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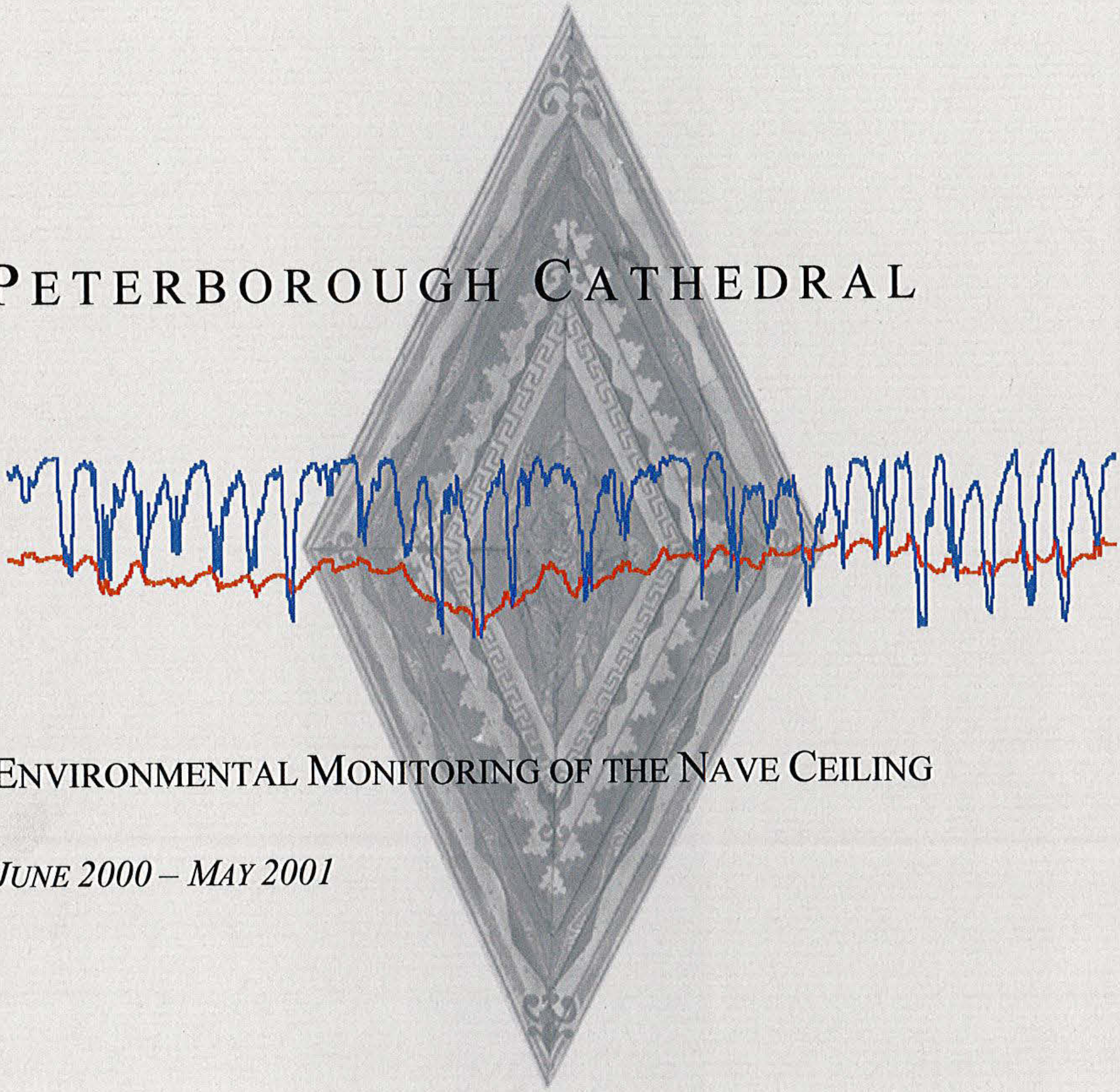

PETERBOROUGH CATHEDRAL

ENVIRONMENTAL MONITORING OF THE NAVE CEILING

JUNE 2000 – MAY 2001

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CONTENTS

Report No: PTB01.2

Date: 27th July 2001

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Acknowledgements

I would like to express my thanks to the Dean and Chapter of Peterborough Cathedral and in particular to the head verger, Nick Drewett and Keith Nelson, for their help and co-operation throughout the project. I am also grateful to the cathedral architect, Julian Limentani and to the other members of the project team for their advice on many aspects of the monitoring programme. In addition, I would like to thank those at English Heritage who have contributed to the programme, in particular Barry Knight and Adrian Heritage. I am also indebted to Richard Lithgow and Hugh Harrison for information regarding the conservation programme. Aspects of the system of environmental monitoring employed for the survey were developed at the Courtauld Institute of Art, Conservation of Wall Paintings Department and I would like to express my thanks for their generous advice and support in this area.

1.0 SUMMARY

The data recorded during the current period confirmed the findings of the previous year, showing that there was a major variation in the environmental conditions above and below the painted ceiling. Although this could be observed throughout the year it was most apparent in the winter months when the ventilation in the body of the cathedral was at its lowest and the Gurney stove were running 24 hours a day. The roof space, by contrast, is heavily ventilated throughout the year and the conditions tended to follow the external microclimate closely. In addition, the installation of a new probe early in 2000, allowed the effect of sunlight falling on the back of the panels to be more closely investigated. This demonstrated not only that the direct solar heating caused extreme fluctuations in the environmental conditions, but also that the additional ventilation, caused by the vents around the windows, had a quantifiable impact on the microclimate in its immediate vicinity.

The question of whether the recorded conditions caused a dimensional response in the ceiling boards (thereby increasing the risk to the paint layer) was also re-examined. Experimental data demonstrates that the period for which boards of these dimensions would need to be exposed to change in relative humidity, in order to elicit a dimensional response, would need to be in the order of 20 to 30 days. Therefore, although the effects of direct solar heating were extreme, they were relatively short lived and would be unlikely to cause significant movement in the boards. In other words there is a significant 'margin or error' for boards such as these, within which very high fluctuations in environmental conditions may occur, without remaining for long enough for the board to equilibrate and thus suffer any significant dimensional change.

The data was then analysed to show the temperature and humidity gradients between the upper and lower sides of the ceiling, throughout the year. This demonstrated that the relative humidity in the roof space remained significantly above that on the lower side of the ceiling for a period of up to seven months. However, despite the possibility that this may cause a minor concave deformation of the board, there was no evidence of deterioration of the paint layer. It appeared possible that this was due to the compressive strength of the paint layer which is likely to be relatively high and may be able to absorb this level of deformation. In order to quantify the true level of any dimensional response, direct measurements are to be undertaken during the next twelve months. In addition, it is hoped that an infra red thermography survey can be used to establish the large scale thermal patterns over the ceiling as a whole.

2.0 INTRODUCTION

The early 13th century painted ceiling at Peterborough Cathedral is currently undergoing a major programme of research and conservation. As part of this work, a detailed environmental survey is being undertaken in order to assess the effect of the microclimate on the condition of the ceiling. Until 1999, environmental monitoring was undertaken by English Heritage. In June 1999, a new dedicated monitoring system was installed in order to allow the continuation of the established programme, as well as allowing the expansion of the survey to provide further diagnostic information on some of the environmental phenomena which had been observed.

Figure 1. Detail of psaltery player in rows 25 and 26 (Photo: PLP 2001)

The first report on the environmental survey was presented in August 2000.[1] The data collected up to this point showed there were major variations in the conditions above and below the ceiling, in particular in the winter months when the body of the cathedral is artificially heated and the ventilation levels are at their lowest. Temperature and humidity gradients across the painted ceiling boards were found to reach very high levels, resulting in significant physical stress. In addition, the insertion of roof lights in the 19th century meant that certain areas of the upper part of the ceiling were subjected to periods of direct sunlight which caused huge fluctuations in temperature and humidity levels. However, despite the clearly unfavourable

[1] Tobit Curteis Associates, *Peterborough Cathedral, Environmental Monitoring of the Nave Ceiling*, March 1998-May 2000

conditions, there did not appear to be significant deterioration of the paint layer of the type which might be associated with the dimensional response of the boards to the microclimatic fluctuations. In order to better understand this phenomenon a number of areas of further investigations were proposed. The results of this work as well as the analysis of the current period of data are discussed in sections 4 and 5 of the report.

The current report, which covers the period from June 2000 - May 2001 is intended to be viewed as an appendix to the 2000 report and should be read in conjunction with it. In order to avoid the reproduction of large sections of the previous report, much of the background and methodological information is not included in the current report. It is the intention to produce a comprehensive report on all aspects of the monitoring programme upon completion of the project.

3.0 EQUIPMENT AND PROGRAMME

3.1 MONITORING METHOD AND DATA PRESENTATION

Thermohygrometric parameters measured at the internal probe groups were relative humidity (RH) ambient temperature (AT), and surface temperature (ST). The external probe, recorded RH and AT only. Thermohygrometric parameters calculated during data analysis were absolute humidity (AH) partial vapour pressure (PP), saturation vapour pressure (Ps) and dew point temperature (DPT).

In order to compare the conditions of the roof space and the body of the cathedral, probes 1 and 2 were situated in areas of shade in bay 36 III on the upper and lower sides of the ceiling.[2] To assess the effect of the solar radiation on the back of the ceiling from the roof lights, probe clusters 3 and 5 were located in areas in Bay 33 IV which were regularly exposed to direct sunlight. An external probe was situated on the north side of the nave roof in order to provide control data. Data was logged on all channels at 30 minute intervals.

Internal RH/AT probes were suspended in front of the ceiling surface from available fixing points. Where internal probes were in direct sunlight (i.e. probe 5), they were shielded behind paper screens. ST probes were attached to the surface using Japanese tissue strips adhered with Paraloid B72. The probe was then insulated using a small block of polystyrene. The external RH/AT probe was protected by a Stevenson screen.

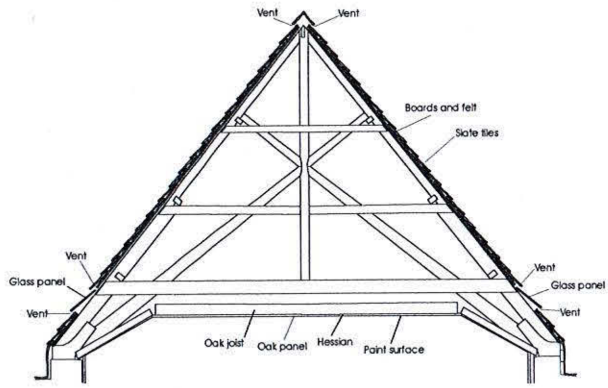

Figure 2. Diagram showing the construction of the ceiling and roof.

The monitoring was carried out using an Eltek 1000RX1 telemetric logging system with TX7 transmitters. RH and AT were measured using Vaisala HMG Z-1 combined probes and ST was measured using EU-U-V2 thermistors.[3] The system was connected via a modem to a standard BT telephone line to allow remote interrogation. Downloading and export of data was carried out using Eltek Darca 1.1.2 software and processing and charting was undertaken with Microsoft Excel 97.

3.2 PROGRAMME

The environmental monitoring has taken place in three distinct stages. Between January 1995 and June 1996, periodic monitoring was undertaken by the English Heritage Mechanical and Engineering Department. Data was supplied as written reports with some illustrative charts. No electronic data was made available. Following this, from March 1998 – June 1999 a second phase of monitoring was undertaken by the English Heritage Ancient Monuments Laboratory. Unprocessed electronic data for the full period was supplied to Tobit Curteis Associates. In June 1999, a new monitoring system was installed by Tobit Curteis Associates. This was intended to replicate the existing system, so that an unbroken run of data would exist from March 1998 to the

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[2] These probes were in identical positions to the English Heritage AML probes so that a continual run of data could be achieved.

[3] The published accuracy levels for the probes are as follows: HMG Z-1 RH +/- 3%, AT+/- 0.3°C. EU-U-V2, ST +/- 0.2°C.

present. The new system also allowed the addition of further probes in order to allow other areas to be monitored.[4]

4.0 Environmental Monitoring

4.1 Artificial Influences on the Microclimate

As was discussed in the previous report, the principal artificial influence on the microclimate is the heating system within the body of the cathedral.

Prior to mid 19th century there was no significant heating in the cathedral. However, in the late 1860s, following the introduction of gas lighting, four coke fired Gurney stoves were installed in the nave, two in the transepts and two in the chancel. In 1963, the coke fired Gurney stoves in the nave and chancel, were upgraded to run on oil. In 1993 they were converted for use with gas and had thermal insulation blocks added in order to increase their long term heat retention, effectively causing them to act as storage heaters.[5]

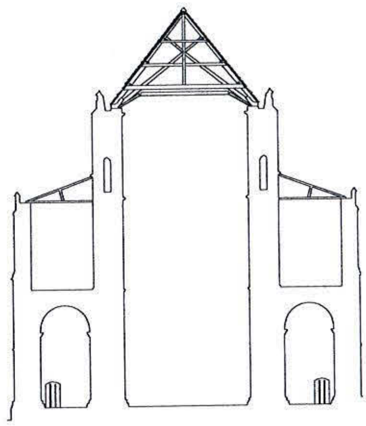

Figure 3. Diagram showing the location of the Gurney stoves.

The heaters are in use from approximately November until May. During the period that the heaters are active, they are run for twenty four hours per day usually at the full setting, although the half setting is occasionally used. The north east nave heater is not usually used, unless a particularly cold period occurs. Of the seven remaining units, all are usually used during the winter, although if the weather is mild, some are occasionally turned off.[6]

Another significant influence on the microclimate is the deliberate ventilation of the body of the cathedral and the roof space. However, as the use of deliberate ventilation is in the cathedral itself is fairly restricted, the effects are limited. Of far more significance is the ventilation in the roof space which is very extensive. As a result the microclimate in the roof space follows the external conditions far more closely than in the cathedral itself.

4.2 Monitoring Results

Although the external conditions in 2000-2001 were marginally cooler and drier than in the preceding twelve months, the results of the current period of monitoring confirmed what had been observed in the 2000 report: principally that there is a very significant variation between the conditions on the upper and lower side of the ceiling.

On the lower side of the ceiling the annual average values for RH and AT were 56.1% and 17.4°C (in the shade). The extremes for RH were 76% and 35% while those for AT were 11°C and 23°C. Summer averages were 61.8% and 19.8°C with diurnal fluctuations of 8% and 3°C. Winter averages were 50.4% and 15.4°C with diurnal fluctuations of 3.5% and 1.5°C.[7]

The equivalent annual conditions in the roof space were 65.2% and 14°C. Extremes for RH were 100% and 43% while those for AT were 32°C and 1.5°C. Summer averages were 61.3% and 19.4°C with diurnal fluctuations of 17% and 5°C. Winter averages were 67.4% and 9.7°C with diurnal fluctuations of 5% and 3°C.

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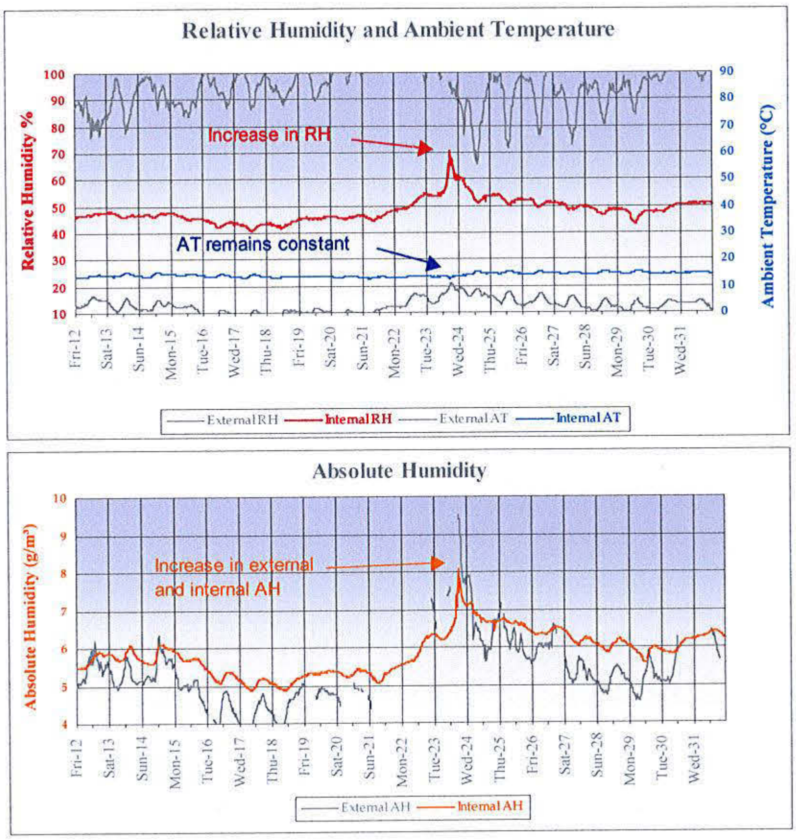
[4] Some sections of data were lost during the programme initial stage of the new programme, due to electronic malfunctions.

[5] Anecdotal evidence suggests that the efficiency of the stoves has been increased since the introduction of the gas. However, there is also anecdotal evidence that the stoves used to glow red hot in the 19th century, so it is in fact possible that the heating was more extreme in the past.

[6] *Pers Comm.* Nick Drewett

[7] Diurnal fluctuations are based on visual estimates.

As was the case in previous years, there was a very large variation in the level of buffering between the external conditions and those in the body of the cathedral, and the external conditions and those in the roof space. In the cathedral itself, the influence of the external conditions was relatively low, in particular in the winter when air exchange (as a result of deliberate ventilation) was at its lowest, and the airspace was artificially heated on a twenty four hour basis by the Gurney stoves. During this period the diurnal fluctuations of the AT were extremely low at approximately 1.5°C. The influence of the AT on the RH was therefore very limited and for much of the period the RH remained very stable. However, on occasions, there were sharp variations in the RH resulting from significant fluctuations in the AH. In almost all cases, this was due to the influence of the external AH, which was itself subject to external temperature fluctuations. Therefore although the external AT had very little influence on the internal AT, it had an indirect but very significant influence on the internal AH and therefore the RH.



Charts 1 & 2. Conditions at probe 1 in January 2001. The increase in external absolute humidity causes an increase in internal absolute humidity resulting in a sharp increase in internal relative humidity, despite the fact that the internal temperature remains fairly constant throughout.

The contrast with the conditions in the roof space was extremely marked. Due to the very high level of air exchange and the low level of thermal insulation, the roof space conditions followed the external conditions relatively closely. In general, the internal AT was marginally higher than the external value (particularly in the winter) and while the internal RH fell to the same low values as it's external counterpart, it tended not to increase to the same level. Nevertheless the level of diurnal fluctuation in the roof space was far higher that in the body of the cathedral.

Although the fluctuations were most significant in the summer months, they could also reach high levels in the winter. However, during the winter months, the effect of the thermal insulation in the roof was at its most obvious, preventing the AT from falling to the same level as the external conditions. A comparison of the AT and ST on the under side of the ceiling showed that the ST was 1 or 2°C lower than the AT as a result of the cooling effect of the microclimate above the boards. By the same measure, the ST in the roof space was 1 or 2°C higher than the AT. As a result the heating in the church was also heating the airspace in the roof, albeit to a far lower level.

The difference between the conditions in the roof space and the body of the cathedral were less marked in the summer months. This is partly due to the fact that the west doors are kept open for much of the summer, resulting in greater ventilation in the body of the cathedral. Therefore, the direct influence of the external conditions is more similar to the roof space (although not of the same level). Also the influence of artificial heating is removed and so the main effect on both the internal and roof space AT is the external AT.

As was the case in the previous year, the effects of direct sunlight on the back of the panels was extremely dramatic, with sharp increase in ST and AT with consequent, and equally sharp, decreases in RH. It was interesting to note that in August 2000, although increases in surface temperature of up to 18°C were seen at probe 3 on the lower side of the ceiling, increases of only 8°C were seen on the upper side of the ceiling. However, by late September the temperature increases were similar. This appears to be due to the fact that the probes are not directly above each other and the angle of the sun is such that probe 5 is not subjected to direct noon sunlight until some weeks after probe 3. In September and October when both probes were receiving sunlight, the peak temperatures at approximately noon were almost identical. However, during the night, the surface temperature in the roof space dropped to several degrees below the temperature on the under side of the boards, presumably as a result of the ventilation with cool external air. During the periods of greatest solar heating, surface temperatures of up to 38°C were reached in the roof space with a diurnal fluctuation of up to 22°C. In these periods the RH dropped to as low as 25% with a diurnal fluctuation of up to 50%.

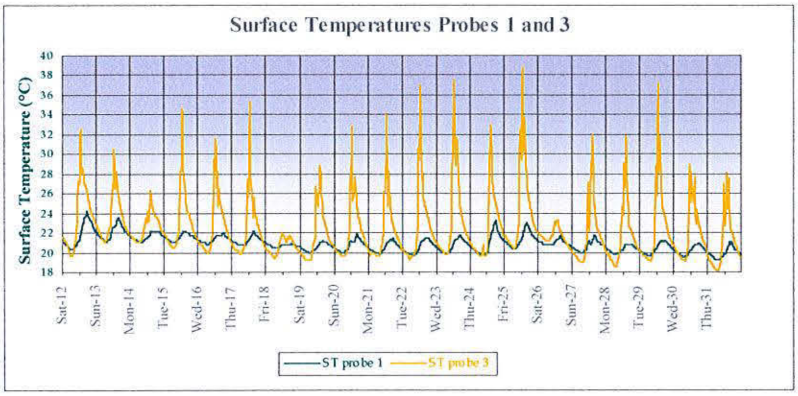


Chart 3. Surface temperatures at probes 1 and 3 in August 2000. The effect of direct solar radiation on the back of the panels above probe 3 is clearly illustrated by the immense rise in surface temperature compared to that at probe 1.

In order to examine the effect that the temperature and humidity gradients between the upper and lower sides of the ceiling may have, the data for the two most recent years was re-processed and charted to show the differences between the upper and lower values over the whole of the year. This clearly shows that during the period May – September, while there were short term variations in particular parameters, the gradients above and below the ceiling tended to cancel each other out. However, during the period October to April, there was a very significant divergence of conditions with the RH in the roof space remaining significantly and constantly above that in the cathedral. During the same period the ambient and surface temperatures in the roof space were constantly lower than in the body of the cathedral. A comparison of the data in the 1999-2000 programme and the 2000-2001 programme showed precisely the same pattern.

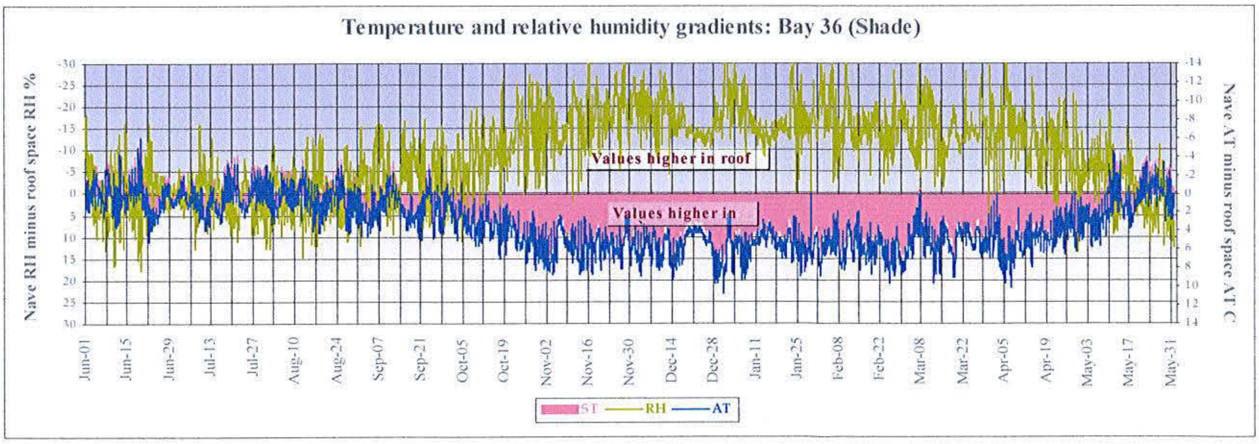


Chart 4. Chart showing the gradients for relative humidity, ambient temperature and surface temperature between probes 1 and two, below and above the ceiling boards. (Full gradient charts for probe 1, 2 , 3 and 5 can be found in section 5 of the report)

A comparison was then made between the conditions in the shade (probes 1 and 2 in bay 36) and in areas subjected to direct sunlight (probes 3 and 5 in bay 33). This showed that although the general pattern was the same the level of variation was greatly reduced. (The effects of periods of direct sunlight creates a slightly more complex image, but the general patterns are clear). The reason for the difference between the areas of sun and shade appears likely to be due to ventilation rather than sunlight. In order to avoid direct sunlight probes 1 and 2 were placed higher in the bay, away from the windows and therefore away from the window vents. As a result, in addition to avoiding direct sunlight, they would also have avoided the level of external air exchange (and consequent cooling) which occurred at probes 3 and 5 during the winter months.

What this discrepancy shows us is not that the conditions differ between bays 33 and 36, but that the conditions between the upper and lower part of row III (and presumably the upper and lower part of row IV) vary due to the levels of ventilation as well as the direct solar heating. The existence of these types of very localised microclimates may well cause variations in the pattern of deterioration across the ceiling as a whole.

An examination of the data for the periods when large services or concerts were taking place showed that the influence on the internal conditions was relatively limited. The precise effect depends to a large extent on the external conditions which often appeared to mask minor effects. However, it appeared that for any a service or concert to have a significant influence on the internal conditions, a congregation of at least 800 was required.

4.0 Discussion and Conclusions

The current data demonstrated the same general patterns which were seen in the previous year, with a high level of buffering between the external conditions and those on the underside of the ceiling, but only a low level of buffering between the exterior and the roof space. During the summer months the gradients above and below the ceiling were less pronounced. However, during the winter, when ventilation in the body of the cathedral was low and the heating was very high, the gradients between the conditions above and below the ceiling were very significant.

In order to address the question of the possible dimensional change in the boards which might be caused by these gradients, the ceiling was examined by Al Brewer who has worked extensively on the response of painted panels to microclimatic variations.[8] He concluded that in order for boards of this size and construction to have any significant dimensional response, the relative humidity on one side of the board would have to remain elevated or depressed for a considerable period of time, possibly between 20 and 30 days. Therefore, the short term fluctuations caused by the sudden heating and cooling associated with direct sunlight and ventilation, although extreme, did not occur for long enough to have a significant impact on the boards. However, seasonal variations in the environmental conditions may be significant enough to cause some level of dimensional response. [9]

The analysis of the data discussed above has now shown that the relative humidity in the roof space remains significantly and constantly above that in the body of the cathedral for a period of up to seven months, while the ambient and surface temperatures during the same period, are lower. This suggests that, in theory, the upper side of the board may expand, causing a slight concave distortion on the front of the board. The higher temperature on the lower side might be expected to cause thermal expansion, but compared to the relative level of hygral expansion this would probably be negligible. The situation would of course be complicated by the fact that one side of the board is coated with oil paint and the other is coated with hessian and glue. However, if we assume that, in theory, this type of distortion could be occurring (in however a limited form) the question remains as to why there is no apparent damage to the paint layer. The answer appears to lie in the compressive as opposed to the tensile strength of the paint layer. Although a paint film such as this has a relatively low tensile strength (i.e. it will break if it is stretched), the compressive strength is relatively high. In other words, if the paint layer is slightly compressed (as would be the case if the ceiling boards distorted in the way described above), it would be able to recover to its original alignment without cracking. Were the distortion of the boards to be of the same level but the other way around (i.e. concave) it is possible that the tensile strength of the paint would be too low, allowing the film to crack. Of course the compressive strength of the paint layer is separate from the strength of adhesion to the

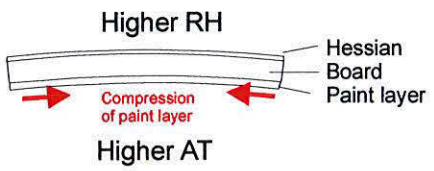


Figure 4. Possible response of the boards to the microclimatic gradients

[8] See Brewer, A. J., 'Practical Aspects of Structural Conservation of Large panel Paintings', *The Structural Conservation of Panel Paintings, Proceedings of a Symposium at the J. Paul Getty Museum*, April 1995, Los Angeles (1998), p.448. Brewer, A.J. 'Effect of selected coatings on moisture sorption of selected wood test panels with regard to common panel painting supports', *Studies in Conservation*, Vol. 36, No.1, London (1991), pp. 9 – 23.

[9] Brewer, J.A., *Observations on Wood Effects for the Nave Ceiling of Peterborough Cathedral*, November 2000

ground layer and board, and if the concave distortion were too great, the paint layer might delaminate causing areas of 'tenting'.

While this explanation for the lack of damage to the paint layer is consistent with the available data, there is still a question as to whether some movement is occurring and is being absorbed by the paint layer, or whether, due to factors such as the hessian, the paint layer and the levels and periods of the thermodynamic gradients, no significant movement is taking place. In order to clarify this issue, proposals were made in 2000 for undertaking direct measurement of the boards using linear transducers in conjunction with the present monitoring system. In this way it would be possible to correlate any detected movement with the relevant environmental parameter. For a number of reasons this has proved more complex than was initially anticipated. However, it is now hoped that it will be possible to install the measuring system later this year.

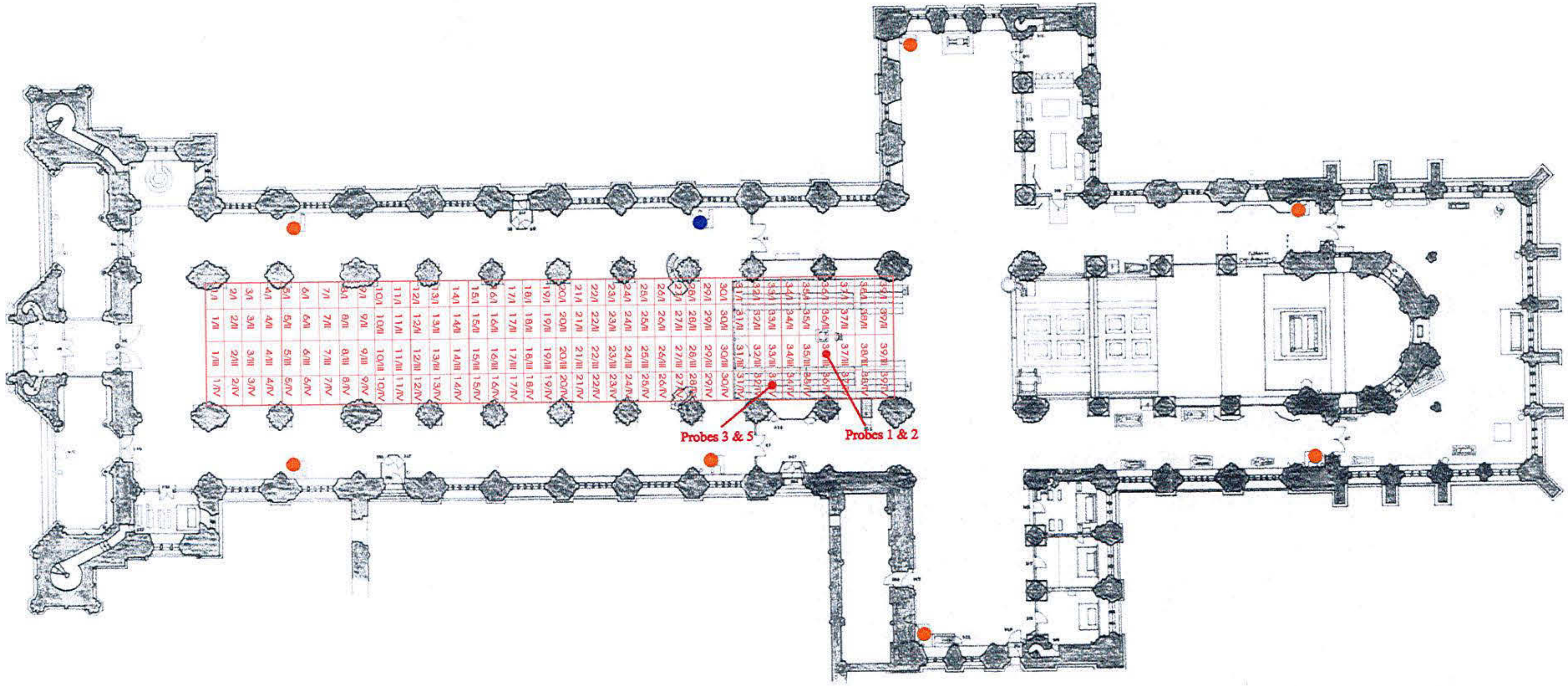
In conjunction with this, it has been proposed that an infra red thermography survey is carried out on one section of the ceiling. While the present monitoring system provides highly accurate data for temperature conditions at specific points, it is not a practical system for providing information on the thermal patterns over large areas of the ceiling. Carefully timed infra red thermography should provide the information necessary to make an assessment of which areas of the ceiling are likely to be subjected to the most extreme gradients and are likely to suffer the most significant (although still minor) levels of movement.

Although it appears that the effects of direct sunlight on the back of the panels are not causing significant movement, they are likely to have a deleterious effect on the hessian backing as well as any other photosensitive materials. As the primary reason for the insertion of the windows (the disruption of the reproductive cycle of the deathwatch beetle) has now been shown to be invalid, it has been decided that the windows are to be covered over. It is understood that this is likely to take place later this year.

The results of the environmental investigations undertaken so far suggest that, with the current conditions, the dynamic response of the individual boards is likely to be very limited. If this is indeed proved to be the case, then it can be surmised that the level of cumulative movement across the roof as a whole will be similarly small, particularly considering the relatively loose way in which the boards are attached to each other. Nevertheless, although the indications are that the current level of risk is low, it is an area which should be monitored over the longer term. The introduction of hew heating and ventilation systems in the church, changes to ventilation and insulation in the roof space as well as the deterioration of the hessian, will all have an impact on the long term stability of the ceiling. Therefore, before any future changes are made, the impact on the microclimate surrounding the ceiling should be carefully considered.

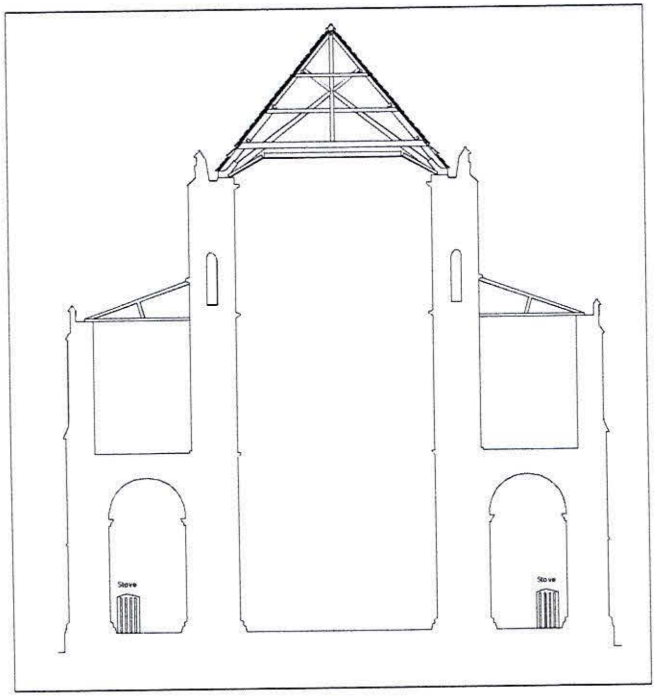
CHARTS & DIAGRAMS

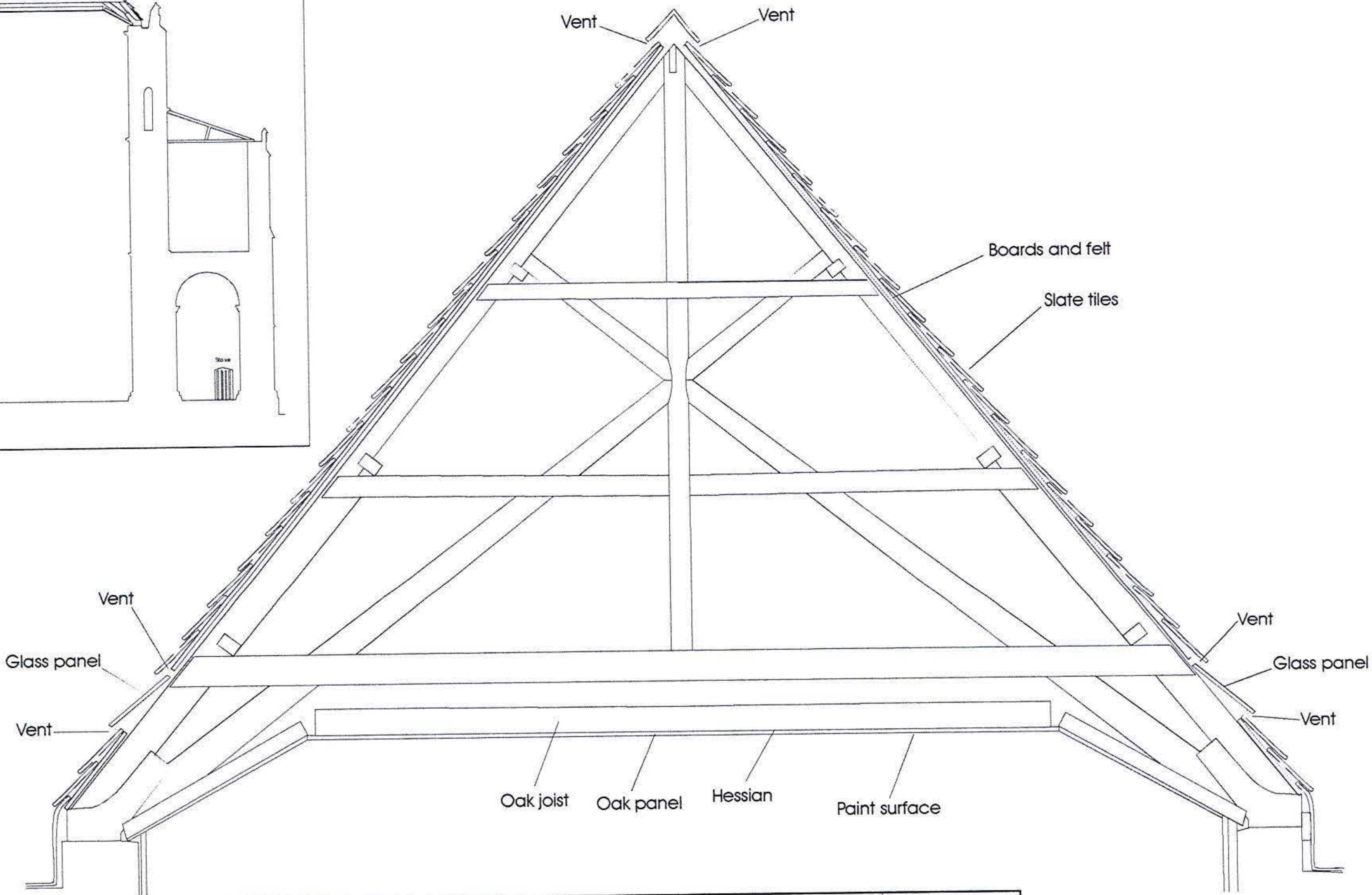
DIAGRAM 1



SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 10m 20m 30m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2001	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

DIAGRAM 2





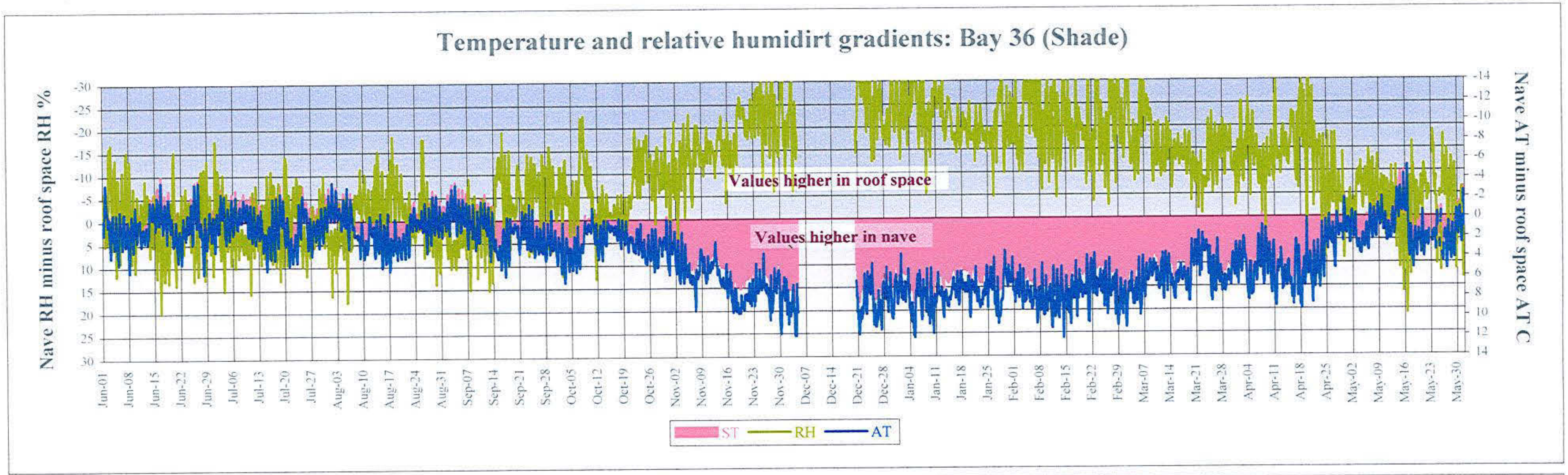
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 1m 2m 3m
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ

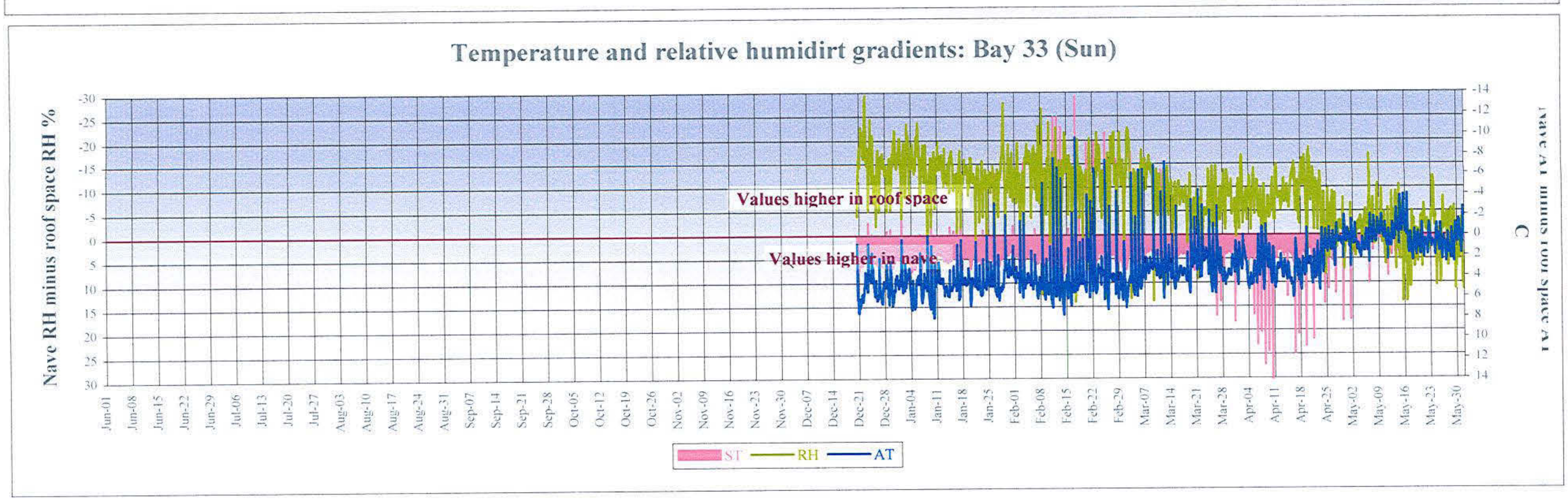
COMPARATIVE CHARTS

Peterborough Cathedral Nave Ceiling

June 1999 - May 2000

Temperature and Relative Humidity gradients





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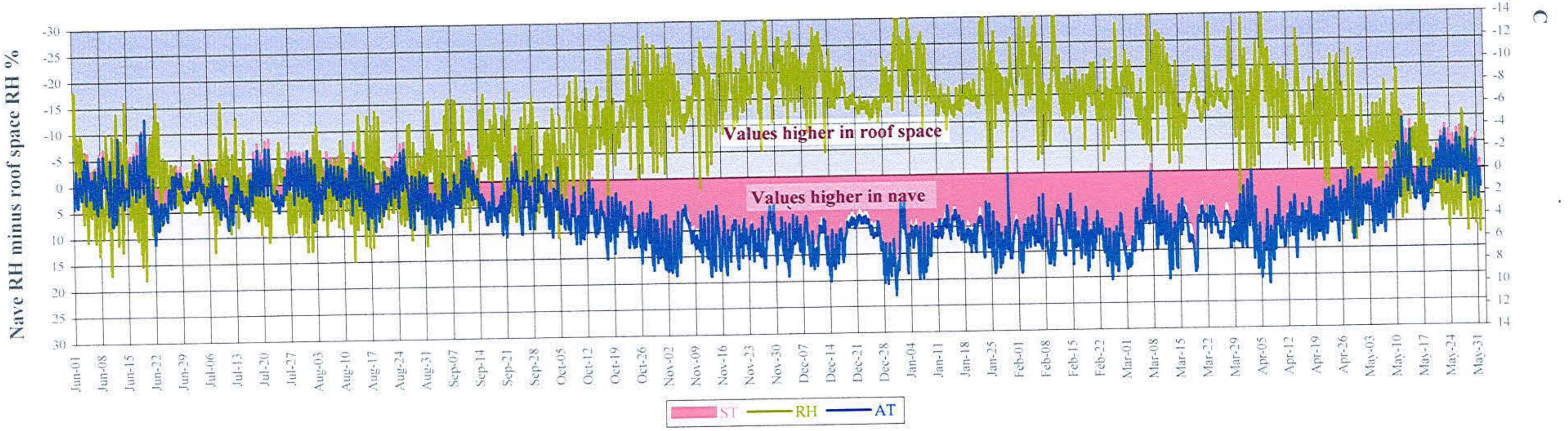
Peterborough Cathedral Nave Ceiling

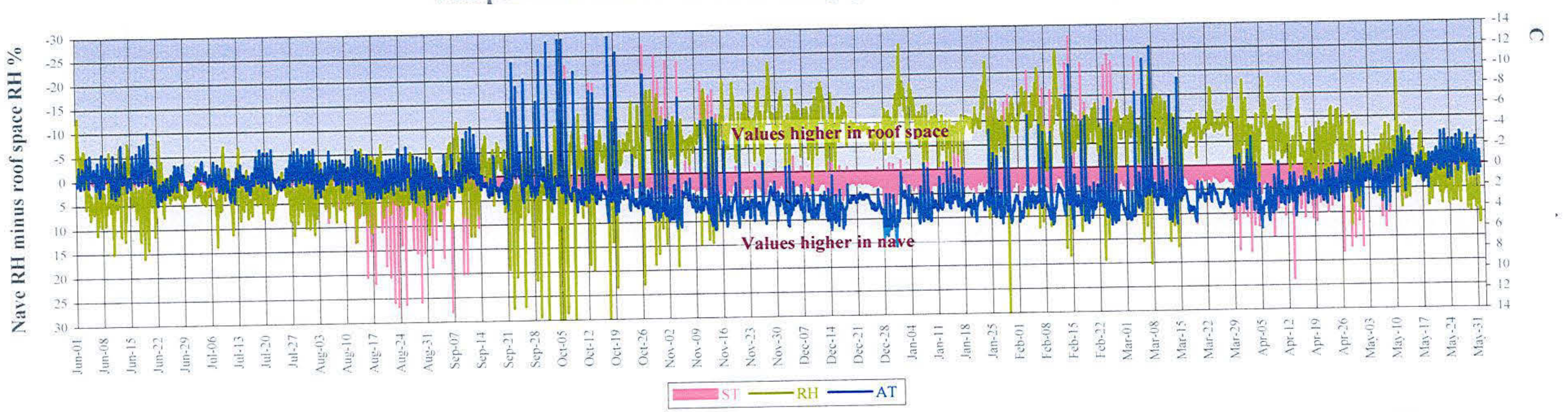
Temperature and Relative Humidity gradients

June 1999 - May 2000

Temperature and relative humidity gradients: Bay 36 (Shade)

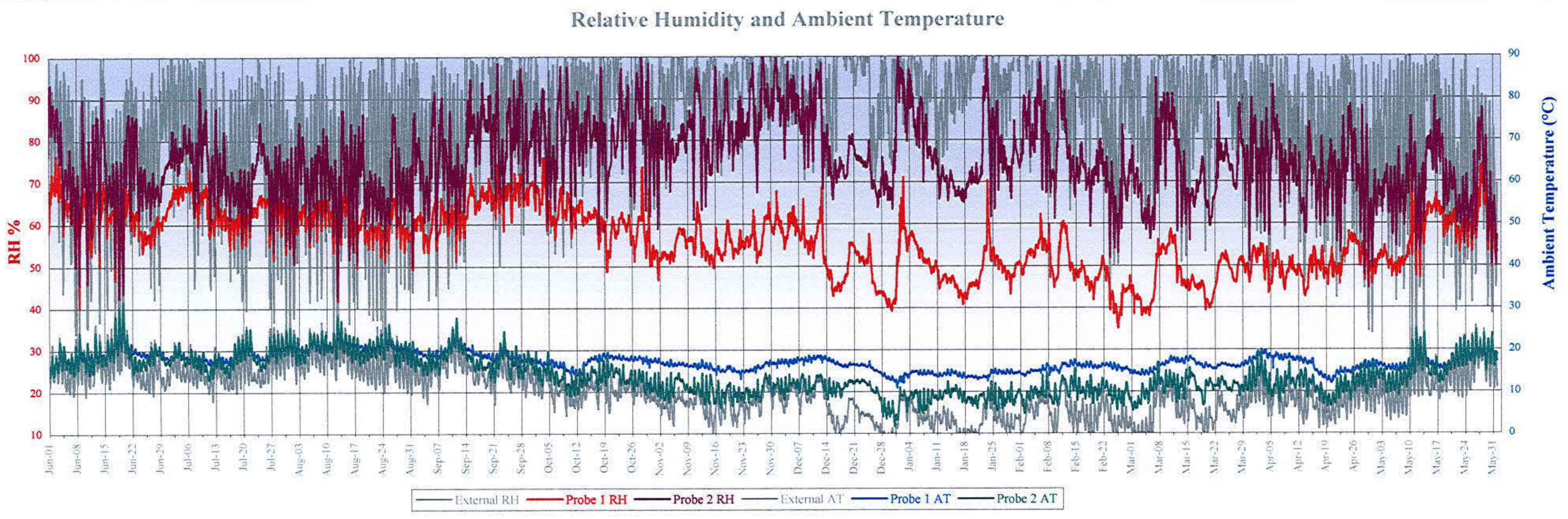


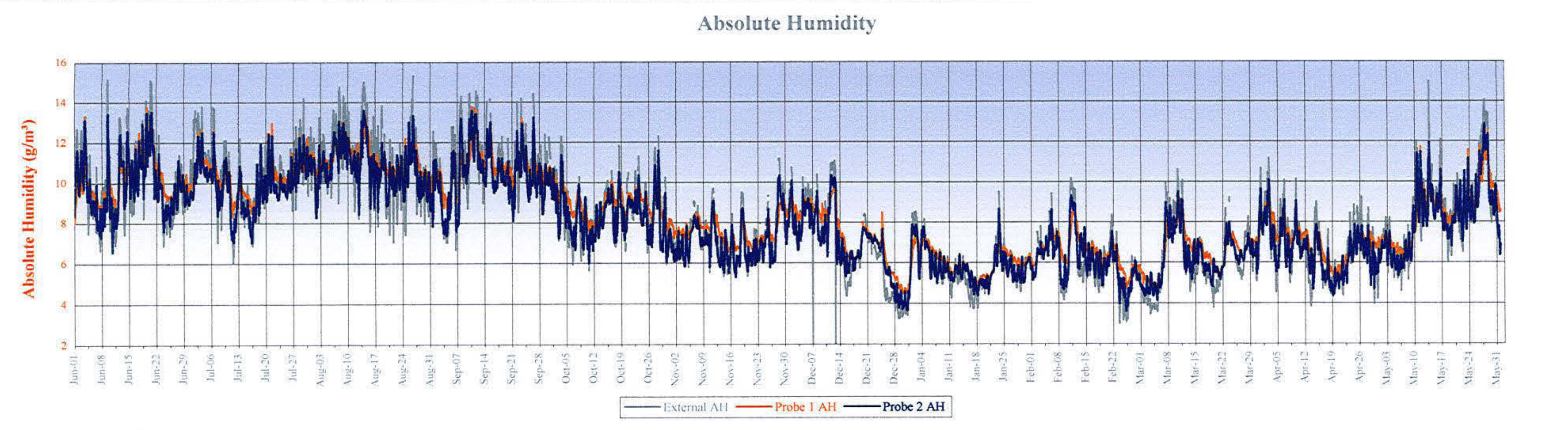
Temperature and relative humidity gradients: Bay 33 (Sun)



Peterborough Cathedral Nave Ceiling

Probe 1: Bay 36 III lower side & Probe 2: Bay 36 III upper side (shade)

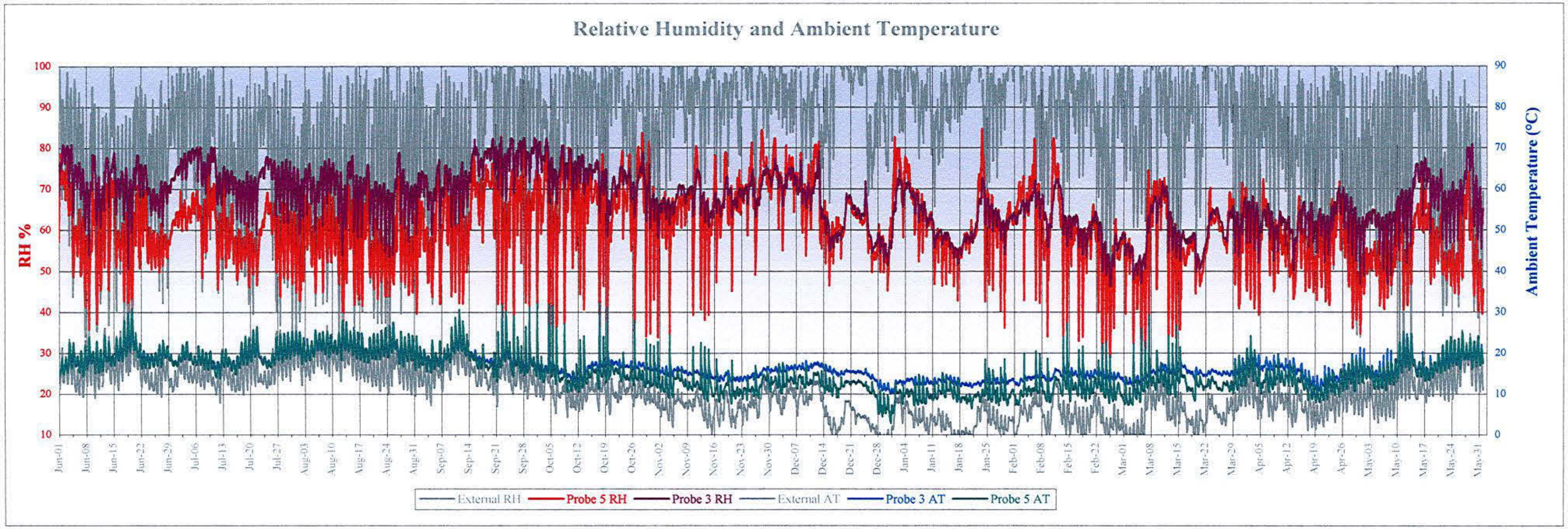


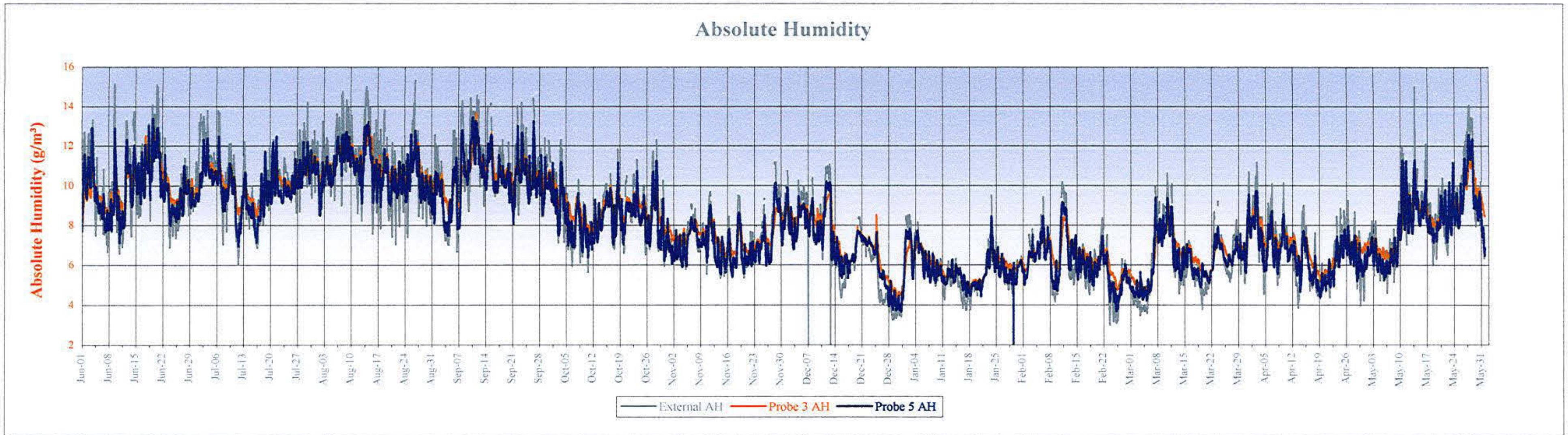


Peterborough Cathedral Nave Ceiling

June 2000 - May 2001

Probe 3: Bay 33 IV lower side & Probe 5: Bay 33 IV upper side (sun)

