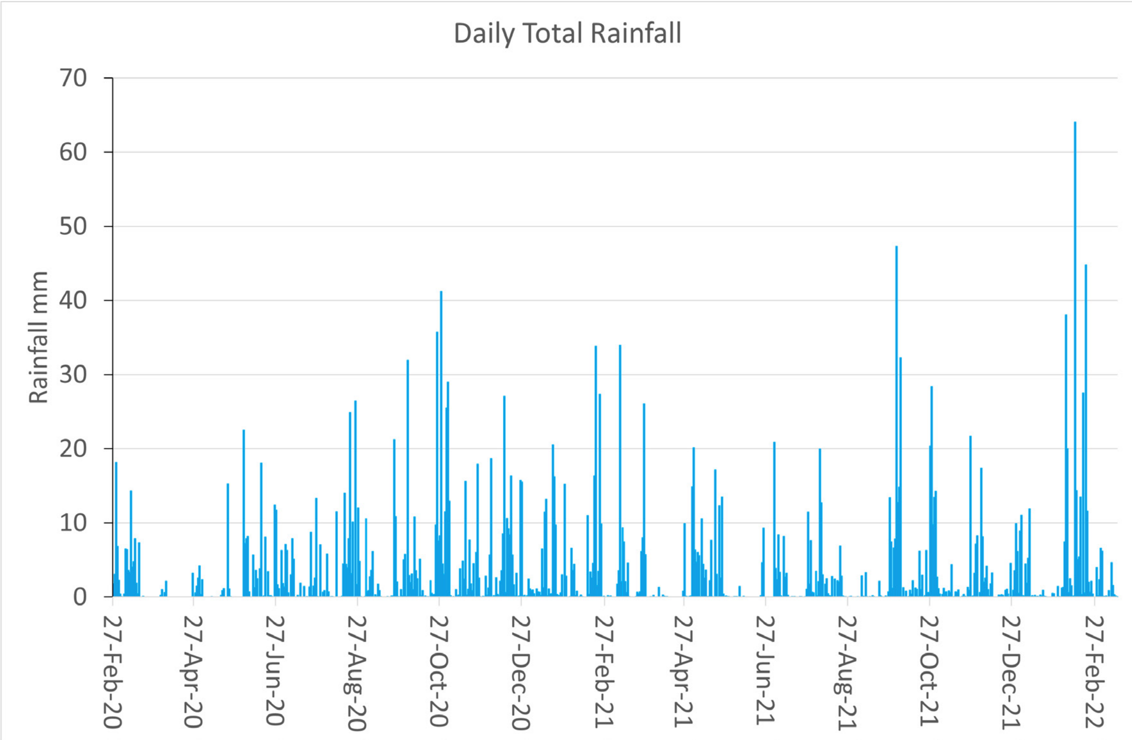


Figure B2.7: Daily total rainfall (weather station rain gauge)

