Annual Report 1
Church Street, Ton Pentre

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Report by: ArchiMetrics Limited

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1.0 Introduction

As part of a larger retrofitting scheme, the solid stone external walls of this terraced house at Church Street, Ton Pentre have been insulated with an aerogel-based insulating plaster, Thermulon, a lime-based product and rendered externally with an air lime product, Vivus No. 2 Render Basecoat. ArchiMetrics have been commissioned to carry out interstitial hygrothermal and U-value monitoring to assess the performance of the insulated wall over a three-year period. Following on from our early-stage U-value report of March 2022, this is our first Annual report which presents findings from our interstitial moisture monitoring as well as an updated measured in situ U-value for the wall.

2.0 Wall & Monitoring Description

The wall at Church Street appears to be constructed of local stone from the Pennant Sandstone formation, these include feldspathic, micaceous, lithic arenites types of sandstone as well as underlying beds of mud and siltstone (see Figure 1).[1] These stones are bedded in a lime mortar with a high proportion of coal dust waste used as an aggregate or filler. As part of this reporting cycle we have revisited the question of the thickness of the stone component of the wall (which, as a rough stone wall will inevitably be an approximate value) and based on site measurements we have used 490 mm as an indicative thickness. As part of retrofitting work, the external wall face has been rendered using Vivus No.2 Render Basecoat to a nominal thickness of 30 mm and internally with Thermulon plus finishes, applied to a depth of ≈ 40 mm, creating an overall wall thickness of about 560 mm.

In September 2021, the installation of interstitial hygrothermal gradient and U-value monitoring equipment commenced in the east facing external wall at first floor level at Church Street in a room used as bedroom (Figure 1). Monitoring commenced in November 2021 and the house was occupied in mid-February 2022.

[1] See British Geological Survey https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=pes

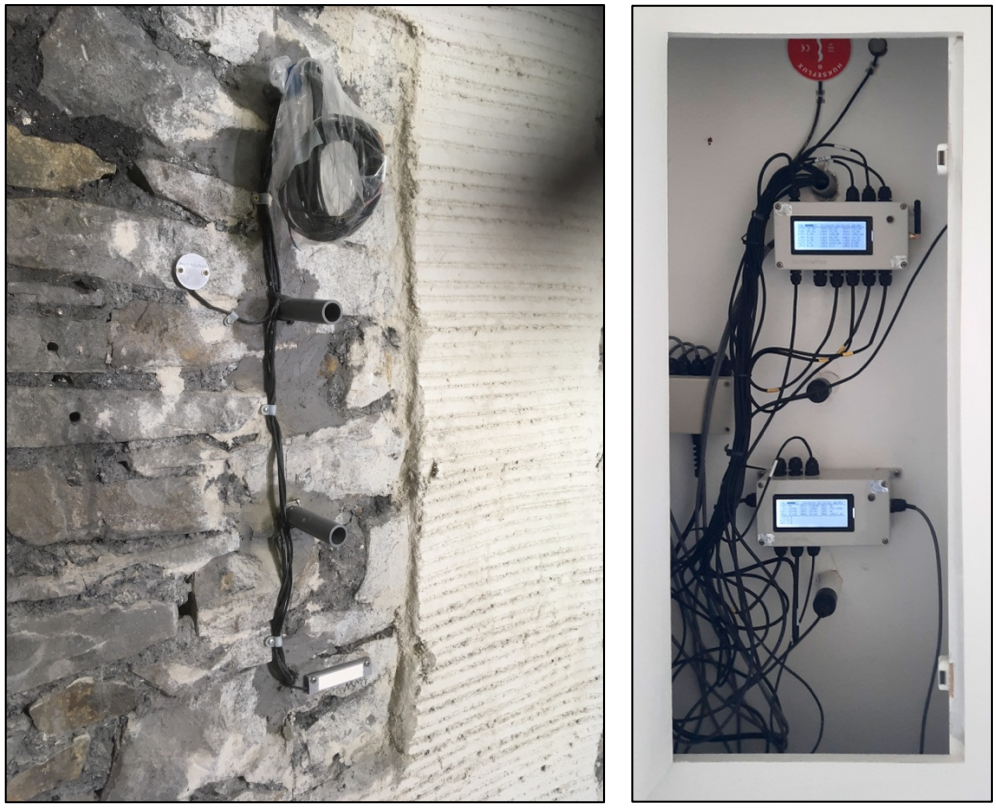


Figure 1. IHGM and U-value monitoring equipment, Church Street- mid-install and within completed cupboard enclosure.

3.0 U-values

3.1 Measured in situ U-value

The measurement of in situ U-values requires an average 10˚C internal/external temperature difference over a set period, around 14 days or longer and therefore is more successfully carried out over the winter months with internal heating in operation. The measurement reported here covers the period 27th November – 17th December 2022 and follows the conventions set out in BS ISO 9869 *Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance*.

The November 2022 measured *in situ* U-value found for the east facing 560 mm insulated stone wall at Church Street is **0.53 W/m²K** (Figure 2). This figure could be compared with the U-value measured early in the year between February and March 2022 of **0.64 W/m²K** *(Figure 3)*. As was previously reported, it is likely that this higher figure is the result of construction moisture, added to the wall during rendering and plastering, increasing the thermal conductivity of wall materials. We predicted that the measured U-value would decrease following the evaporation of this moisture, particularly over the warmer summer months. Indeed, the hygrothermal monitoring shows the reduction in moisture that is taking place through the wall section during this time (Figures 5 & 6). This loss of moisture from materials seems to have resulted in a 17% decrease in the measured U-value.

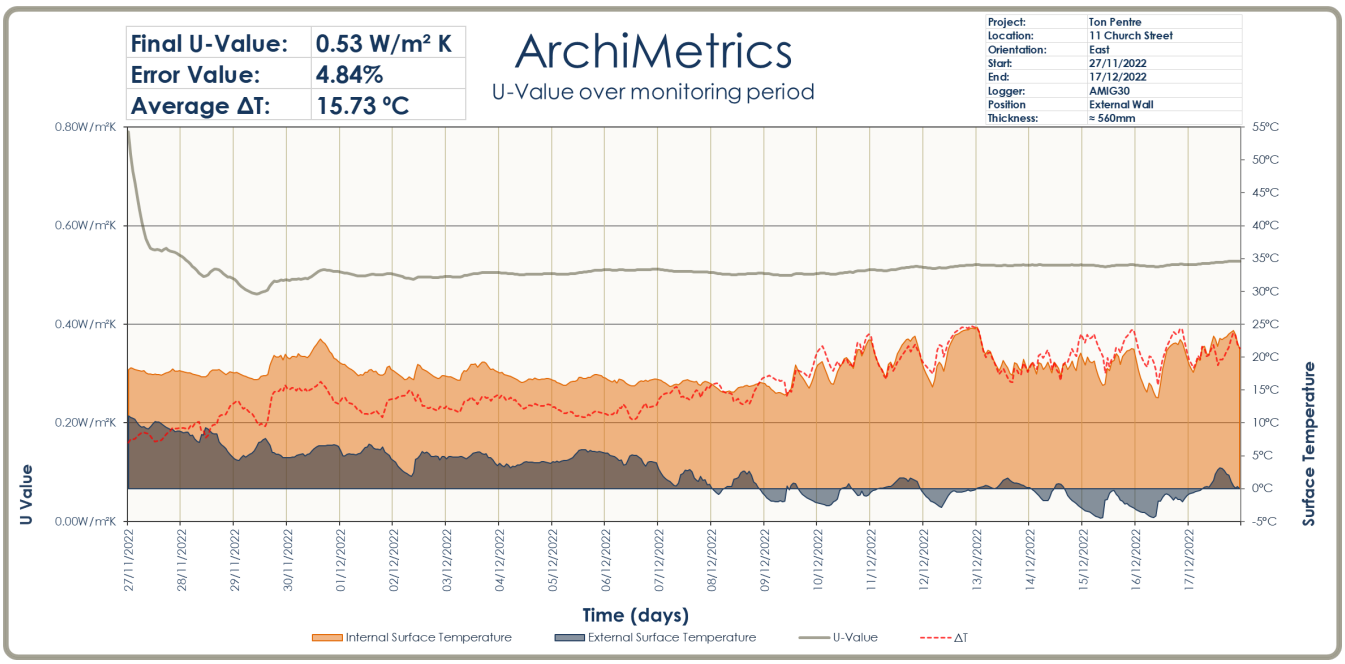


Figure 2. Measured in situ U-value, November – December 2022, Church Street, Ton Pentre.