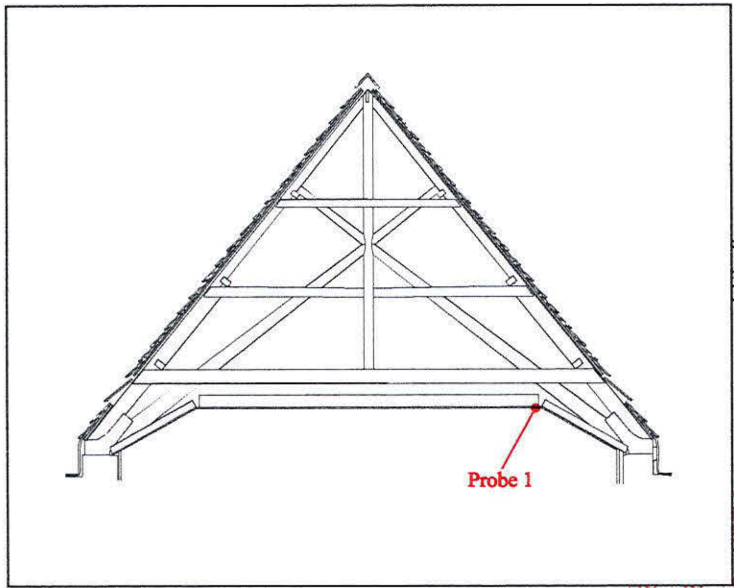


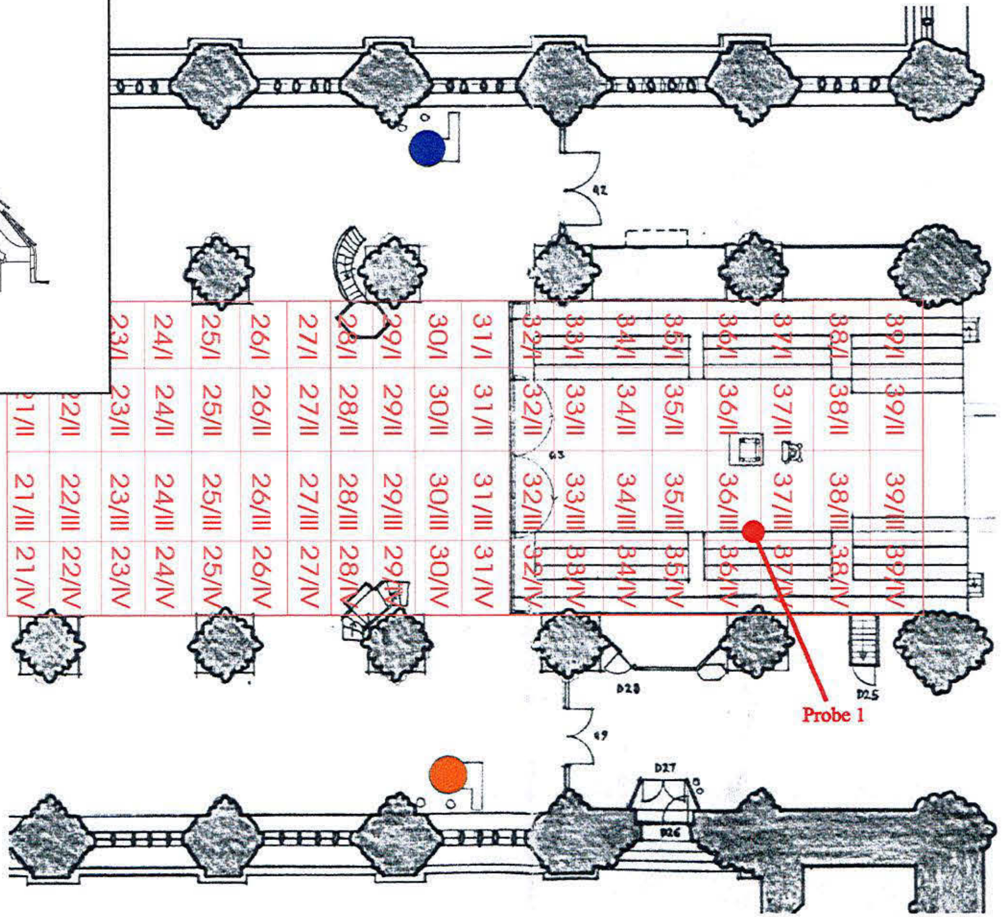


Probe 1

Bay 36 III lower side (Shade)

Diagram 3



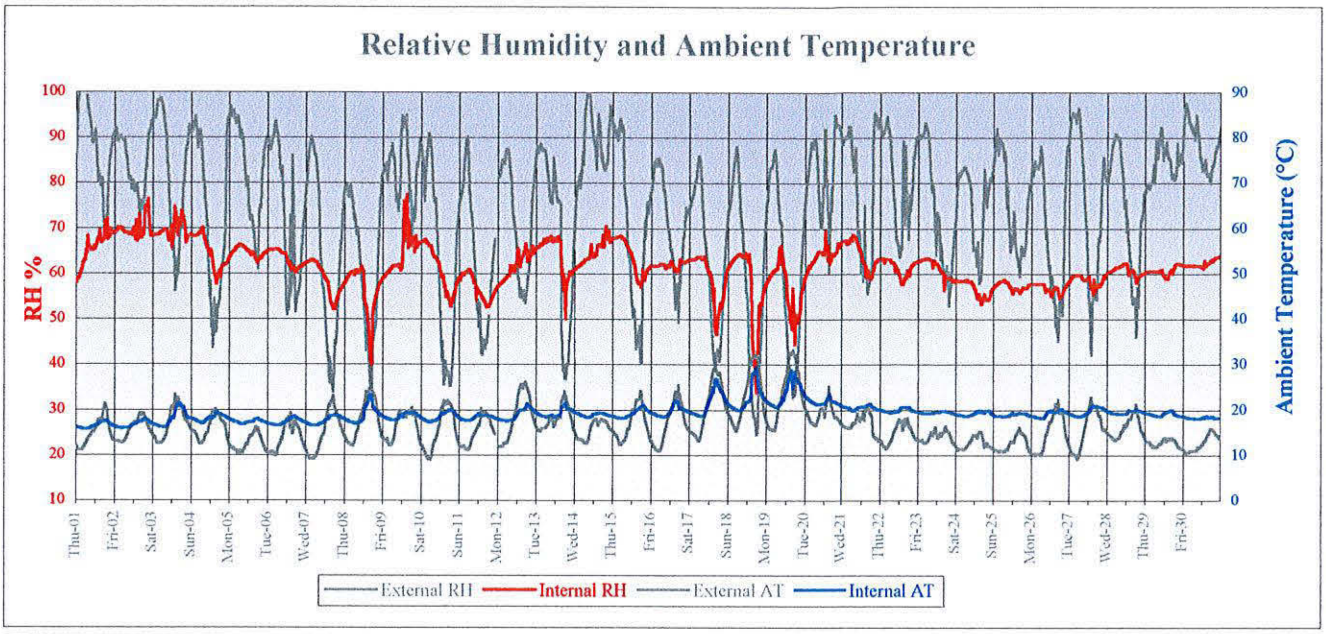


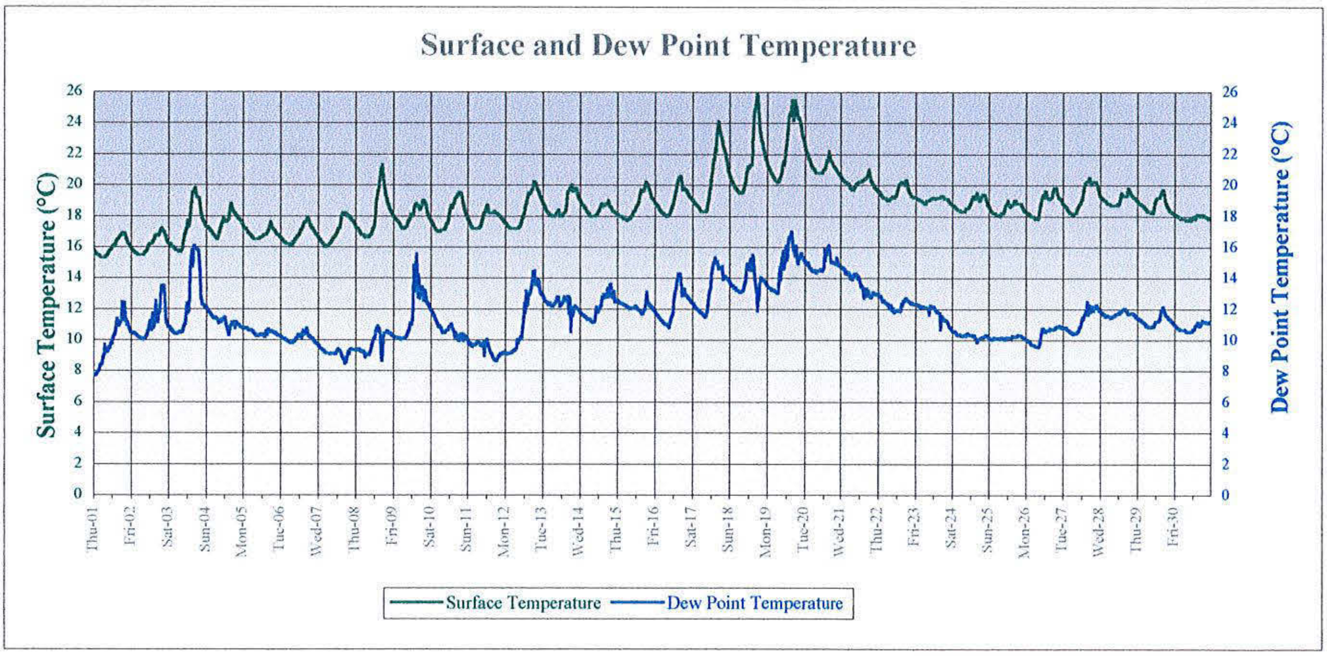
Site: Peterborough Cathedral	Type: Probe and stove locations	0m 10m 20m	Full use stove
Area: Plan (Base plan drawn by Julian Limentani)	Date: July 2001	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

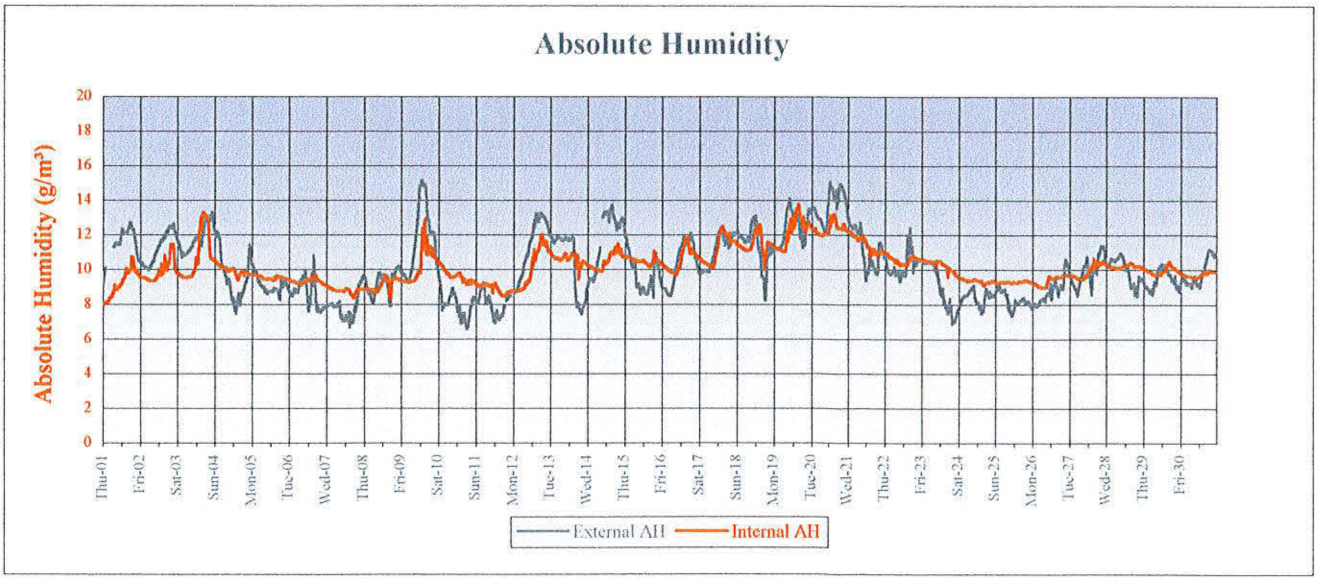
Peterborough Cathedral Nave Ceiling

June 2000

Probe 1: Bay 36 III lower side (shade)



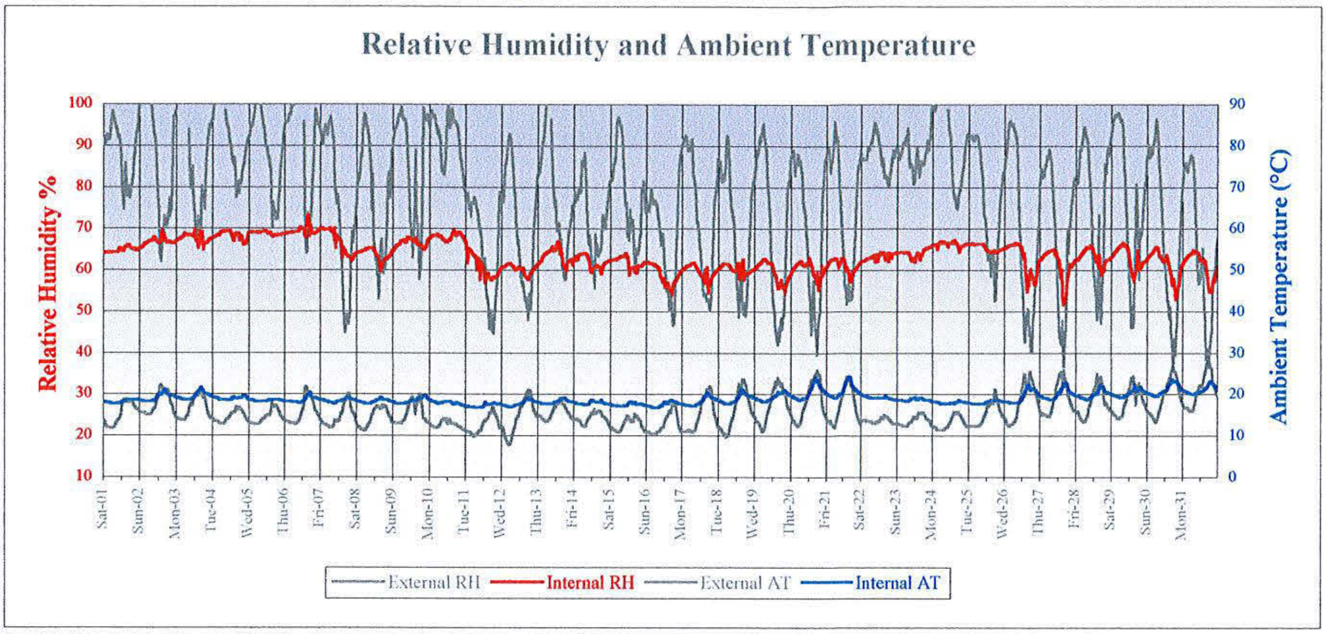


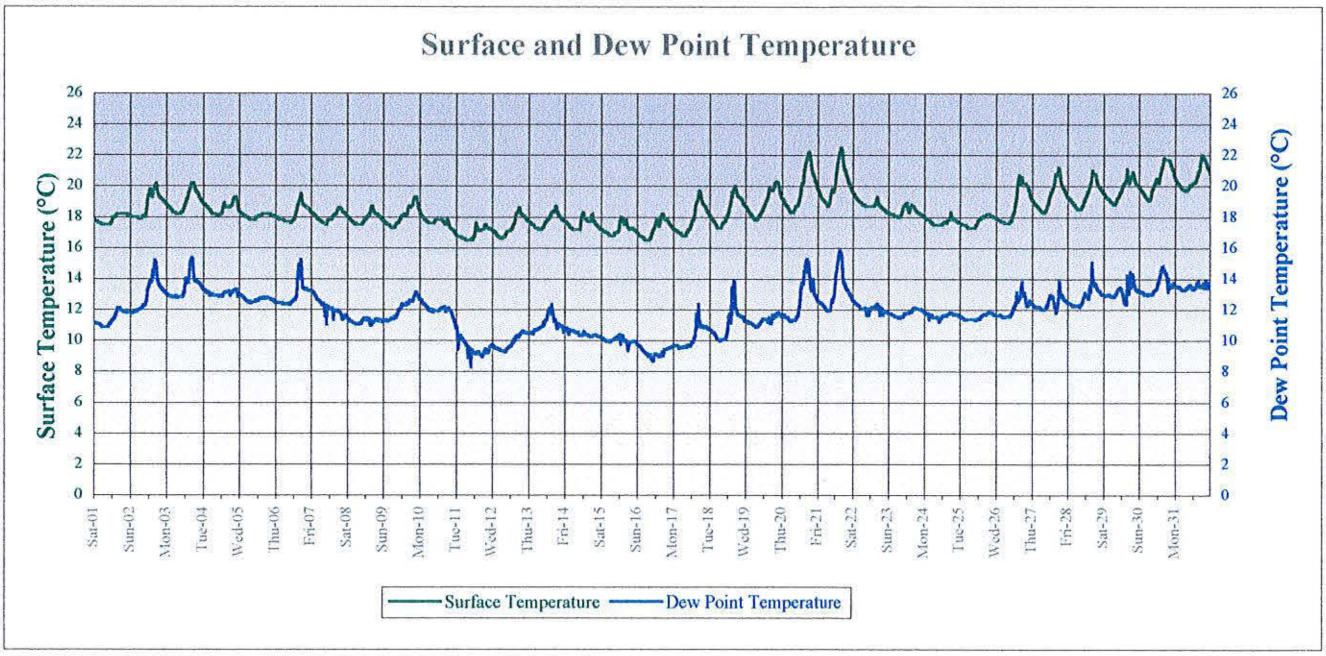


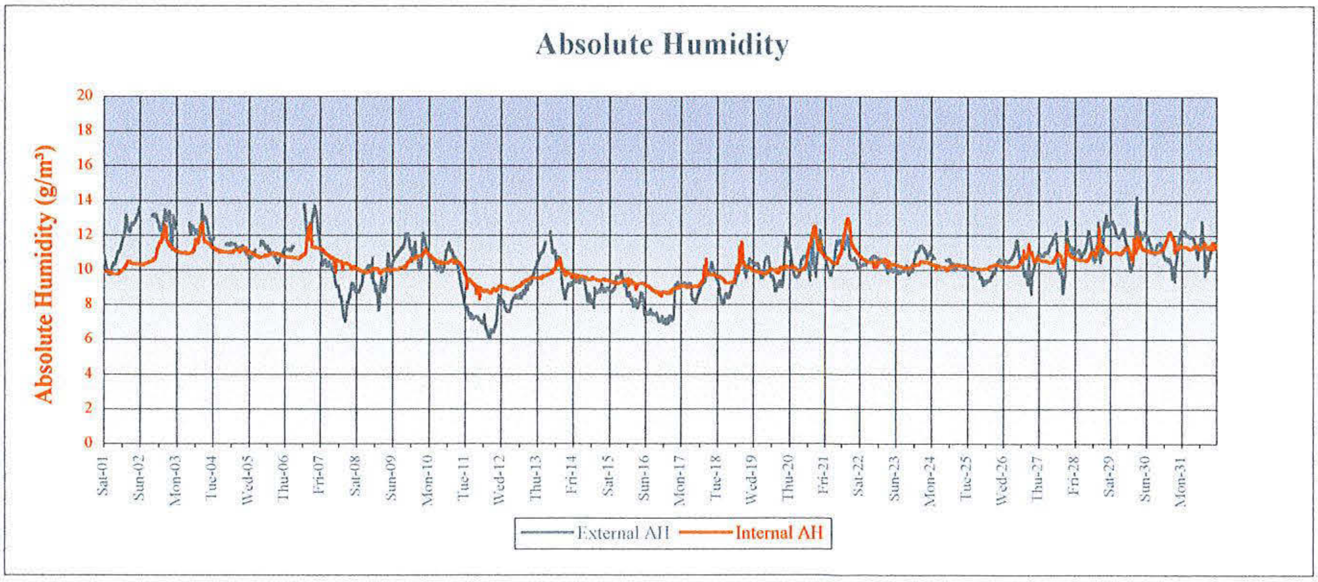
Peterborough Cathedral Nave Ceiling

July 2000

Probe 1: Bay 36 III lower side (shade)



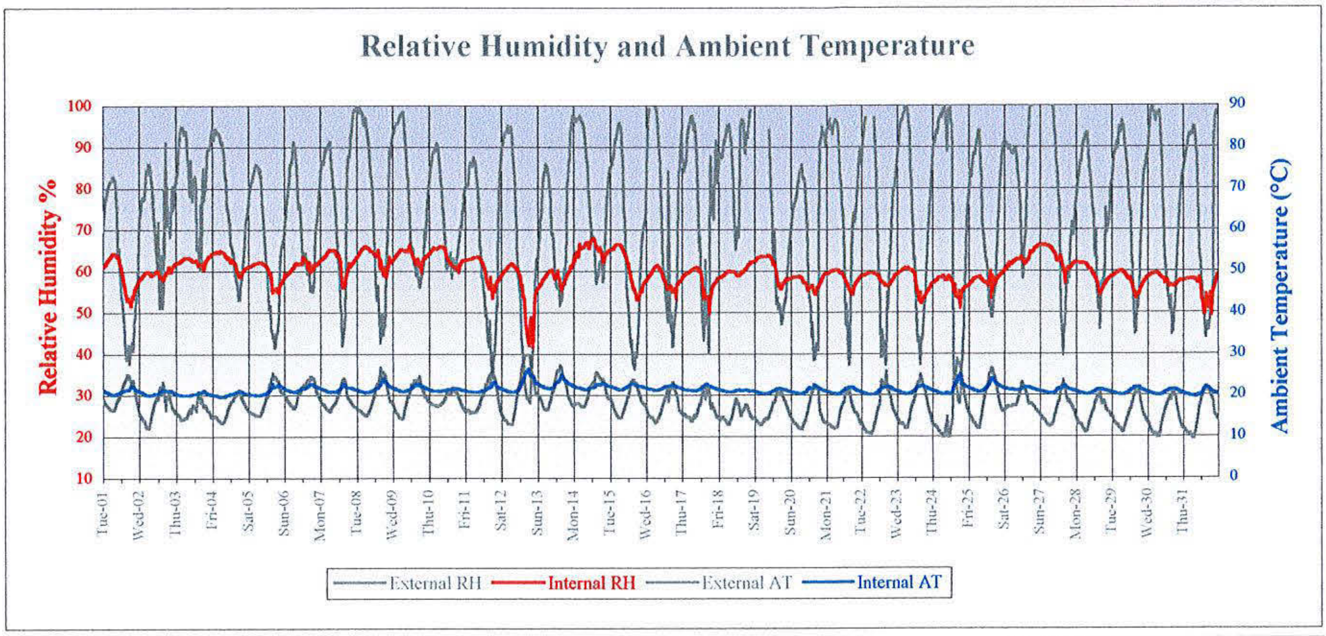


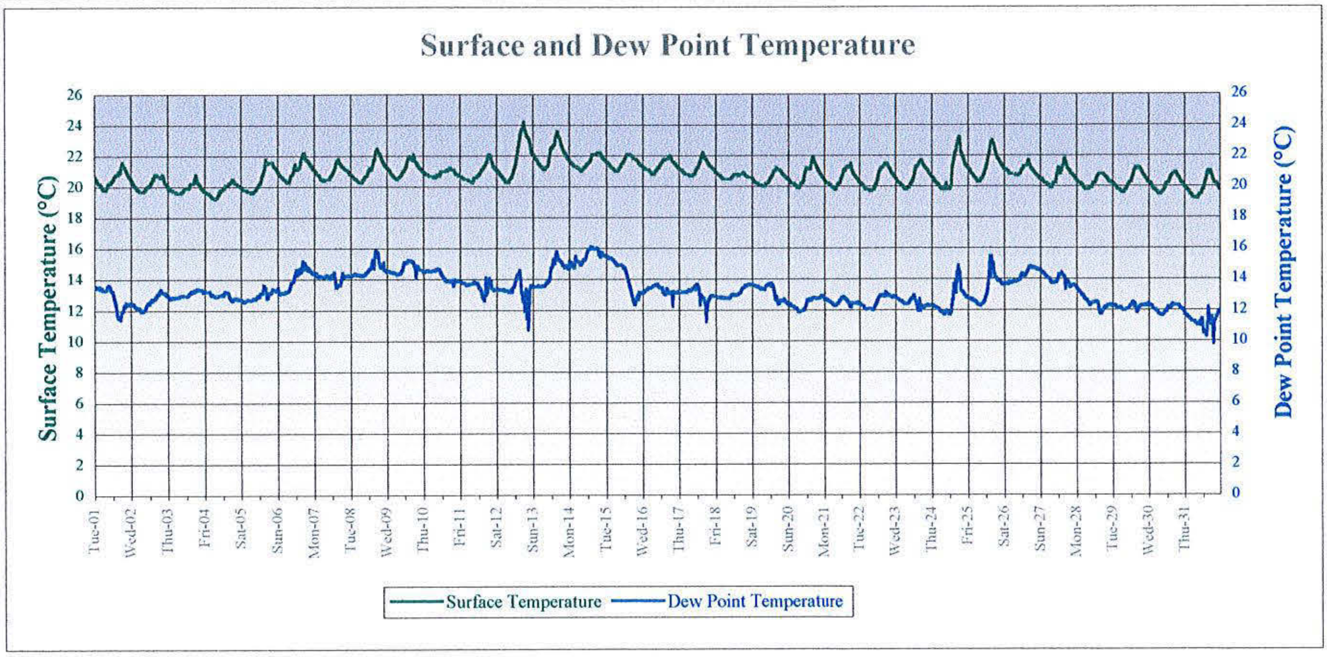


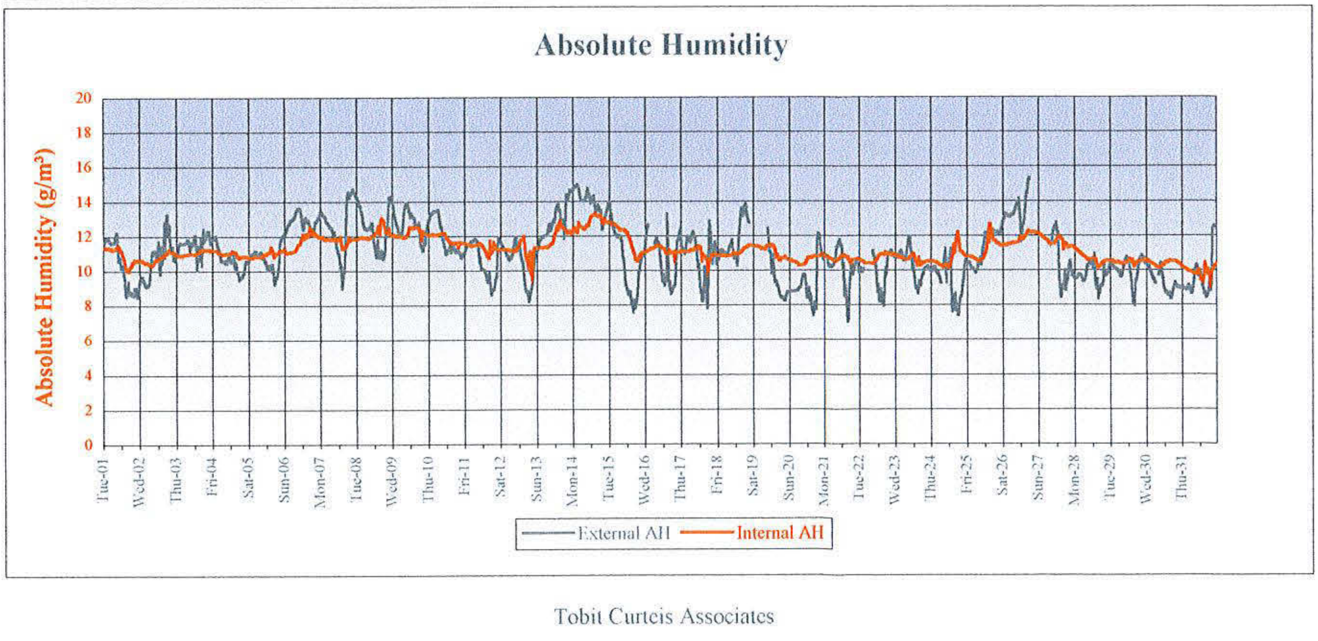
Peterborough Cathedral Nave Ceiling

August 2000

Probe 1: Bay 36 III lower side (shade)



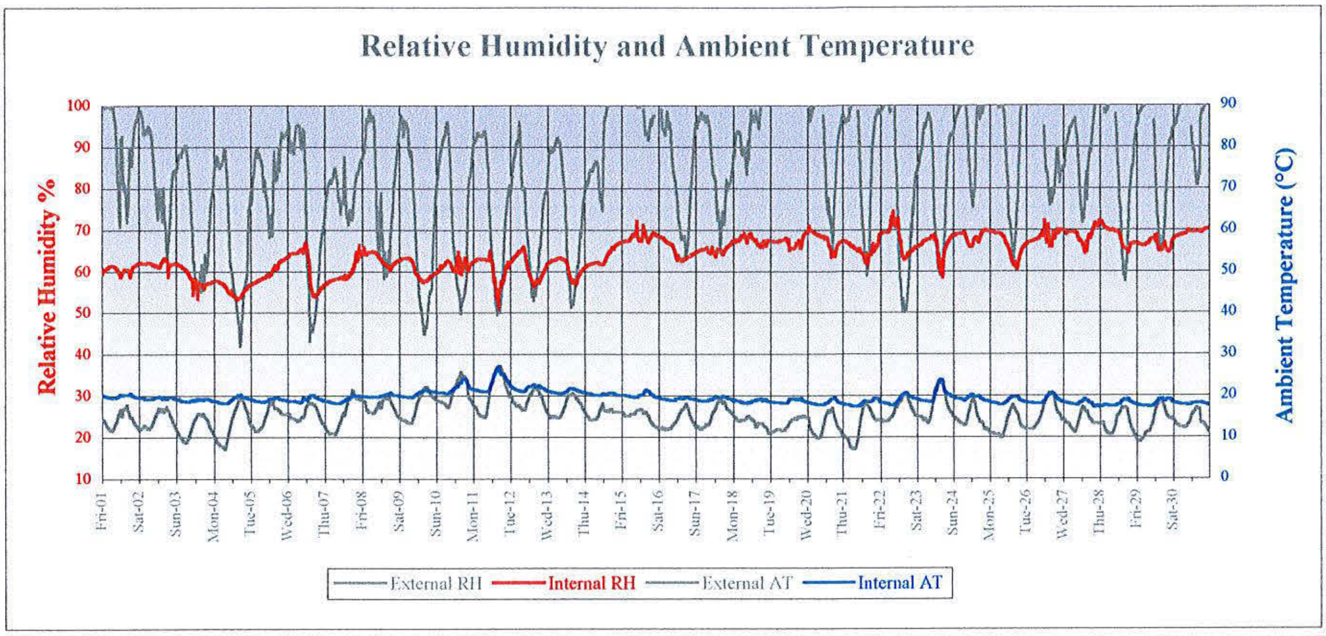


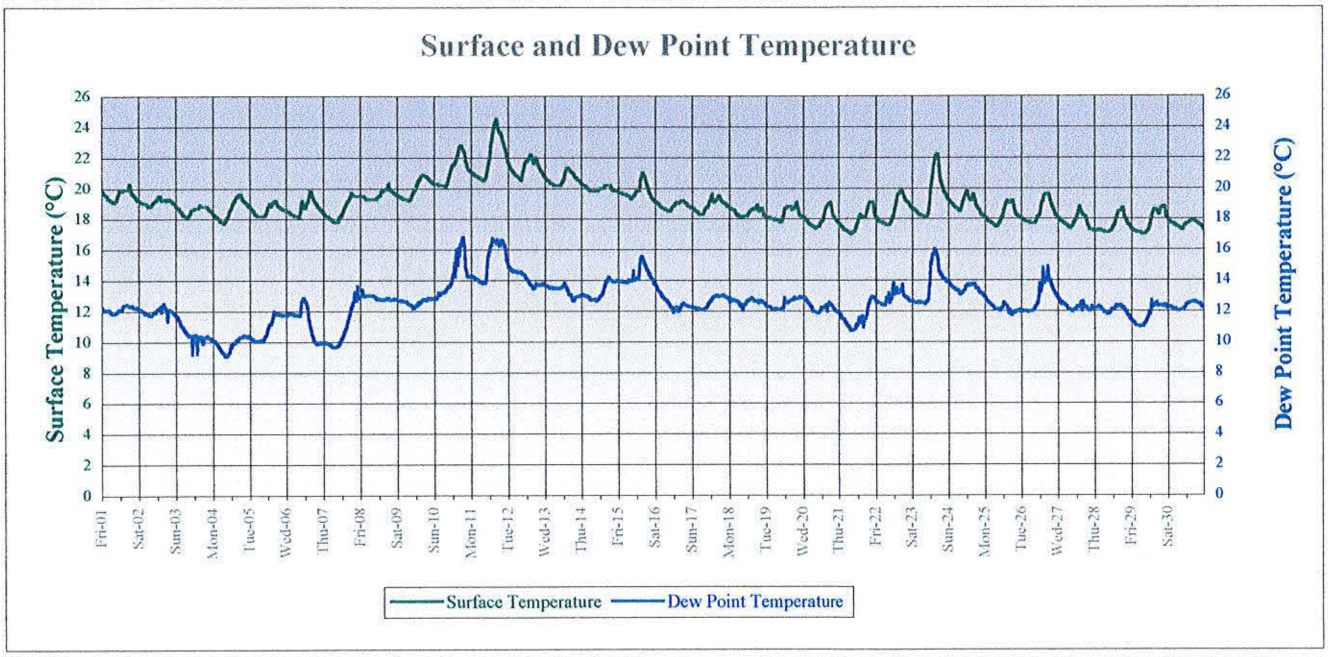


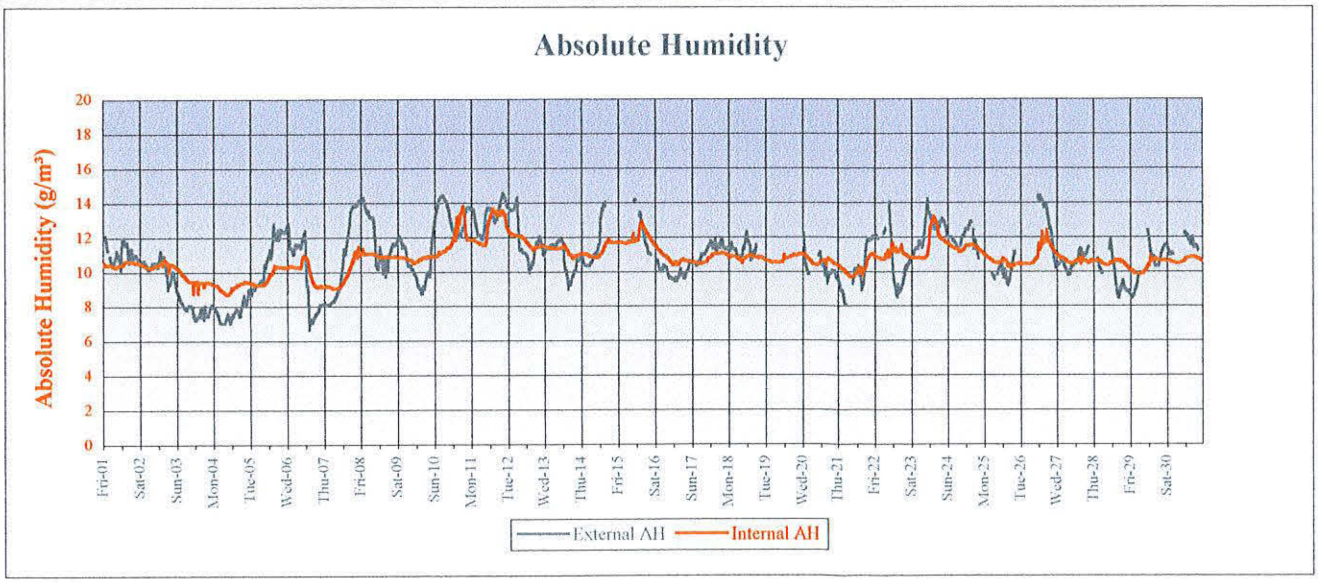
Peterborough Cathedral Nave Ceiling

September 2000

Probe 1: Bay 36 III lower side (shade)



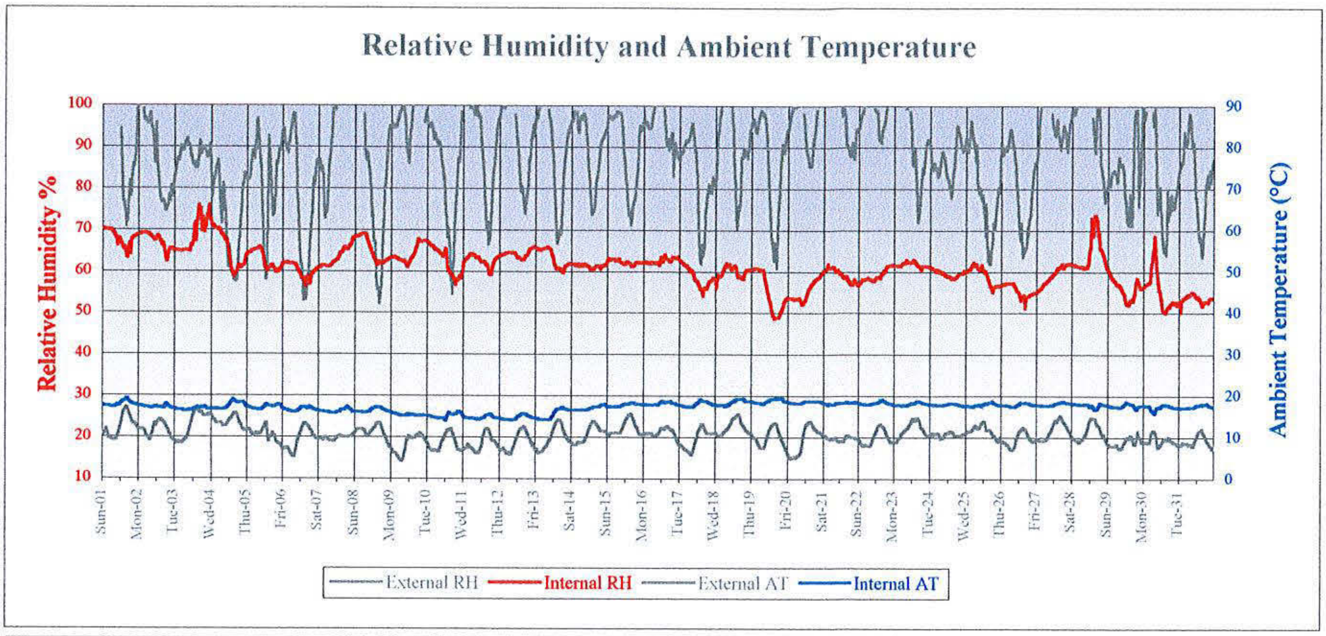


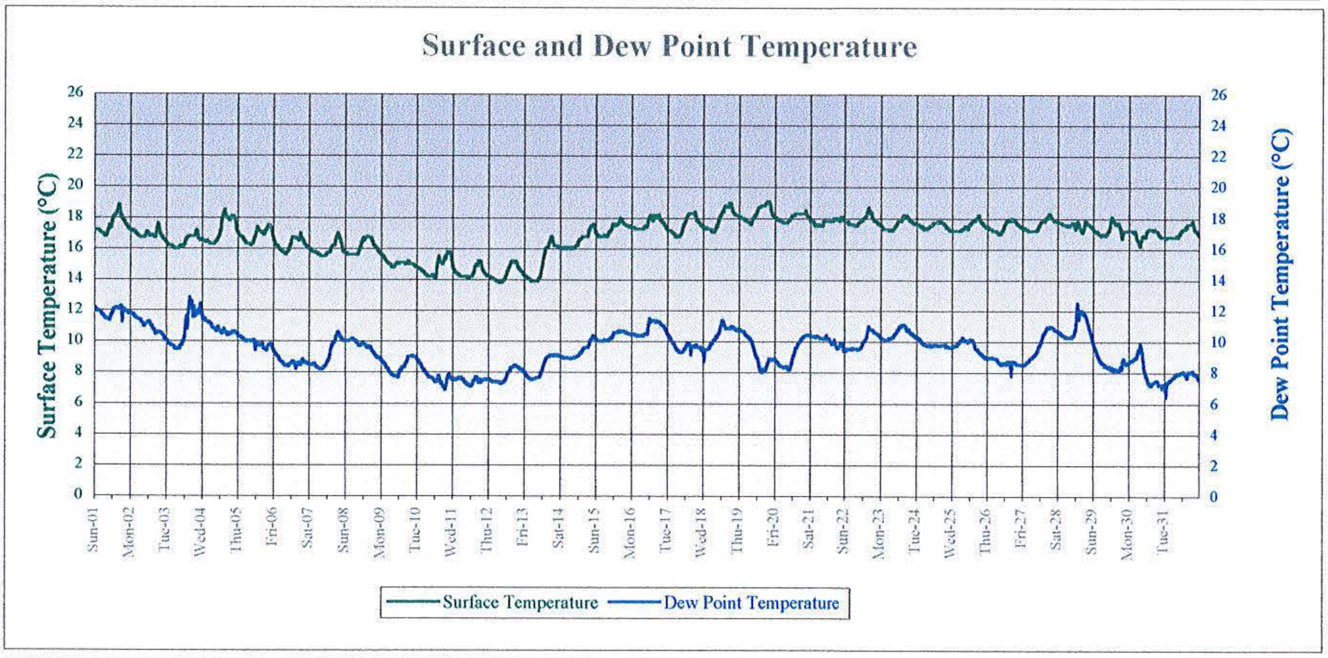


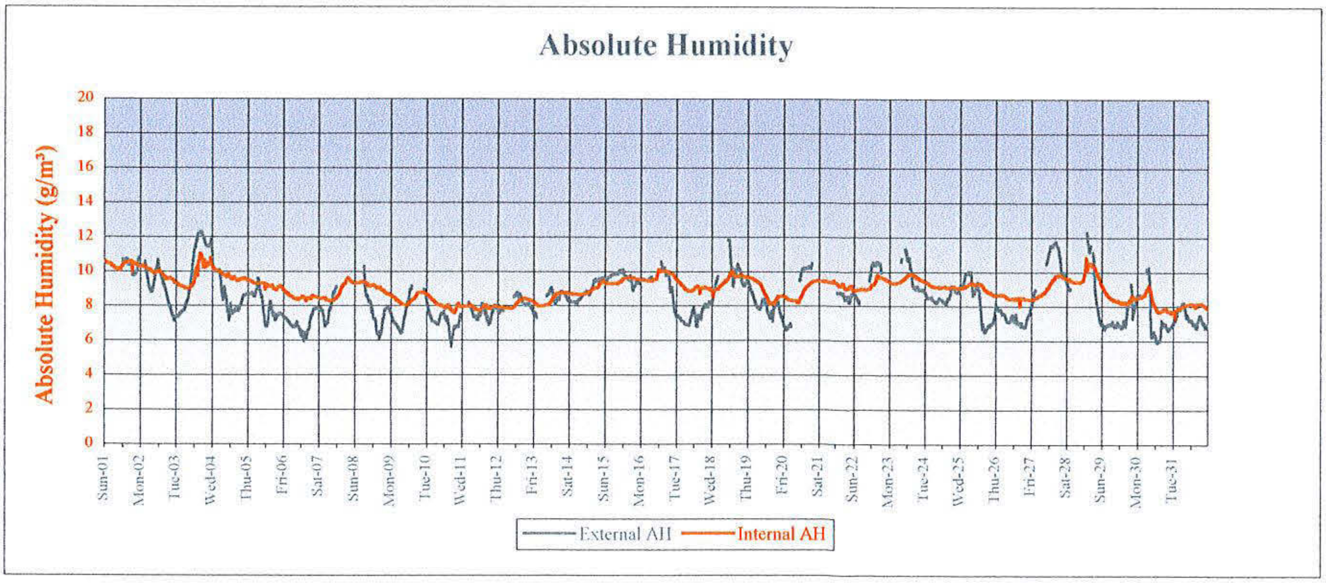
Peterborough Cathedral Nave Ceiling

October 2000

Probe 1: Bay 36 III lower side (shade)



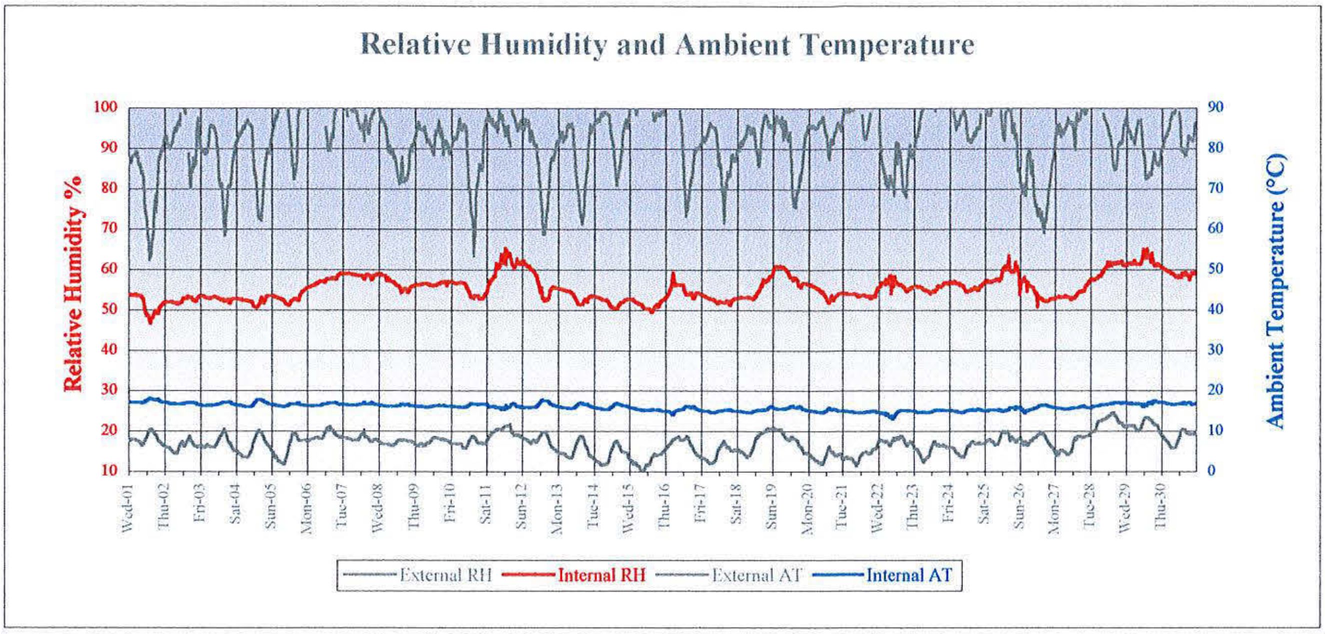


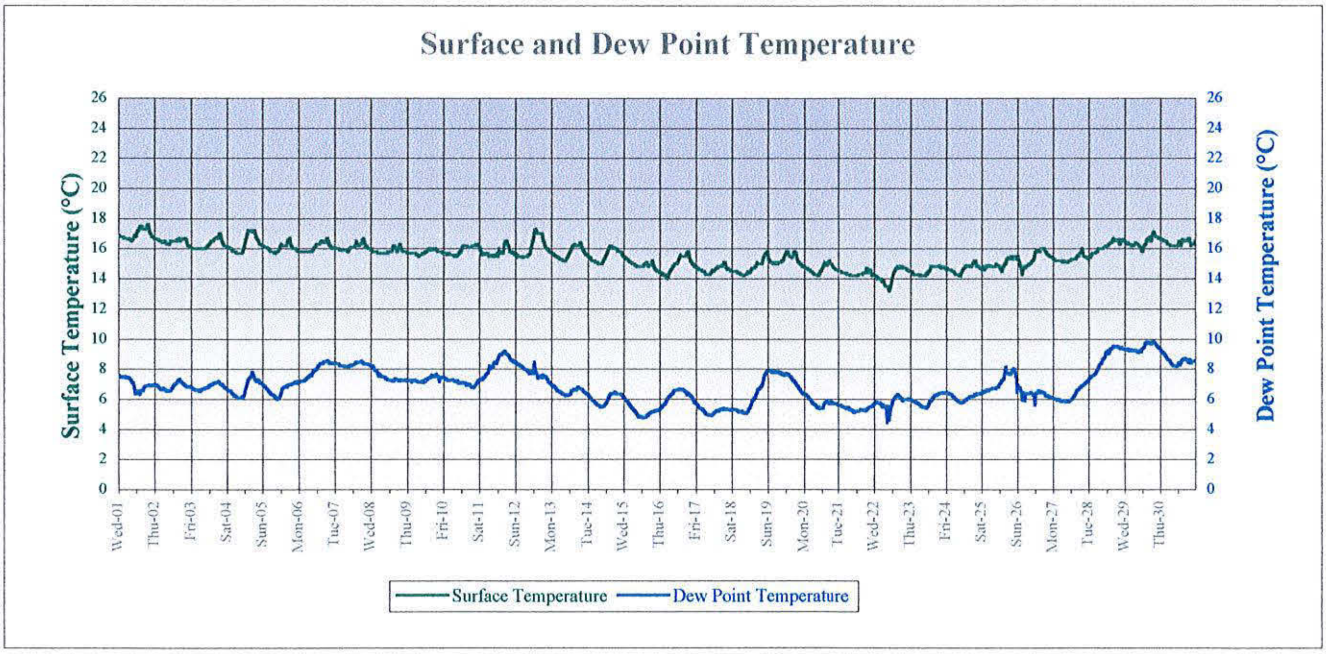


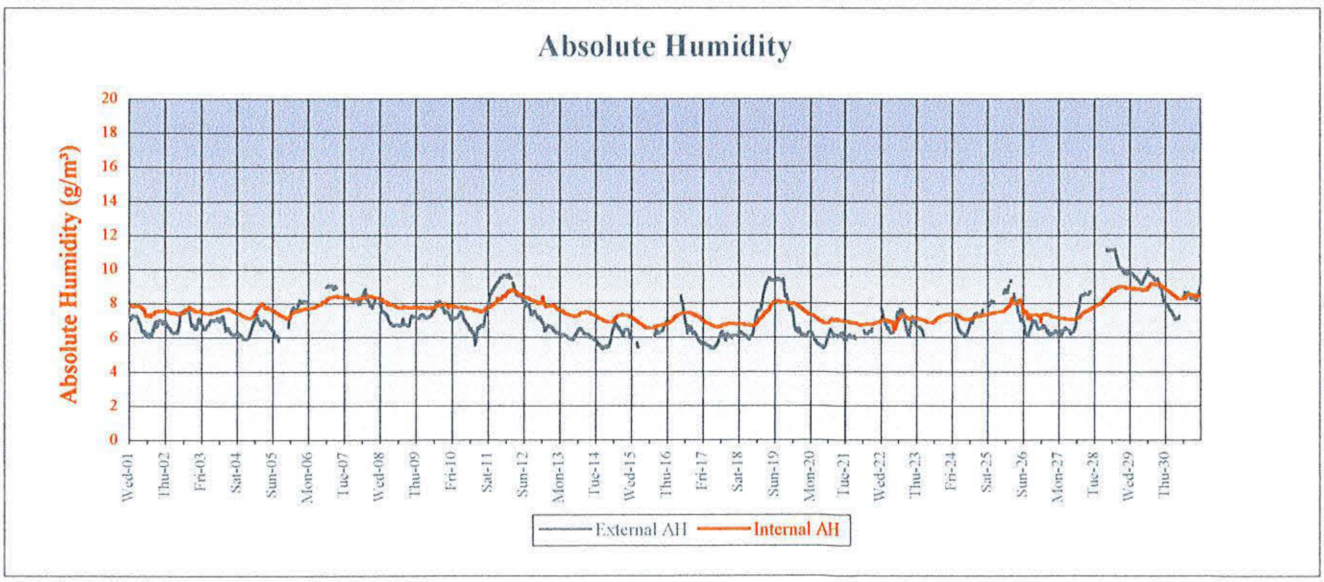
Peterborough Cathedral Nave Ceiling

November 2000

Probe 1: Bay 36 III lower side (shade)



