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An Analysis of Drying Data from a Medieval Hall after Flooding

Prepared for Historic England by
Dr Brian Ridout and Iain McCaig

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Front cover: Inscriptions on quoin stones recording historic flood water levels.

SUMMARY
Remediation companies are often employed to dry buildings following floods. This process usually entails the use of dehumidifiers, air blowers and heaters, accompanied by frequent site visits to monitor progress. At some stage in the process it will be decided that the building is sufficiently dry to stop monitoring and to remove the equipment. But how accurately can this assessment be made? Following the flooding of a medieval hall in 2015, detailed records of the progress of drying were kept by the remediation company employed to carry out this task. This report presents an analysis of the data recorded, and considers the factors affecting the accuracy of moisture monitoring and assessment in such cases.

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1 INTRODUCTION

Remediation companies are often employed to dry buildings following floods. This process usually entails the temporary installation of dehumidifiers and air blowers but the hiring of these is expensive. Frequent monitoring visits also add to the cost so that professional drying can lead to a significant financial outlay.

At some point during the task a decision has to be made that the building is sufficiently dry to stop monitoring and to remove the equipment. Presumably this will be when the surveyor's measuring devices give dry readings, but this presents a problem because the surveyor will not know what moisture contents would have been obtained before the flood and thus what a normal reading would be.

Moisture meter readings are especially difficult because it is only possible to derive anything like a reliably accurate relationship between moisture content and electrical properties in wood. Many meters overcome this problem by providing a reference scale from 0 to 100. This is useful for comparisons but provides no information about where on the scale would be acceptably dry for any particular material.

Another debatably useful idea is 'wood moisture equivalent'. This is telling us what the moisture content would have been for those electrical properties measured if they had been in wood. This seems to be very tenuous logic because there are many characteristics from density and surface contact with capacity meters to contact and salts with resistance meters, which might produce artificial results.

We now have the careful records made by the drying company at a medieval hall. These provide a good opportunity to analyse how drying progressed and was monitored following the flood in late December 2015.

2 THE CHAPEL

2.1 Drying equipment

The Equipment Installation Sheet shows that one Condensing Dryer K2 was used. This is a refrigerant machine, which processes 500m^3 air/hour. This was installed on the 13th January and removed on the 17th February.

An Axial Fan was also used. Axial fans produce a linear flow so they would be useful for drying a flat surface. The power of this fan is not given. It was also installed on the 13th January but was not removed until the 19th May.

13th January is taken as Day 1 in this report.

2.2 Measuring equipment

A Tramex digital capacitance meter (MRH III) was used. The manufacturers claim this can read to at least 25mm depth. The Tramex MRH III also records temperature/relative humidity and these parameters are also supplied on the drying sheets.

2.3 Monitoring locations

Figure 1 shows the sketch from the first Drying Sheet showing the locations where measurements were taken during each visit. Presumably the meter was placed on the floor in approximately the correct position each time, but there must be material variation. There are no indications of the heights above floor for the pew end measurement (11 to 14). Figure 2 indicates the construction.

2.4 Results

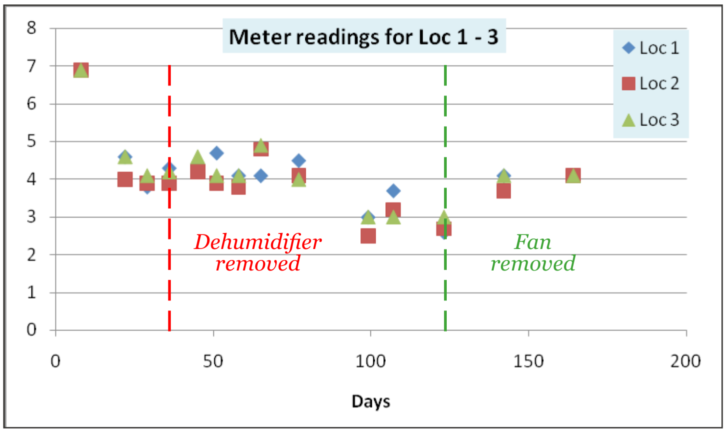
Results are presented here as a series of graphs so that the effects of equipment removal can be visualised.

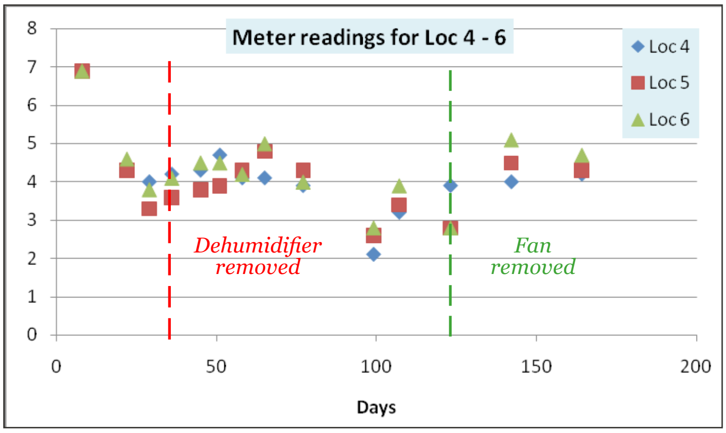
All of the 10 floor locations gave similar readings.