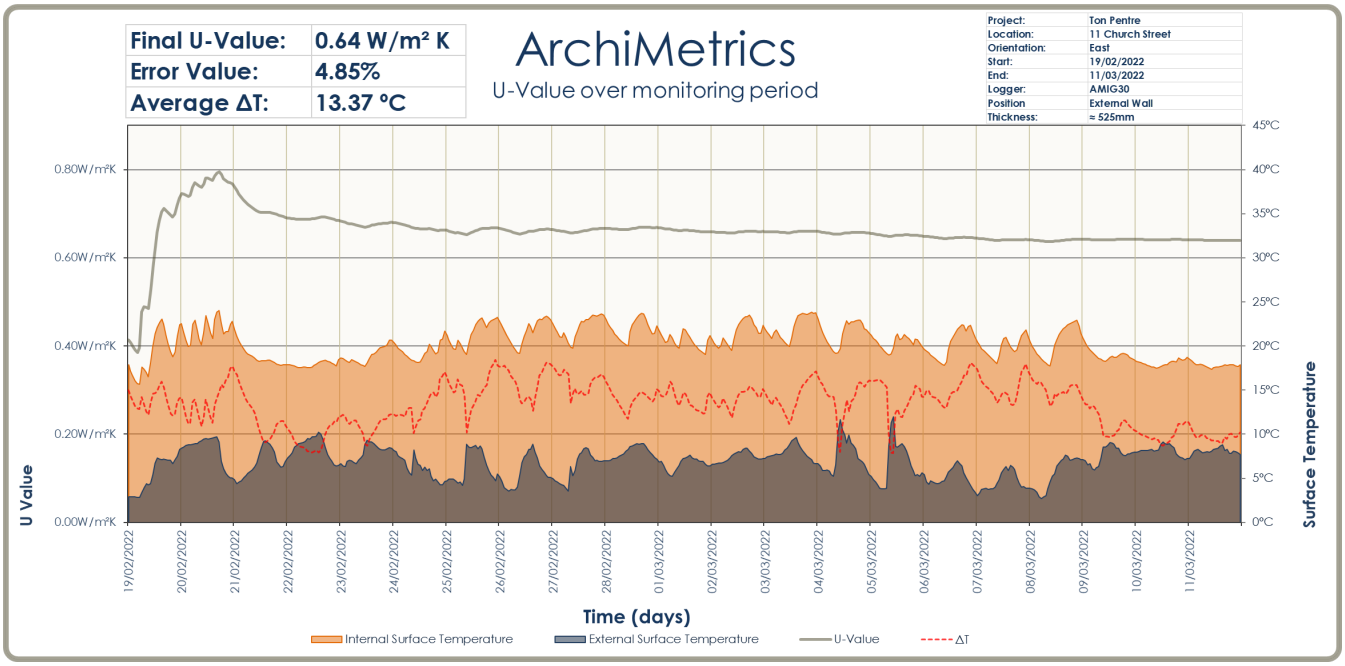


Figure 3. Measured in situ U-value, February – March 2022, Church Street, Ton Pentre.

3.2 Compensated U-value

As part of the monitoring installation a second heat flux plate was installed on the external surface of the stone wall where it was, subsequently, covered with the new Vivus external render. This experimental arrangement allows for the production of a 'compensated' U-value, that is a measurement of thermal transmissivity which discounts the energy input into the wall via solar radiation. As can be seen in Figure 4, the east facing bedroom wall at Church Street receives a not insignificant amount of heat as a result of solar radiation (eSR) on a daily basis, where this input will be increased on clear, sunny days. If the influence of this energy input is

discounted from the measured U-value, we find a compensated U-value of 0.66 W/m²K. That is to say a U-value which mostly takes account solely of heat flowing out of the wall from the interior and in this way is more comparable to that of a steady-state calculation, see 3.3.

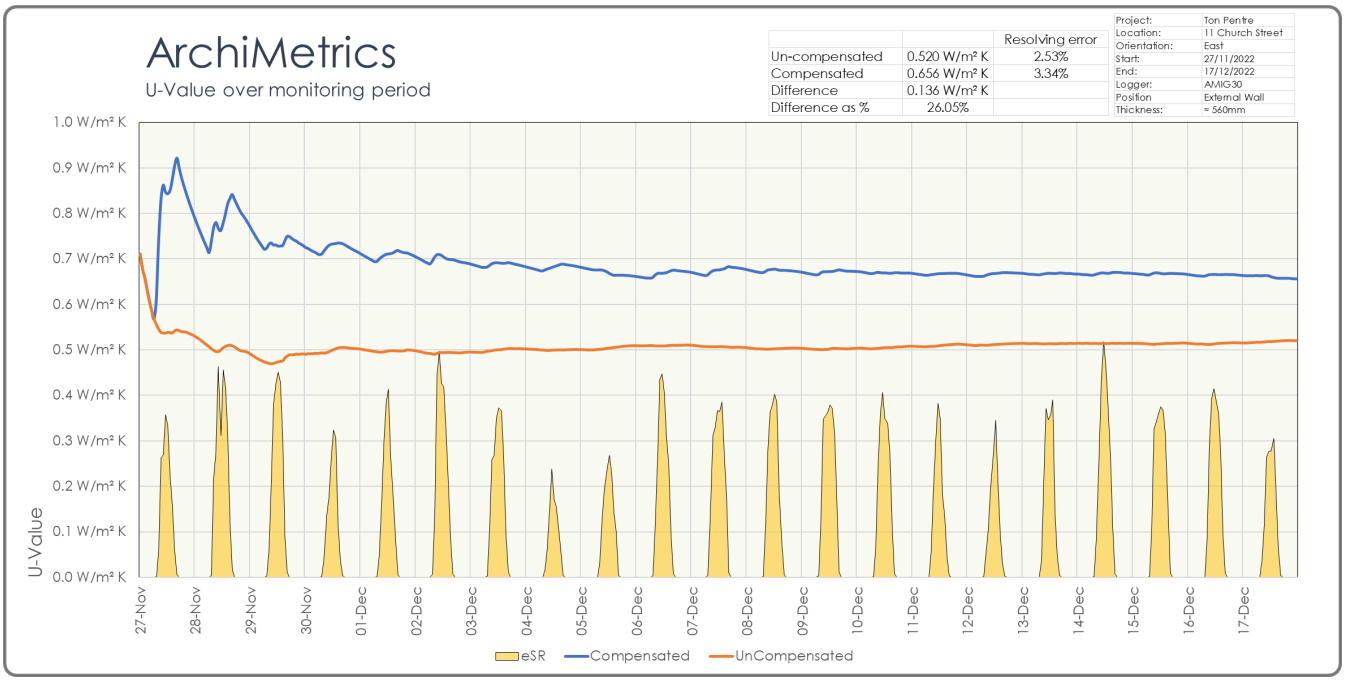


Figure 4. Compensated measured in situ U-value, November – December 2022, Church Street, Ton Pentre

3.3 Calculated U-value [2]

In our U-value report of March 2022 we provided three different calculated U-values (following BS EN ISO 6946 *Building components and building elements — Thermal resistance and thermal transmittance*) for the insulated stone wall at Church Street. These were based on three different densities of Pennant Stone and a 70:30 stone/mortar ratio derived from mapping the internal surface area of the wall. Following our revision of the thickness of the stone part of the wall for this report, we have repeated these calculations taking into account the increased wall thickness and results are provided in Table 1, below. (For more information regarding calculation methodology please see our previous U-value Report, March 2022.)