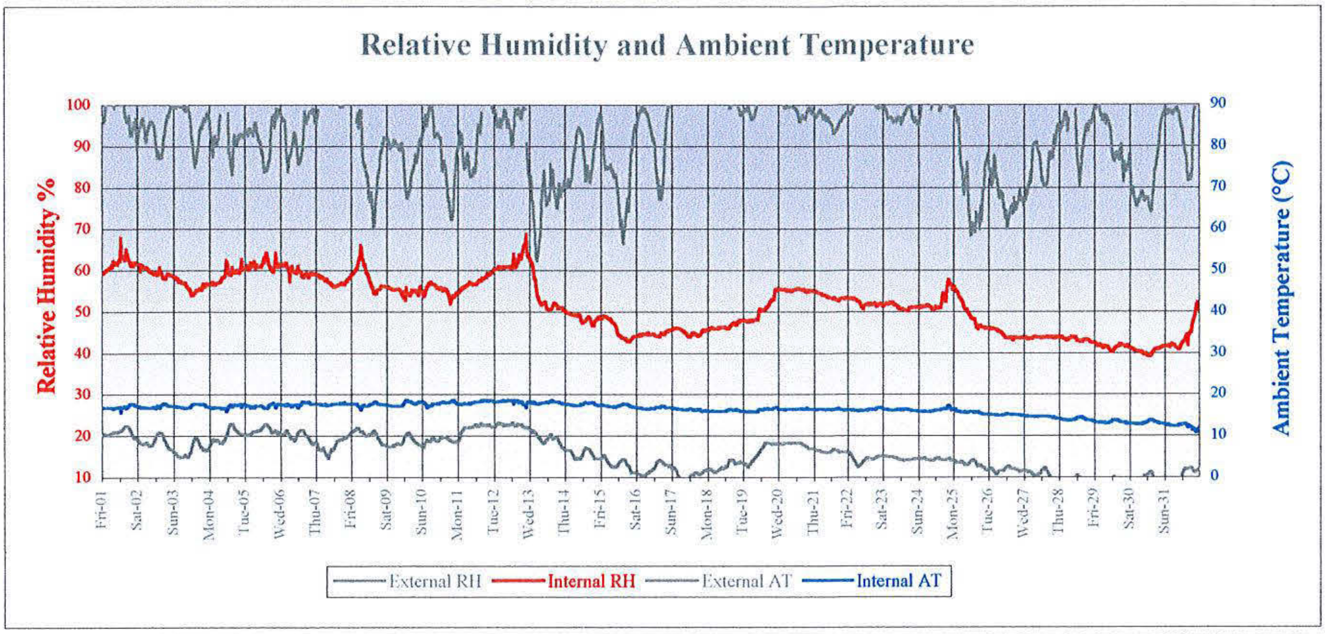


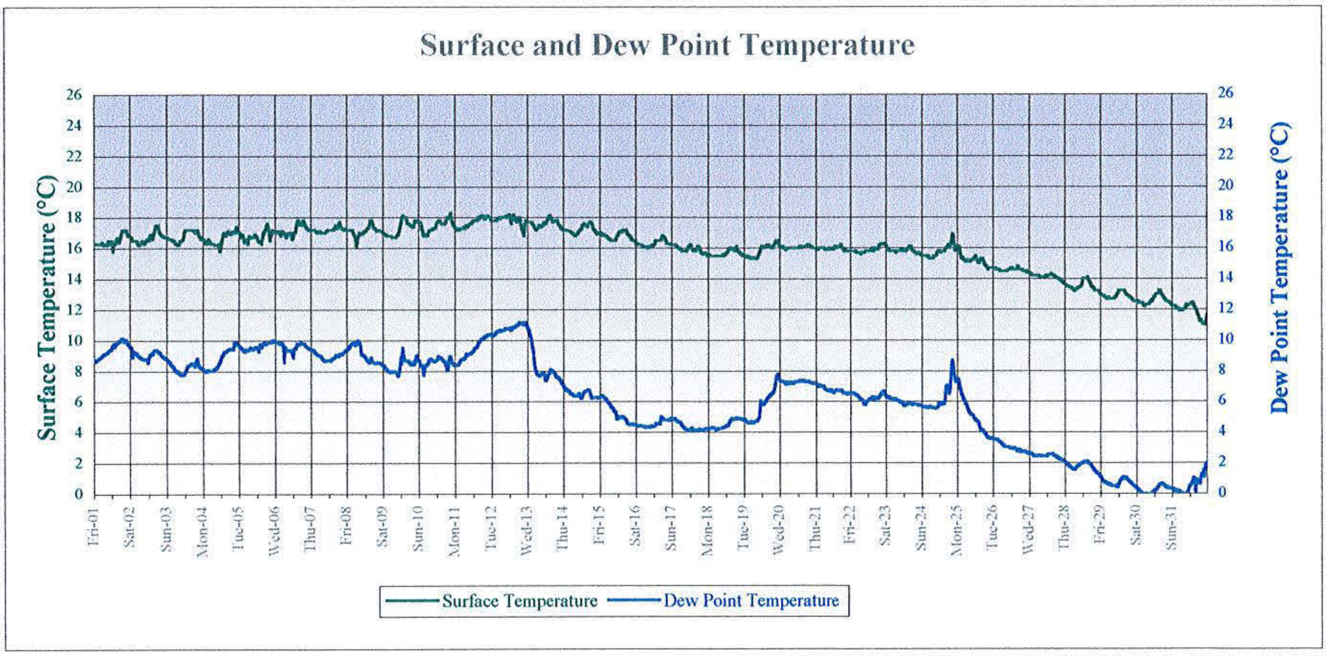


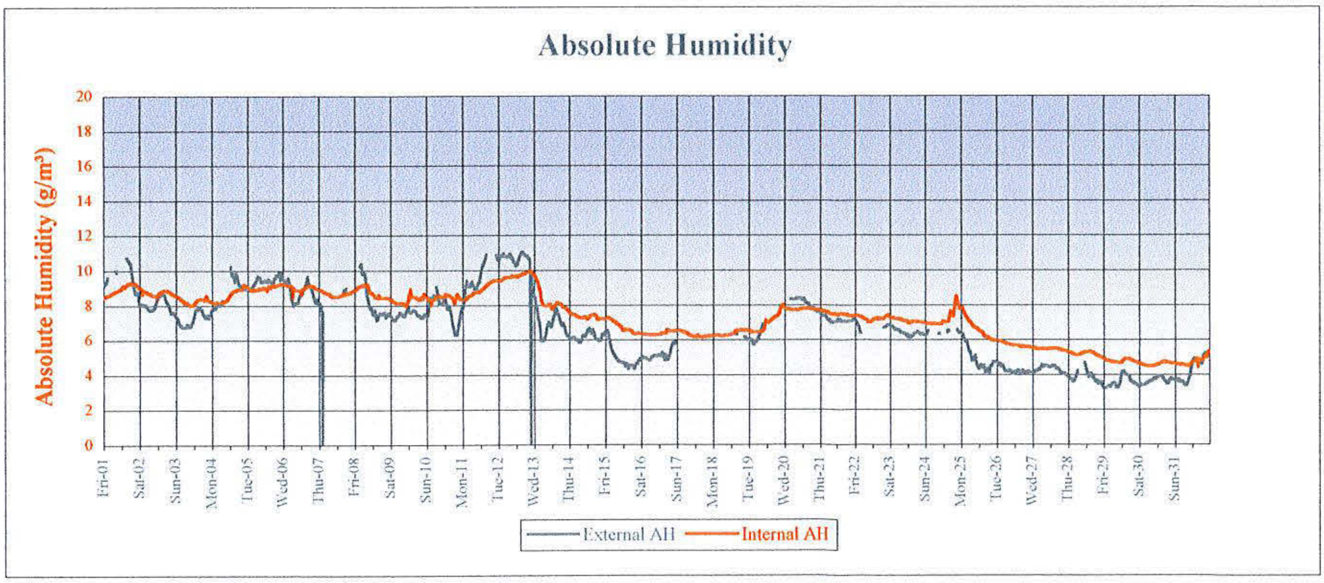
Peterborough Cathedral Nave Ceiling

December 2000

Probe 1: Bay 36 III lower side (shade)



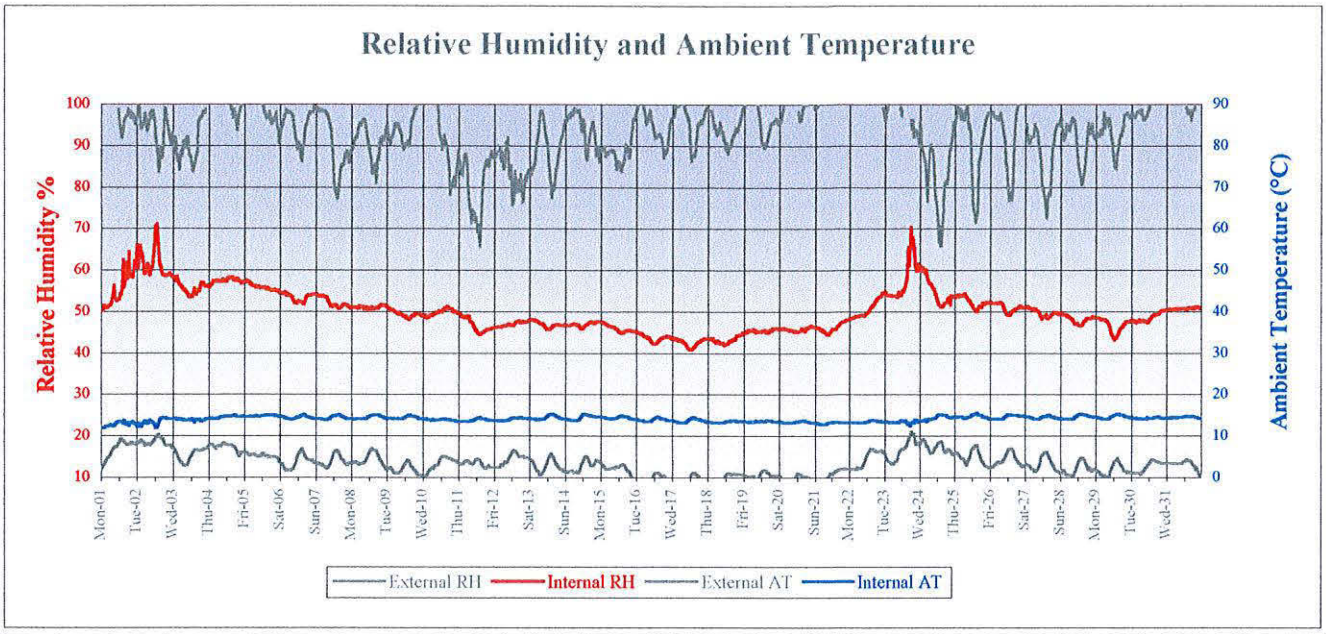


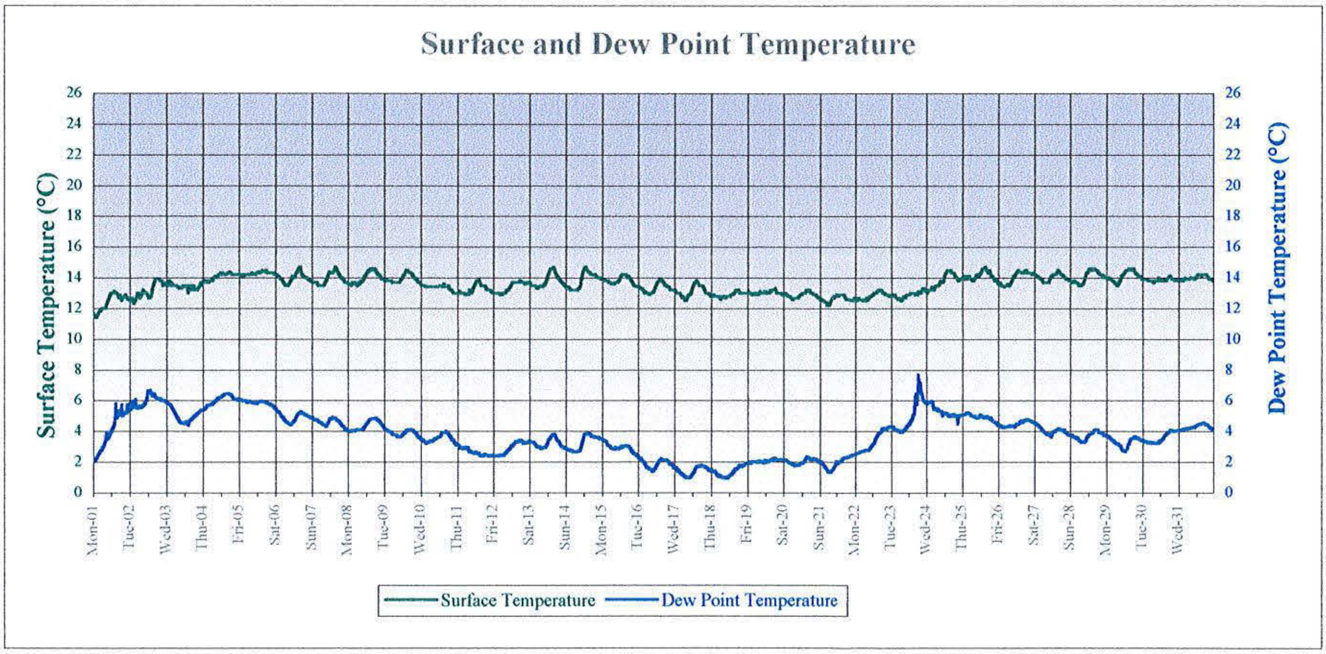


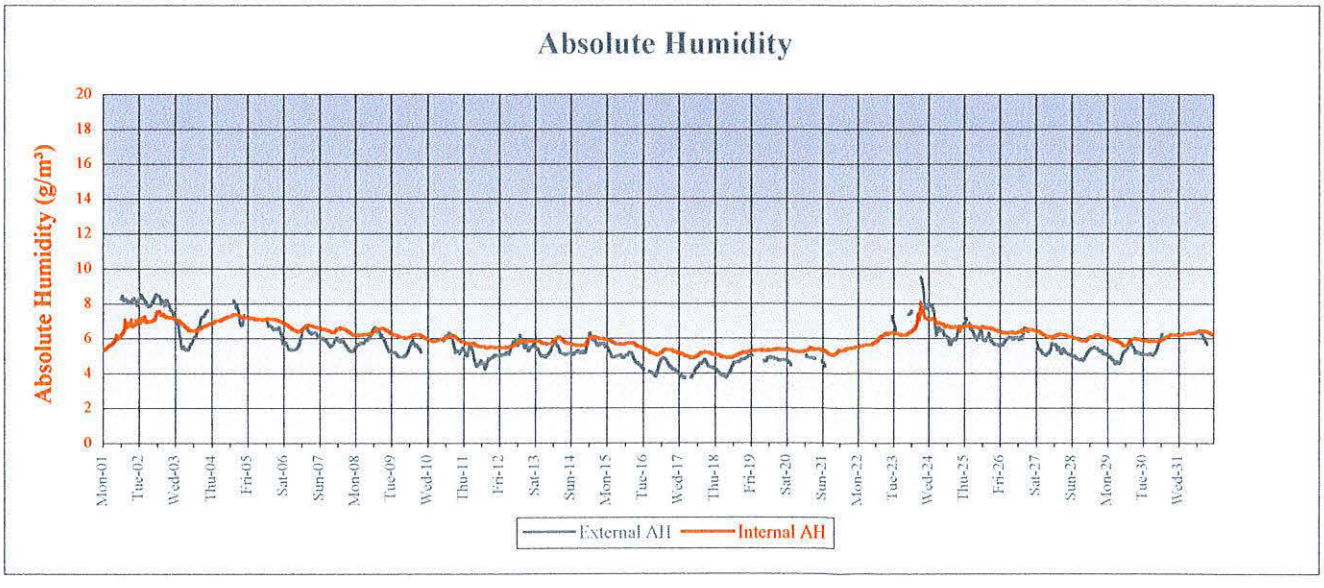
Peterborough Cathedral Nave Ceiling

January 2001

Probe 1: Bay 36 III lower side (shade)



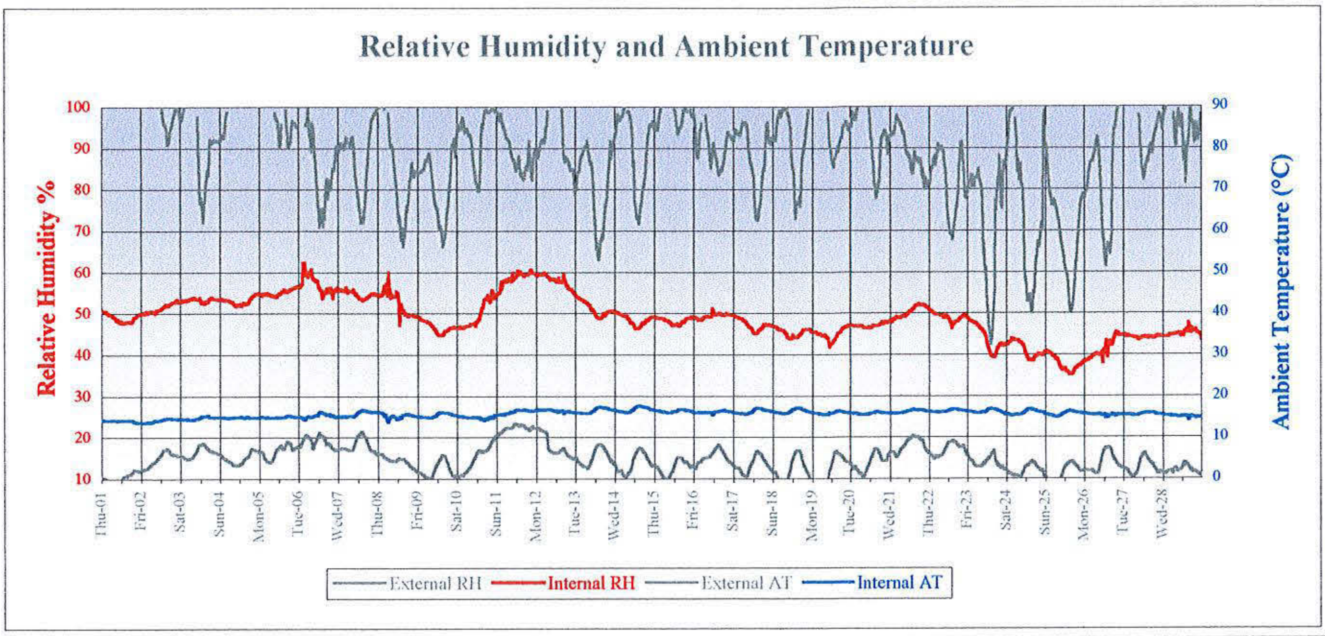


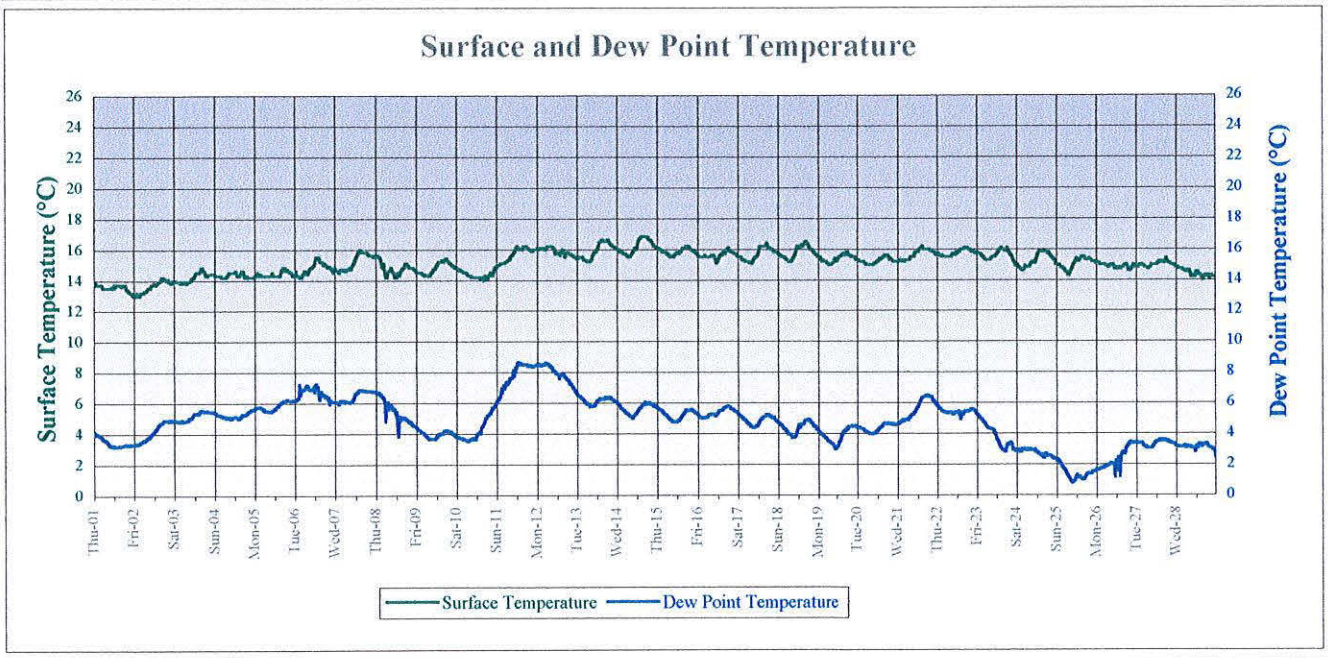


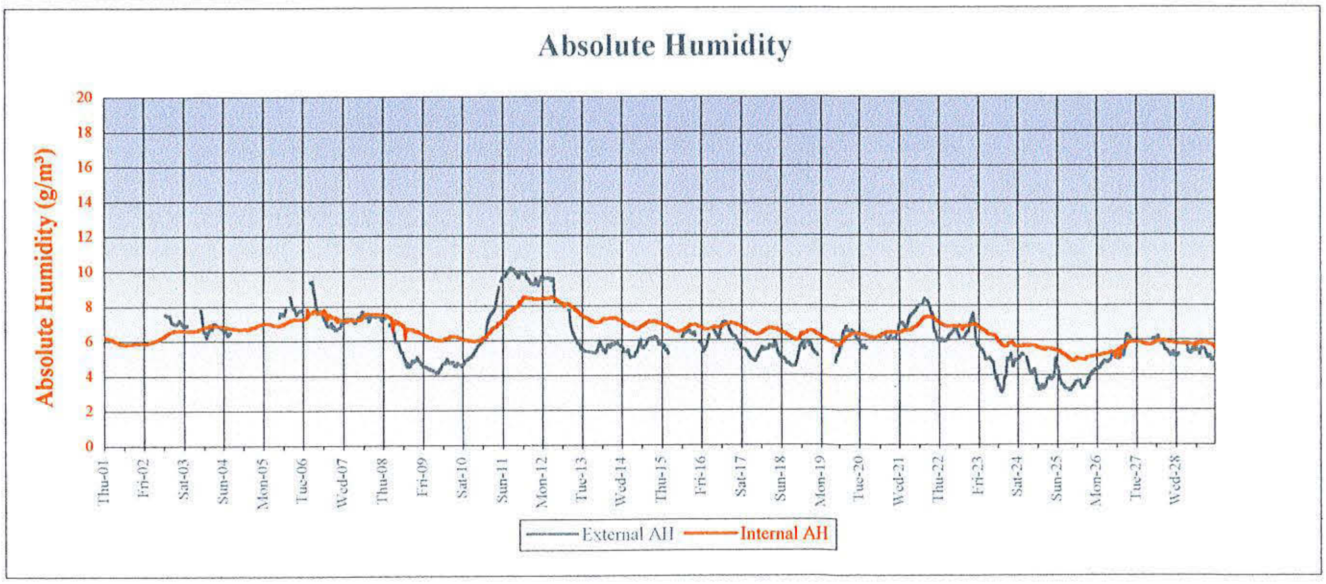
Peterborough Cathedral Nave Ceiling

February 2001

Probe 1: Bay 36 III lower side (shade)



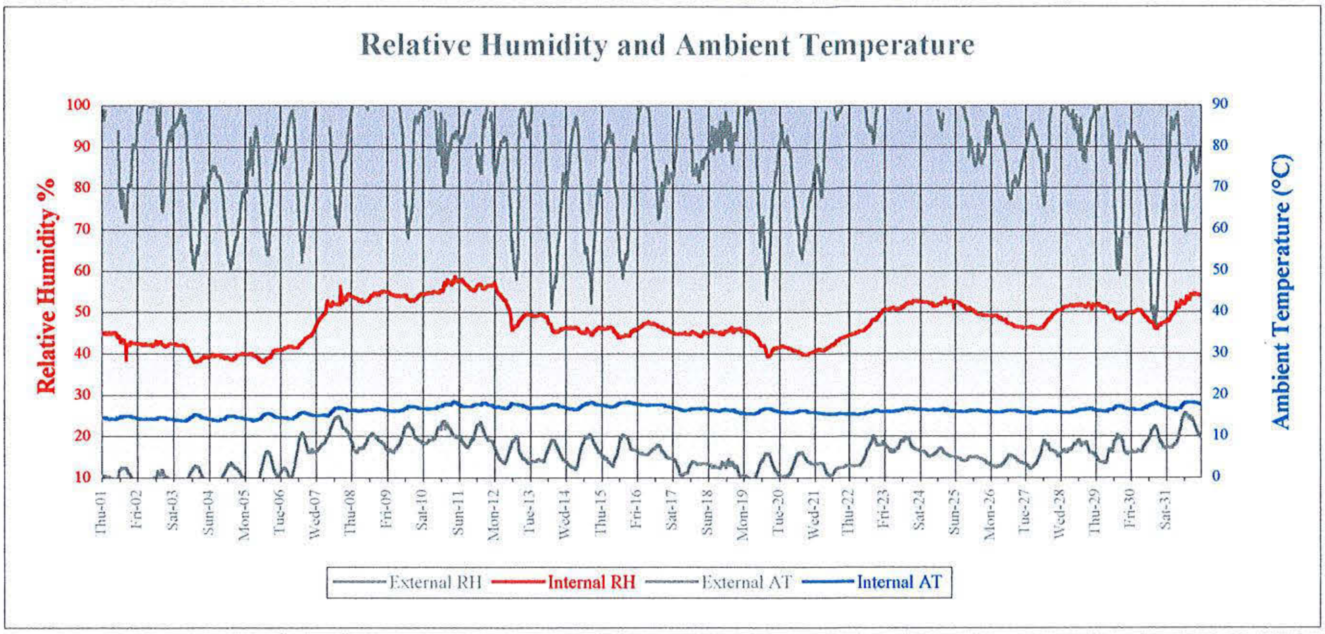


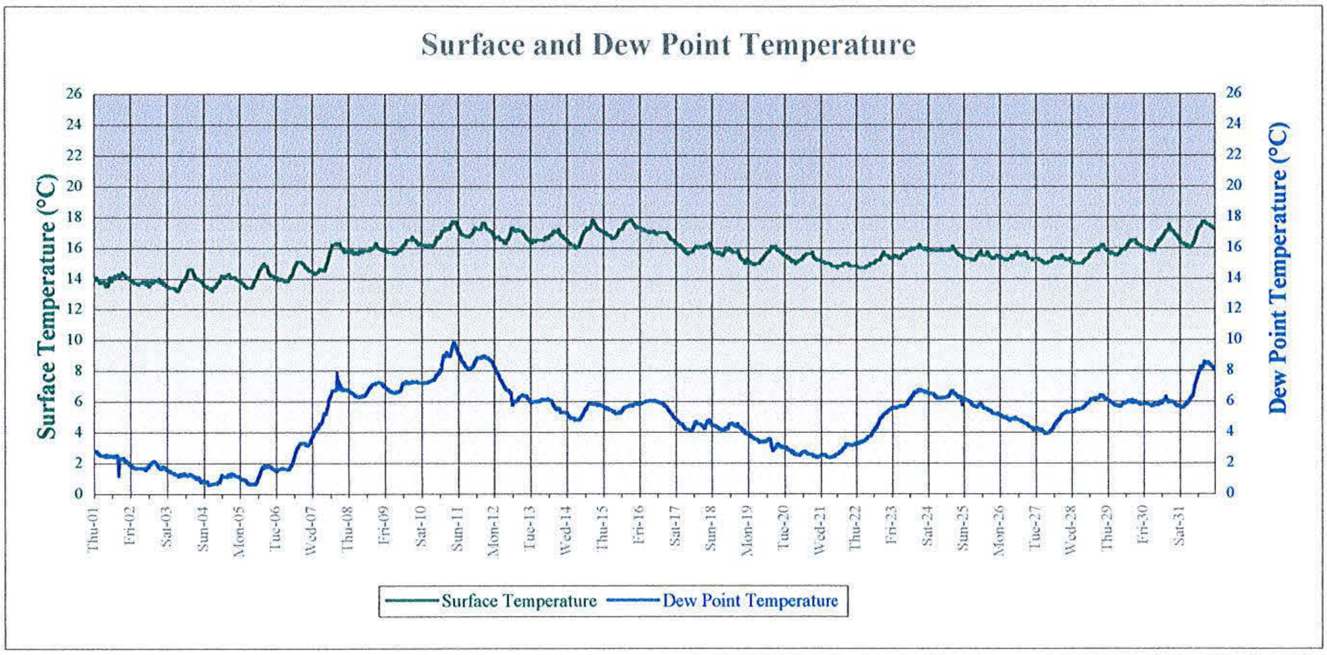


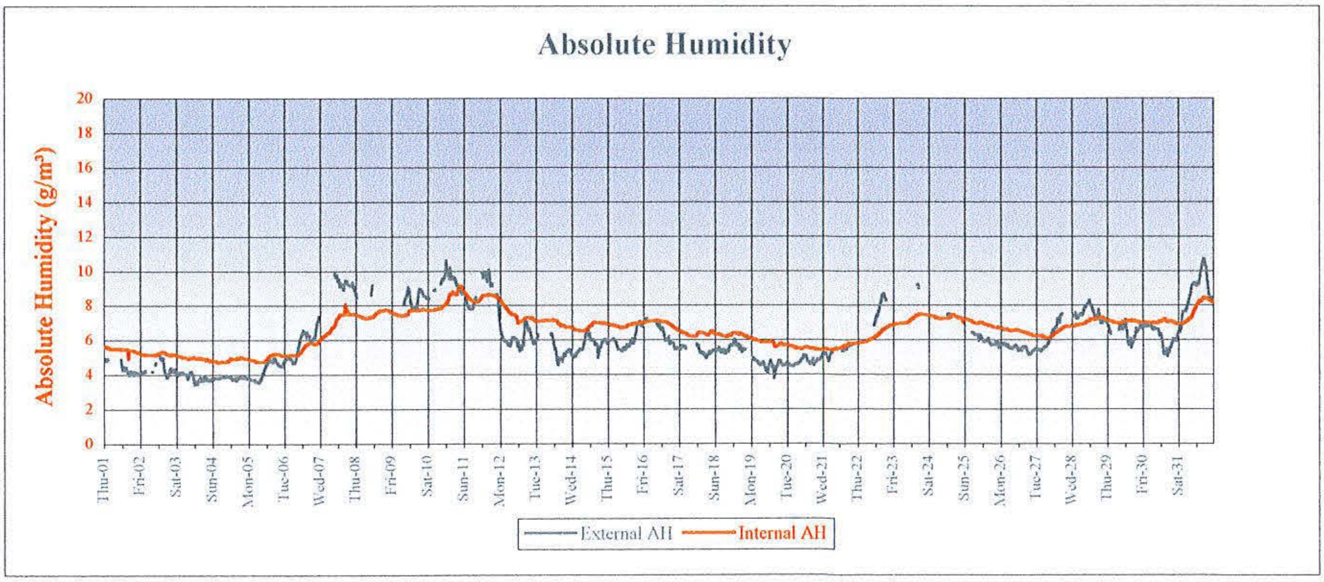
Peterborough Cathedral Nave Ceiling

March 2001

Probe 1: Bay 36 III lower side (shade)



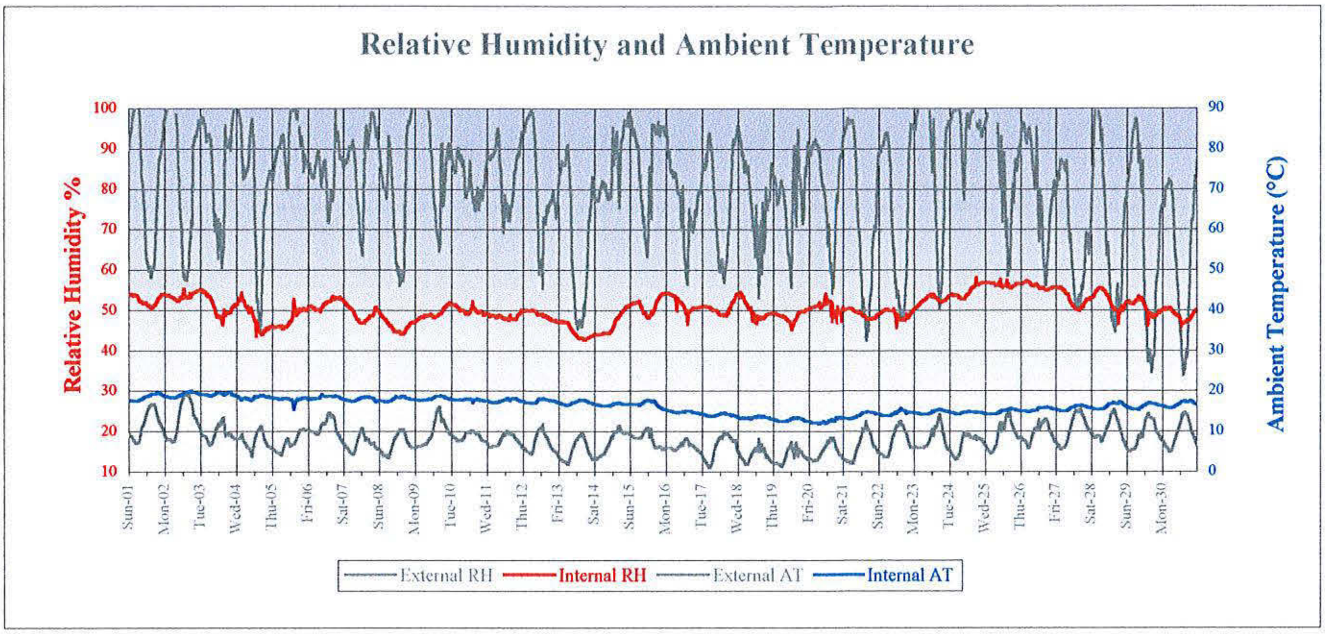


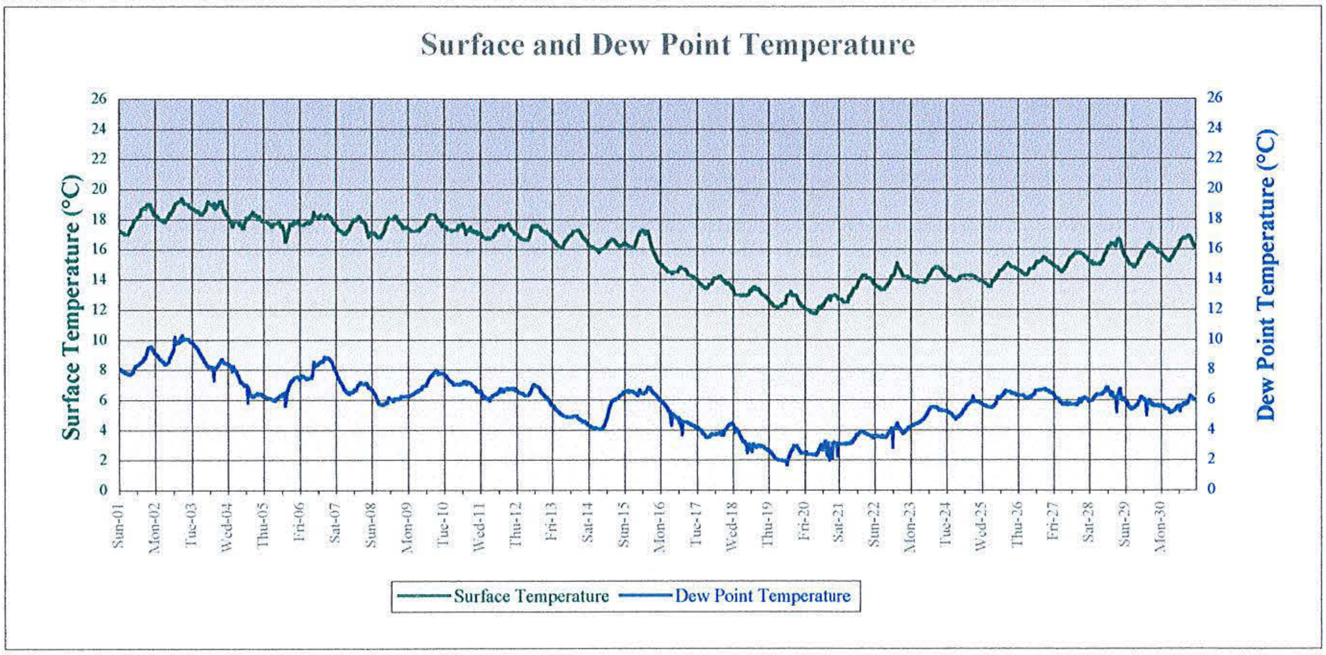


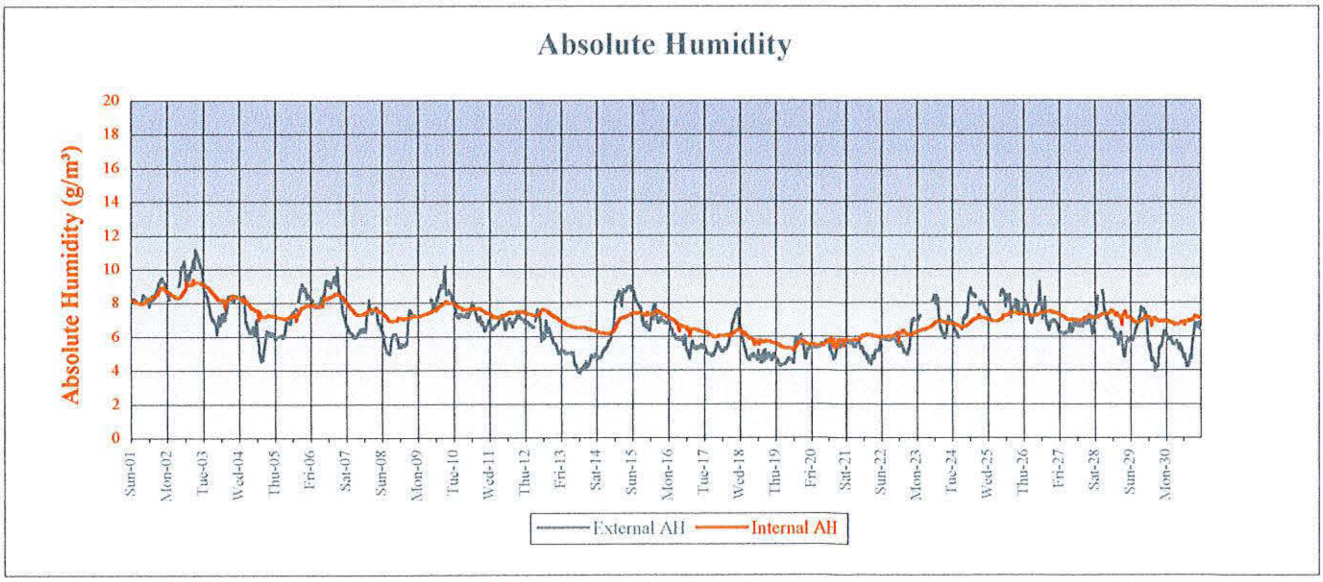
Peterborough Cathedral Nave Ceiling

April 2001

Probe 1: Bay 36 III lower side (shade)



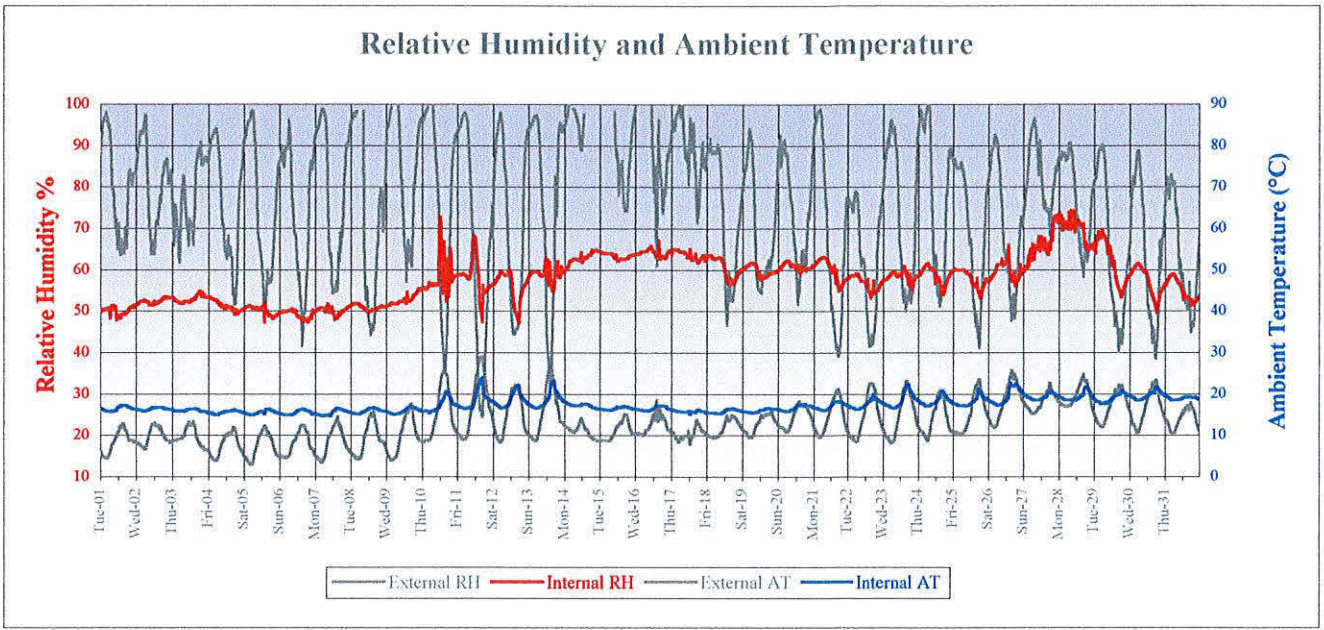


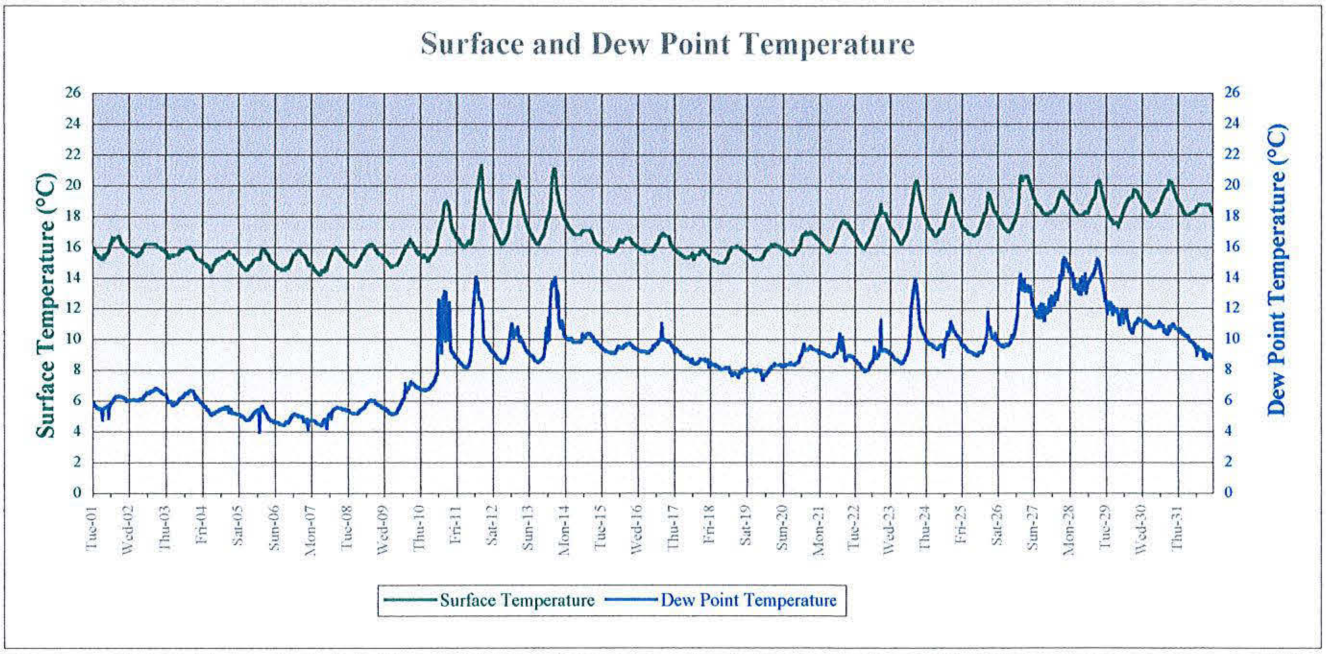


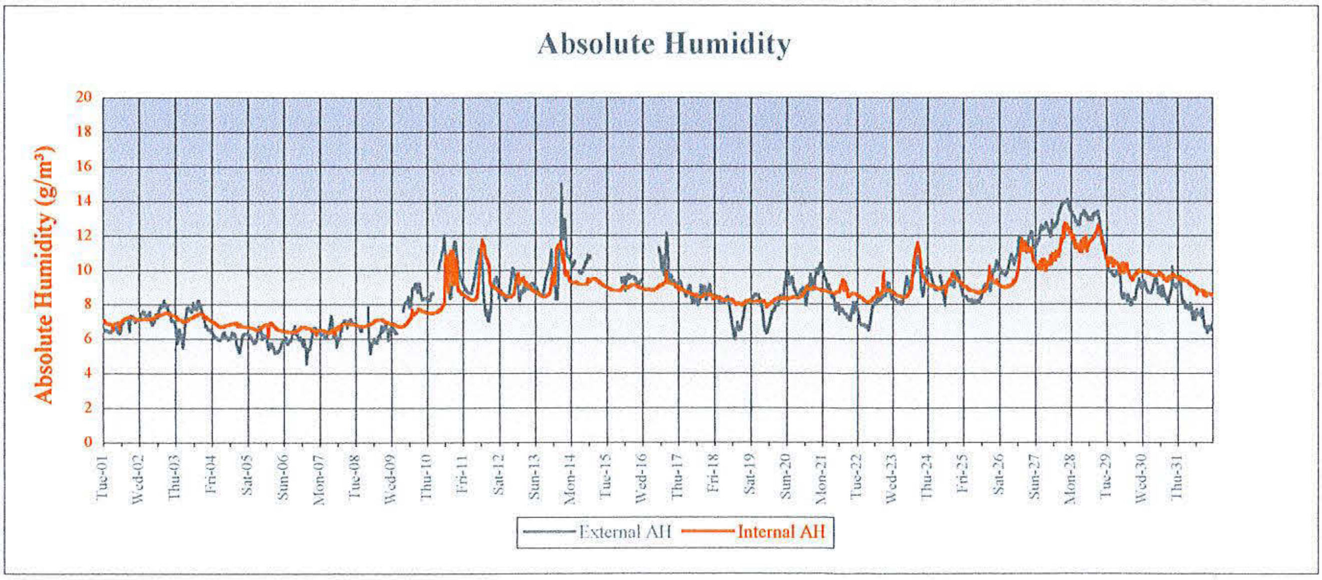
Peterborough Cathedral Nave Ceiling

May 2001

Probe 1: Bay 36 III lower side (shade)



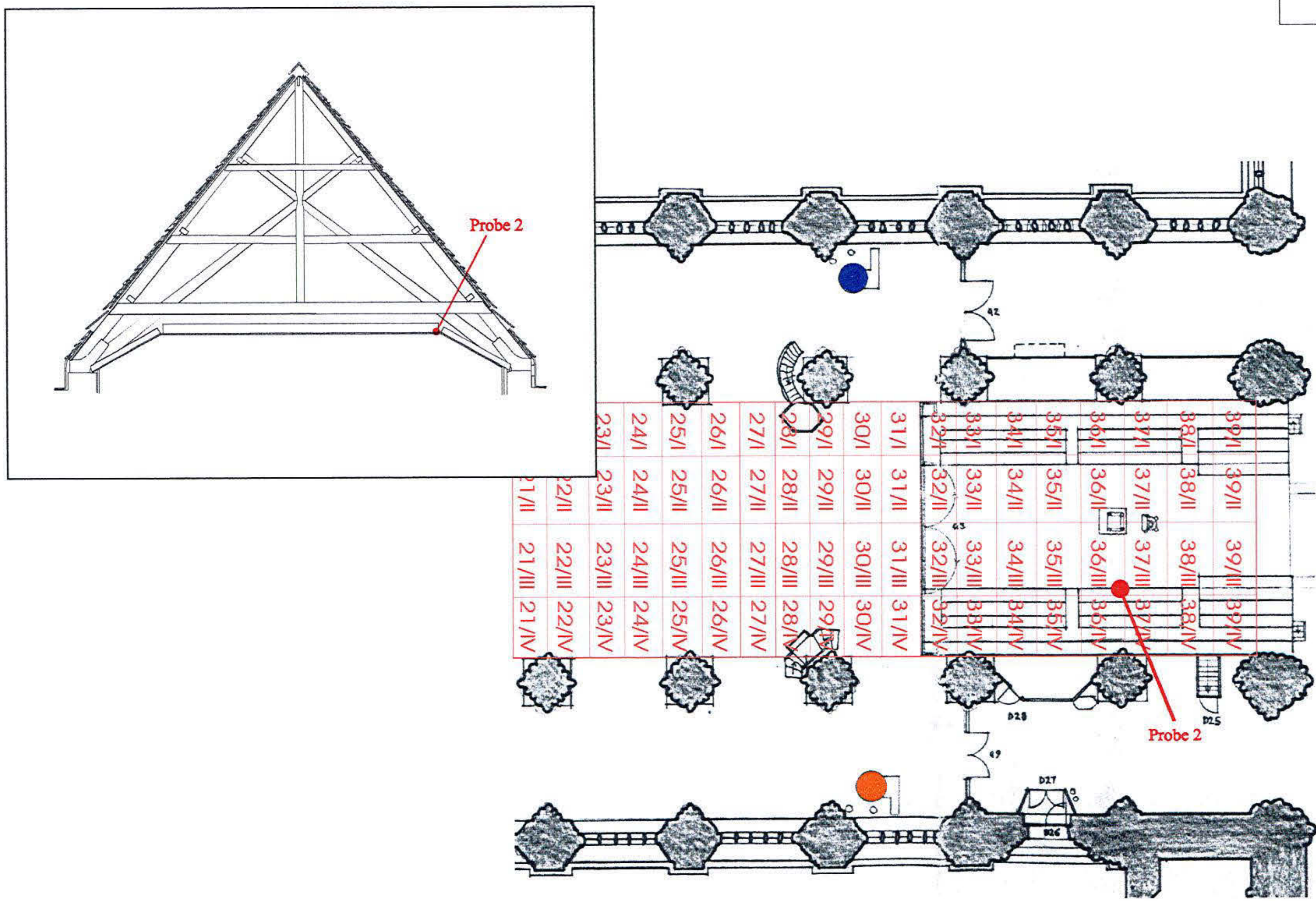




PROBE 2

BAY 36 III UPPER SIDE (SHADE)

DIAGRAM 4

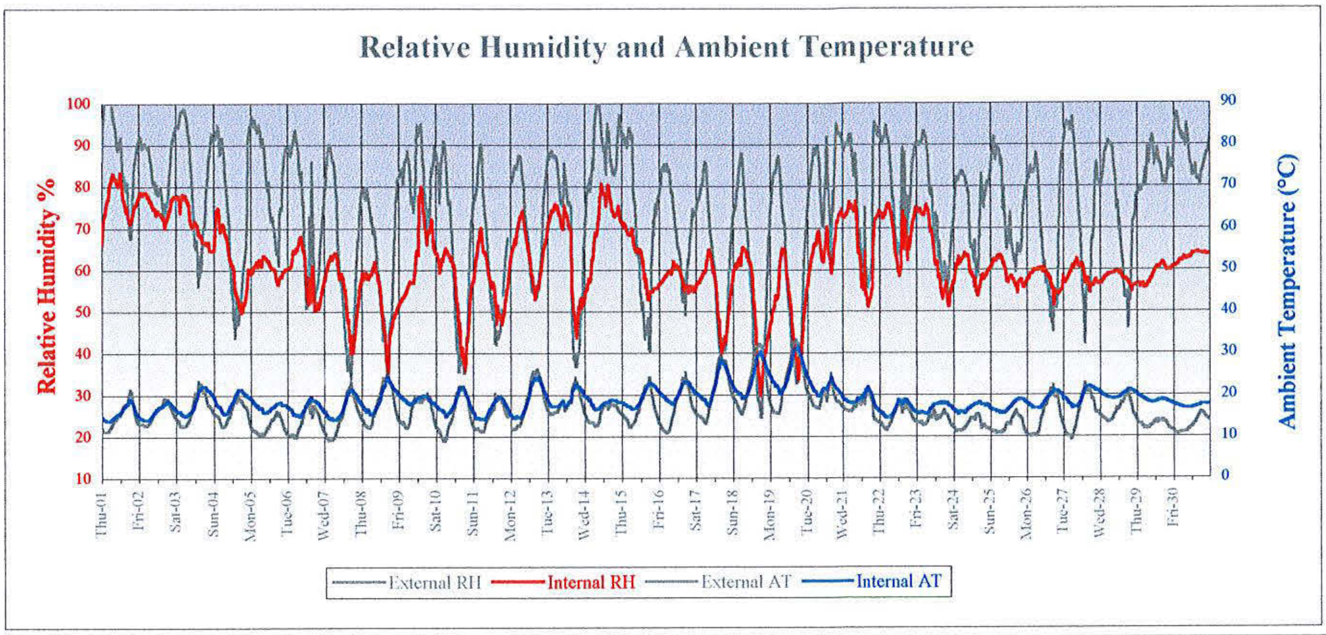


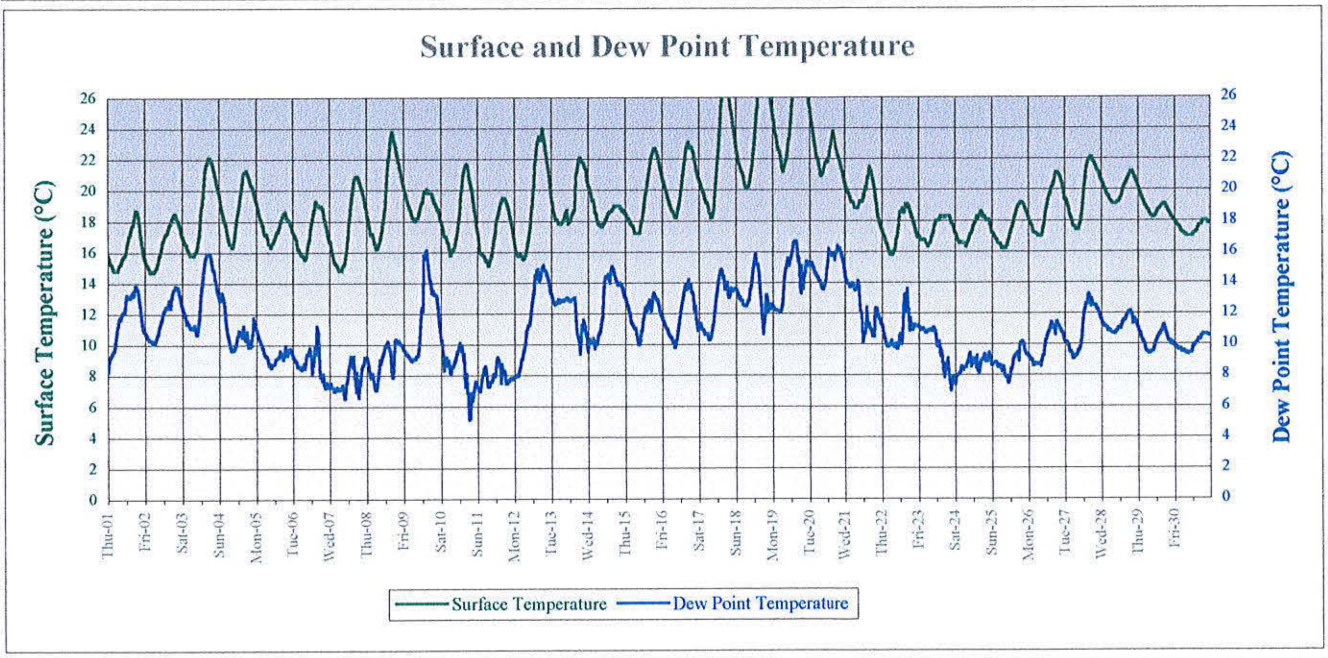
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2001	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