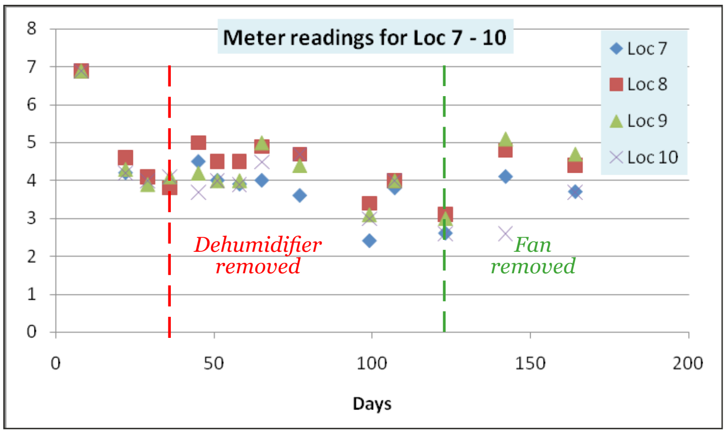
The starting floor reading, 8 days after the drying equipment was installed, was 6.9 in all locations. This would seem to be some kind of default value since all readings were never so consistant again and the same starting reading was given for the Hall (see 3.4). By the time the dehumidifier was removed on Day 36 (17th February) the mean reading had dropped to 4.0 ± 0.22. We do not know whether this would have happened anyway, but it certainly would have been an improvement had the starting reading been genuine. We have ignored the starting values for this report.

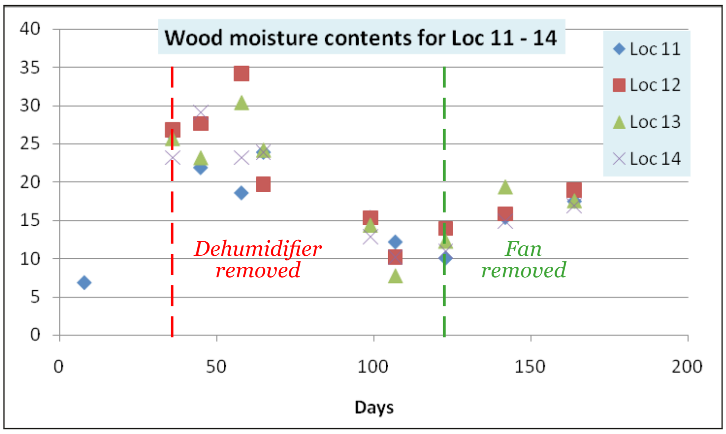
Figure 1: Plan of the chapel.

On Day 65 (21st March) the mean readings had risen to 4.6 ± 0.40 despite the fan. However readings taken when the fan was removed on Day 123 (19th May) gave 2.8 ± 0.18. This suggests that air movement had some effect, at least at the surface, although the year was getting steadily warmer which might have an effect.









Figures 3–6: The Chapel: Meter readings from locations 1–14.

But by Day 142 (7th June) the mean had risen again to 4.2 ± 0.74. On Day 164 (29th June) it was still 4.2 ± 0.35, but by Day 245 (23rd September) it had sisen to 4.4 ± 0.39. This all suggests that 4.0–4.6 would be the normal readings expected from the floor and that range was obtained during the second visit on Day 22 (3rd February) when the mean was 4.4 ± 0.21. That is 22 days after the dehumidifier and fan were installed.

The following table compares results from the beginning of the monitoring period with the end (in red).

Table 1: The Chapel: Comparing results from the beginning and end of the monitoring period					
Loc	Day 23	Day 46	Day 123	Day 165	Day 245
1	4.6	4.4	2.6	4.1	5.3
2	4.0	4.2	2.7	4.1	3.9
3	4.0	4.6	3.0	4.1	5.1
4	4.3	4.3	3.9	4.2	4.1
5	4.3	3.8	2.8	4.3	4.0
6	4.6	4.5	2.8	4.7	4.2
7	4.2	4.5	2.6	3.7	4.5
8	4.6	5.0	3.1	4.4	4.5
9	4.3	4.2	3.0	4.7	4.9
10	4.2	3.7	2.6	3.7	3.4
11	–	21.9	10.1	15.4	–
12	–	27.6	13.9	15.8	–
13	–	23.2	12.3	19.4	–
14	–	29.1	11.0	14.9	–

The table shows the drop around Day 123, which is either caused by seasonal change (now May and so the floor was warmer) or by the laminar fan. However the same drop did not occur at the same time in the adjoining Hall where the seasonal change would have been the similar but there was no fan. It therefore seems likely that the accelerated laminar air flow caused a surface drying that was interpreted as 'the dry point' but the effect was lost when the fan was removed.

The wood moisture contents (locations 11–14) are more promising, but wood equilibrates with relative humidity and so the dehumidifiers should have an effect.

