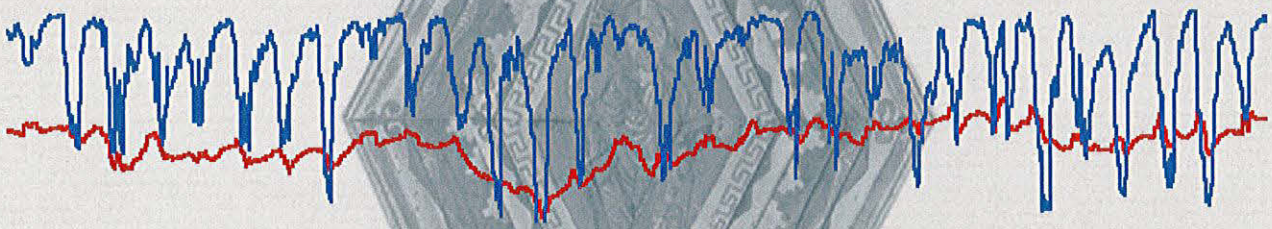
TOBIT CURTEIS ASSOCIATES

PETERBOROUGH CATHEDRAL



ENVIRONMENTAL MONITORING OF THE NAVE CEILING

MARCH 1998 – MAY 2000

36 Abbey Road Cambridge CB5 8HQ Tel 01223 501958 Fax 01223 304190 E-mail tca@tobit-curteis-associates.co.uk

Tobit Curteis B.A.(Hons.) Dip. Conservation (Courtauld Institute)

VAT REG No. 636 9463 04

CONTENTS

Report No: PTB01.1

Date: 2nd August 2000

Author: Tobit Curteis Associates
36 Abbey Road, Cambridge CB5 8HQ.
Tel 01223 501958 Fax 01223 304190

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, 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 environmental monitoring programme has been undertaken as part of the conservation of the nave ceiling, in order to assess the possible effects of the microclimatic conditions on its deterioration.

Analysis of the data has shown that there is a very significant temperature and humidity gradient across the ceiling, as a result of the extreme variations between the conditions in the body of the cathedral and those in the roof space. While the body of the cathedral is strongly buffered by its closed structure and high level of heating, the buffering in the roof space is minimal, with very little insulation and a high level of external ventilation. The lack of buffering in the roof space also results in significant diurnal fluctuations in the environmental conditions which reflect those externally. As a result, the upper and lower sides of the ceiling boards are subjected to wide variations in conditions, not only on a seasonal basis, but also on a daily one. In addition, the insertion of roof lights in the 1920s has caused large areas of the upper side of the ceiling to be subjected to direct sunlight, on a regular basis. During these periods, temperatures on both the upper and lower sides of the ceiling can reach very high levels, with a resulting sharp decrease in relative humidity.

The level of the microclimatic fluctuations that has been observed would suggest that there should be significant dimensional response in the wooden boards, which would normally result in the delamination and flaking of the paint layer. However, in the areas that have so far been treated, no such patterns of deterioration have been observed. There also appears to be no sign of cumulative movement across the ceiling as a whole causing large scale structural damage.

Therefore, although the conditions are far from ideal, if there is no resulting deterioration, there must be a question as to how much environmental control is necessary or justifiable. In order to assess whether environmental controls should be implemented, it will be necessary to identify whether the wood has a dimensional response to the environmental fluctuations, which is being absorbed by the paint layer, or whether there is simply no dimensional response from the panels. In order to achieve this, methods of measuring movement within the panels are currently being examined, with the intention that a suitable system can be installed during the current phase of monitoring. Once the information on the level of dimensional response is available, the benefits of specific environmental controls will be more easily assessed.

2.0 INTRODUCTION

The painted ceiling at Peterborough Cathedral is currently the subject of a major programme of research and conservation. As part of this work, a programme of environmental monitoring is being undertaken in order to assess the effect of the microclimate on the condition of the ceiling. Until 1999, the monitoring was undertaken by English Heritage. In June 1999, a new system was installed in order to allow the continuation of the established programme as well as the expansion of the monitoring to incorporate areas which may provide further information on the environmental phenomena already observed.

The current report marks the conclusion of the first twelve month period since the installation of the new monitoring system, and includes a full presentation and analysis of the data from this period. In addition, it draws together all available data from the previous phases of monitoring, in order to allow a comprehensive assessment of the information available to date.[1]

It is intended that the environmental monitoring programme continues for at least the duration of the conservation work (currently expected to be completed in 2003), in order that the impact of the environmental conditions on the whole of the ceiling can be fully examined.

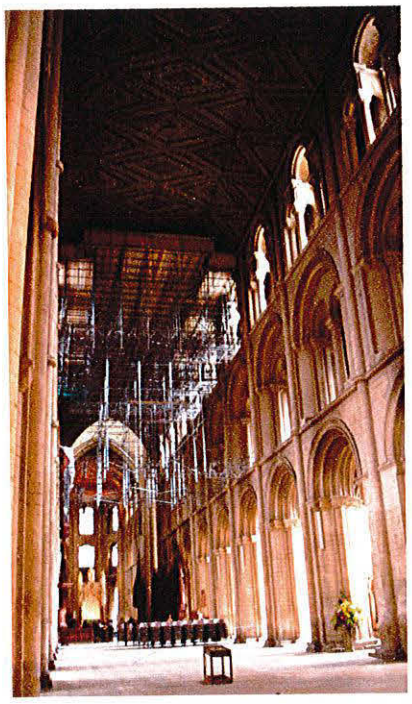


Figure 1. View of the nave, facing east. (Photo: TCA 2000)

[1] A significant part of the information in the current report was presented in a preliminary report in January 2000.

3.0 THE CEILING AND ROOF STRUCTURES

Figure 2. Detail of the painted ceiling. (Photo: TCA 2000)

The 12th century ceiling is a complex heterogeneous structure consisting of timber boards coated on their underside with a number of paint layers and on their upper side with a layer of hessian, adhered with animal glue. Although most of the boards are the original oak, there are numerous repairs using pine and other softwoods. The boards are nailed directly to the joists and noggins above, as well as being nailed to each other along their edges. The ceiling, consists of 39 bays in four tiers and measures approximately 62.2m x 11.6m. *(Diagrams 1 & 2)*

The nave roof consists of a timber structure on which there are thin wooden boards, a layer of felt and large slate tiles. The roof was largely renewed in the 1830s by the architect Edward Blore and then heavily restored in 1924 by Leslie Moore, the cathedral architect. It is also possible that structural repairs were carried out in the 1740s at which time the ceiling was largely repainted and in the 1880s, when the crossing tower was rebuilt.

On both the north and south sides, the lower part of the tiling was replaced in the 1920s restoration by a course of reinforced glass panels, which have large ventilation gaps with wire grills at both the top and bottom. In addition, there are a series of regularly spaced vents in the lead covering at the apex of the roof. With the exception of the marginal effect of the hessian (applied by Moore in the 1920s), there is no additional insulation between the roof boarding and the upper side of the ceiling. A full and detailed characterisation of the ceiling and its condition is provided in the condition surveys and conservation reports. [2]

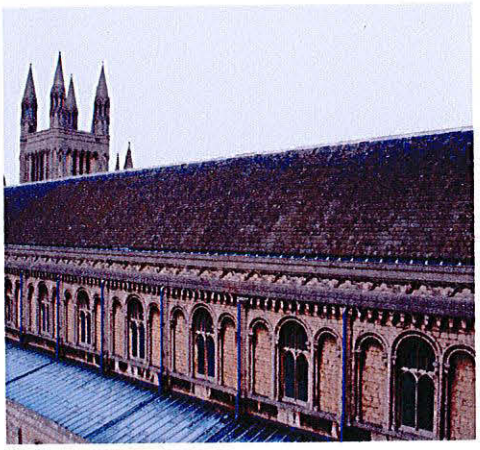


Figure 3. South side of the roof. (Photo: TCA 2000)

4.0 METHODOLOGY AND EQUIPMENT

4.1 SOURCES OF ENVIRONMENTAL DETERIORATION

The two main sources of environmental deterioration which are of concern in relation to the ceiling are liquid water and water vapour. The principal source of liquid moisture is the infiltration of water from a damaged roof structure. Although some areas of staining on the hessian suggest that this has been a factor in the past, there is no evidence that infiltration continues to occur on any significant scale. Therefore, the moisture source currently of most relevance is water vapour, relating to the hygroscopicity of the ceiling and the possibility of condensation. As the ceiling is a composite structure, it is necessary to consider the possible impact of certain environmental conditions on the individual layers as well as on the structure as a whole.

Because of its chemical and physical structure, and the resulting level of hygroscopicity, wood remains highly responsive to fluctuations in relative humidity, even when extremely old. The level of dimensional response to such changes is primarily a function of the moisture content (MC) of the wood. In general the level of shrinkage is linearly proportional to changes in the MC. The dimensional response is also effected by the specific gravity (or density) of the wood. Therefore oak, which has a higher specific gravity than most pine, is subject to greater levels of shrinkage and swelling.[3] However, in order to address the response of the wood to fluctuations in relative humidity (RH) it is necessary to consider the equilibrium moisture

---

[2] The Perry Lithgow partnership & Hugh Harrison, *Peterborough Cathedral: The Nave Ceiling, Phase 1: Rows 36-40, Condition Survey and Conservation Treatment*, June 1998

[3] Hoadley, R.B., 'Chemical and Physical Properties of Wood', *The Structural Conservation of Panel Paintings, Proceedings of a Symposium at the J. Paul Getty Museum*, April 1995, Los Angeles (1998), p.3

content (ECM) - that is the balance between the ambient RH and the level of water in the cell walls at a given temperature. Although EMC is dependant on wood type, a typical value at 20°C and 65% RH would be approximately 12%.[4] Because water molecules within the cell walls are more strongly held by chemical and physical bonds than those in the surrounding air, a greater level of energy is required to desorb them than is required to absorb them in the first place. This gives rise to an hysteresis effect which, in practical terms, means that the EMC and therefore dimensional changes, may be buffered from short term fluctuations in RH.

The response to moisture is also governed by the dimensions and cut of the individual board. As wood has an anisotropic structure, dimensional change in different planes can be vastly different. While for oak, one might expect longitudinal shrinkage from green to oven dry of no more than 0.1% – 0.2%, radial shrinkage may be up to 5.2% and tangential shrinkage, as much as 10%.[5] The cut of the boards also has a significant influence on the direction of any movement, and boards which are cut tangentially across the grain are more likely to warp than those cut radially.[6] In addition, the ratio of exposed surface to volume of wood influences the level of reactivity to moisture, so that thin boards can be effected more than thicker panels. [7]

The uneven cycles of movement resulting from fluctuations in RH will inevitably cause increased stresses across individual boards which are fixed at specific points, as well as across groups of boards which are attached to each other. In both cases, the possibility of cracks occurring around the fixing points is very significant. In addition, tightly restrained boards may be at risk as a result of cracking occurring due to compression setting.[8]

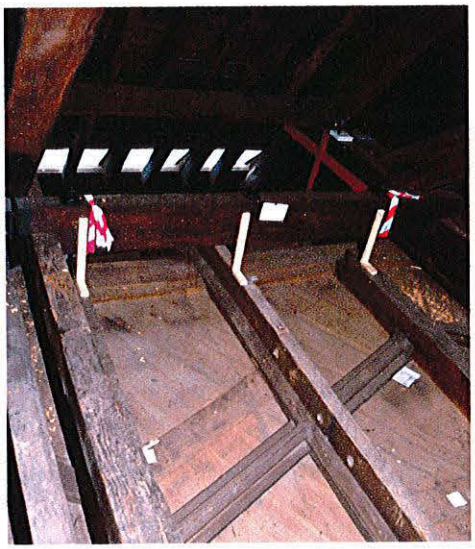


Figure 3. Detail of the back of the roof in bay 34 III. Note the windows at the base of the roof on the south side. (Photo: TCA 2000)

The situation at Peterborough is further complicated by the fact that the front and the back of the panels are coated with different materials and the surrounding microclimates differ enormously. The use of organic coatings on wood panels has also been shown to have a significant effect on the levels of moisture sorption of the wood itself, making the effect on the ceiling panels harder to predict.[9]

The effect of the hessian and animal glue applied to the upper sides of the boards further complicates the situation. While the exact nature of the glue used to adhere the hessian to the back of the ceiling boards is not known, it is believed that it is an animal or fish glue, the principle constituent of which would be the protein collagen. Due to its chemical structure, collagen is very hygroscopic and particularly susceptible to fluctuations in relative humidity, which can cause significant expansion and contraction.[10]

Despite the fact that tests have shown that the strength of the hessian has deteriorated by up to 90%,[11] the fluctuations in relative humidity are also likely to cause some level of dimensional response. While machine woven canvas is likely to contract with an increase in humidity, loose weave materials such as hessian are likely to be effected less, in the same conditions. The level to which the deteriorated hessian is currently supporting or

---

[4] Knut, N., *The Restoration of Paintings*, Cologne (1999), p.20

[5] *Op. Cit.* Hoadley, p.15

[6] 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.

[7] Wadum, J., 'Microclimate Boxes for Panel Paintings', *The Structural Conservation of Panel Paintings, Proceedings of a Symposium at the J. Paul Getty Museum*, April 1995, Los Angeles (1998), p.498

[8] Compression setting occurs as a result of the compression of the cellular structure caused when wood expands under restraint, in response to an increase in RH. When the RH is reduced, the wood may have lost volume and will try to pull away from its fixing points.

[9] 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.

[10] Horie, C.V, *Materials for Conservation*, London (1987), p.142

[11] Tests on the residual strength of the hessian were undertaken by Dr Christina Young at the Tate Gallery.

strengthening the ceiling structure is not entirely clear. However it is apparent that major fluctuations in the environmental conditions may cause an increase in tension between the hessian and the panels, which, under some condition, might cause delamination and a decrease in the support currently provided to the boards.

Therefore, the risk of deterioration can be seen as being of two orders. The first of these is small scale deterioration, which would include cracks to individual boards, delamination and flaking of the paint layer and delamination of the hessian. The second concern is of large scale deterioration of the ceiling structure itself, as a result of cumulative small alterations, causing large scale movement.

4.2 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 present. The new system also allowed the addition of further probes in order to allow other areas to be monitored.[12]

4.3 MONITORING METHOD AND DATA PRESENTATION

The aim of the monitoring programme was to provide data to allow an informed assessment of the impact of the environmental conditions on the present and future condition of the ceiling.

The thermohygrometric parameters measured were relative humidity (RH), Ambient Temperature (AT) and Surface Temperature (ST). In order to allow the calculation of Absolute Humidity (AH) and Dew Point Temperature (DPT) internal probes were grouped in RH/AT and ST clusters.

In order make the data more accessible, the information for each probe cluster is charted both monthly and annually. RH, AT and AH are overlaid on the equivalent external data so that direct comparisons can readily be made. ST and DPT are shown on the same chart in order that instances of predicted condensation are clearly visible. In addition, charts are provided showing a comparison between the RH, AT and ST at each individual probe site, so that variations can be examined.

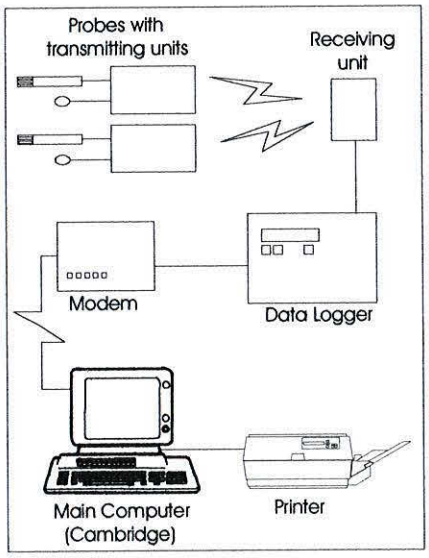


Figure 5. Schematic diagram showing the structure of the current monitoring system

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.[13] 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.

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 either side of the ceiling.[14] 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

---

[12] Some sections of data were lost during the programme due to electronic malfunctions.

[13] 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.

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

Table 1. Probe positions and channel numbers

PROBE	POSITION	ST	AT	RH
1	Bay 36 III ceiling lower side (shade)	1	2	3
2	Bay 36 III ceiling upper side (shade)	4	5	6
3	Bay 33 IV ceiling lower side (sun)	7	8	9
4	External, north side		10	11
5	Bay 33 IV ceiling upper side (sun)	12	13	14

regularly exposed to direct sunlight. An external probe was situated on the north side of the roof in order to provide control data. A summary of probe positions and channel numbers are shown in table 1. 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.

5.0 ENVIRONMENTAL MONITORING

5.1 MACROCLIMATIC CONTEXT

Peterborough is situated in a low lying area of East Anglia, south west of the Wash, where the average height above sea level is less than 61m. *(Figure 6)* Due to this topography, the cathedral is one of the highest points in the vicinity and is relatively exposed.

As with the rest of the country, the predominant wind direction is from the south west, although in spring, more northerly winds are experienced. The average wind levels throughout the year are relatively high for the south of England. Nevertheless, the mean annual temperature in the area is between 9°C and 10.5°C, well within the national average.

East Anglia is one of the driest areas of the country with an annual rainfall of approximately 600mm. Peterborough itself has a rainfall closer to 550mm.[15]

During the period 1971 – 1980, an annual average relative humidity of 80% was recorded for the region as a whole. However, during the recent period of monitoring the annual average outside the cathedral roof was only 75%. As may be expected, the diurnal fluctuations of relative humidity and ambient temperature vary considerably between the summer and winter months. *(Figure 7)*

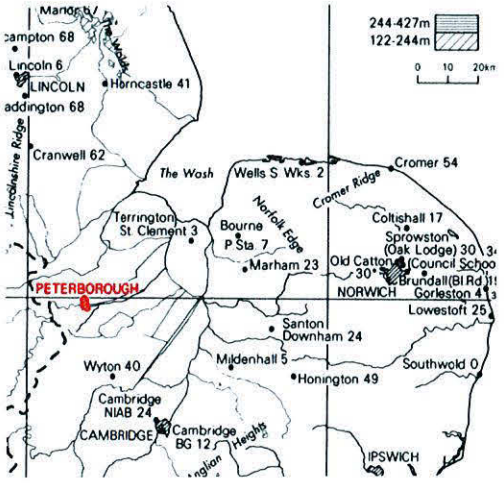


Figure 6. Topographical map of the area East Anglia *(Met Office 1989)*

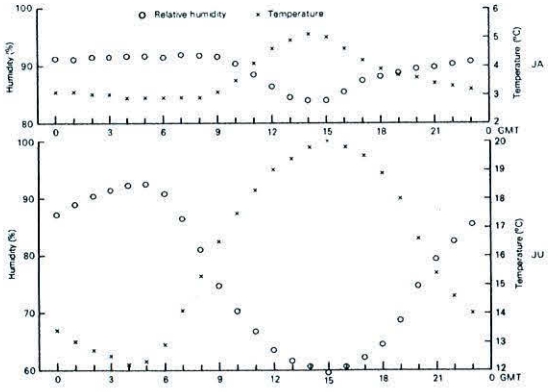


Figure 7. Average diurnal variation of RH & AT at Stansted for January and July during 1971 – 80. *(Met Office 1989)*

[15] Meteorological Office, *The Climate of Great Britain, East Anglia and Lincolnshire, Climatological Memorandum,* 133, rev. ed., 1989

5.2 INFLUENCES ON THE MICROCLIMATE

5.2.1 HEATING

Prior to mid 19th century there was no significant heating in the cathedral. 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, these were upgraded to run on oil and in 1993 they were converted for use with gas. During the 1993 alterations, thermal insulation blocks were added to the stoves in order to increase their long term heat retention, effectively causing them to act as storage heaters.[16]

The stoves in the nave are situated in the north and south aisles at the east and west ends of the nave. Smoke stains can be seen directly above them on the aisle vaults and on the inner walls of the clerestory and triforium directly above, giving a clear illustration of the passage of hot air and combustion products.[17]

Figure 8. Stove in the north aisle. (Photo: TCA 2000)

The heaters are in use from approximately mid November until mid March. 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 milder, some are occasionally turned off.[18]

The stoves are fitted with water trays which can be used to increase the level of water vapour in the internal environment, through evaporation. Although these have not been regularly used in recent years, a test was carried out between December 1995 and January 1996. The trays of each of the three active stoves in the nave were filled with eight gallons of water each day at 7am. These were found to have completely evaporated by 3pm. During the period that the trays were used, the relative humidity in the nave was reported to have remained higher than would otherwise have been the case.[19] However, calculations based on the weight of water to the approximate volume of the nave suggest that even with no air exchange, and assuming the most benign conditions, the AH could not have been increased by more than approximately 0.5 g/m^3 per hour (during use).

5.2.2 VENTILATION

Although some of the windows in the triforium and clerestory are fitted with hinged lights, these are now kept permanently closed and in most cases the operating cords have been removed. Therefore, the main ventilation to the body of the cathedral is provided solely by the south and west doors.[20] In both cases, twin door systems are employed so that direct air exchange is limited, unless both doors are fixed open at the same time. Although this is avoided for most of the year, for occasional large services and other events, it is necessary that the doors (particularly those at the west end) remain fixed open for significant periods. From approximately June until August, the west doors are fixed open during the day.[21] Spot tests were carried out in order to assess the general impact that the opening of the doors would have on the internal environmental conditions. These showed that, in the centre of the nave at 1.5m, the level of air transfer was both swift and significant, with the internal temperature dropping by 3°C and the relative and absolute humidities

---

[16] 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.

[17] It is presumed that most of the smoke occurred when the stoves were coke and oil fired.

[18] *Pers Comm.* Nick Drewett

[19] English Heritage, *Peterborough Cathedral Environmental Monitoring*, 2nd November 1995 to 31st January 1996, unpublished report.

[20] Small levels of ventilation would be possible through minor irregularities in the building fabric.

[21] On fine days both the inner and outer door are opened, while in bad weather, the outer (glass doors) are kept closed. *Pers Comm.* Nick Drewett

increasing by up to 21% and 1.1g/m^3 respectively, within three minutes.[22] Although the doors were open for approximately four minutes no significant change in conditions was recorded at the east end of the ceiling where the monitoring probes are located.[23] This suggests that in order to have a significant effect on the internal environment at ceiling height, the doors would need to be open for a considerable length of time.

Figure 9. Windows on the south side of the nave roof. (Photo: TCA 2000)

The principal sources of ventilation within the roof void, from the external environment, are the vents above and below the glass panels in the north and south sides, as well as those at the apex of the roof. Irregularities in the roof structure and the loosely fitting doors to the parapets would also provide minor sources of ventilation. Ventilation from the body of the cathedral can occur when the east access door is open and through irregularities and damage to the ceiling structure. However, ventilation from these sources is very limited in comparison to the external sources.

5.2.3 Building Use

The use of the building by worshipers and other visitors has both an indirect and a direct influence on the interior microclimate. The indirect effect is achieved through the requirement for heating while people are in the building as well as the need to use access points, which, in turn, allow ventilation. The direct influence is caused by the introduction of moisture to the environment as a result of breathing and perspiring, and the introduction of wet clothing. (A single person may be expected to expire 50g/h water vapour.[24])

In general, in an air space as big as that in the cathedral (approximately 56,500 m^3), the influence of people will be marginal. However, for certain large services such as on Christmas Eve when a congregation of 1500 - 1600 may be present, the influence should be taken into account.

5.3 Monitoring Results

Analysis of the data showed a very clear humidity and temperature gradient between the upper and lower sides of the ceiling, throughout the year. This is most significant in the winter when there may be a variation of over 30% RH and 10°C. However in the summer, the conditions are closer, with variations generally of no more that 5% RH and 4°C. *(Charts 1 & 2)*

The conditions on the underside of the ceiling are relatively stable during the winter months, with an average RH of approximately 45 – 48% and a very stable AT averaging 18 – 19°C. Variations in internal RH appear to be due to fluctuations in the external RH rather than changes in internal AT. This is reflected in the internal AH which, although heavily buffered, generally reflects the movement of the external AH.

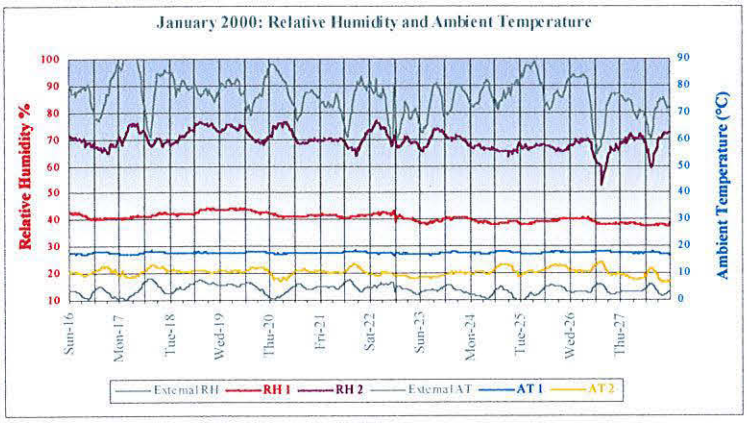
The conditions in the summer also show a significant level of buffering from the external microclimate. However, the fact that the doors are open for much of the time, and without the controlling influence of the artificial heating, the internal conditions follow the pattern of their external counterparts far more closely. Average conditions in July 1999 were 59% RH and 22°C AT, with diurnal fluctuations averaging approximately 6% and 3°C. Average External condition for the same period were 70% RH and 18°C, with diurnal fluctuations of approximately 50 % and 6 °C. *(Charts 1 & 2)*

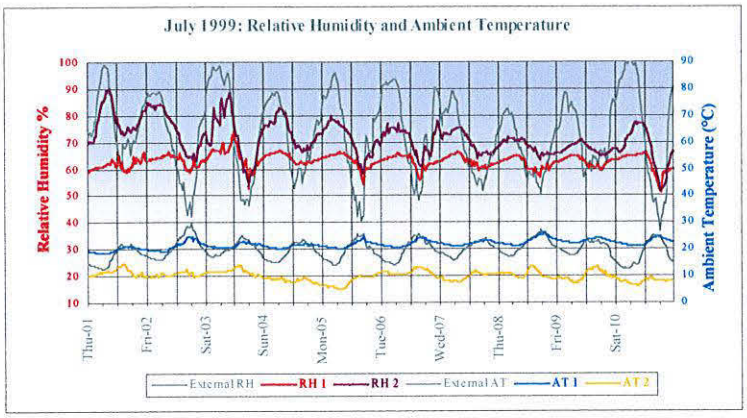
---

[22] External conditions at the time of the test (13:50, 14/01/00) were 84% RH and 5.5°C.

[23] The doors were open at 13:50 and a reading was logged at approximately 13:57.

[24] Camuffo, G et al, '*The Conservation of Artworks and Hot Air Heating Systems in Churches: Are They Compatible? The Case of Rocca Pietore, Italian Alps*, Studies in Conservation, Vol 44, No. 3, London (1999), p. 211





Charts 1 & 2: The charts show the variations in the pattern of internal relative humidity and ambient temperature at probes 1and 2 during July 1999 and January 2000. The divergence in the conditions above and below the ceiling is apparent throughout the year but is particularly extreme in the winter. The stability evident in the conditions at probe 1 in January is due largely to the buffering effect of the closed building in conjunction with the high level of constant heating. The lack of buffering is very apparent at probe 2 during the same period.

Throughout the year, the surface temperature of the ceiling remained marginally below the ambient temperature, apparently as a result of the cooling of the boards by the microclimate in the roof space. The differential was slightly more apparent in the winter than in the summer.

Sudden changes in ambient temperature, resulting from the doors being open, were clearly visible during winter, which had an immediate impact on the relative humidity and ambient temperature. In summer, the contrast between internal and external conditions were less significant and therefore sudden changes were smaller and less obvious. The ingress of external air usually caused a mild increase in the absolute humidity as the external level was generally higher than that inside. Irregularities such as this were short lived, and the AT and therefore RH returned to their previous levels within one or two hours of the incident. *(Chart 3)* Interestingly the events recorded in the cathedral diary when the doors were open, did not always show on the environmental data. It is thought possible from anecdotal evidence that wind direction might have a significant impact on the level of air exchange, as well as occasions when both the west and the south doors are open at the same time, increasing the speed and level of air exchange.

