Monitoring Results

Observations Report 6: Roof Conditions

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Monitoring Description:

In 2017, Holyrood Park Lodge was subject to an extensive programme of refurbishment in order to improve the comfort and energy efficiency of the building. As part of this work the roof in the south-facing gable of the Lodge was insulated with 100 mm of woodfibre insulation fitted between the rafters creating a 'warm-roof'. In October 2018, interstitial hygrothermal gradient monitoring (IHGM) was installed in this roof. The monitoring is designed to look at temperature and relative humidity (RH) conditions through the insulated roof section and in particular at the difference between the 'as-designed and built' detail which incorporates an air gap, in comparison with an experimental section in an adjoining set of rafters, where the air gap is not present. Ambient conditions inside the space of the attic and externally are also being measured. This report presents the findings from the first twelve months of monitoring (November 2018 – October 2019) with results shown as a series of graphic analyses with a written commentary.

Figures 1 & 2. South-facing gable, Holyrood Park Lodge, East-facing roof slope, external and internal views 2018

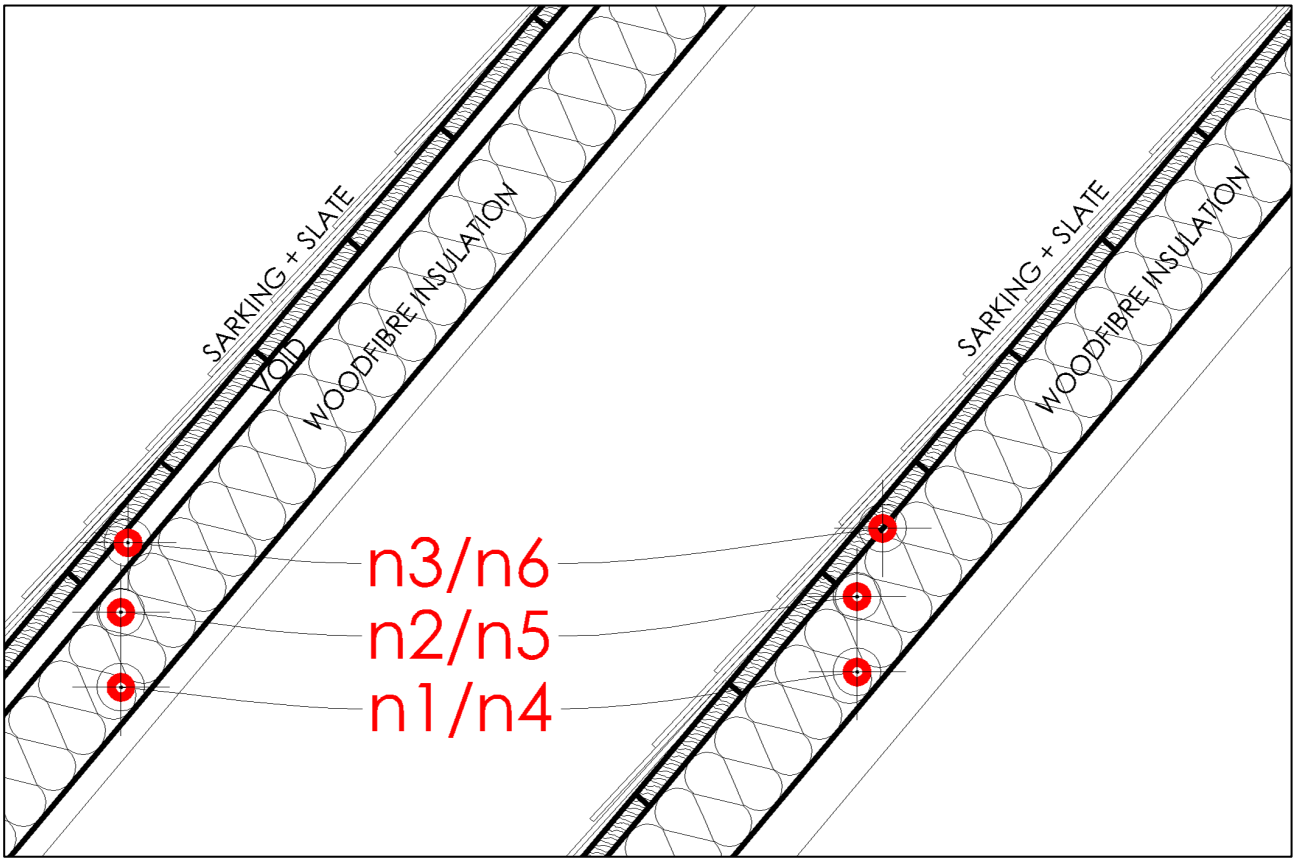

Figure 3. Cross-Section Through The Two Insulated Roof Conditions, With And Without Air Gap, showing Sensor Node Positions, South-Facing Gable, Holyrood Park Lodge.