3 THE HALL

3.1 Drying Equipment

The installation sheet shows that four Dri-eze 1200 dehumidifiers were installed on Day 1 (13th January). These are refrigerant type units designed to remove 55 litres/day. One was taken away on Day 126 (19th May), but the others were not decommissioned until the 17th October.

Four CTR150 units were also installed between the 18th and 20th January. These are desiccant dehumidifiers that blow out warm dry air (though not a laminar flow). The manufacturer's specification states that they remove 25 litres/day and provide 330m3 of airflow/hour. As with the refrigerant units, one was removed on the 19th May, but the others were not decommissioned until Day 277 (17th October).

3.2 Monitoring equipment

The same Tramex meter as used in the Chapel.

3.3 Monitoring locations

Figure 7 is taken from the first Hall Drying Sheet.

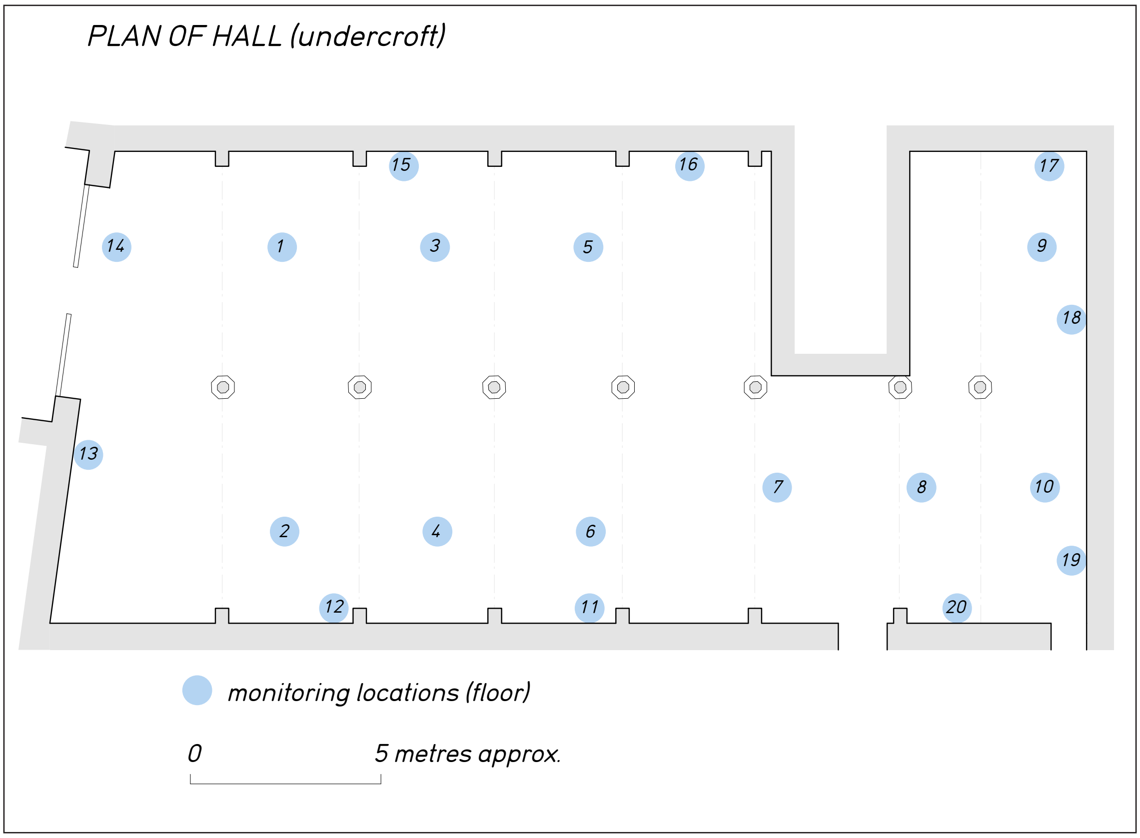
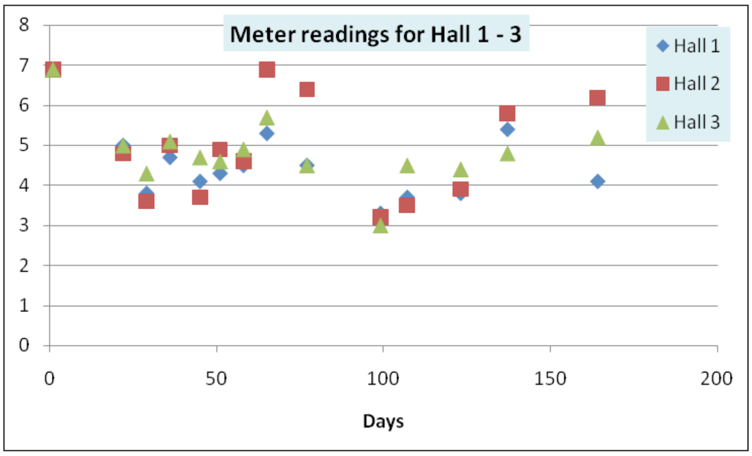
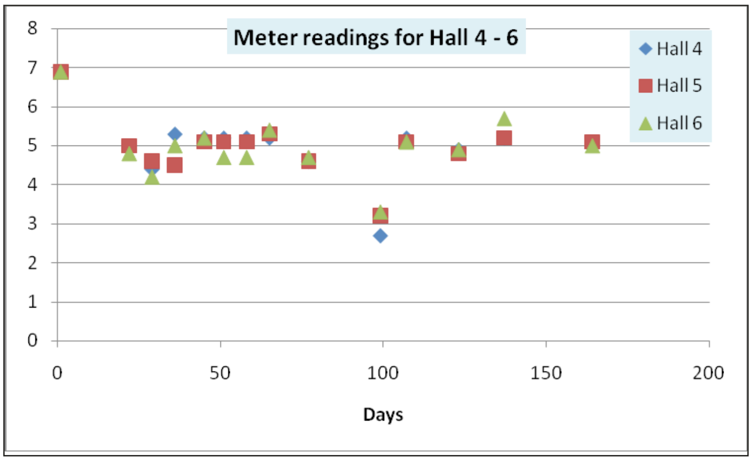