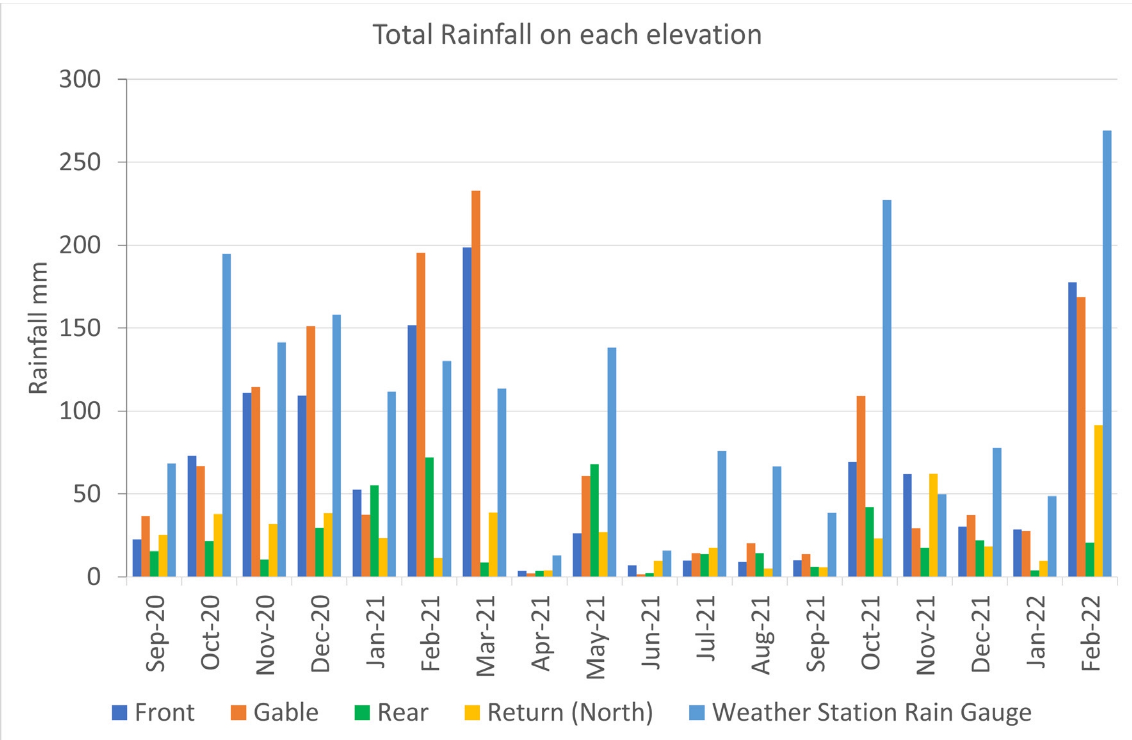


Figure B2.8: Monthly total rainfall incident on each elevation

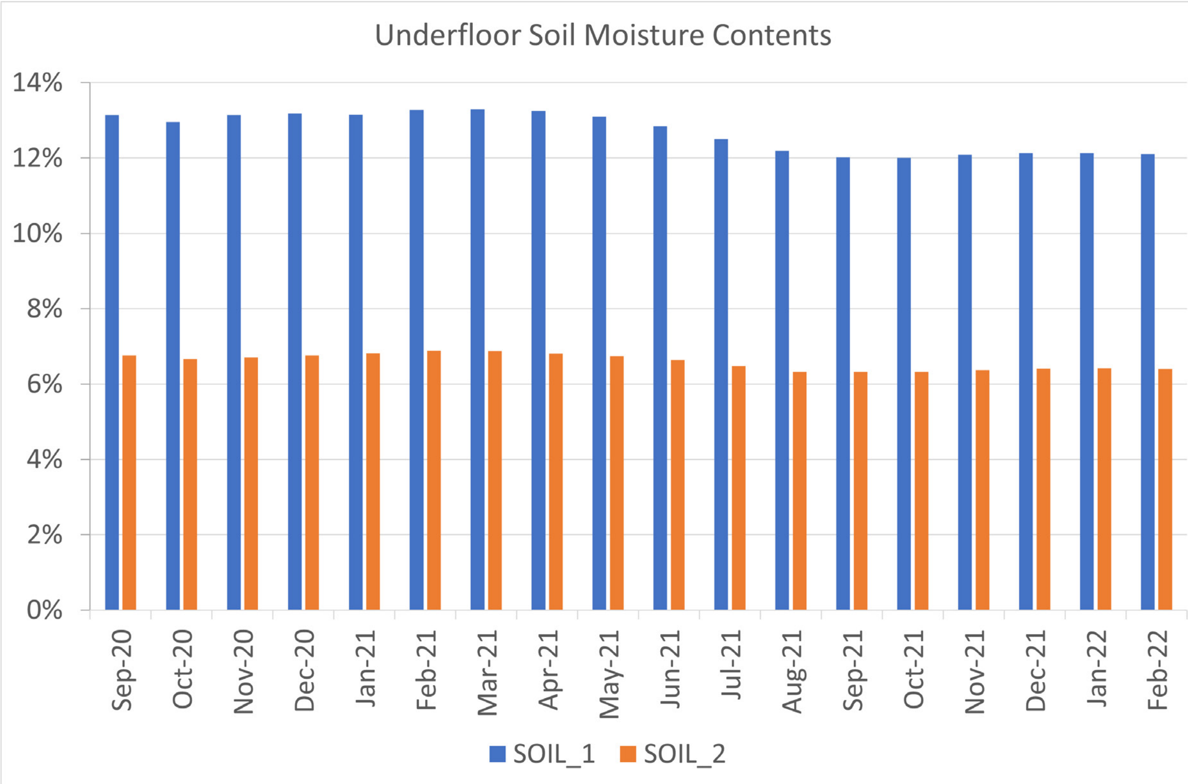


Figure B2.9: Underfloor soil moisture contents

Interface Relative Humidity and Temperatures

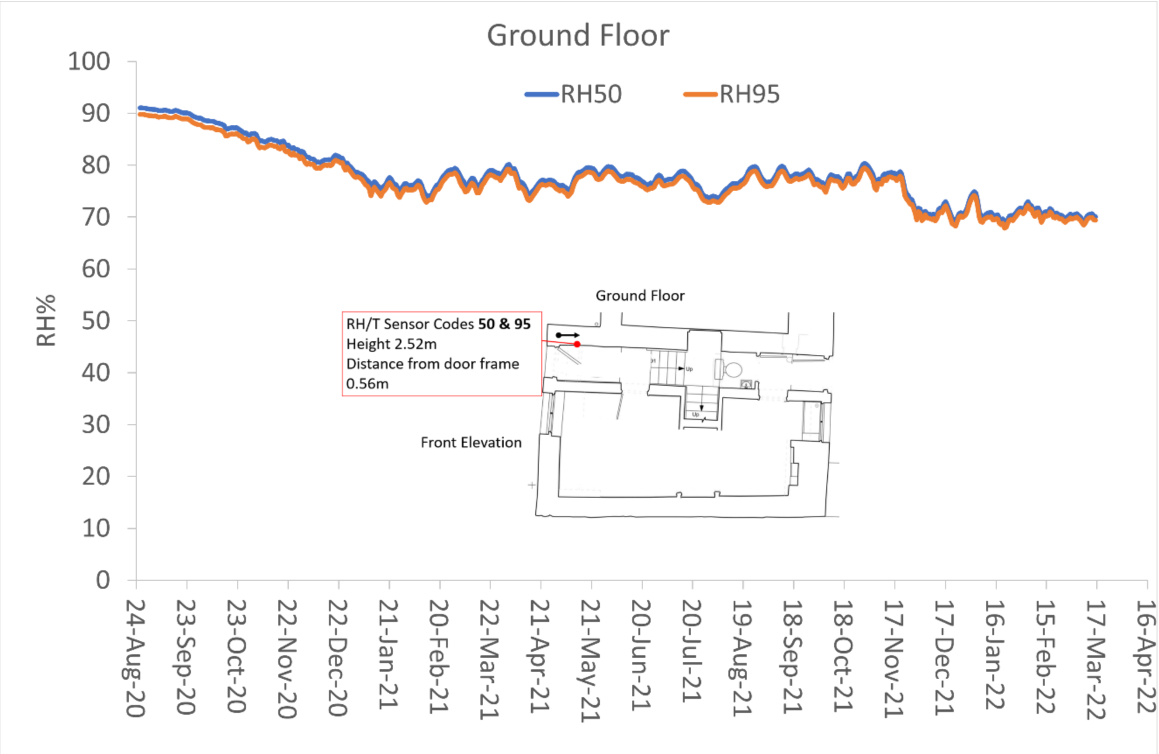


Figure B2.10a: Ground floor return (north) – Interface RH

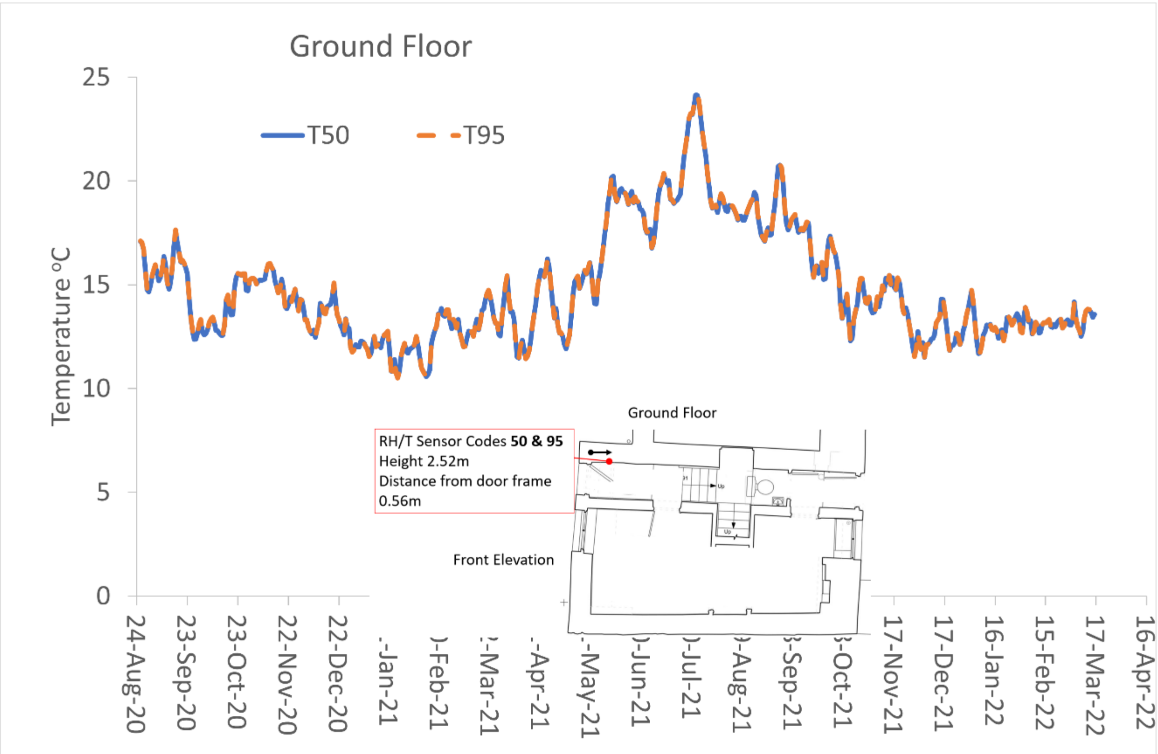


Figure B2.10b: Ground floor return (north) – Interface Temperature

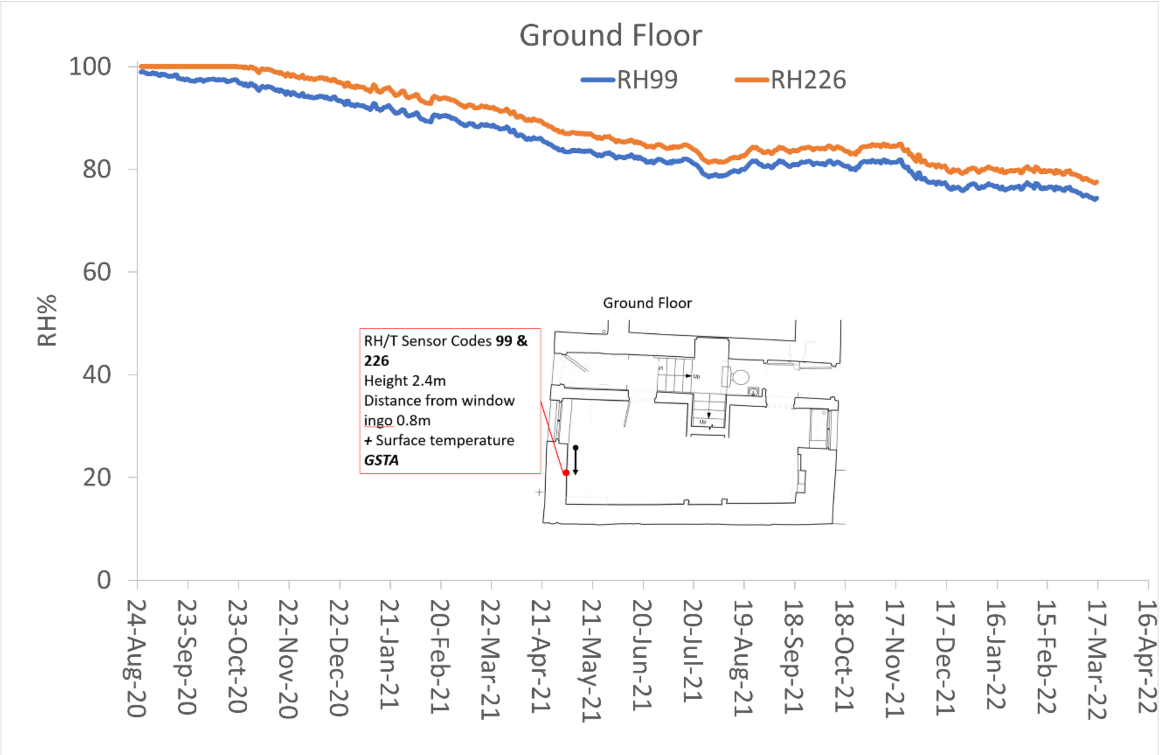