Methodology

The roof at Holyrood Park Lodge is of slate with bitumen under-felt laid on 19mm sarking boards supported by 150 mm x 62 mm rafters. The central, flat part of the ceiling in the Meeting room of the south-facing gable was previously insulated between the joists with sheep's wool of varying depths. Refurbishment work has changed the line of the insulated envelope within the attic space, sheep's wool has been removed and 100 mm of woodfibre insulation has been fitted between the rafters, with a nominal 30 mm air gap between insulation and sarking boards, extending down into the coom spaces. Bespoke IHGM equipment, comprising of six combined temperature and RH sensors has been installed in and around the insulation in two adjacent rafter spaces centrally located on the east-facing slope of the roof (see Figures 1 and 2). Three of these sensors (n1 – n3) measure conditions within the insulation configuration which incorporates an air gap; n1 is located close to internal conditions within the attic, at a depth of 25 mm from the internal surface of the woodfibre, n2 measures conditions in the insulation closer towards the external side of the roof at a depth of 75 mm. The third sensor, n3, is positioned within the 30 mm air gap between the upper side of the insulation and the sarking boards (Figure 3). The other three combined sensors take measurements in insulation fitted between rafters where the woodfibre board has been pushed up to meet the sarking boards thus eliminating the 30 mm air gap. Sensors n4 and n5 are located at the same depths within the woodfibre insulation, 25 mm and 75 mm respectively, and n6 sits in the interstitial space between the insulation and the sarking board. Temperature and RH values are logged every 5 minutes by an ArchiMetrics datalogger. Ambient temperature and RH conditions are also measured in two places within the attic space; in proximity to the gable and centrally, in proximity to the monitoring array. These measurements are made every 10 minutes and recorded locally on proprietary dataloggers. Sensor specifications for both the IHGM and ambient measurements are given below:

Sensor Specifications:

IHGM Fabric Conditions (AMIG29)	
Relative Humidity	
Accuracy	±3%
Repeatability	±0.1%
Resolution (typical)	0.05%
Long-term drift	< 0.5% per year
Temperature	
Accuracy	±0.4˚C
Repeatability	±0.1˚C
Resolution (typical)	0.01˚C
Long-term drift	< 0.04˚C per year

Ambient Conditions (AMHB09 & AMHB10)	
Relative Humidity (RH)	
Accuracy	±2.5%
Resolution	0.05%
Long-term drift	< 1% per year
Temperature	
Accuracy	±0.2˚C
Resolution	0.04˚C
Long-term drift	< 0.01˚C per year

Findings from the hygrothermal sectional monitoring are presented in a number of 'over time' analyses using either daily aggregated or monthly aggregated data. Figures 4 and 5 show RH values for the six sensors over the year (November 2018 – October 2019) and Figures 6 and 7 plot the difference between the two sets of sensors, comparing the RH and temperature values from n1 – n3, the 'insulation plus gap' section, with those of n4 – n6 the 'no gap' section. Internal and external ambient conditions, temperature and RH are also shown over time plotted as un-aggregated values (Figures 8, 9 and 10). All analyses also include, in the top right corner, statistical tables that use un-aggregated data to detail minimum, maximum and average values over the year. There has been some data loss between November 2018 and January 2019 for the IHGM fabric monitoring and 10 days of data for the beginning of February is absent from the ambient conditions analyses which will impact these values.