Figure 7: Plan of the Hall.

3.4 Results

The following graphs do not include the removal of equipment because although two of the eight were taken away after 126 days, the remainder were retained throughout the entire monitoring period.





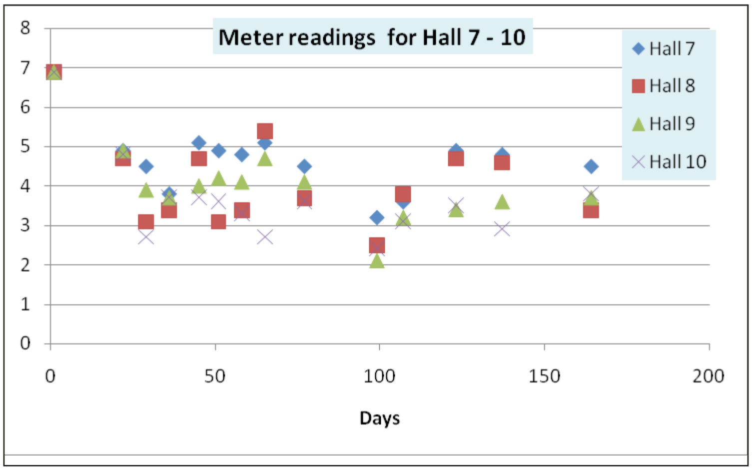
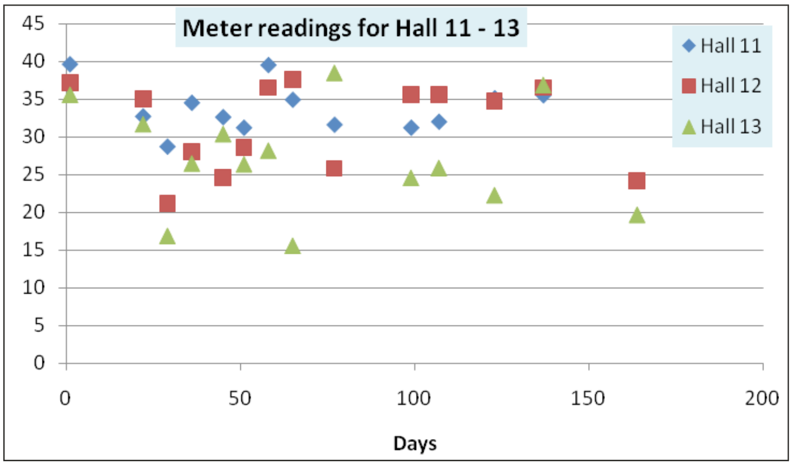
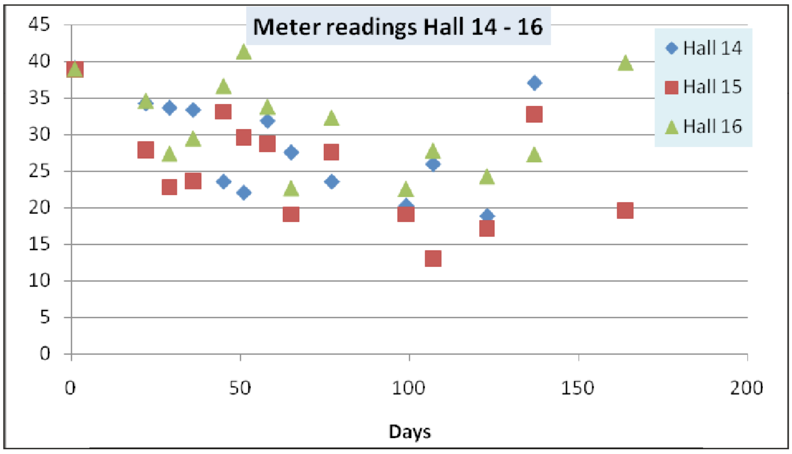
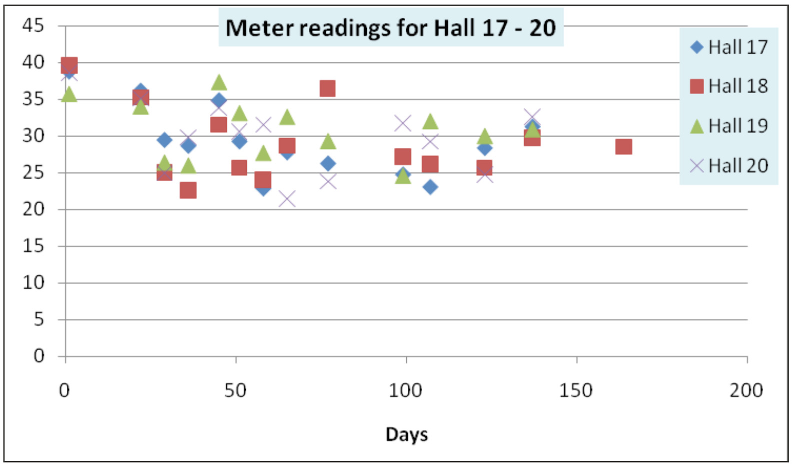