[2] On 9th March 2023 Sam Cryer. Thermulon founder, provided new lambda values for the Thermulon insulating plaster. New U-value calculations have been undertaken for the wall at Ton Pentre using the new lambda value and these are provided in an Appendix to this document.

Table 1. Quantities used in U-value Calculations for Church Street and calculation results for a revised overall wall thickness of 560 mm

Layer	Thickness mm	Material	Lamdba W/mK	Calculated U-value W/m²K
External Render	30	Vivus No.2 Basecoat Render	0.80	
Stone	319	Pennant Stone low - 1800 kg/m3	1.20	**0.87 W/m²K**
		Pennant Stone mid - 2400 kg/m3	2.30	**0.99 W/m²K**
		Pennant Stone high - 3000 kg/m3	3.80	**1.05 W/m²K**
Mortar	137	Lime mortar	0.70	
Internal Plaster	40	Thermulon Insulating Plaster + finishes		
Total	560 mm			

As can be seen from the table above, the U-values calculated for the insulated solid stone wall at Church Street now range from **0.87 – 1.05 W/m²K** depending upon the density/conductivity of the stone material selected (a small adjustment to the range previously found, 0.90 – 1.07 W/m²K). Whilst these standard U-values represent the sort of heat loss figures that might be conventionally calculated for this wall, it is of note that the measured U-value and compensated U-value indicate quite significantly lower heat loss, **0.53 W/m²K**, **0.66 W/m²K** respectively, than that identified by the calculations. This was also the case with the early-stage measured U-value of 0.64 W/m²K, and as previously noted this difference has increased due, we believe, to the drying of wall materials. We will repeat U-value reporting next year and it will be interesting to see how much variation we find in comparison to the 2022 measurements.

4.0 Hygrothermal Monitoring

Three combined temperature and relative humidity (RH) sensors (n1 – n3) have been installed at different depths through the 560 mm thick wall section. The n1 sensor is positioned at the interface between the stone masonry and the Thermulon insulating plaster, at a depth of approximately 40 mm from the internal wall surface. The two other sensors are positioned within the stonework; n2 at ≈ 340 mm and n3 at ≈ 440 mm, measured from the internal wall surface. In addition, three material moisture sensors, measuring moisture content (%MC) have been installed in the wall; MC1 at the interface between the stone and insulating plaster, MC2 at approximately 200 mm depth and MC3 around 400 mm. Unlike the RH sensors which sample moisture vapour within the air to determine a humidity profile for the wall, these sensors are fully coupled to their surrounding stone and mortar materials and use resistivity measurements to derive %MC values for these materials.

Temperature and RH monitoring measures and logs conditions at 5-minute intervals with %MC values recorded every 30 mins. Results are provided as a series of graphic analyses which look at the different temperature and moisture quantities in a number of different ways. There is also an analysis of internal surface risk and room conditions using measurements of temperature and RH made from the internal and external surfaces of the wall.

4.1 Material Moisture (%MC)

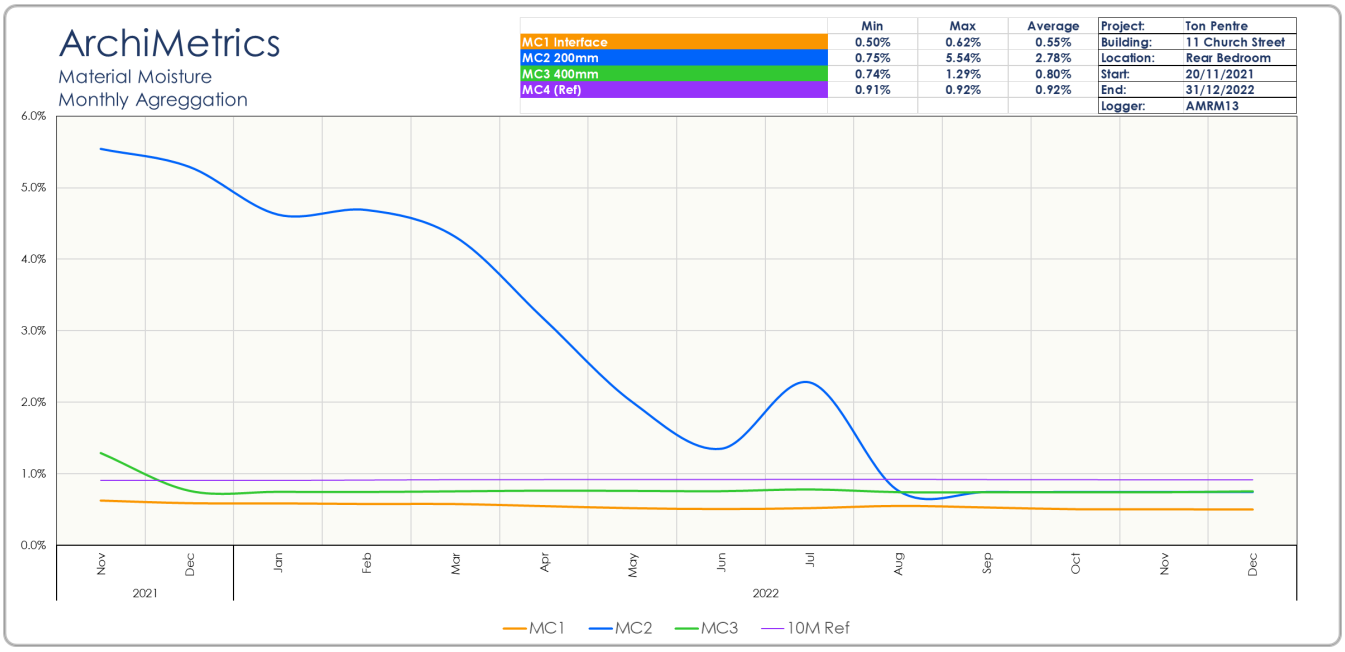


Figure 5. Material Moisture (%MC) Church Street, Ton Pentre, November 2021 – December 2022.

It should be noted at the outset that the %MC value 0.5% represents the technical limits of our measurements, this value also indicates low moisture content conditions. As can be seen in Figure 5, moisture at MC3, in proximity to the external side of the wall, reduces from 1.29% to reach a low 'equilibrium' condition, ≈ 0.74% within the first two months from the commencement of monitoring. Measurements from MC1, the interface sensor show 'dry' conditions from the commencement of monitoring, a maximum %MC value is recorded in November 2021 of 0.62% and this reduces slightly over approximately the first month to a wintertime value of ≈ 0.55%. A further small reduction takes place at MC1 in May through to July 2022, to a minimum value of 0.5% which increases very slightly again through August and September but then returns to the 0.5% low for the rest of the year. In contrast with conditions in proximity to the internal and external sides of the wall, moisture is much higher towards the centre of the wall, MC2. Here moisture is at a peak value of 5.54% at the start of monitoring. However, it is clear from the analysis that moisture quantities at this location also reduce, albeit more slowly, further away sources of heat (internal room heating, external solar radiation) and further away from the wall surfaces where moisture can exit materials by evaporation. The trace at MC2 shows three stepped periods of moisture reduction typical of a drying response. There is an initial phase from November to January 2022 where %MC values fall below 5%, there is a brief %MC increase in February followed by a steep fall through the spring into early summer and by June %MC at MC2 is around 1.4%. There is then, once again, an increase in quantities in July before %MC reduces again in August and by September and for the rest of the year %MC at MC2 is very similar to that of MC3, ≈ 0.75%.