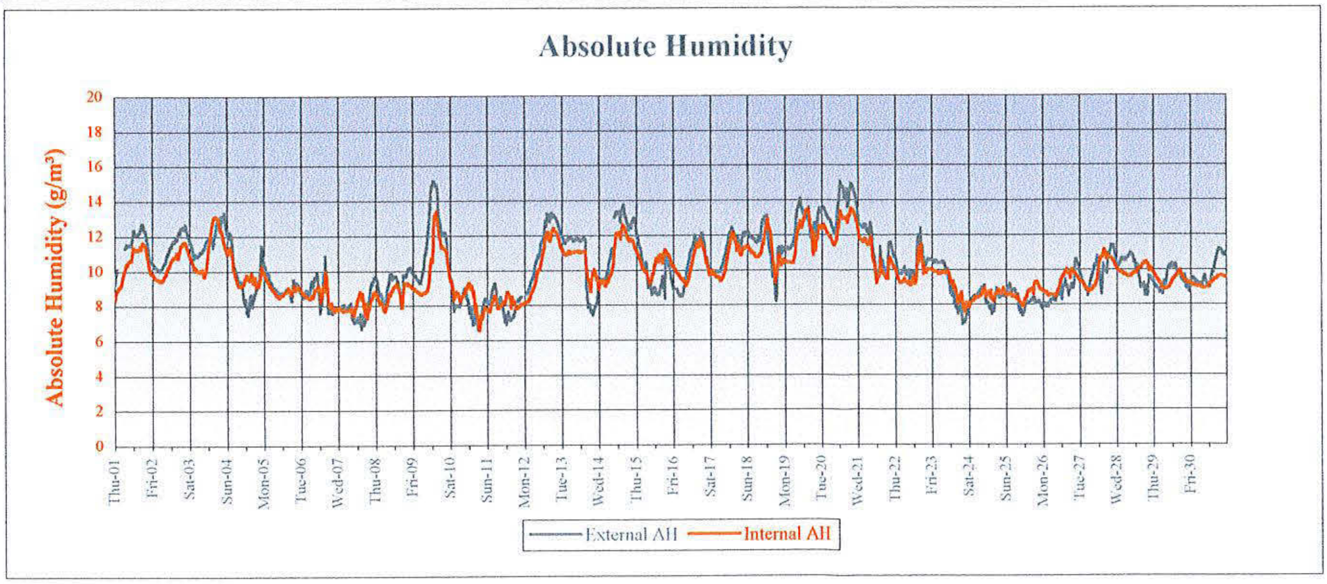
Peterborough Cathedral Nave Ceiling

June 2000

Probe 2: Bay 36 III upper side (shade)



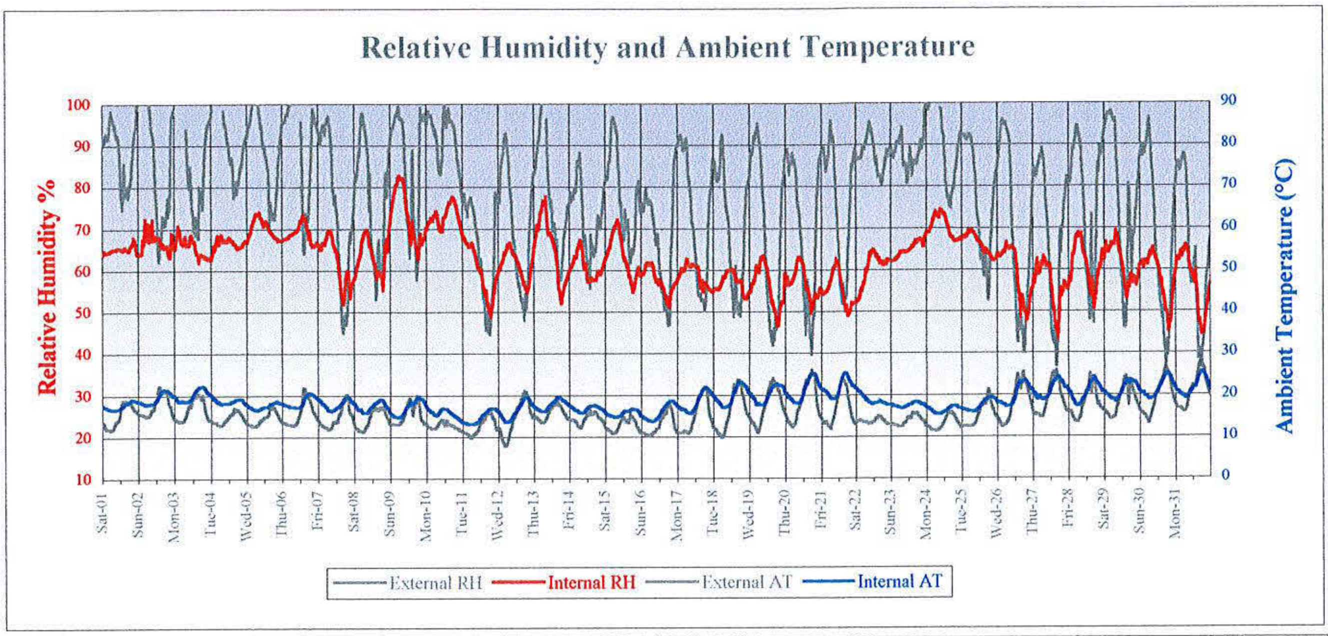


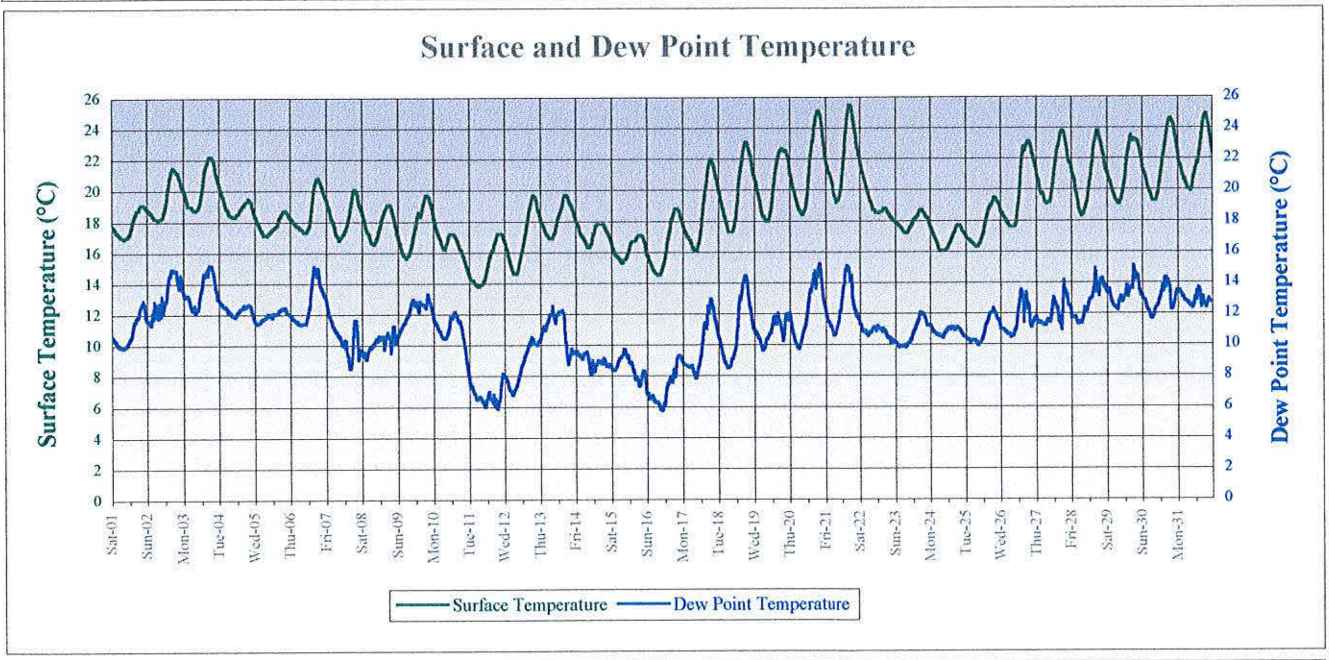


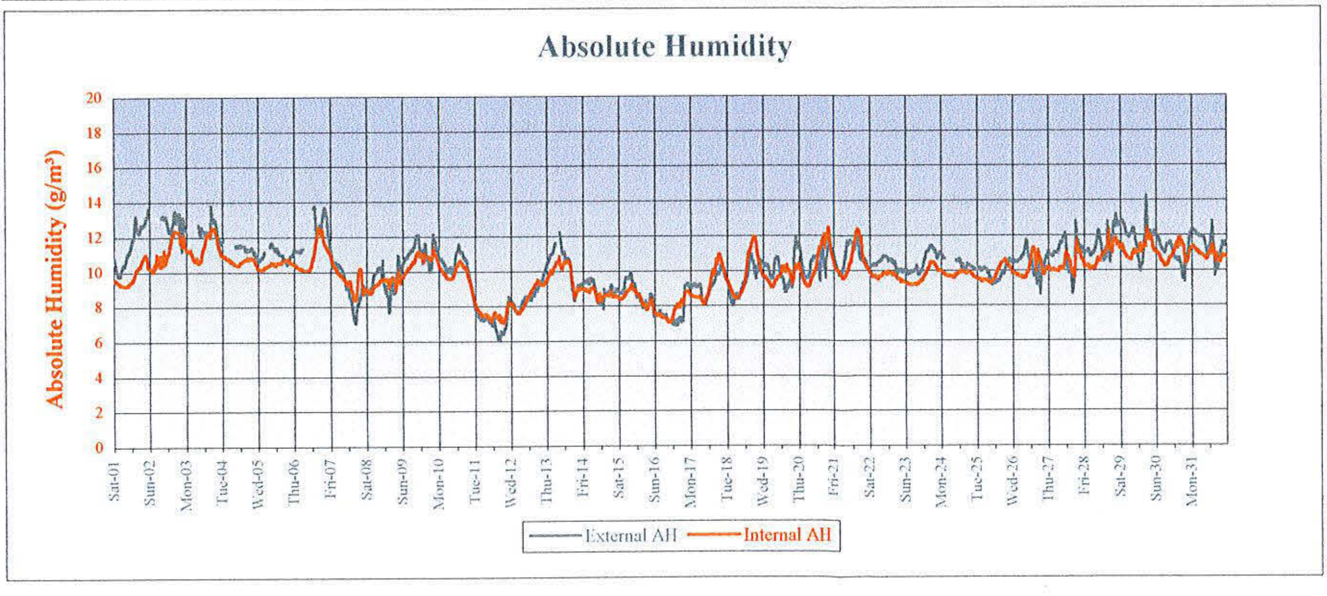
Peterborough Cathedral Nave Ceiling

July 2000

Probe 2: Bay 36 III upper side (shade)





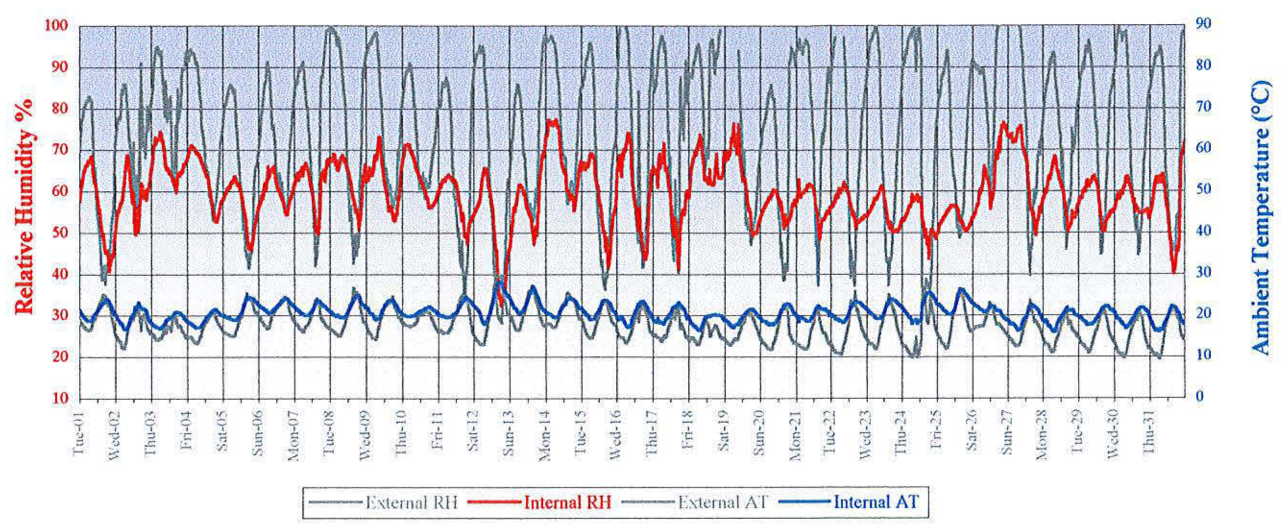


Peterborough Cathedral Nave Ceiling

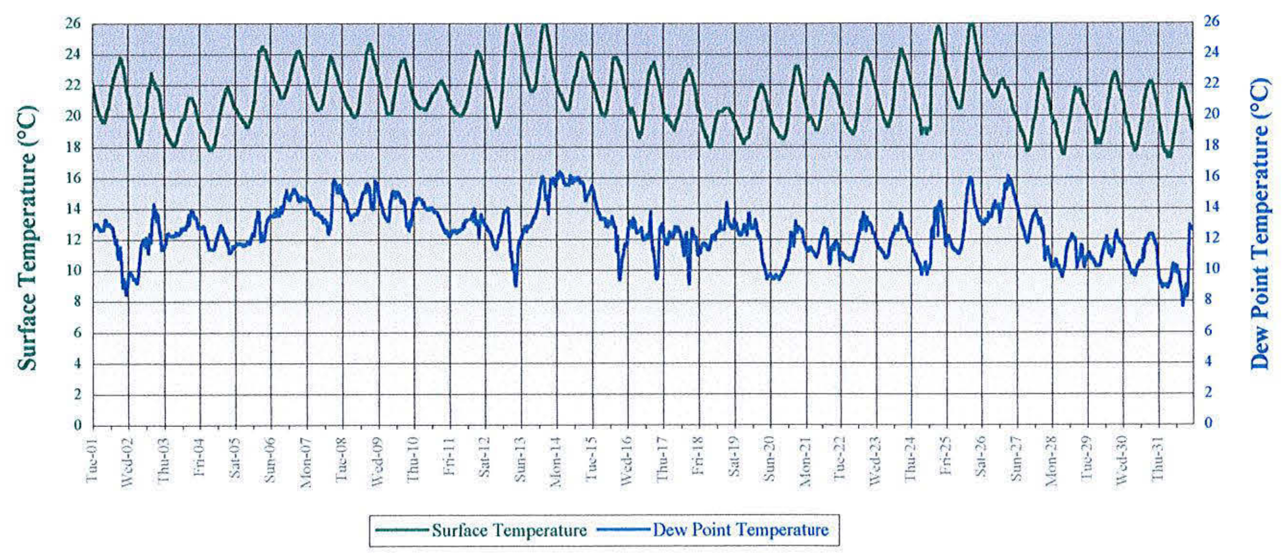
August 2000

Probe 2: Bay 36 III upper side (shade)

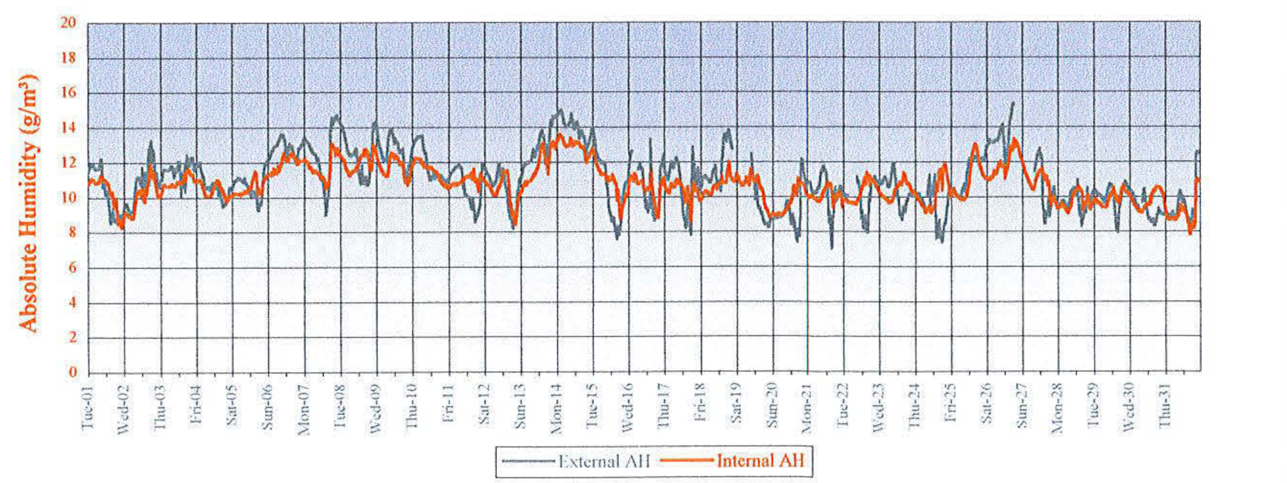
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



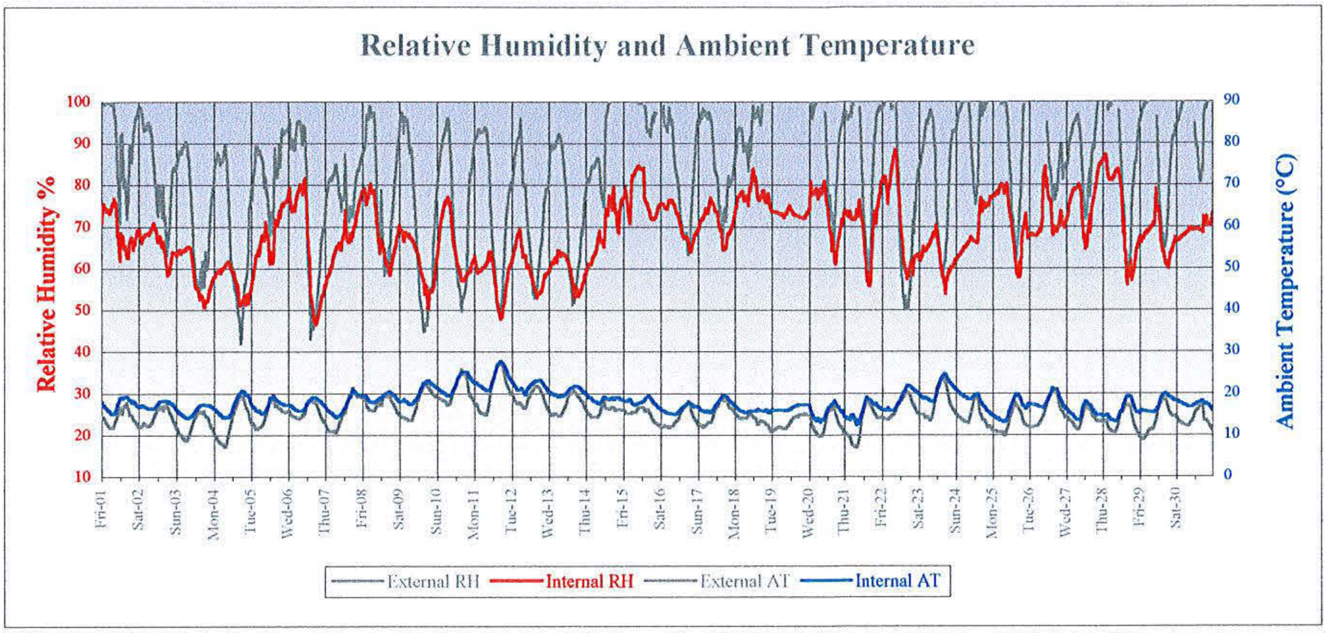
Absolute Humidity

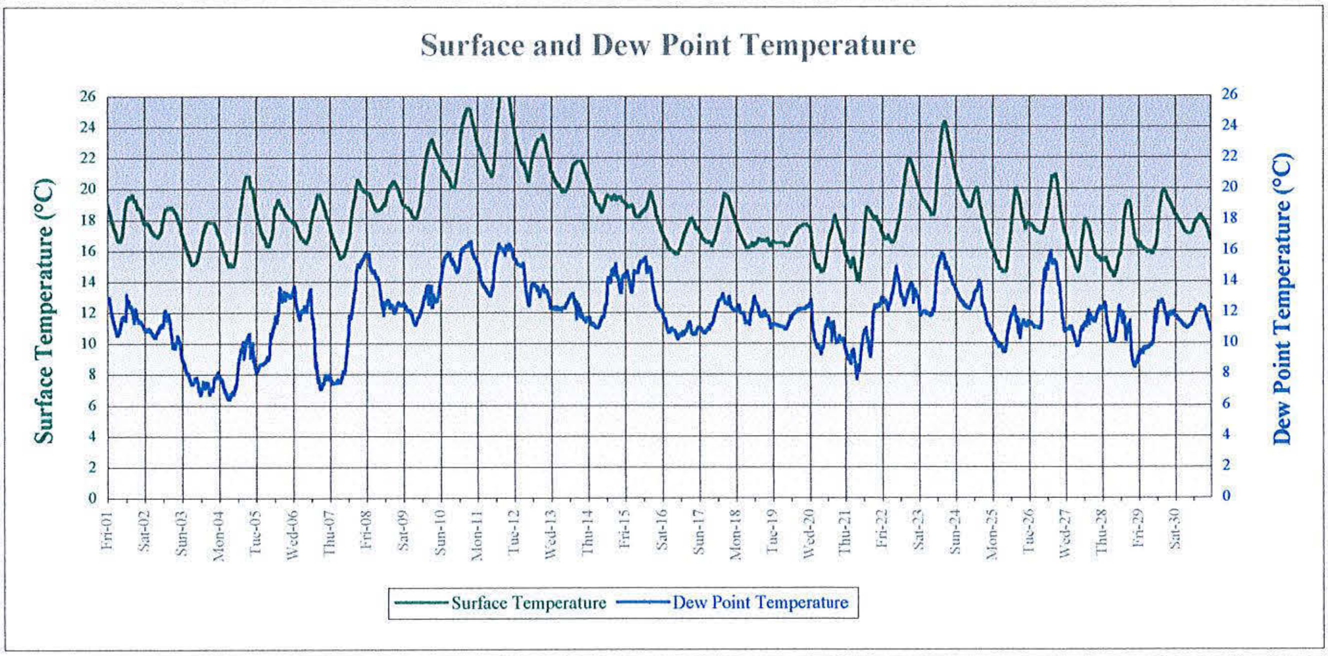


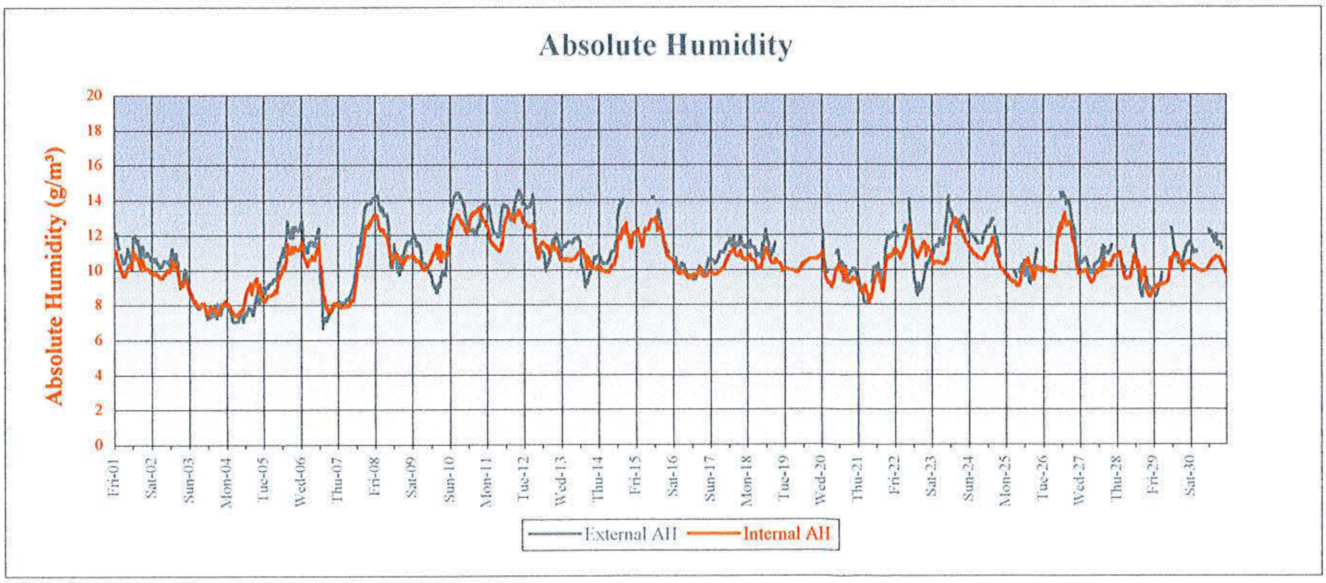
Peterborough Cathedral Nave Ceiling

September 2000

Probe 2: Bay 36 III upper side (shade)



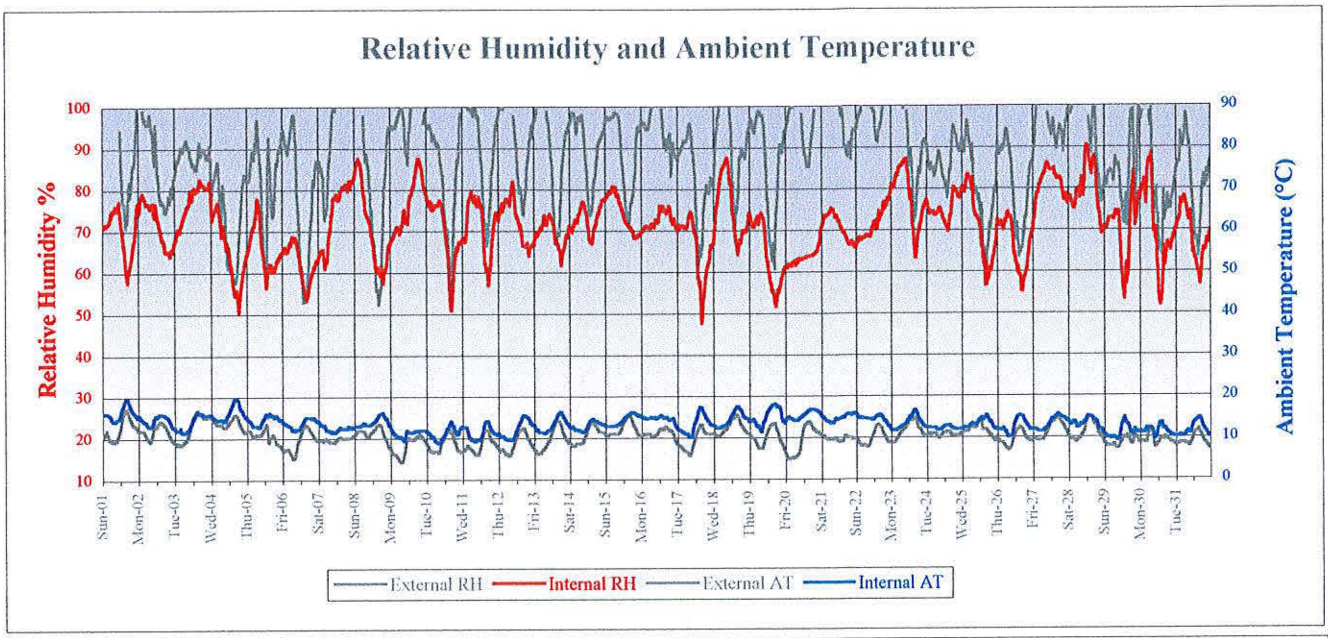


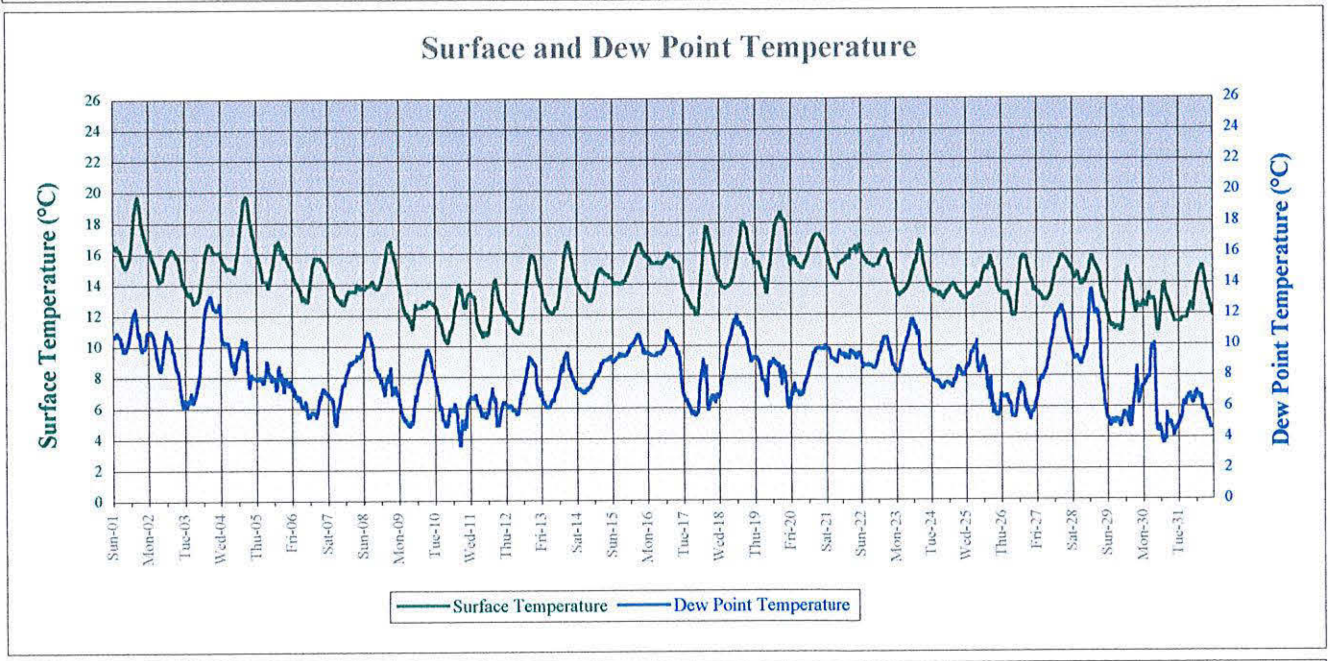


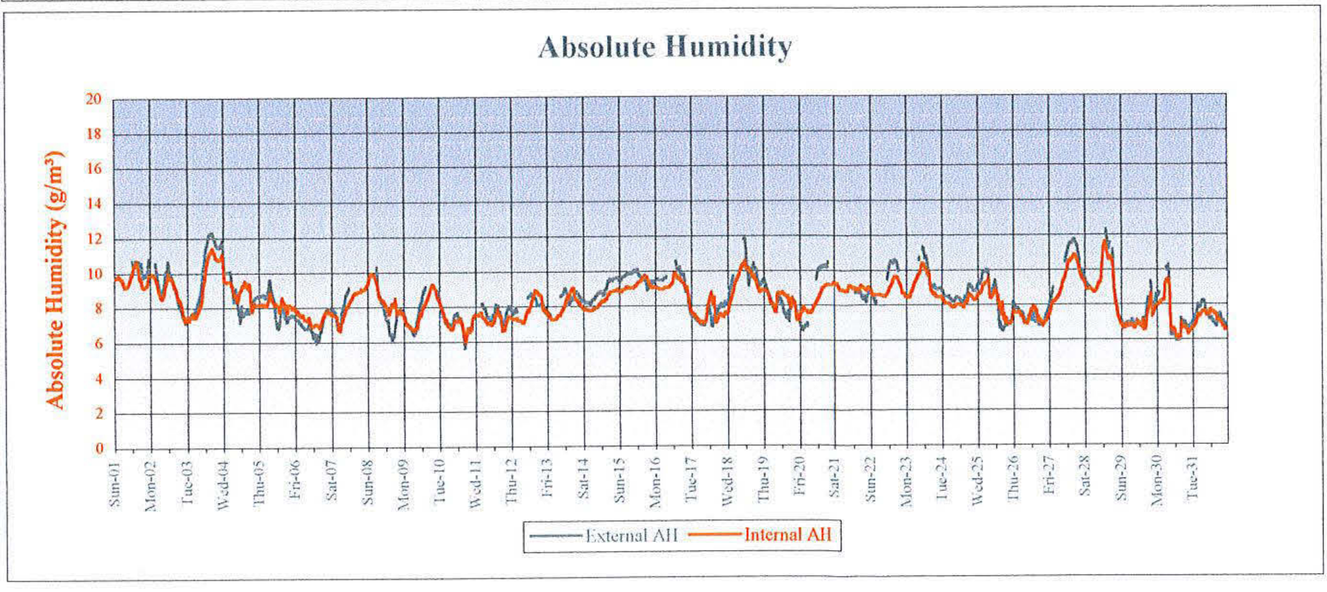
Peterborough Cathedral Nave Ceiling

October 2000

Probe 2: Bay 36 III upper side (shade)



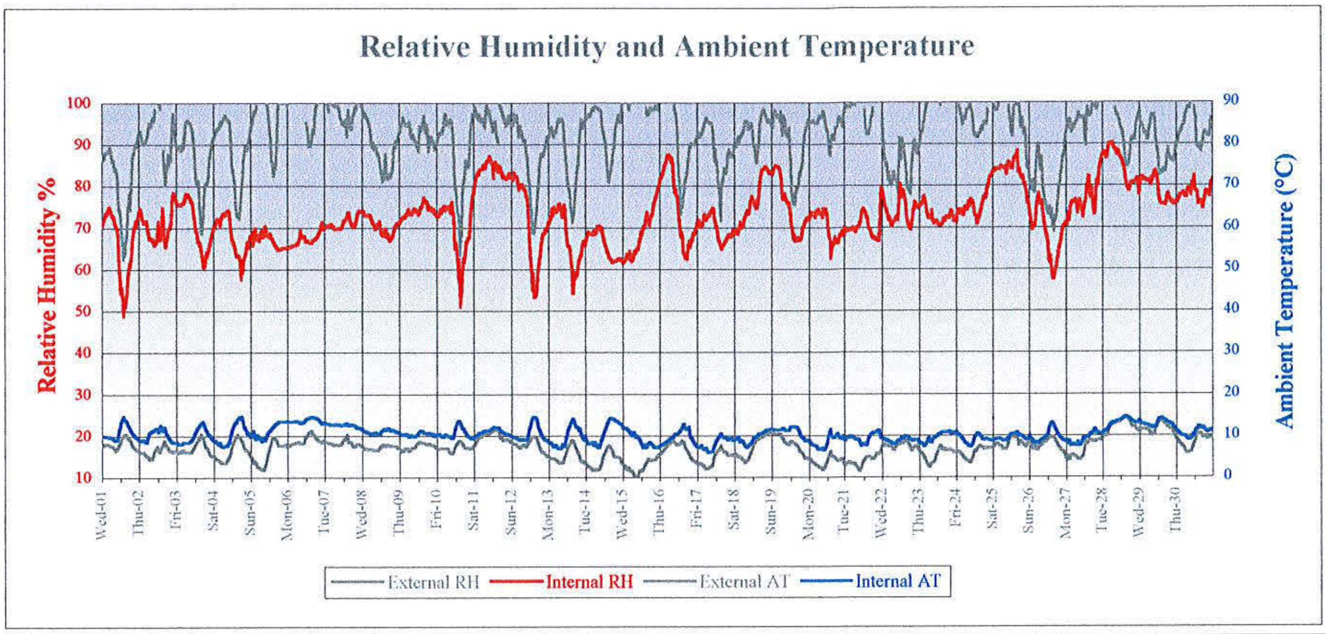


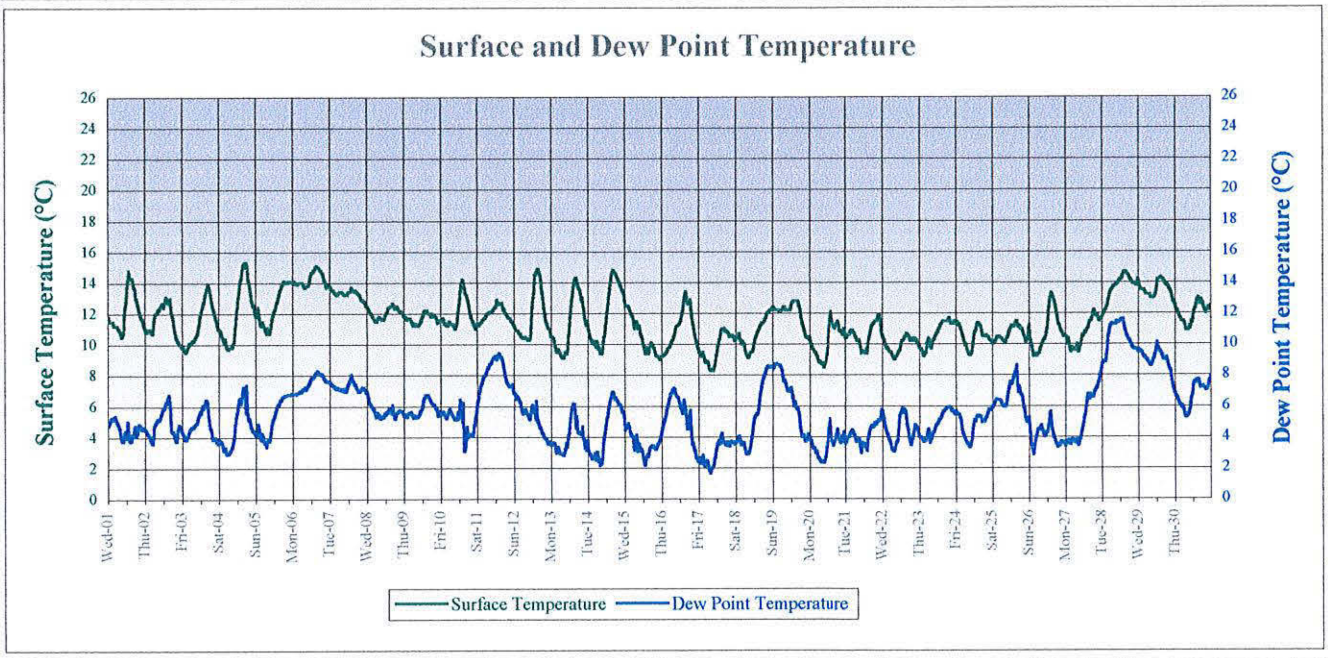


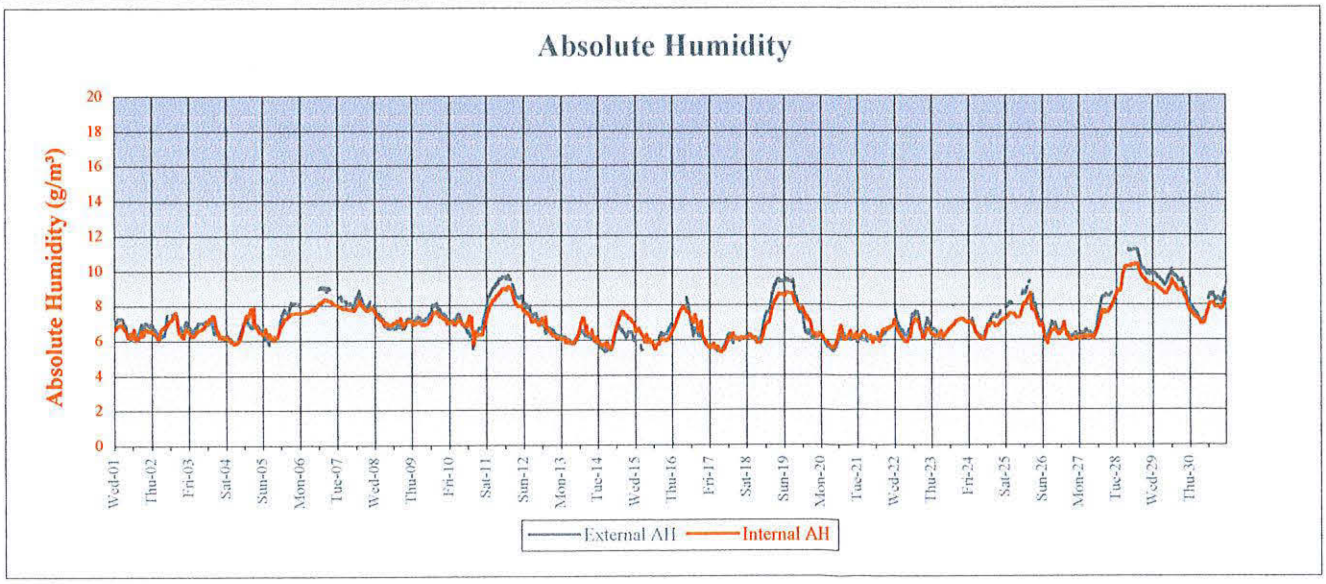
Peterborough Cathedral Nave Ceiling

November 2000

Probe 2: Bay 36 III upper side (shade)



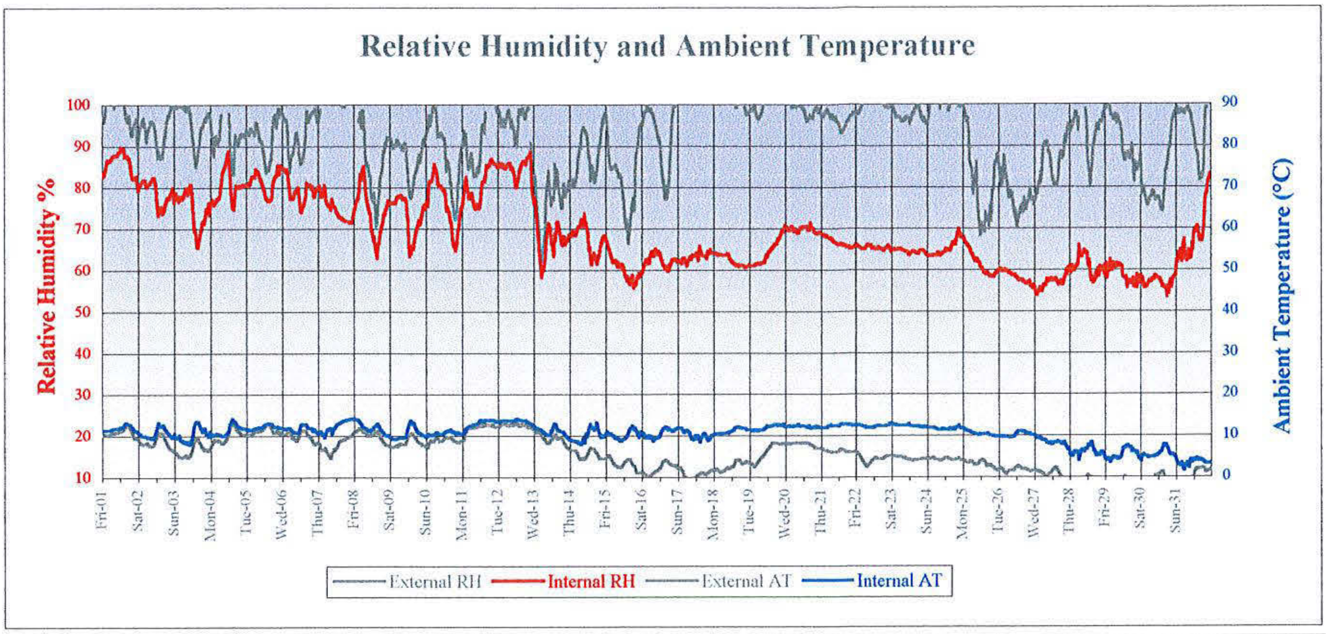


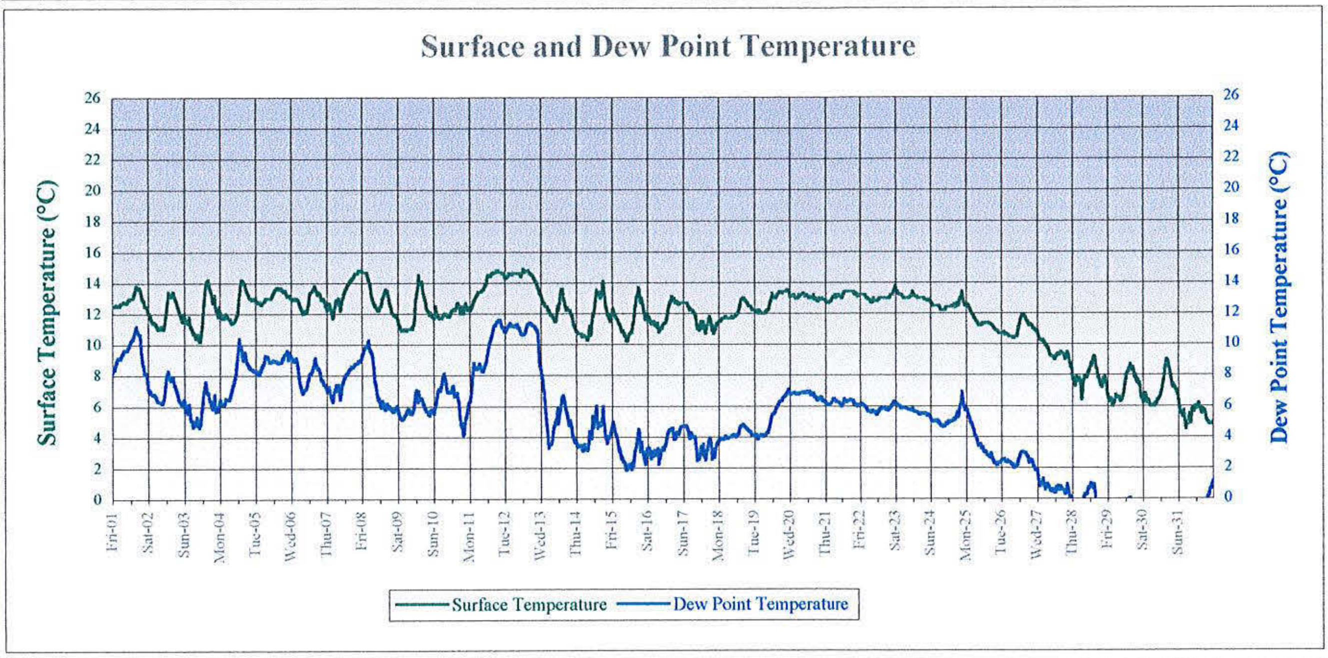


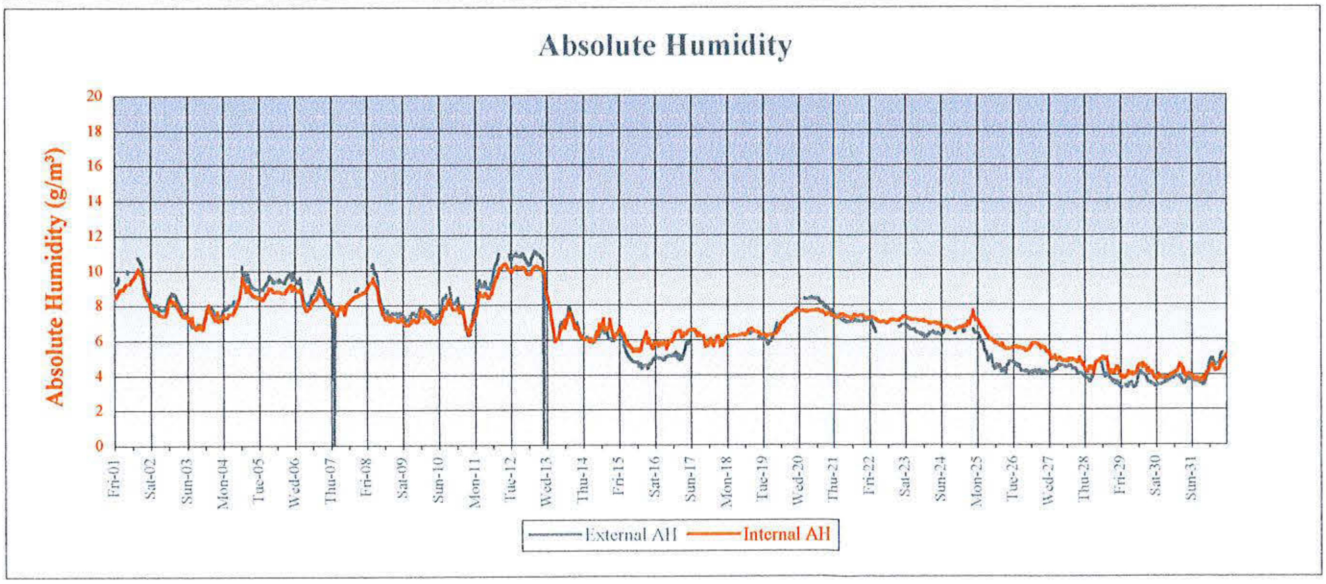
Peterborough Cathedral Nave Ceiling

December 2000

Probe 2: Bay 36 III upper side (shade)



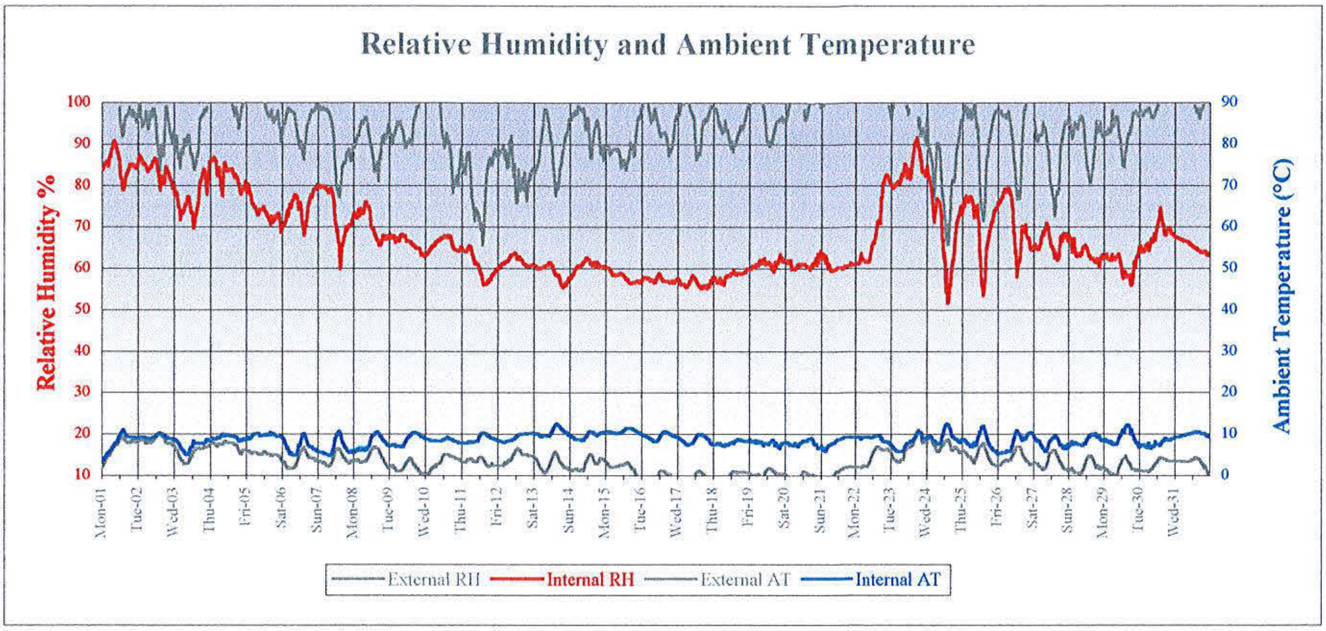


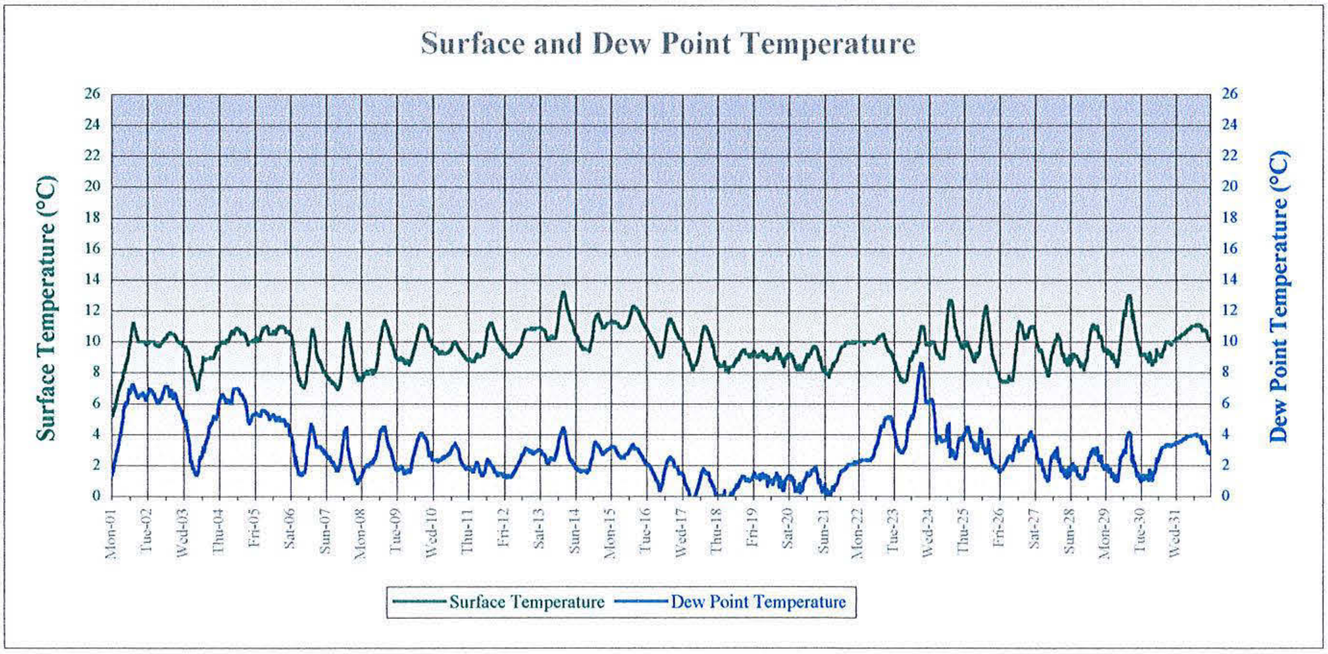


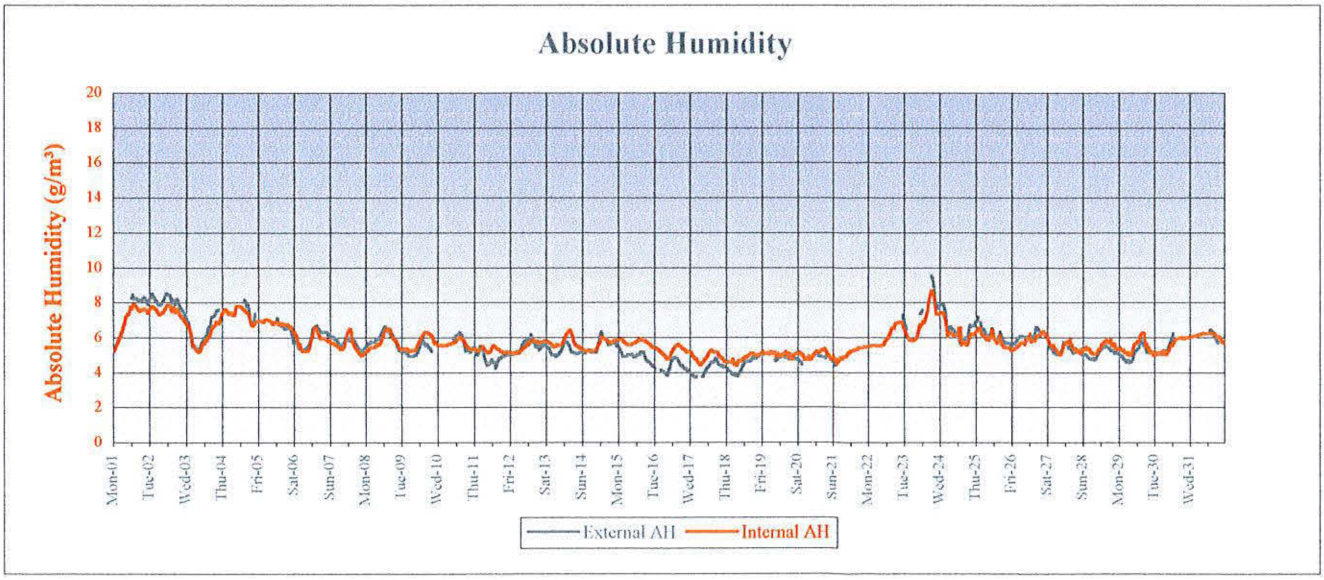
Peterborough Cathedral Nave Ceiling

January 2001

Probe 2: Bay 36 III upper side (shade)