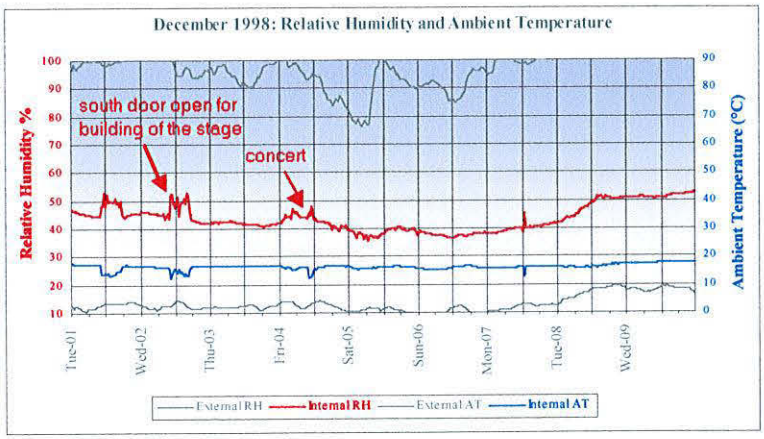


Chart 3: Conditions at probe 1 during December 1998 showing the impact of the doors being open during the preparation for and presentation of, a concert in the nave. Note the sharp fall in ambient temperature causing a marked increase in the relative humidity.

Although the roof structure provides a certain level of buffering, the internal conditions within the roof space followed the external conditions, far more closely than is the case for the underside of the roof. Average conditions at probe 2 for December 1998 (which were typical of the winter months) were approximately 74%

RH and 10°C, with diurnal fluctuations of up to 20% and 4°C. Average external conditions for the same period were 97% RH and 7°C, with diurnal fluctuations of 10% and 6°C. The internal absolute humidity during this period shadowed the external conditions almost exactly, while remaining 0 – 1g/m^3 below.

The conditions in July 1998 indicated that the level of air exchange was as significant in the summer as in the winter. Average readings at probe 2 during July were approximately 64% RH and 19°C AT with diurnal fluctuations of up to 25% and 10°C. Corresponding external figures were 80% RH and 16°C, with diurnal movements of up to 55% and 15°C. As in the winter, internal AH shadowed the external figure almost exactly while remaining marginally lower. Both summer and winter figures clearly demonstrate the high level of air exchange, and while the roof structure offers some level of buffering, the high level of ventilation makes this very limited.

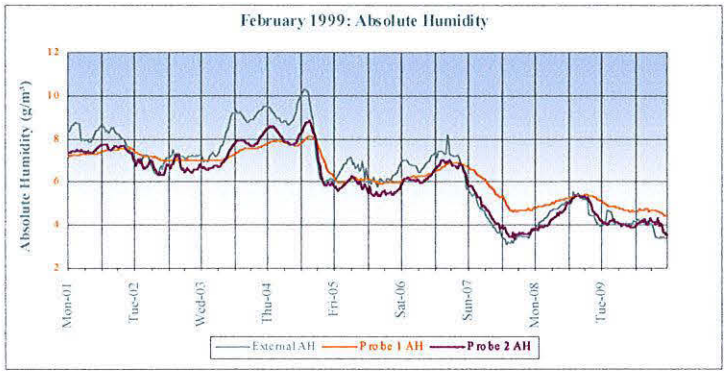


Chart 4: The absolute humidity at probe 2 follows the external values far more closely than that at probe 1, demonstrating the differing levels of buffering above and below the ceiling.

In contrast to the surface temperatures recorded on the under side of the ceiling, the surface temperature on the upper side of the panels was found to remain noticeably higher than the ambient temperature throughout the year, indicating the level of heat transference through the panels. This phenomenon is most significant in the winter when the differential might be as much as 2.5°C. However in the summer, it is usually no more than 0.5°C

At no point during the year did dew point temperature rise above surface temperature (indicating the formation of condensation) on either side of the ceiling. However, on the upper side of the ceiling, dew point temperature was approached on a number of occasions during the spring and autumn, usually as a result of a sudden increase in relative humidity. While surface condensation was unlikely to occur at these points, it is entirely possible that interstitial condensation may have taken place.

A reassessment of the available data from the 1995 – 1996 programme showed similar conditions to those discussed above. However, the monitoring programme also included a number of probes measuring RH and AT at different heights in the nave. The data provided (and the written assessment) had the surprising conclusion that there was almost no temperature gradient between ground and ceiling level (24.3m). Spot tests carried out in January 2000, in a number of areas of the nave confirmed that this was the case, with a difference between ground and ceiling level of no more than 1 - 2°C AT and resultantly small variations in RH.

While probes 1 and 2 were located in positions which were not subject to direct sunlight from the roof lights, probes 3 and 5 were placed in areas which received direct sunlight, in order to assess the impact of solar radiation on the effected areas of the panels. Probes 3 and 5 were installed in June and December 1999 respectively, and so the available data at the time of the preliminary report was limited. However, the data now available gives a far clearer indication of the conditions on areas of the ceiling that are subjected to regular direct sunlight.

It was clear from the data recorded at both probe 3 and 5 that solar radiation has a clear and very significant impact on the conditions on the areas of the ceiling below the windows. During September 1999, increases in surface temperature of 15 - 20°C within two hours were recorded on regular occasions at probe 3. A corresponding small rise in AT and drop in RH was also recorded. However similar changes in RH and AT were also seen at probe 1 (in the shade) and may merely have occurred due to the increase in external AT. The small rise in AH which coincides with the increase in ST may be occurring as a result of bound water being released from the panels due to evaporation.

The data recorded in February 2000 showed that both ambient and surface temperature at probe 5 (on the upper side) rose more significantly than at probe 3. *(Chart 5)* However, by April, the rise in ambient temperature was similar and the rise in surface temperature was far greater at probe 3 (lower). The reason for this is not entirely clear although it may be associated with the changing angle of the sun at this time of year, falling preferentially on different sections of the panels.

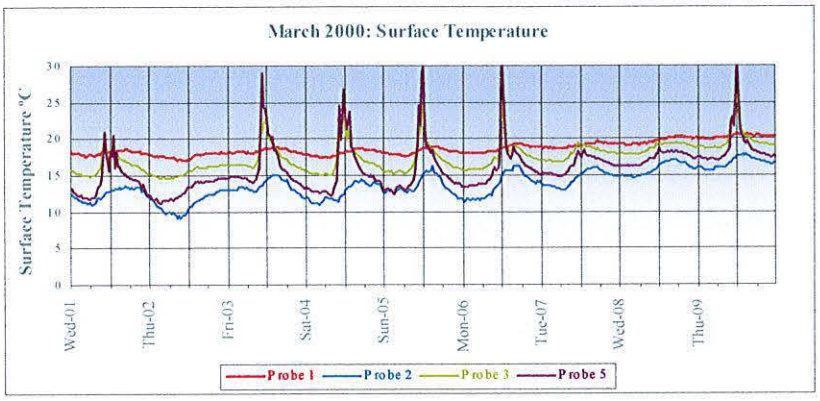


Chart 5: Comparison of the surface temperatures in March 2000, clearly demonstrates the effect of direct sunlight on panel 33IV.

Throughout the period monitored, it was apparent that the divergence in conditions on either side of the roof was far greater in the areas of shade than in those which were exposed to full sunlight. The reason for this appears to be that in the areas of shade, the determinant factors were the ambient heating and the levels of ventilation, which varied significantly on either side of the ceiling. However in areas subjected to direct sun, the predominant factor was the heat generated by the sunlight which influenced both relative humidity and possibly the absolute humidity (as a result of increased deposition of moisture from the boards).

During the winter, the ST was lower at probe 3 (underside sun) than was the case at probe 1 (underside shade). It appears possible that the reason for this is that the ventilation gaps around the window are allowing cold external air to pass directly across the areas of the ceiling which, in the summer, receive direct sunlight. As probe 1 is away from the windows (and in shade), the external air will have reached an equilibrium before it passes over this area.

6.0 DISCUSSION AND CONCLUSIONS

Although there are numerous possible phenomena which can be caused by the unstable environmental conditions, there are three areas which are of particular concern in this case. These are the direct effect of the microclimate on the paint layers, the indirect effect of the microclimate on the paint layers as a result of dimensional change of the boards and the effect of the microclimate on the overall structure of the ceiling.

The extreme temperature and humidity gradient across the ceiling is a matter of some concern. Depending on the condition and structure of the individual sections of the ceiling, it is possible that this might cause increased stresses both across individual boards and between groups of boards and their supporting structures. Similarly, the large changes in the conditions between summer and winter and the diurnal fluctuations in the roof space throughout the year, appear likely to cause movement and increase the likelihood of cracking and other forms of deterioration. Monitoring carried out on painted wooden churches in Norway showed a direct dimensional response of individual wooden panels to changes in RH, with similar patterns of activity recorded for both parameters.[25]

However, despite the far from ideal microclimate, the condition surveys carried out for the conservation programme suggest that the boards have not deteriorated significantly in recent years. Most of the cracking is believed to be historic and, although paint delamination is relatively widespread, the nature and patterns of deterioration do not indicate that it is related to the dimensional changes within the boards. The most significant delamination appears to be located on certain types of repainting only and is thought to be occurring

[25] Olstad, T. M., 'Medieval Churches in a Cold Climate – Parish Churches or Museums', *Preventive Conservation Practice, Theory and Research, Preprints of the International Institute for Conservation Ottawa Congress, 12 – 14th September, 1994,* London (1994) p.101

as a result of faulty technique. [26] While this type of deterioration may have an environmental element, it is very different from the type of delamination which one might expect if significant dimensional change was occurring in individual boards, on a regular basis. It is also clear that, despite the extreme conditions encountered in the areas of the ceiling which are exposed to direct sunlight, there are no large scale patterns of differential deterioration in these areas.[27]

In theory, the fluctuations in RH in the roof space could lead to a dimensional change of up to 2.5% across the grain of the oak boards.[28] However, many of the fixings are relatively loose, so that considerable movement may be possible within the structure of the ceiling.[29] Therefore, it is feasible that much of the structural movement which might occur if the boards were rigidly fixed at all points, is in fact being compensated for by the fact that individual boards are able to move over each other, and thus absorb much of the dimensional response to the microclimatic changes.

However, even if this is the case, the lack of damage to the paint layer resulting from movement within individual boards is puzzling, as it appears to suggest that despite the very significant environmental fluctuations, little dimensional response is taking place. One explanation for this is the possible buffering effect of the large ceiling structure due to the hysteresis effect of the wood, discussed above. However, this would only account for short term fluctuations in microclimate, rather than the large fluctuations which take place over the year as a whole. The information currently available suggests either that the dimensional response of the wood is so low as to be insignificant, or that the interface between the paint and the wood is absorbing whatever dimensional change is occurring. Either way, it is important that the nature of any activity is qualified so that, before any attempt is to be made to alter the environmental conditions, we can predict the possible effect on both the paint layer and the structure of the ceiling that this might have.

On the basis of the data available for the preliminary report in January 2000, the following points were made:

- Is there significant dimensional response in individual boards resulting from environmental fluctuations which, for some reason, is not presenting in the form of deterioration to the paint layer ?

- Is there dimensional response which is cumulative over large areas of the roof, causing significant movement or distortion within large areas of the structure. Could this lead to serious deterioration in the future ?

- Should we be measuring the levels of movement on either a small or large scale (i.e. for a small group of boards or for an entire bay), in order to be able to quantify it ?

- Should we consider introducing active controls on the environmental conditions within the body of the cathedral (heating management, water trays, control on ventilation) ?

- Should we consider controlling the roof space environment (covering windows, controlling ventilation, increasing insulation levels) ?

- What is the long term prognosis for the hessian backing, given the conditions we have recorded ? How much structural support does it give? Is it likely to deteriorate to the level where it will need to be replaced and if so, when ?

- While the author can comment on the impact of the environmental conditions on the polychrome surface of the ceiling, the dimensional response of large and complex wooden structures such as this, is entirely outside the author's field of experience. Given that the potential consequences are extremely serious if a problem does exist, do we have the relevant expertise within the project team to address this? If not,

---

[26] *Op. Cit.* The Perry Lithgow Partnership and Hugh Harrison

[27] It should be noted that although significant numbers of the boards in level IV(the area on the south side which would be in the sun) have been replaced, this would have occurred before the insertion of the windows.

[28] Calculations of movement are based on the equations used in Hoadley, R.B., 'Chemical and Physical Properties of Wood', *The Structural Conservation of Panel Paintings, Proceedings of a Symposium at the J. Paul Getty Museum*, April 1995, Los Angeles (1998), p.12

[29] *Pers comm.* Hugh Harrison.

should we consult an expert in the dimensional response of historic panel paintings, with regard to the movement on a small scale and/ or a civil engineer, regarding possible large scale movements ?

The response to the preliminary report from the team members demonstrated a widespread opinion that any movement which may be occurring within individual sections of the ceiling is likely to be absorbed by boards moving over each other as a result of the loose fixing. As a result, it appears unlikely that any significant large scale cumulative movement is occurring across the roof as a whole.[30]

However, the question of why there is so little deterioration of the paint layer despite the extreme environmental conditions, remains unanswered. In order to take this further it will be necessary to examine the possible reasons in a systematic manner. The first area which needs to be addressed is whether or not there is any significant dimensional response in the wood to the fluctuations in the environmental conditions. Methods of quantifying the dimensional response are currently being assessed and it is hoped that a programme of measurement will take place during the next phase of environmental monitoring.

On the basis of the results of the measuring exercise, the possible advantages or disadvantages of introducing environmental controls can be examined. In conjunction with this, the question of the long terms properties of the hessian and the consequences of any further deterioration for the structural stability of the ceiling, should also be addressed.

It was clear that, while there is a wide range of expertise within the present conservation team, the question of dimensional response of large painted wooden structures, such as the nave ceiling, is an extremely complex issue, which crosses numerous disciplines, some of which are not presently represented. Therefore, advice on certain aspects of the problem which have been highlighted by the results of the environmental monitoring, will need to be sought from outside sources.

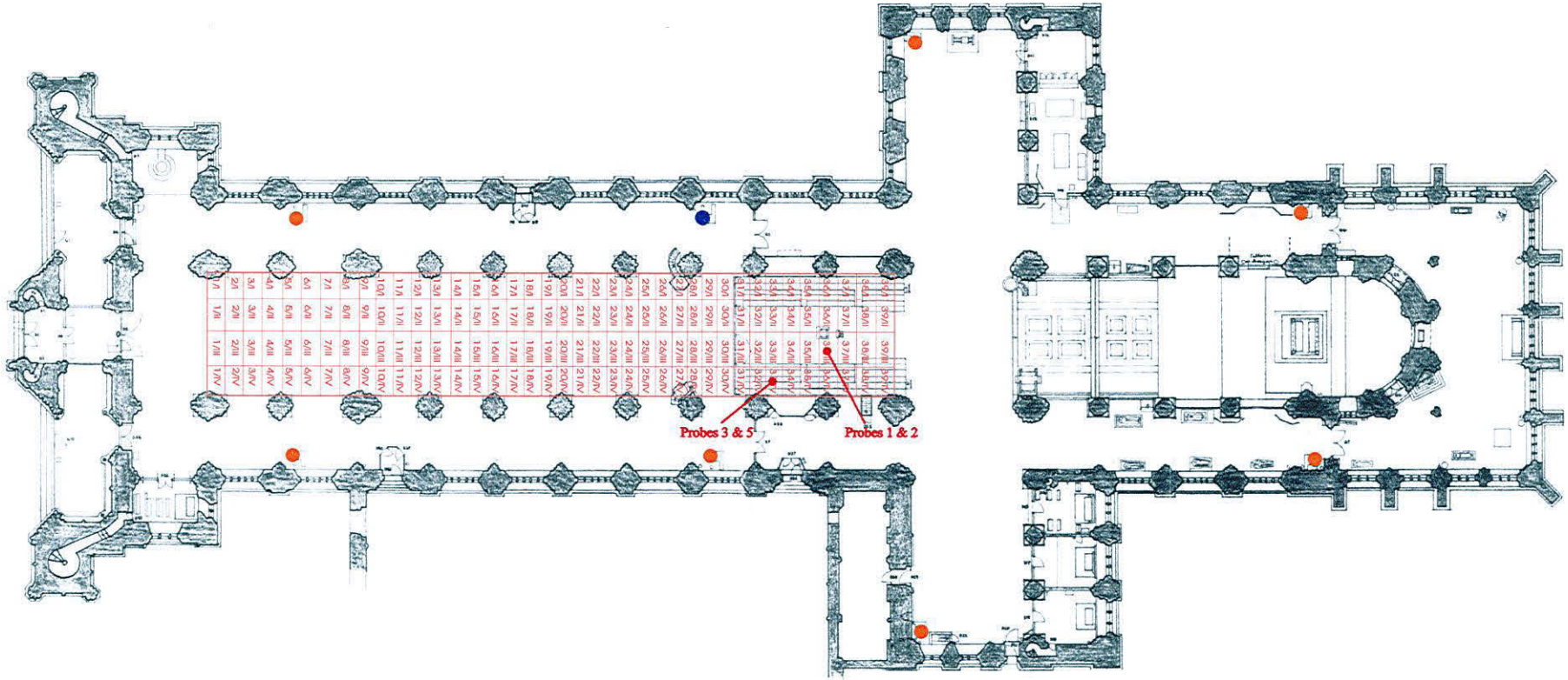
The results of the monitoring programme at this stage suggest that, despite the microclimatic conditions, the ceiling does not appear to be deteriorating. Therefore the question must be asked, if there is no apparent deterioration, why should we make any changes to the current environment. It is possible that the situation is more stable than the environmental data might suggest and, if this is the case, then there may be a strong argument for minimum or no intervention. However, there are a number of important factors which we do not fully understand which could yet have a significant impact on the long term condition of the ceiling. Therefore before deciding on the nature and level of any interventive measures, we should attempt to define the problem more accurately, so that we have a clear idea of what the long term effect of any intervention might be.

---

[30] Letter Hugh Harrison to Julian Limentani, 11th February 2000, letter D J Goode to Julian Limentani, 8th March 2000.

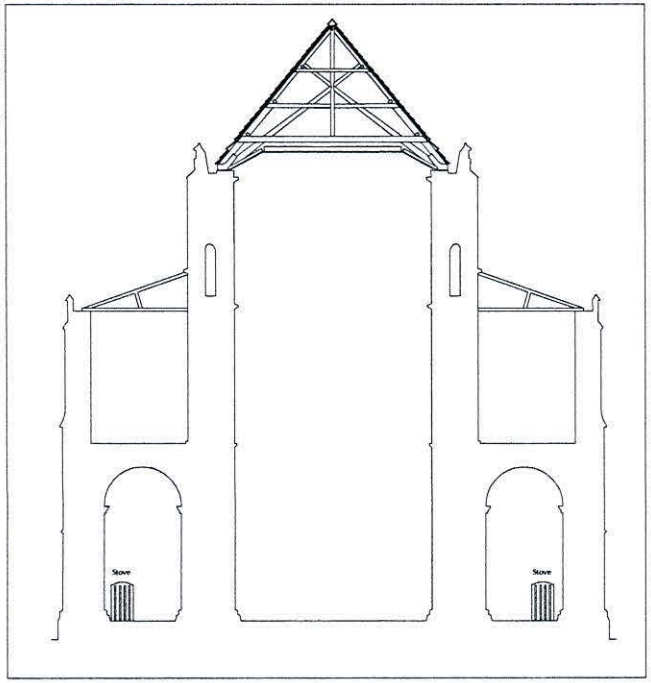
DIAGRAMS AND CHARTS

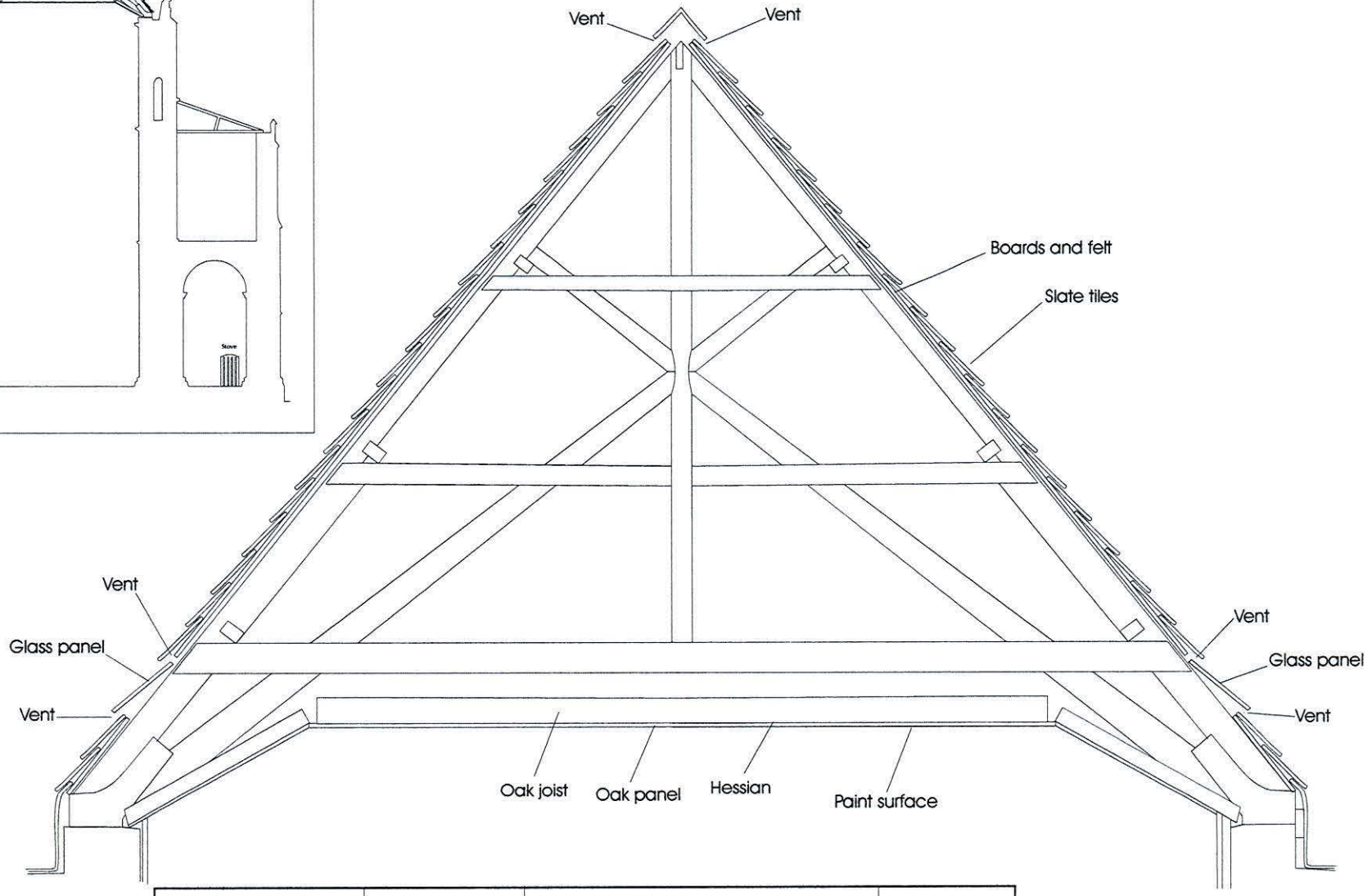
DIAGRAM 1



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 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

DIAGRAM 2



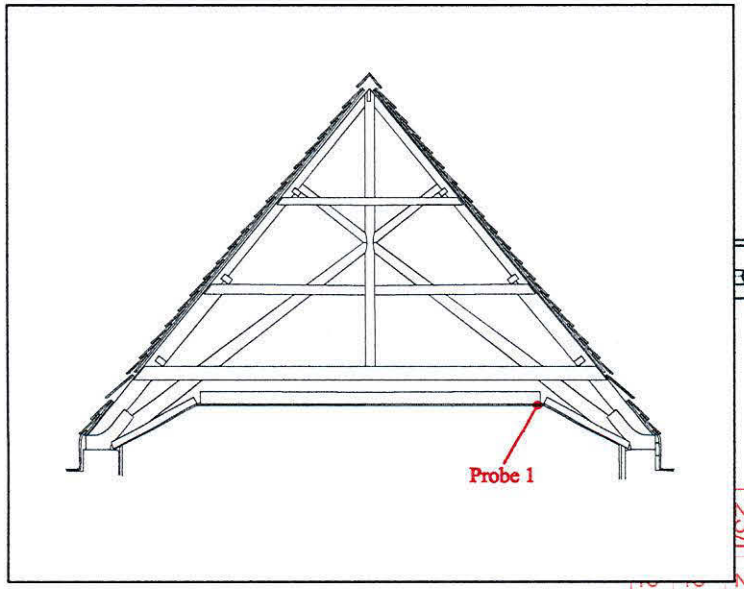


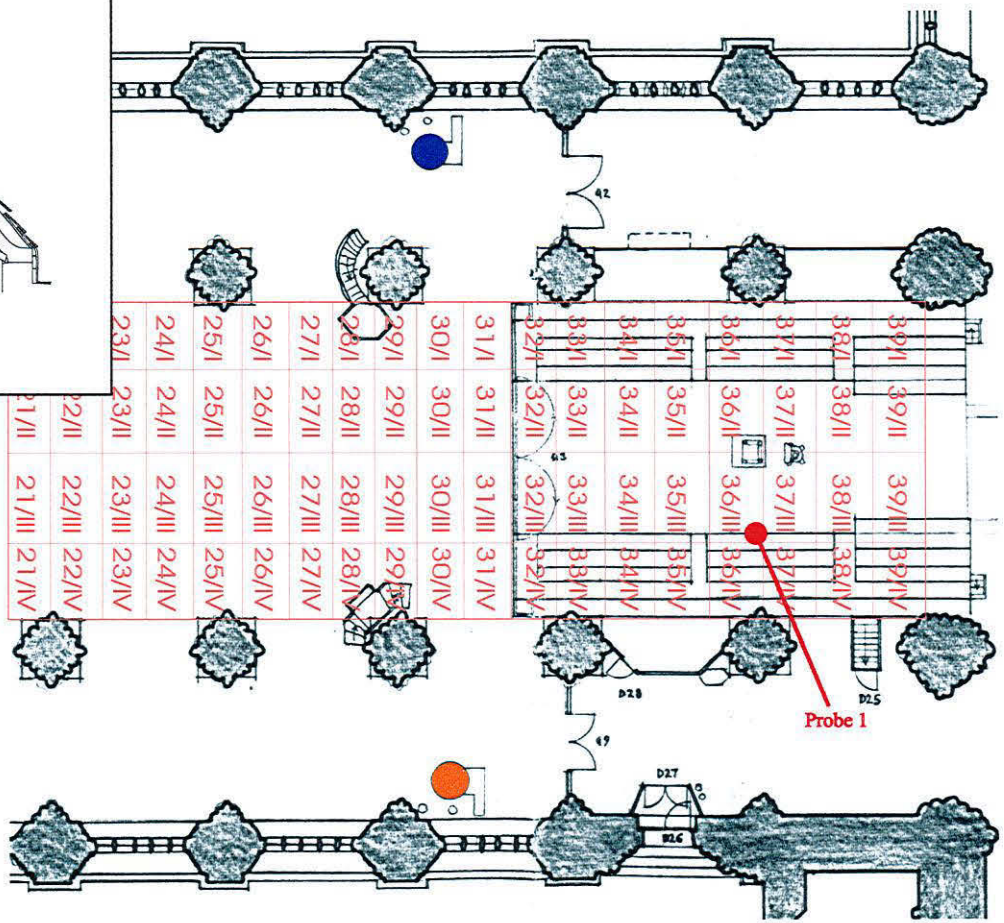
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 1m 2m 3m	
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	

PROBE 1

BAY 36 III LOWER SIDE (SHADE)