By September all three %MC sensors show low %MC through the wall section, close to the boundary of our measuring capabilities. As perhaps might be expected %MC at MC1 is the lowest of the three measured locations, ≈ 0.5%, as this interface location, at ≈ 40 mm depth, is in closest proximity to a wall surface and internal conditions. However, conditions within the

masonry wall itself, around the centre as well as towards the external wall face, are very similar, around 0.7 %MC and might be considered to show low %MC for the stone part of the wall section. It should be noted that this measurement technique requires the sensors to be coupled to wall materials using lime putty mortar which is itself a wet material and thus measurements made early on in the monitoring cycle may be influenced by the drying of this material. However, sensors were installed in early September and monitoring commenced over two months later, therefore, it could be assumed that some amount of drying of the lime putty had already taken place prior to the start of these analyses. Nevertheless, the influence of the moisture from this material cannot completely be excluded from these results.

4.1.1 Gravimetric %MC Measurements

As part of our equipment installation processes, we made gravimetric measurements from materials sampled at the approximate depths of our material moisture monitoring sensors. These measurements were made prior to the application of wet internal and external plaster and render finishes and therefore may represent higher than the walls, normal, dynamic 'equilibrium' profile. The results of these measurements can be found in Table 2 below and show generally low %MC. As would be expected these measurements show lower %MC for stone materials in comparison to that of mortar. We have also found low material moisture conditions at approximately these same wall depths from our monitoring of the wall, post-refurbishment with annual average of 0.55% at MC1, interface, and 0.80% at MC3. The MC2 annual average is higher, 2.78%, as %MC was raised at this location during the first half of 2022 but has now been seen to have reduced (Figure 5).

Table 2. Gravimetric %MC site measurements, Church Street, Ton Pentre, 3rd September 2021

Sensor ID & depth	Stone %MC	Mortar %MC	AMRM13 Average %MC
MC1 @ ≈ 40 mm (interface)	0.32 %	1.81 %	0.55%
MC2 @ ≈ 200 mm	0.24 %	2.01 %	2.78%
MC3 @ ≈ 400 mm	0.15 %	1.88 %	0.80%

4.2 Moisture Vapour

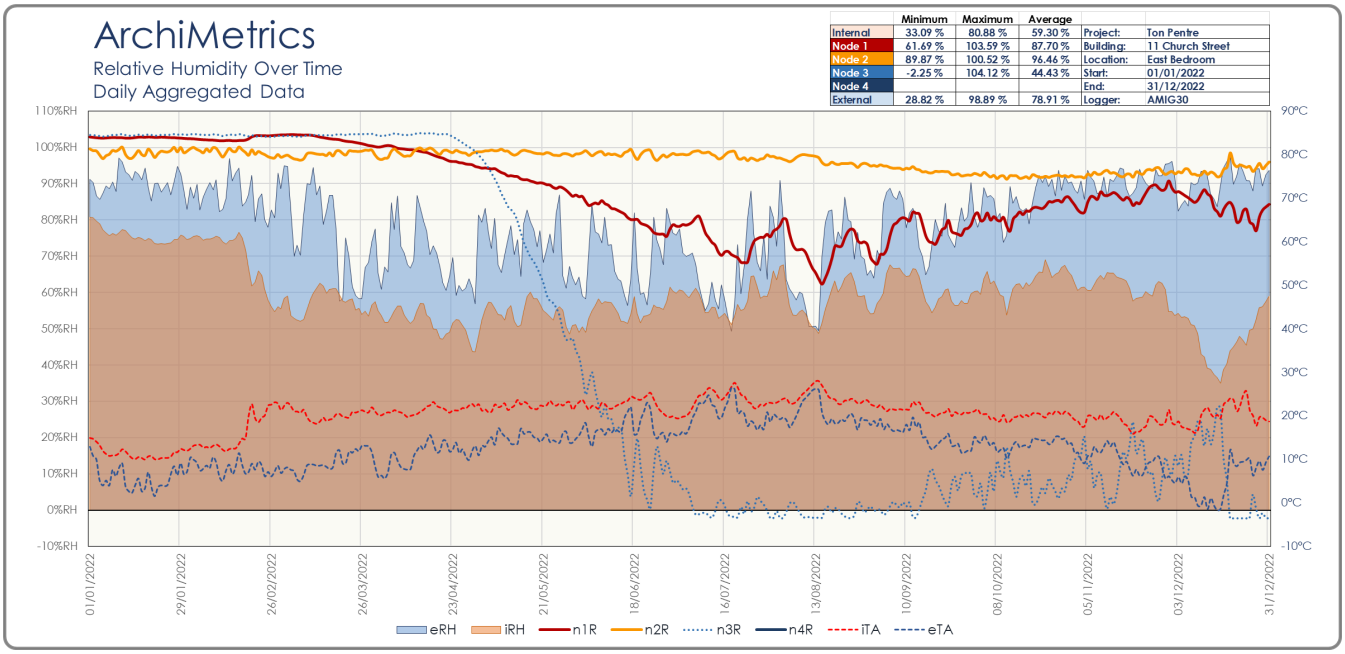


Figure 6. RH over time, Church Street, Ton Pentre, January 2022 – December 2022

There are clear signs of 'drying' (vapour reduction) over the year from the bedroom wall at Church Street. The sectional RH records for the wall, Figure 6, shows high RH at all three sensor positions at the start of the monitoring period, January – March 2022. The interface sensor, n1 and the sensor closest to external conditions, n3, both show RH above 100%. RH above 100% is a conceptual impossibility, however, the manner by which these measurements are made mean that when RH is very high, at or around dew point, it is possible for values above 100% to be recorded. We choose to report these values as they provide additional information about the direction of vapour change within the wall. Here, they allow us to see when reductions in vapour levels start to commence, prior to values falling below the 100% threshold. While RH measured at n1 and n3 in proximity to the internal and external sides of the wall is very high, it is also high at n2, peaking up to 100% and this remains the case for quite a protracted period, until mid-July 2022. External and internal temperatures are at their highest through July and August and during these months RH at n2 starts to reduce until it reaches a minimum value of ≈ 90% in October. Thereafter RH at n2 increases through the winter months, with a peak around 98% coinciding with a sudden rise in external temperatures following a period of low, ≈ 0˚C conditions in mid-December. However, by the end of the year RH is slightly lower at n2 in comparison with the start of the year, with peaks around 95%.

RH responses from the other two sensors, n1 and n3, show more volatile and marked RH reductions measured from the wall section. When occupation commences in Church Street, in February 2022, a small increase in RH at the interface sensor, n1, is observed. This increased vapour is likely to be as a result of evaporative drying in response to the increased heat input to the internal side of the wall as the bedroom starts to be heated (this temperature change is clearly seen in the iTA trace in Figure 6). At the same time vapour slightly increases at n1 it, temporarily, slightly decreases at n2, perhaps because the new heat input reduces the vapour saturation of the air at this location. But because this part of the wall

is further from that source of heat, the temperatures are not sufficient to provoke evaporation from materials. As external temperatures increase through spring some drying is encouraged deep within the wall and therefore RH increases at n2 and returns to its 100% peaks at the end of March. As external temperatures rise through March, RH at the interface, n1, begins to fall as evaporated moisture is lost from the wall structure. RH at n1 falls steadily until the end of June when we observe two further peaks in July and August, indicative of evaporative drying, where base line RH falls to new low values, the lowest occurring following the August peak when RH at n1 reaches its annual minimum, during peak external temperatures, of 62% RH. Thereafter, as external and to a lesser extent internal temperatures begin to reduce RH starts to increase again and peaks ≈ 90% at the start of December. However, as with n2, over an annual cycle RH can been seen to have reduced in this part of the wall section where it is around 84% by the year end.