Findings

Fabric Conditions

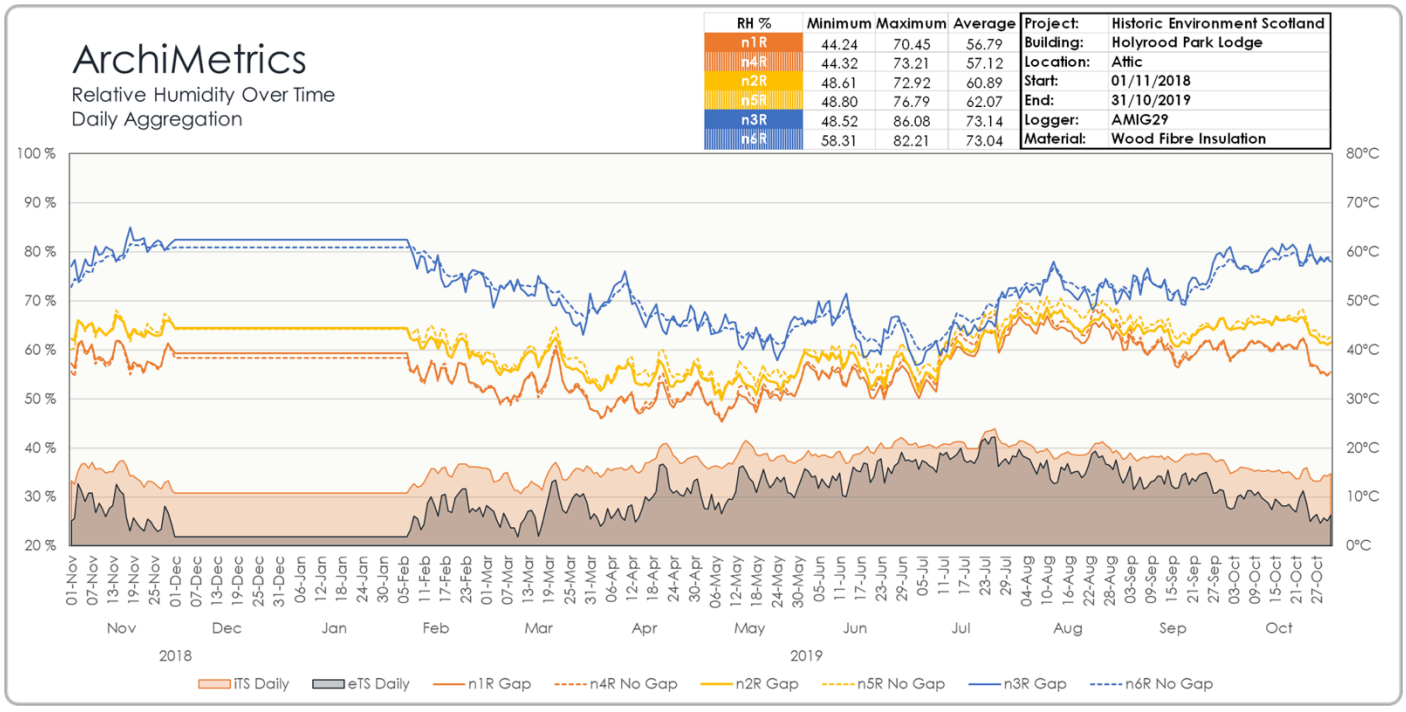

Figure 4. RH Over Time, Daily Aggregation, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

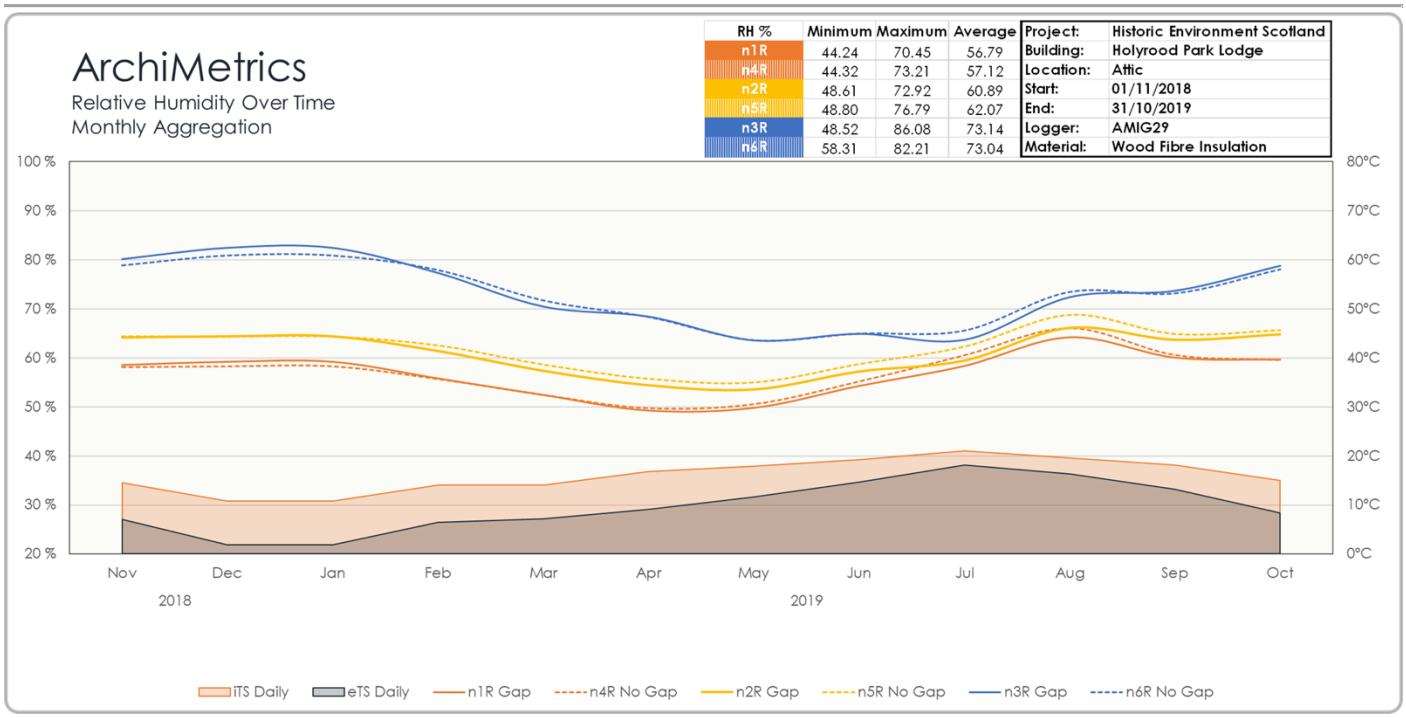

Figure 5. RH Over Time, Monthly Aggregation, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

As can be seen in Figures 4 and 5, RH increases in proximity to external conditions and is highest throughout the year at measurement nodes 3 and 6, being on average 73%. RH is seen to decrease at these outer nodes during the first half of the year to the end of May 2019 and in July starts to increase again. RH measured within the woodfibre insulation averages 57% at n1 and n4 and 61% and 62% respectively at n2 and n5. It also falls through February to April 2019 but starts to increase from May onwards. This results in a closer alignment of RH values, roughly between 60 – 70%, across all measurement nodes through both sections in July 2019. This annual pattern of RH distribution, with more similar sectional RH through the summer, is perhaps to be expected. It is like the arrangement we typically see through measured wall sections, where RH is higher towards the external side of the building envelope and RH values become more closely aligned through the fabric section over the spring and summer months. Within the woodfibre insulation RH is at it's highest in August. The smallest maximum value of the four sensors during this month within the insulation is 70% measured at n1, the 25 mm deep sensor closest to internal conditions in the 'normal' arrangement, which includes an air gap. The highest value for August being 77% measured at n5, the 75mm deep sensor in the insulated section with no air gap.