DIAGRAM 3





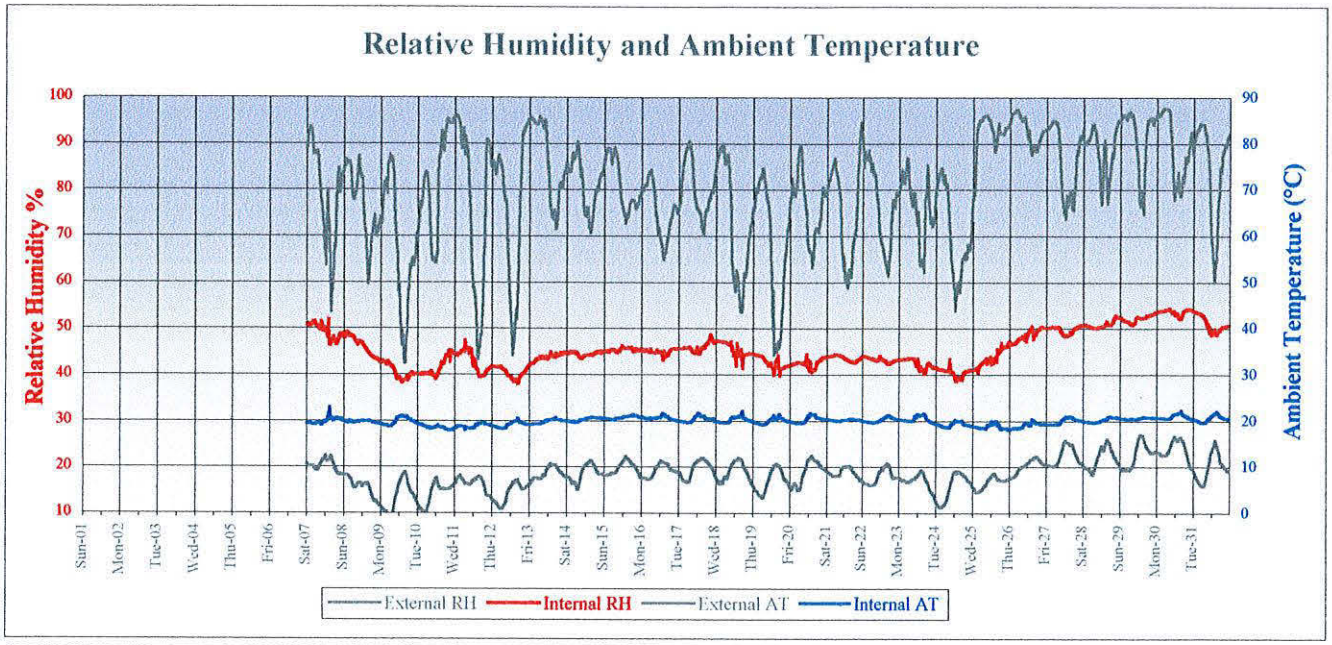
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 10m 20m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

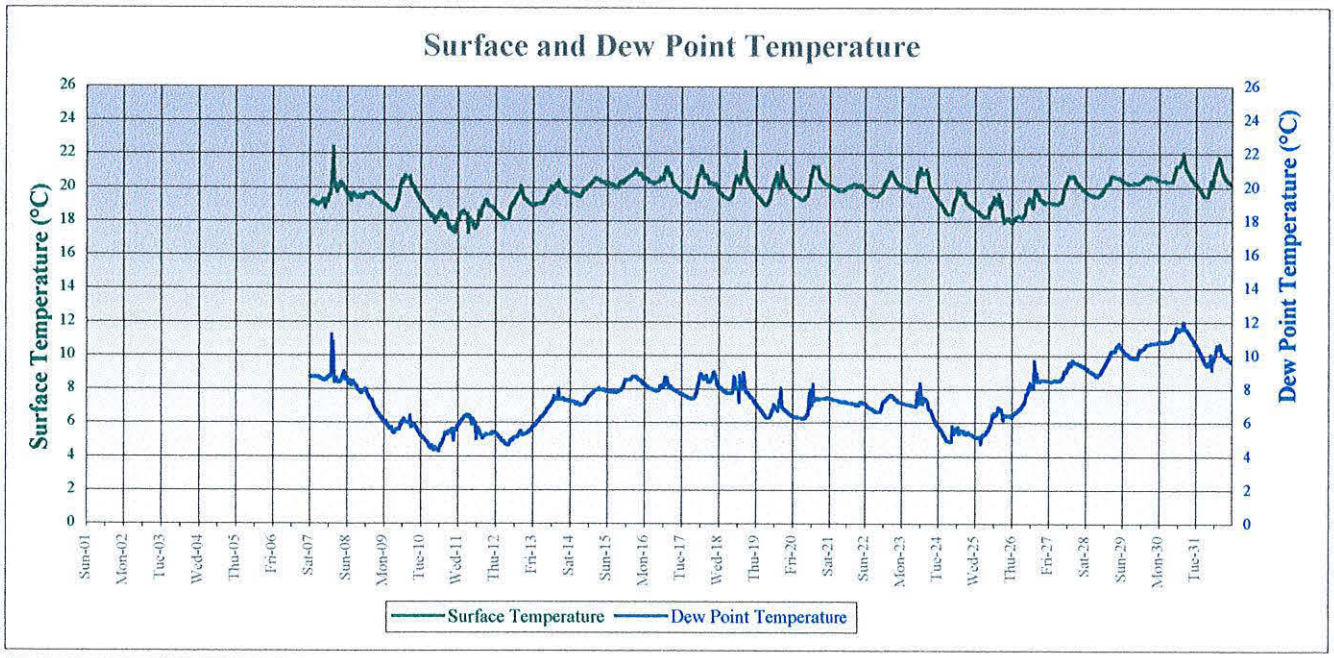
THIS PAGE IS INTENTIONALLY BLANK

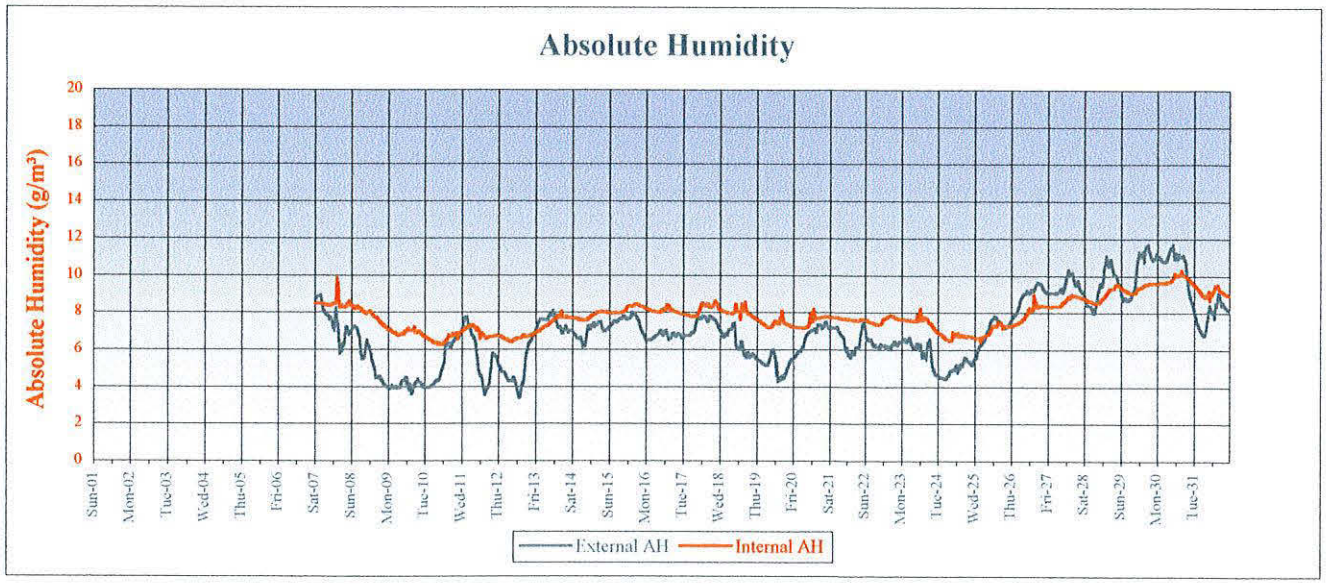
Peterborough Cathedral Nave Ceiling

March 1998

Probe 1: Bay 36 III lower side (shade)



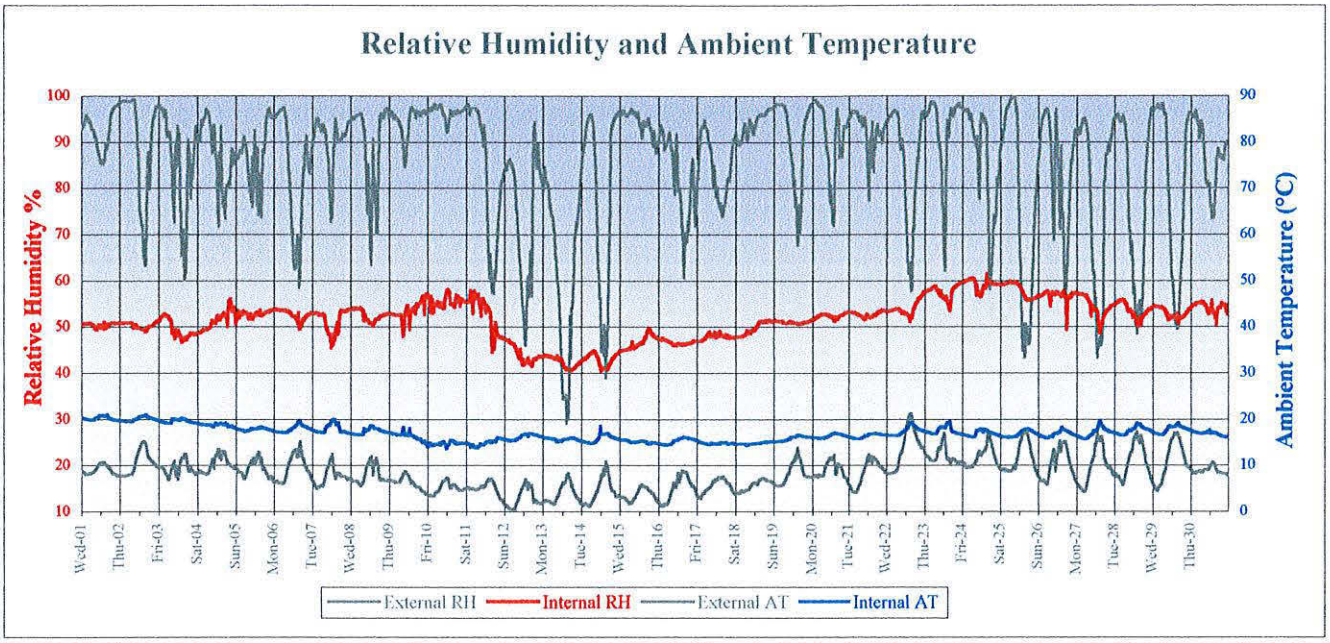


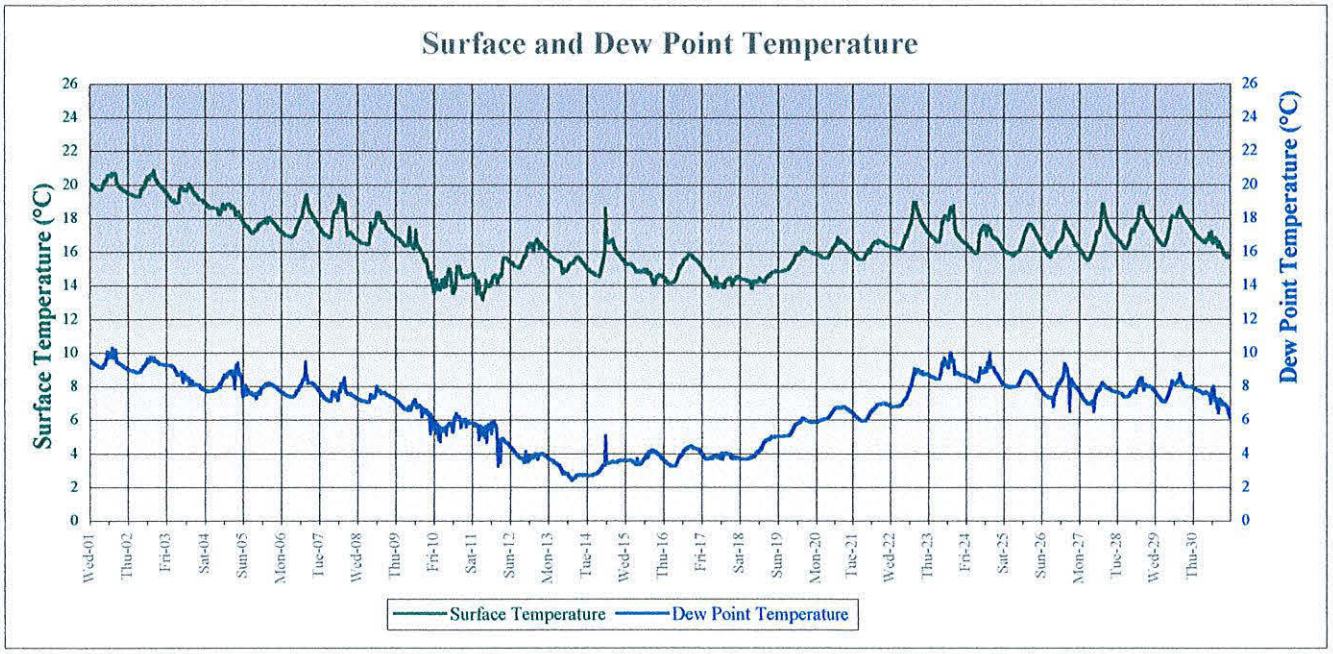


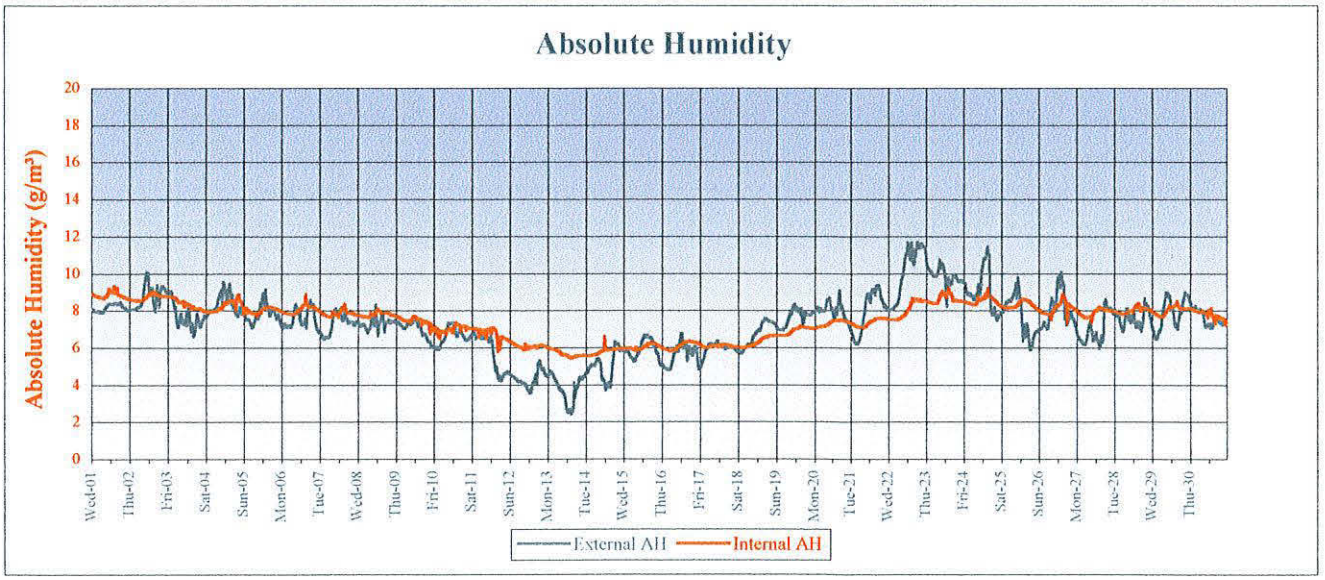
Peterborough Cathedral Nave Ceiling

April 1998

Probe 1: Bay 36 III lower side (shade)



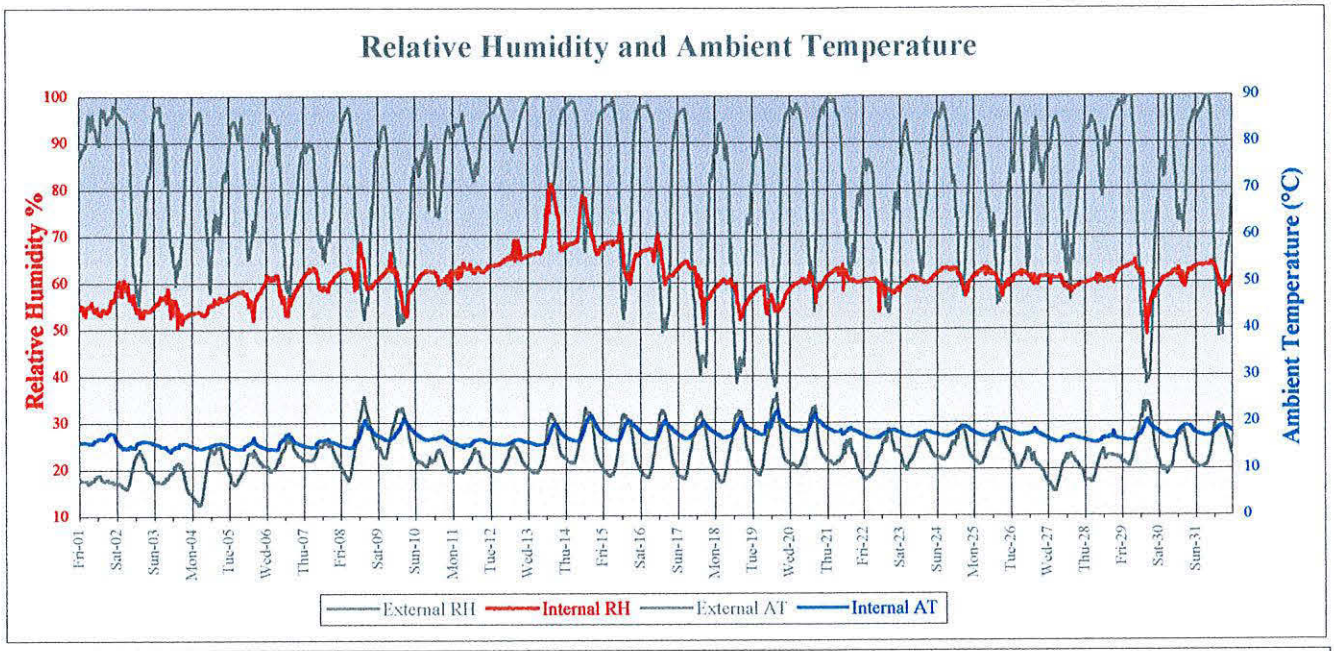


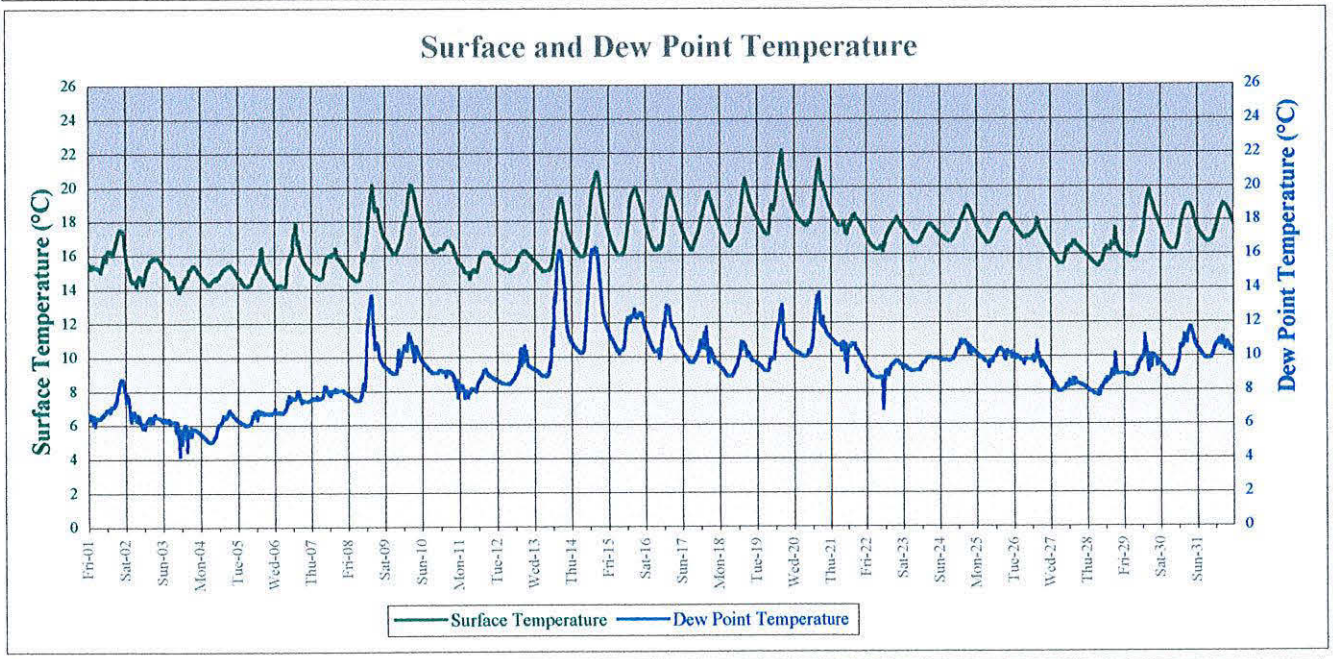


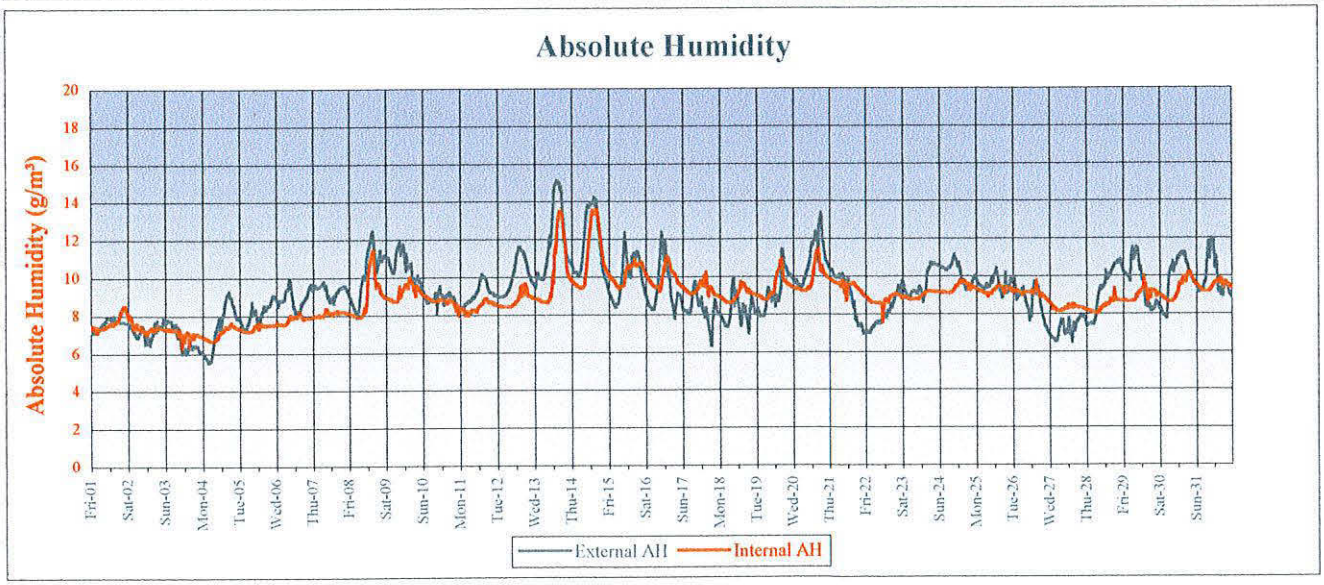
Peterborough Cathedral Nave Ceiling

May 1998

Probe 1: Bay 36 III lower side (shade)



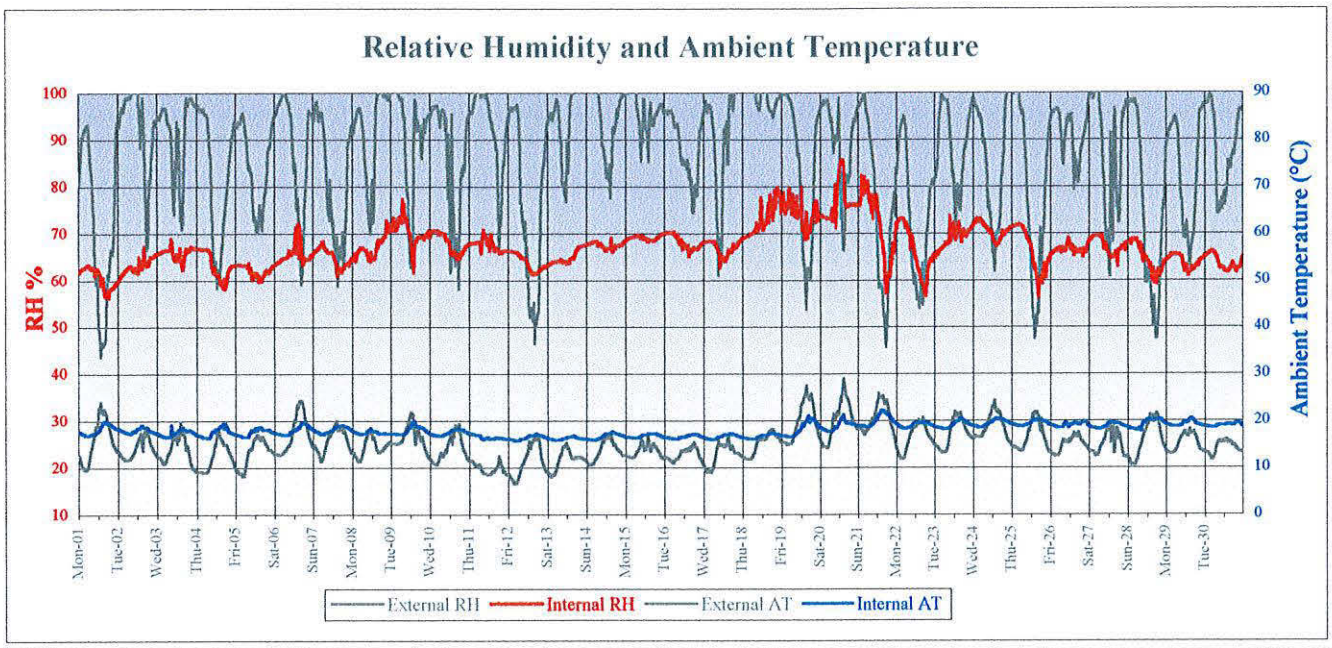


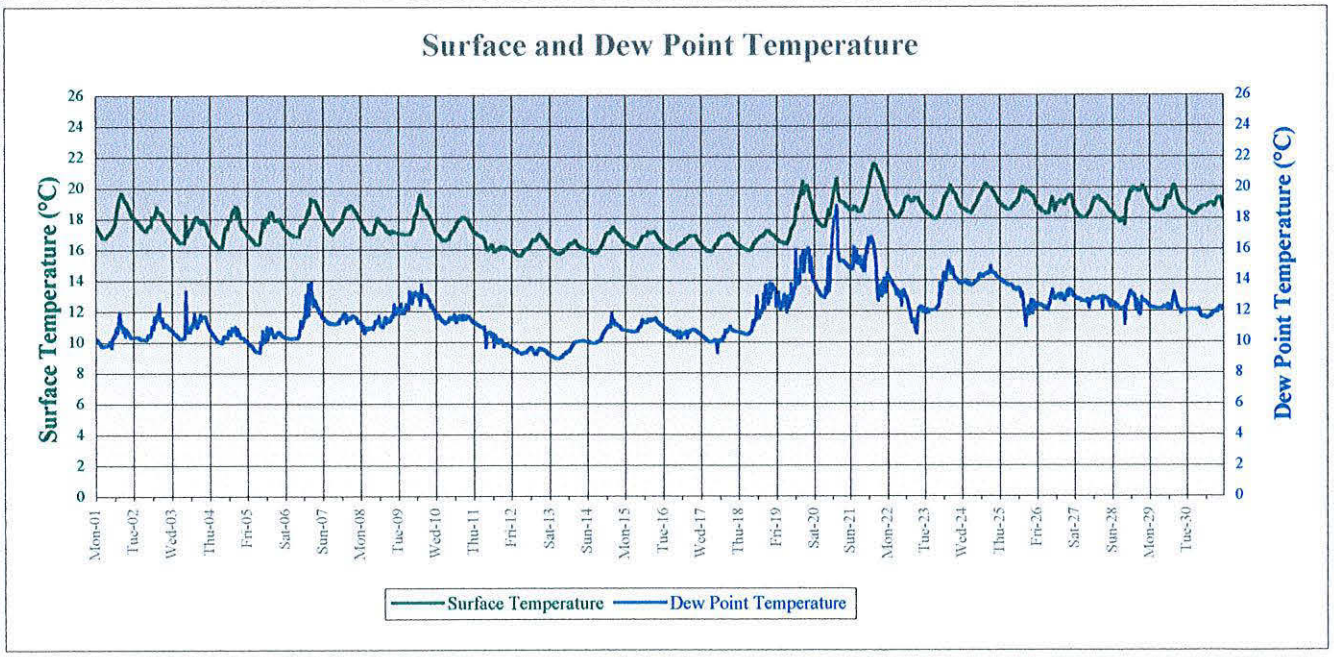


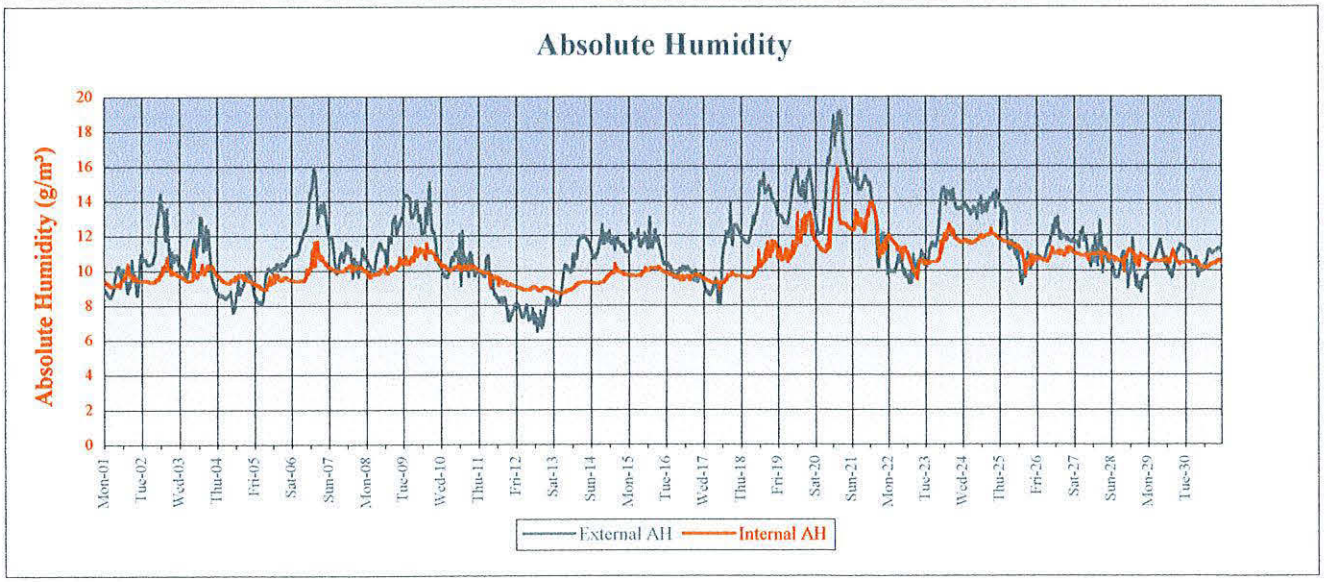
Peterborough Cathedral Nave Ceiling

June 1998

Probe 1: Bay 36 III lower side (shade)