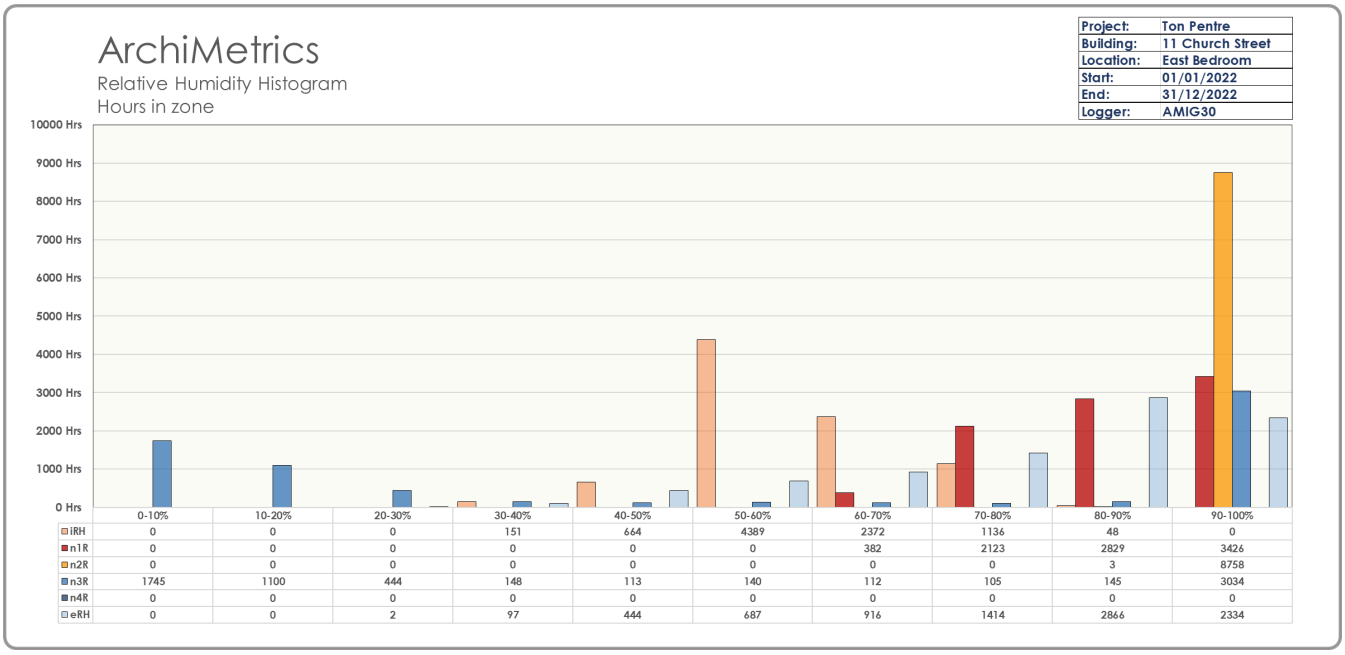
RH responses measured at n3, towards the external side of the wall, are very similar to those found for n1 at the beginning of the year. Like responses at n2, deeper within the wall, there is a very slight reduction in RH at n3 for a few weeks when heating commences inside the house in February. In March RH is back at its peak around 104% and then, at the end of April we start to see RH falling quite rapidly at n3. This is something we might expect as external temperatures increase and materials in proximity to the new lime render begin to dry more rapidly. However, we might expect to have seen RH increase for a time in response to increased evaporative drying prior to observing a fall in RH at n3 and the speed of reduction is unusually rapid. We have never previously observed such an RH response measured from within a wall section, however the RH trace was not akin to that of a failing sensor and given that we were measuring novel materials, in consultation with the team, it was decided that the sensor should remain in place for the time being. By June RH at n3 was reading 0% and at times -2% through July – September, untenable values. Despite this the sensor was kept in position in order to see if, with the onset of colder wintertime weather, RH would be seen to increase at this location as would be expected. Initially an increase did occur, although values remained unrealistically low, peaking around 30% in mid-December before falling below 0% again. During a service visit to the property on 17th February 2023 we decided to replace the n3 sensor and since this time RH at n3 is seen to be very similar to that of n2 and is currently around ≈ 95%. We have examined the previous n3 sensor and can find nothing ostensibly wrong, it does not appear to be damaged and reports correct RH readings under controlled conditions. We cannot provide an explanation for what now appears to have been its failure other than perhaps, in proximity to the air lime render some reaction has occurred in response to the caustic environment resulting in low RH measurements. Due to the apparent failure of this sensor, measurements made at n3 from April 2022 onward should be treated with caution and n3 plots in the over time analyses are presented as dotted lines to indicate this.

4.2.1 RH & %MC Comparison

In the first year at Ton Pentre we have found that, after a period of drying, most obviously within the central part of the wall section, %MC values are now low, < 1% MC, through the wall section. This is not the case for sectional RH which, although it has fallen somewhat over the year remains quite high. It is not unusual to find divergence between records of %MC and

those of RH, particularly when materials which have been wet, or subject to excessive moisture, are drying and are in the process of establishing their normal 'in-service' condition. In other 'drying' walls we have observed a lag in RH responses where vapour within the wall remains quite high despite the moisture content of materials being relatively low. We would therefore expect, over the next few years of monitoring, to see RH continuing to fall, year-on-year, until vapour responses reflect the longer-term dynamic equilibrium condition for vapour within the wall section.

4.2.2 RH Histogram



	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
iRH	0	0	0	151	664	4389	2372	1136	48	0
n1R	0	0	0	0	0	0	382	2123	2829	3426
n2R	0	0	0	0	0	0	0	0	3	8758
n3R	1745	1100	444	148	113	140	112	105	145	3034
n4R	0	0	0	0	0	0	0	0	0	0
eRH	0	0	2	97	444	687	916	1414	2866	2334

Figure 7. RH histogram, Church Street, Ton Pentre, January 2022 – December 2022.

The histogram in Figure 7 shows the total number of hours of %RH measured through the Church Street wall section in 2022 for the three wall sensing nodes, n1 – n3, (as well as internal and external RH conditions) grouped in 10% RH brackets. Given that this wall was refurbished with new plaster and render (both wet materials applied directly to the masonry) it is perhaps not surprising that in the first year following this work we find the highest number of hours for all three sensors, n1 – n3, are recorded in the highest RH bracket, 90 – 100% (the low values shown for n3 are erroneous, as above). The reductions in RH at the interface, n1, show as additional hours where RH has been between 60 – 90%, although for the majority of time through the year conditions at n1 have been above the nominal 80% risk threshold value. Sensor n2 records all time annually above the 80% threshold, with only 3 hours outside the 90 - 100% bracket. Nevertheless, as has been stated above, we would expect to see RH reduce through the wall section as materials continue to dry with the hope that various parts of the wall section no longer spend the majority of time annually measuring RH above 80%.