If RH measurements are used to provide an indication of risk to fabric (when this is defined as the risk of mould growth in/on organic materials at humidities above 80%) it can be seen that this threshold is likely to be exceed over the winter months on the cold side of the insulation beneath the sarking board at n3 and n6 (data for December and January is missing but the overall trend would indicate this is probable). However, RH also declines here during the spring and summer falling to lows of 49% (n3 – gap) and 58% (n6 – no gap) and is, on average, below 80% at both locations. The inclusion of December and January measurements, absent from this analysis, would likely result in a slight increase in overall average RH at these two locations? Measurements are continuing to be made over this current winter period, 2019 - 2020, and will be reported on next year.

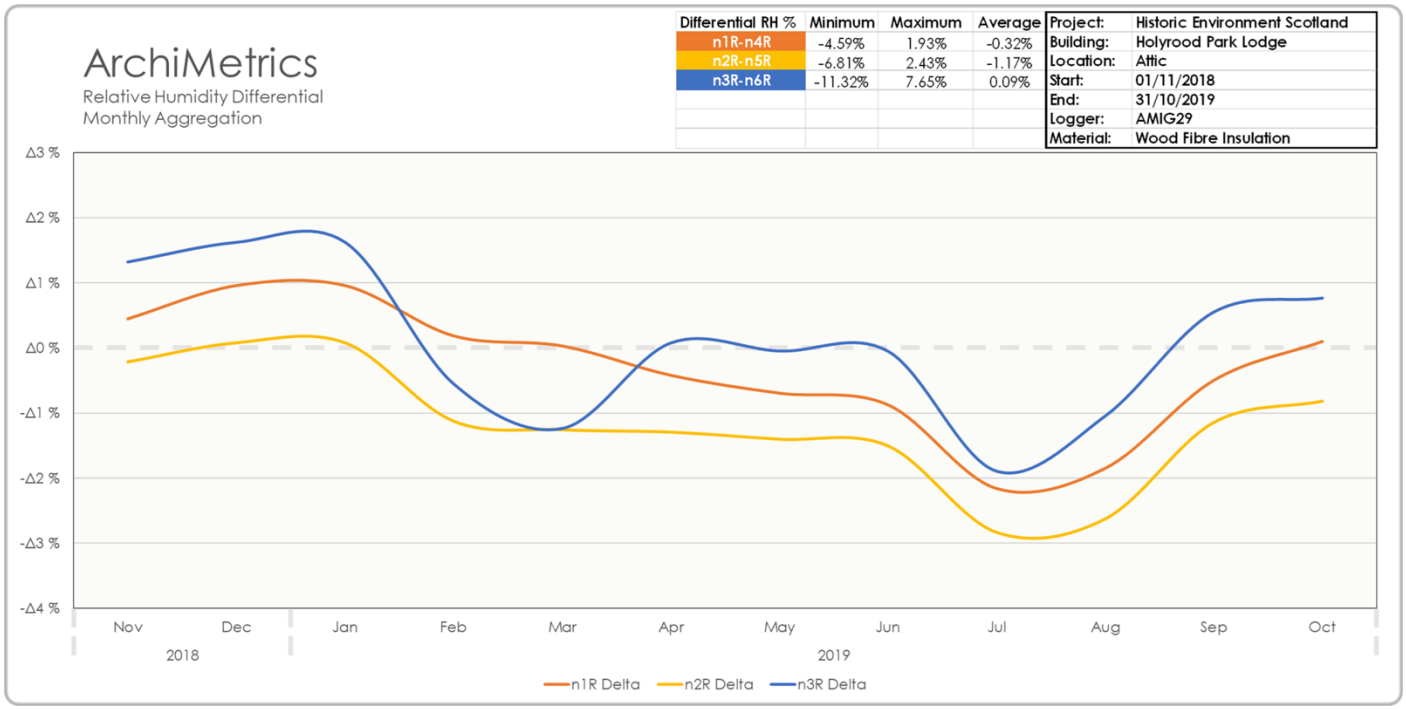

Figure 6. RH Differential, Monthly Aggregation, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