Figure B2.11a: Ground floor front elevation (west) – Interface RH

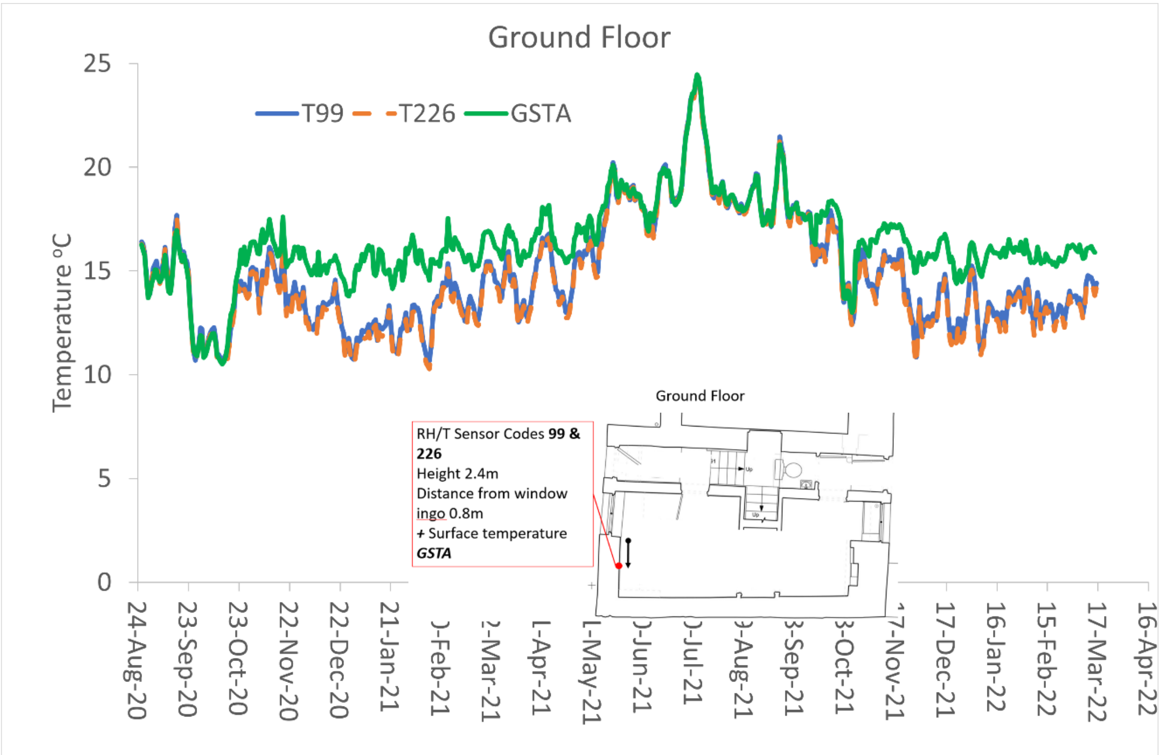


Figure B2.11b: Ground floor front elevation (west) – Temperatures

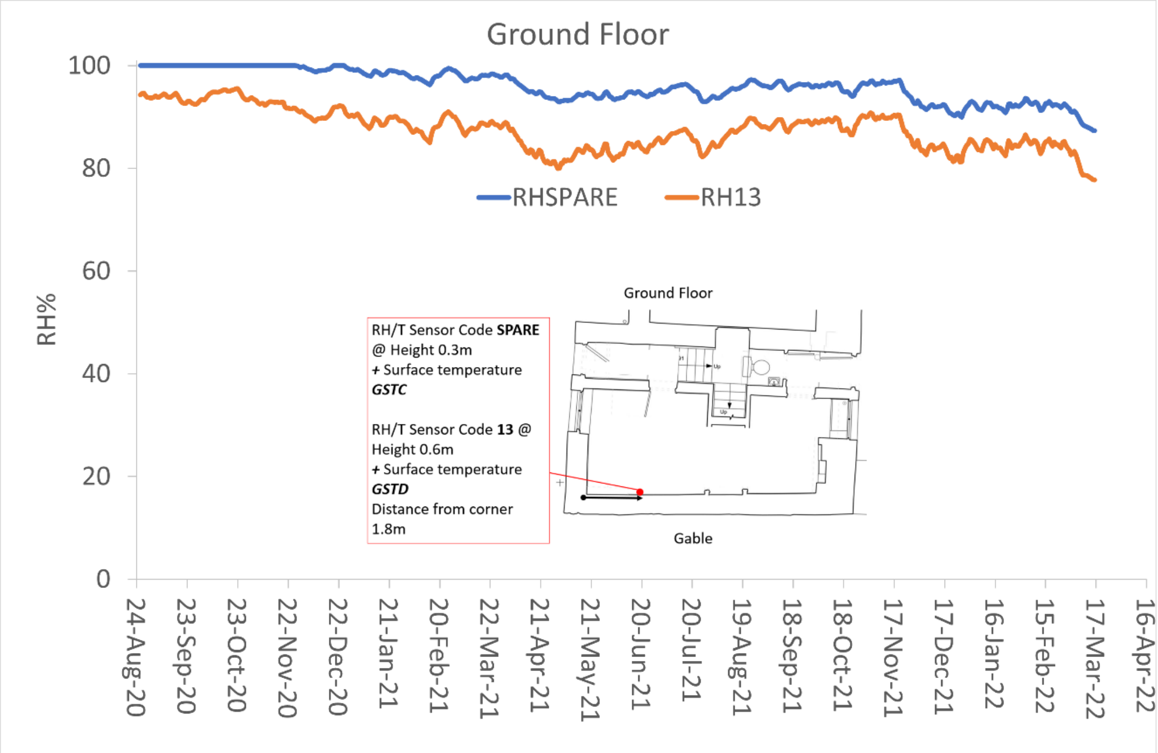


Figure B2.12a: Ground floor gable (south) – Interface RH lower positions

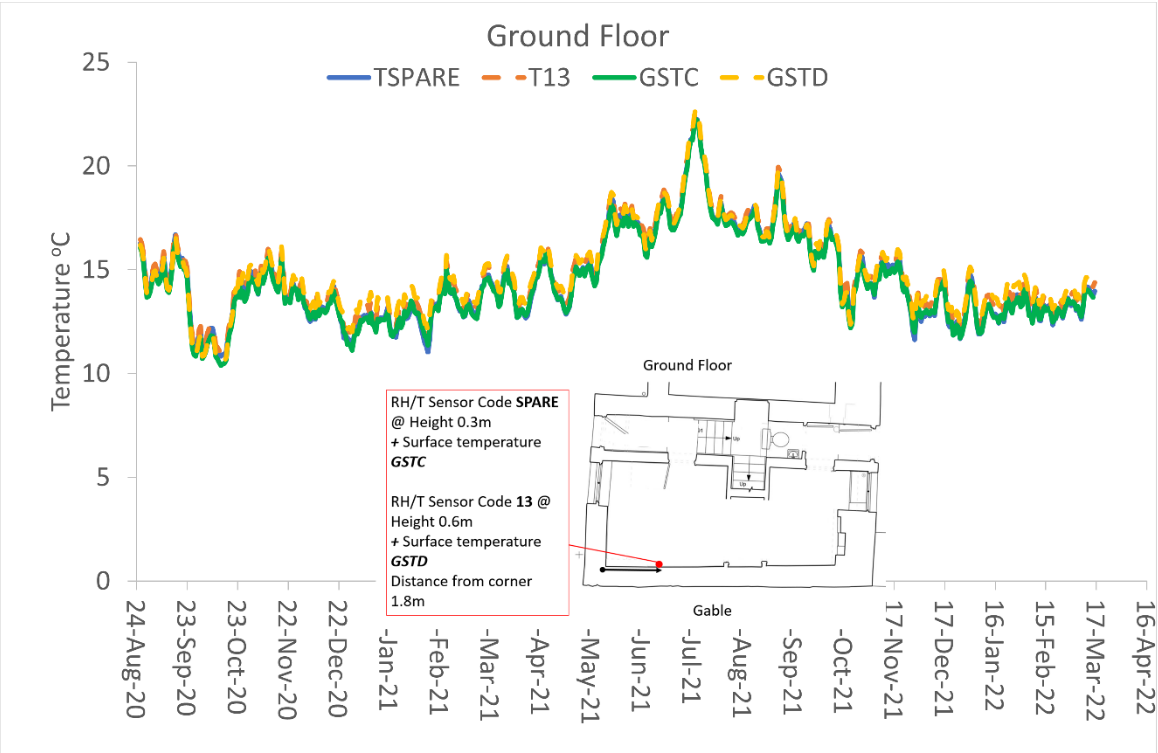


Figure B2.12b: Ground floor gable (south) – Temperatures lower positions

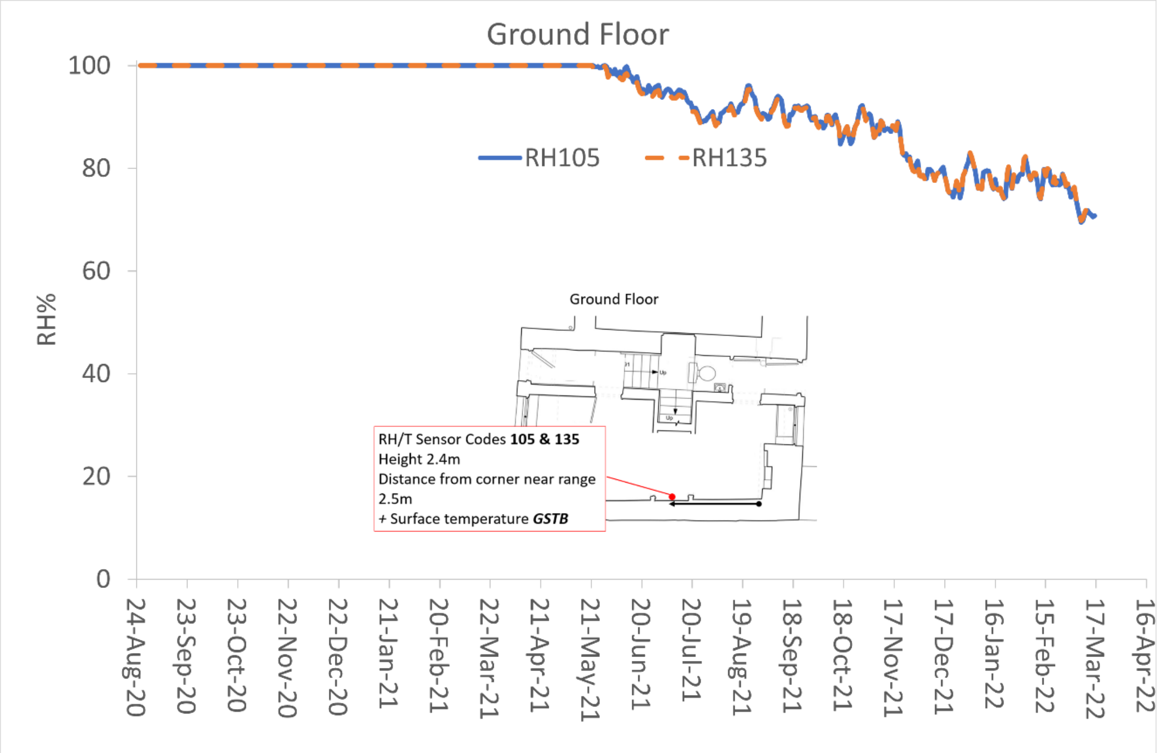


Figure B2.13a: Ground floor gable (south) – Interface RH upper position