4.2.3 Saturation Margins over time

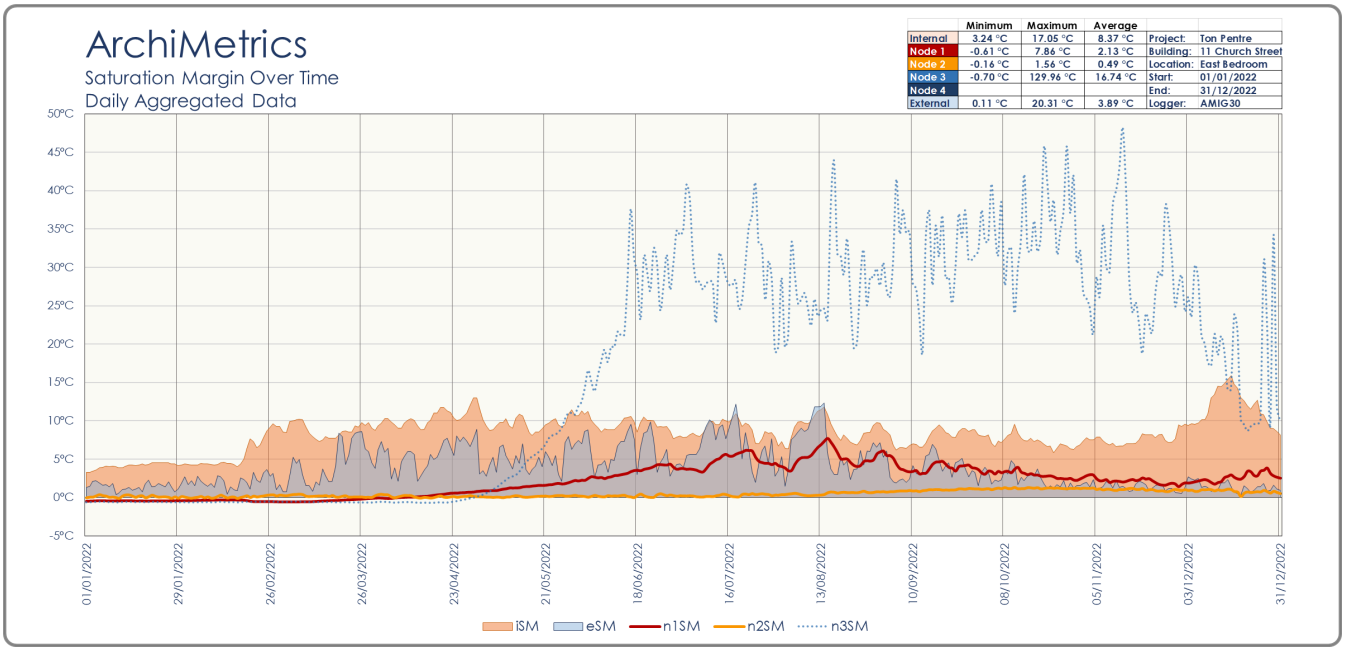


Figure 8. Saturation Margins over time, Church Street, Ton Pentre, January 2022 – December 2022.

RH measurements from the three hygrothermal sensors installed in the wall section are also used to create a saturation margins over time analysis, Figure 8. The 'Saturation Margin' indicates the temperature difference, in degrees centigrade, between the temperatures measured at the three points within (and either side of) the wall, and the temperature reduction required for the air measured at those same locations to reach saturation or dew point (100% RH). Figure 8 shows that as the wall has dried somewhat over the year, conditions at n1 and n2 have moved away from saturation conditions (n3 should be discounted). As could be anticipated from the previous RH analyses in Figures 6 and 7, n1 at the interface has the higher ˚C margin, being on average 2.1 ˚C for the year. Conditions at n2 have been much closer to dew point and the annual average margin here is 0.5 ˚C. However, once again, we would expect to see a year-on-year improvement in these margins as the wall continues to dry and vapour quantities reduce through the wall section resulting in an increase in ˚C margins.

4.2.4 Hygrothermal Section – Saturation Margins

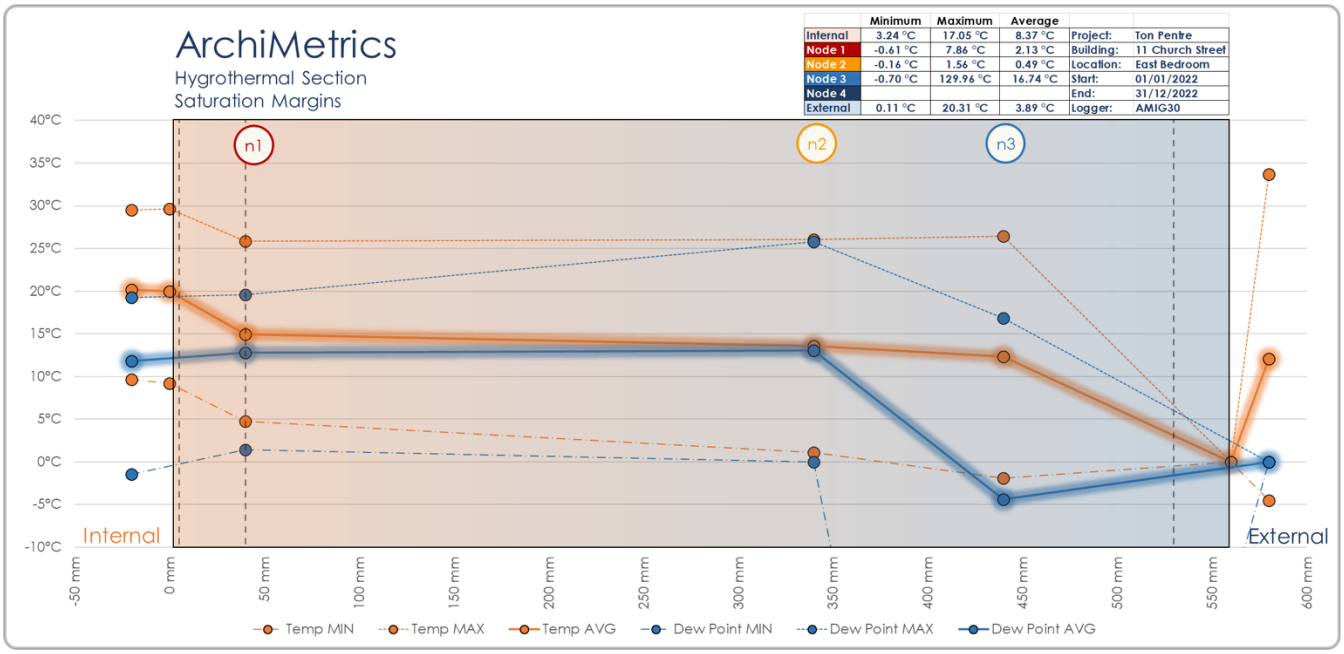


Figure 9. Saturation Margins Section, Church Street, Ton Pentre, January 2022 – December 2022.

Figure 9 shows saturation margins through the wall section, where average, as well as maximum and minimum values, are plotted for the three hygrothermal sensor nodes, as well as internal and external conditions. Once again, gradients plotted to and from n3 should be discounted in this analysis. As a result of the high RH measured at n2 throughout the year, Figure 9 shows the near convergence of measured and dewpoint temperatures to be the dominant condition at this location through 2022, meaning it is possible that at times moisture is close to being present as a liquid, or forming here as interstitial condensation. The wider average saturation margin for n1, of 2.1˚C, is also visible in Figure 9, indicating that vapour saturation is not the predominant condition in this part of the wall. Once again, we would hope that future hygrothermal sections for this wall will show the monitored locations moving away from saturated conditions as the wall continues to reduce its construction moisture and move towards equilibrium conditions.