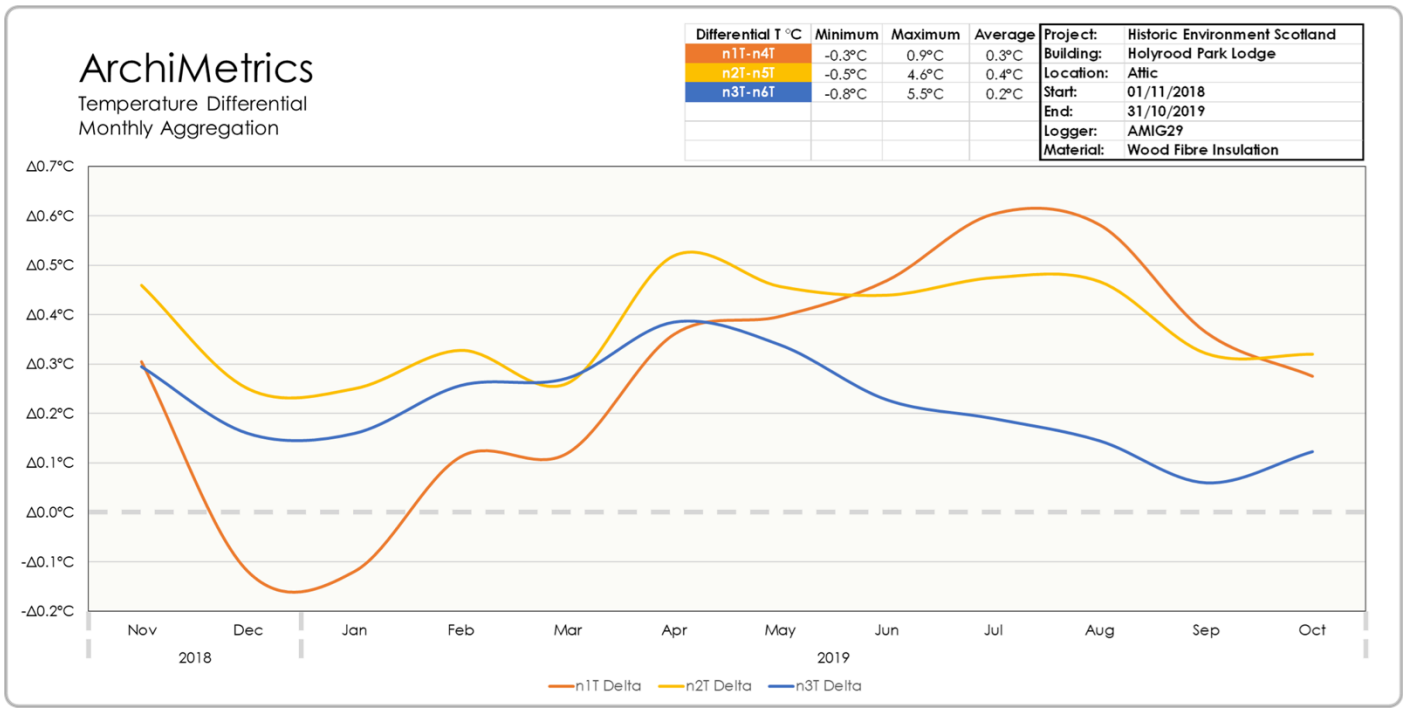

Figure 7. Temperature Differential, Monthly Aggregation, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

Figures 6 and 7 show that, overall, there has been little difference between temperature or RH conditions measured through the two insulated roof sections, with and without an air gap, over the past year. In terms of RH, measurements made within the woodfibre material show slightly higher RH in this material from the section that does not include an air gap. However, this position is reversed for the outer most sensors, n3 and n6, where measurements made within the formal air gap show, on average very slightly higher RH, although this difference is very small. An examination of the minimum and maximum values for n3 and n6 shows that

the greatest range of difference occurs between measurements made in the 30 mm air gap (n3) and those in the equivalent 'no gap' interstitial space between the sarking board and woodfibre insulation at n6 (no gap). The period of the year that sees the greatest differences between n3 and n6 being mid-summer. Despite this range of differences (-11.32 – 7.65) RH conditions at n3 and n6 are, overall, very similar, with an average difference of only 0.09% RH, the positive value indicating that RH is fractionally higher at n3, within the air gap. Conversely, when measured within the woodfibre material RH is, on average, slightly higher in the section that does *not* incorporate an air gap. At n1 and n4, in proximity to internal conditions, the average difference is -0.32% RH but increases to -1.17% when measured closer to the exterior side at sensors n2 and n5. Once again, the greatest difference between these sensor pairings occurs in mid-summer and of the three comparative measurement locations conditions at a depth of 75 mm within the woodfibre insulation (n2 and n5) sees the greatest average difference overall. However, when the error factors of the measurement sensors are accounted for all these differences would seem to be negligible.

Likewise, thus far, temperature measurements through the two sections would seem to indicate that there is no significant difference between the two insulation treatments with average differences of; 0.3˚C for the inner woodfibre pairing, n1 and n4, 0.4 ˚C for the outer woodfibre nodes, n2 and n5 and 0.2 ˚C for the air gap/no gap nodes, n3 and n6. As might be expected there are similarities between the temperature and RH statistical records. The greatest range of temperatures over the year is measured once again at the outer most nodes, n3 and n6 (-0.8 ˚C – 5.5 ˚C) but this location also has, overall, the most stable conditions with the smallest average differential, 0.2 ˚C. The greatest average difference of the three node pairings is, like RH, found for the deeper, 75 mm, woodfibre sensors, n2 and n5, being 0.4˚C. One difference between temperature and RH differential responses is found for the period of the year when the sensor pairings are at their greatest difference. This occurs around April time for the outer and centrally placed pairings, n3 and n6, n2 and n5, but towards the end of summer for the nodes in closer proximity to the internal attic space, n1 – n4.