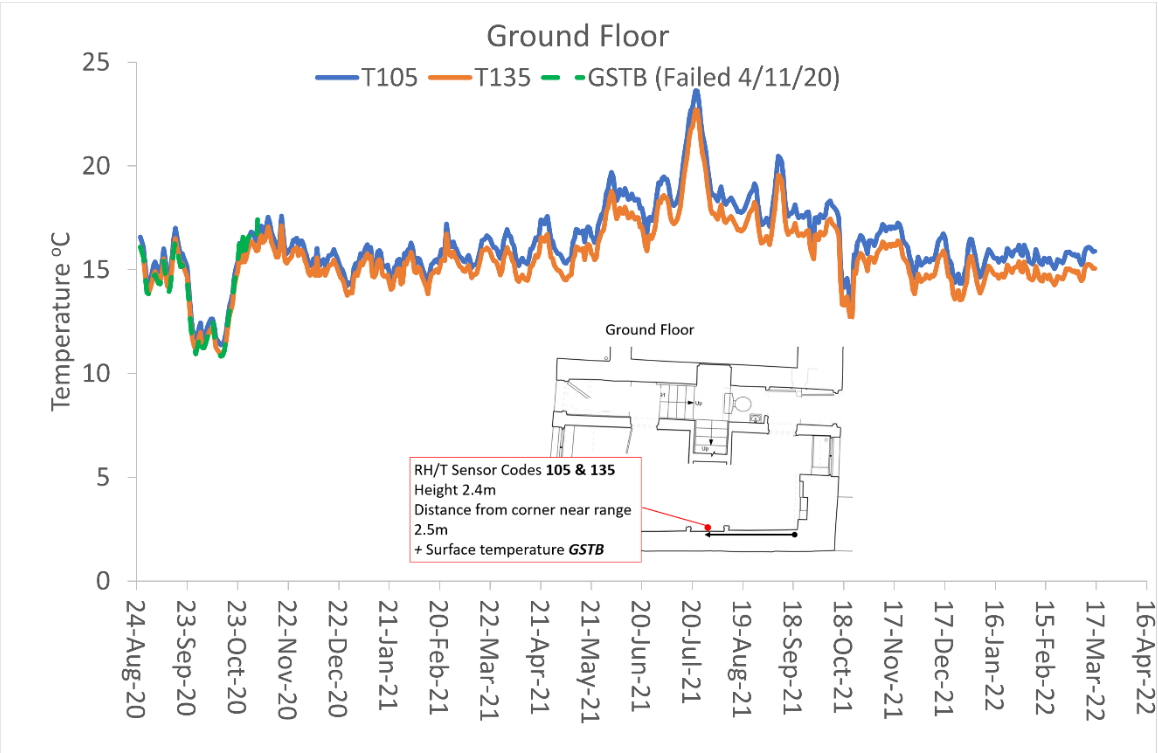


Figure B2.13b: Ground floor gable (south) – Temperatures upper position

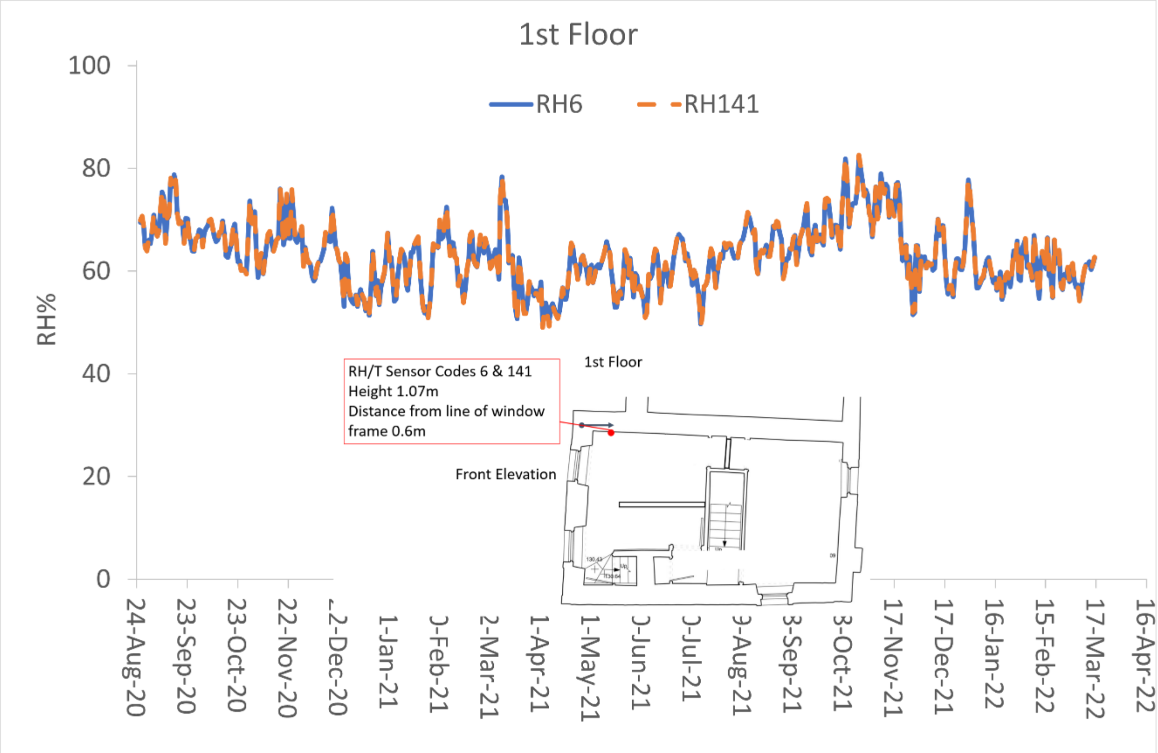


Figure B2.14a: First floor return (north) – Interface RH

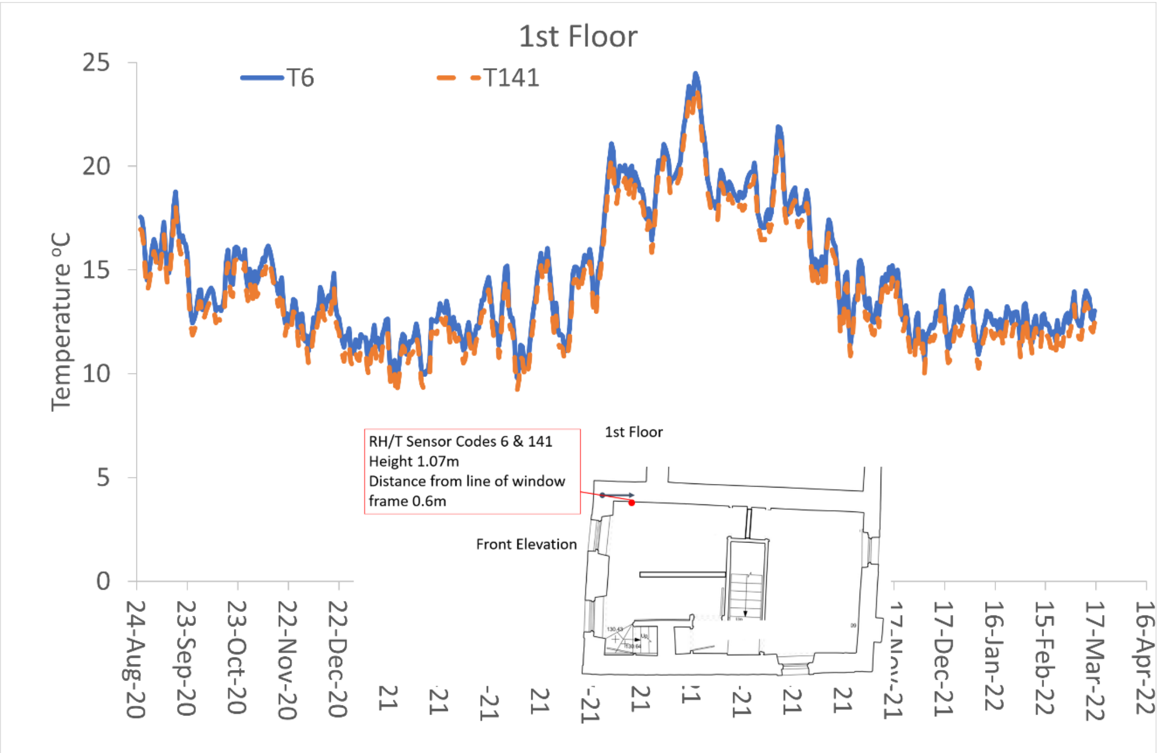


Figure B2.14b: First floor return (north) – Interface Temperature

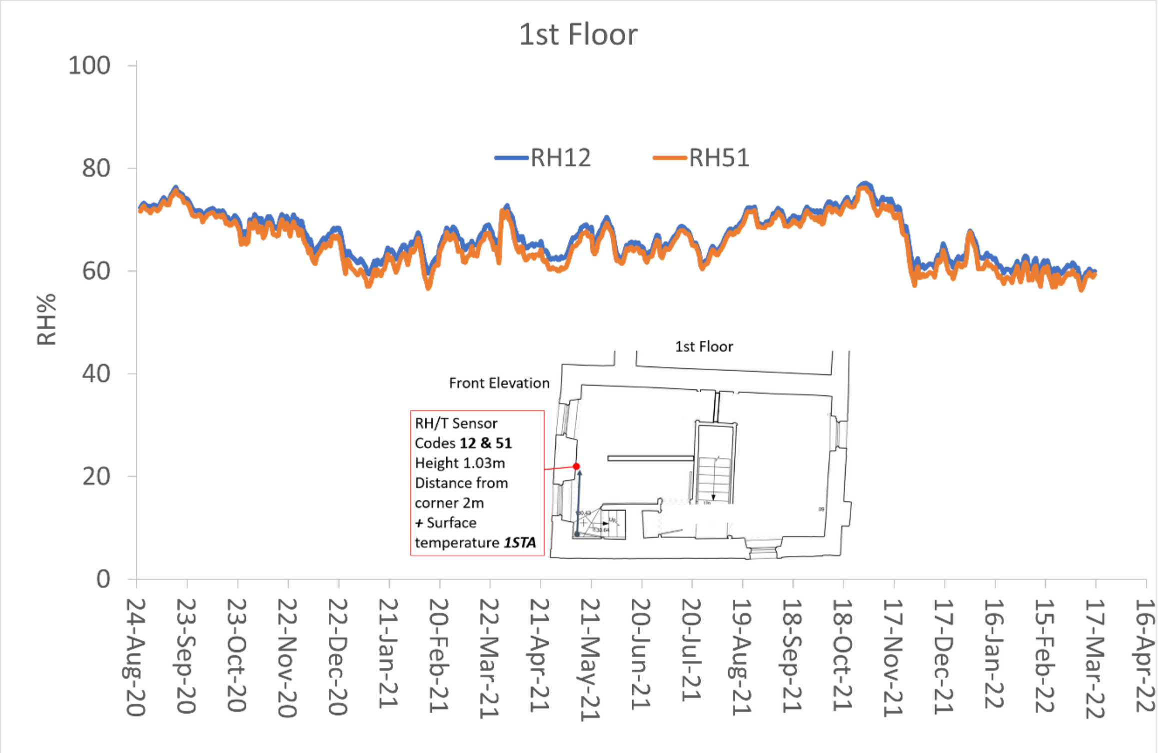


Figure B2.15a: First floor front elevation (west) – Interface RH

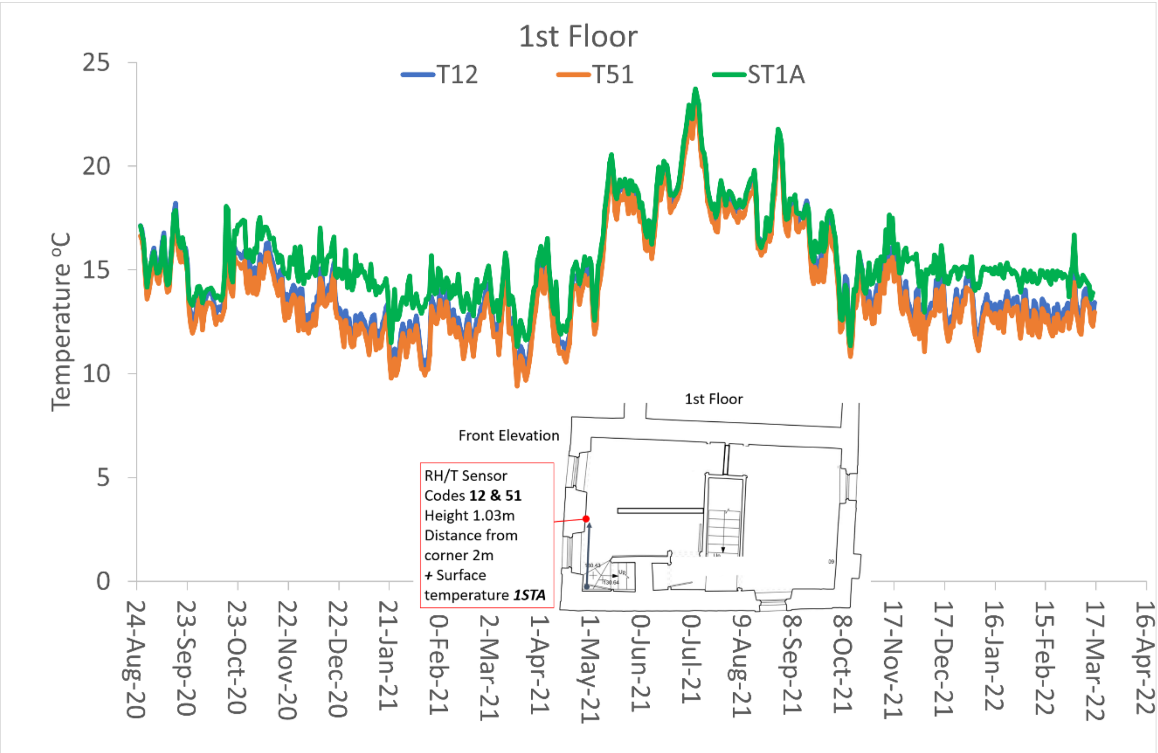


Figure B2.15b: First floor front elevation (west) – Temperatures