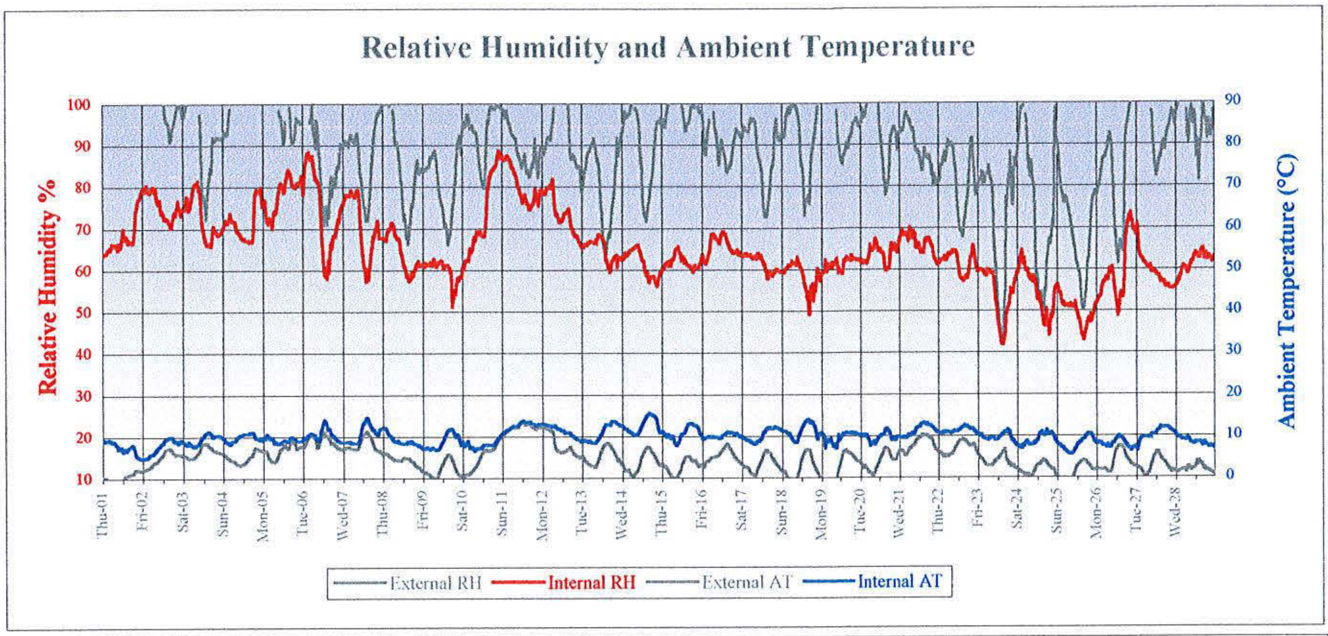


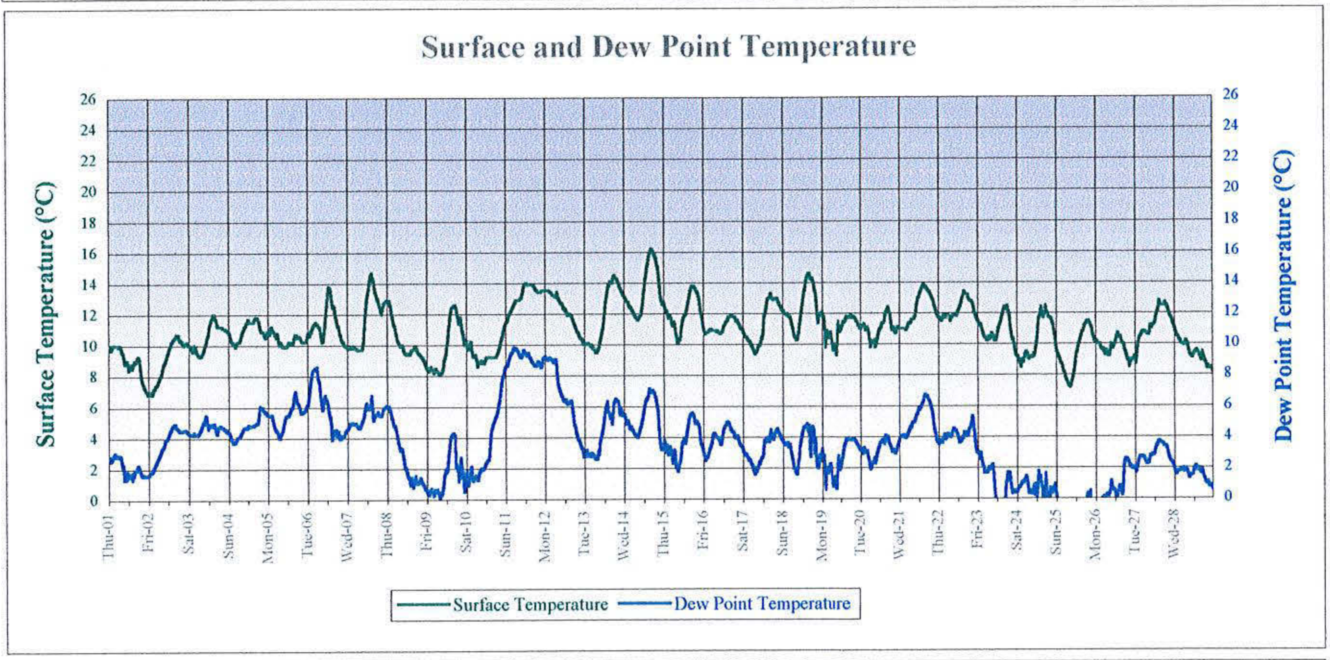


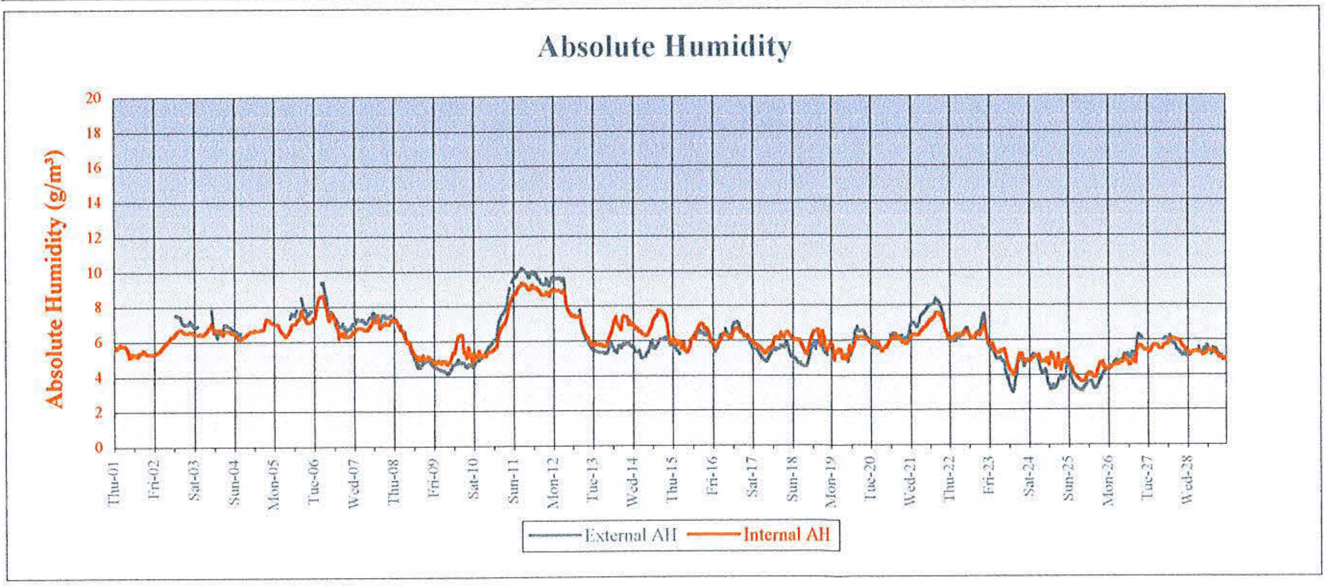
Peterborough Cathedral Nave Ceiling

February 2001

Probe 2: Bay 36 III upper side (shade)

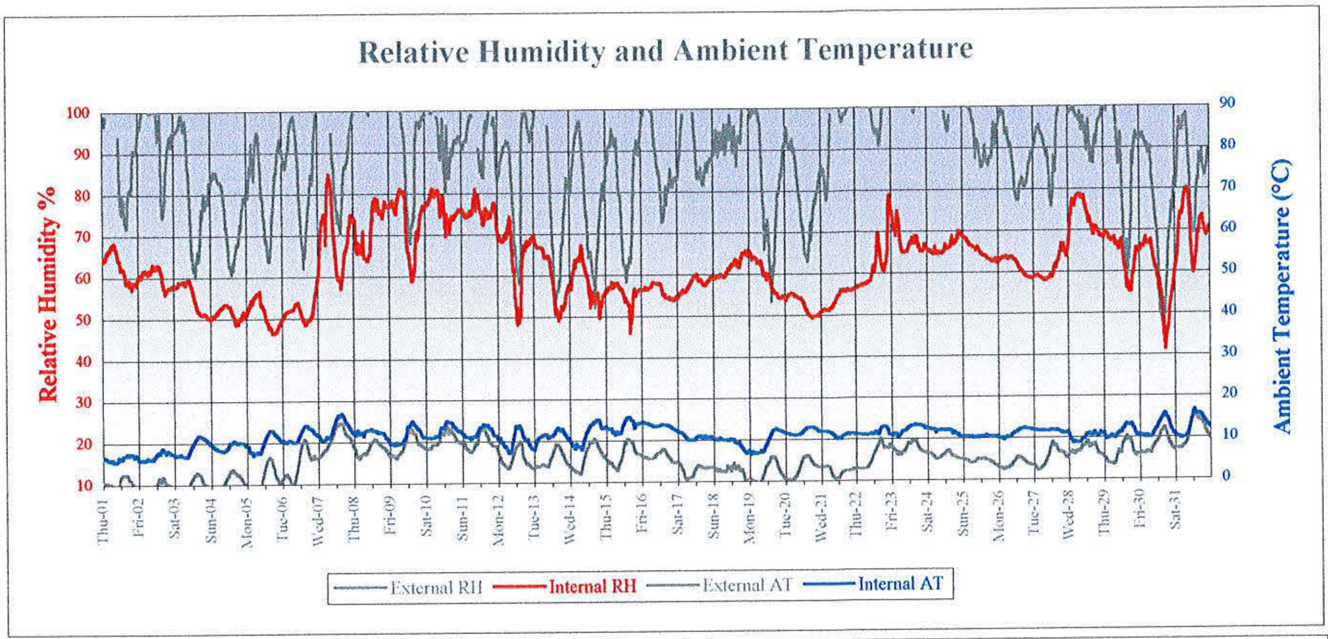


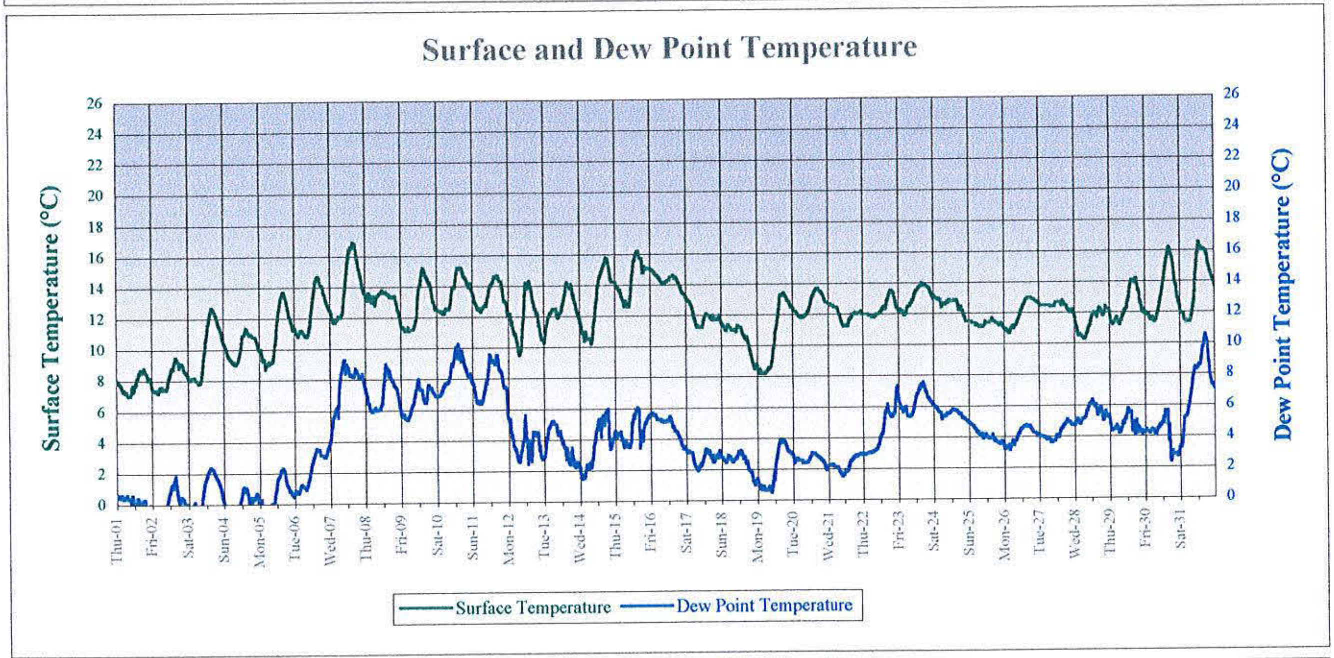


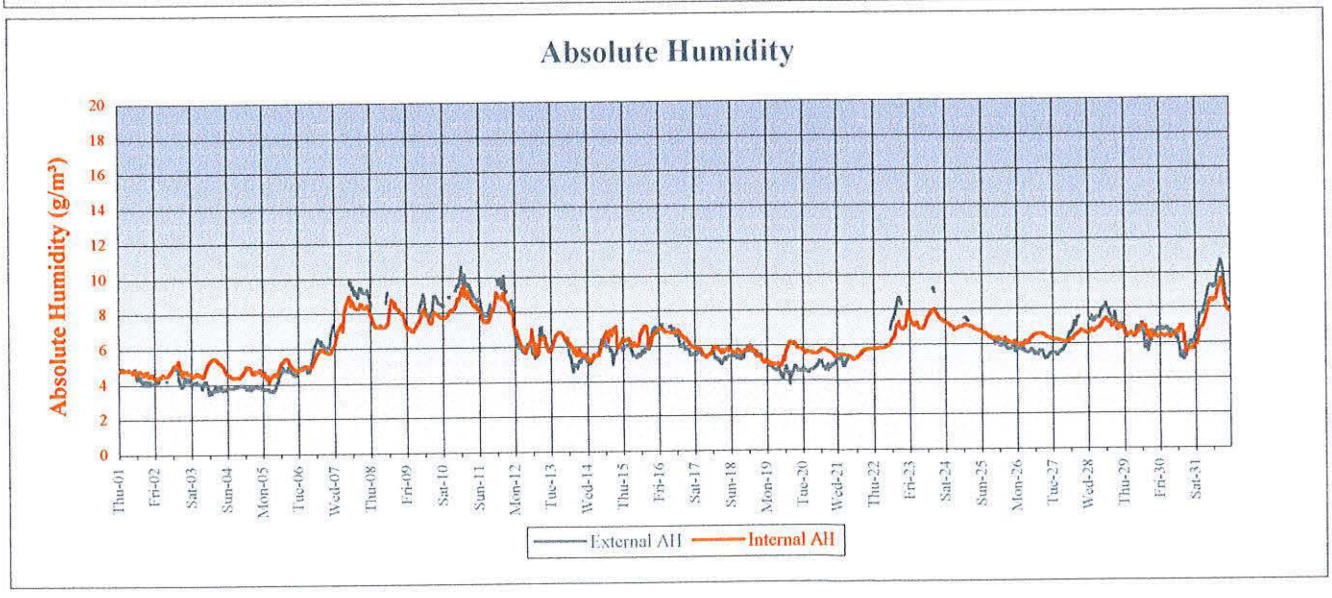


Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)

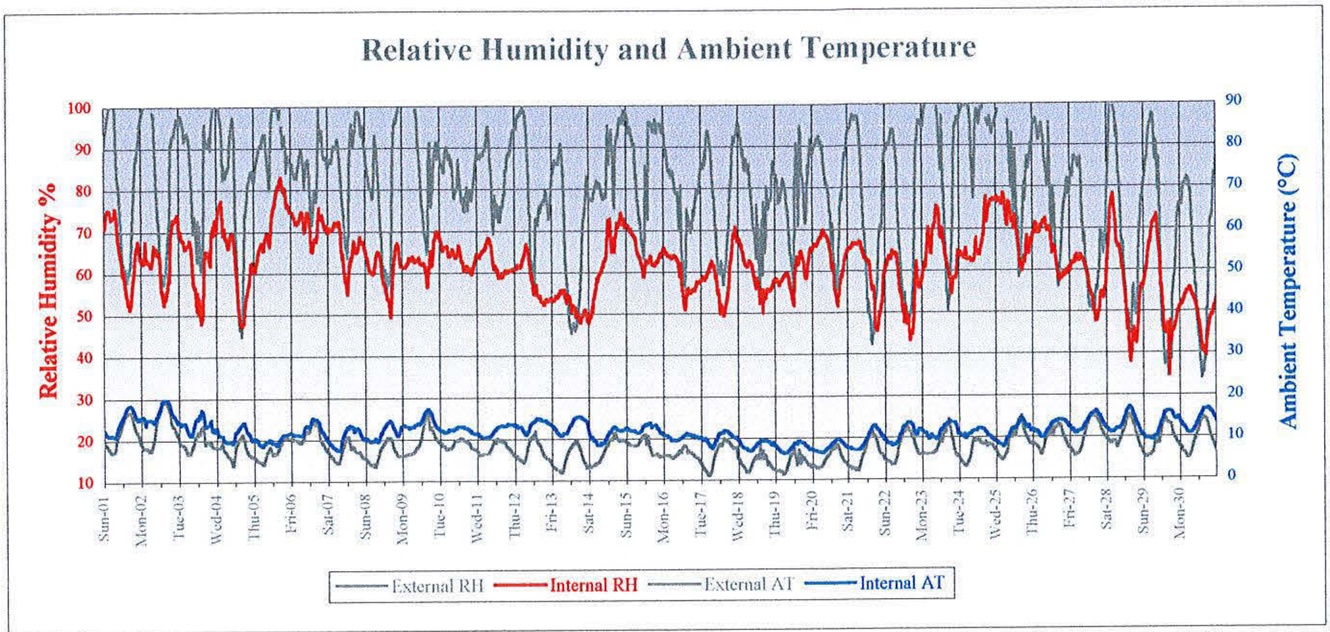


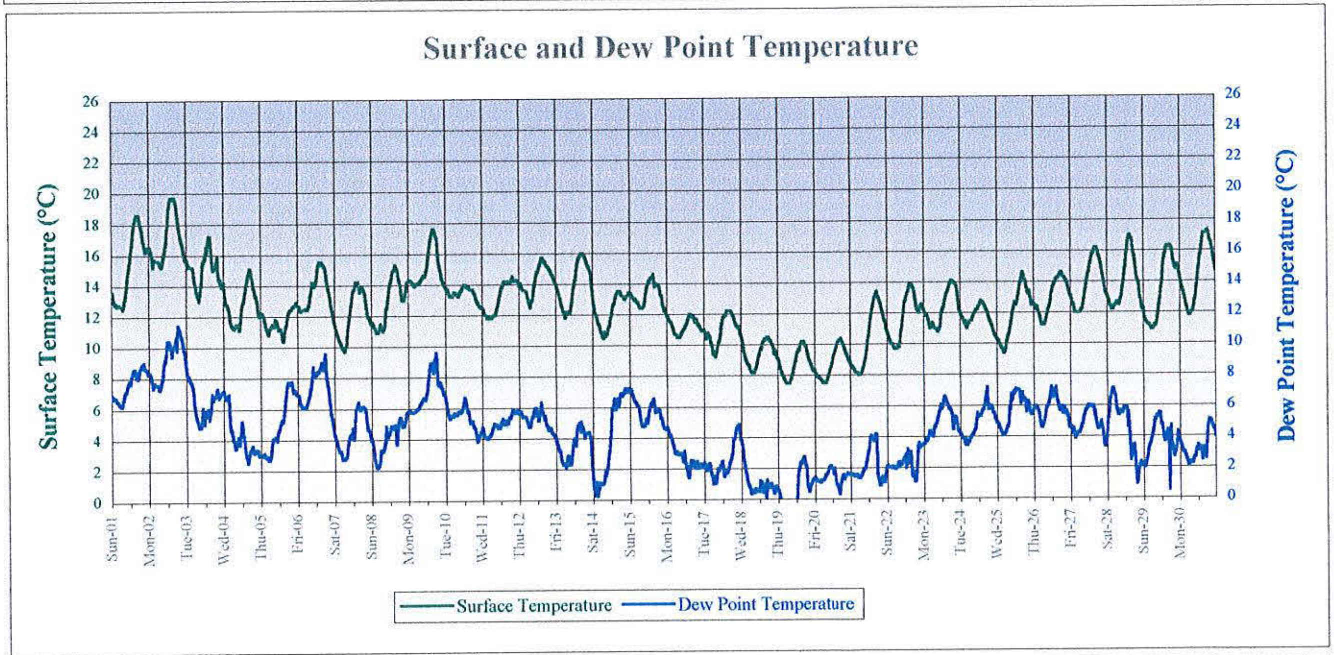


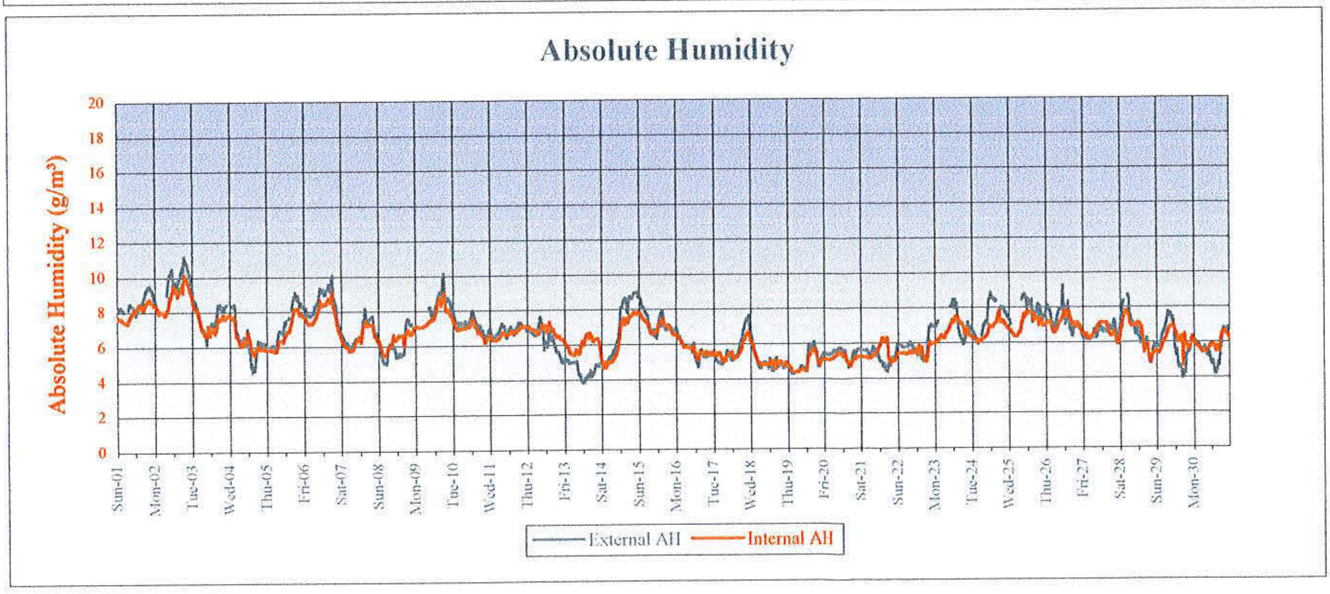


Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)



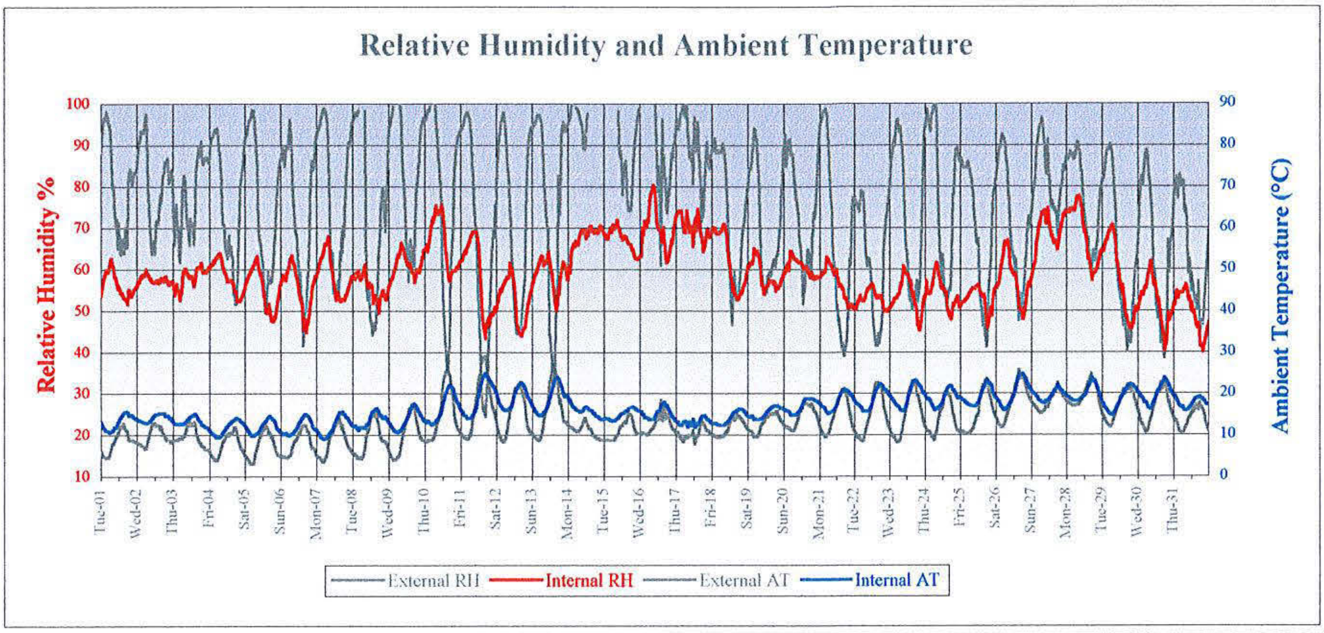


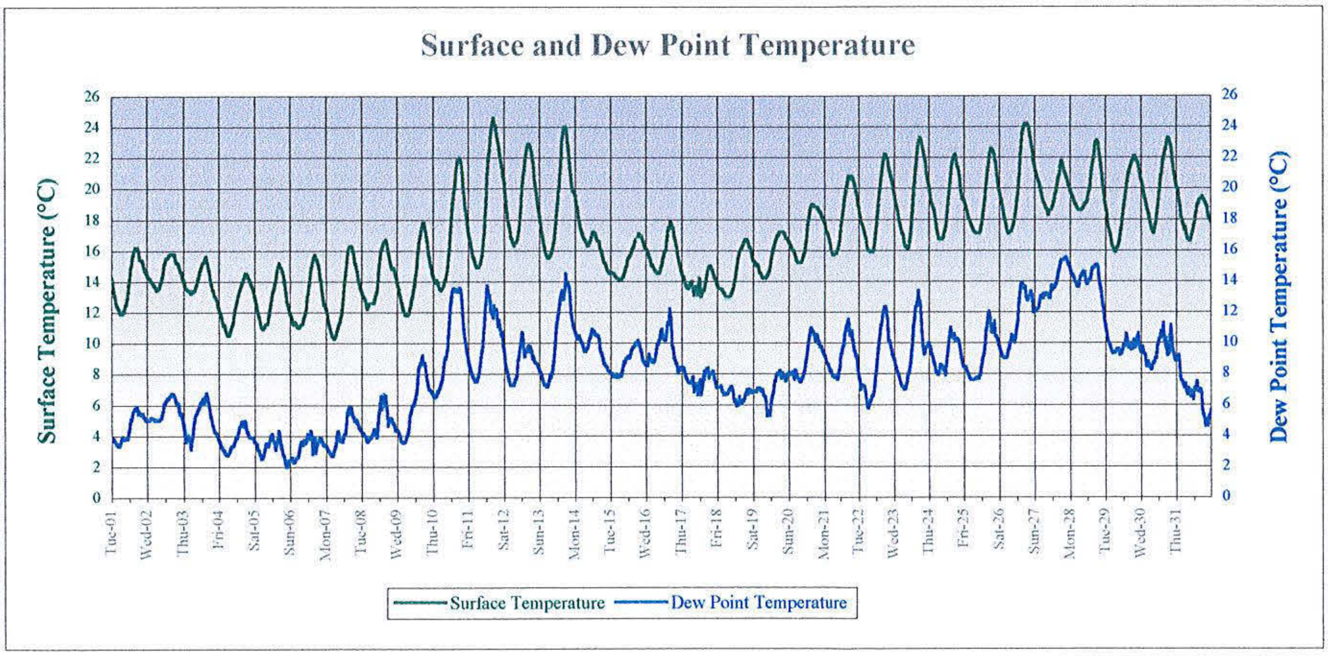


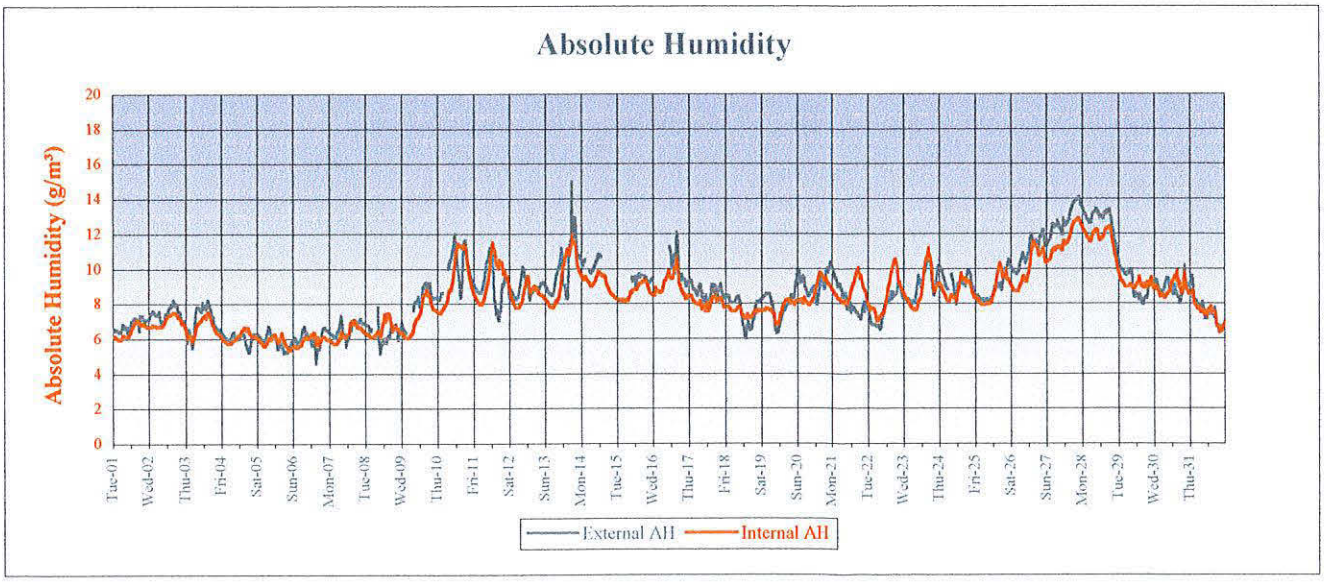
Peterborough Cathedral Nave Ceiling

May 2001

Probe 2: Bay 36 III upper side (shade)



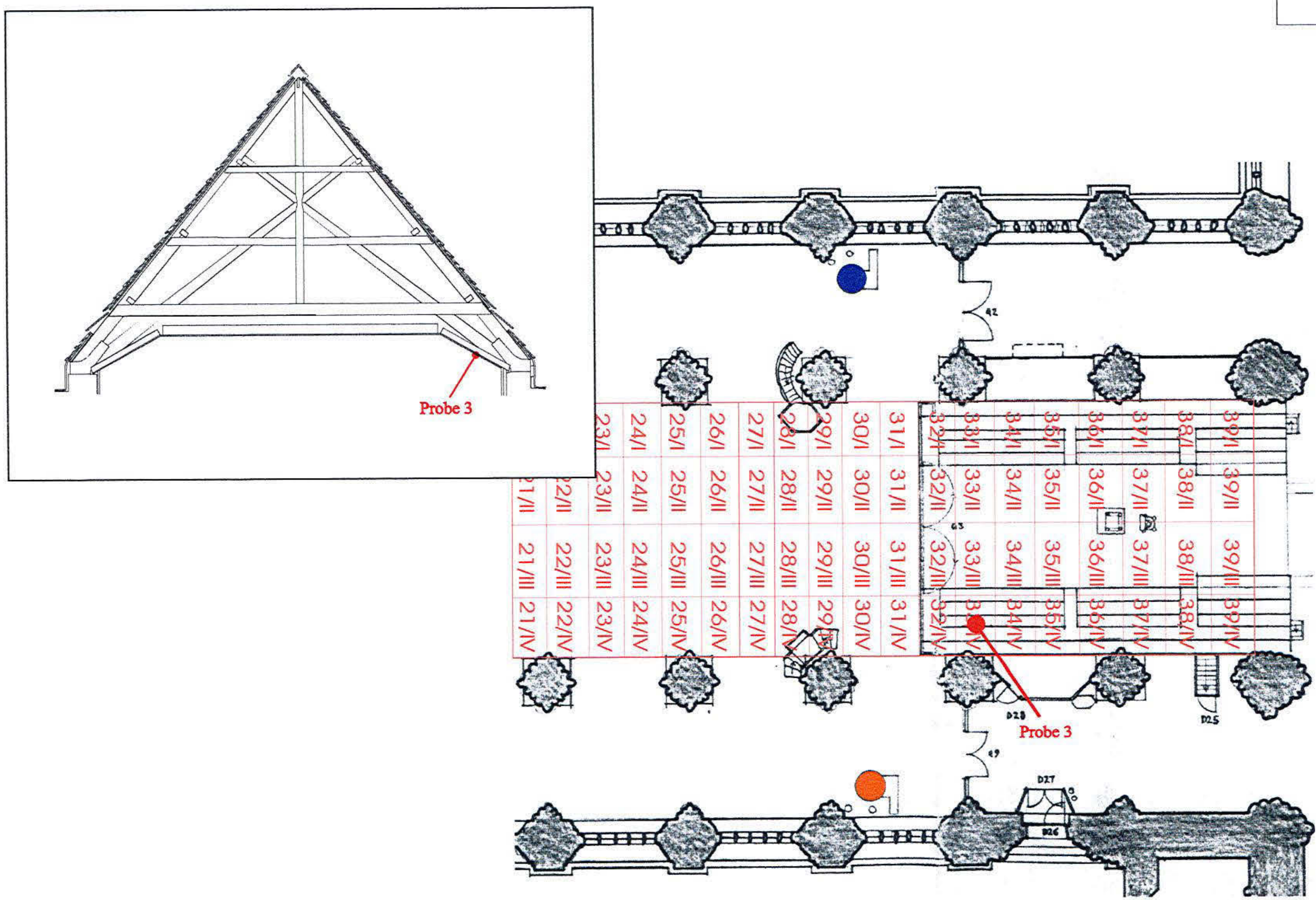




PROBE 3

BAY 33 IV LOWER SIDE (SUN)

DIAGRAM 5

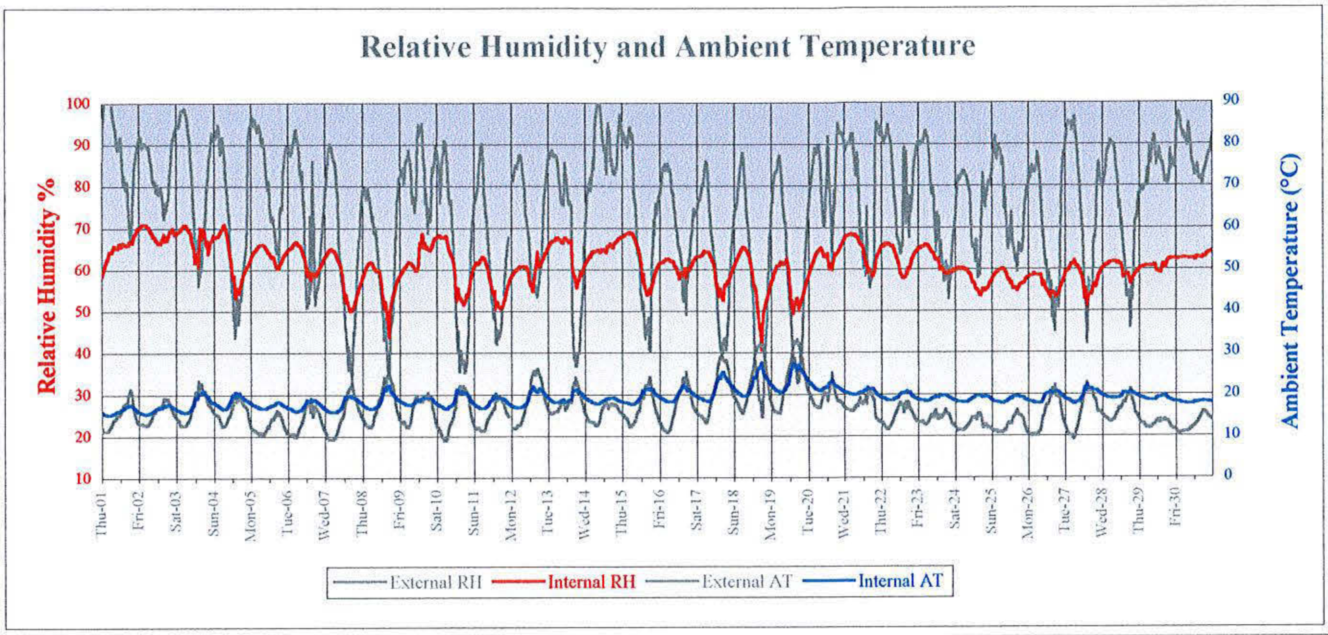


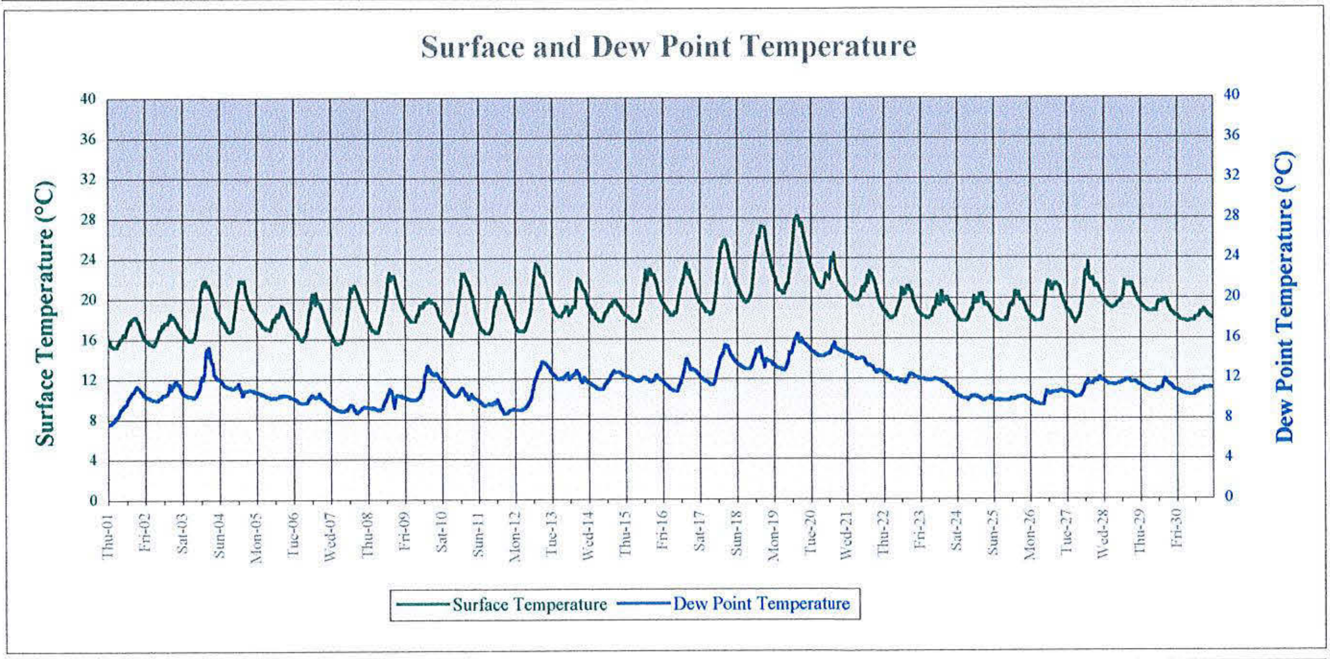
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2001	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

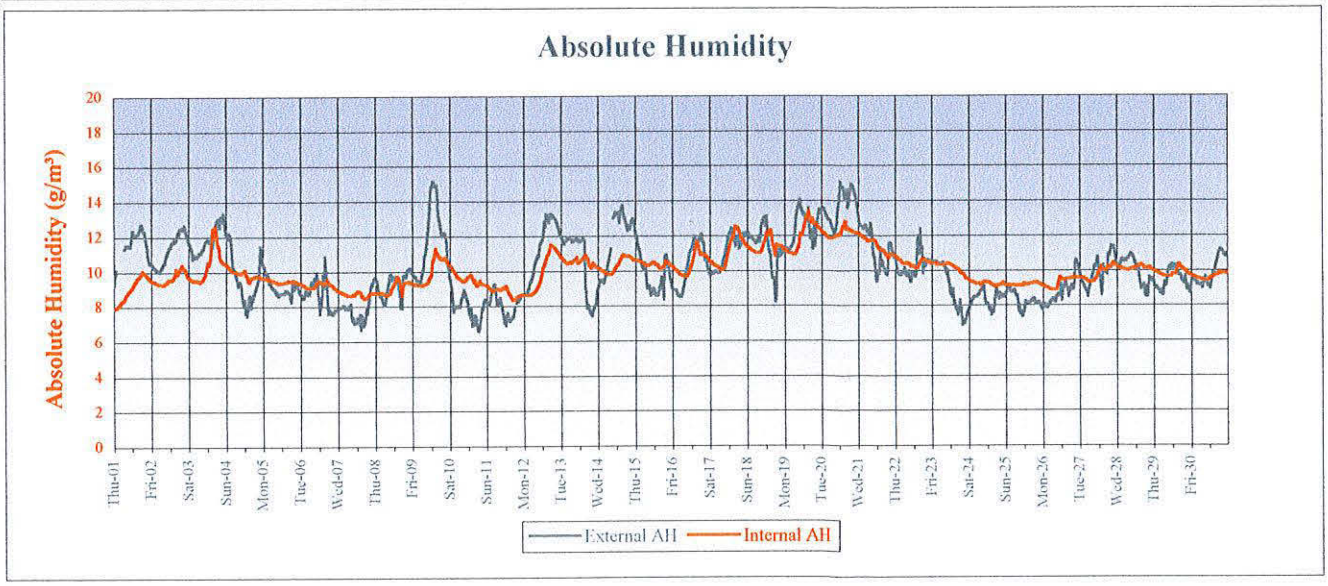
Peterborough Cathedral Nave Ceiling

June 2000

Probe 3: Bay 33 III lower side (sun)



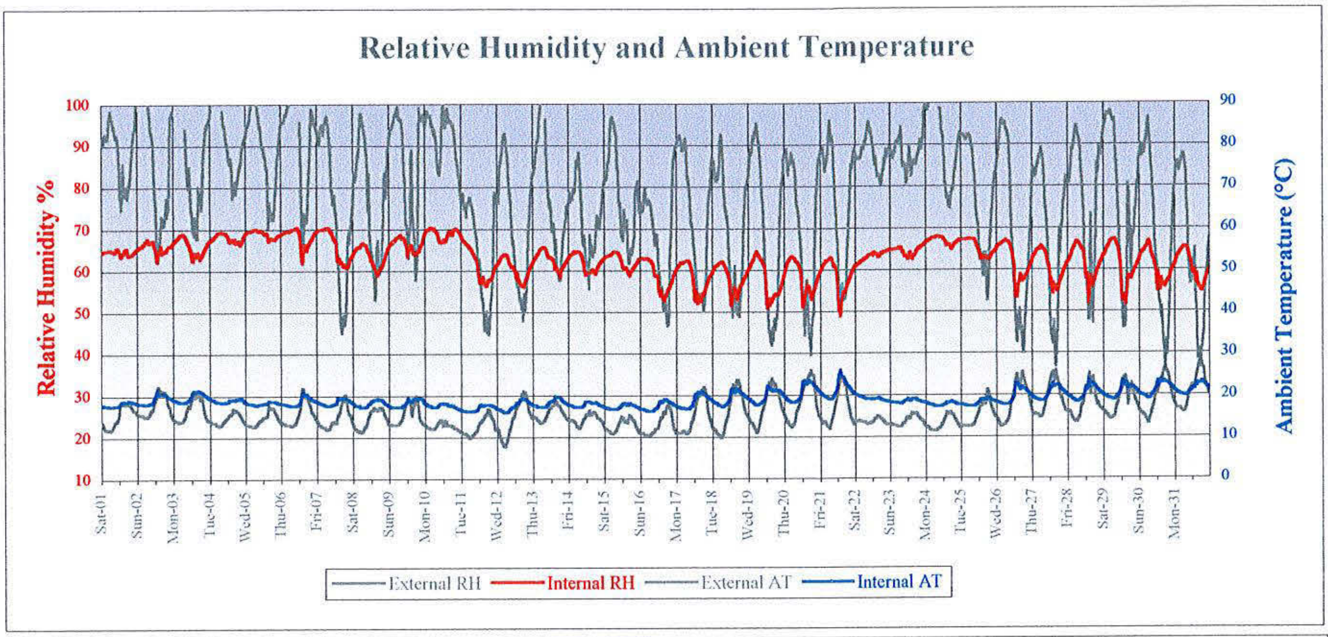


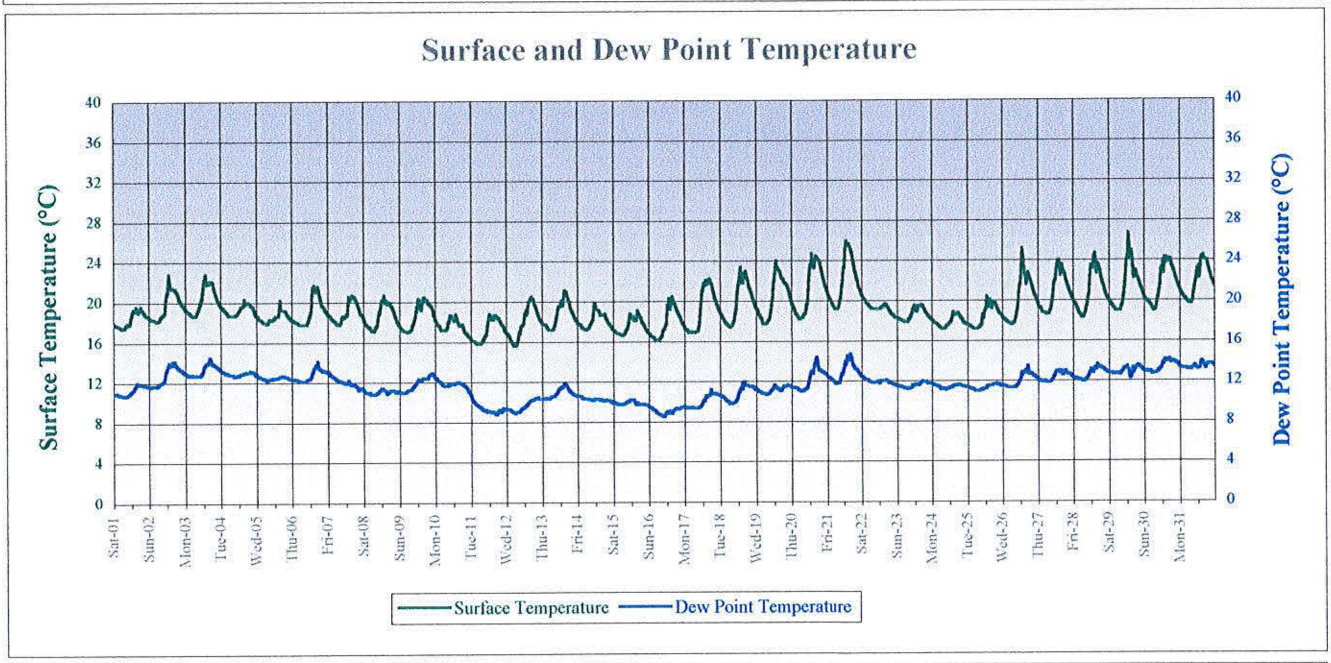


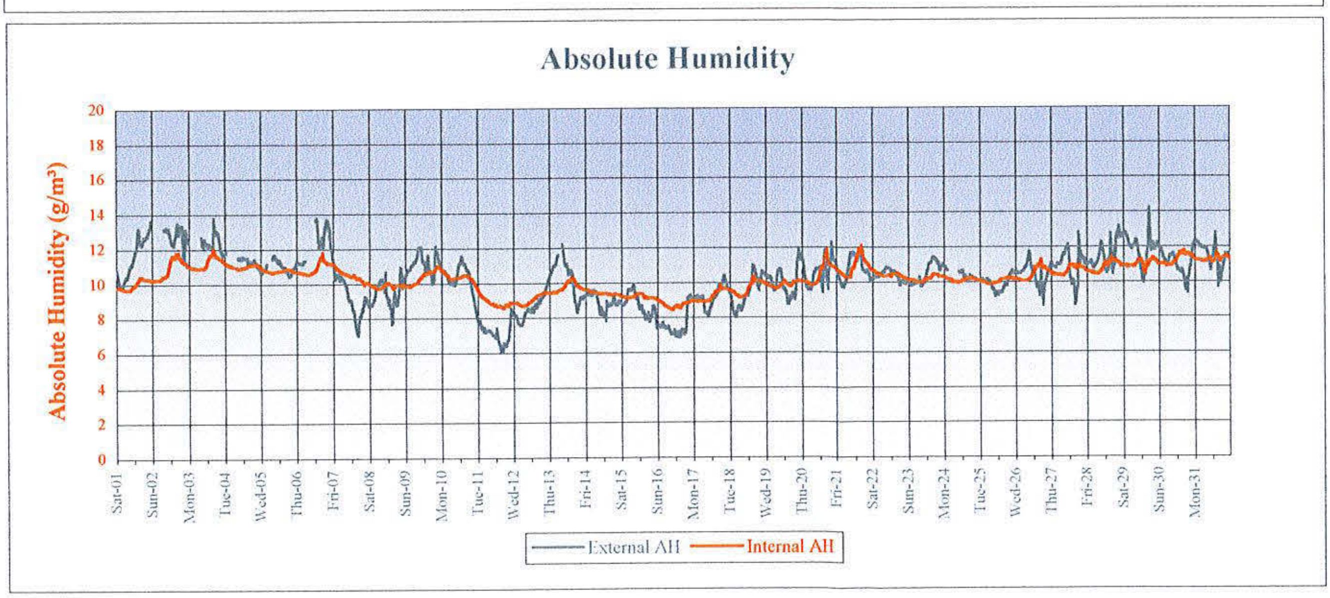
Peterborough Cathedral Nave Ceiling

July 2000

Probe 3: Bay 33 III lower side (sun)

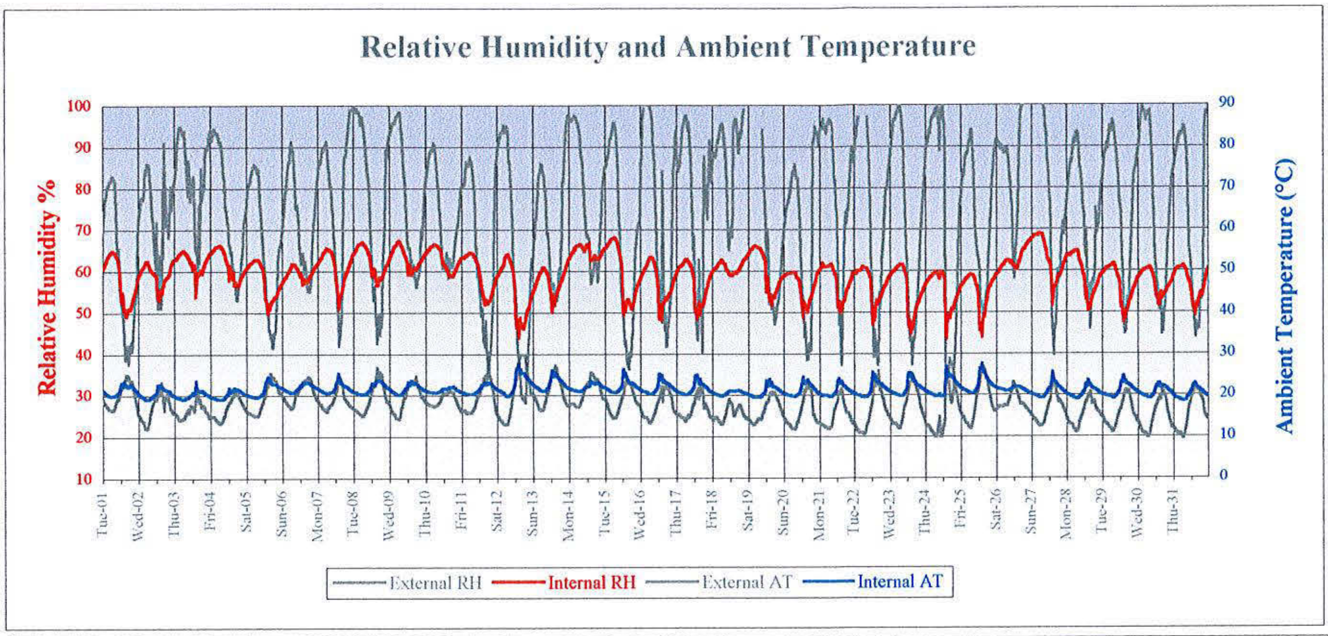


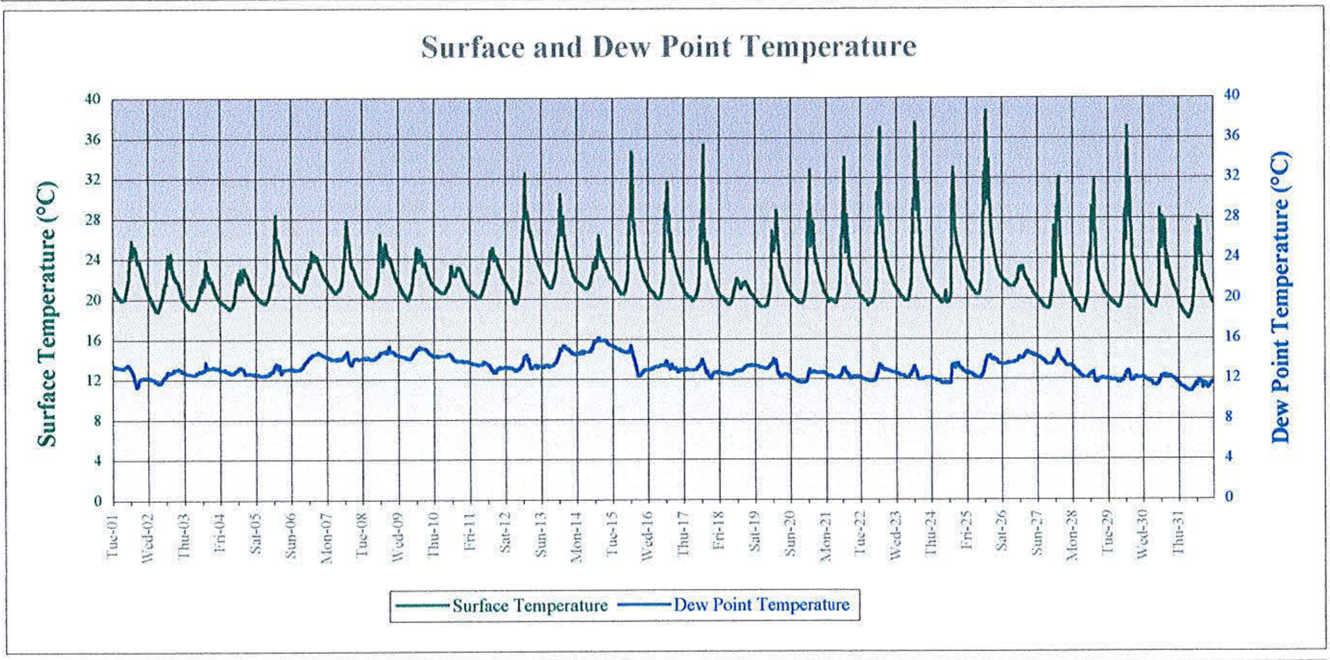


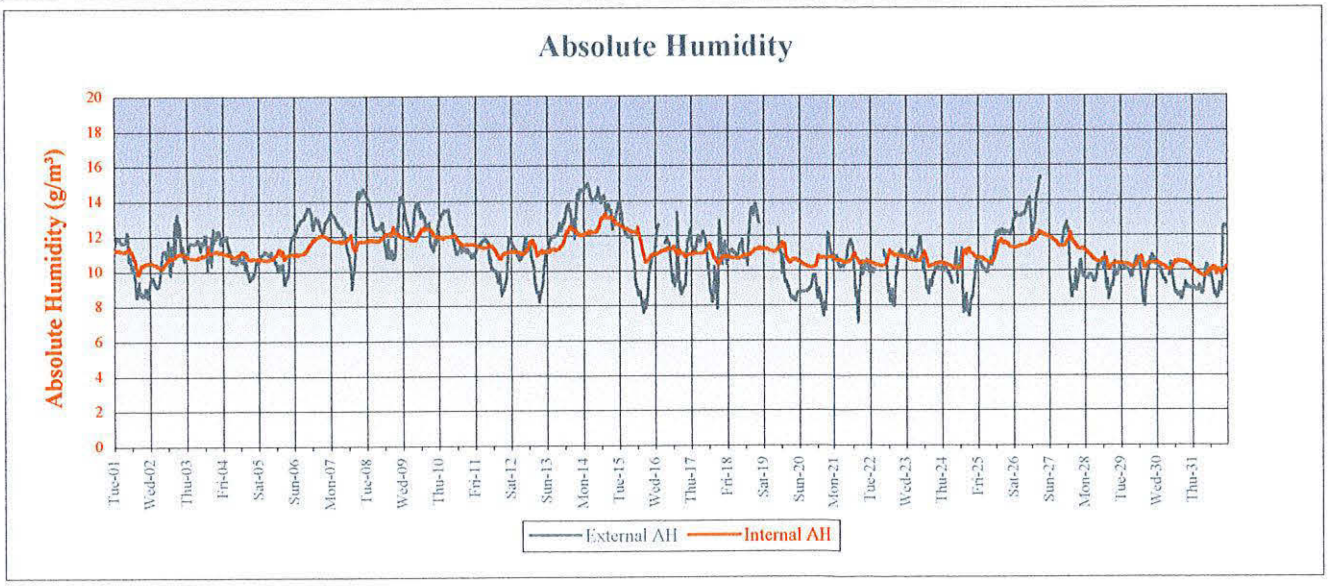


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)