Ambient Conditions

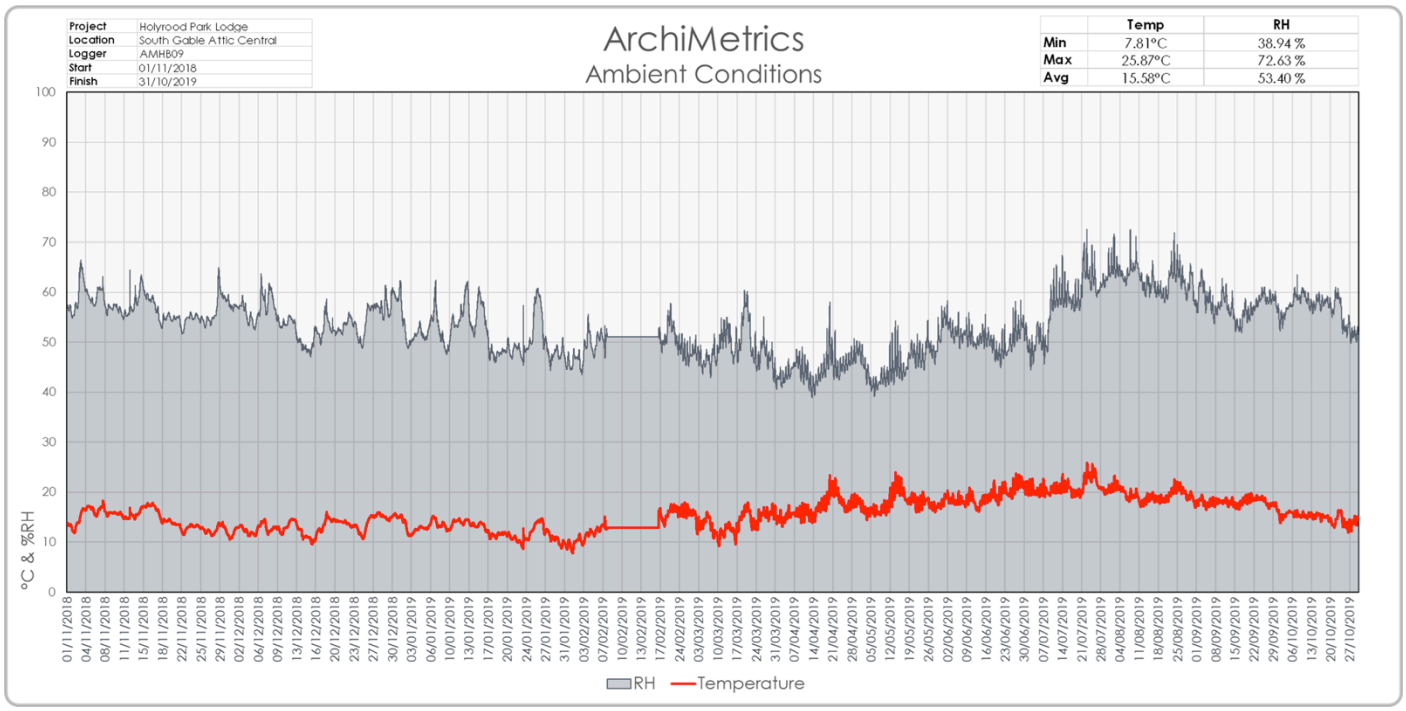

Figure 8. Ambient Conditions, Attic- Central, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