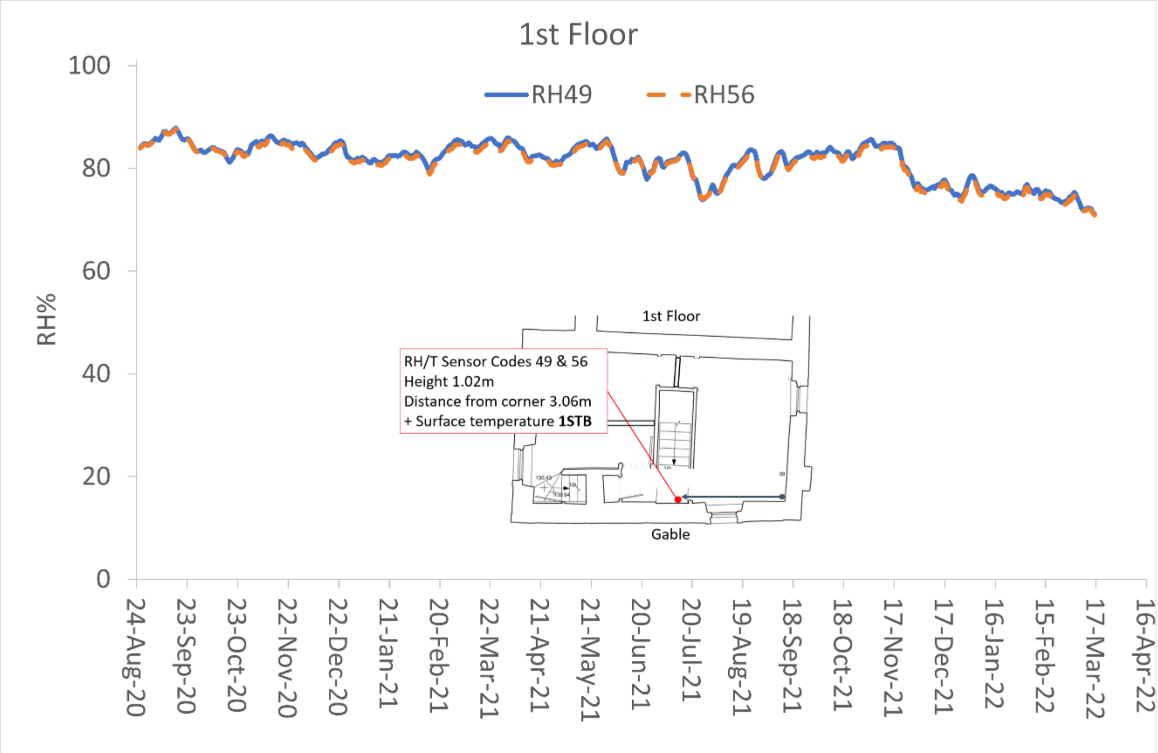


Figure B2.16a: First floor gable (south) – Interface RH

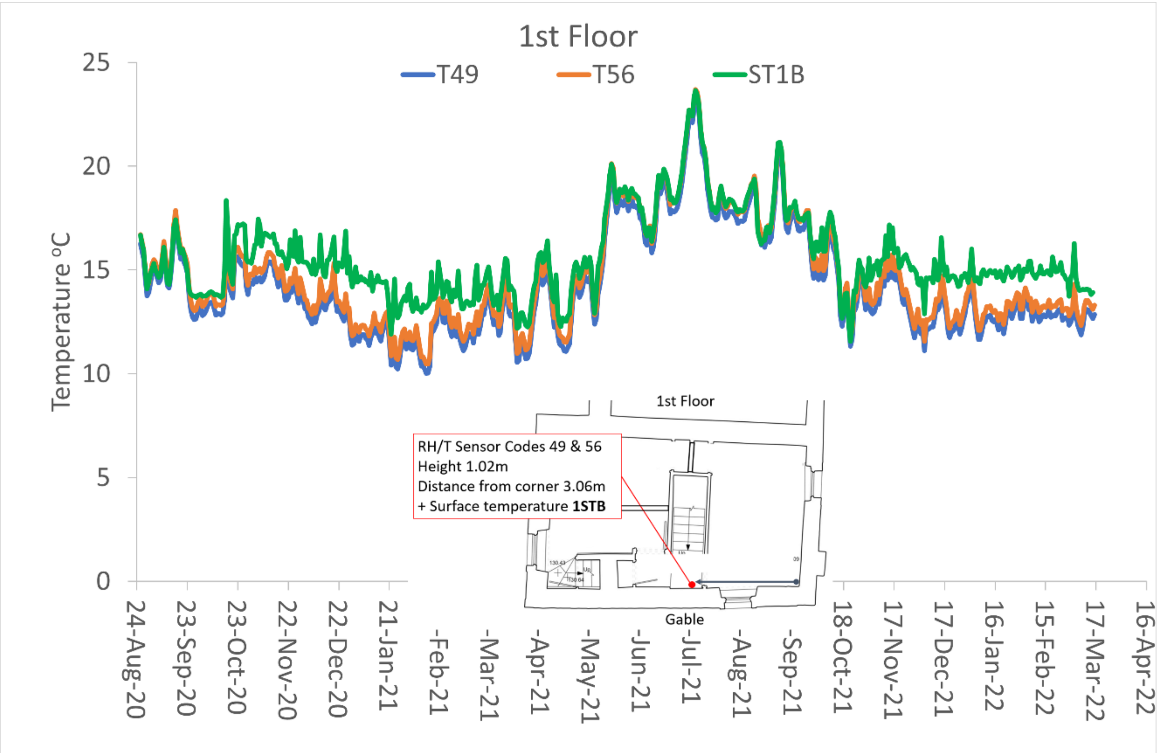


Figure B2.16b: First floor gable (south) – Temperatures

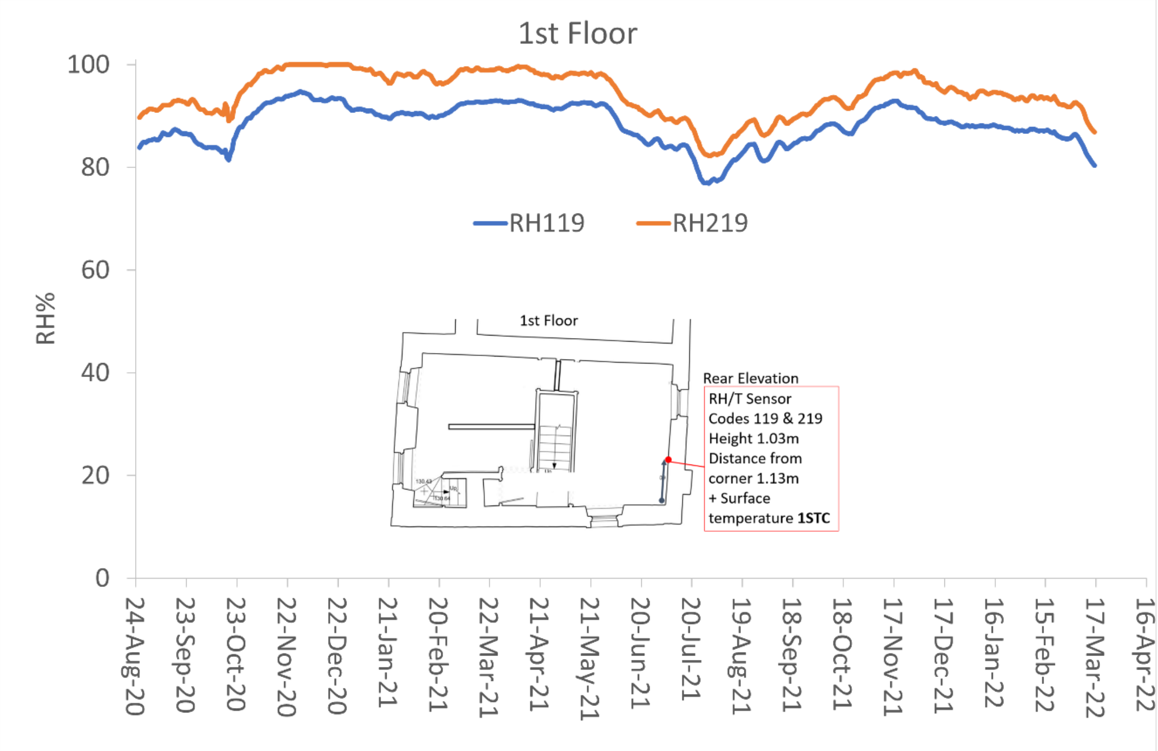


Figure B2.17a: First floor rear elevation (east) – Interface RH

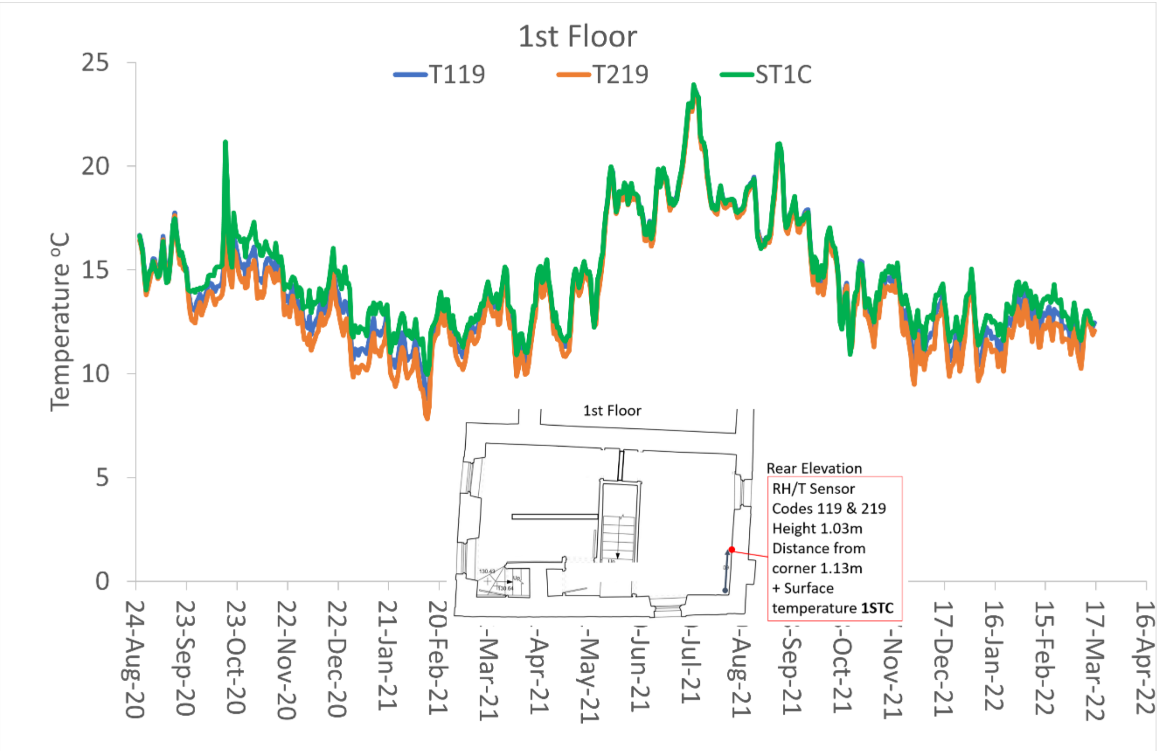


Figure B2.17b: First floor rear elevation (east) – Temperatures

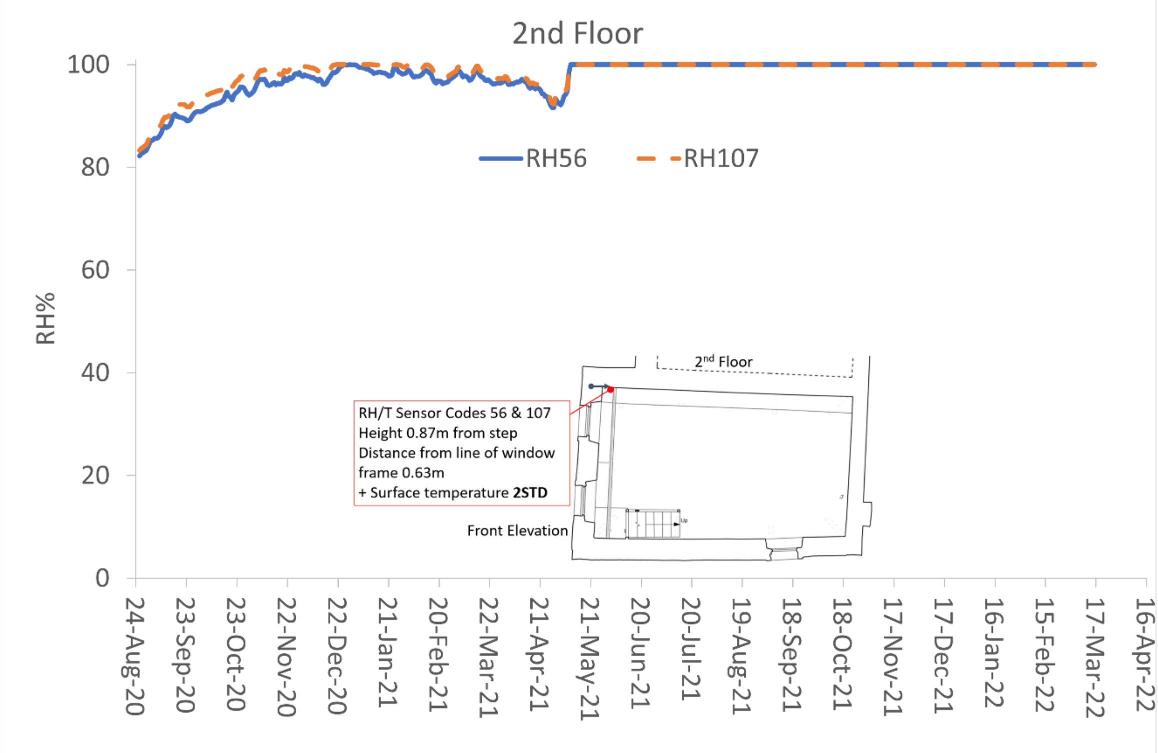