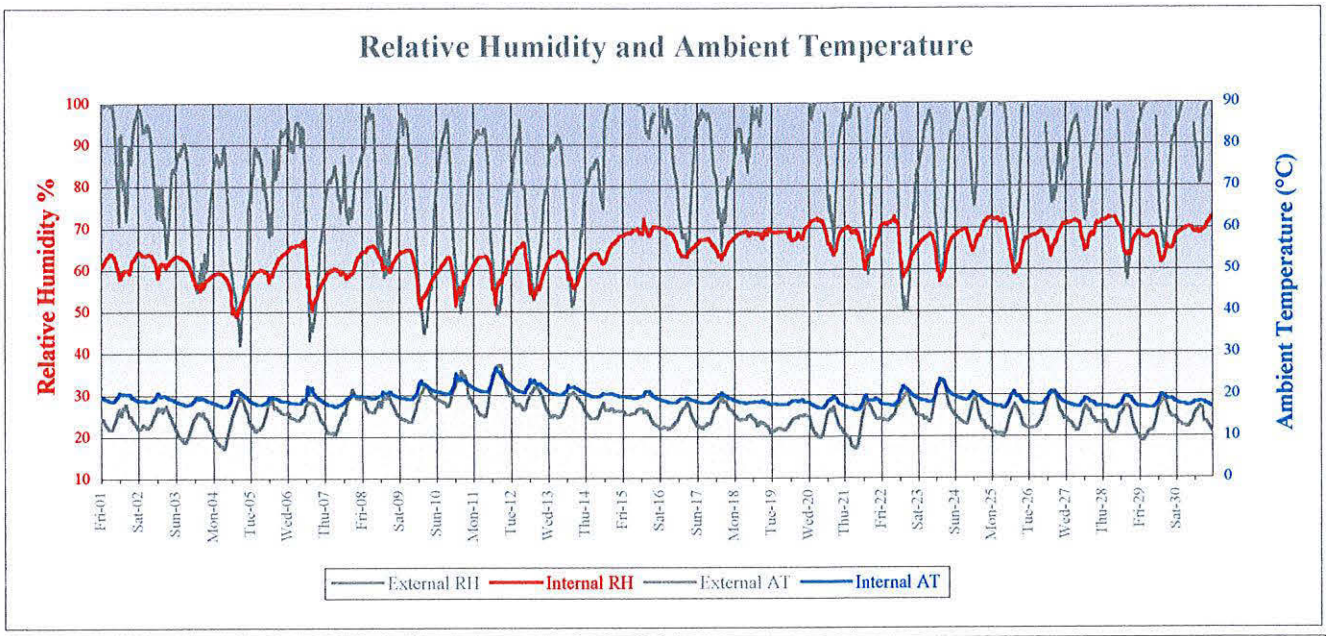


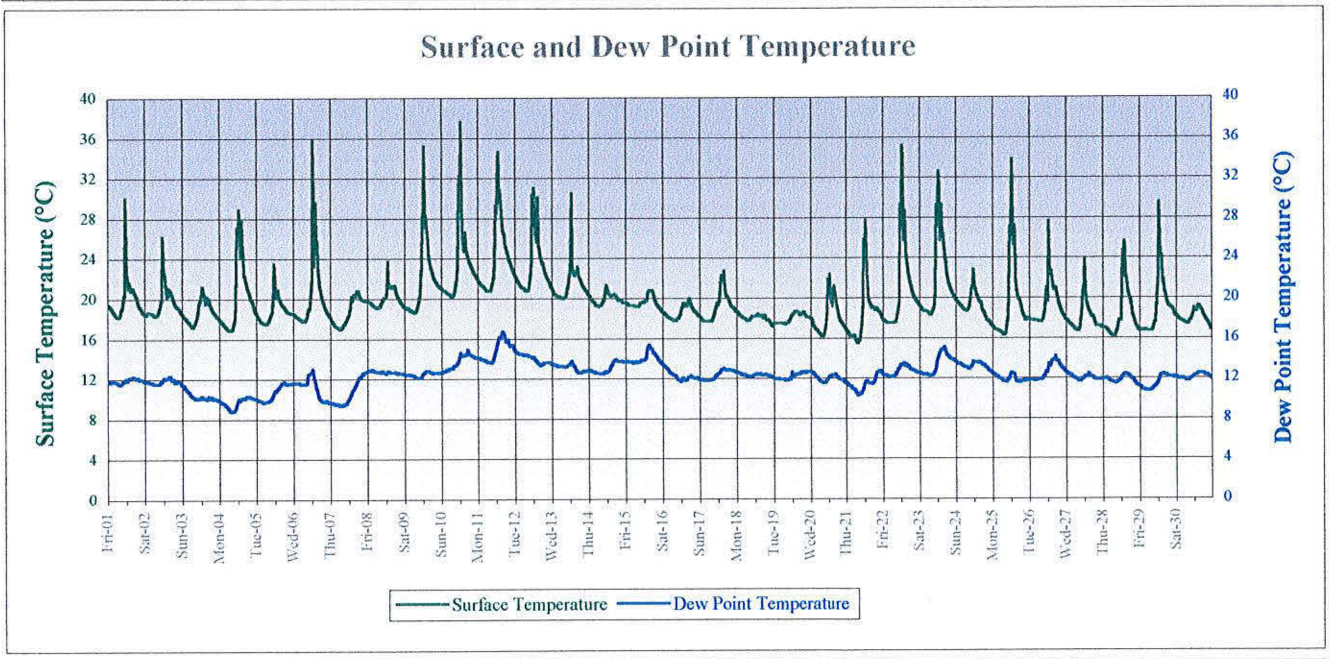


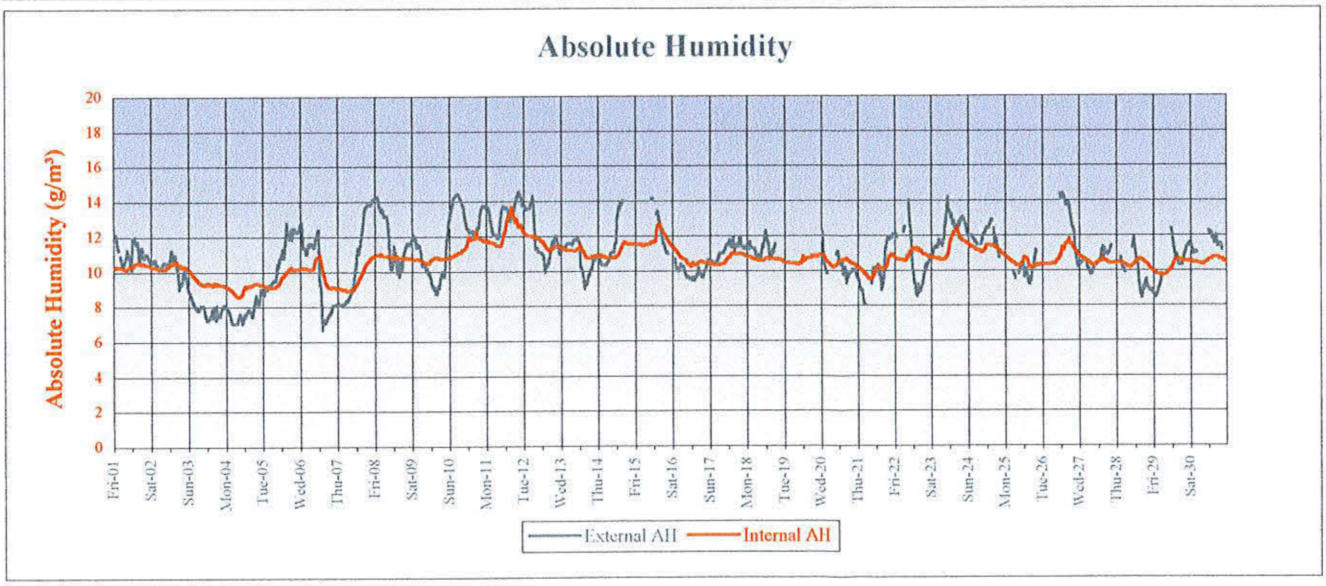
Peterborough Cathedral Nave Ceiling

September 2000

Probe 3: Bay 33 III lower side (sun)



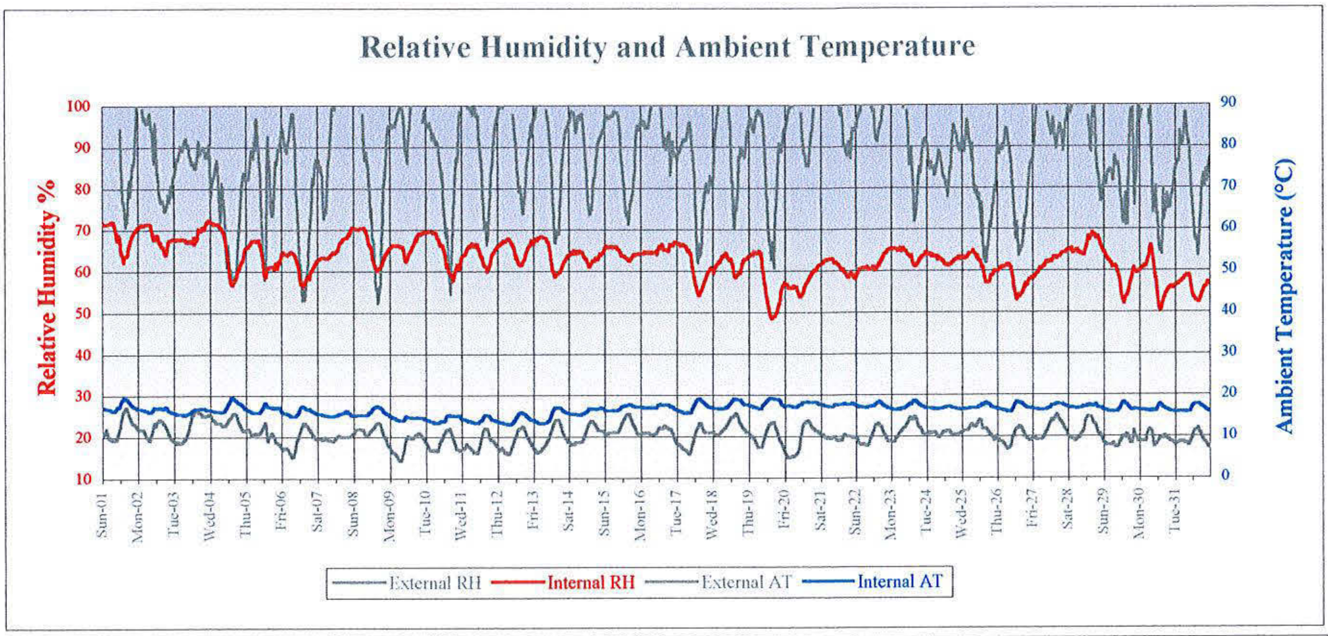


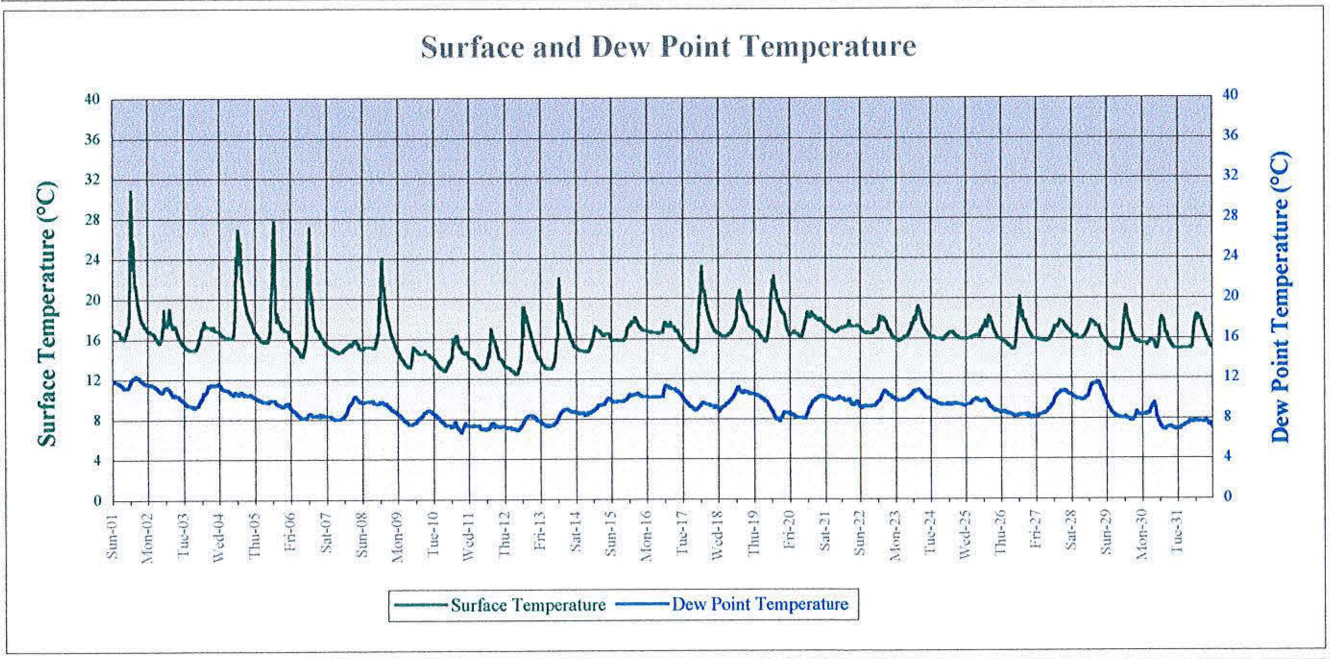


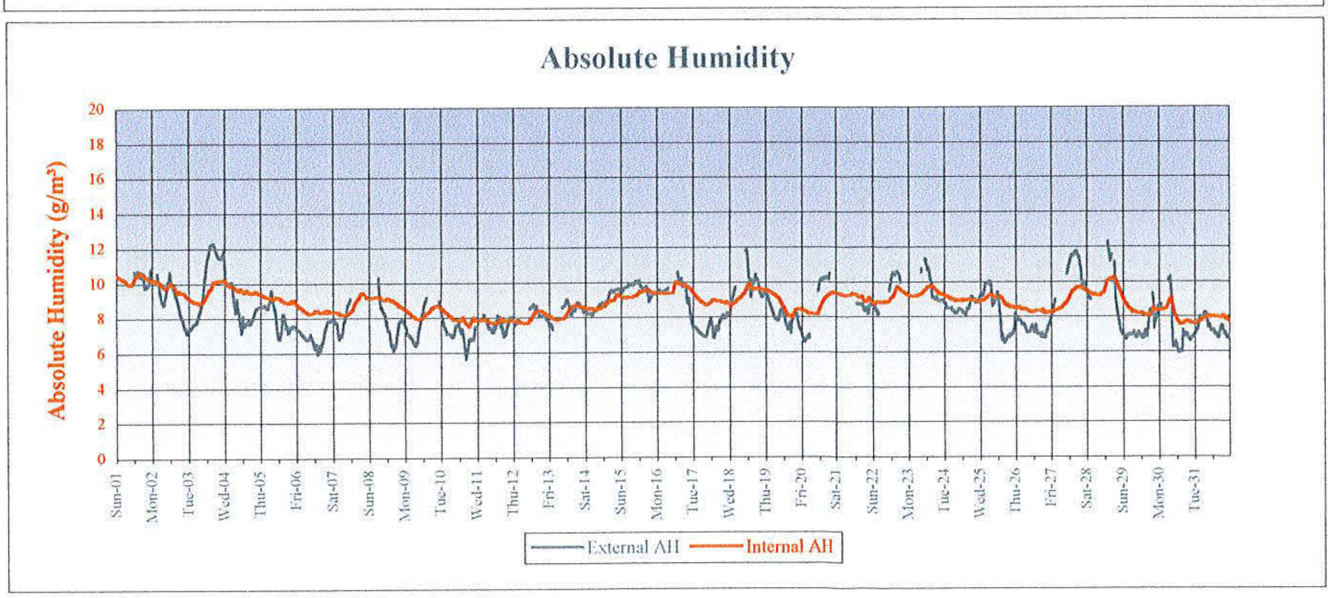
Peterborough Cathedral Nave Ceiling

October 2000

Probe 3: Bay 33 III lower side (sun)



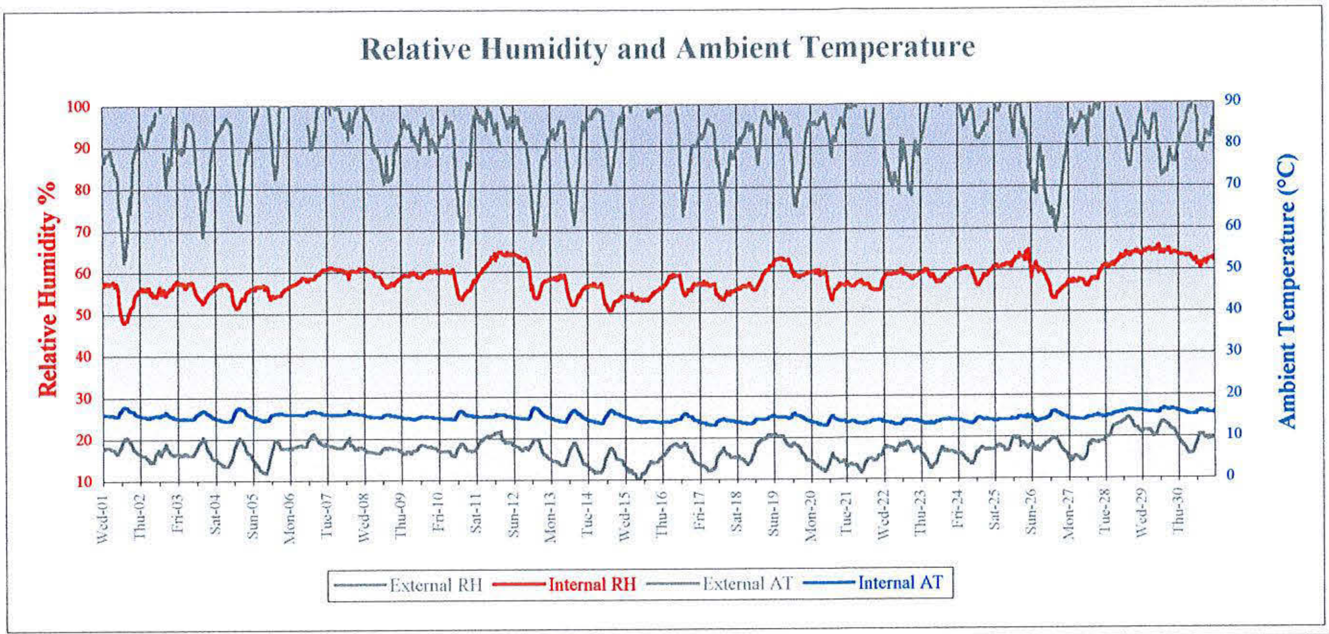


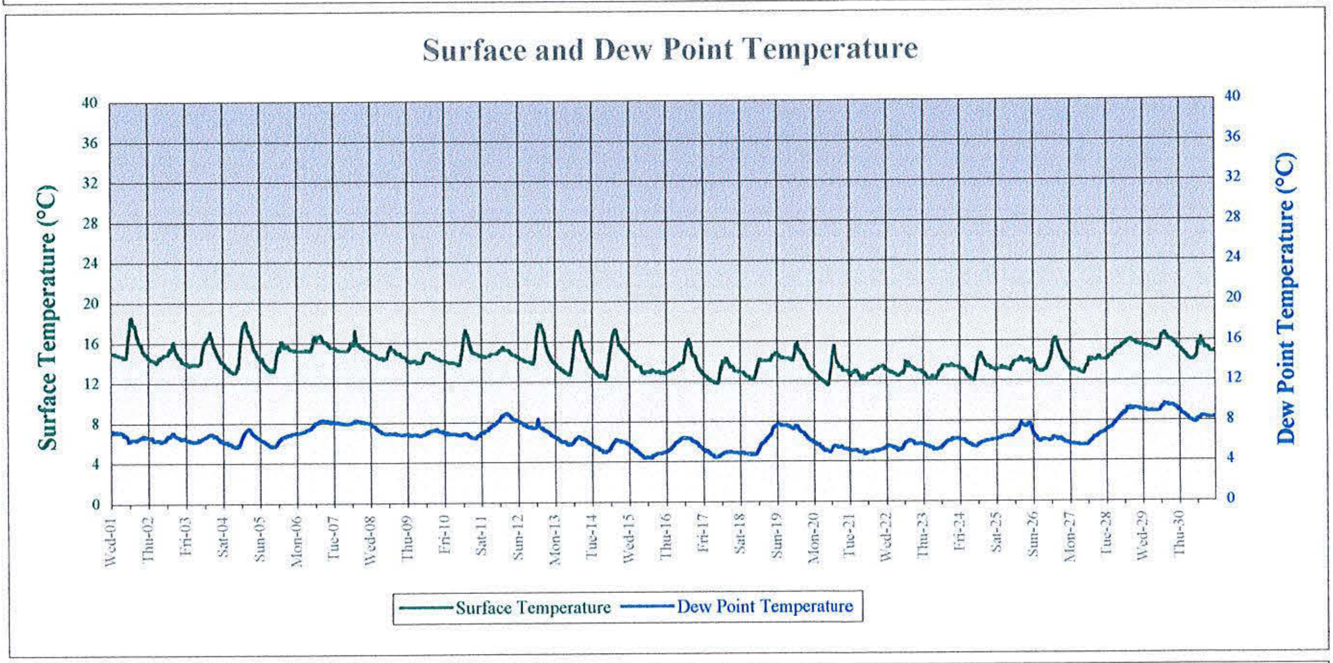


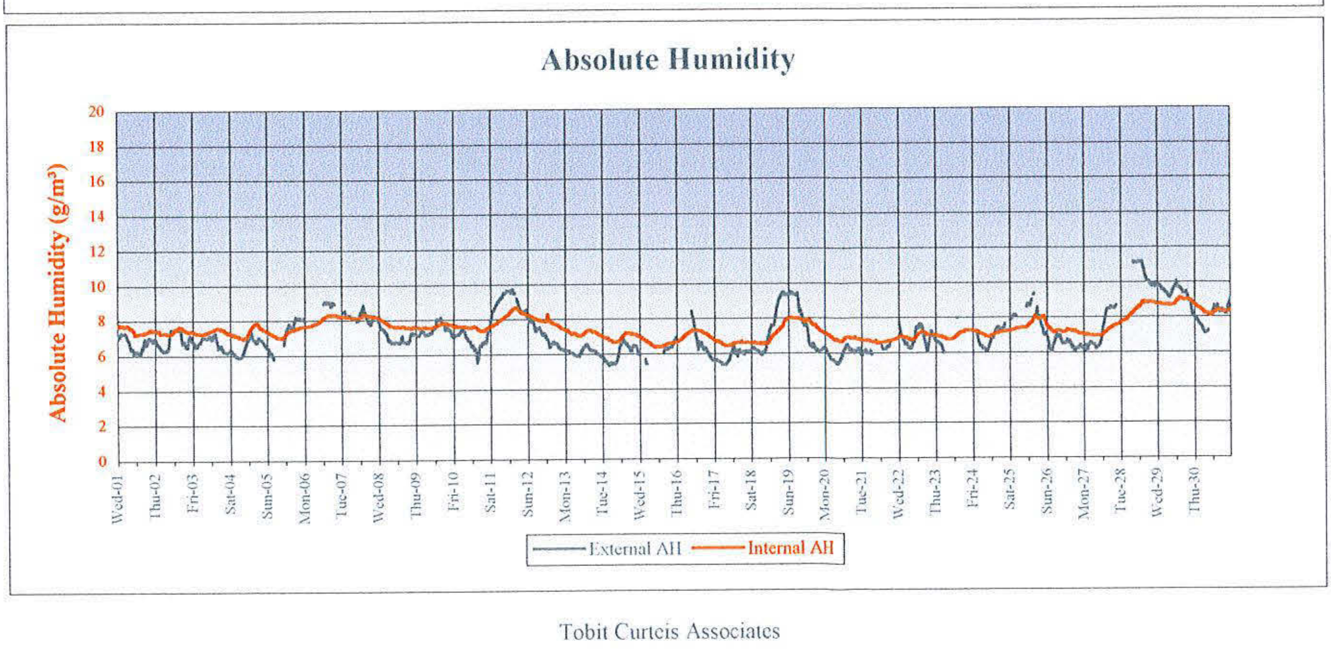
Peterborough Cathedral Nave Ceiling

November 2000

Probe 3: Bay 33 III lower side (sun)



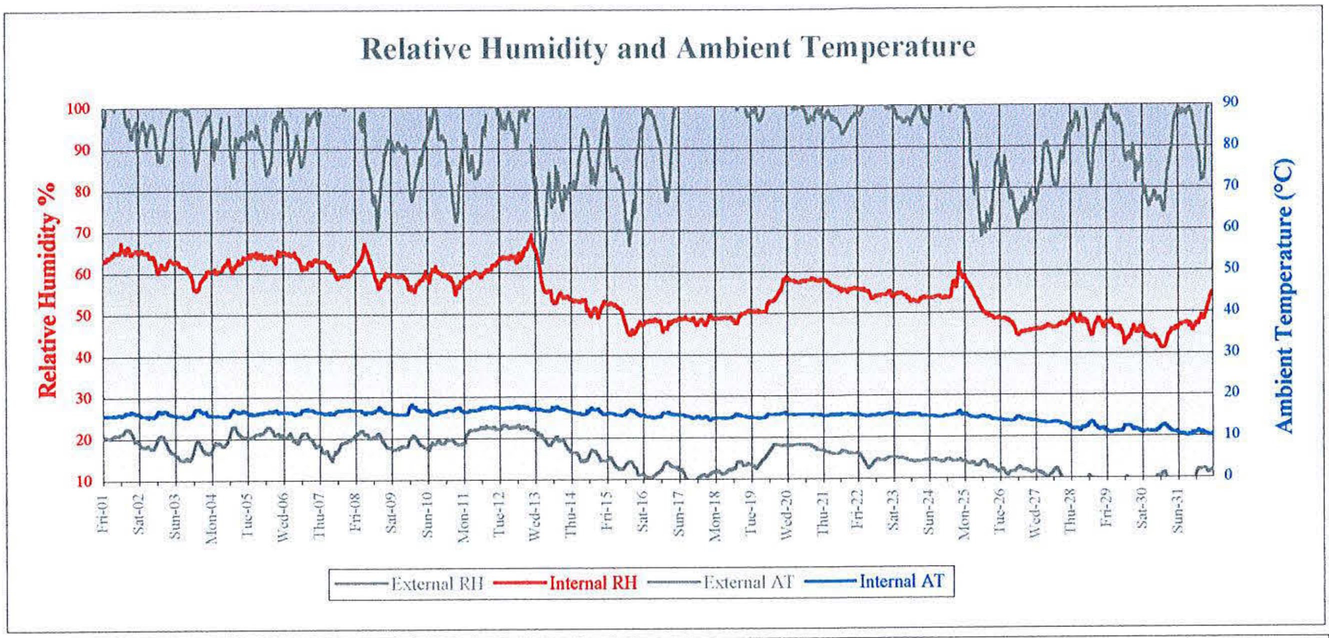


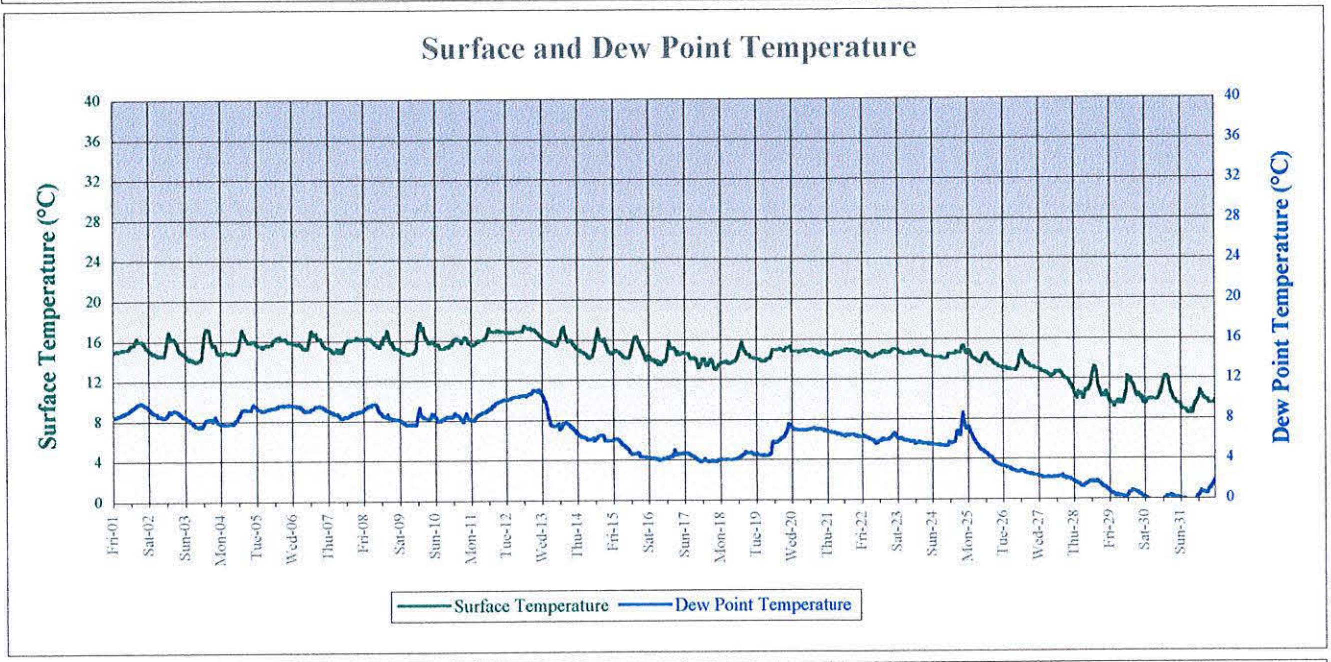


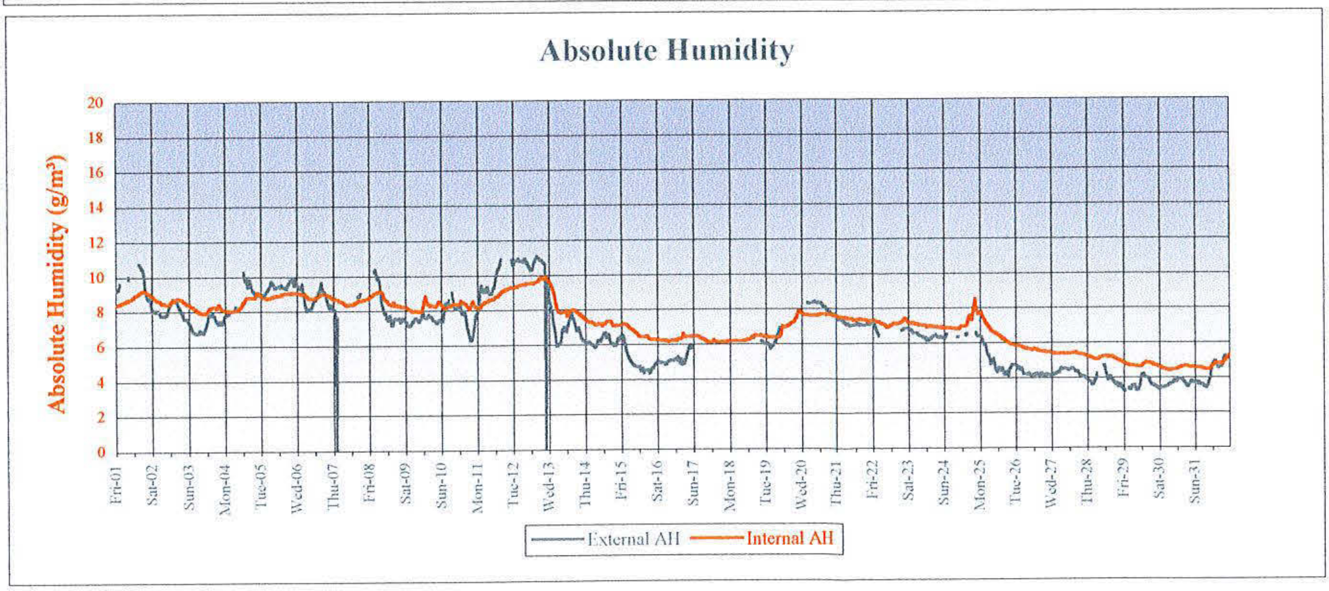
Peterborough Cathedral Nave Ceiling

December 2000

Probe 3: Bay 33 III lower side (sun)



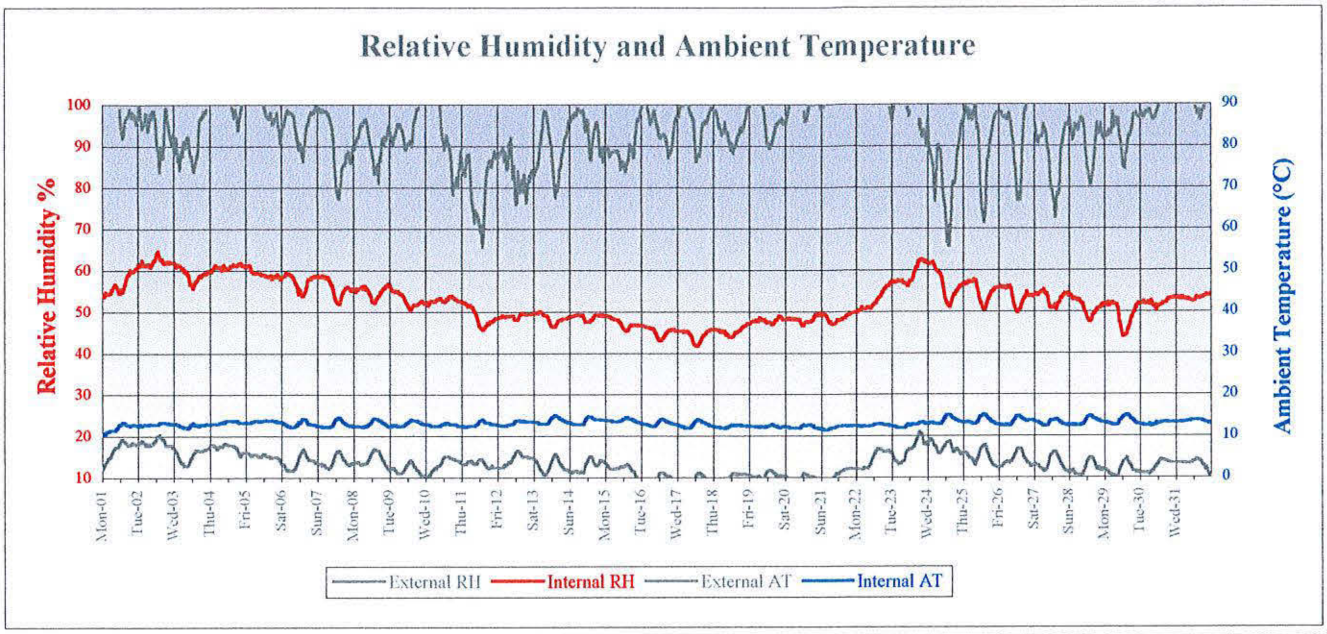


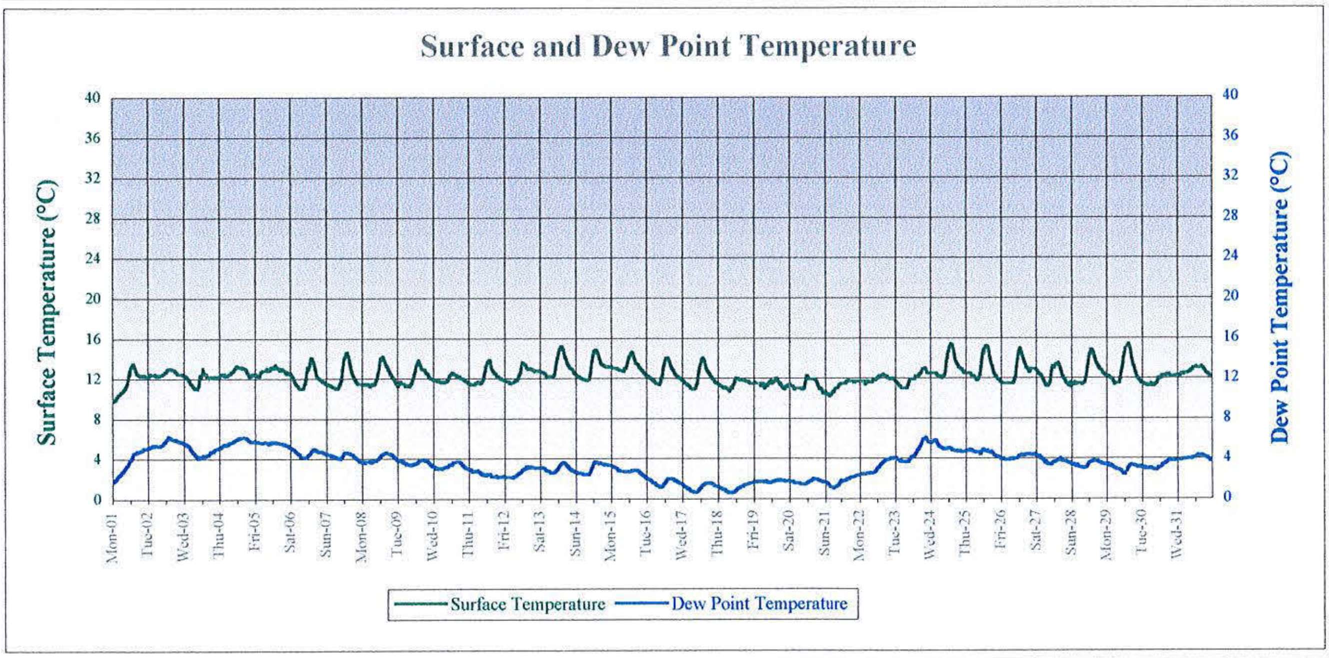


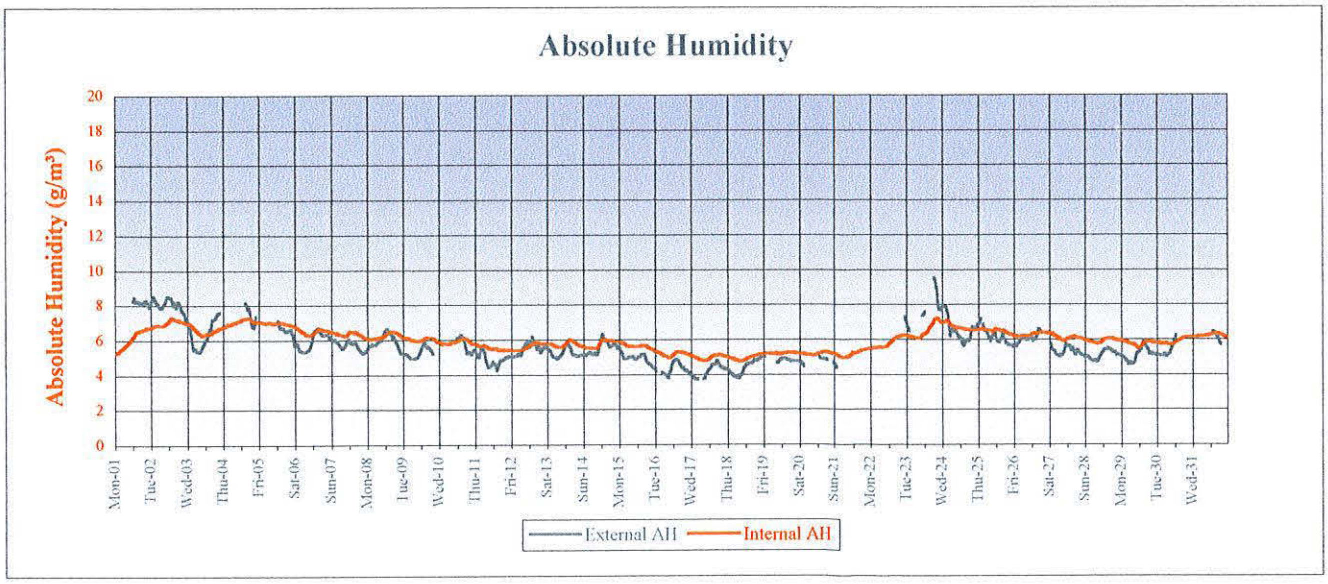
Peterborough Cathedral Nave Ceiling

January 2001

Probe 3: Bay 33 III lower side (sun)



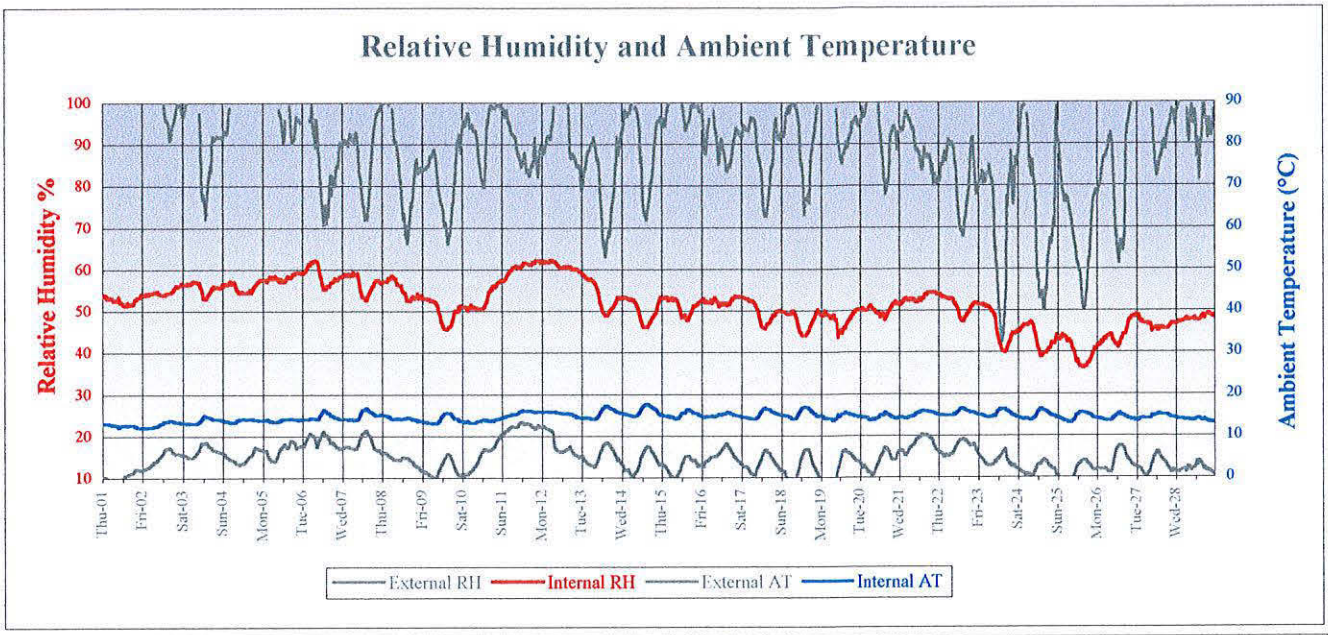


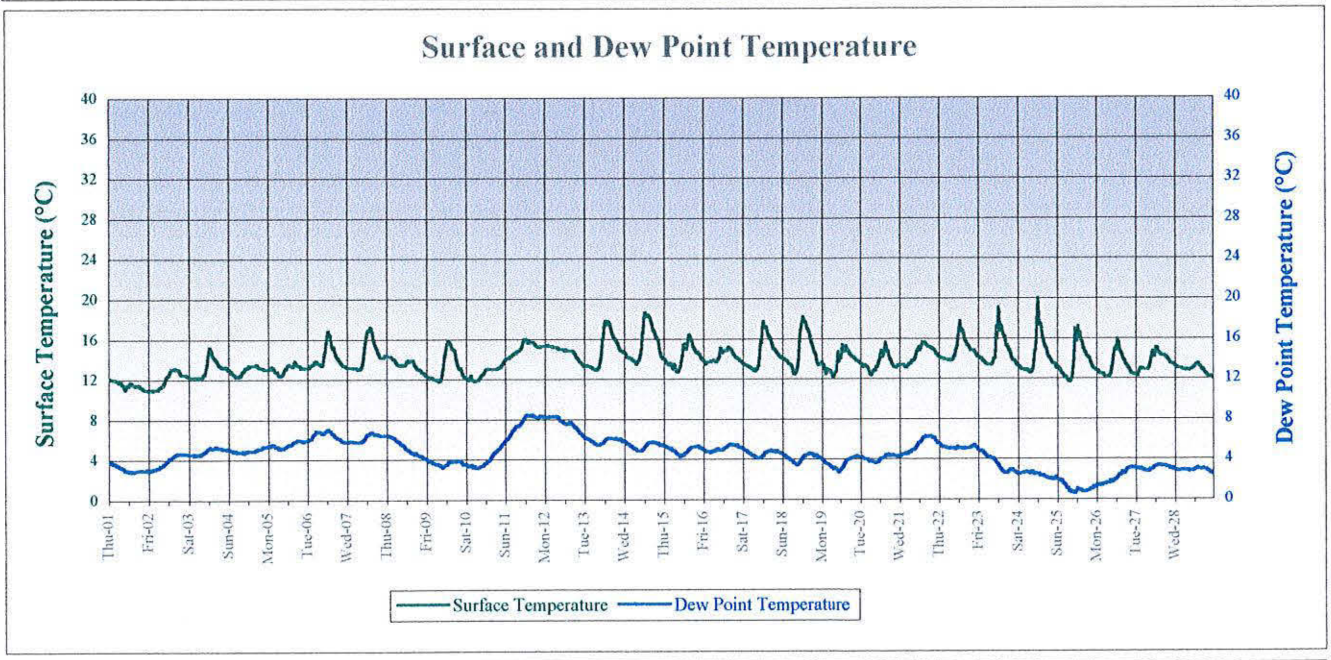


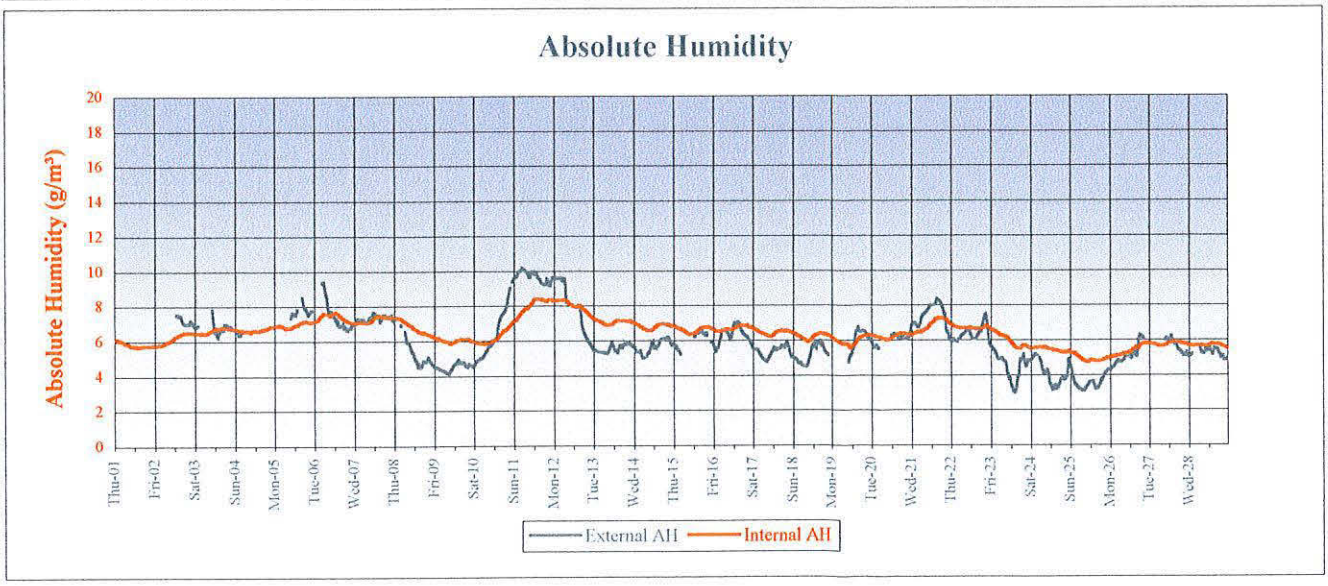
Peterborough Cathedral Nave Ceiling

February 2001

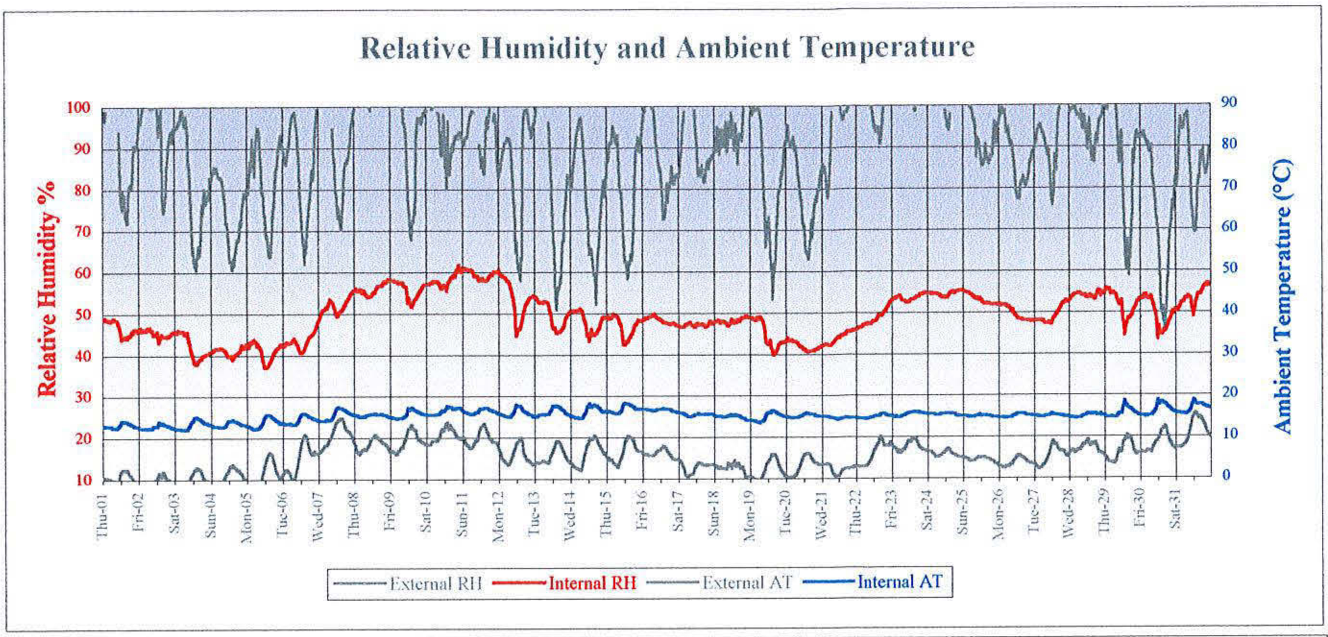
Probe 3: Bay 33 III lower side (sun)