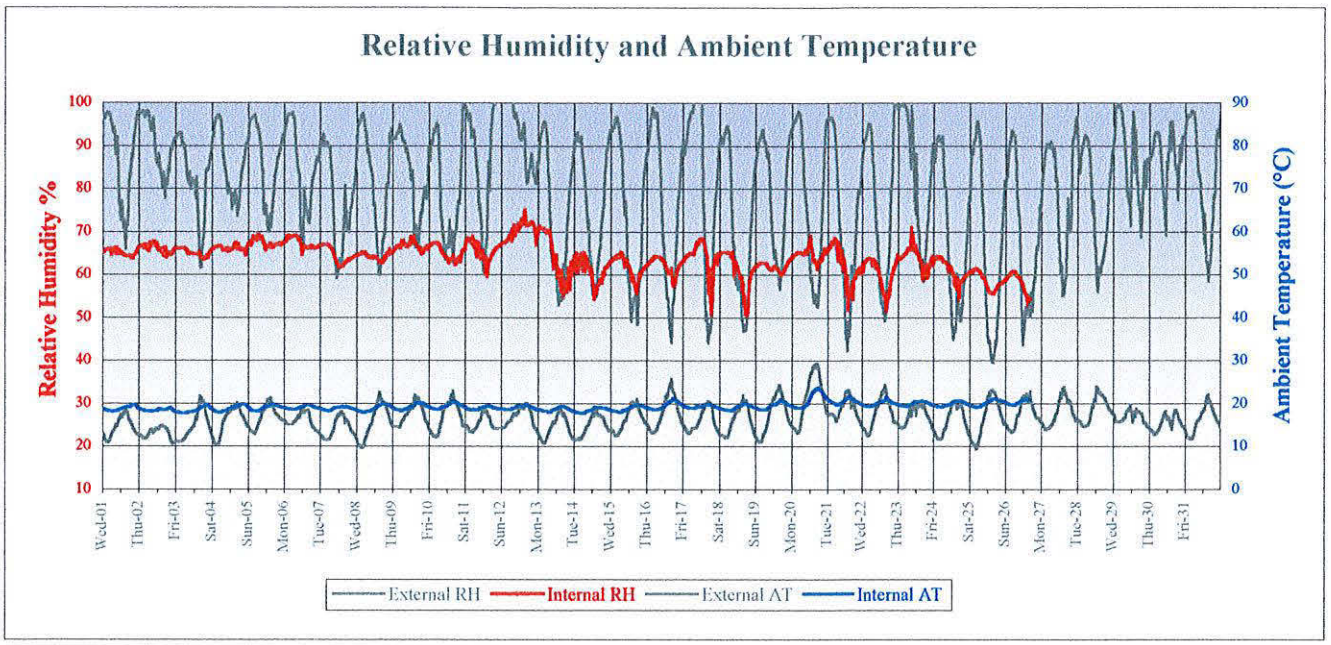


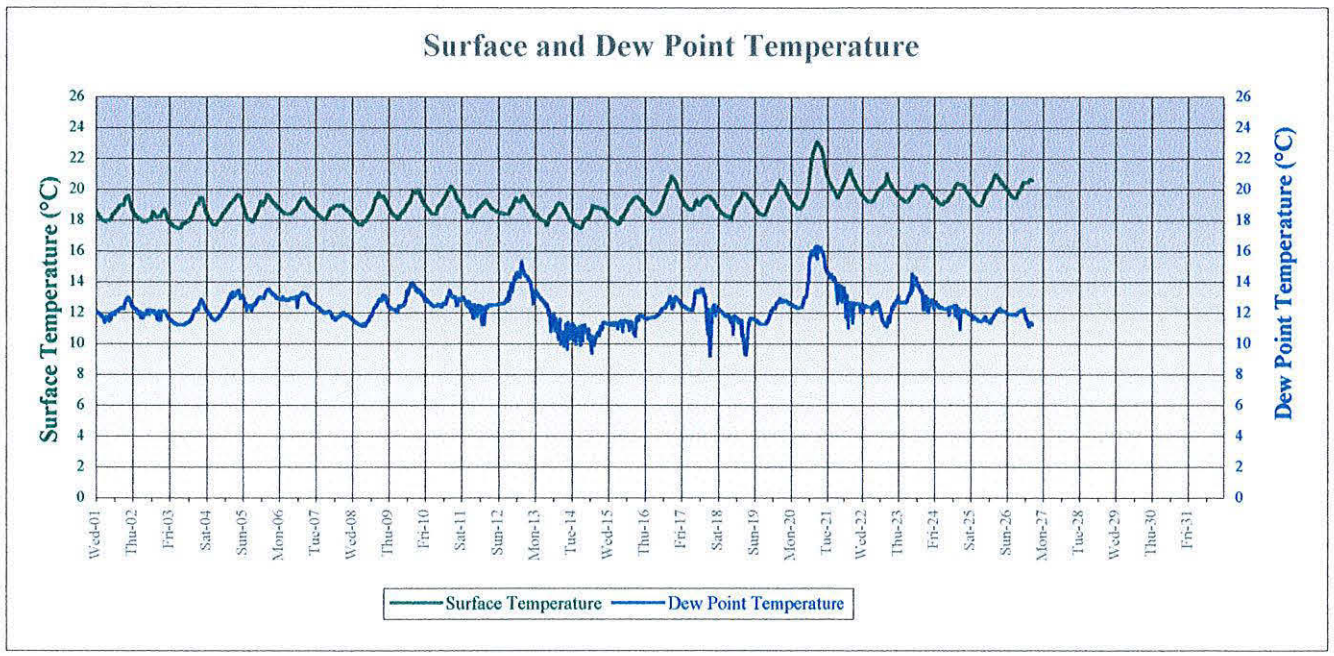


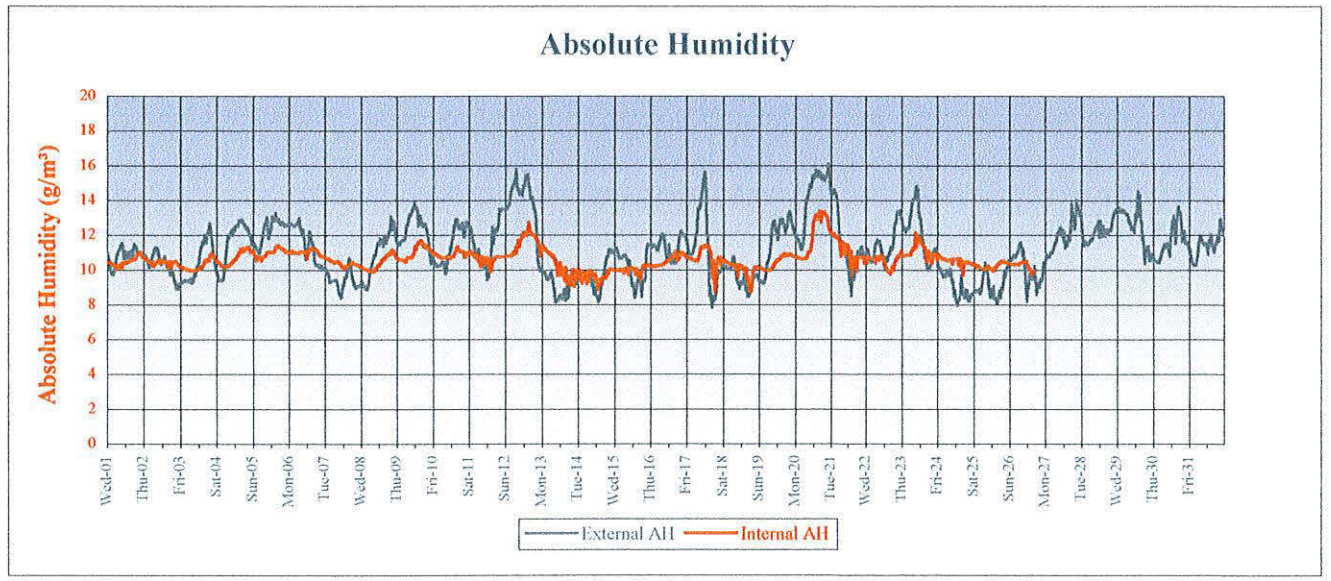
Peterborough Cathedral Nave Ceiling

July 1998

Probe 1: Bay 36 III lower side (shade)



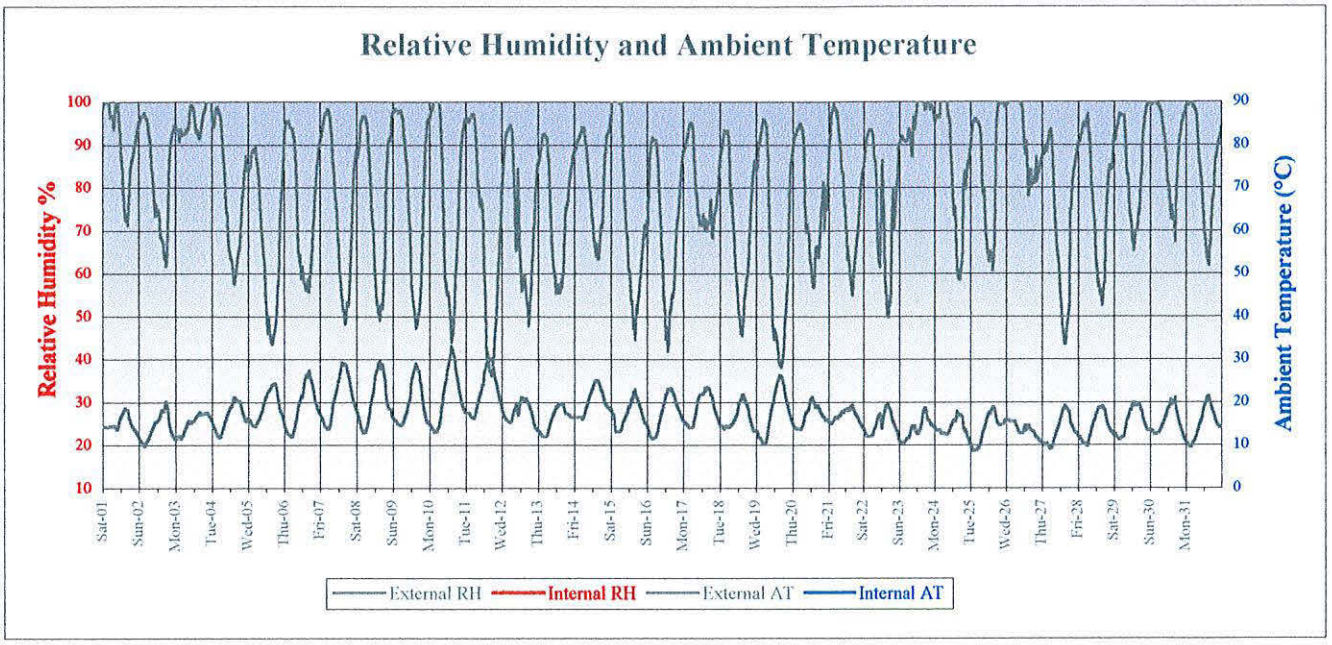


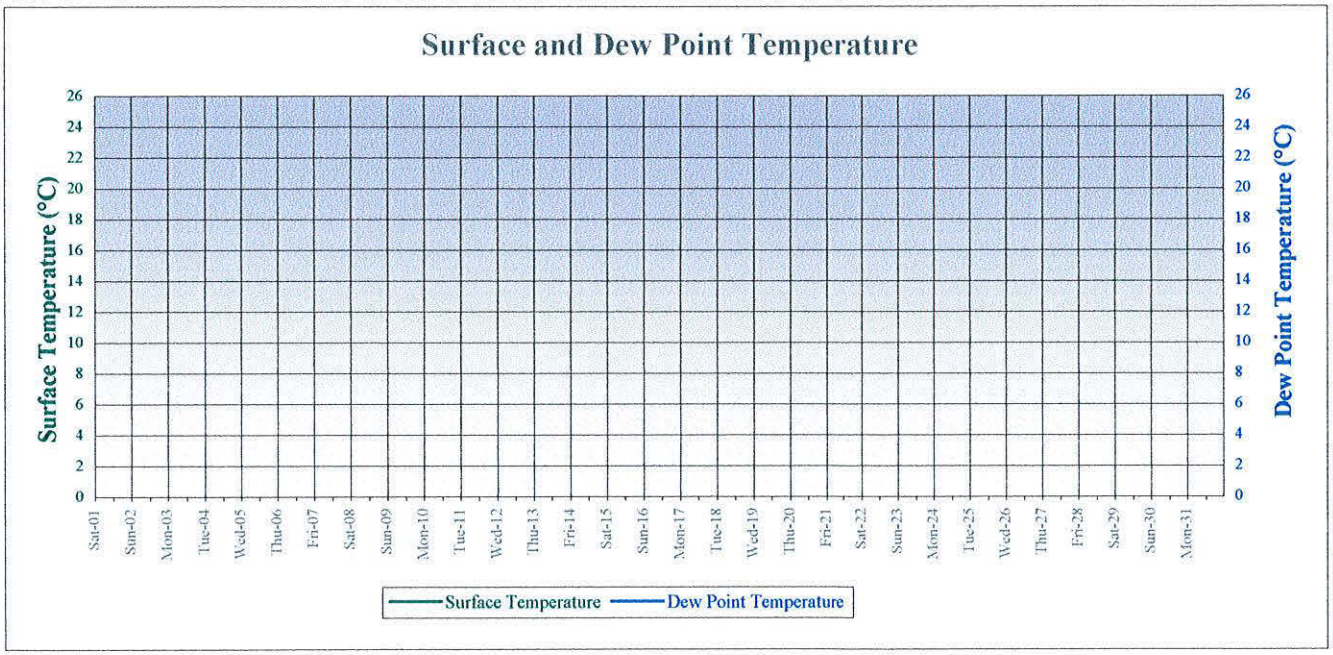


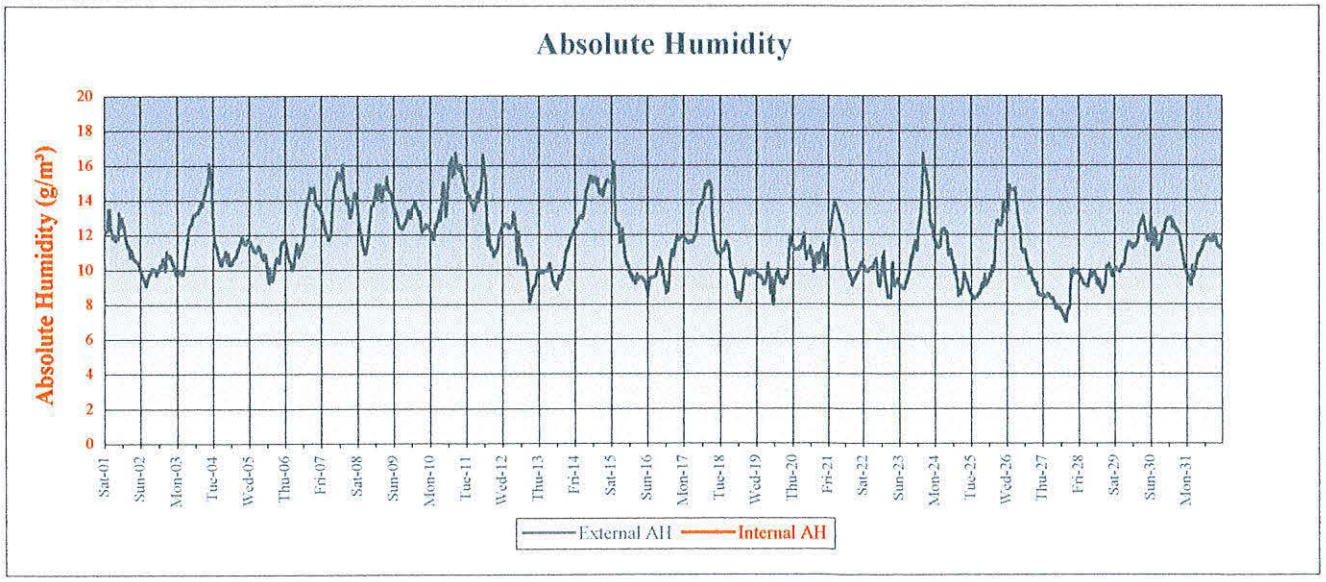
Peterborough Cathedral Nave Ceiling

August 1998

Probe 1: Bay 36 III lower side (shade)



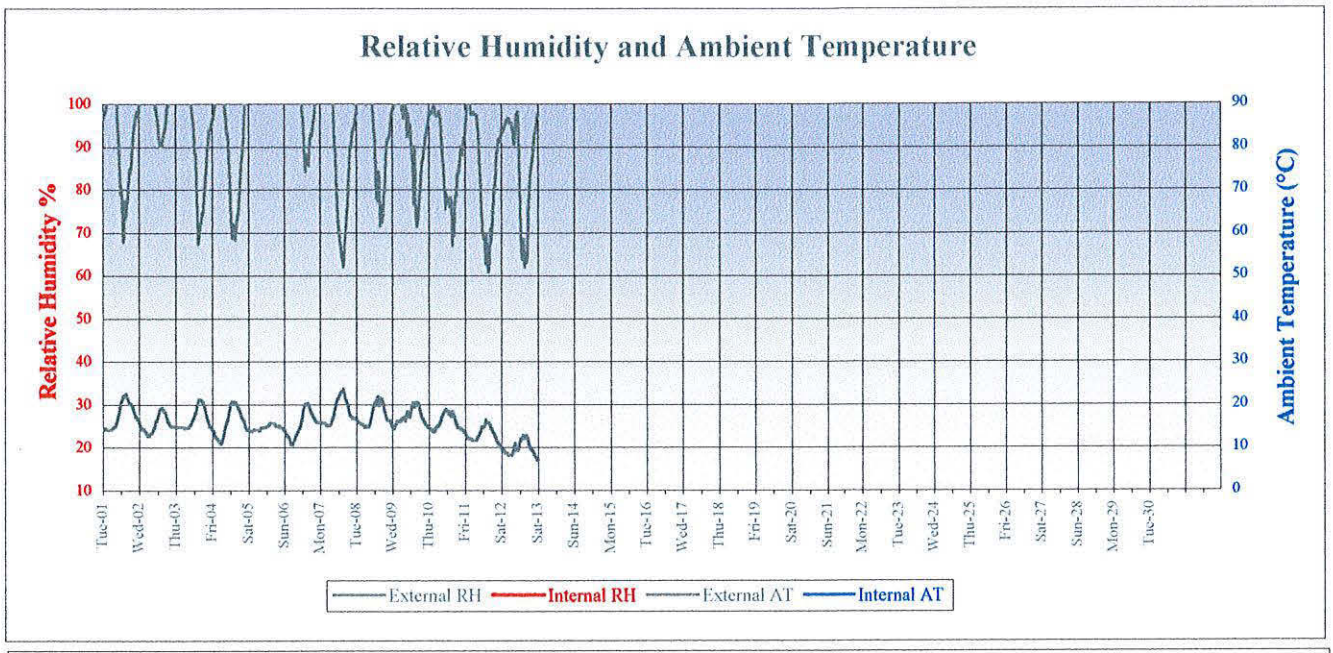


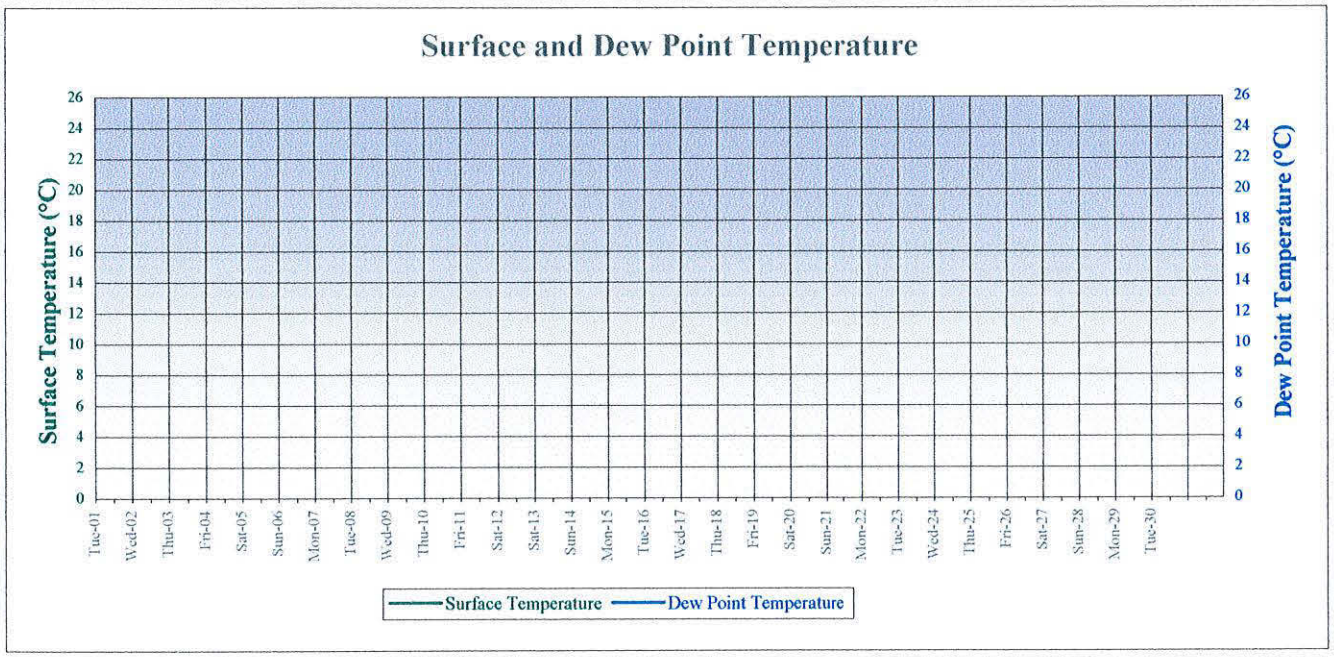


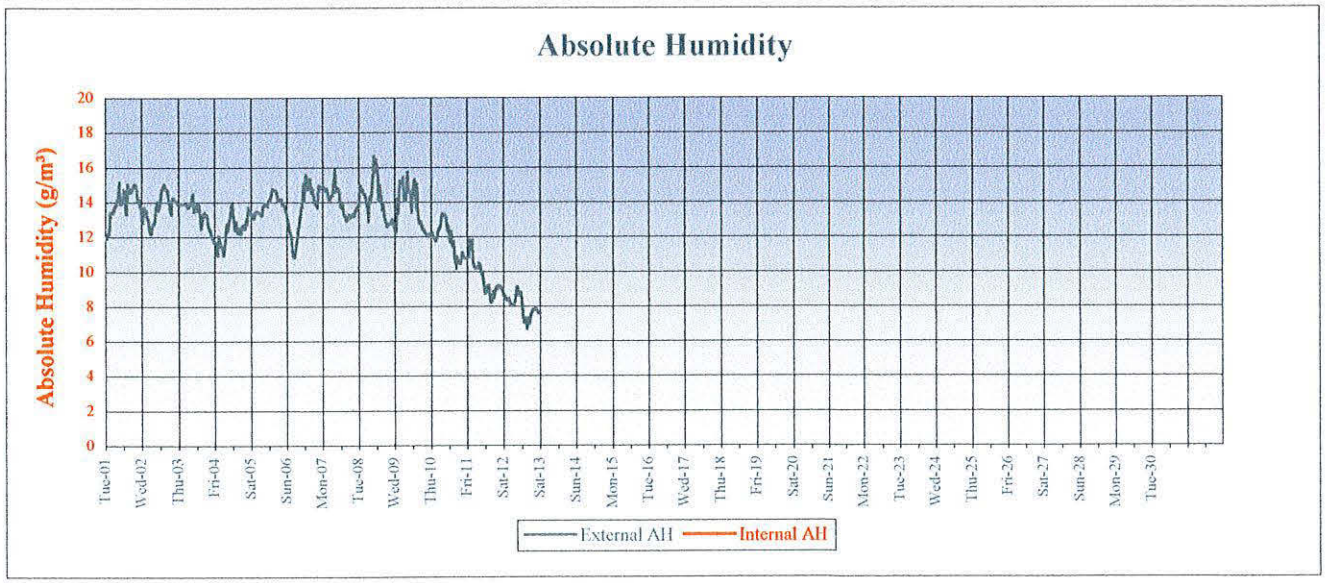
Peterborough Cathedral Nave Ceiling

September 1998

Probe 1: Bay 36 III lower side (shade)