Figure B2.18a: Second floor return (north) – Interface RH

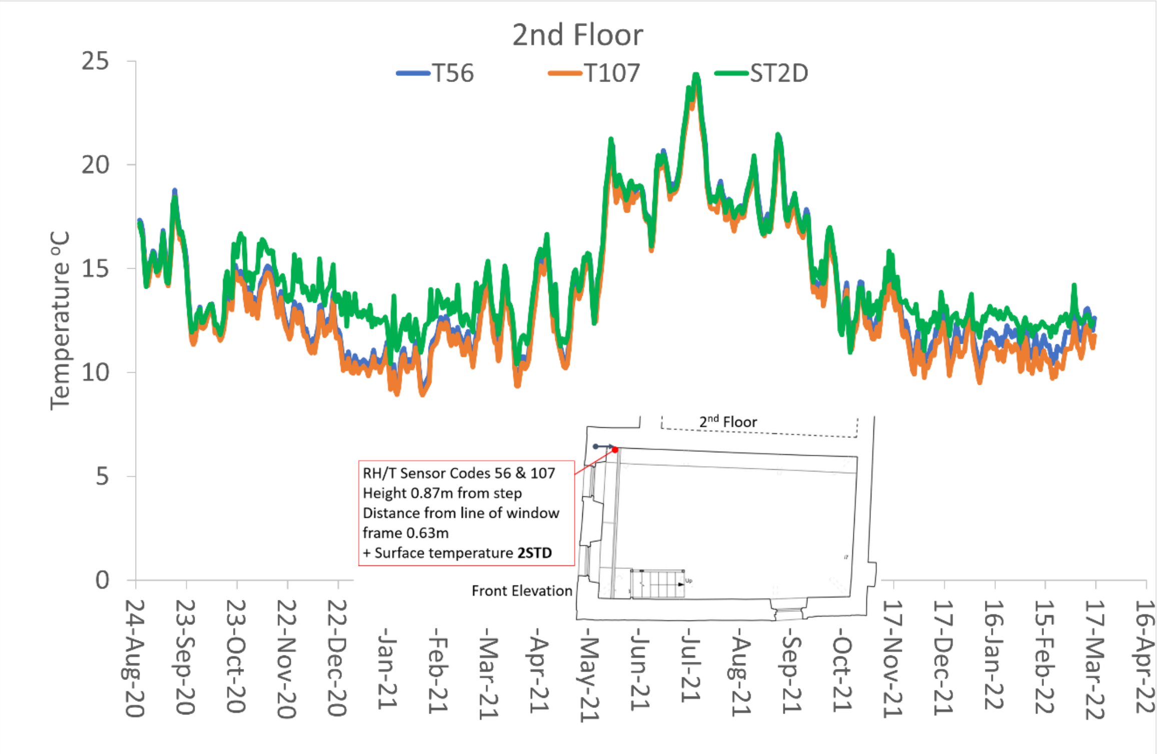


Figure B2.18b: Second floor return (north) – Temperatures

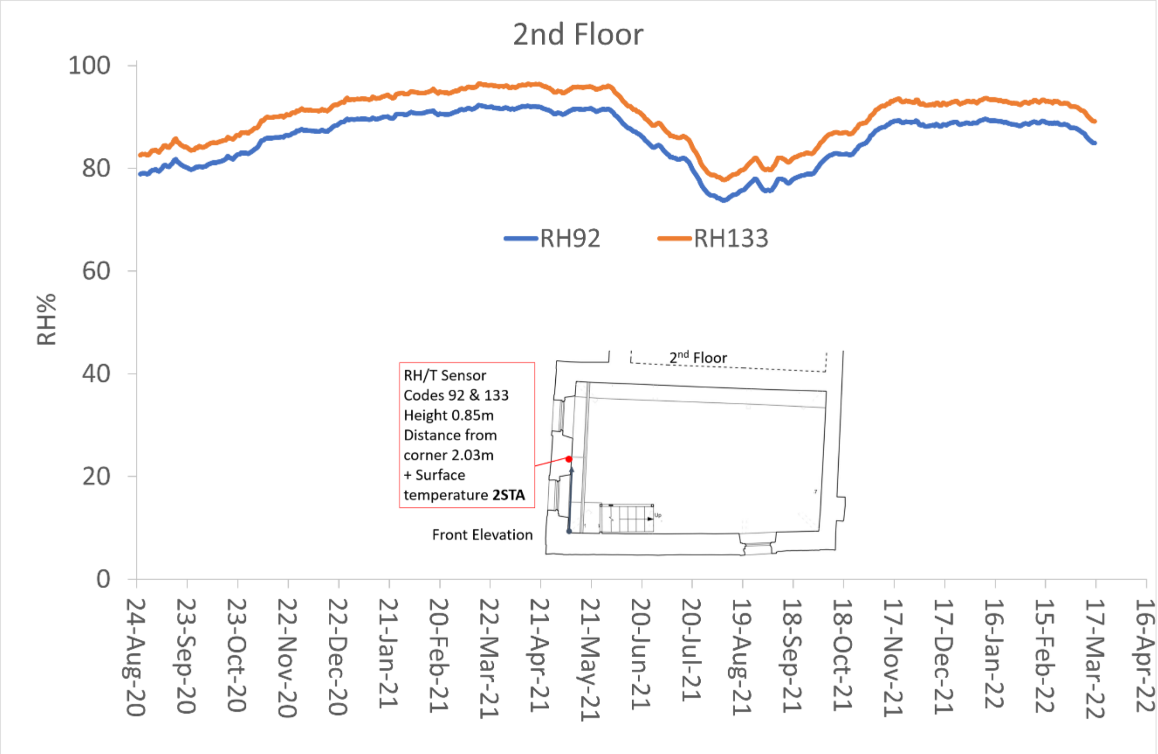


Figure B2.19a: Second floor front elevation (west) – Interface RH

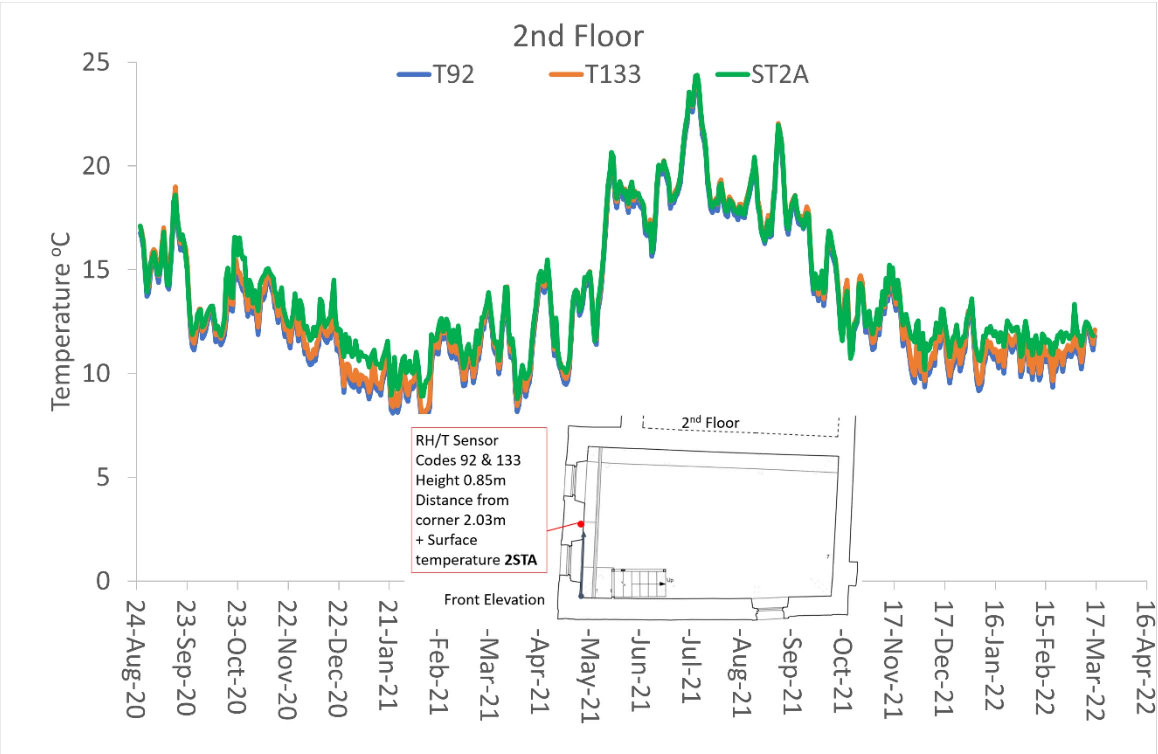


Figure B2.19b: Second floor front elevation (west) – Temperatures

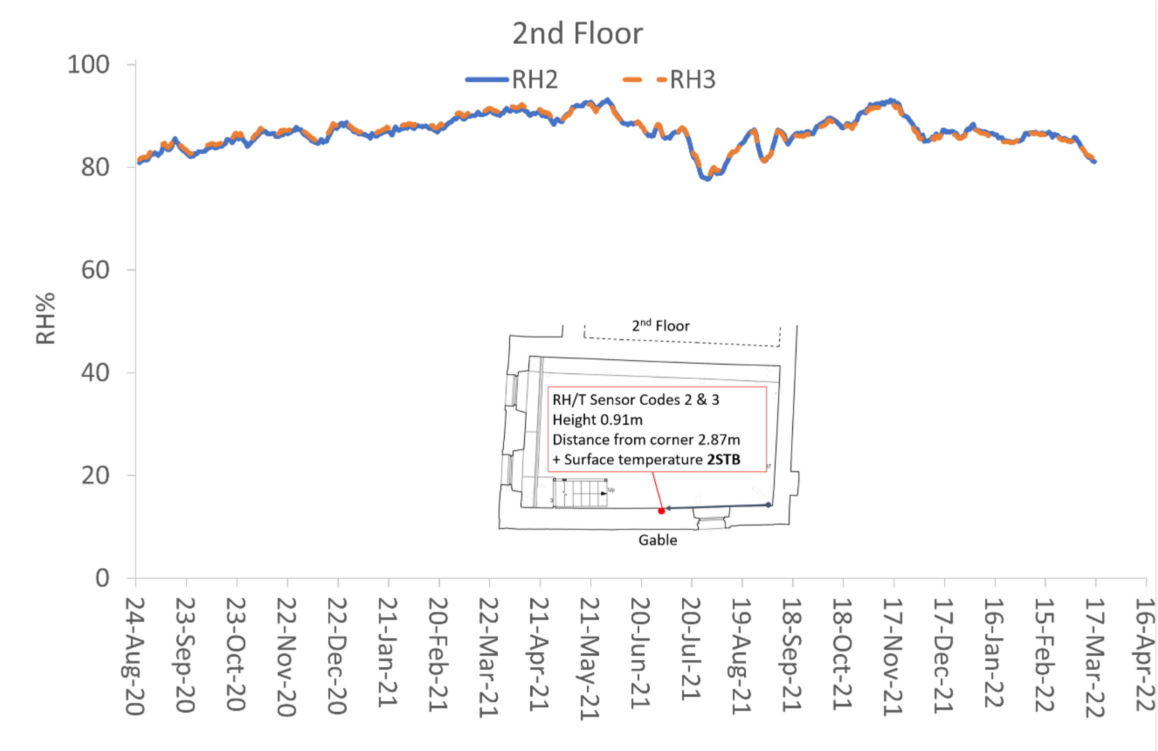


Figure B2.20a: Second floor gable (south) – Interface RH

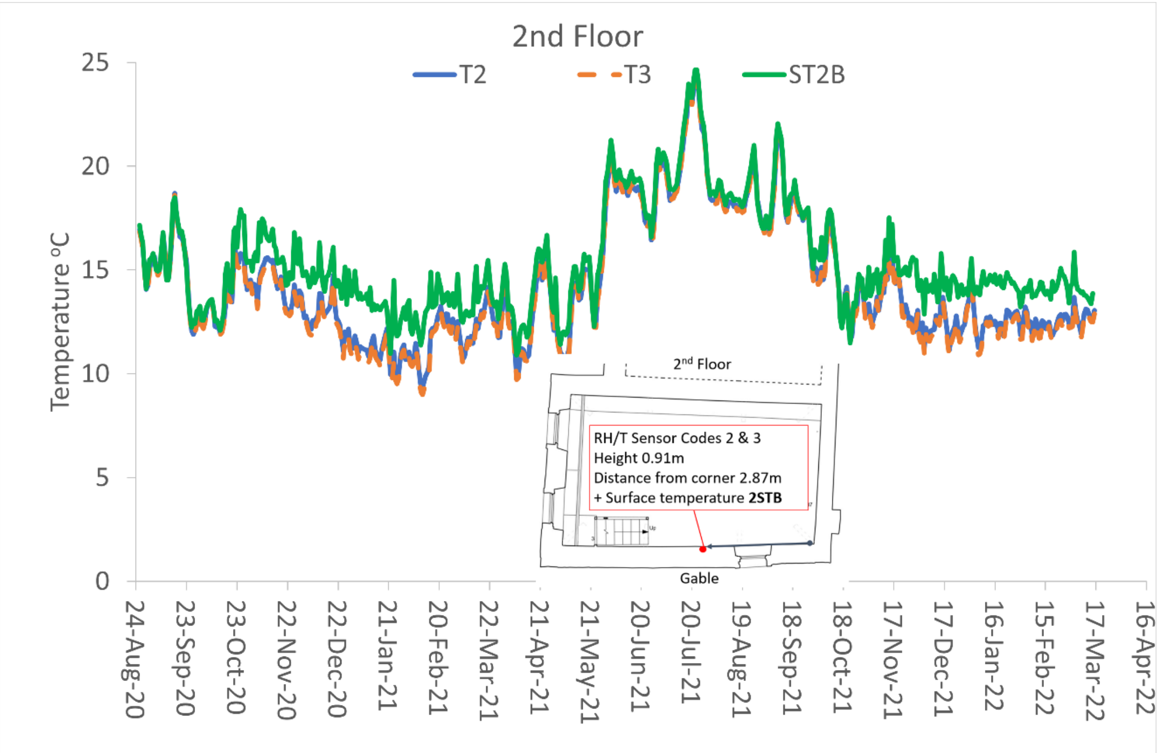