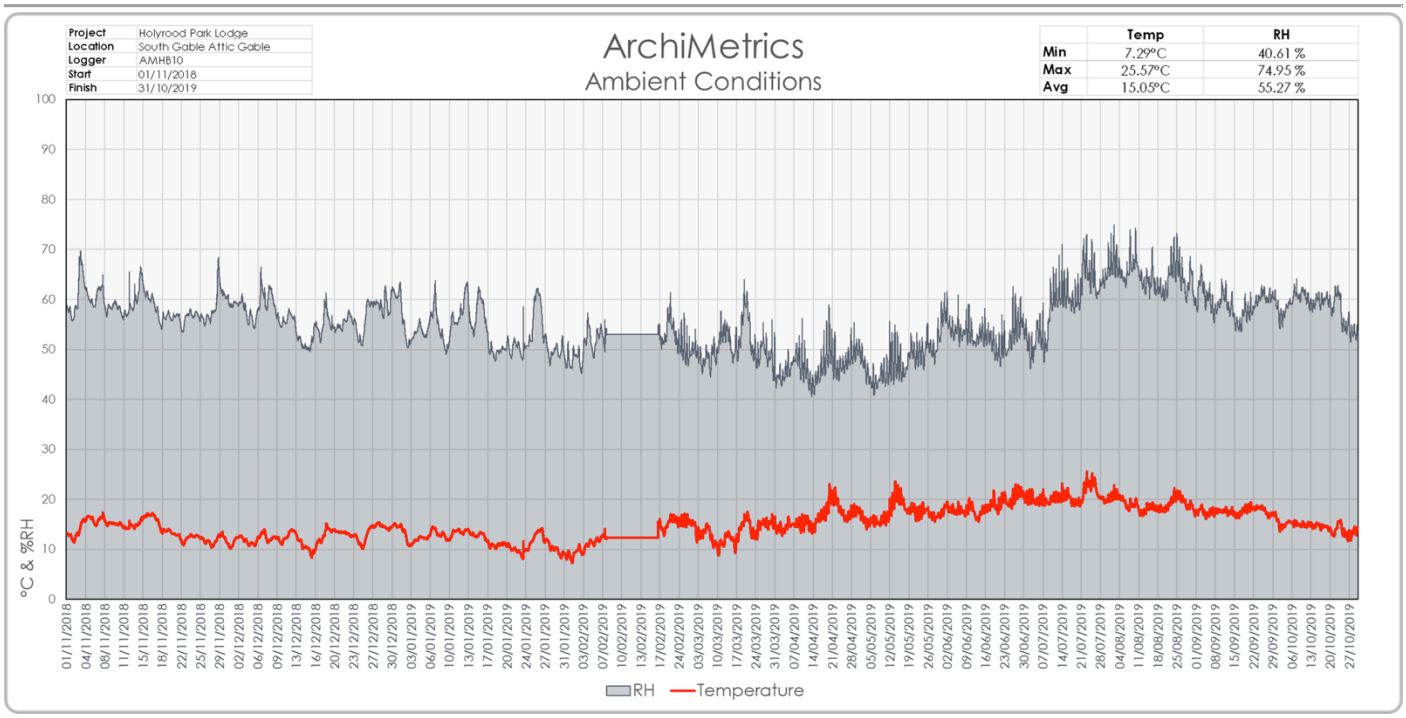

Figure 9. Ambient Conditions, Attic – Gable End, South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

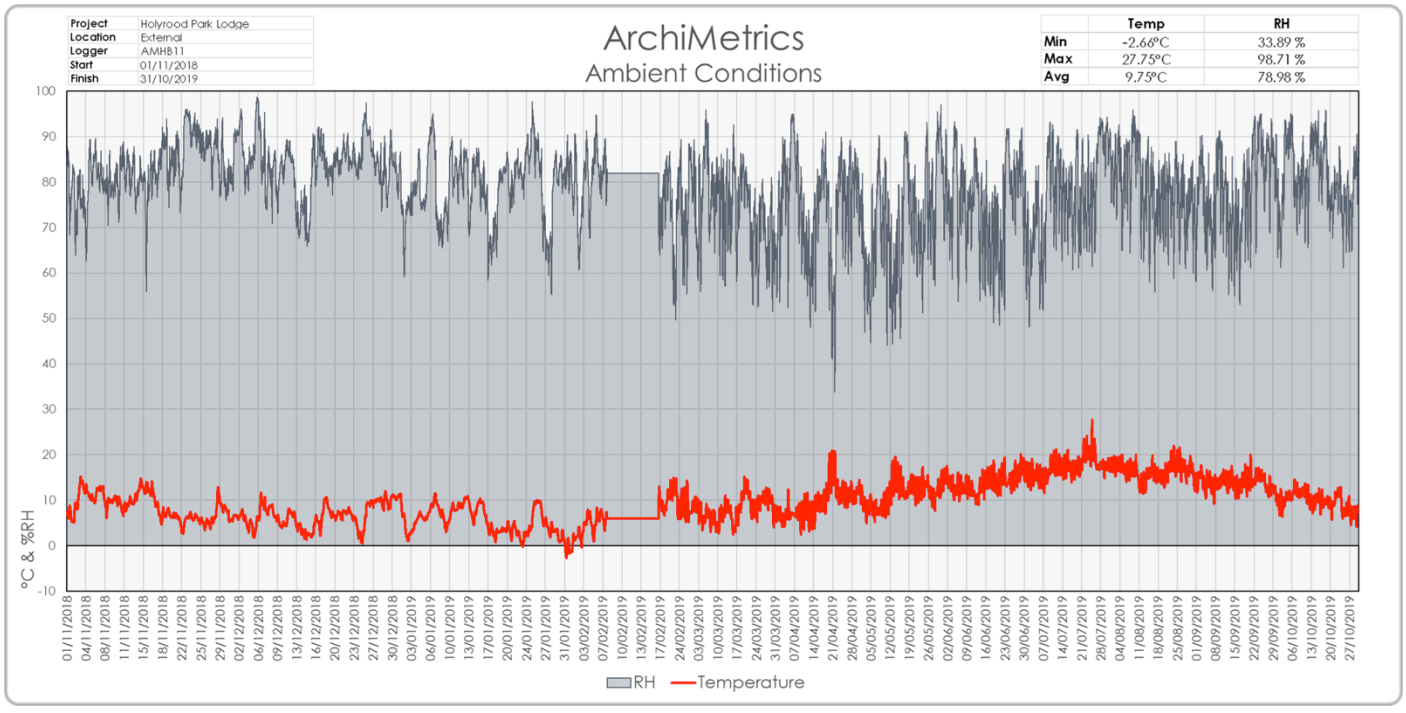

Figure 10. External Ambient Conditions, East elevation of South Gable Roof, Holyrood Park Lodge, November 2018 – October 2019.