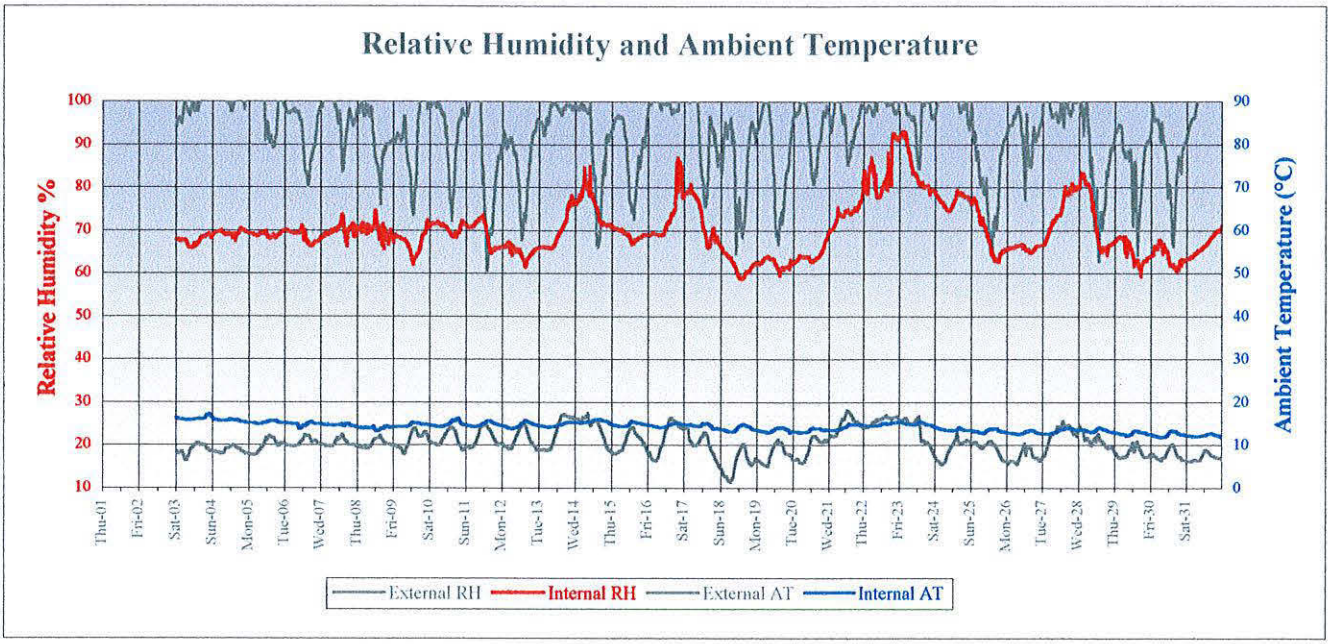


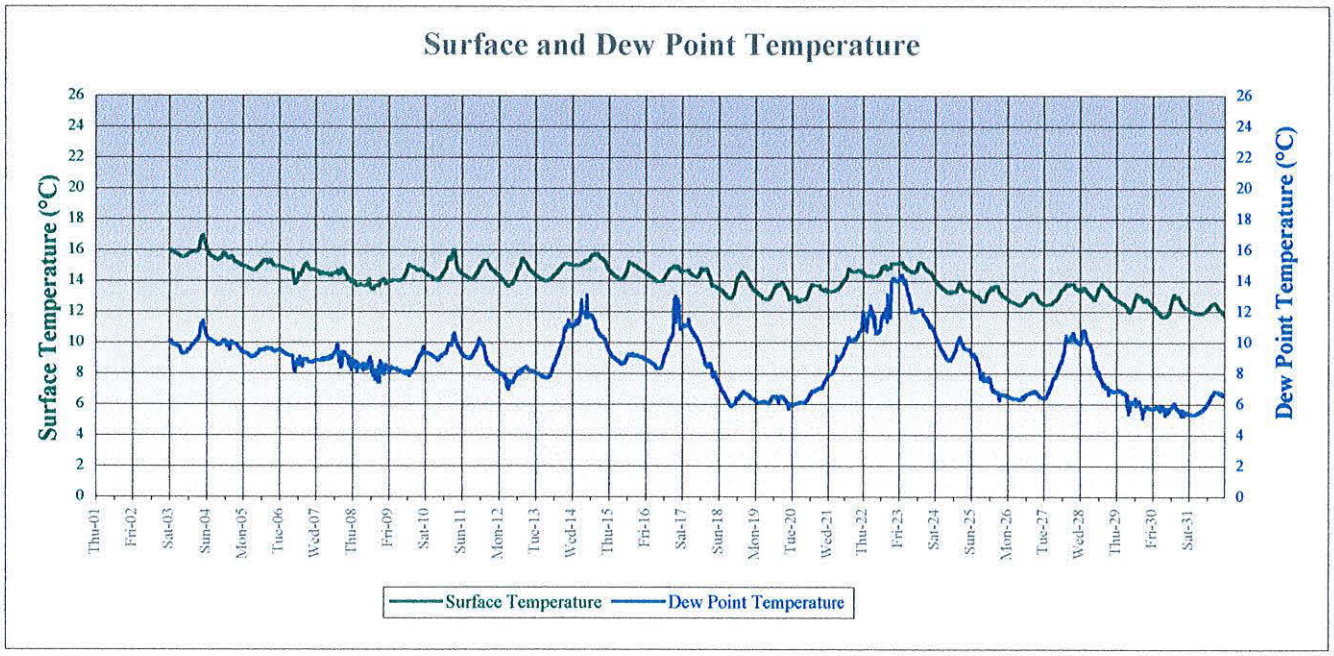


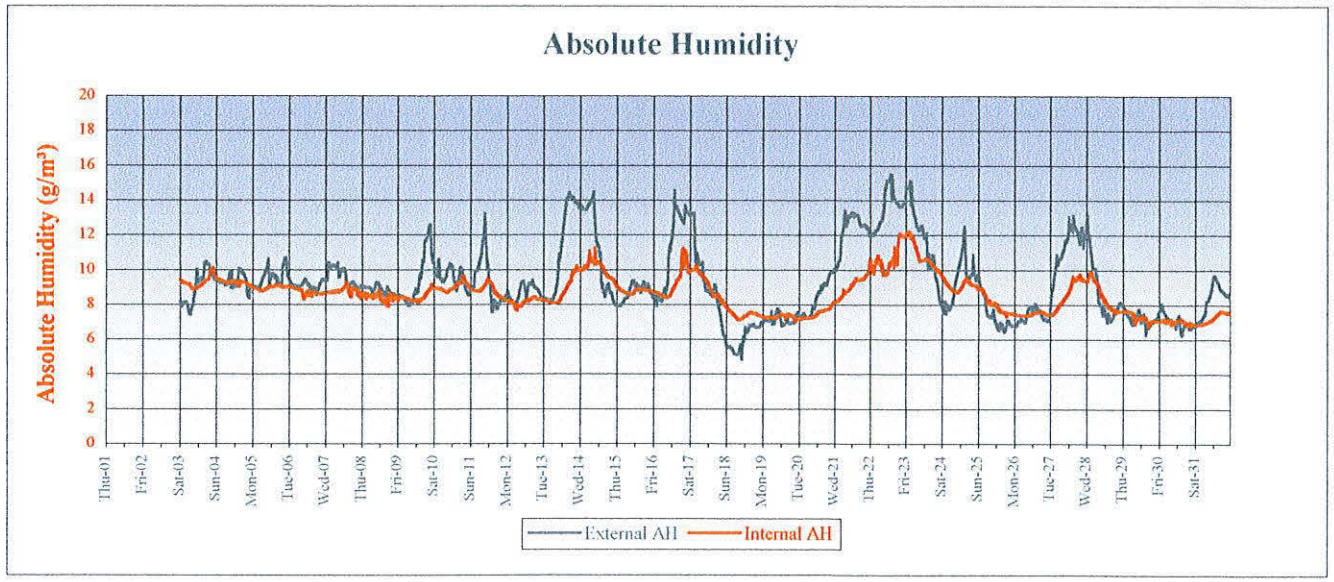
Peterborough Cathedral Nave Ceiling

October 1998

Probe 1: Bay 36 III lower side (shade)



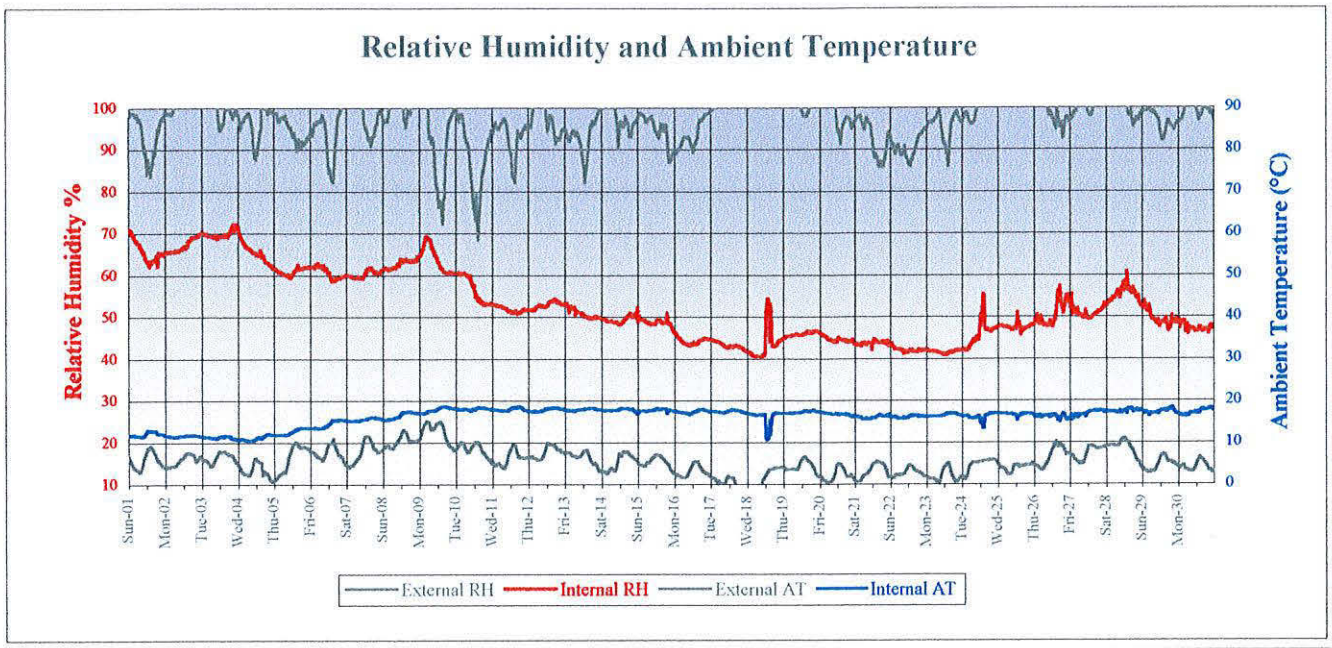


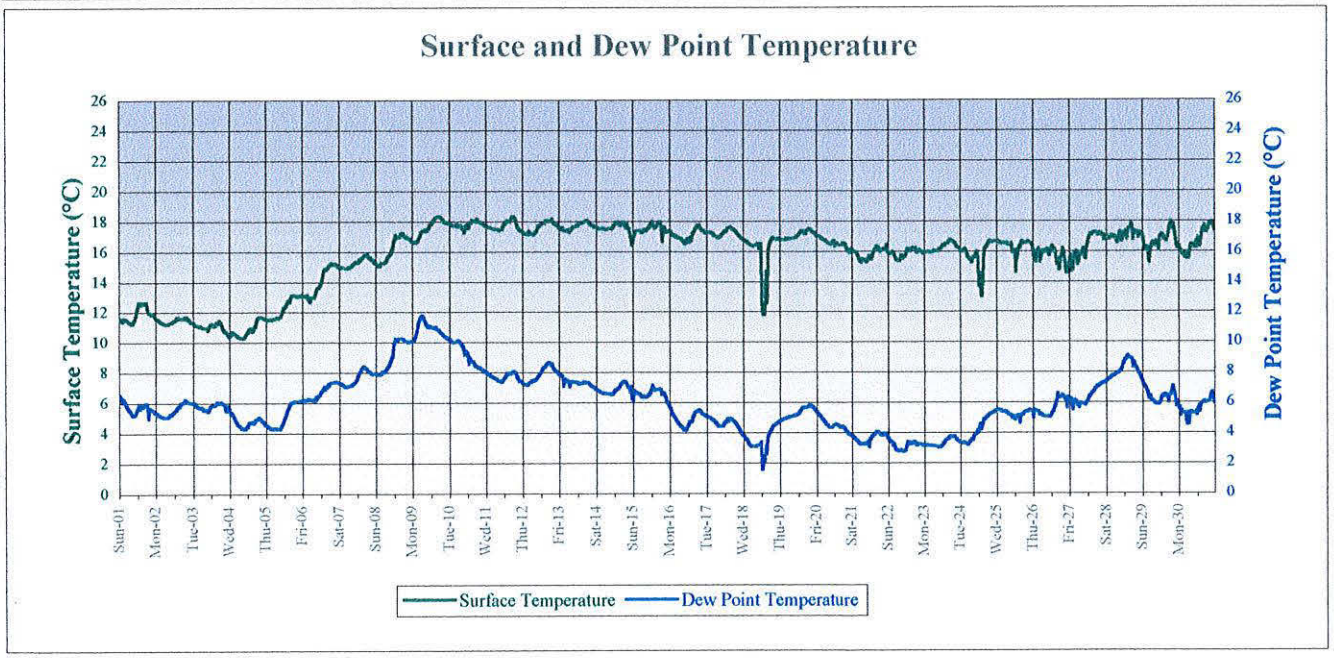


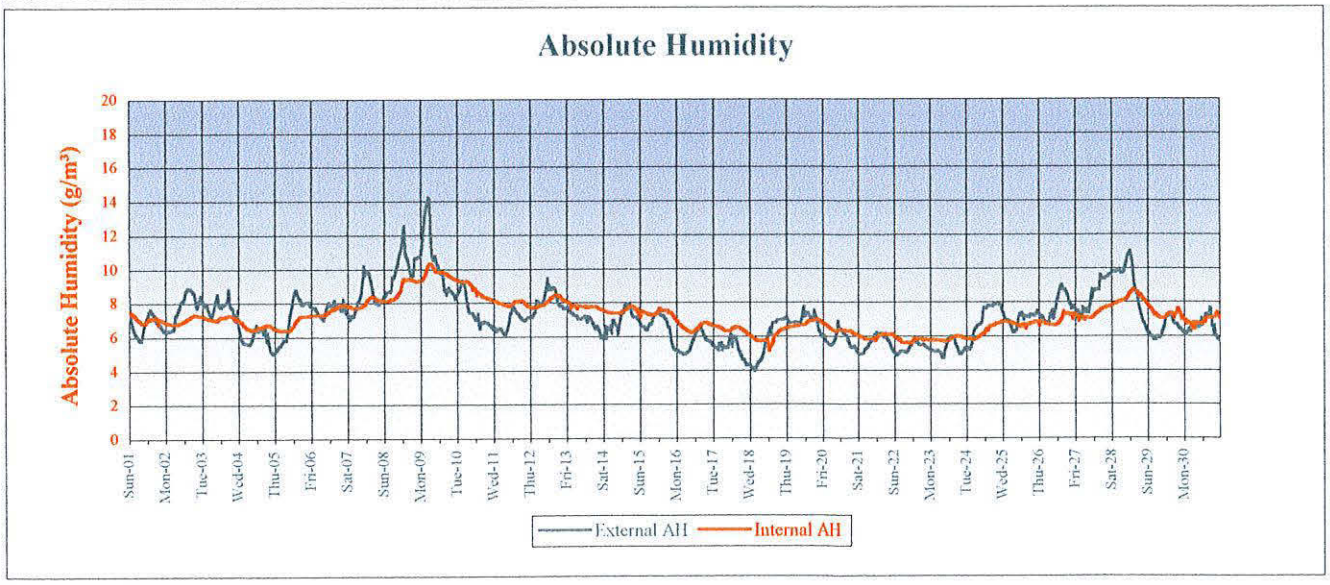
Peterborough Cathedral Nave Ceiling

November 1998

Probe 1: Bay 36 III lower side (shade)



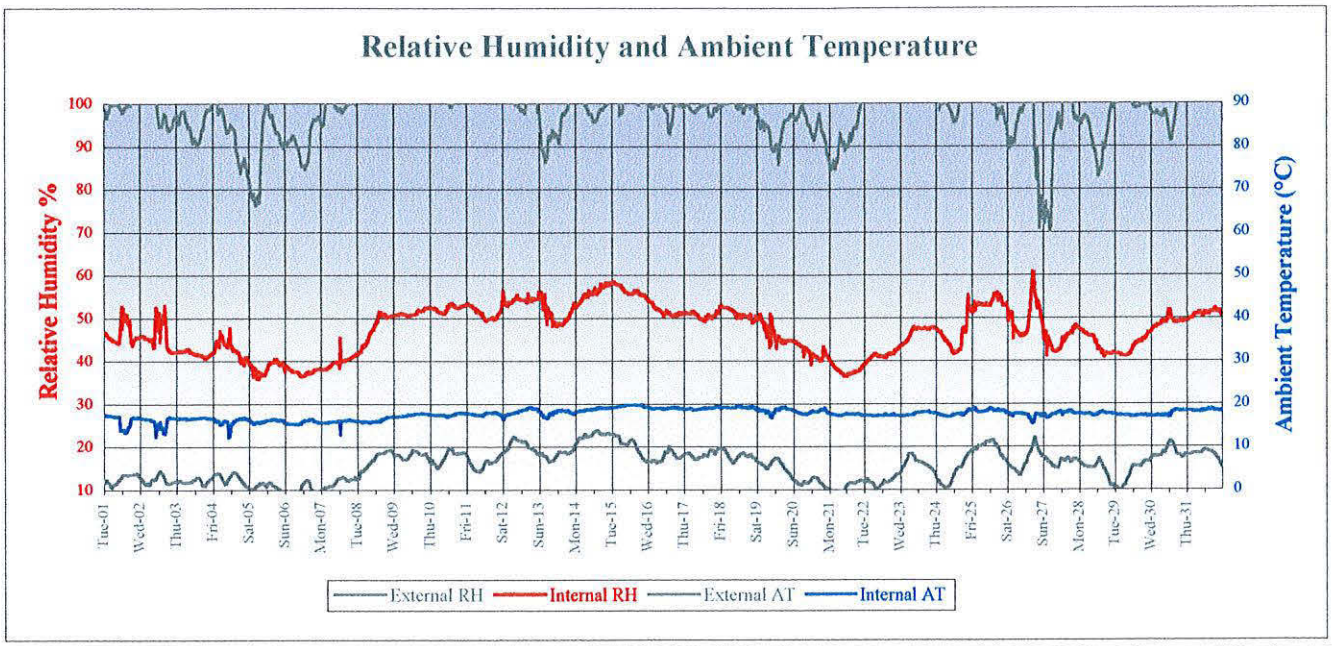


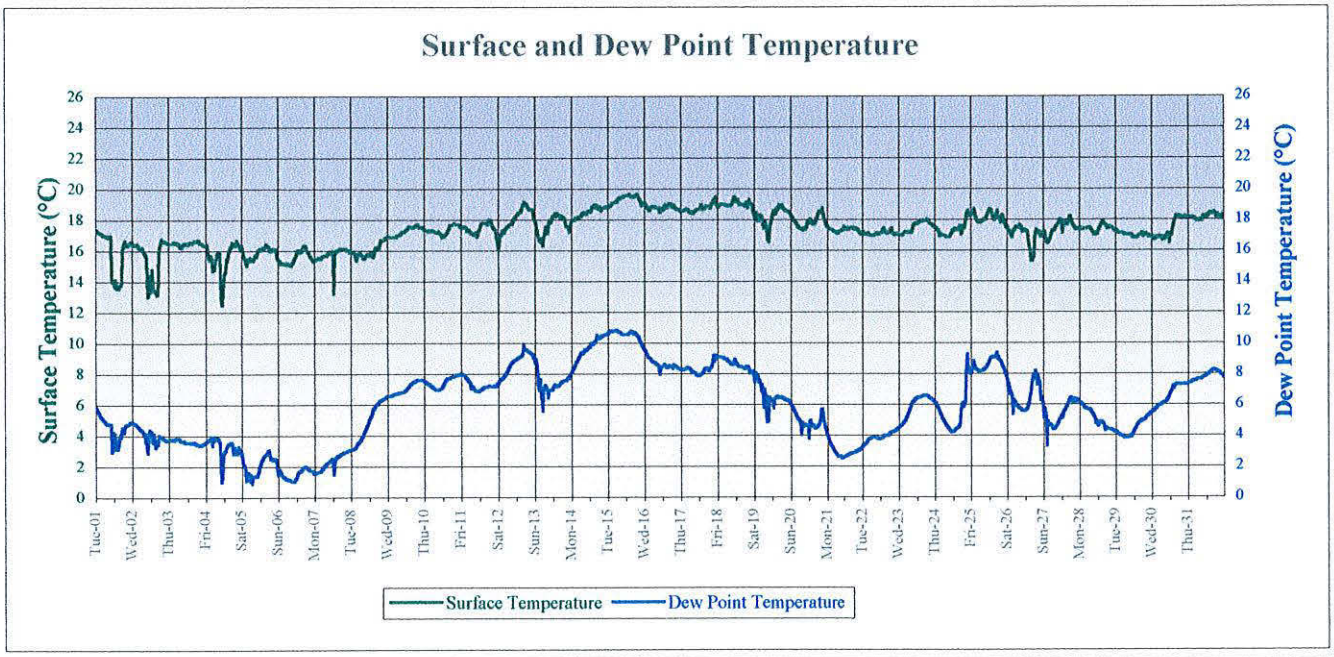


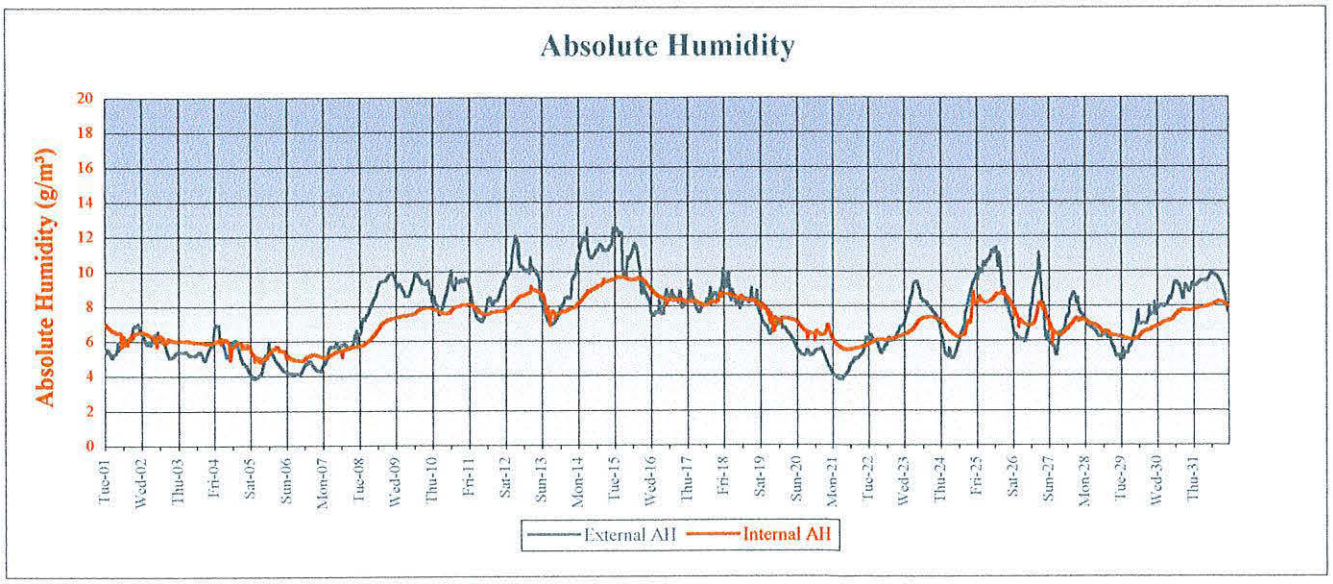
Peterborough Cathedral Nave Ceiling

December 1998

Probe 1: Bay 36 III lower side (shade)



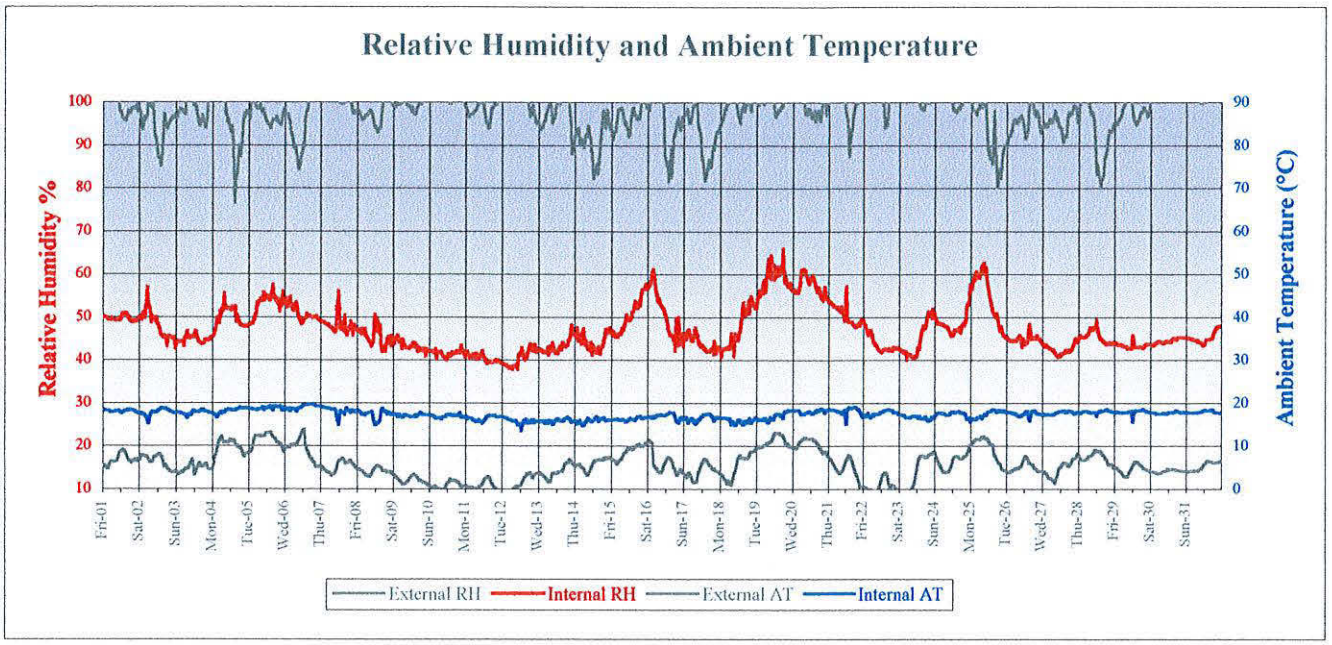


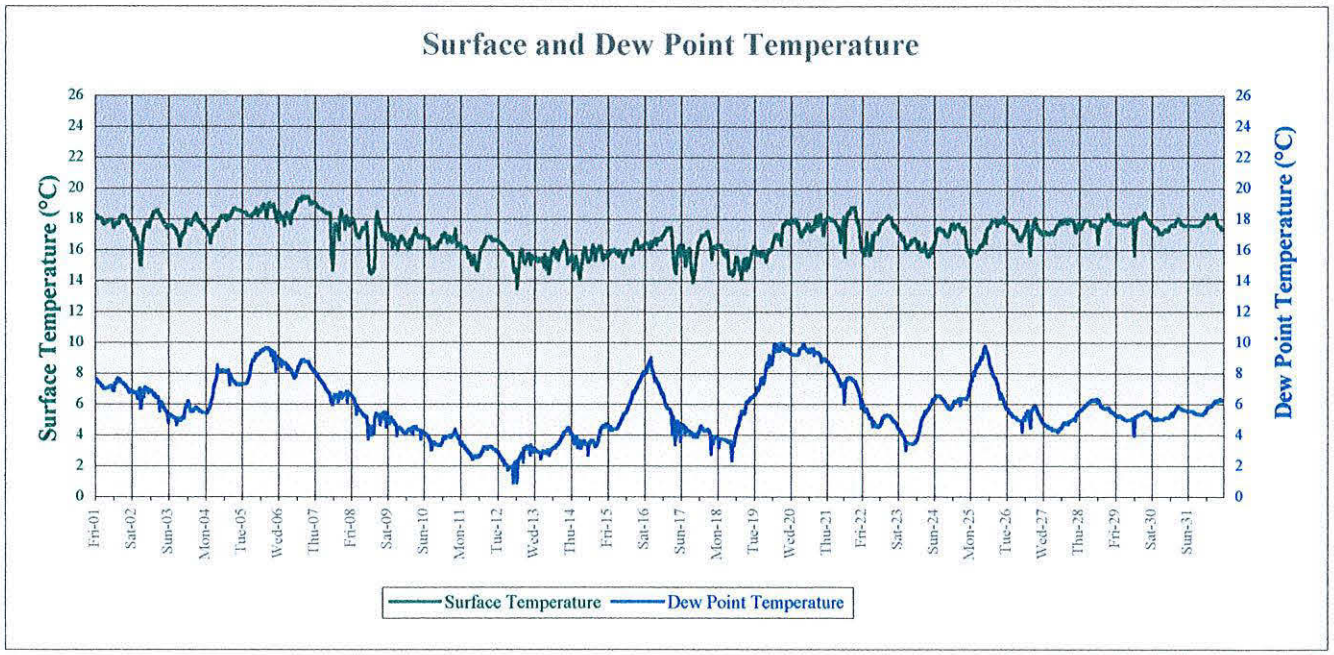


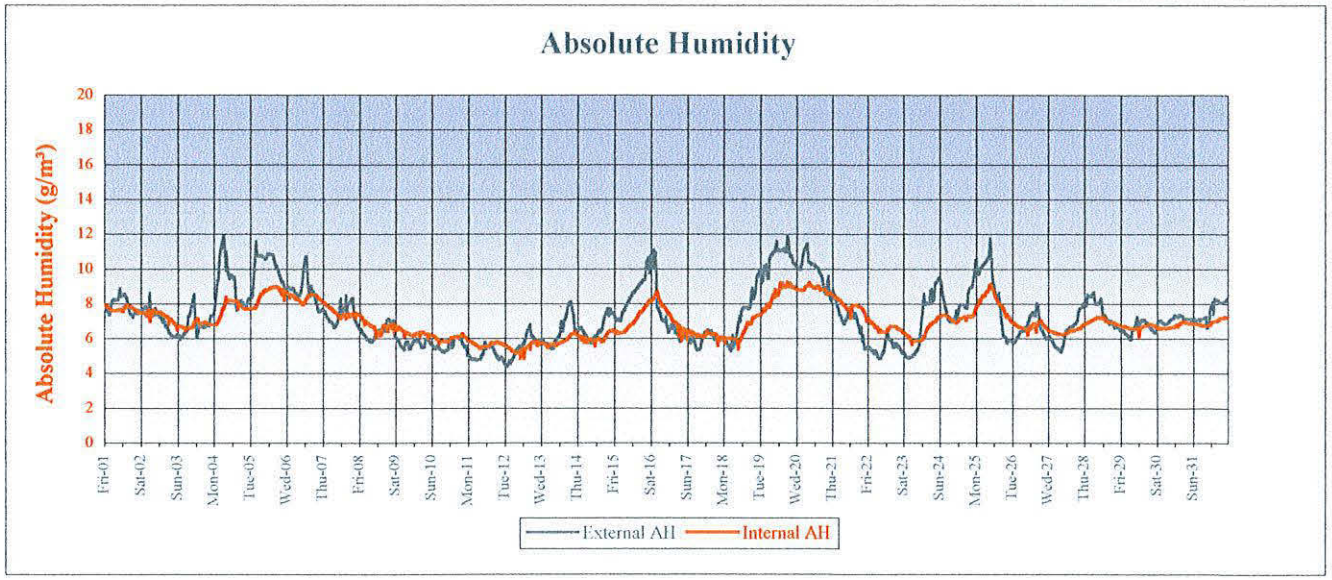
Peterborough Cathedral Nave Ceiling

January 1999

Probe 1: Bay 36 III lower side (shade)