Figure 8–10: The Hall: Meter readings from locations 1–10.







Figures 11–13: The Hall: Meter readings from locations 11–20.

The first set of readings for Hall 1–10 all start again at 6.9, which would seem to be some form of default value. A final set of readings, which could not be included in the graphs, was taken on the 23rd September (Day 253). The following table compares results from the beginning of the monitoring period with the end (shown in red).

Table 2: The Hall: Comparing results from the beginning and end of the monitoring period

Hall	Day 23	Day 52	Day 124	Day 165	Day 253
1	5.0	4.3	3.8	4.1	5.2
2	4.8	4.9	3.9	6.2	4.9
3	5.0	4.6	4.4	5.2	5.5
4	5.0	5.2	4.9	5.1	5.7
5	5.0	5.1	4.8	5.1	5.0
6	4.8	4.7	4.9	5.0	5.1
7	4.9	4.9	4.9	4.5	5.3
8	4.7	3.6	4.7	3.4	5.6
9	4.9	4.2	3.4	3.7	3.5
10	4.8	3.6	3.5	3.8	3.7
11	32.7	31.2	35.1	-	32.6
12	35	28.6	34.7	24.1	38.4
13	31.7	26.4	22.3	19.7	29.1
14	34.3	22.1	18.9	-	26.7
15	27.9	29.6	17.2	19.6	26.3
16	34.6	41.3	24.3	39.8	26.7
17	36.1	29.2	28.3	-	28.1
18	35.2	25.6	25.6	28.5	32.6
19	34	33.1	30	-	35.7
20	35.1	30.6	24.7	-	27.4

The mean of the meter readings taken from the floor flag stones (Hall 1–10) on Day 23 was 4.9 ± 0.11. After 230 days using 6 -8 dehumidifiers the mean was 4.9 ± 0.76.

Wall measurements taken from brick (apparently 1 ft above the floor according to the data sheets) are much higher and may be 'wood moisture equivalents'. The starting mean (Hall 11–20) was 33.6 ± 2.50 and by Day 230 it had dropped to 30.3 ± 4.17. If this does represent moisture then the drop would be insignificant.

4 DRY READINGS AND SUBSTRATE VARIABILITY

One problem that became apparent in judging drying was the lack of 'dry data' when the meter has a comparative scale from 0–100. There is no level to aim for when a dry reading is unknown.

The opportunity arose to undertake a further investigation on the 17th April 2017. This was nearly 14 months after the flood and the building was in full use. We have taken this as the basic level of dryness before the flood. The drying company's methodology was repeated using the same model of moisture meter as they used.

It became apparent that for some reason the drying company had divided capacitance readings on their comparative scale by 10 and we have done the same.

4.1 The Chapel

The monitoring locations shown in Figure 1 are on the tiled floor, but the sketch only shows approximate locations and so the potential effect of material variation must be ascertained. Small differences in readings between monitoring visits may just be the results of measuring different tiles. We therefore measured three positions on each tile (intervals in a line across the width) in four equally spaced rows of tiles across the chapel floor (see Figure 14). The results are shown in Table 3.