Ambient (temperature and RH) conditions are being measured in two locations in the attic space of the roof of the south-facing gable at Holyrood Park Lodge. AMHB09 measures conditions centrally within the attic space at the underside of the rafters on the east-facing roof slope. AMHB10 is also fixed to the underside of a rafter but is adjacent to the stonework of the gable end of the attic, which unlike the rafters spaces, is not insulated. It appears that over the past year there has been very little difference between conditions at the two measurement points (Figures 8 and 9). As might be expected, the more central measurement, away from the uninsulated gable end has been, on average, very slightly warmer by 0.5˚C in

the past year. Also, therefore, on average, RH has been slightly higher towards the colder gable end, being 55% as opposed to 53% in the centre of the attic space. Overall RH within the attic is seen to fall from November 2018 to its lowest point in April 2019, the minimum recorded being 39%. After this it increases again to peak in July and August, reaching a maximum of 75%. Externally RH increases, as would be expected, through the winter and reaches its highest point, 99%, in December. Thereafter, it falls and like interior conditions reaches a low of 34% in April 2019 before gradually rising again in a series of intermediate steps through the summer and into the autumn (Figure 10).

When these ambient condition trends are looked at in comparison with RH measured through the two insulated roof sections, it can be seen that, broadly speaking RH measured within the woodfibre insulation material (n1, n2, n4, and n5) mirrors that of conditions measured within the attic space. Albeit RH measured within the woodfibre is, understandably, slightly higher, and reaches its lowest and highest values about a month after those measured within the attic, in May and August, due to the moisture buffering effects of the woodfibre. At the start of the monitoring period RH measured on the cold side of the insulation, at n3 and n6, is similar to that of exterior conditions, in that it peaks during the winter months, although inside the roof RH is approximately 10% RH lower than that of external conditions. However, RH measured beneath the sarking boards is at its lowest in July, three months after its lowest point externally and coinciding with peak internal RH. Thus it would seem that RH within the woodfibre is principally driven by internal conditions albeit with about a month offset and peaks in the summer when the humidity of ambient air is at it's highest. (Although this is not a heated space, conditions in the attic and woodfibre will also benefit from drier centrally heated air entering the space from the room below during the winter months meaning RH is lower here over the winter period.) Conversely, conditions on the cold side of the insulation are closely, but not as directly, related to those of the external environment. RH peaks over the winter but the air within the air gap (n3) and the interstitial space beneath the sarking boards (n6) takes longer to 'dry' and thus reaches its lowest RH values in July in comparison with April for external conditions. This is probably because the normal processes of evaporation by which materials reduce their winter moisture loads take longer in these enclosed spaces within the roof. Whilst RH is found to be lower at this time in the section which incorporates an air gap, as previously observed, taken on an annual basis the RH difference between the two conditions, with and without air gap, is minimal.

Summary

- Measurements made through the roof sections show that RH increases in proximity to external conditions.
    - It is highest throughout the year at measurement nodes 3 and 6, on the cold side of the insulation, being on average 73% RH.
    - Within the woodfibre insulation RH averages 57% at n1 and n4, (25 mm deep) in closer proximity to internal attic conditions and 61% and 62% at n2 and n5, (75 mm deep) and closer to external conditions.
- RH exceeds 80% over winter at n3 and n6 but falls below this in February and is below this risk threshold for the majority of the year.
- There is little difference, over the past year, between the RH conditions measured in materials through the two different roof sections, with and without an air gap.
    - RH is, on average, very slightly higher within the woodfibre insulation in the section that does not incorporate an air gap. On average these difference are -0.32% at 25 mm (n1 – n4) and -1.17% at 75 mm (n2 – n5).
- Temperature measurements also indicate that, over the past year, there is no significant difference between the two insulation treatments.
    - Annual average ˚C differences between sensor pairs are 0.3˚C (n1 and n4), 0.4 ˚C (n2 and n5) and 0.2 ˚C for the air gap/no gap nodes, n3 and n6.

- Internal ambient attic conditions measured centrally and at the uninsulated gable end, also show little difference between the two locations.
- RH behaviour measured within the woodfibre follows that of internal conditions albeit with a one-month delay and is, on average, slightly higher than RH measured within the attic.
    - This is mostly likely the result of the buffering effect of the woodfibre material.
- RH measured at n3 and n6, on the cold side of the insulation, is similar, although lower by approximately 10%, to that of external conditions during the winter.
- Springtime RH reduction is retarded and falls more slowly at n3 and n6 reaching its lowest values three months after those measured from the external environment.
    - This is due to the enclosed nature of these small spaces beneath the sarking boards, both with and without an air gap, meaning evaporative drying takes place more slowly.