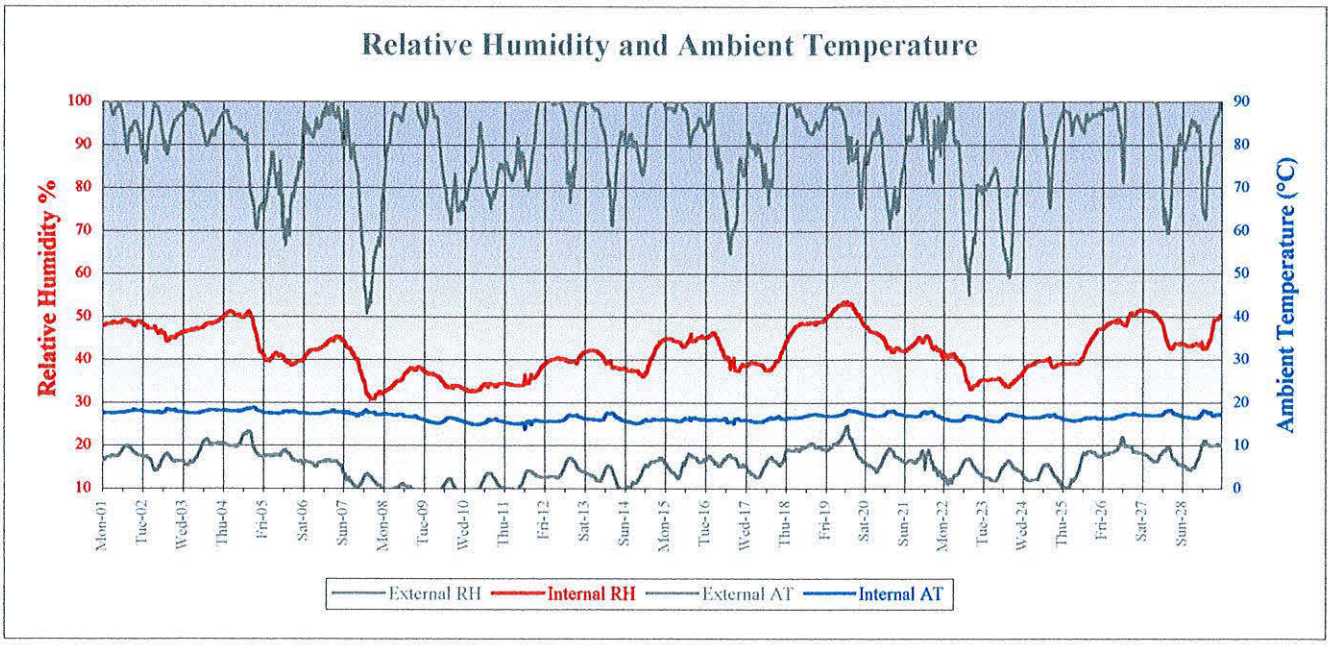


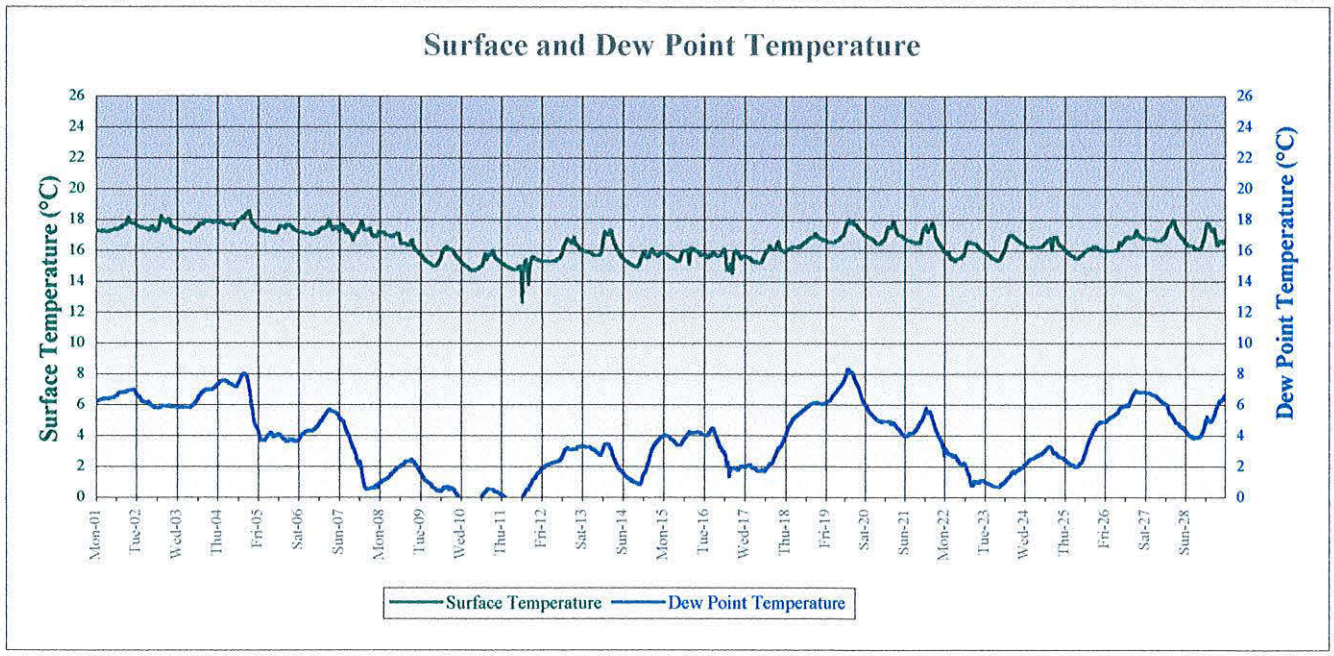


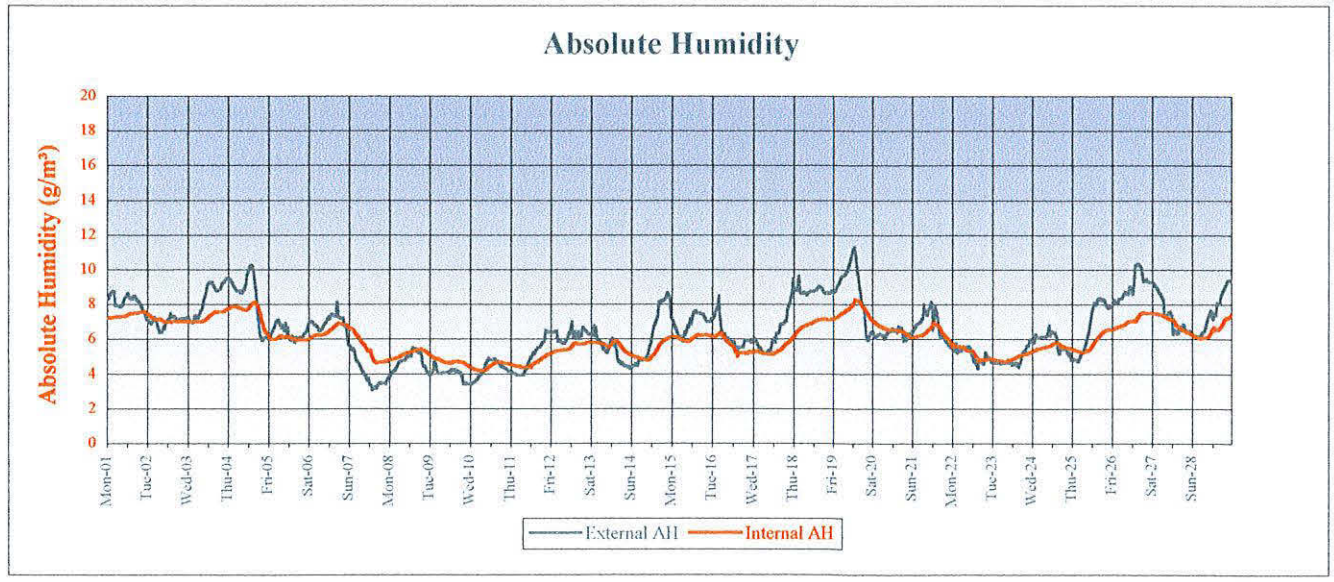
Peterborough Cathedral Nave Ceiling

February 1999

Probe 1: Bay 36 III lower side (shade)



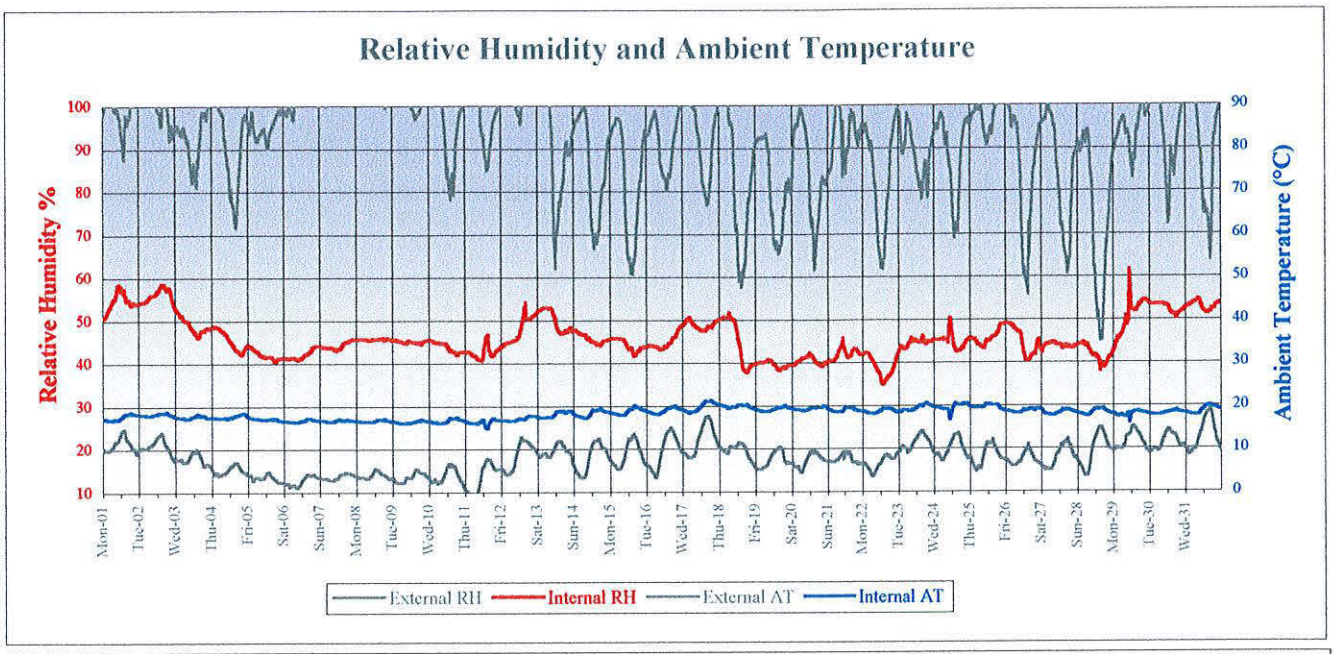


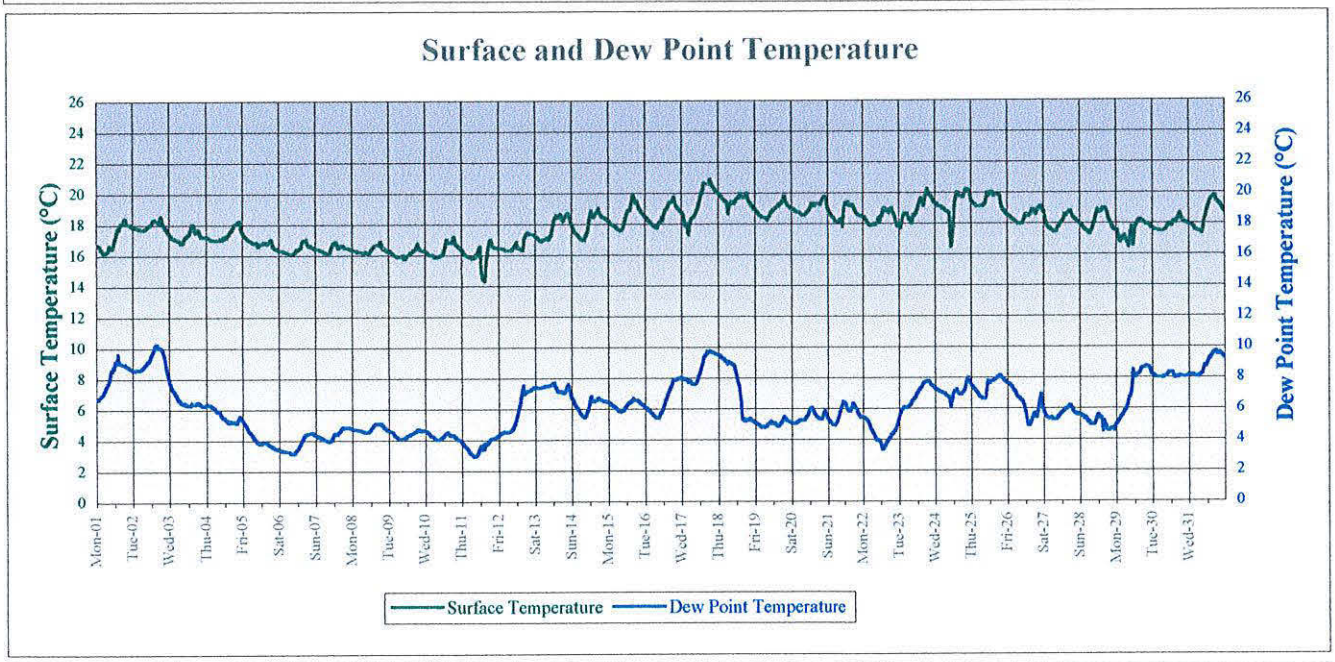


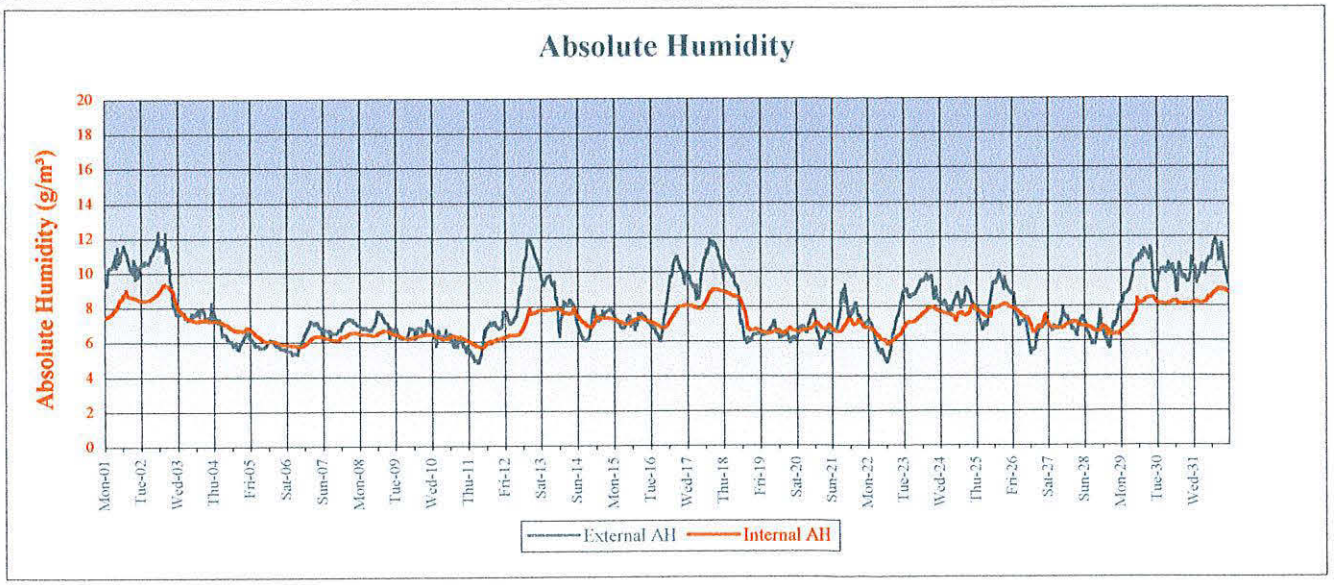
Peterborough Cathedral Nave Ceiling

March 1999

Probe 1: Bay 36 III lower side (shade)



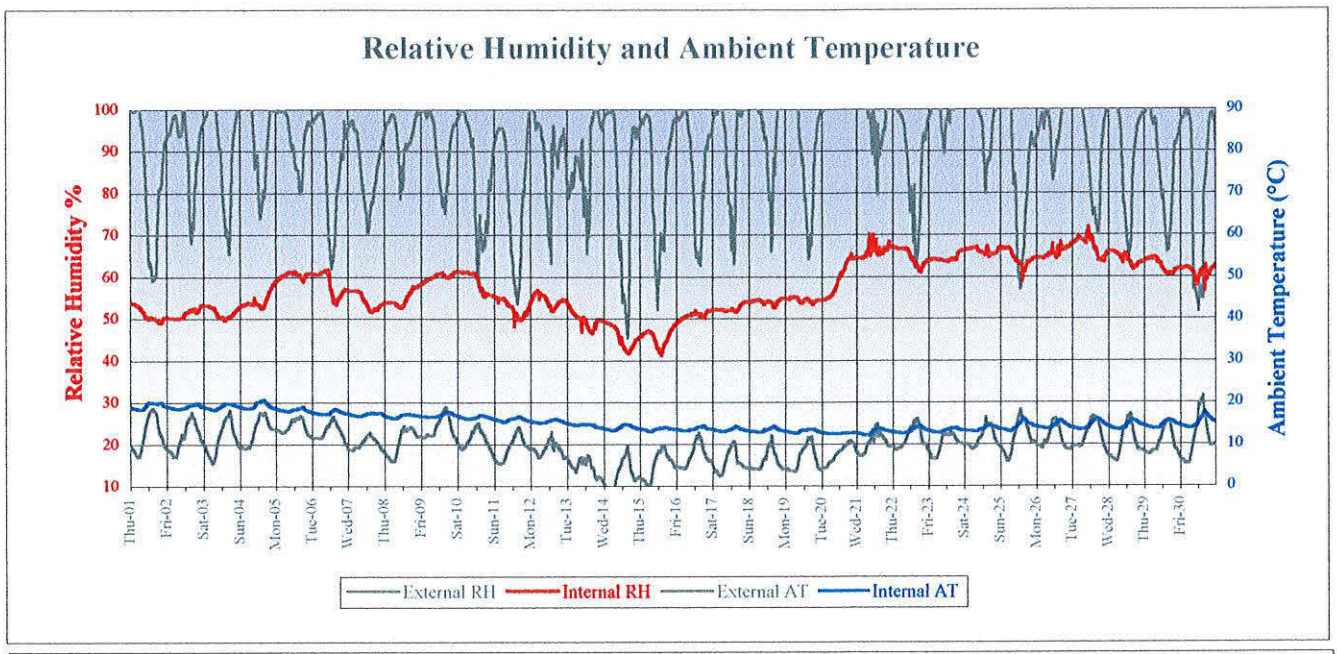


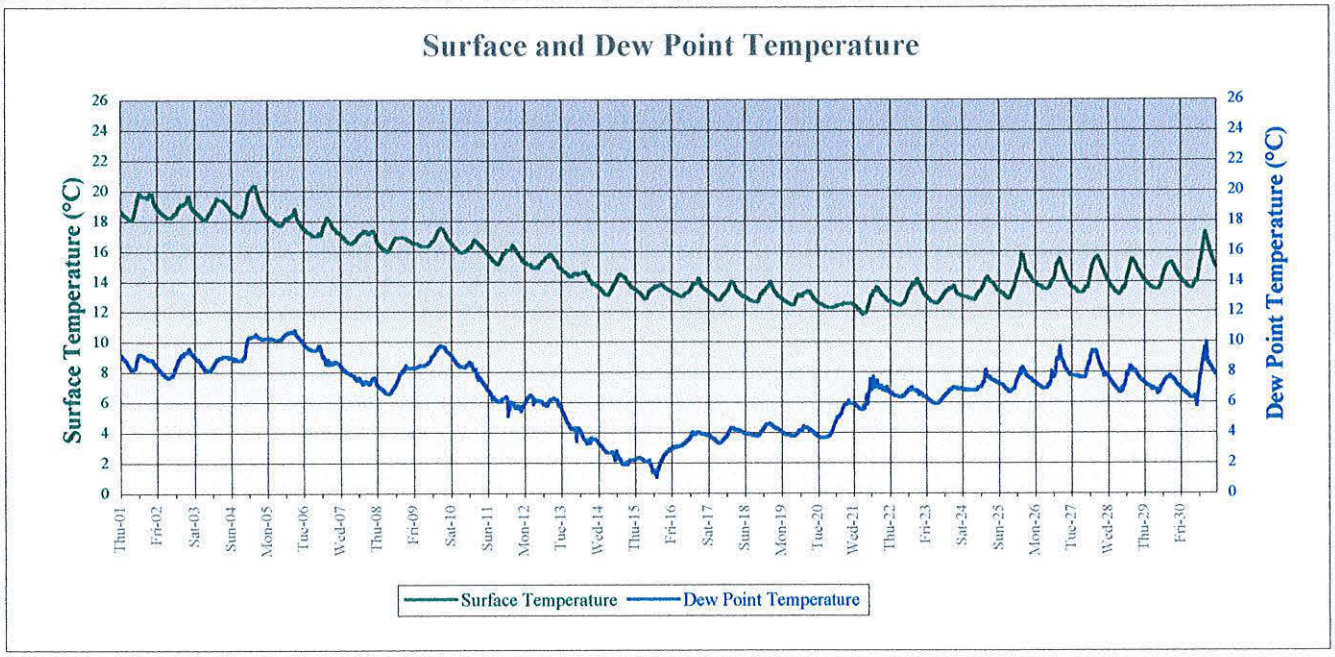


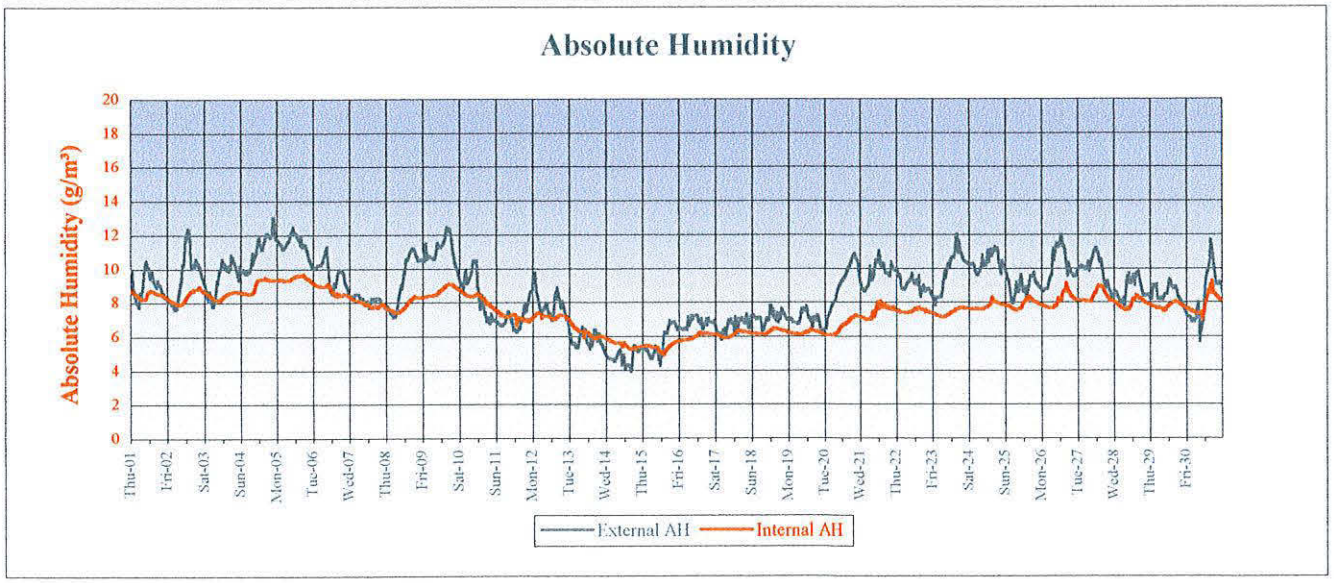
Peterborough Cathedral Nave Ceiling

April 1999

Probe 1: Bay 36 III lower side (shade)