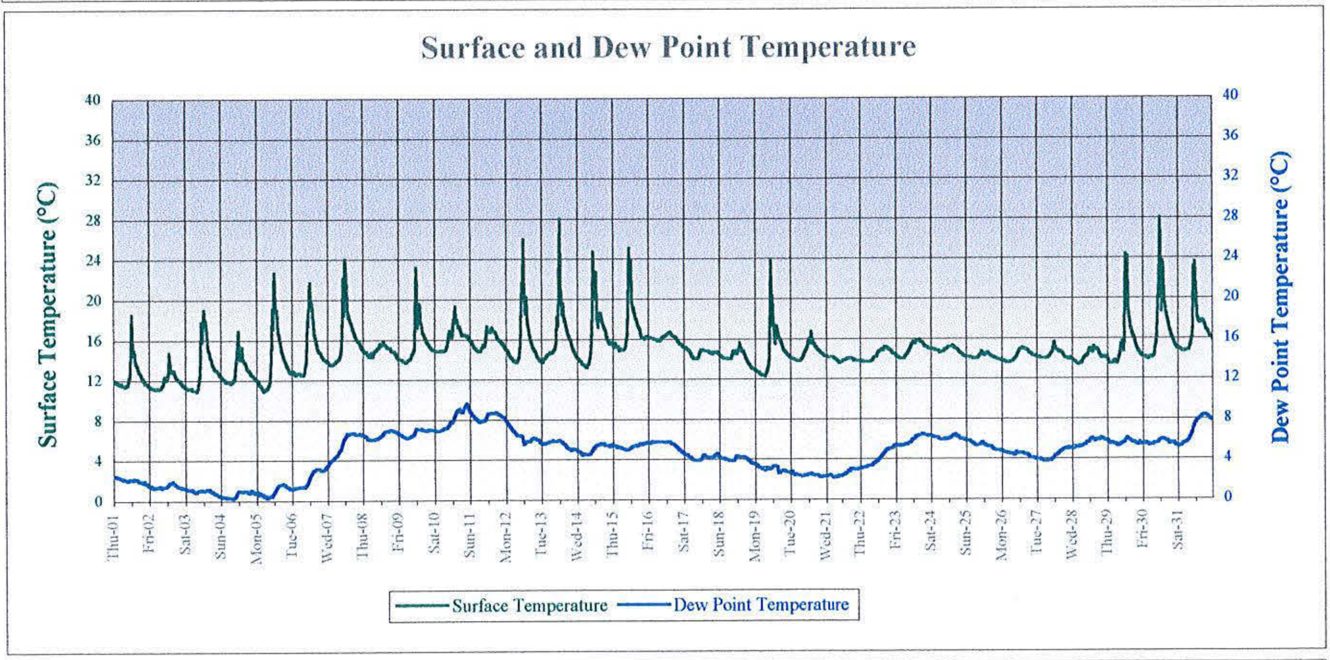


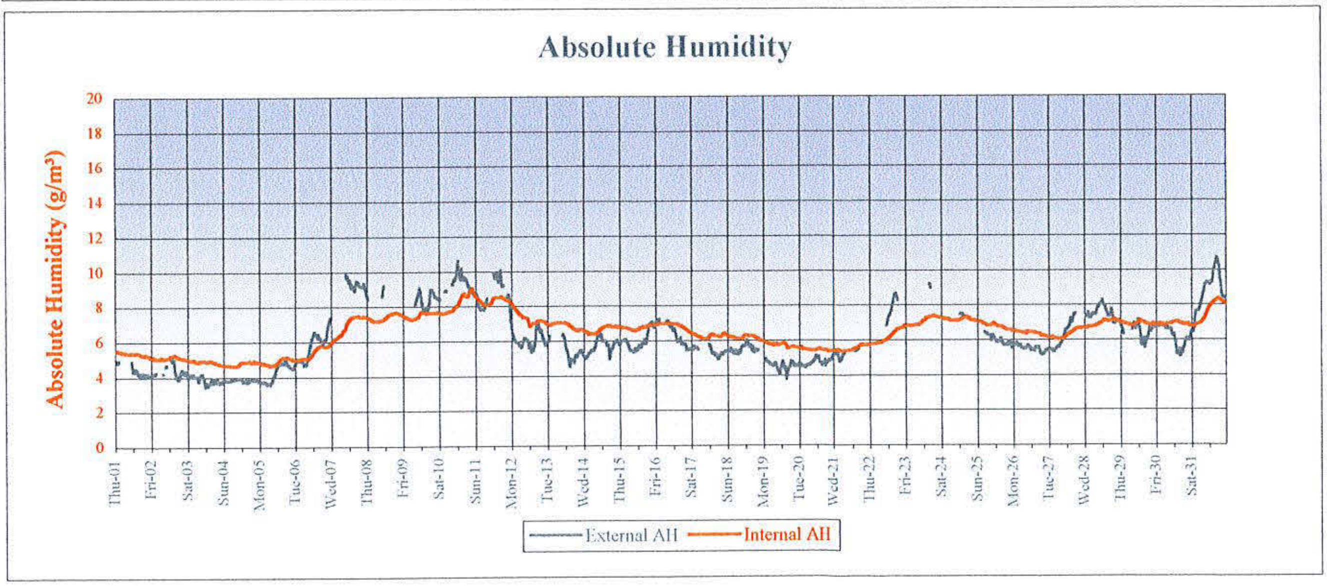




Probe 3: Bay 33 III lower side (sun)

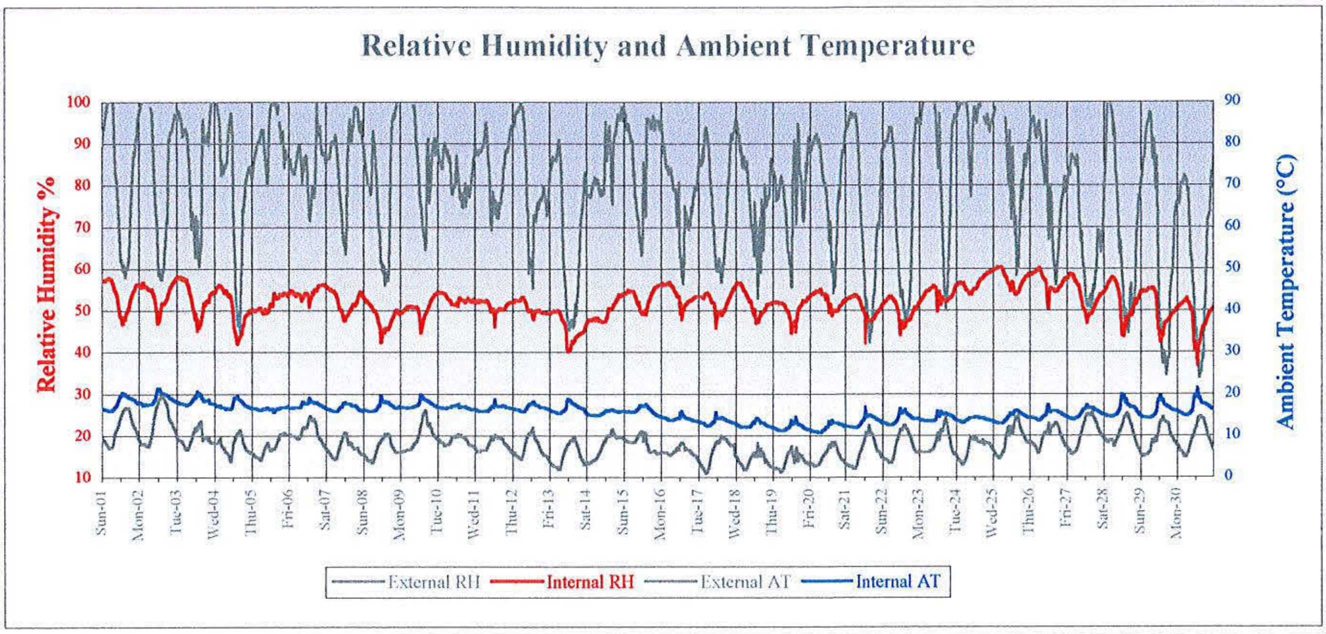


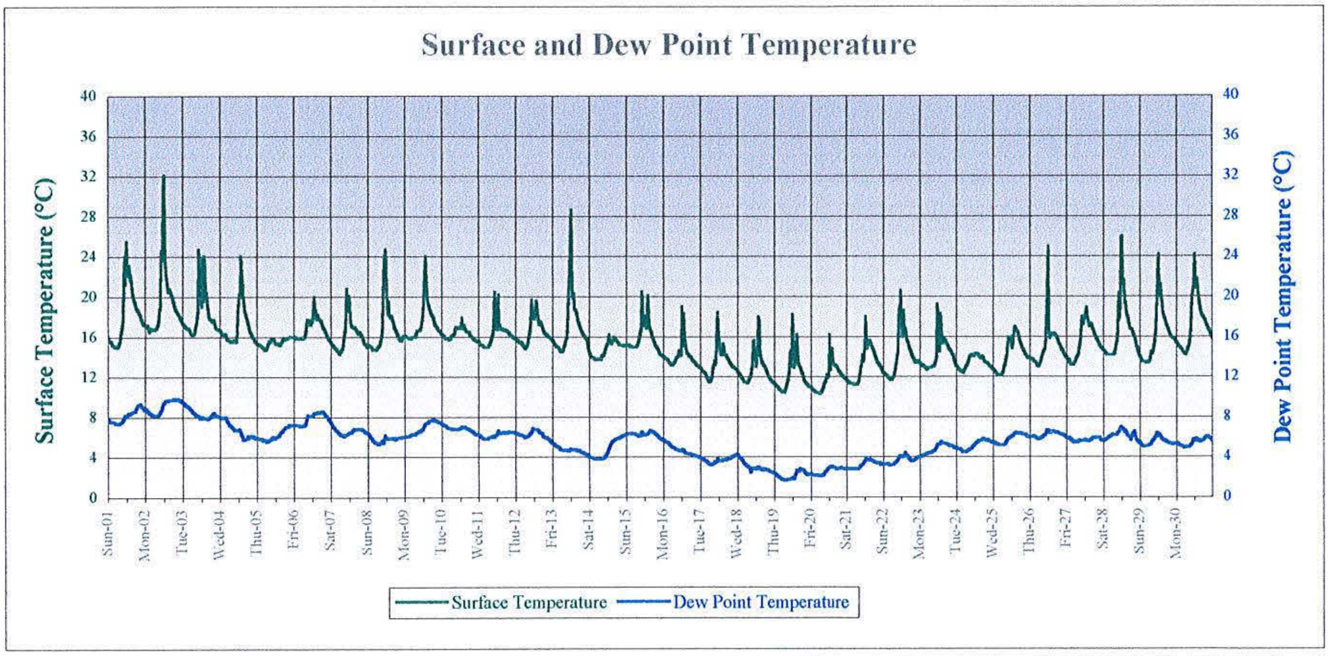


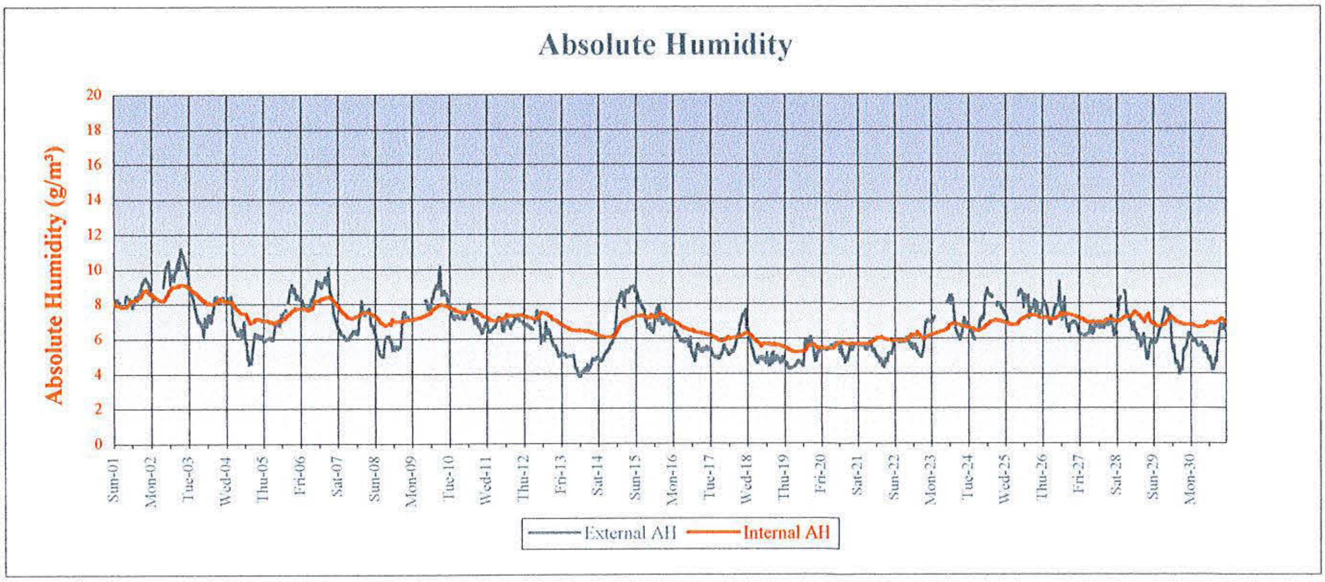


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)



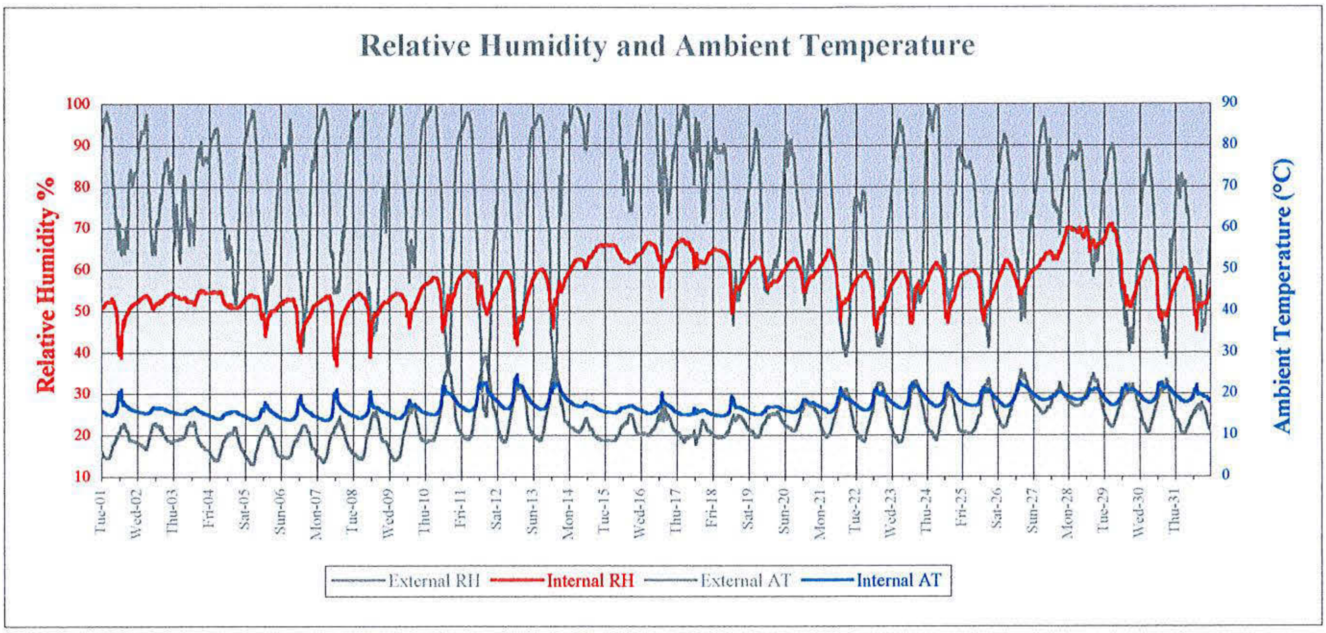


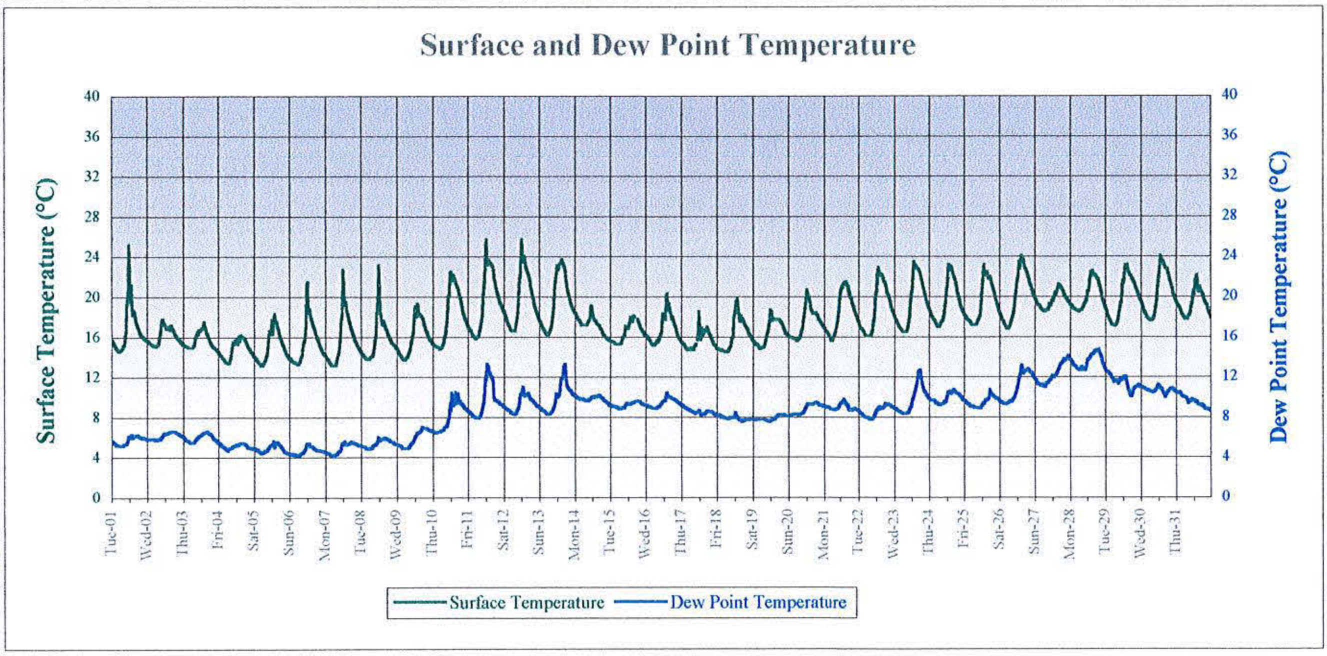


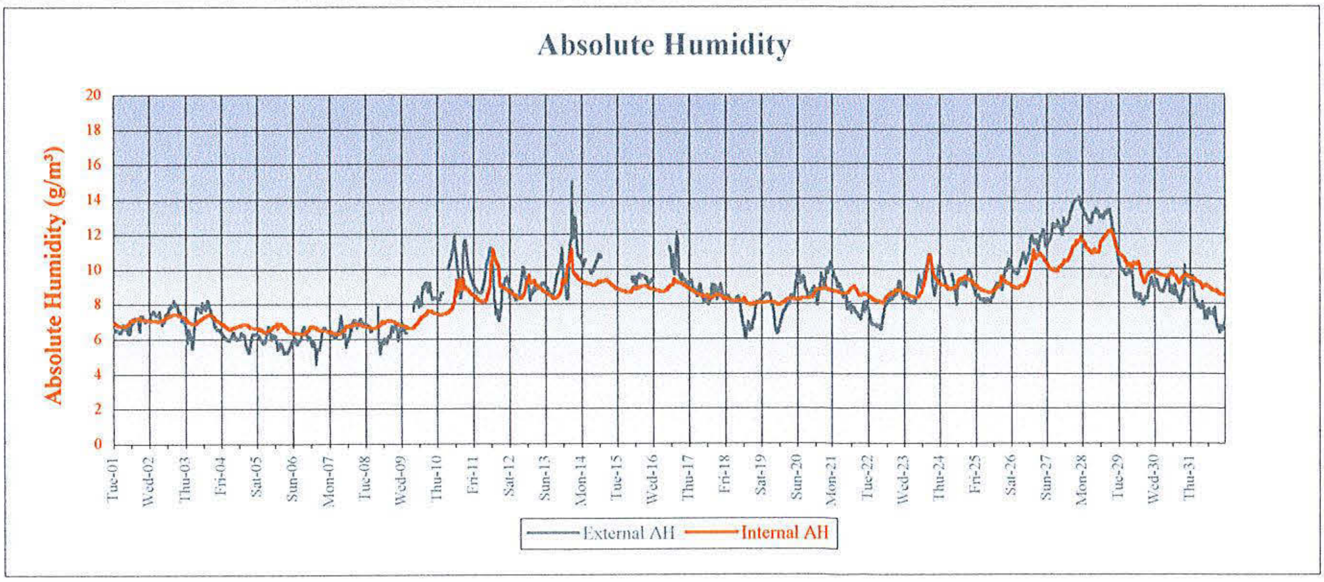
Peterborough Cathedral Nave Ceiling

May 2001

Probe 3: Bay 33 III lower side (sun)



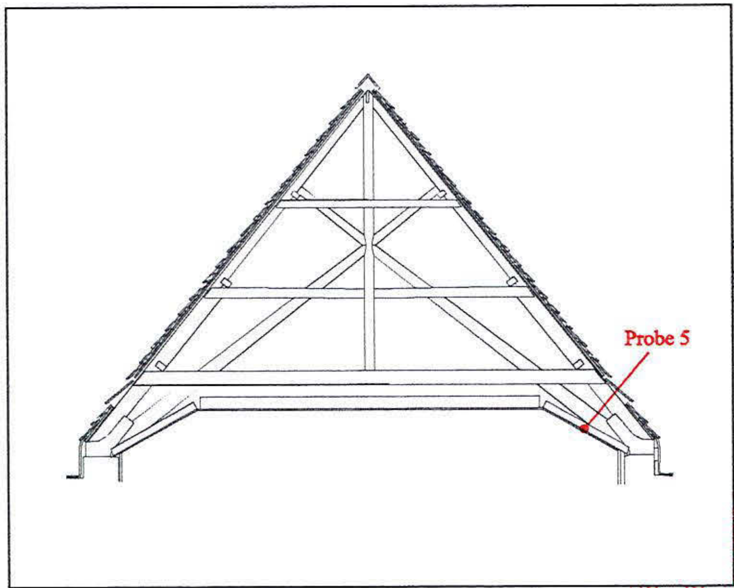


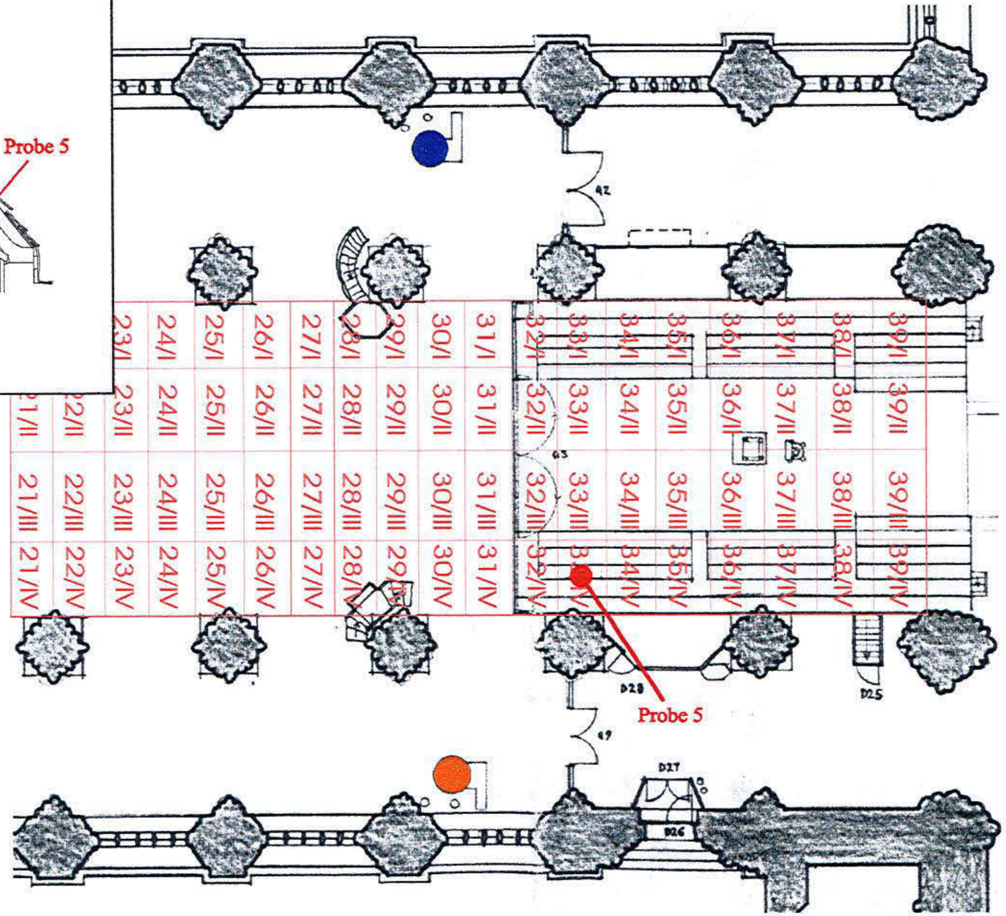


PROBE 5

BAY 33 IV UPPER SIDE (SUN)

Diagram 6



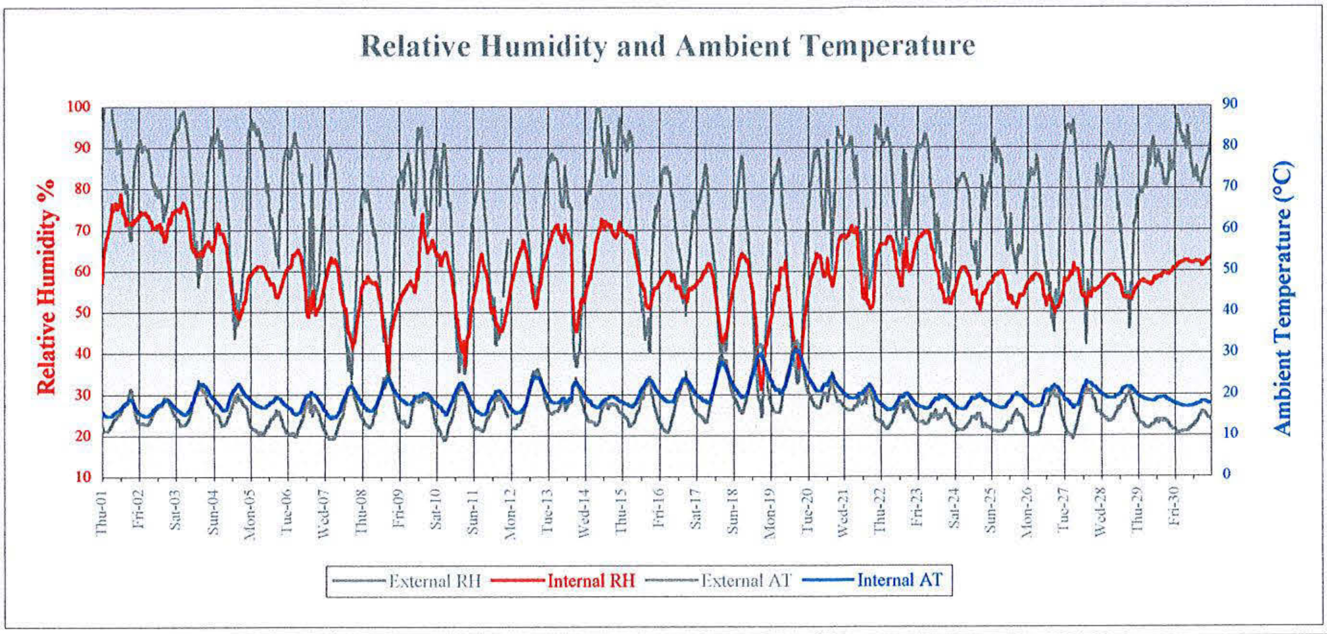


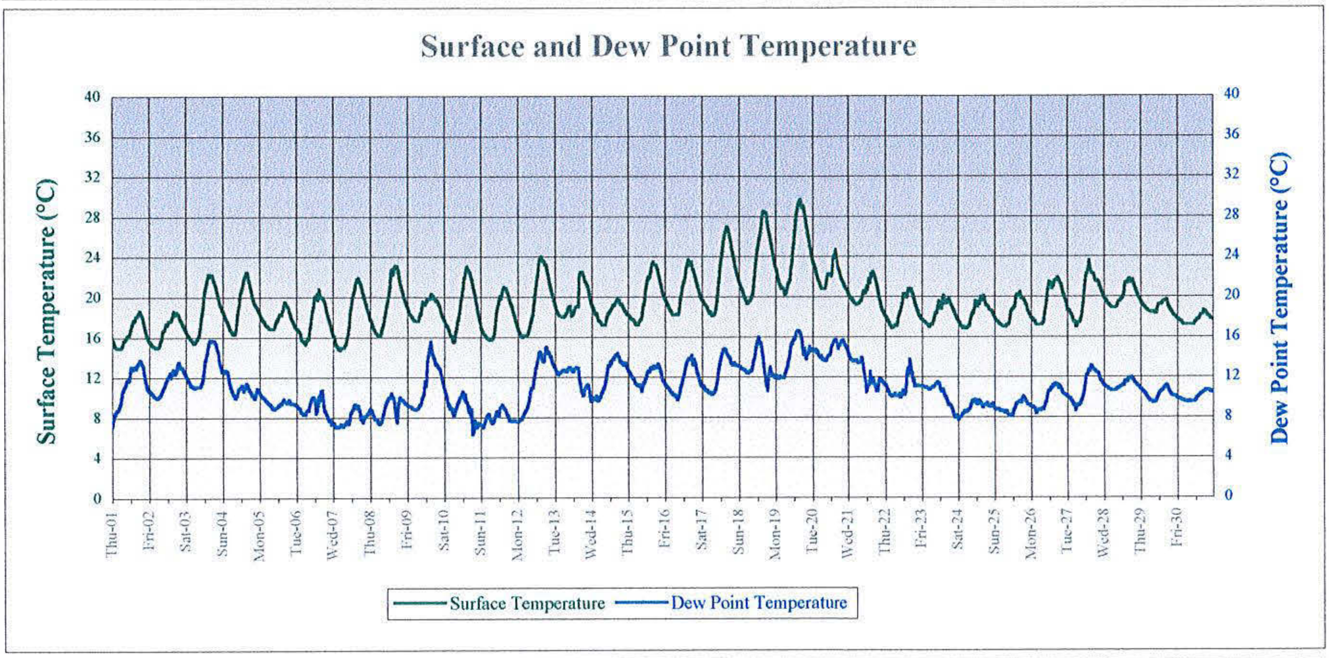
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2001	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

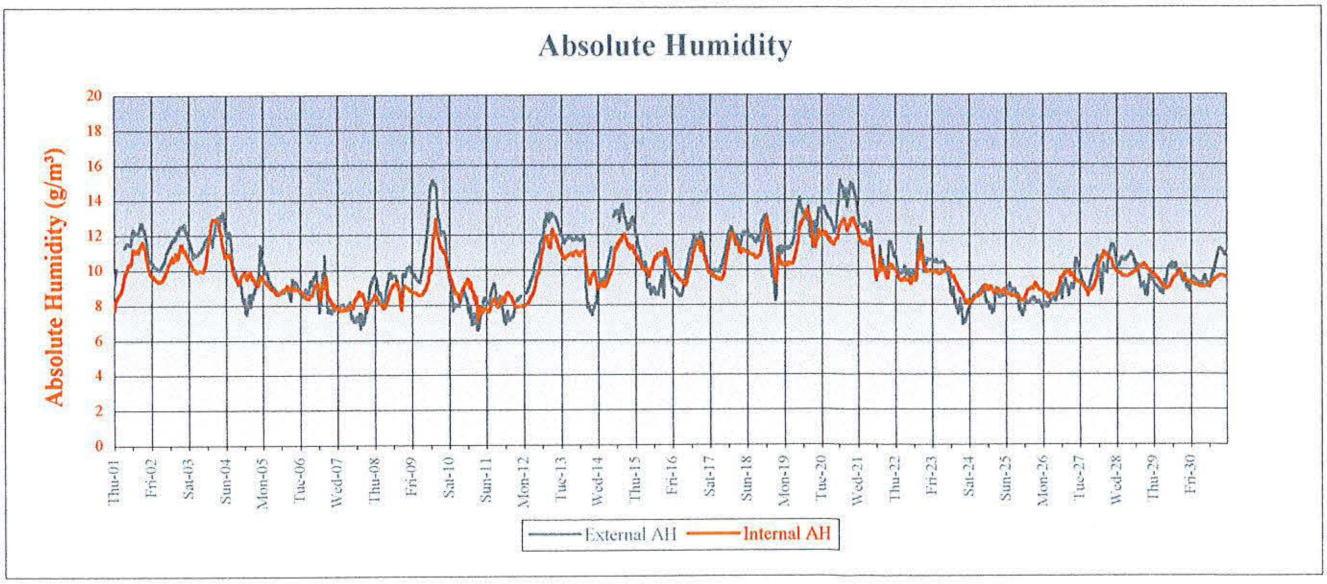
Peterborough Cathedral Nave Ceiling

June 2000

Probe 5: Bay 33 III upper side (sun)

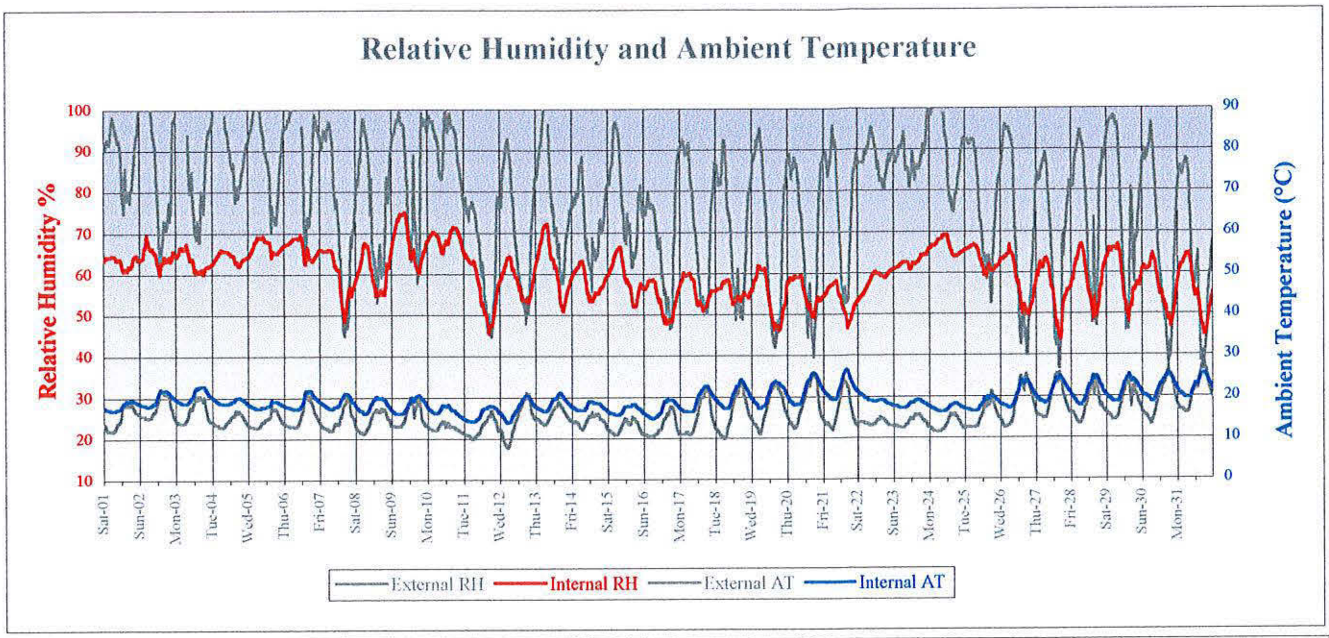


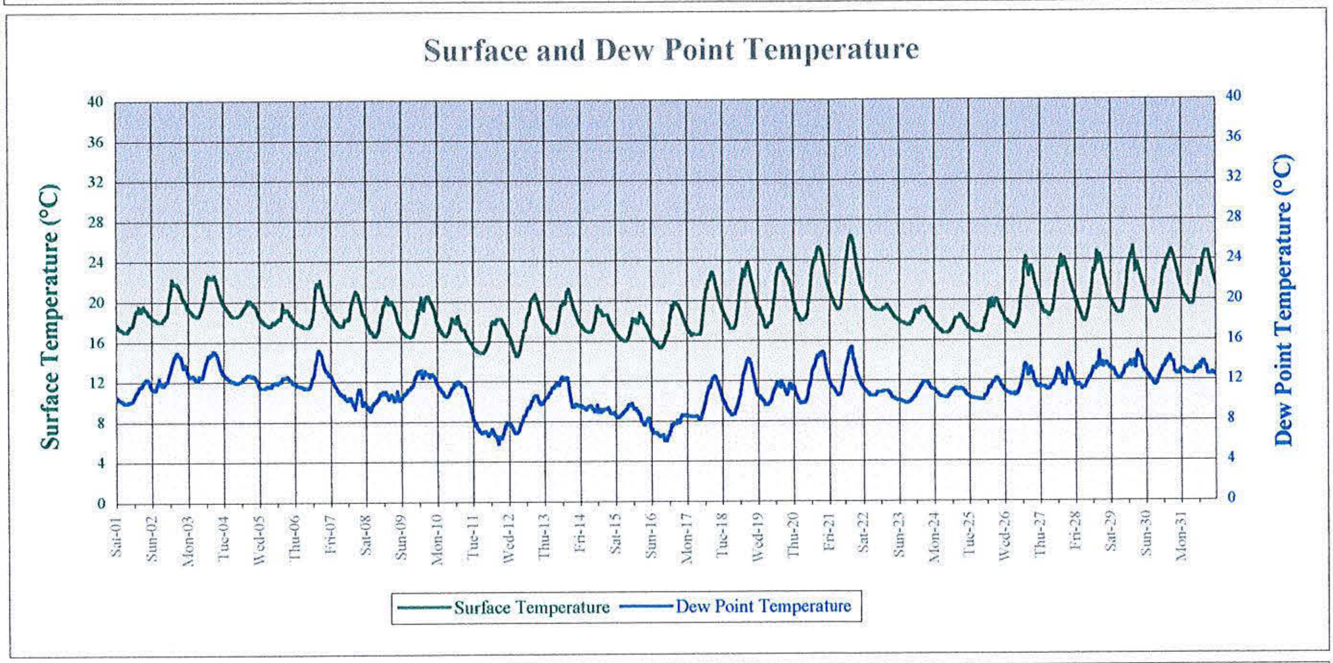


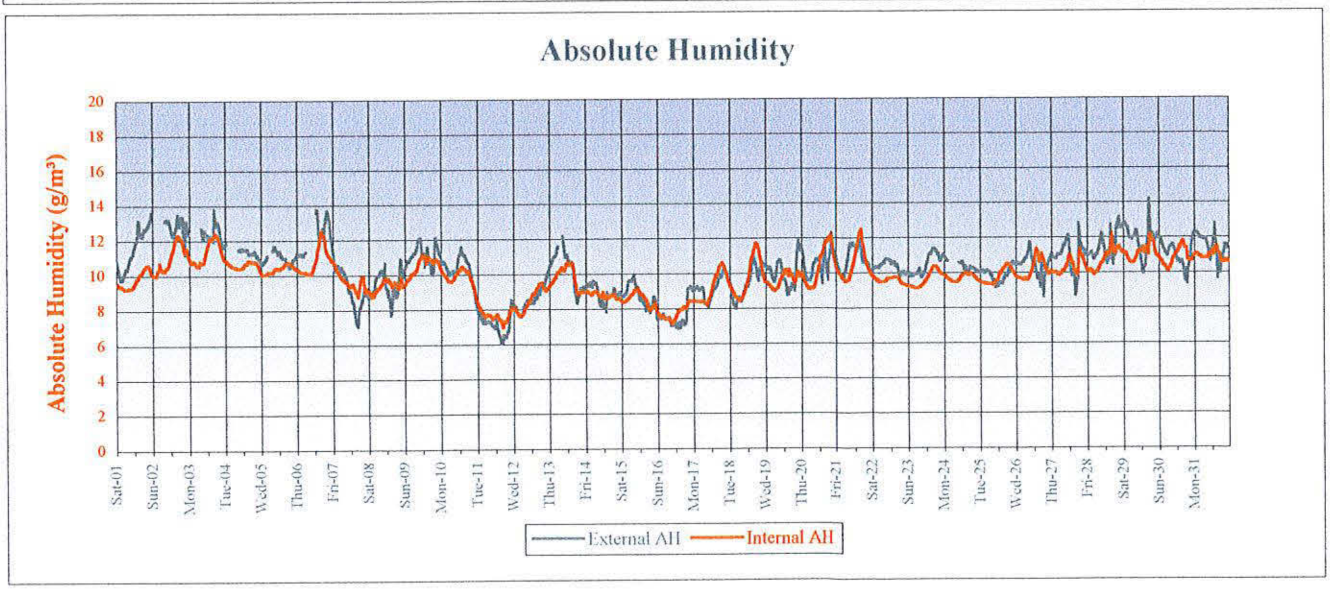


Peterborough Cathedral Nave Ceiling

Probe 5: Bay 33 III upper side (sun)



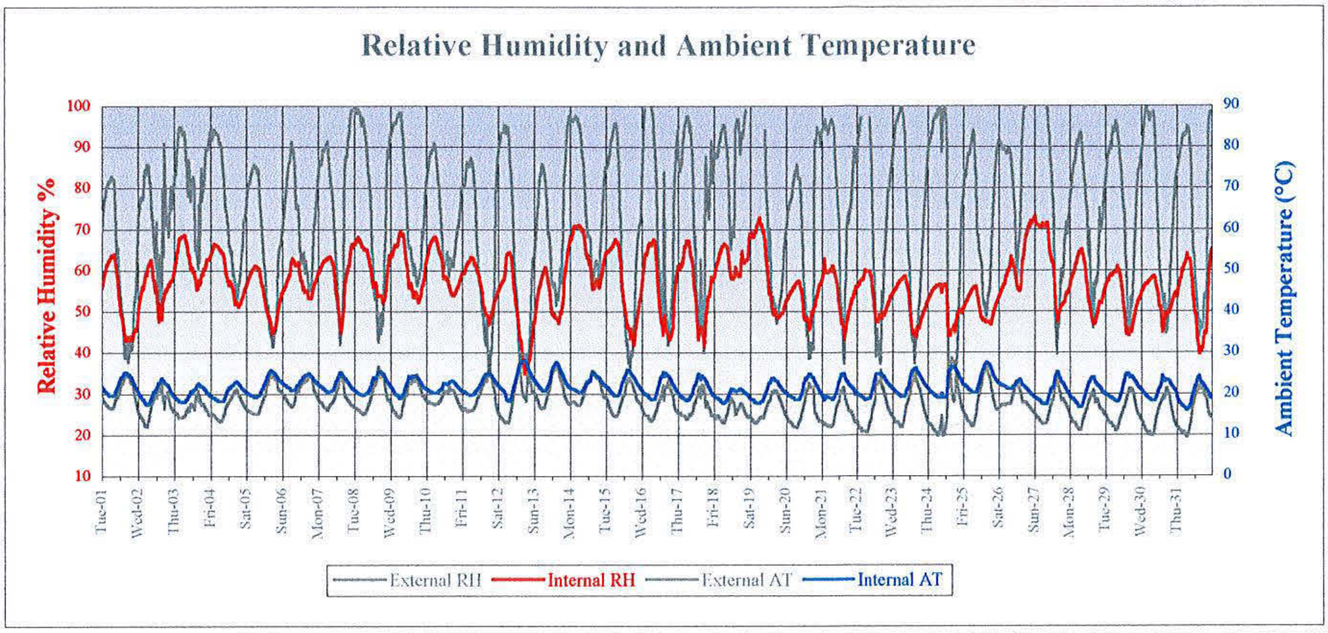


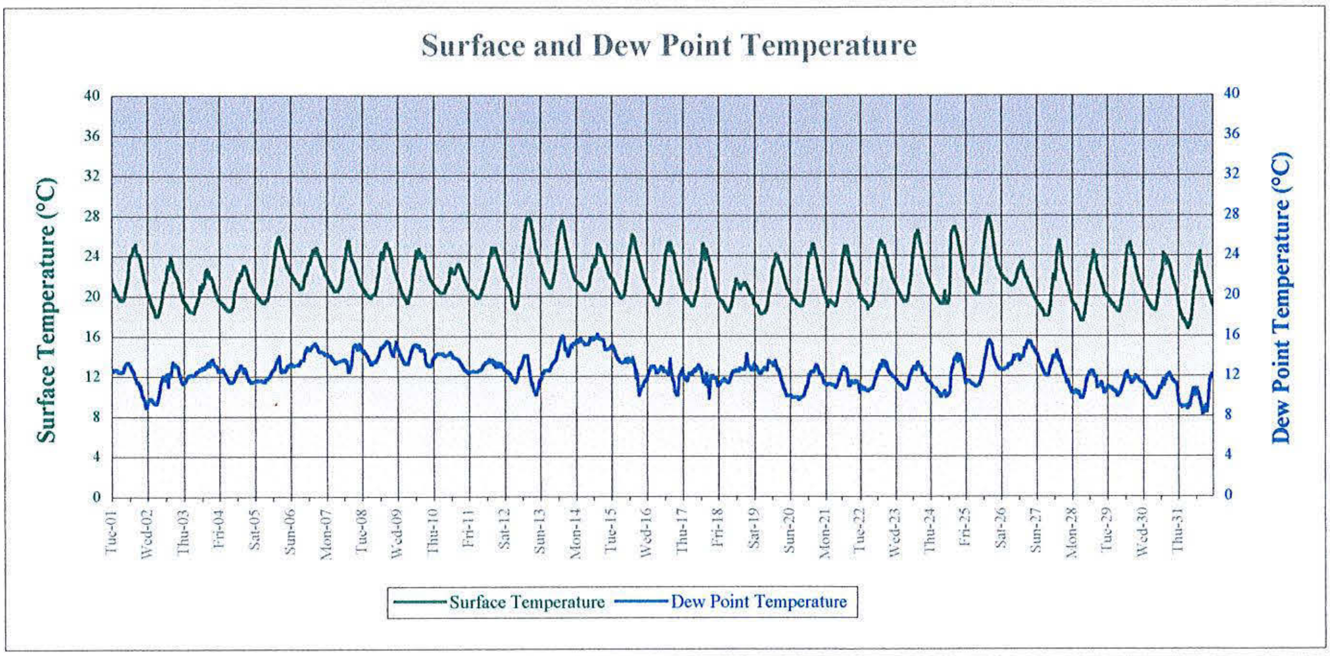


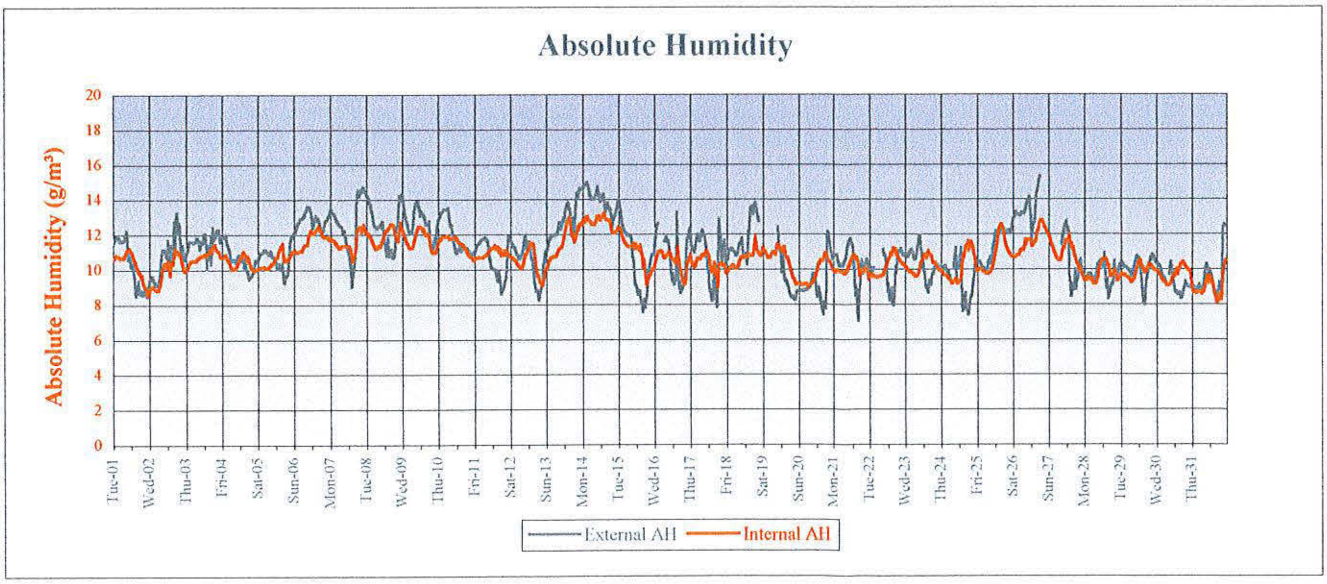
Peterborough Cathedral Nave Ceiling

August 2000

Probe 5: Bay 33 III upper side (sun)



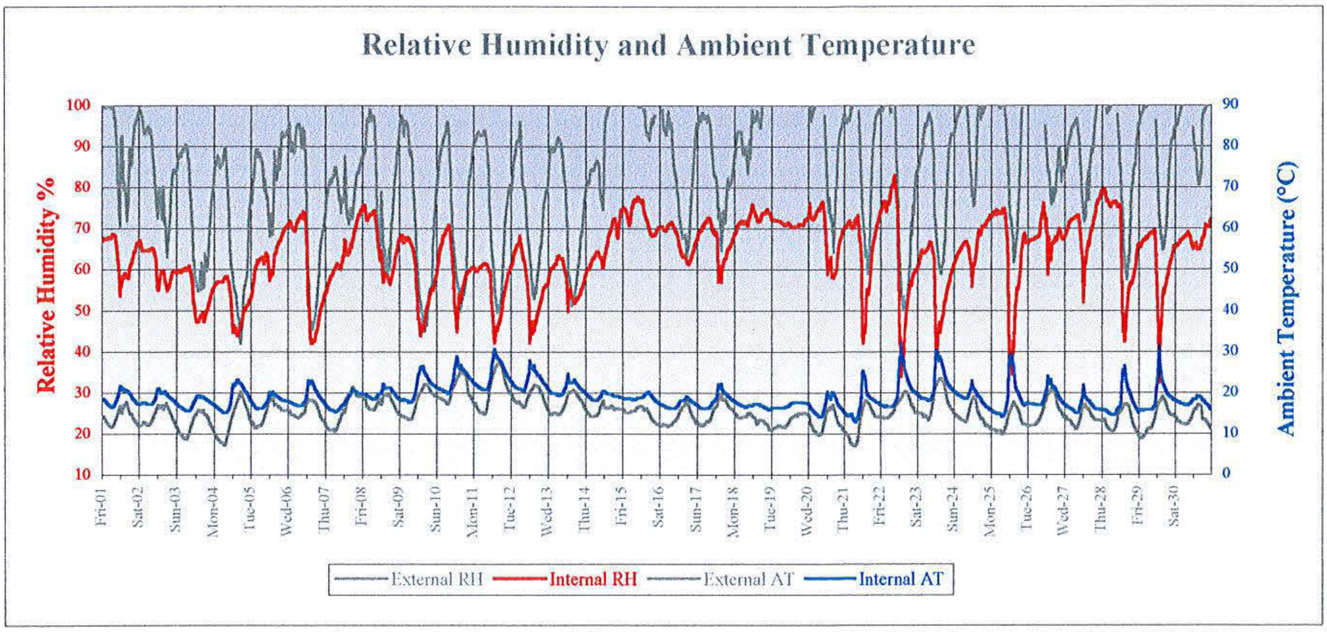


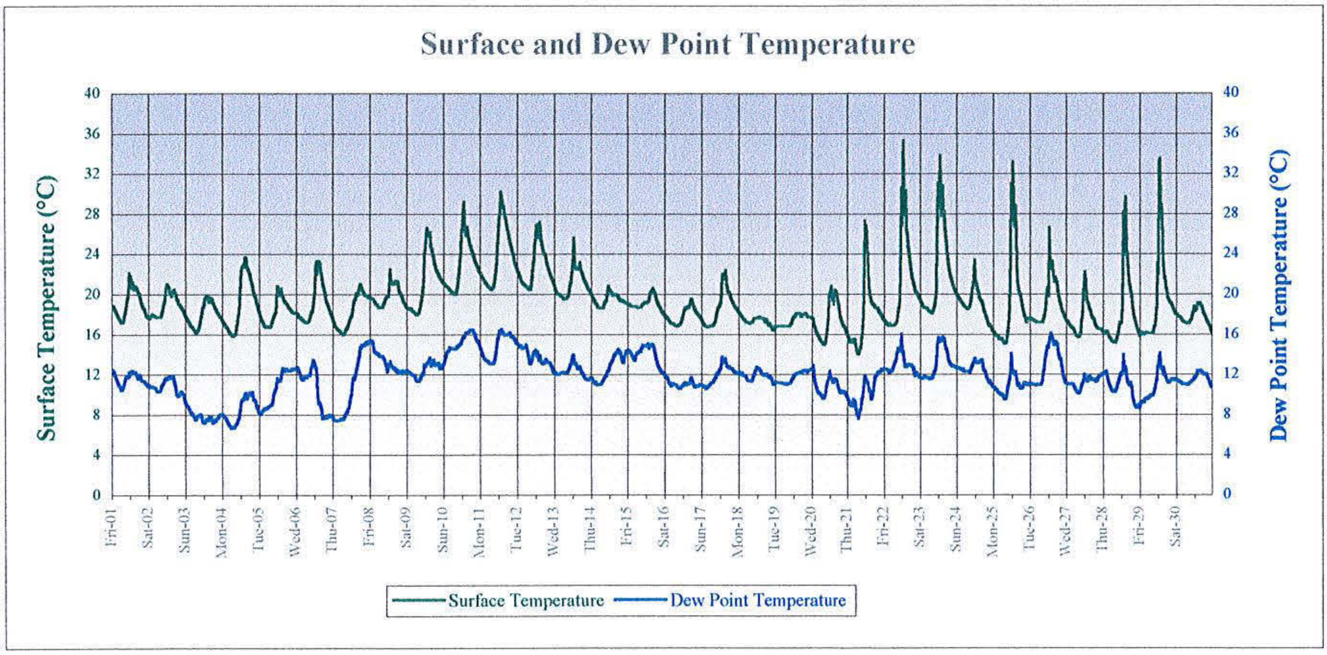


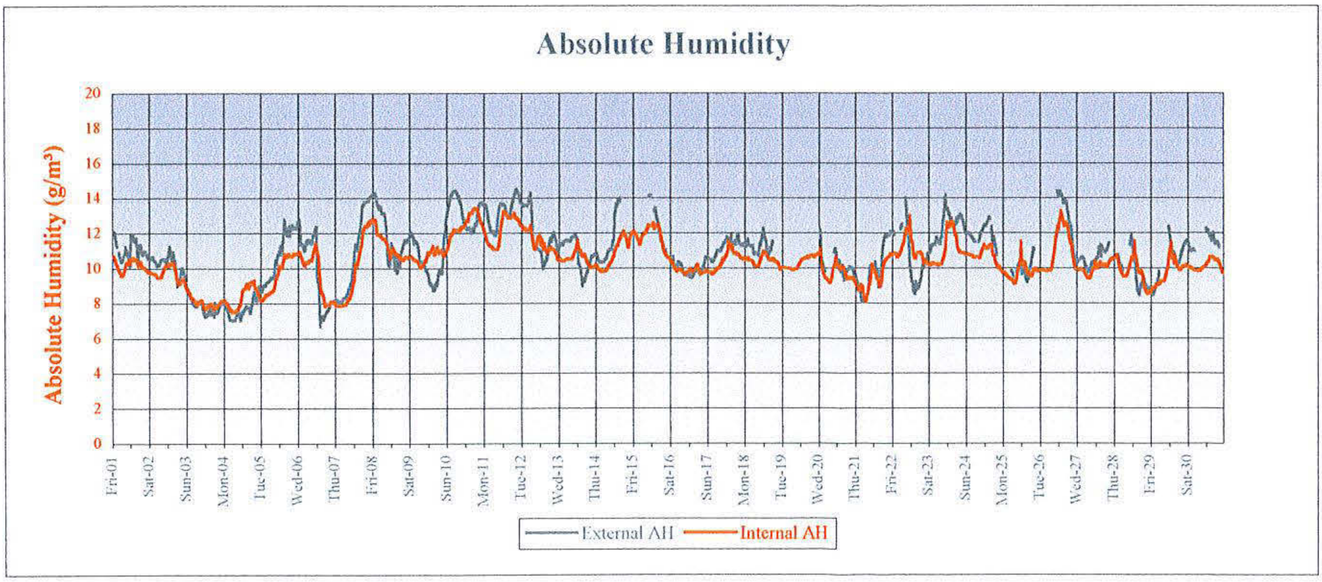
Peterborough Cathedral Nave Ceiling

September 2000

Probe 5: Bay 33 III upper side (sun)