Figure B2.20b: Second floor gable (south) – Temperatures

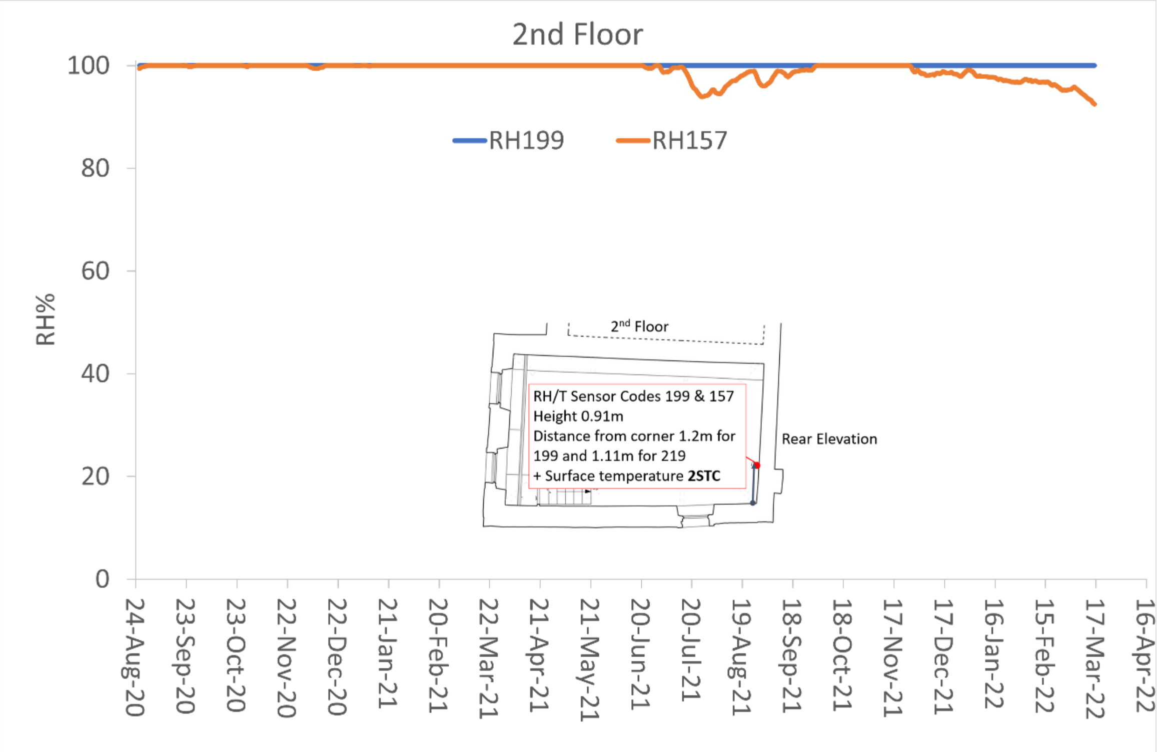


Figure B2.21a: Second floor rear elevation (east) – Interface RH

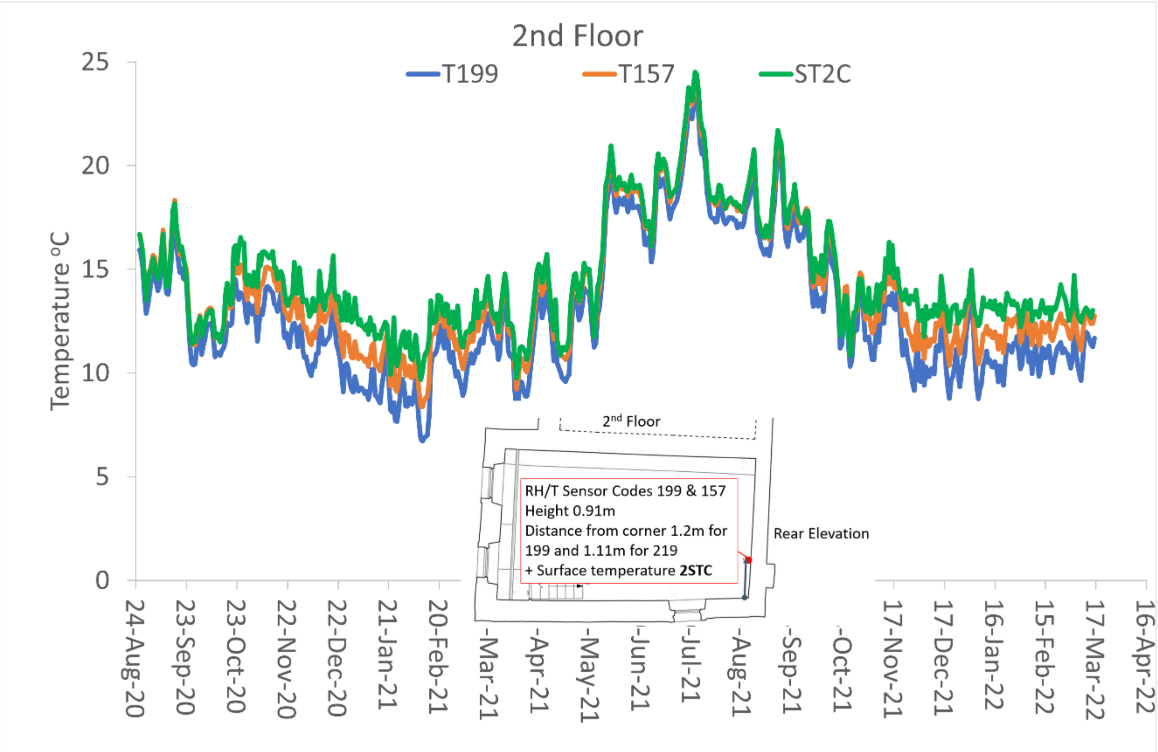


Figure B2.21b: Second floor rear elevation (east) – Temperatures

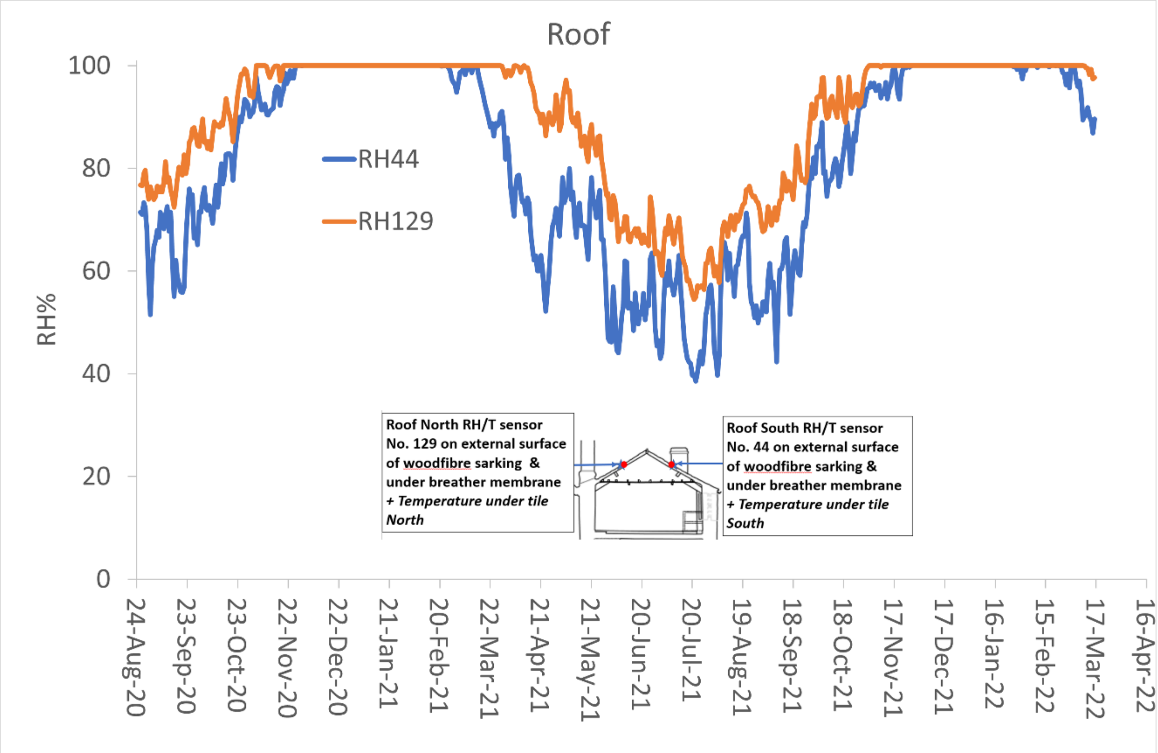


Figure B2.22a: Roof relative humidities between sarking and breather membrane

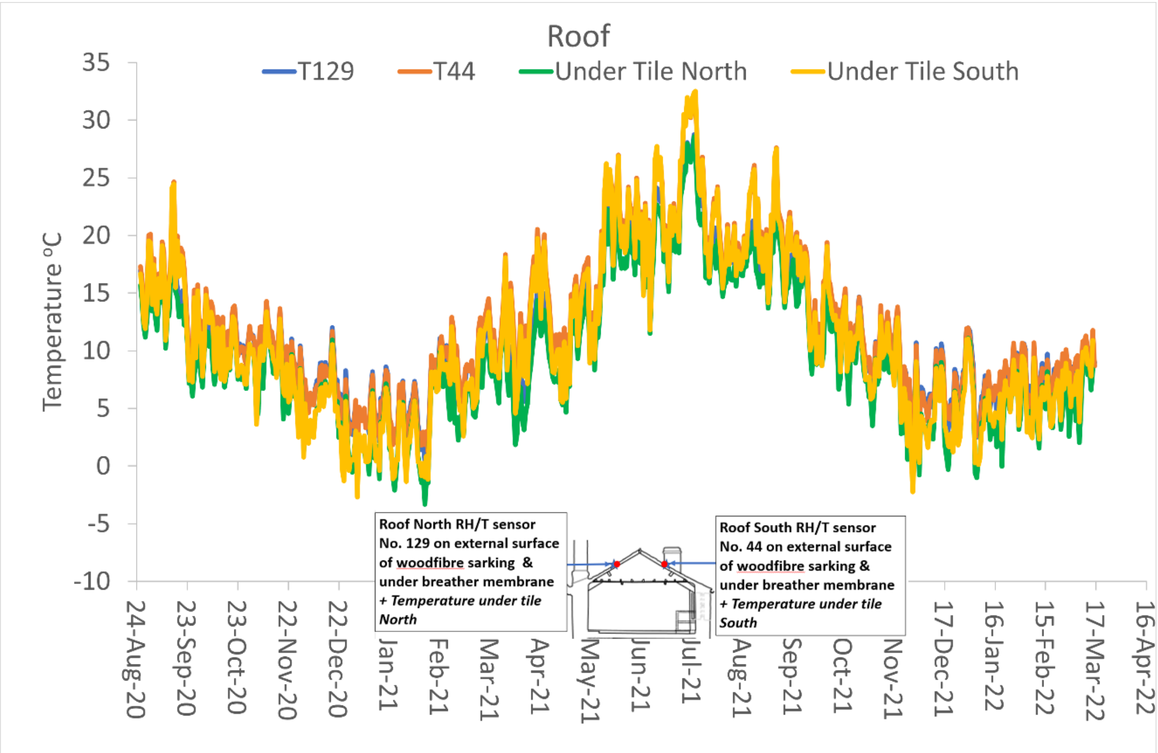


Figure B2.22b: Roof temperatures between sarking and breather membrane and under tiles