Table 3: The Chapel: Results									
	a	b	c	d	e	f	g	h	Mean (sd)
A1	5.4 5.7 6.5	5.4 6.0 4.9	5.4 6.4 6.3	5.8 6.3 5.5	5.6 5.0 3.6	4.6 6.1 6.2	5.7 6.4 6.5	6.0 5.9 5.1	5.7 ± 0.72 (n = 24)
A8	5.5 5.6 4.1	6.0 6.2 6.0	6.4 6.2 6.1	6.5 6.1 5.6	4.7 5.9 4.8	5.5 5.3 4.8	3.9 5.0 6.1	5.1 5.9 5.4	5.5 ± 0.70 (n = 24)
A16	5.9 6.0 6.3	5.0 4.8 4.8	3.3 2.9 3.9	4.8 3.3 4.2	6.2 6.5 6.3	5.9 6.0 4.9	6.2 6.0 6.0	5.5 5.4 5.9	5.3 ± 1.11 (n = 24)
A24	6.0 5.8 5.5	6.1 6.0 6.5	4.1 3.6 4.4	5.1 5.2 5.6	6.7 6.6 6.7	6.6 6.7 6.4	6.1 6.5 6.7	6.9 6.6 6.9	5.9 ± 0.90 (n = 24)
Mean (sd)	5.7 ± 0.60 (n= 12)	5.6 ± 0.62 (n= 12)	4.9 ± 1.35 (n= 12	5.3 ± 0.90 (n= 12)	5.7 ± 0.99 (n= 12)	5.8 ± 0.72 (n= 12)	5.8 ± 0.74 (n= 12)	5.9 ± 0.61 (n= 12)	

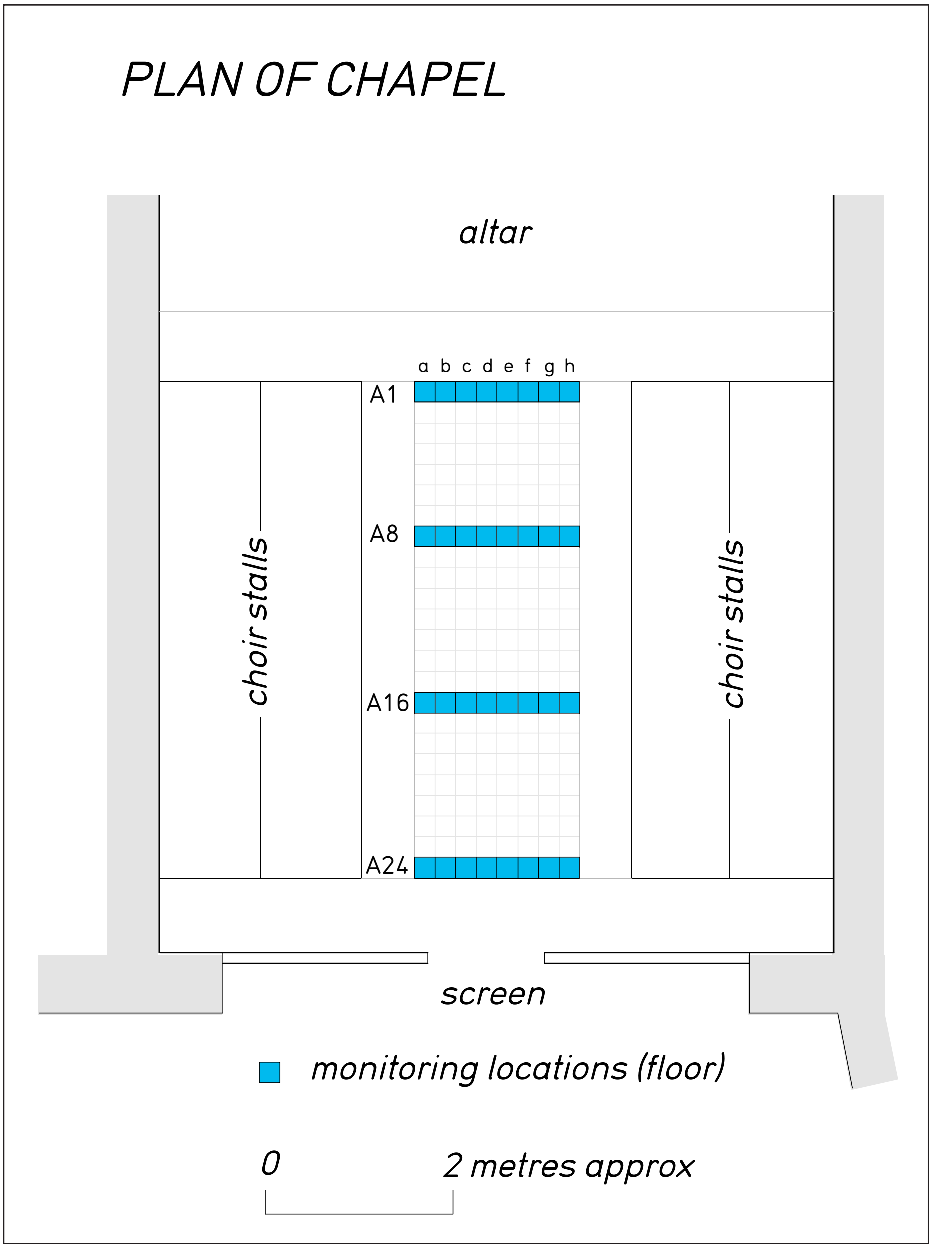


Figure 14: Measuring locations on the tile floor of the chapel.