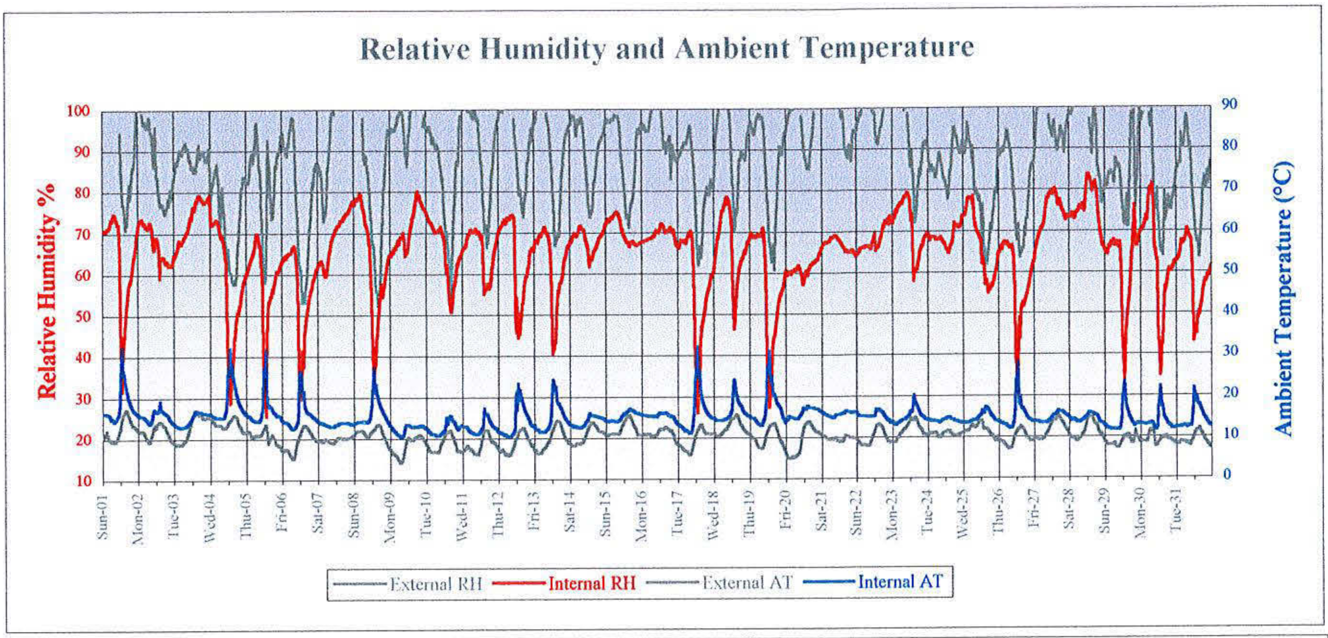


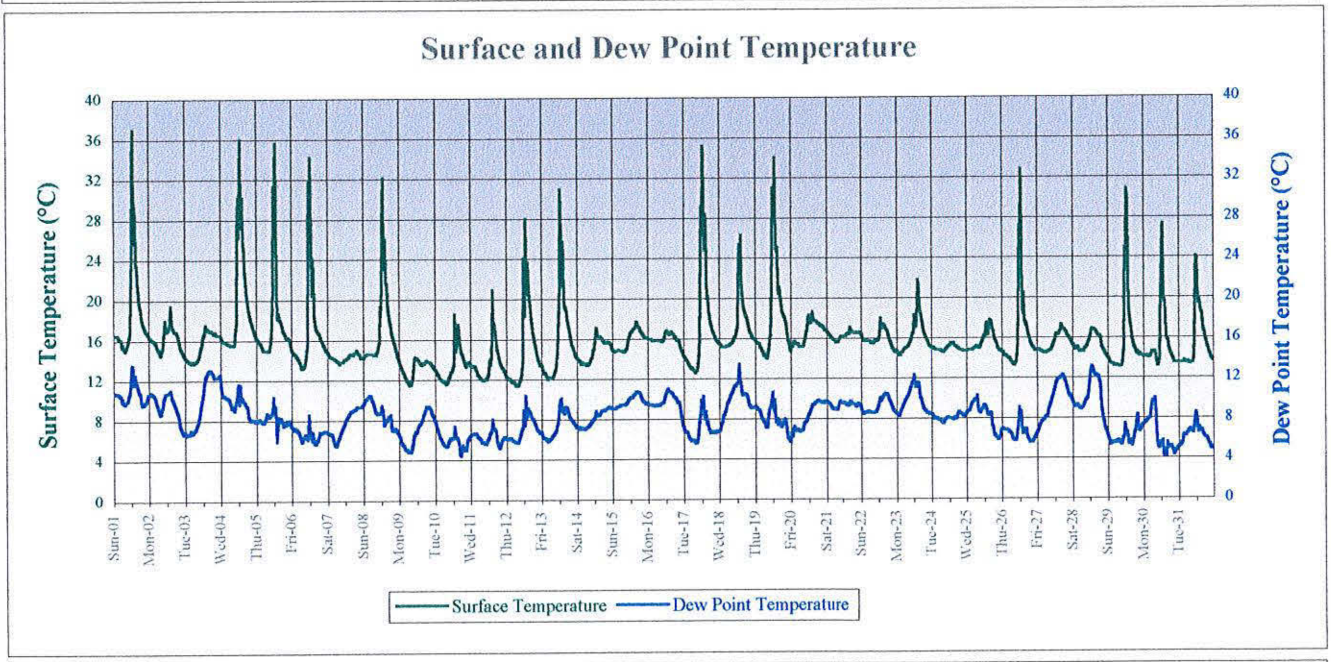


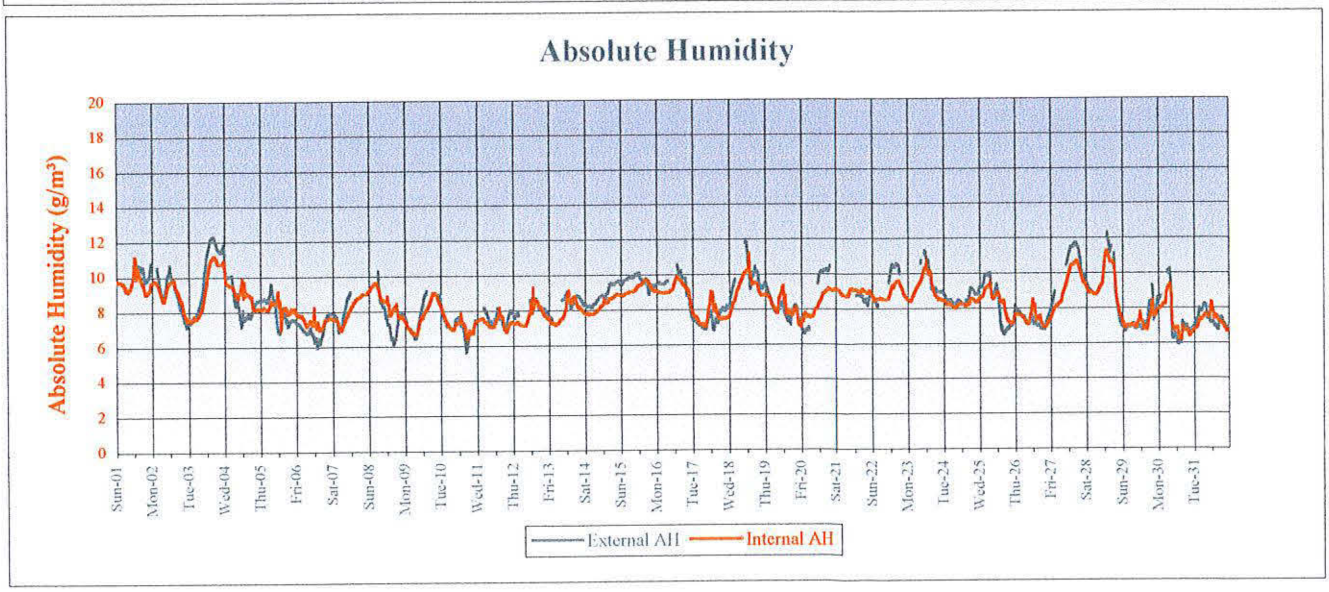
Peterborough Cathedral Nave Ceiling

October 2000

Probe 5: Bay 33 III upper side (sun)



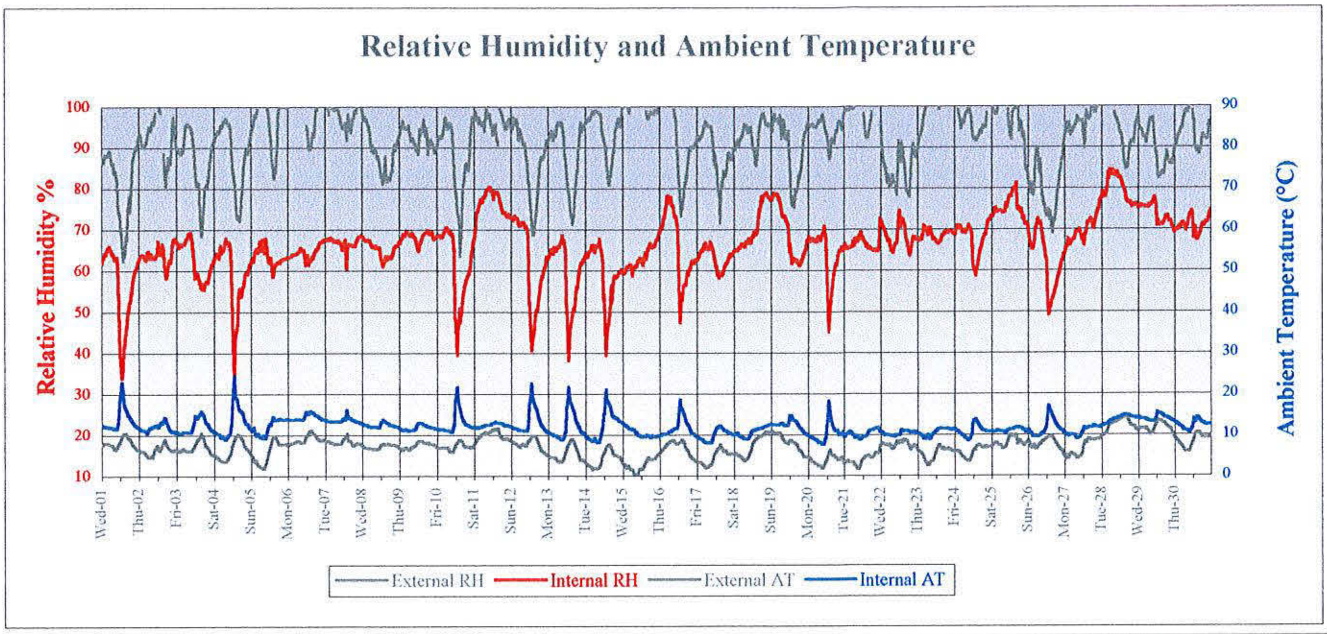


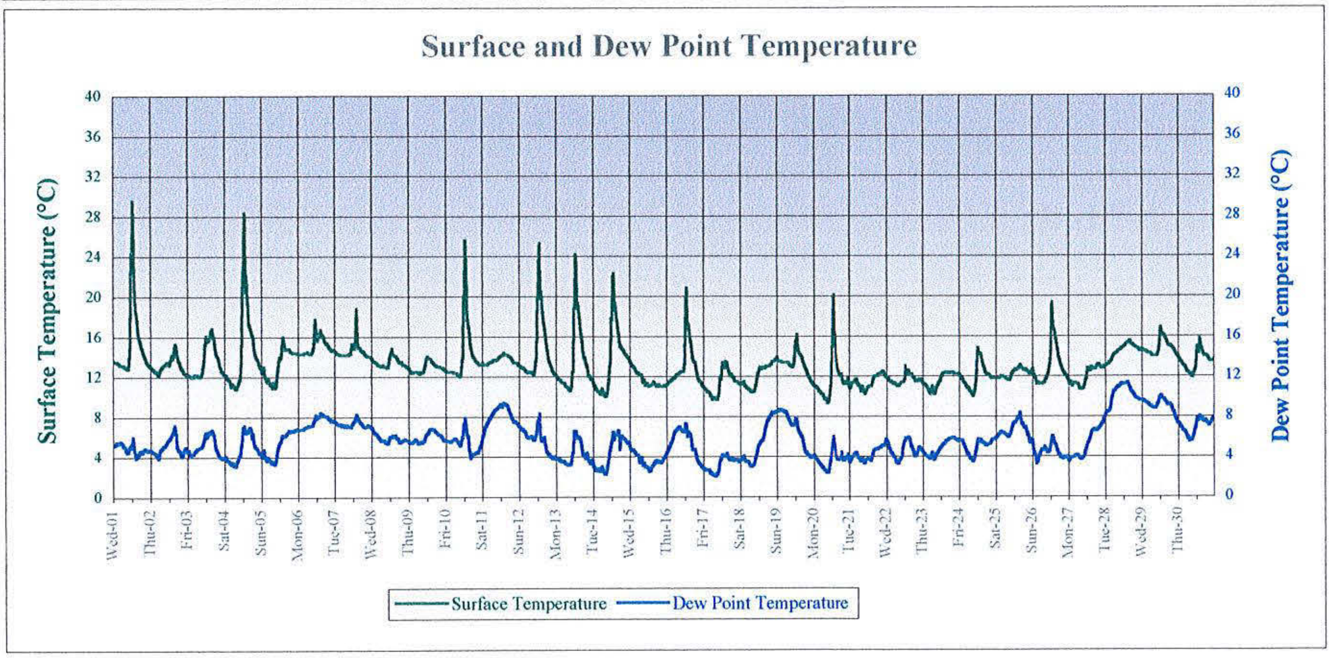


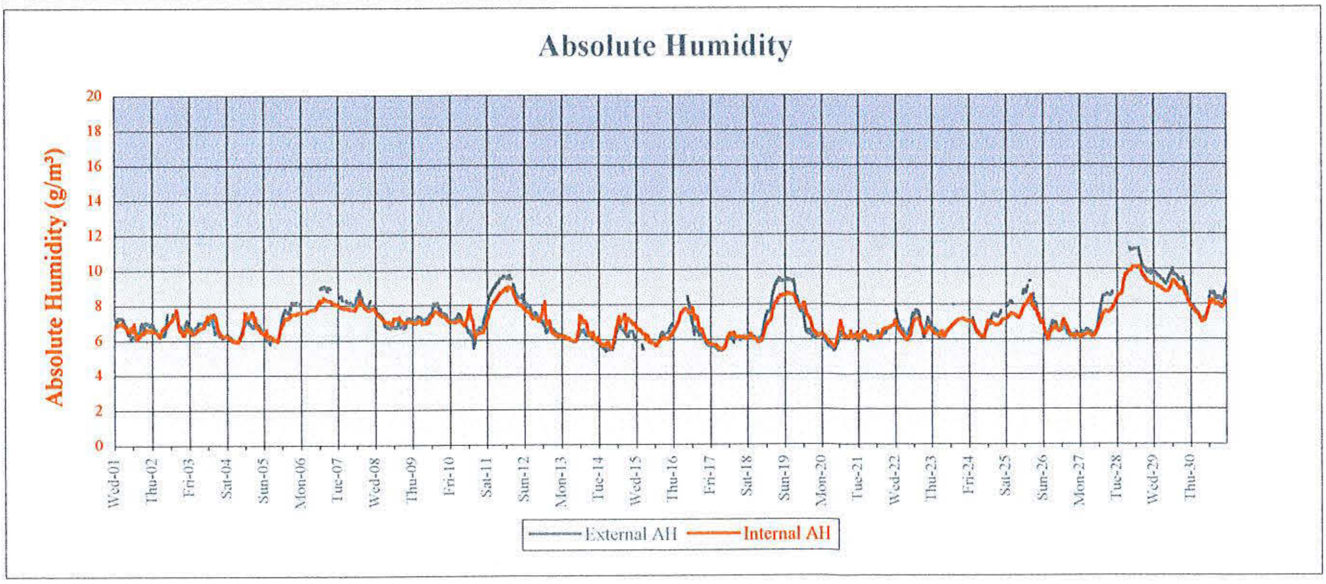
Peterborough Cathedral Nave Ceiling

November 2000

Probe 5: Bay 33 III upper side (sun)



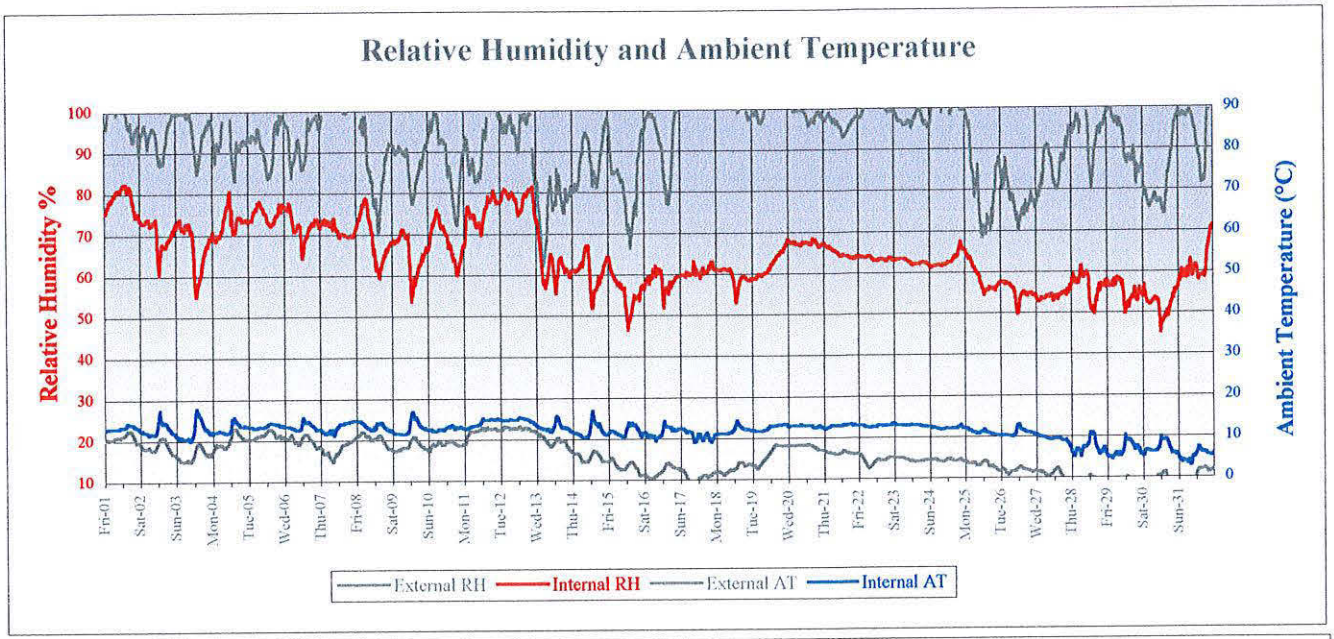


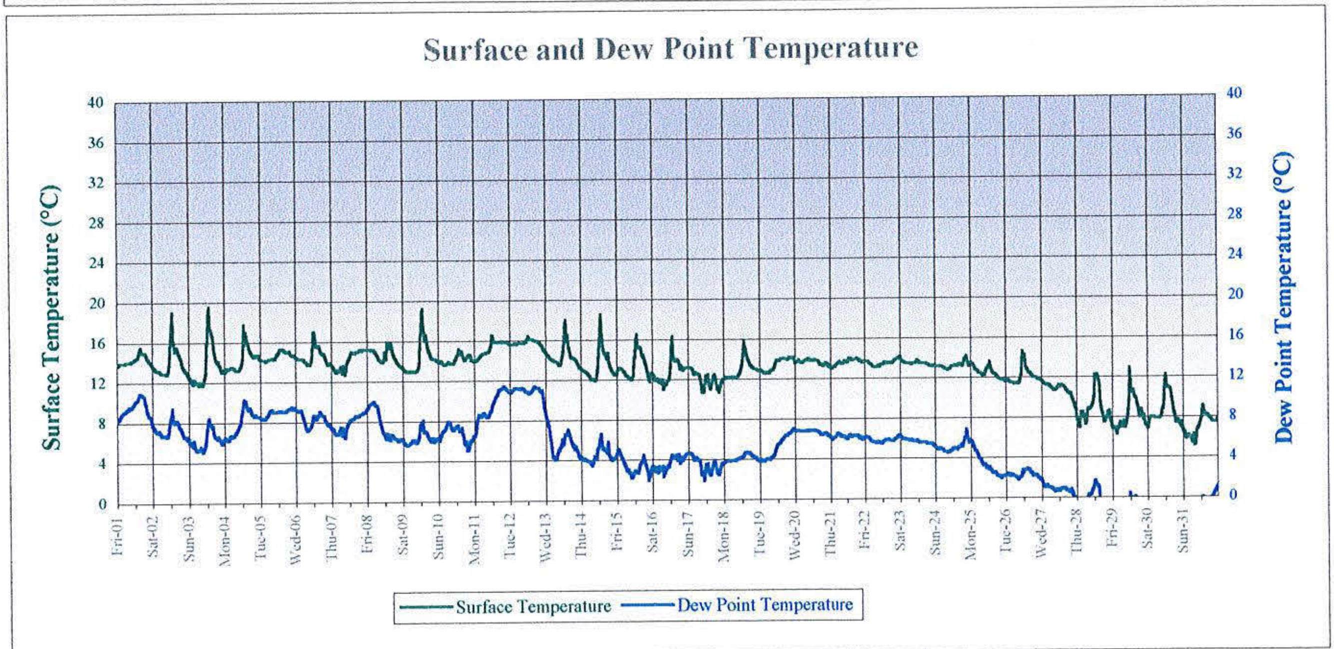


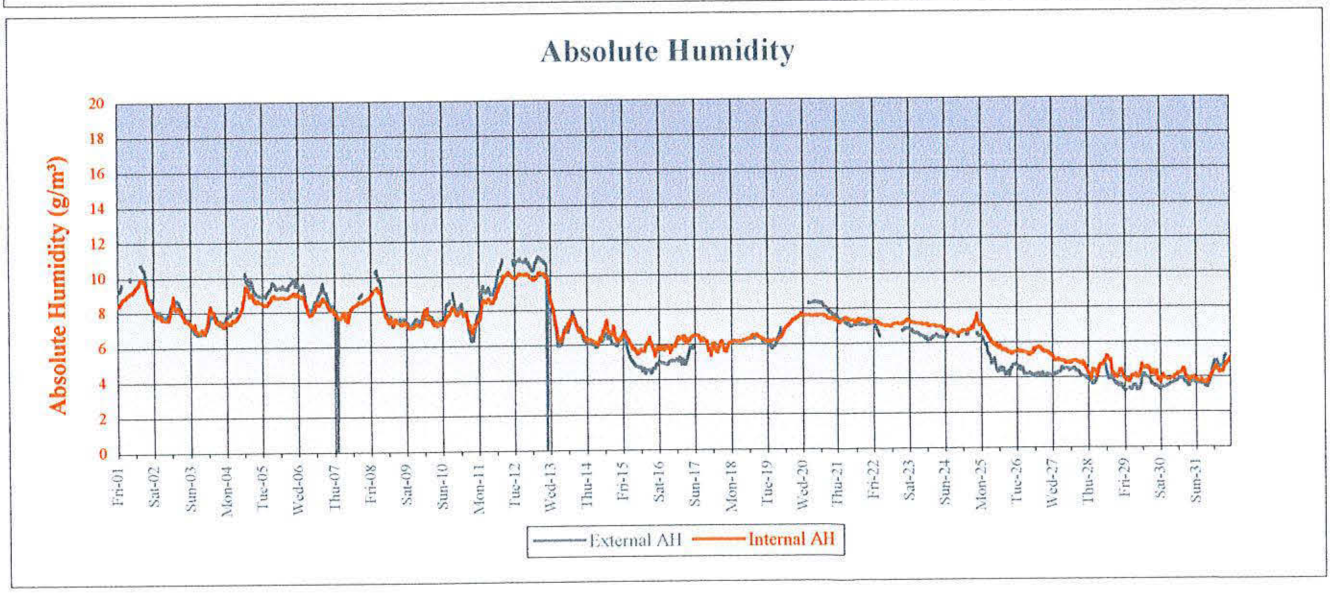
Peterborough Cathedral Nave Ceiling

December 2000

Probe 5: Bay 33 III upper side (sun)



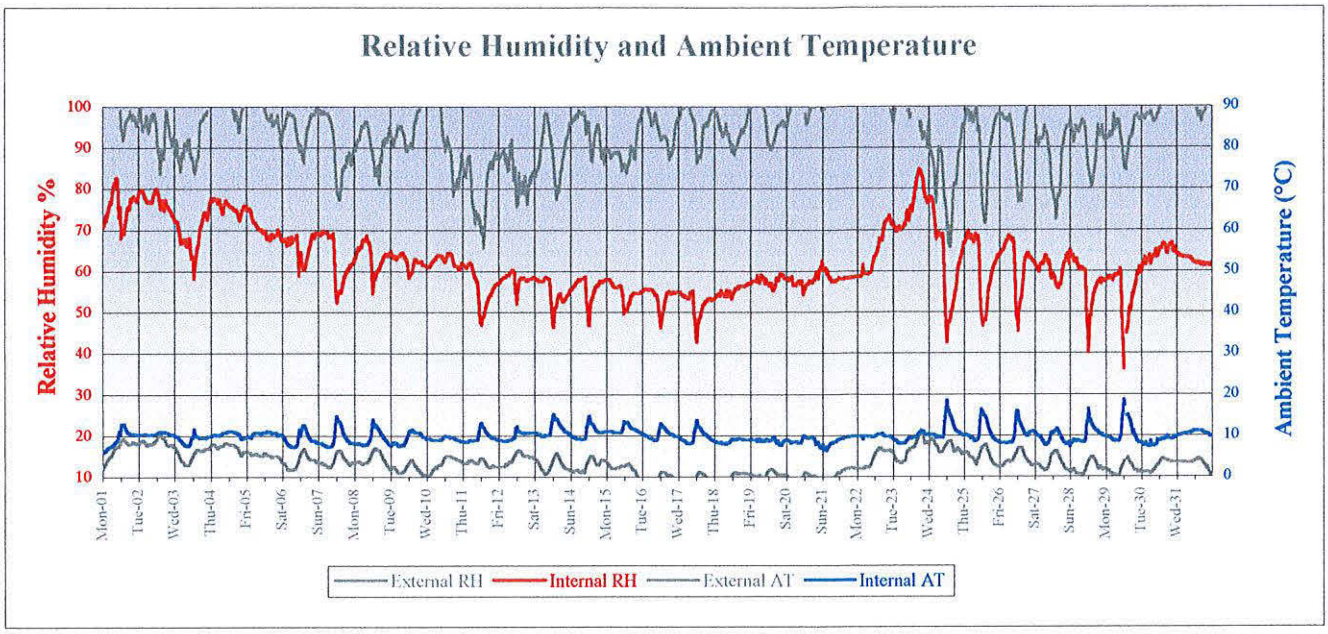


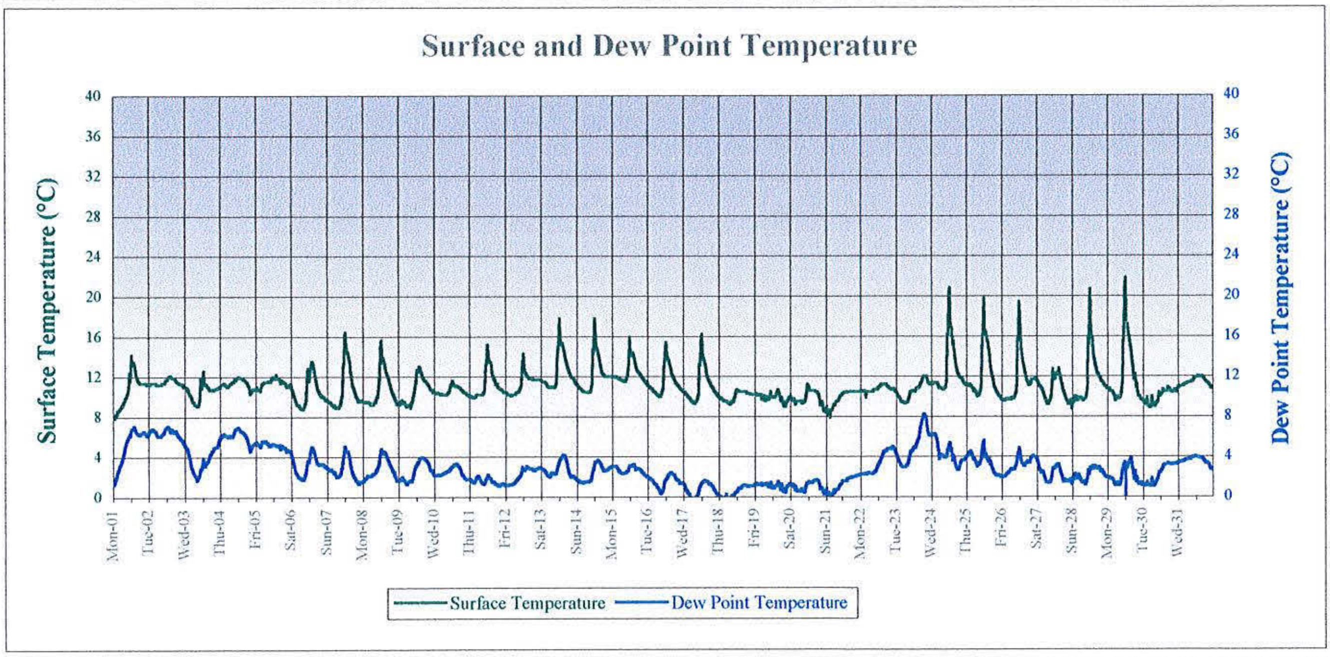


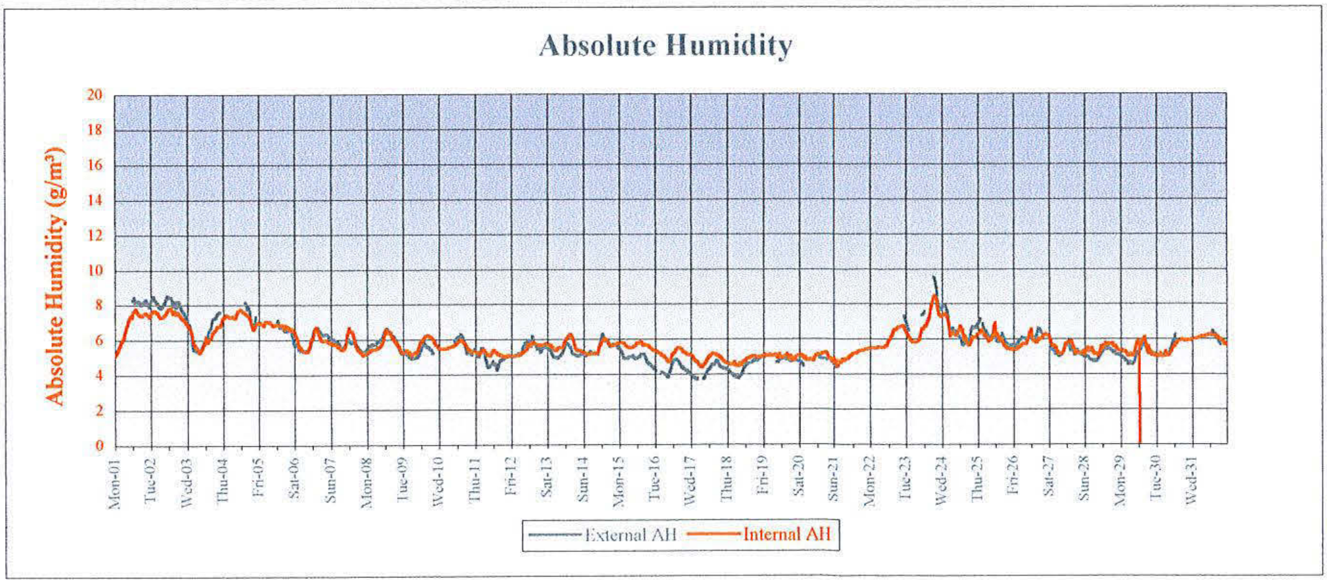
Peterborough Cathedral Nave Ceiling

January 2001

Probe 5: Bay 33 III upper side (sun)



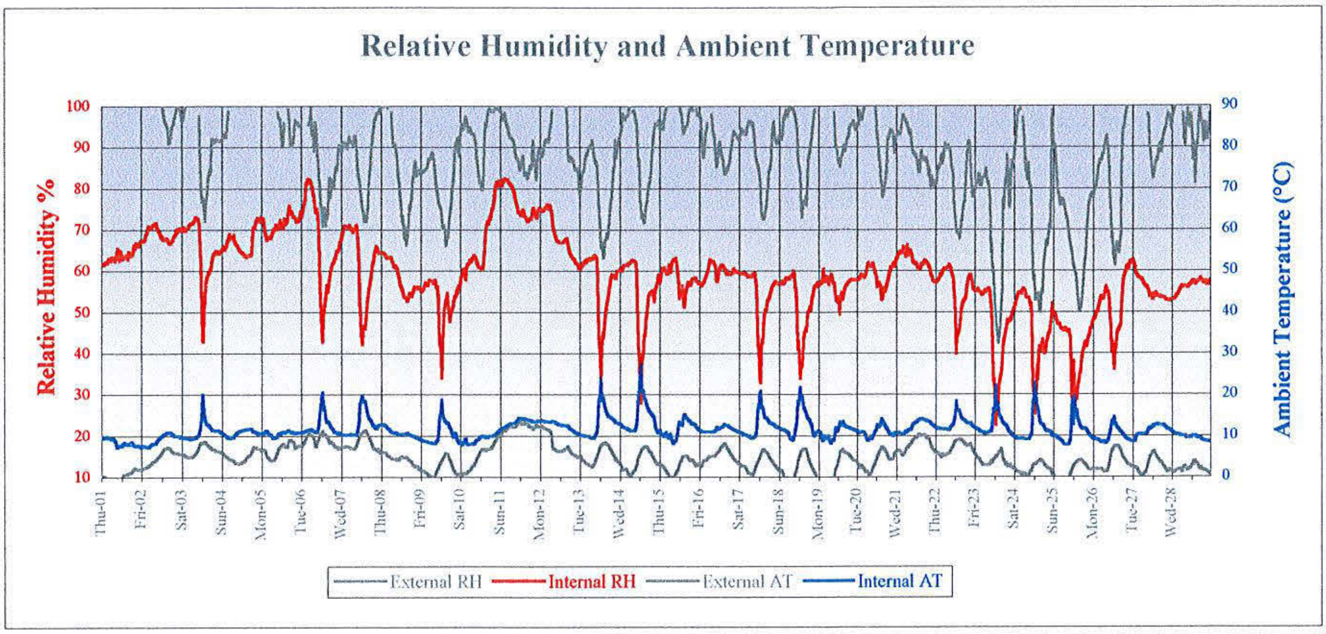


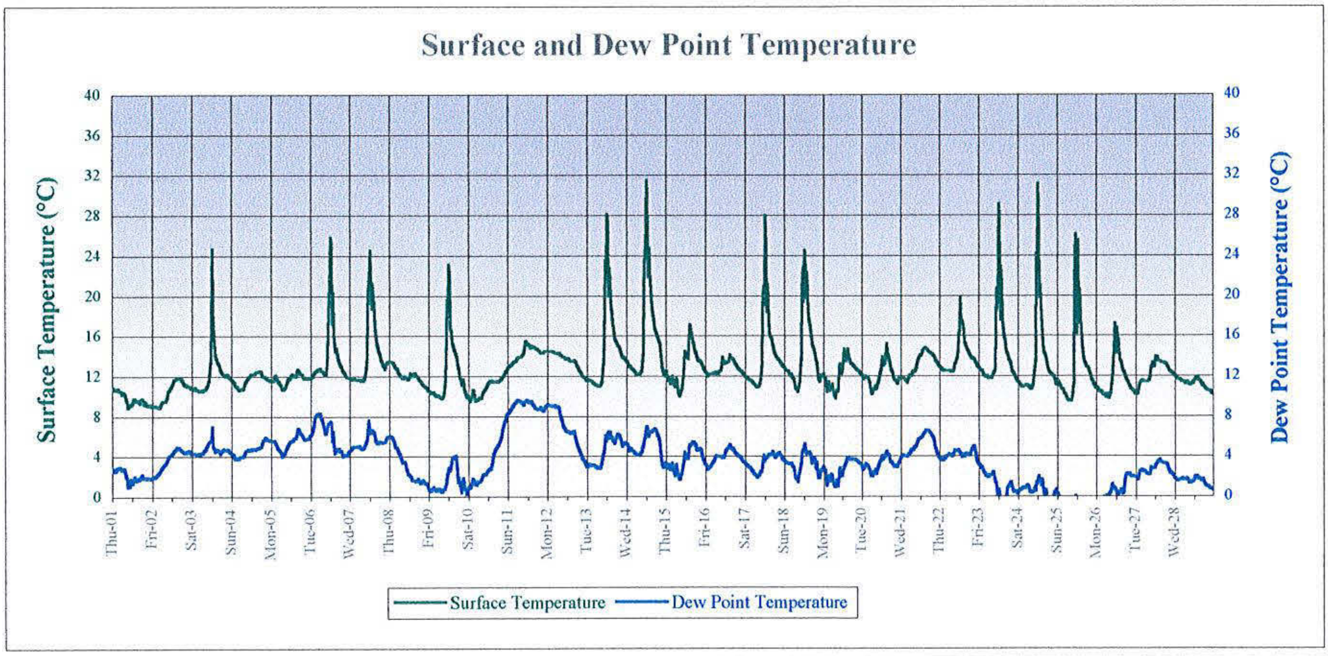


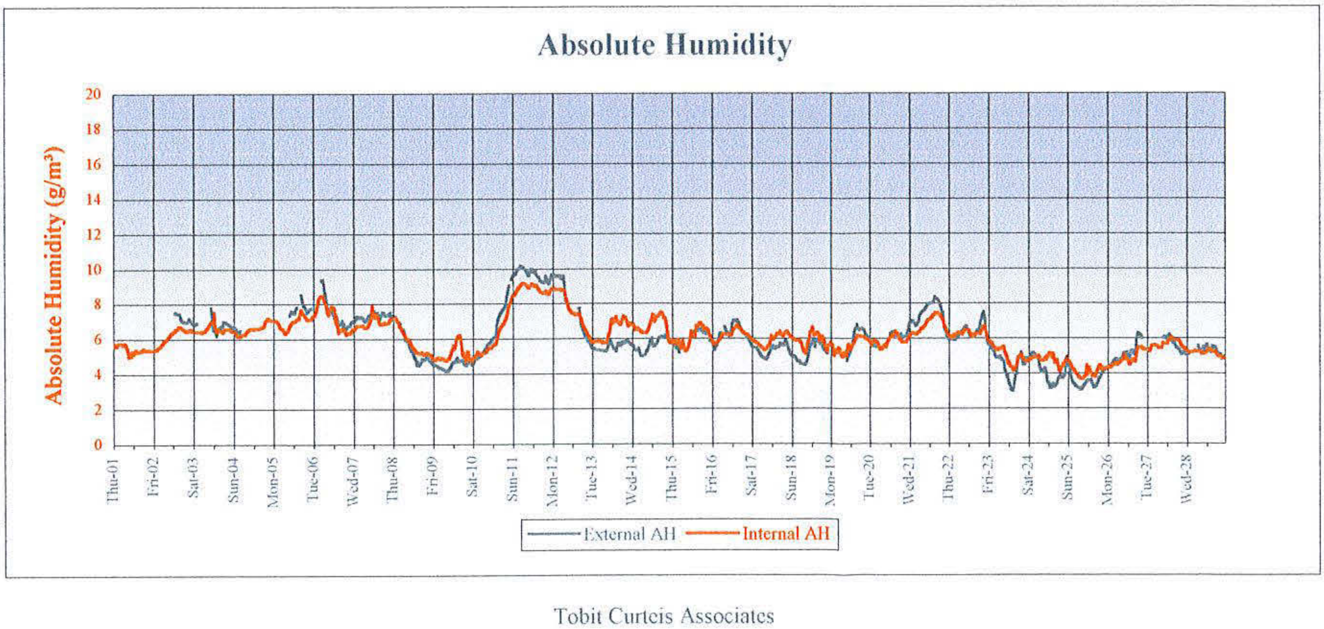
Peterborough Cathedral Nave Ceiling

February 2001

Probe 5: Bay 33 III upper side (sun)



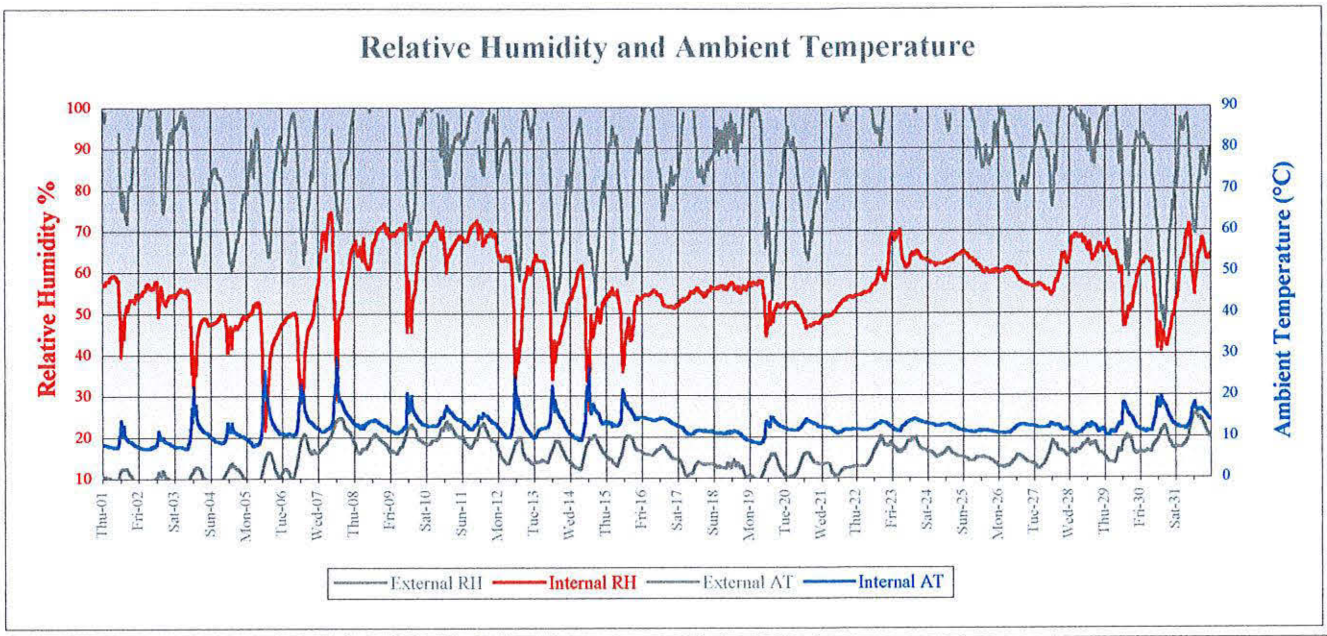


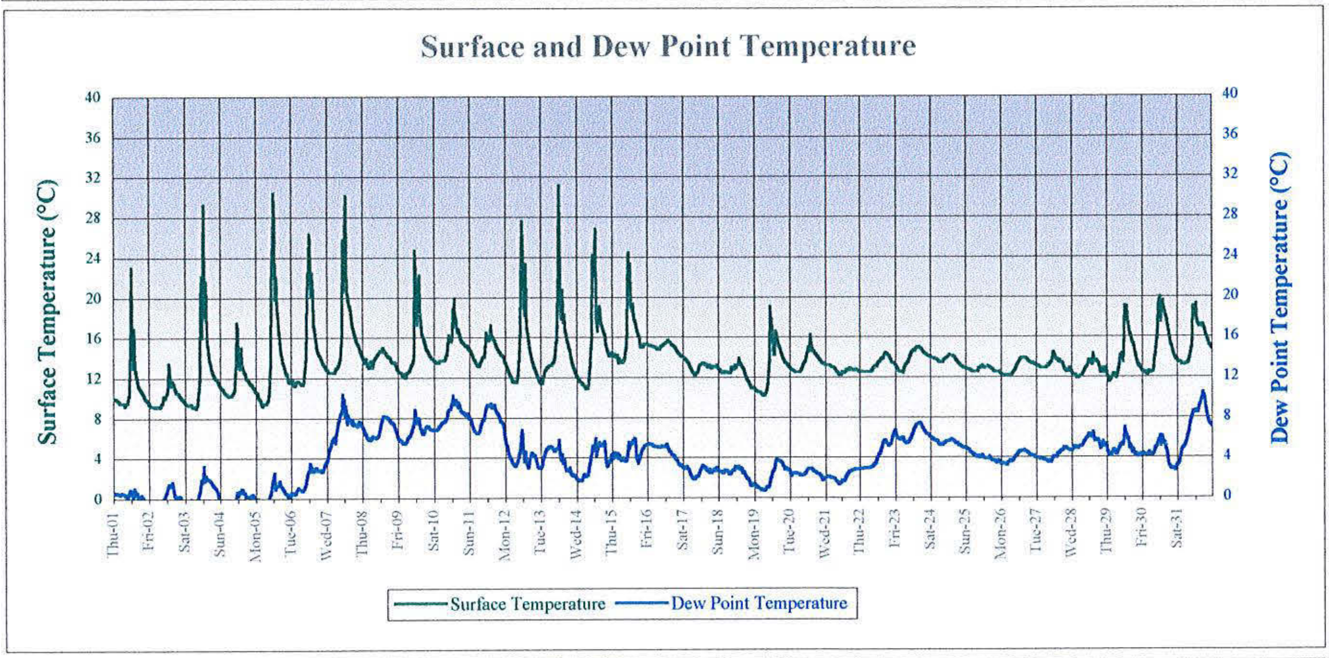


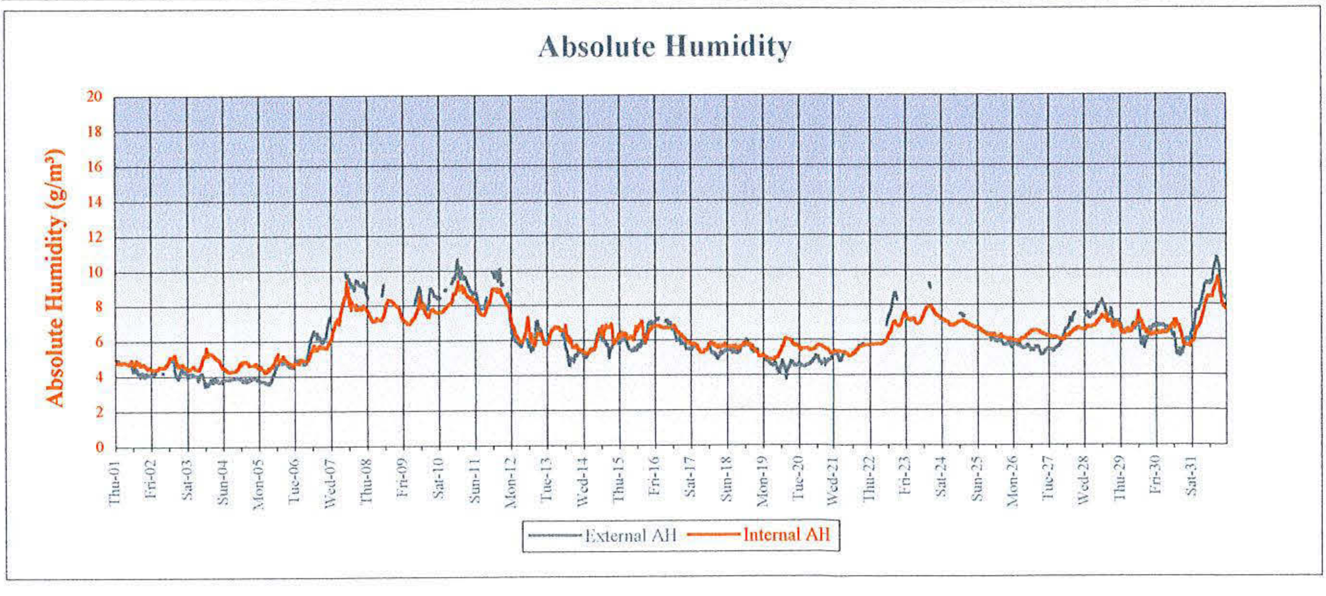
Peterborough Cathedral Nave Ceiling

March 2001

Probe 5: Bay 33 III upper side (sun)



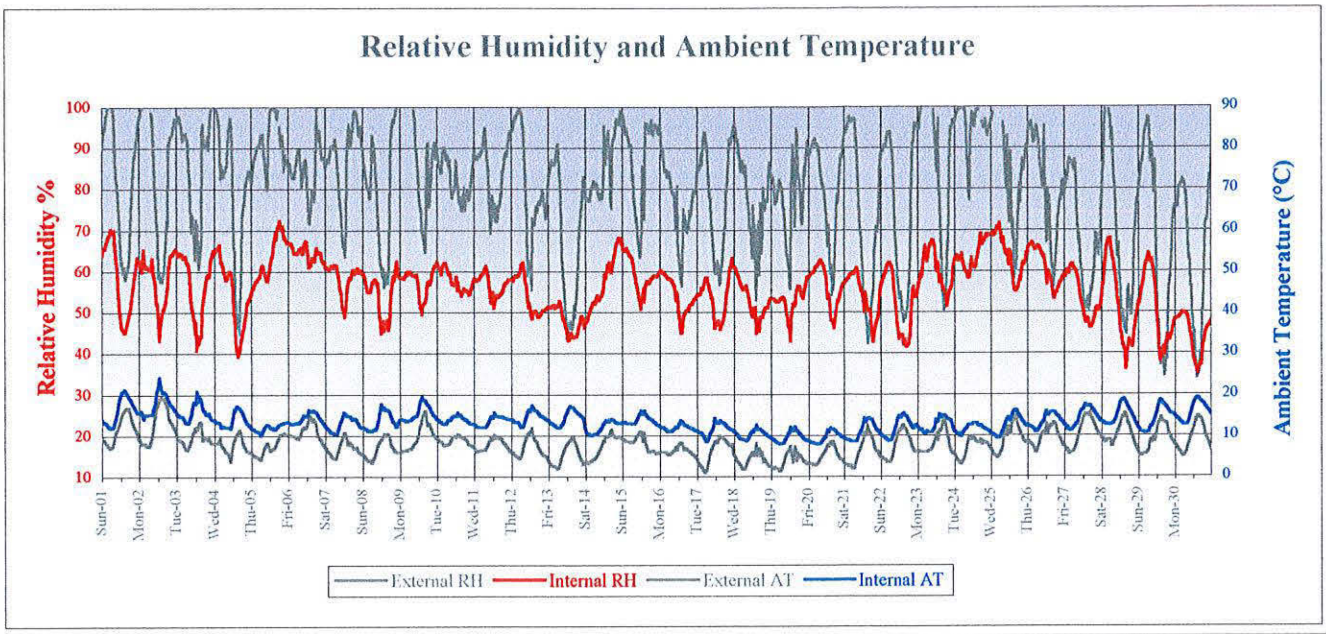


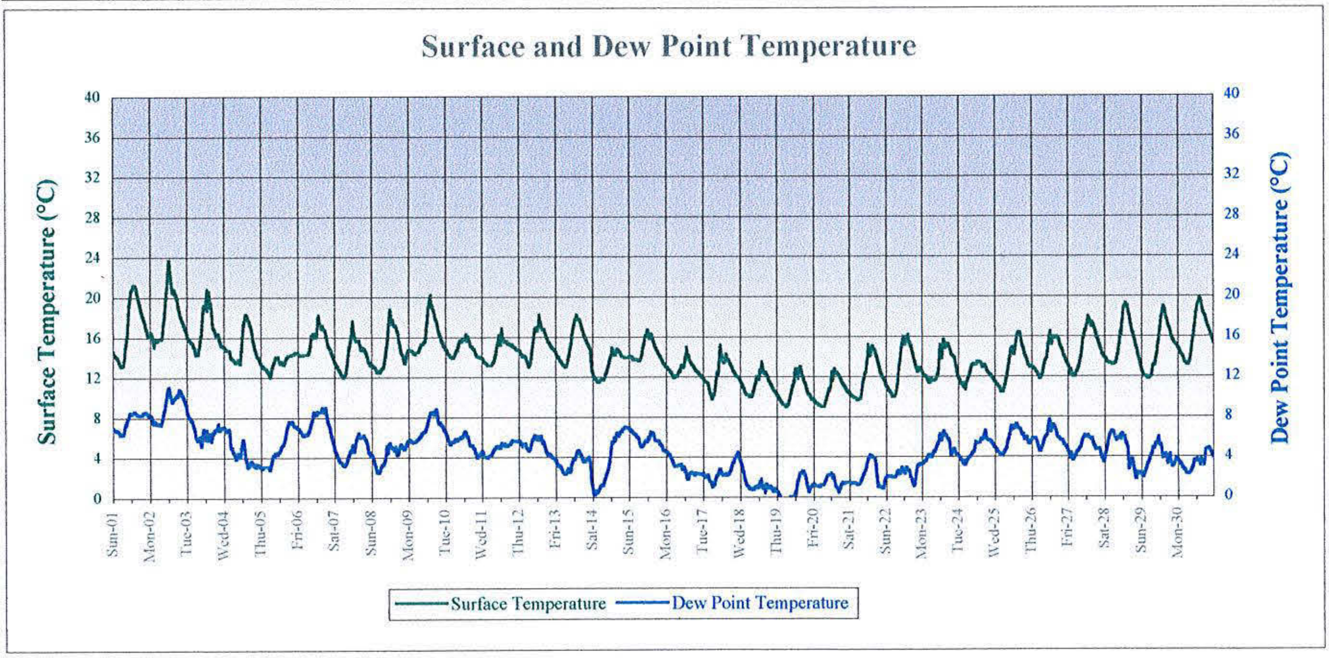


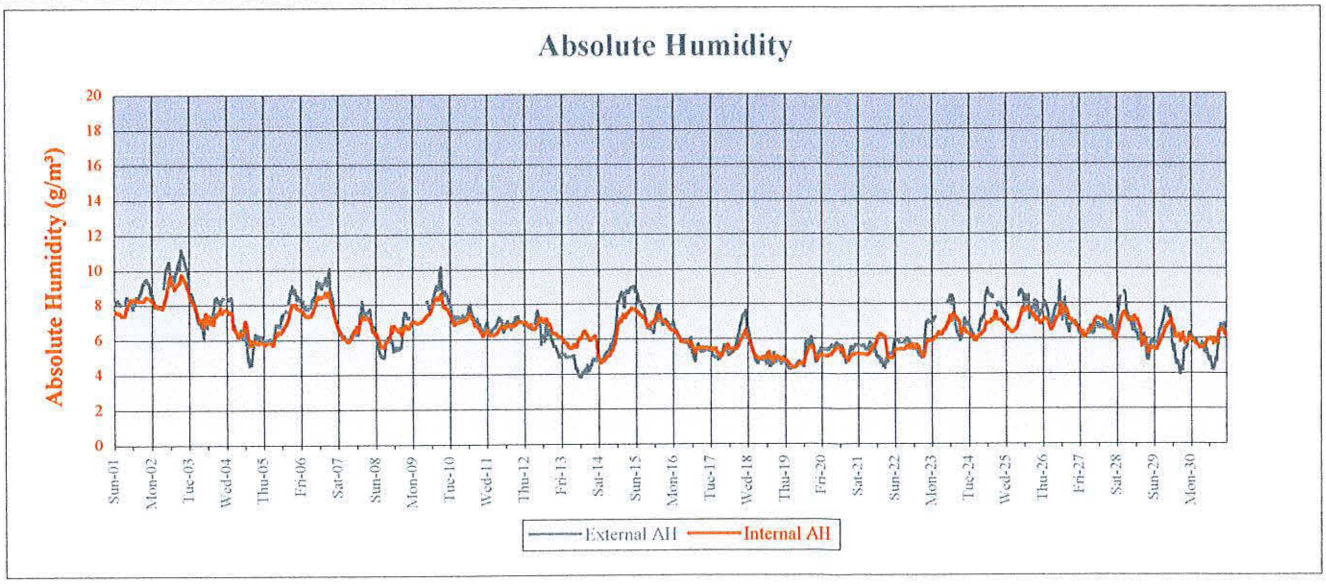
Peterborough Cathedral Nave Ceiling

April 2001

Probe 5: Bay 33 III upper side (sun)







Peterborough Cathedral Nave Ceiling

Probe 5: Bay 33 III upper side (sun)