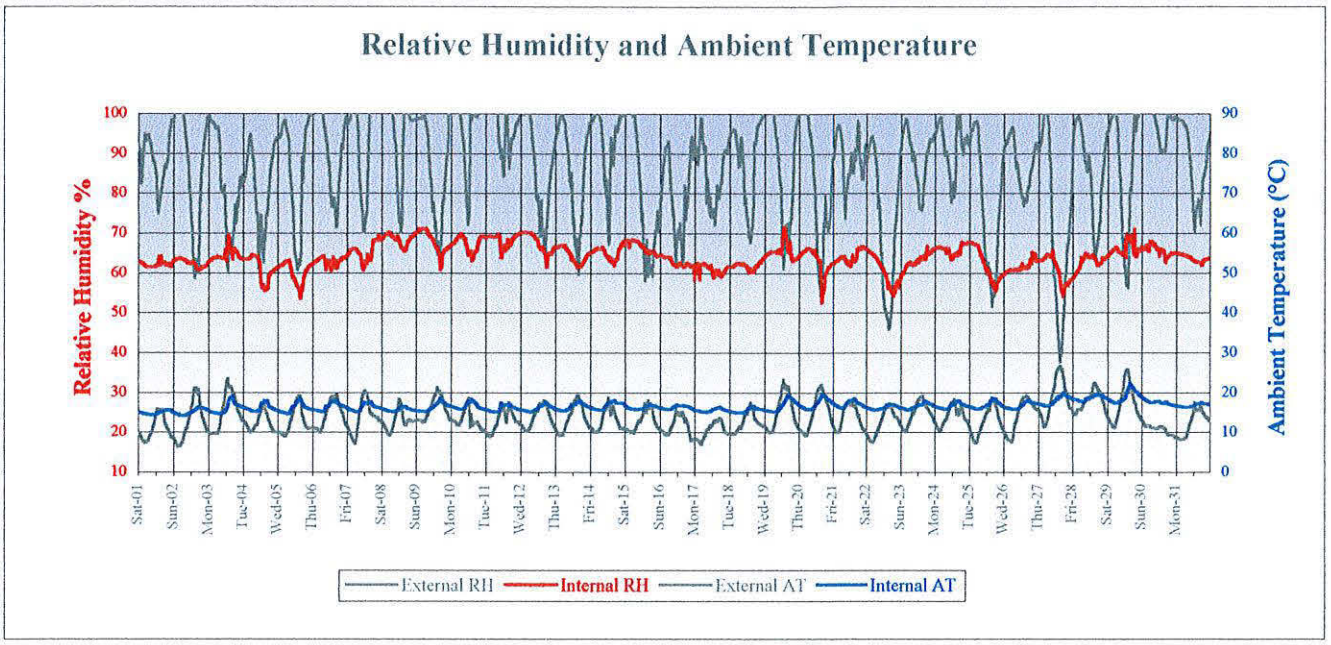


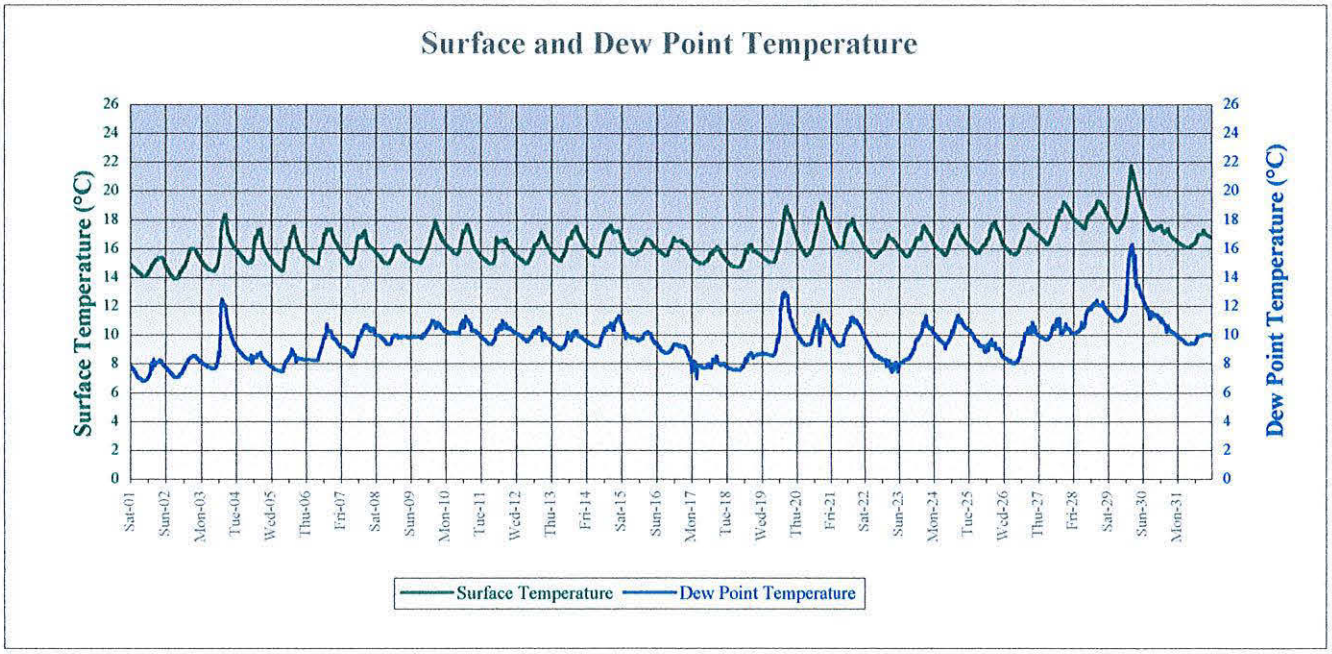


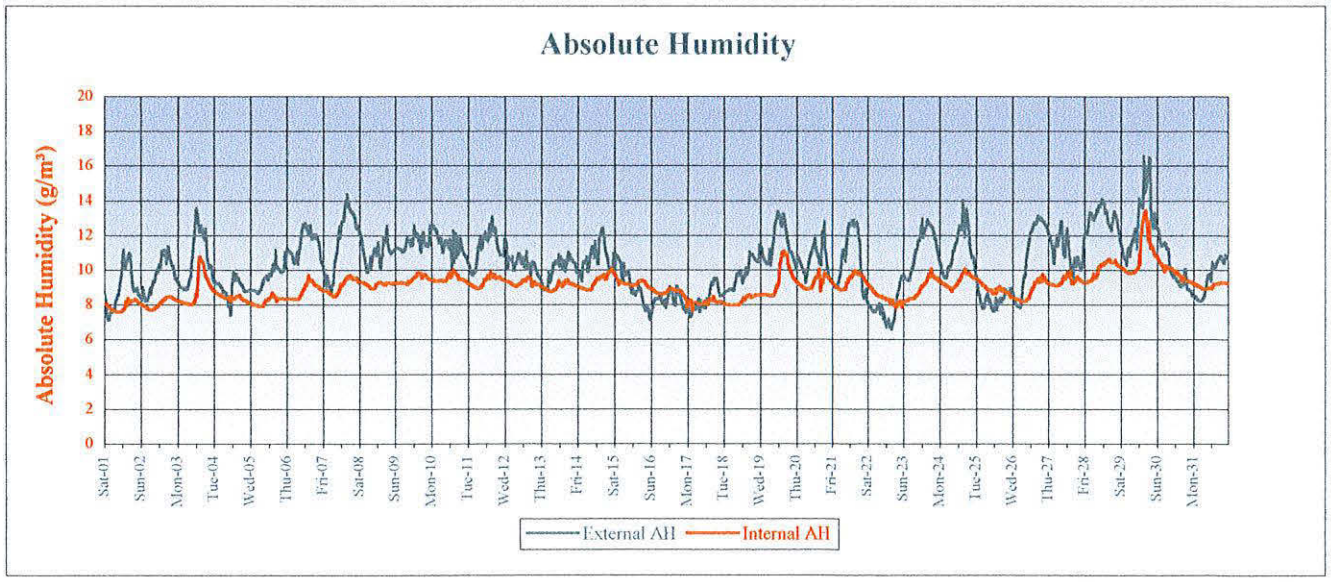
Peterborough Cathedral Nave Ceiling

May 1999

Probe 1: Bay 36 III lower side (shade)



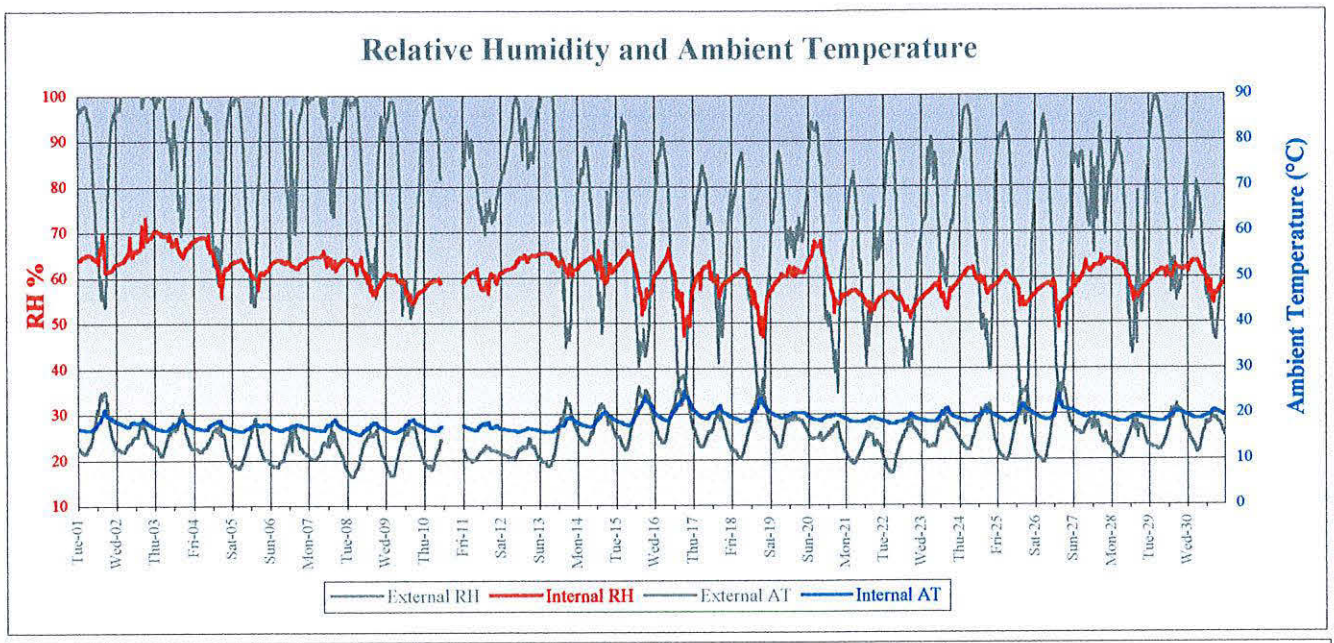


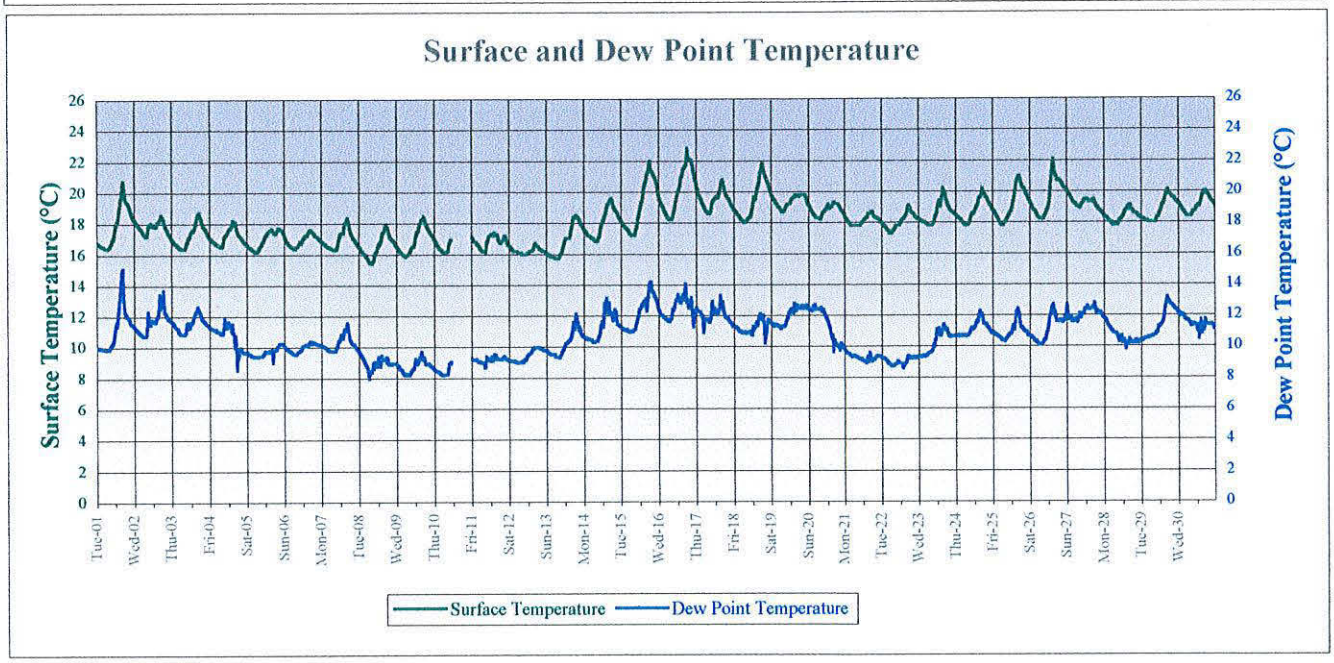


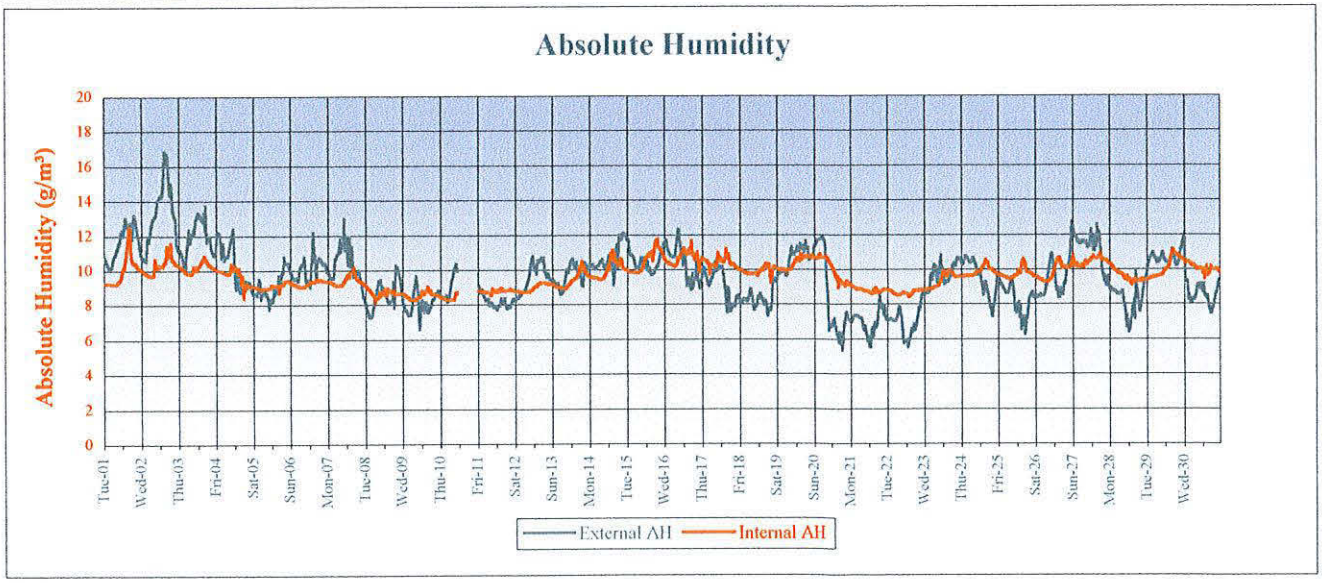
Peterborough Cathedral Nave Ceiling

June 1999

Probe 1: Bay 36 III lower side (shade)



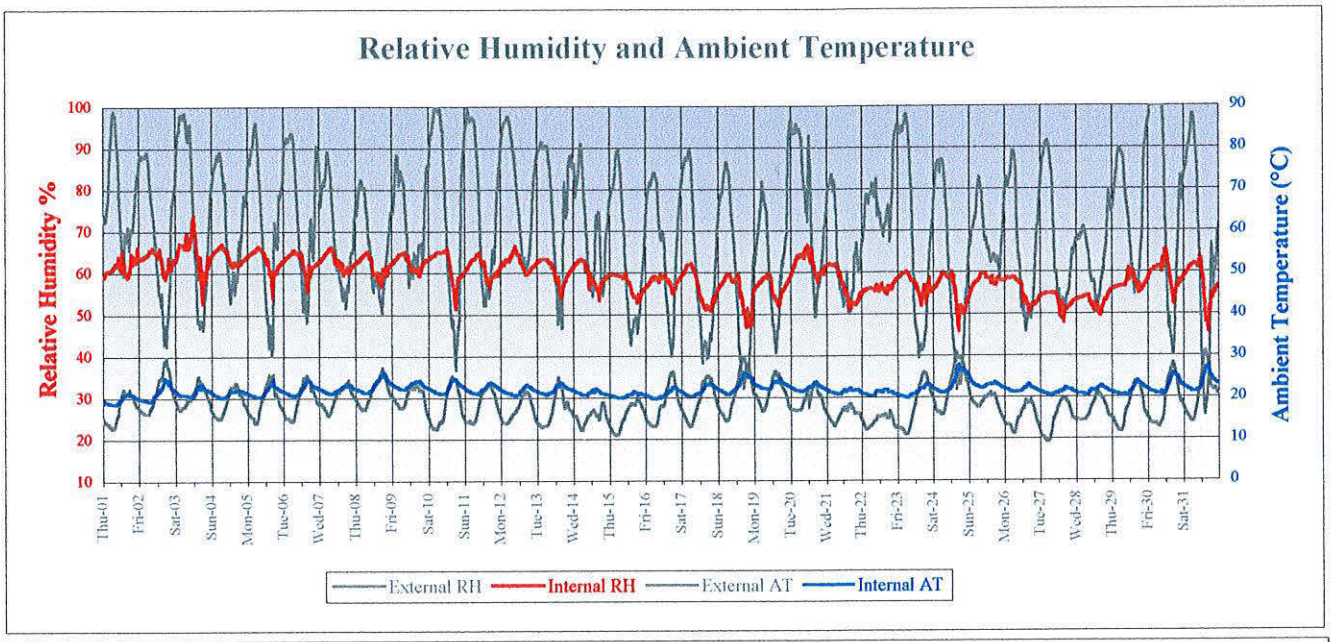


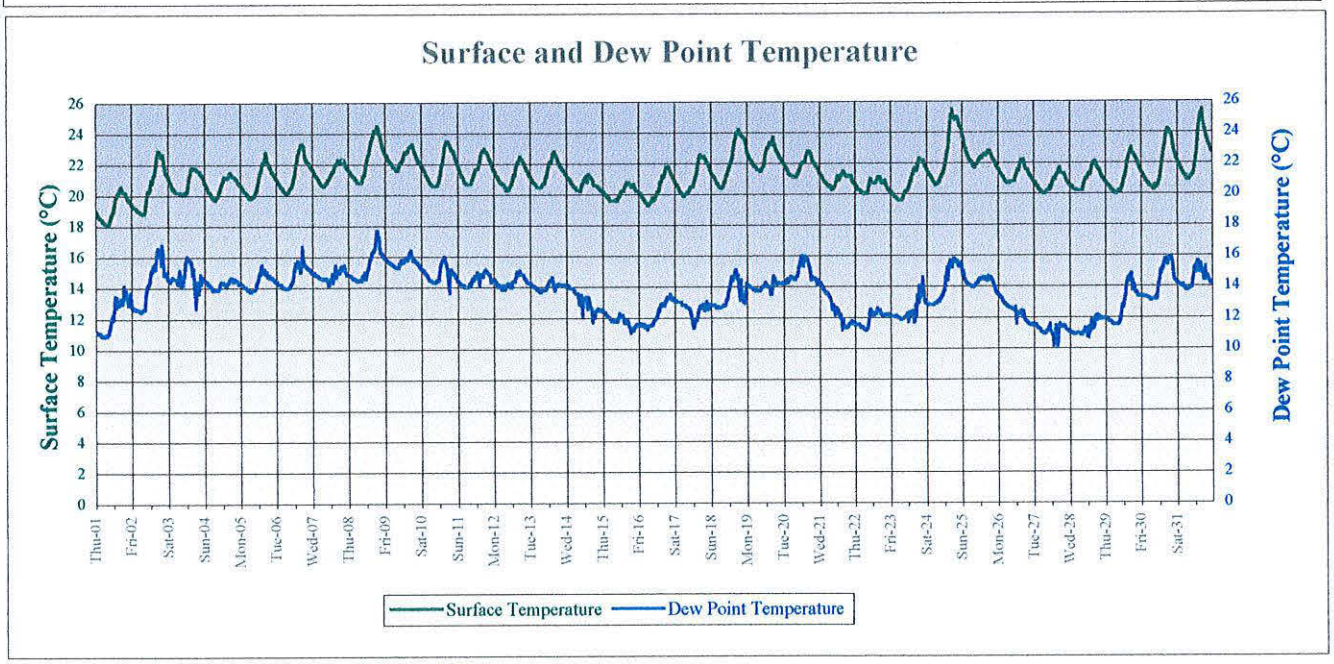


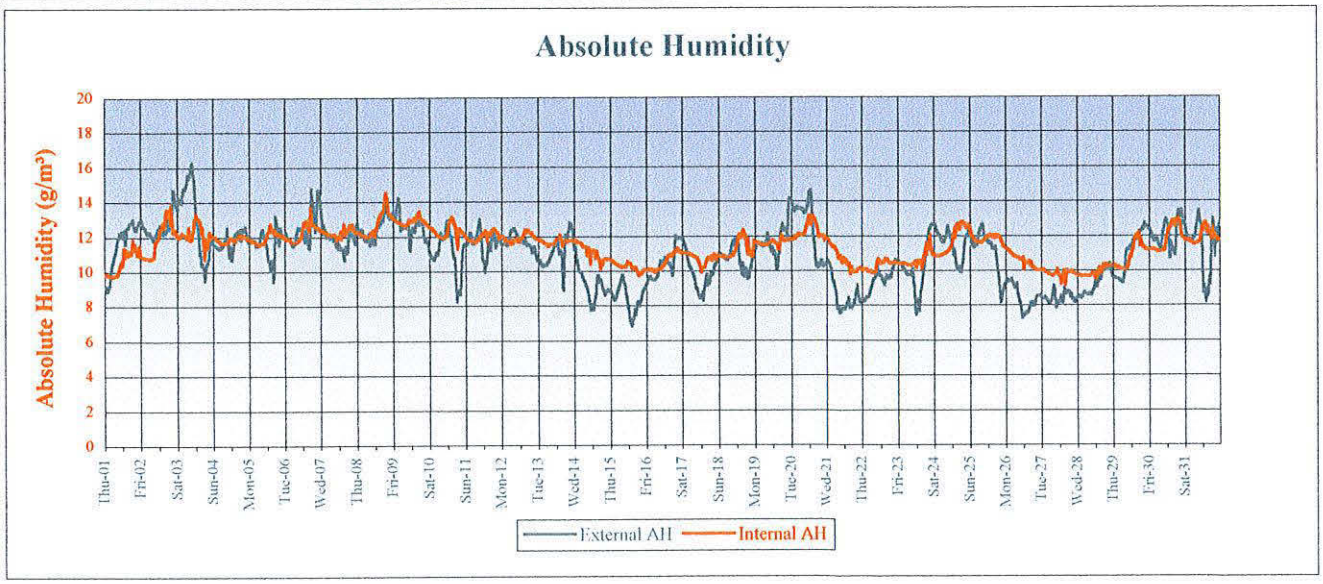
Peterborough Cathedral Nave Ceiling

July 1999

Probe 1: Bay 36 III lower side (shade)