Some individual tiles (eg A1a & A8g) give variable readings depending on surface coarseness, but the means from the width of the chapel (a to h) and its length (A1 –A24) are so similar that moisture distribution can be considered uniform with no gradients. The mean for the entire data set was 5.6 ± 0.88 (n = 96). The drying company results may be compared with this statistic, which is generally a little higher than the readings they obtained. Some of this may be basic instrument variation.

If there is no potential damp gradient across the floor then the mean values from the drying company's monitoring data for each visit can be directly compared. This is done in the following graph.

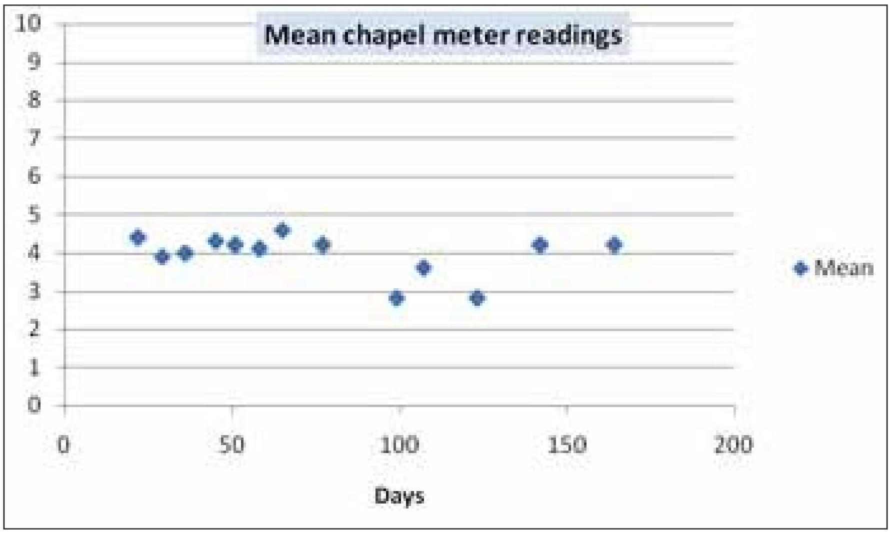


Figure 15: The Chapel: Mean meter readings.

Figure 16: Readings were affected by surface coarseness.

The table and the graph show that the tiles were dry at the time the first set of readings were taken. The fan had a surface effect and dropped the readings a little around day 120, but they increased again when the fan was removed.

4.2 The Hall

The Hall floor was similarly investigated, taking three readings each floor slab in five rows across the width of the building. The outer slabs were 1m from each side wall and the central reading was mid-way between columns. Readings were very similar and are not tabulated here. There was no gradation across the Hall or from end to end. The dry mean reading was 6.5 ± 0.31, which is again a little higher than the readings obtained by the drying company.

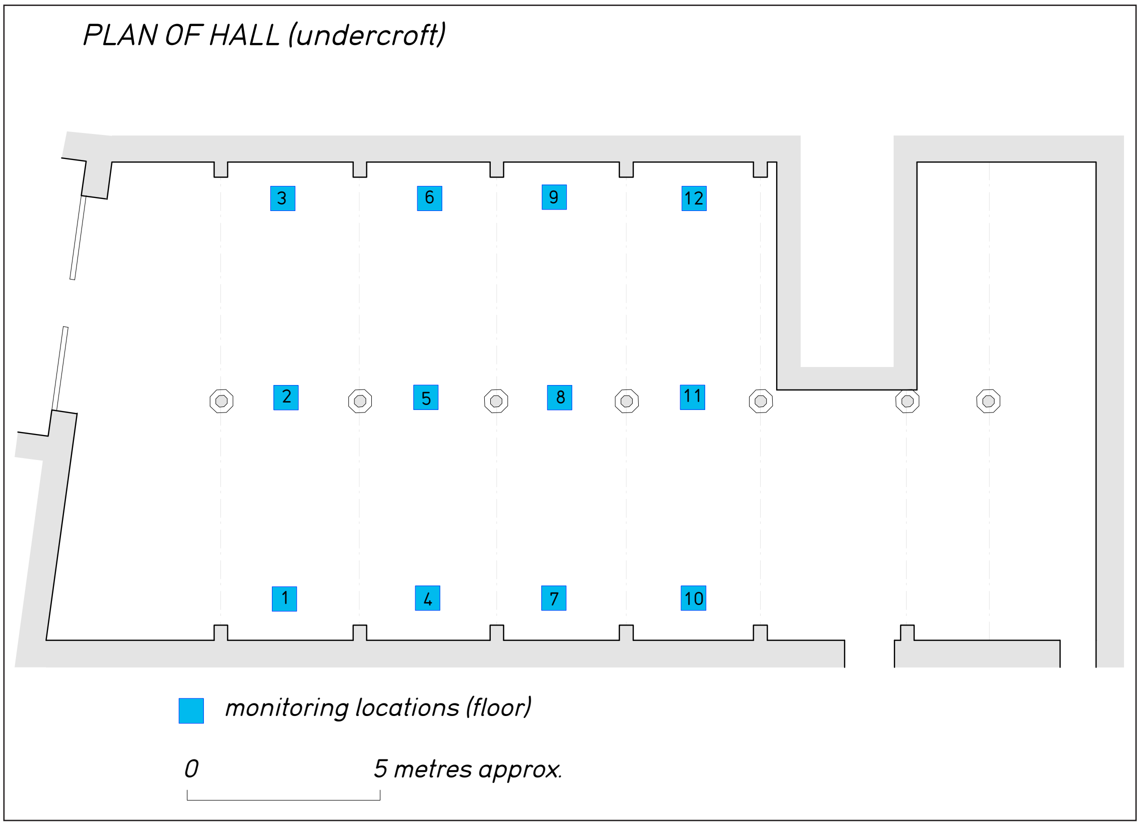


Figure 17: Plan of the Hall (undercroft).