4.2.5 Absolute Humidity over time

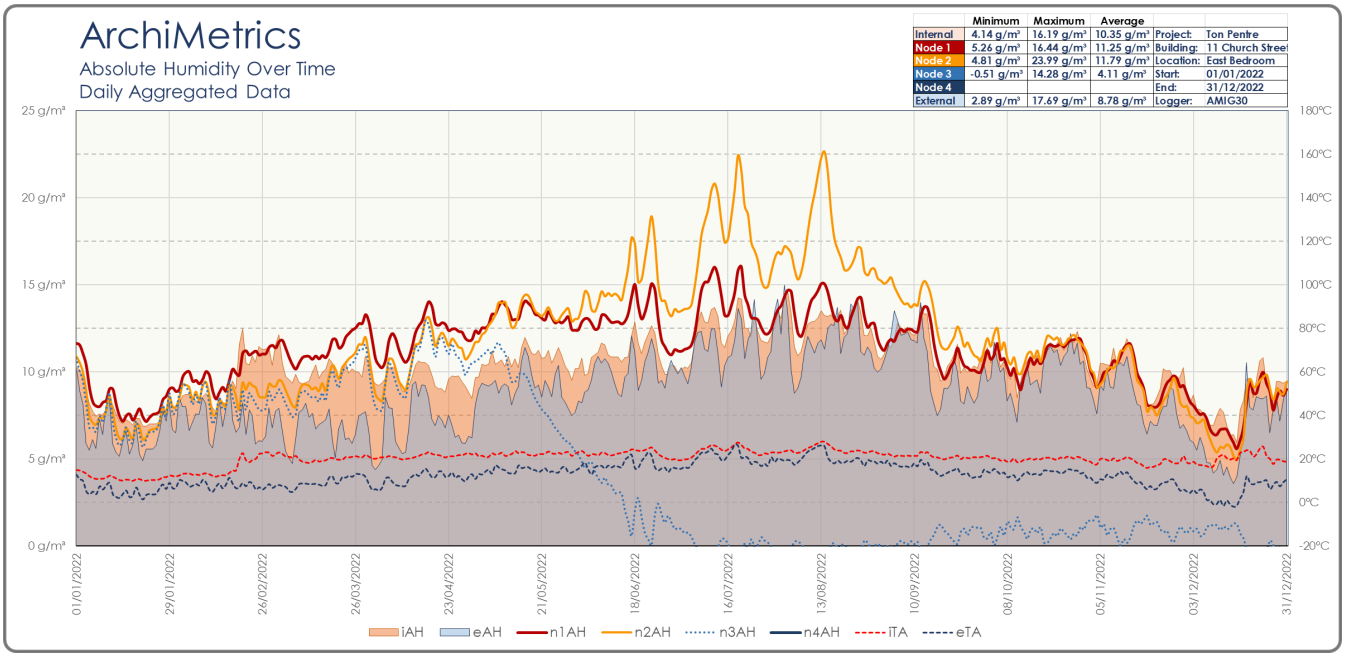


Figure 10. Absolute Humidity over time, Church Street, Ton Pentre, January 2022 – December 2022.

The vapour profile of the wall can also be examined as the quantity Absolute Humidity (AH) a measurement of the mass of vapour by volume, g/m^3, at the three sectional nodes, as well as the internal and external environments, Figure 10. At the start of monitoring weights of vapour are quite similar across all three nodes, where the lowest weights are recorded at n3, towards the external side of the wall and the highest at the interface, n1. A change is seen with the onset of internal heating at Church Street in February which causes vapour at the n1 interface, in closest proximity to internal conditions, to increase in relation to that of n2 and n3, as it does in the internal room environment. This suggests that the warmer temperatures encourage vapour production at this location from moisture bound within the wall materials as well as evaporation into the room environment where the warmer air can support more moisture vapour. AH at n1 continues to be somewhat raised in comparison with the masonry section of the wall until around mid-April which again reflects the difference between vapour quantities in the internal and external environments. After April this difference diminishes as vapour in the external atmosphere beings to increase with the advent of warmer external temperatures and by May AH at n1 interface is lower than that of n2. Both n1 and n2 show AH peaks through the summer in response to peaks in external temperatures presumably driving the evaporation of moisture into the atmosphere as well as the air within the wall materials. Sensor n1 records maximum peaks of 16.4 g/m^3 in July but peaks at n2 show much higher weights, the highest being 24 g/m3 in August. By October vapour quantities at the two locations are once again quite similar although it is of note that AH at n1 now sits between that of internal and external AH, rather than being higher than that measured from the surrounding conditions. We have found from other wall measurements that when materials contain excessive moisture AH quantities are often higher than those of the internal and external environments which the wall bisects, as was the case at the start of the year. That AH quantities now result in a plot line that sits approximately between that of the two bracketing environments, lower than that of internal conditions, suggests that n1 may be close to its

dynamic equilibrium state, although this can only be confirmed by future measurements. It is also of note that AH at n2 has also been detached and higher than that of the internal and external environments for much of the spring and summer months, when most drying takes place. Nevertheless, following this drying phase we might expect this node to show AH slightly lower than that of the external environment, which it is closest to, however this is not the case suggesting there is still a quantity of perhaps excess moisture at this location which is yet to be dispersed. Something also confirmed by the high RH measurements we continue to find for this location.

4.2.6 Absolute Humidity Section

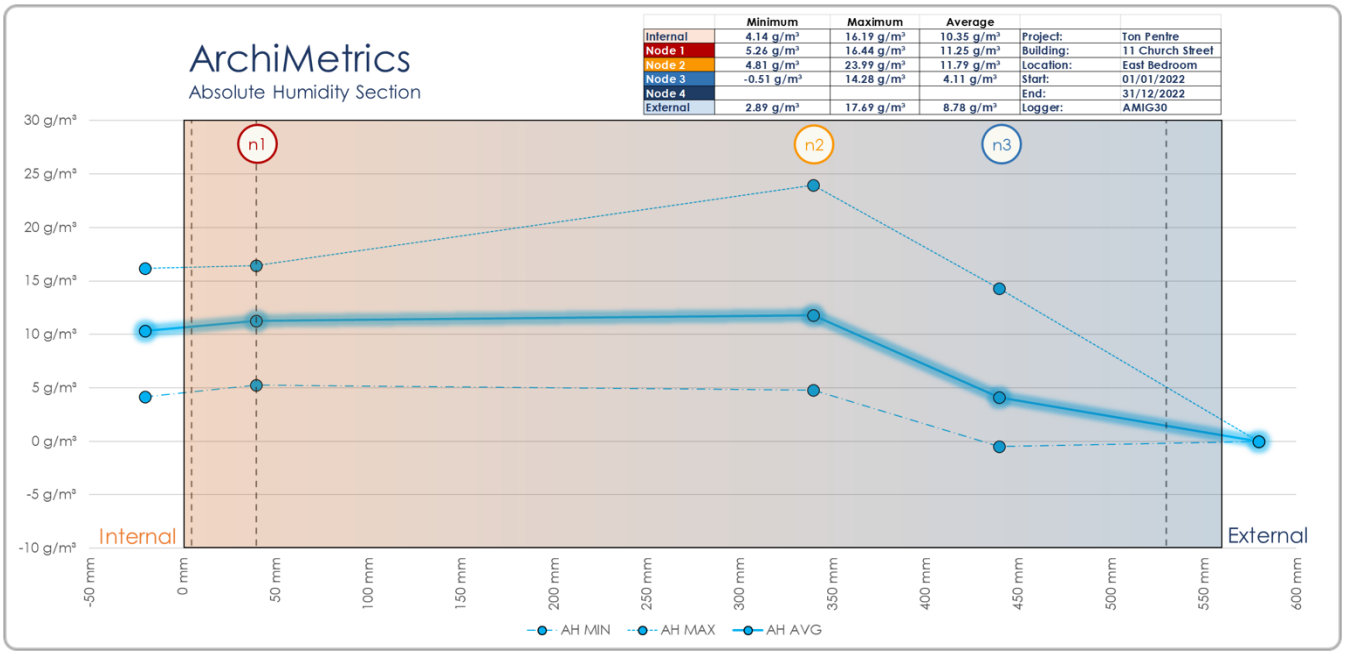


Figure 11. Absolute Humidity Section, Church Street, Ton Pentre, January 2022 – December 2022.

Like the plot of saturation margins shown in Figure 9, AH can also be looked at as averaged and maximum and minimum quantities through the year, Figure 11 (plots to and from n3 are erroneous). Looked at as averaged weights of vapour over the year we find there is not much difference between the interface n1 location and n2 deeper within the masonry of the wall, where AH is 11.3 g/m3 and 11.8 g/m3 respectively. We can expect both these values to reduce next year although, as above perhaps the greater reduction will take place at n2 if more drying has taken place through this year at n1 meaning at this location the wall is closer to equilibrium conditions.