Dowel Moisture Contents

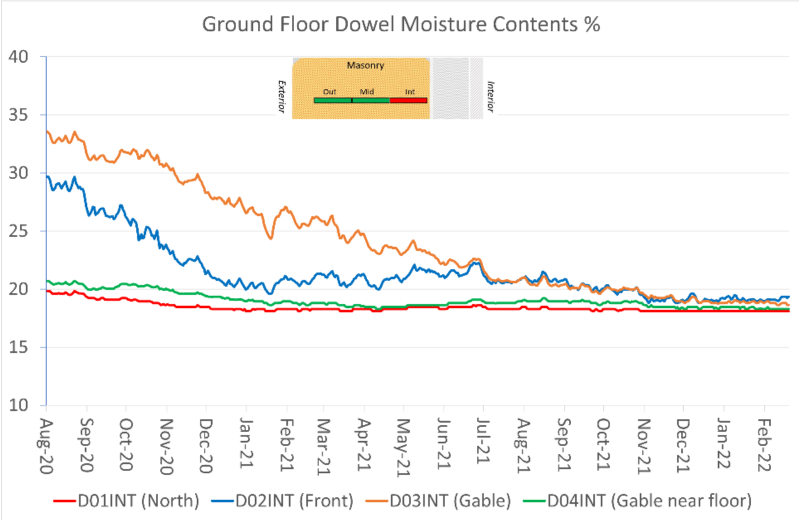


Figure B2.23a: Ground floor dowel moisture contents – inner section

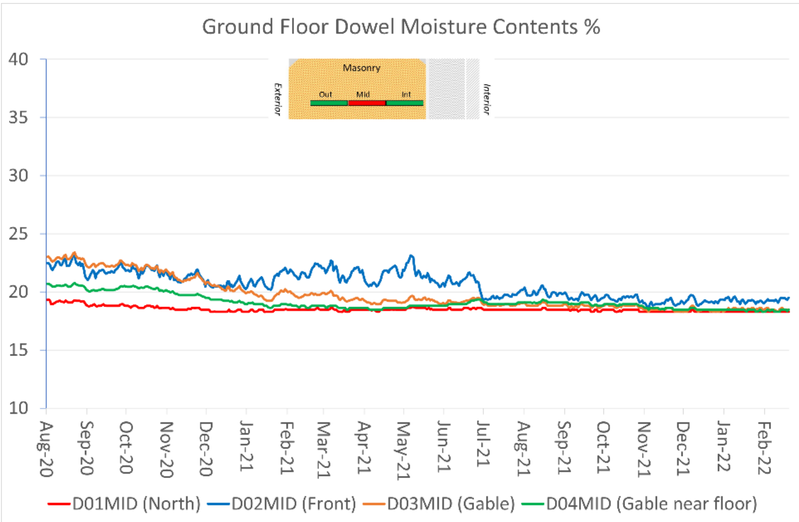


Figure 23b: Ground floor dowel moisture contents – middle section

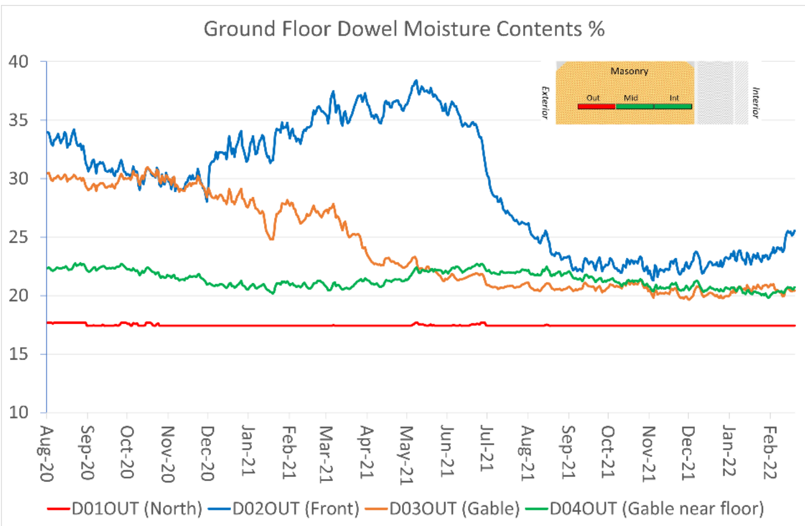


Figure B2.23b: Ground floor dowel moisture contents – outer section

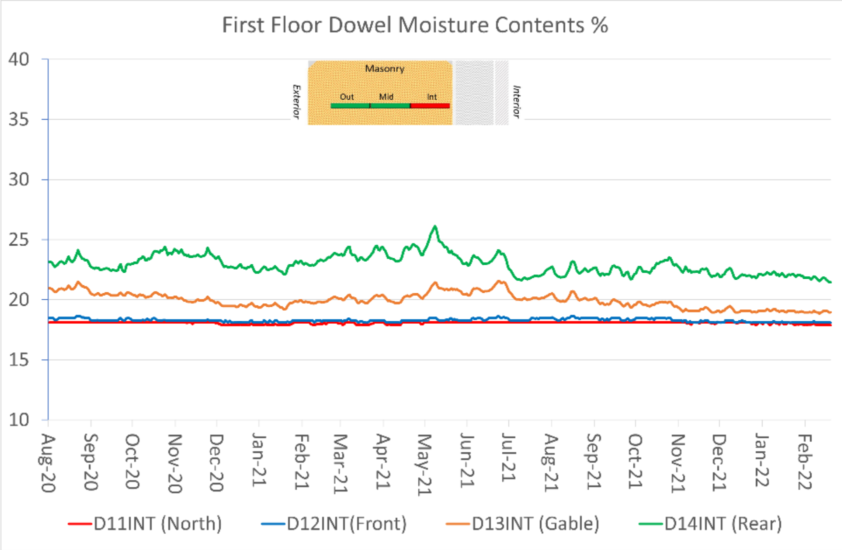


Figure B2.24a: First floor dowel moisture contents – inner section

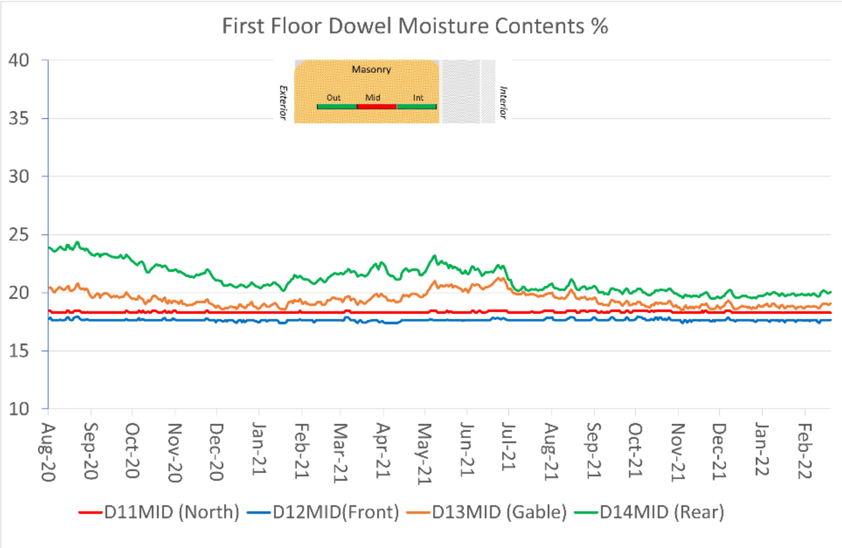


Figure B2.24b: First floor dowel moisture contents – middle section

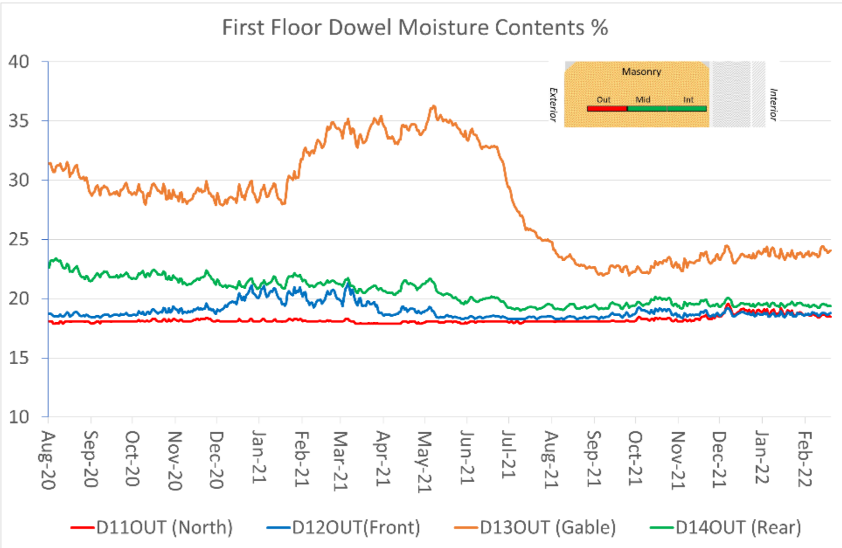


Figure B2.24c: First floor dowel moisture contents – outer section

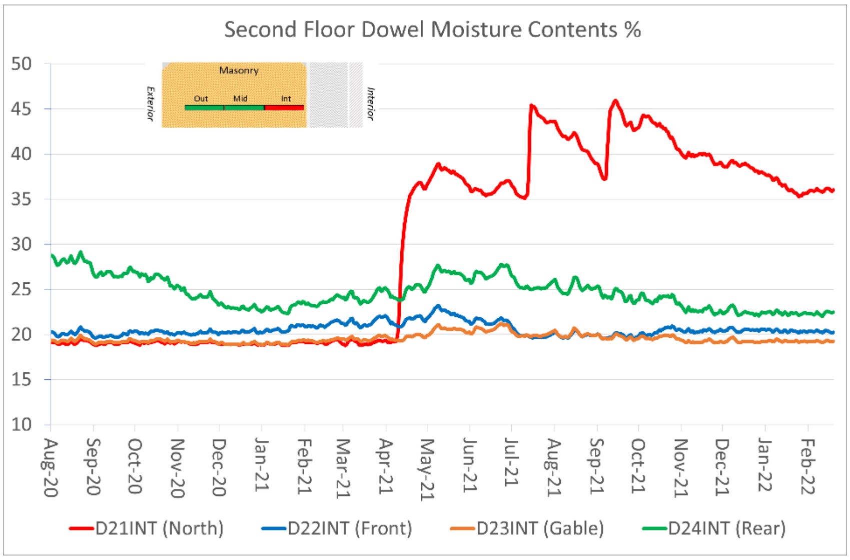


Figure B2.25a: Second floor dowel moisture contents – inner section

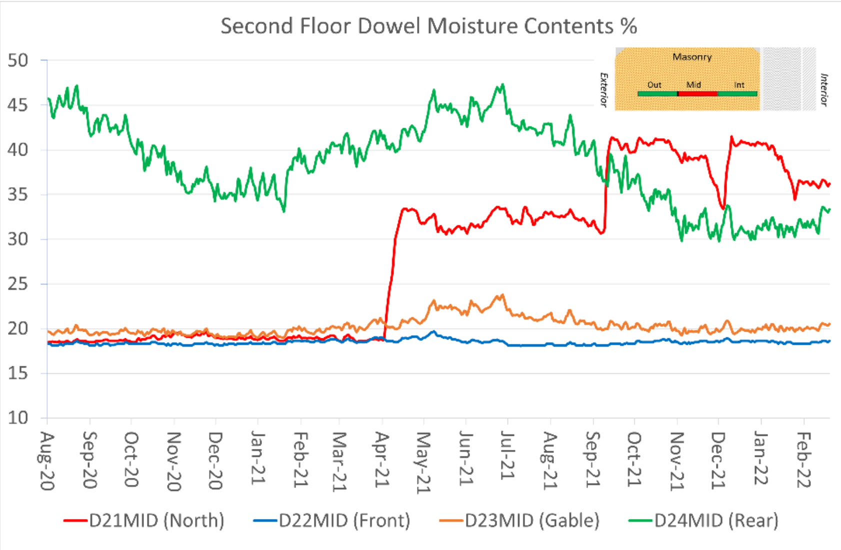


Figure B2.25b: Second floor dowel moisture contents – middle section

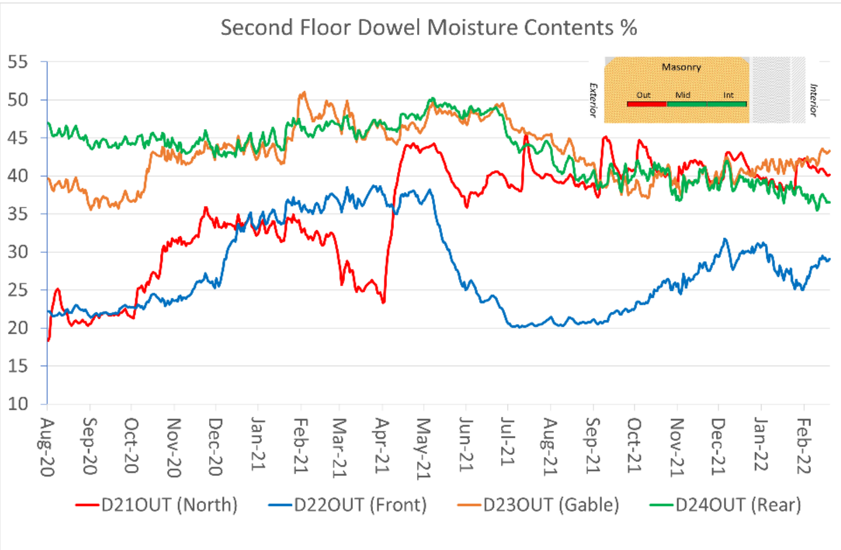


Figure B2.25c: Second floor dowel moisture contents – outer section

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ISSN 2398-3841 (Print)
ISSN 2059-4453 (Online)