The graph of these mean values is so similar in outline to the graph from the chapel that there may be meter user variation at each visit - the monitoring sheets bear the initials eleven different surveyors. We found that the capacitance readings obtained depended on the pressure applied to the meter. We positioned the meter under its own weight, but if it was held at the surface or held down then there was a significant reduction or increase in the readings. Method standardisation is evidently essential.

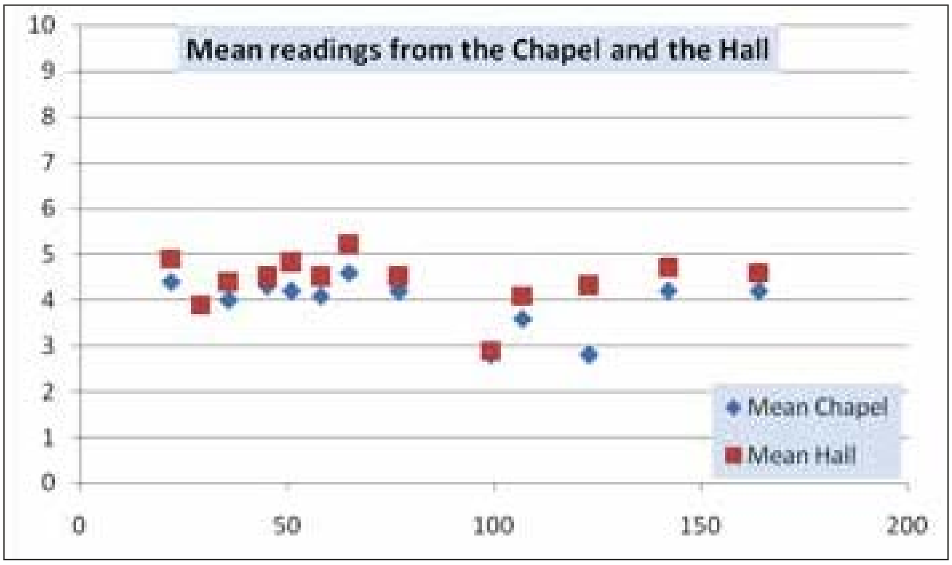


Figure 18: The Chapel and the Hall: Mean meter readings.

Readings from the Hall walls were resistance readings taken with the meter fitted with electrodes. The capacitance sensors were broad and spaced some distance apart so that this would not be an easy instrument to use on an uneven surface. The resistance readings were provided as a wood moisture equivalent, but there was so much variation, particularly between stone surfaces (which barely gave a reading because the electrodes could not penetrate) and the mortar joints that the method could not be used for monitoring with any appreciable accuracy.

5 DISCUSSION

The results from the Chapel would indicate that, whilst dryers and fans may be capable of lowering surface moisture contents and maintaining these until no more water migrates towards the surface, the effect can only be evaluated by switching off the equipment for a while and allowing everything to equilibrate. If this is not done then a surface effect may lead to the erroneous conclusion that the structure is dry. There is also the problem that readings from before the flood are not available. The consequence, if there is not a pause in the procedure, is that expensive equipment could be used for a very long period in the pursuit of a drying point that is never reached. In this example, it appears that the drying point had already been reached, before the readings were started.

The results from the adjoining Hall show no significant drop in readings that would lead to the belief that the structure was drying. This may have been the reason why the dehumidifiers were used for so many months. Some of the problem may be that the meters, used in resistance mode, gave highly variable readings in the stone walls, whilst in capacitance mode on the floor slabs the results depended on how the meter was used. The apparent drop in the Hall and Chapel floor readings on day 100 coincided with a different surveyor using a meter with a different serial number. There would also have been substrate variation at each location because there were no fixed measuring points.

6 CONCLUSIONS

The drying company data does not provide any evidence that the use of up to nine dehumidifiers and one air blower had any significant drying effect on the flagstone floors and stone/brick walls over a 253 day drying regime. It seems likely that the building fabric had significantly dried before monitoring commenced. Timber performed better because this equilibrates with relative humidity, which the dehumidifiers could control and the meters could provide an actual rather than comparative reading.

This analysis does indicate the need to turn off the equipment after a few days and allow the building to equilibrate so that the moisture being drawn from the structure can be evaluated. It also suggests that the method used to take the readings must be standardised.

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