5.0 Room Conditions

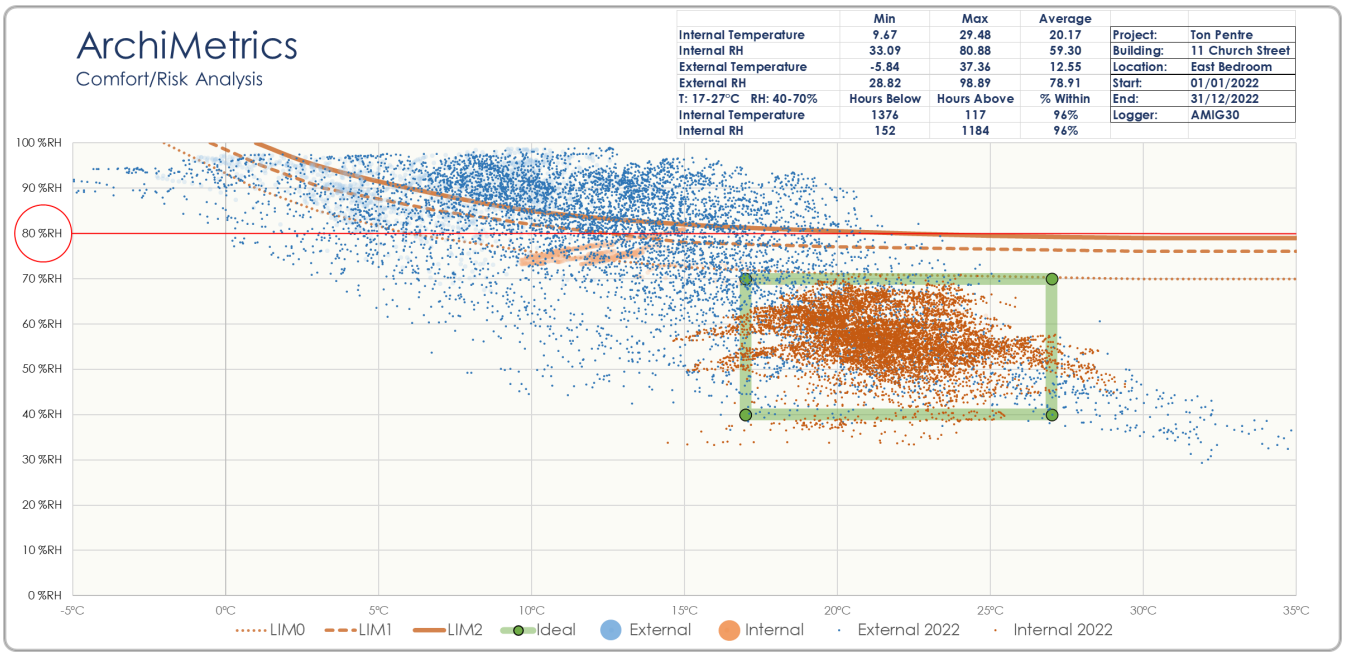


Figure 12. Room Conditions, Comfort/Risk, Church Street, Ton Pentre, January 2022 – December 2022.

Figure 12 uses the temperature and RH data measured from the internal and external environments in proximity to the hygrothermal wall section monitoring to provide an analysis of both room comfort and also fabric risk, that being the risk of mould growth to internal surfaces.

5.1 Comfort

Room temperature and RH 'ideal' comfort parameters are defined by a green rectangle in Figure 12 representing the ranges 17 – 27˚C and 40 – 70% RH. Each measured temperature and RH data point (at a five-minute measuring interval) is mapped as a small orange dot for internal conditions and a blue dot for external. As can be seen in Figure 12, the vast majority of internal condition measurements are confined within the comfort ranges, with only a small number of measurements showing RH below 40% or temperatures below 17˚C or above 27˚C. From the table above the graphic analysis, it can be seen that when factored as time over the whole year 'ideal' conditions are achieved 96% of the time. There is, however, a cluster of internal data points showing lower temperatures, between 10 – 15˚C and concomitantly higher RH, around 70 – 80%. From the RH over time analyses, Figure 5 we know that these conditions persisted in the room early in the year prior to the house being occupied and the bedroom being heated. The average temperature measured for the room over the year is 20˚C with average RH begin 59%. However, these averages will have been slightly impacted by the lack of heating at the start of the year, therefore, with continuity of occupation, in 2025's Annual report we might expect average temperatures to have increased somewhat with the addition of 2023 and 2024 data and RH to be slightly reduced.

5.2 Fabric Surface Risk

Following Sedlbauer, Figure 12 also features three 'limiting isopleths for mould' (LIM) plots these denote threshold temperature and RH values above which mould growth might be viable on three different substrates, LIM0 being an ideal growth medium such as agar, LIM1 representing easily biodegradable materials such as wallpaper and LIM2 being less biodegradable, porous materials such as plasters, mineral building materials and timber.[3] 80% RH is also an often-quoted general threshold value indicating the risk of mould growth, particularly on internal surfaces. In Figure 12 it can be seen that some internal temperature and RH data points, which originate from the period when the room was not occupied or heated, stray above the lower of the two isopleths, LIM 0 and LIM1, indicating a brief risk of mould growth on an ideal medium or biodegradable materials. A very small number of RH measurements show room RH to have been above 80%, the maximum recorded value being 81% but none of these are plotted above the third, LIM2, isopleth which represents common porous building materials meaning there appears to be very little, if not minimum risk, of mould growth on surfaces over the year, especially once the room has been occupied.

[3] Sedlbauer, K., 2001. *Prediction of mould growth fungus formation on the surface of and inside building components.* [PDF] Stuttgart and Valley, Germany: Fraunhofer IBP

APPENDIX I

Updated U-Value Calculations

On March 9th 2023, Thermulon provided new lambda values for their insulating plaster. At their request, we have therefore re-calculated the U-values found for the insulated wall at Ton Pentre, see Table 3 below.

Table 3. Ton Pentre Calculated U-values with new Thermulon lambda value, March 2023.

Layer	Thickness mm	Material	Lamdba W/mK	Calculated U-value W/m²K
External Render	30	Vivus No.2 Basecoat Render	0.80	
Stone	319	Pennant Stone low - 1800 kg/m3	1.20	**0.59 W/m²K**
		Pennant Stone mid - 2400 kg/m3	2.30	**0.64 W/m²K**
		Pennant Stone high - 3000 kg/m3	3.80	**0.66 W/m²K**
Mortar	137	Lime mortar	0.70	
Internal Plaster	40	Thermulon Insulating Plaster + finishes		
Total	560 mm			

The new calculated U-values are significantly lower than those reported in section 3.3 above and more closely grouped. This is because the new lambda value is lower than that used in the previous calculations and the Thermulon plaster, as the insulating component within the wall build up, now contributes more to the overall thermal resistance of the wall.

As previously explained, we have calculated a range of U-values for the insulated wall at Church Street based on different densities of Pennant stone, the principal constituent of the wall. Using the new lambda value for Thermulon plaster gives a range of calculated U-values **0.59 – 0.66 W/m²K**. This range shows an improved fit with the range of U-values that have been measured from the wall, **0.53 – 0.66 W/m²K**, albeit for different reasons, as the range of measured U-values are the result of reductions in wall moisture as well as corrections for solar influence. The lowest measured U-value, **0.53 W/m²K,** is 10% lower than the lowest calculated U-value**, 0.59 W/m²K**, where we believe the measured U-value shows lower heat loss than the previous measured U-value (**0.64 W/m²K)** as a result of drying that has taken place through the substrate during 2022. Interestingly, the highest calculated U-value, **0.66 W/m²K**, accords with our 'compensated' U-value (see section 3.2) which is the product of an experimental technique which tries to eliminate solar influence from the measured U-value. The compensated U-value, therefore, potentially provides a better comparative base with calculated U-values, which, as steady-state calculations, only account for heat flow in one direction. However, it should also be noted that our calculations are based on an assumed 40 mm thickness of Thermulon plaster and that, ultimately, without a base case (uninsulated) measurement for the wall at Ton Pentre it is not possibly for us to precisely quantify the contribution that the Thermulon plaster makes to the heat loss reduction of this wall.