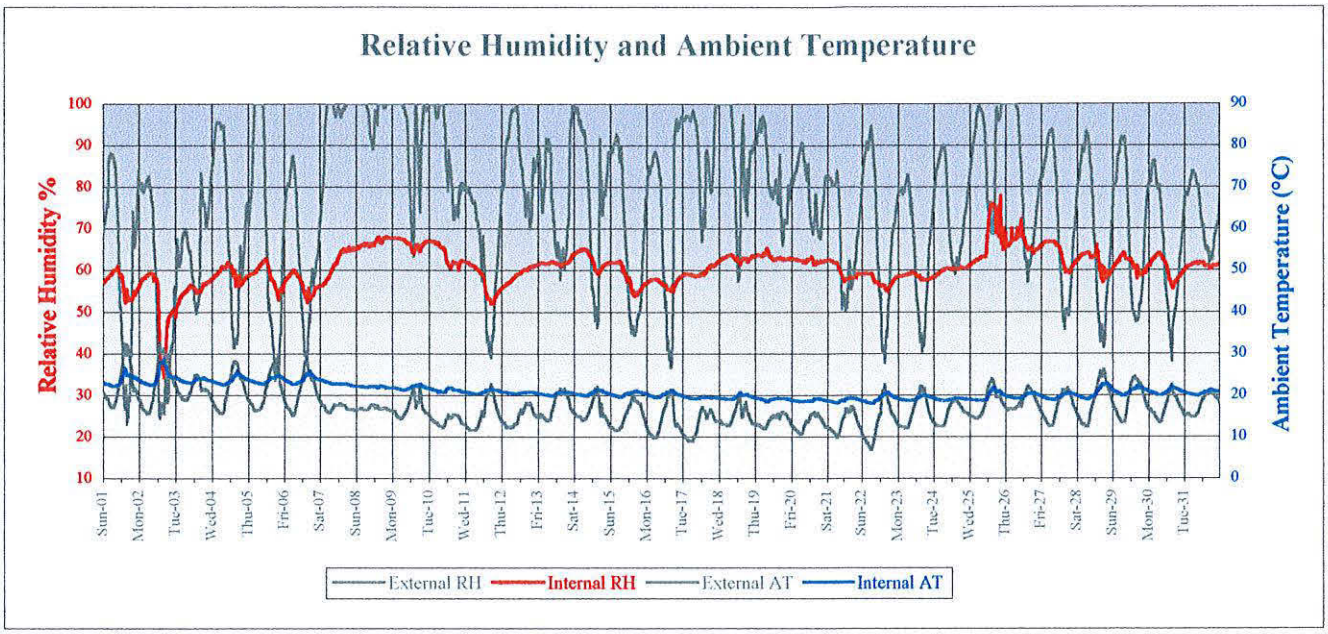


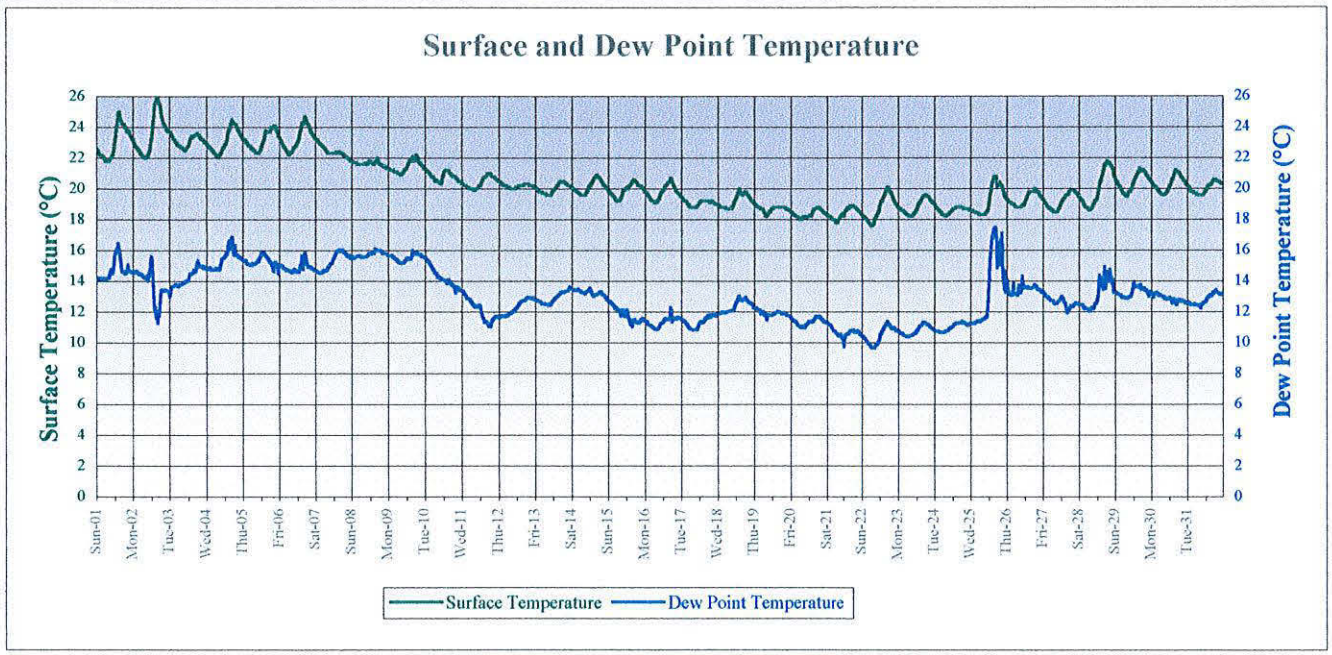


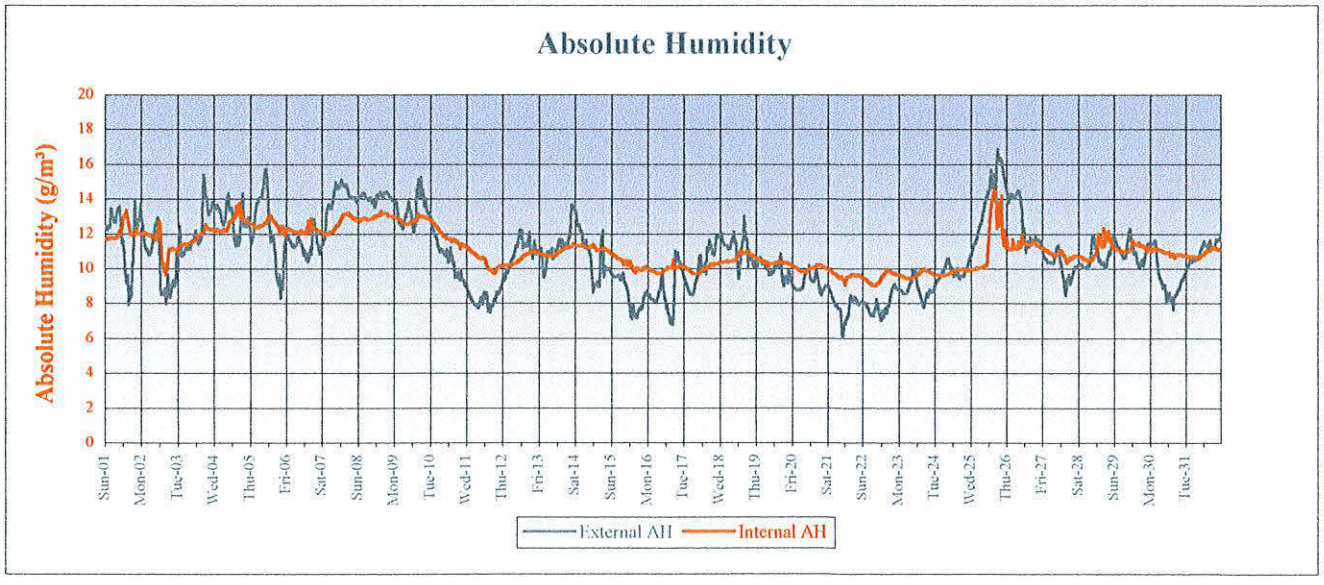
Peterborough Cathedral Nave Ceiling

August 1999

Probe 1: Bay 36 III lower side (shade)



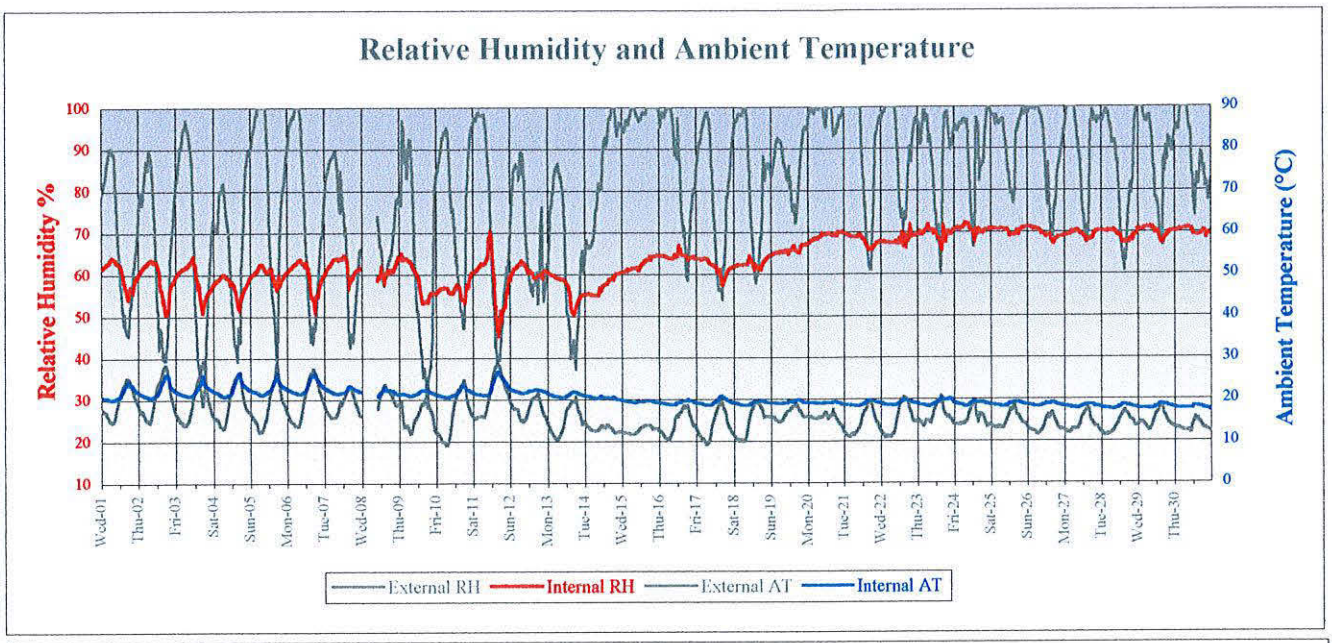


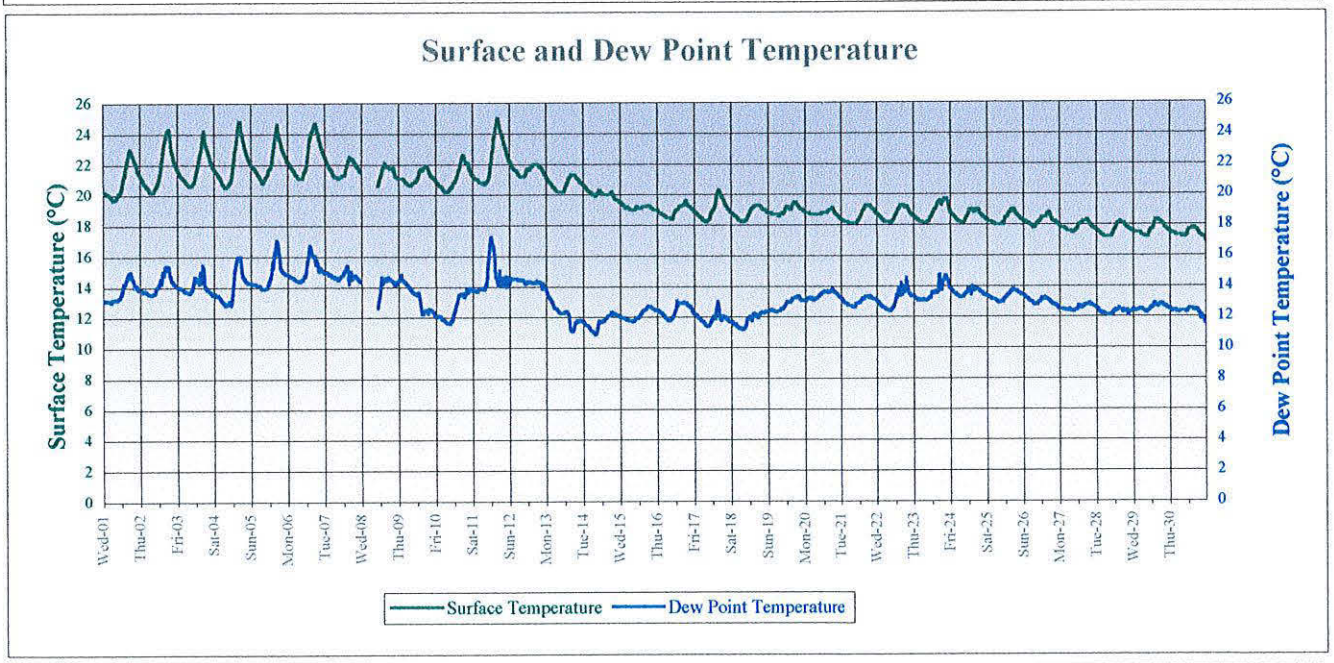


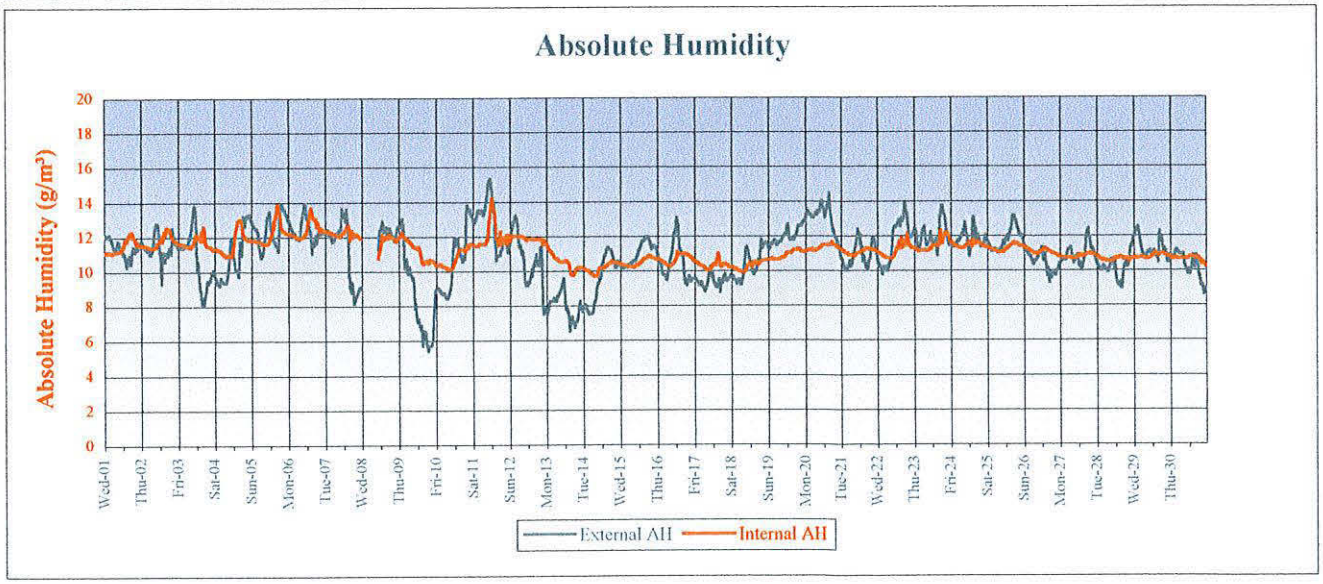
Peterborough Cathedral Nave Ceiling

September 1999

Probe 1: Bay 36 III lower side (shade)



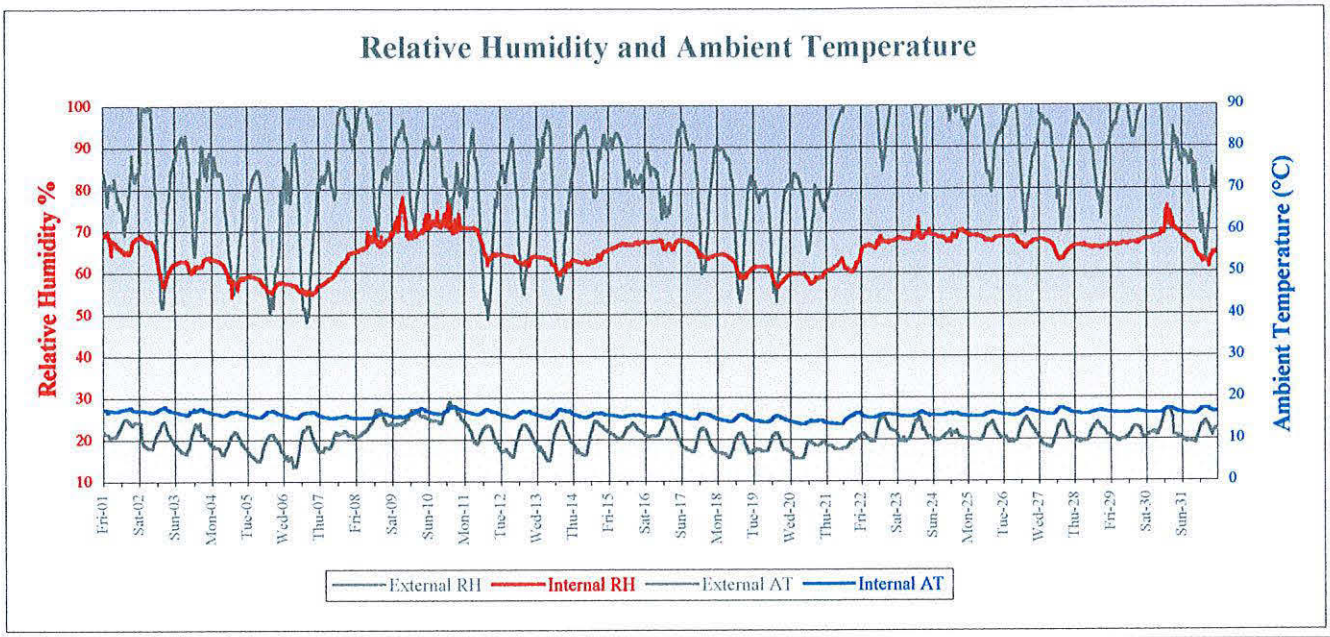


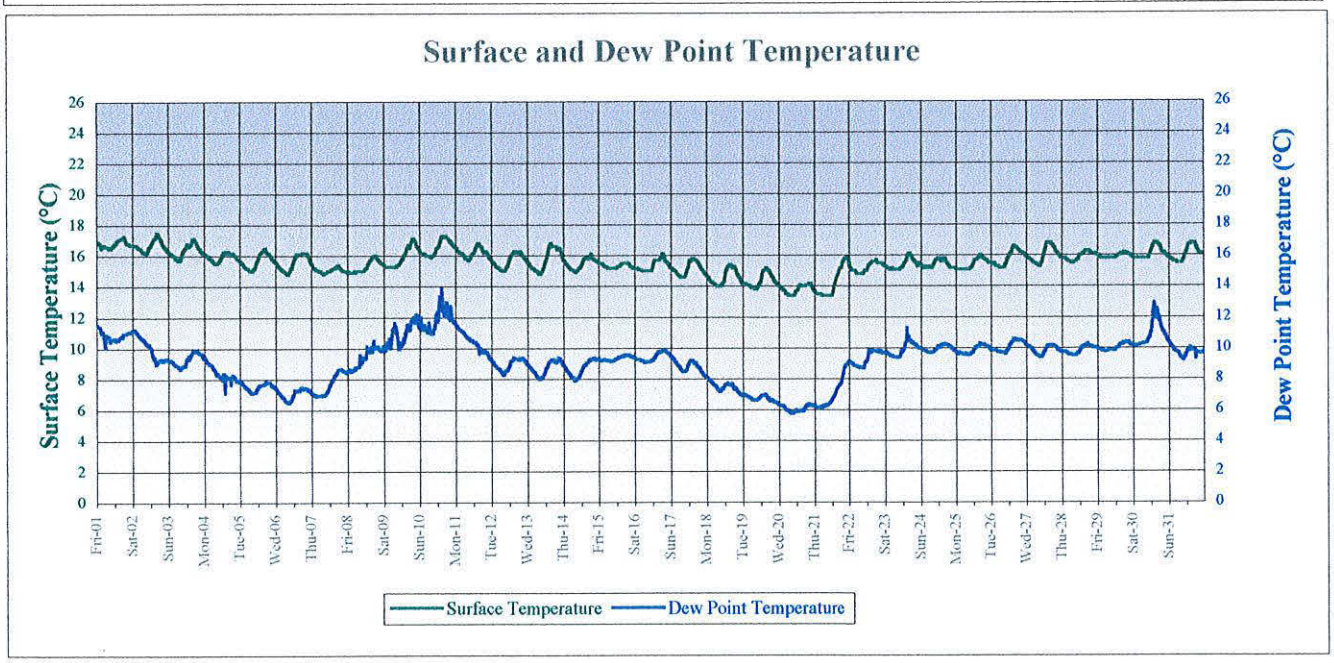


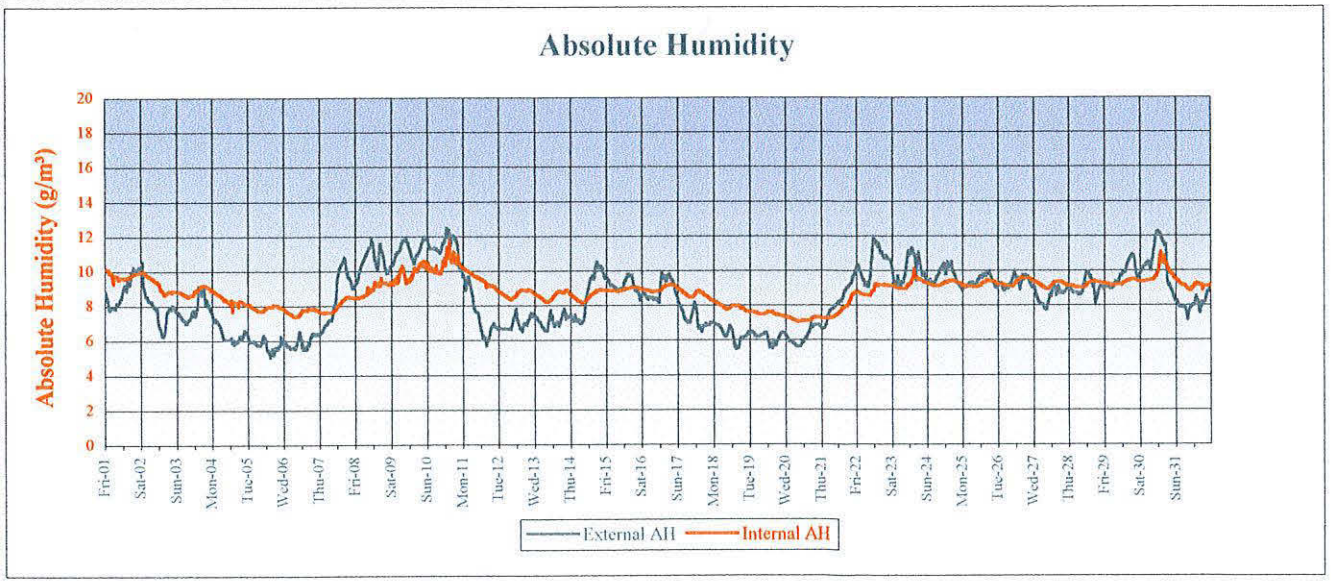
Peterborough Cathedral Nave Ceiling

October 1999

Probe 1: Bay 36 III lower side (shade)



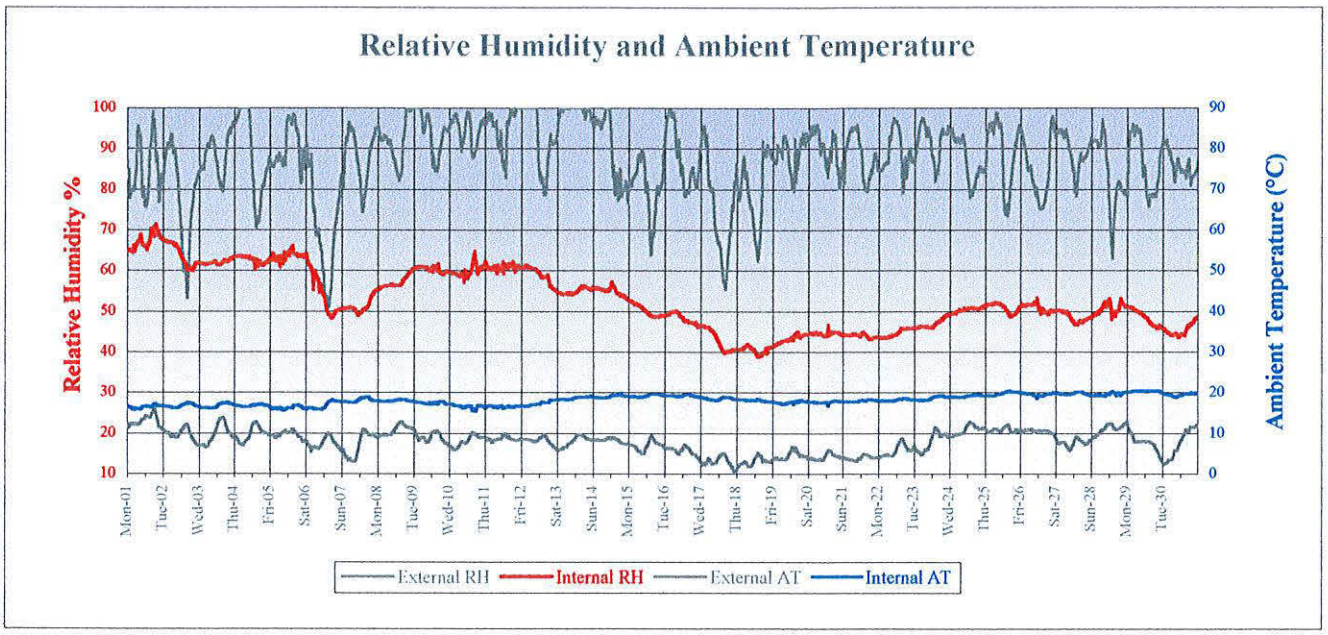


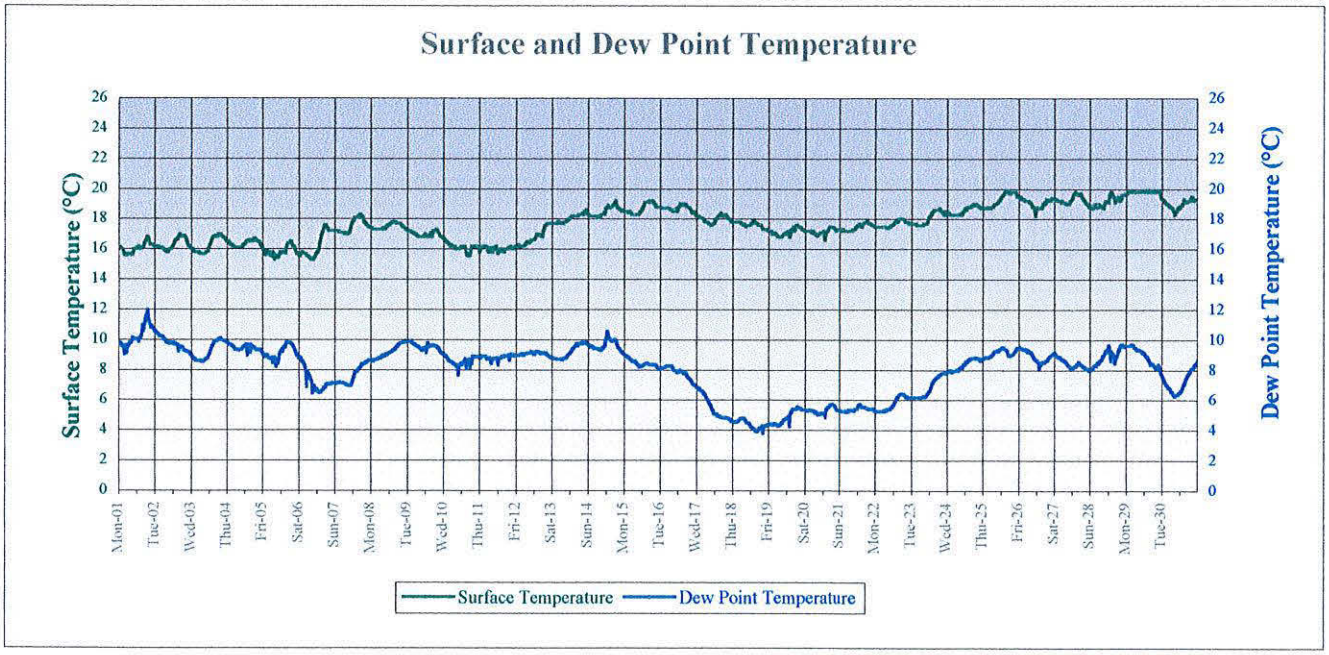


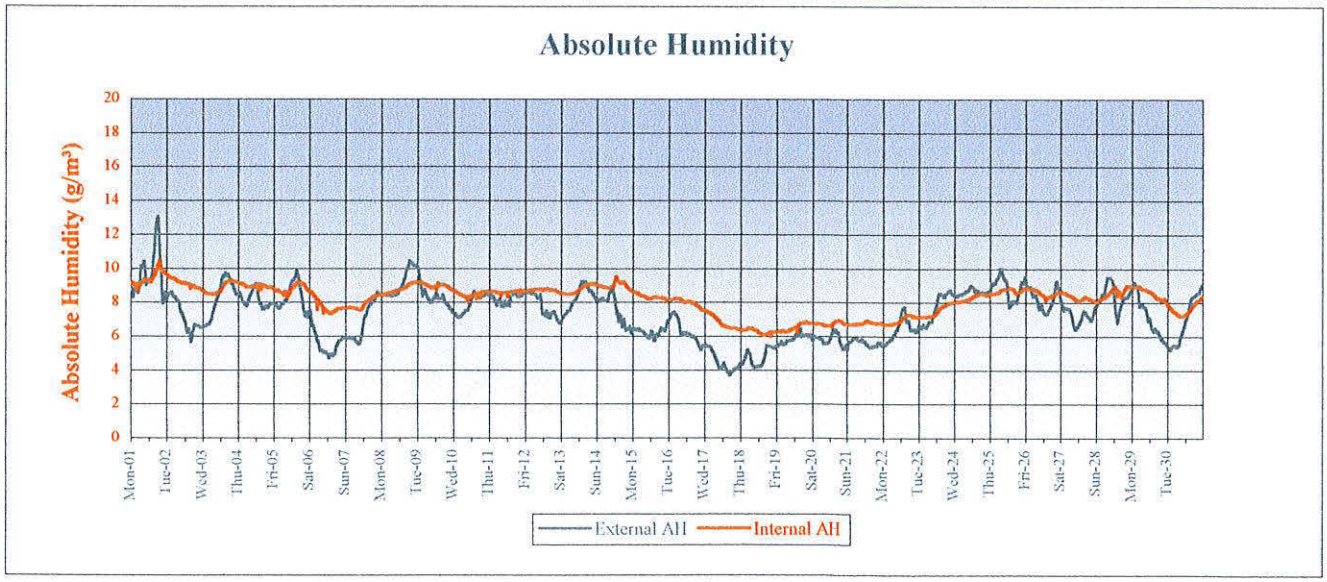
Peterborough Cathedral Nave Ceiling

November 1999

Probe 1: Bay 36 III lower side (shade)



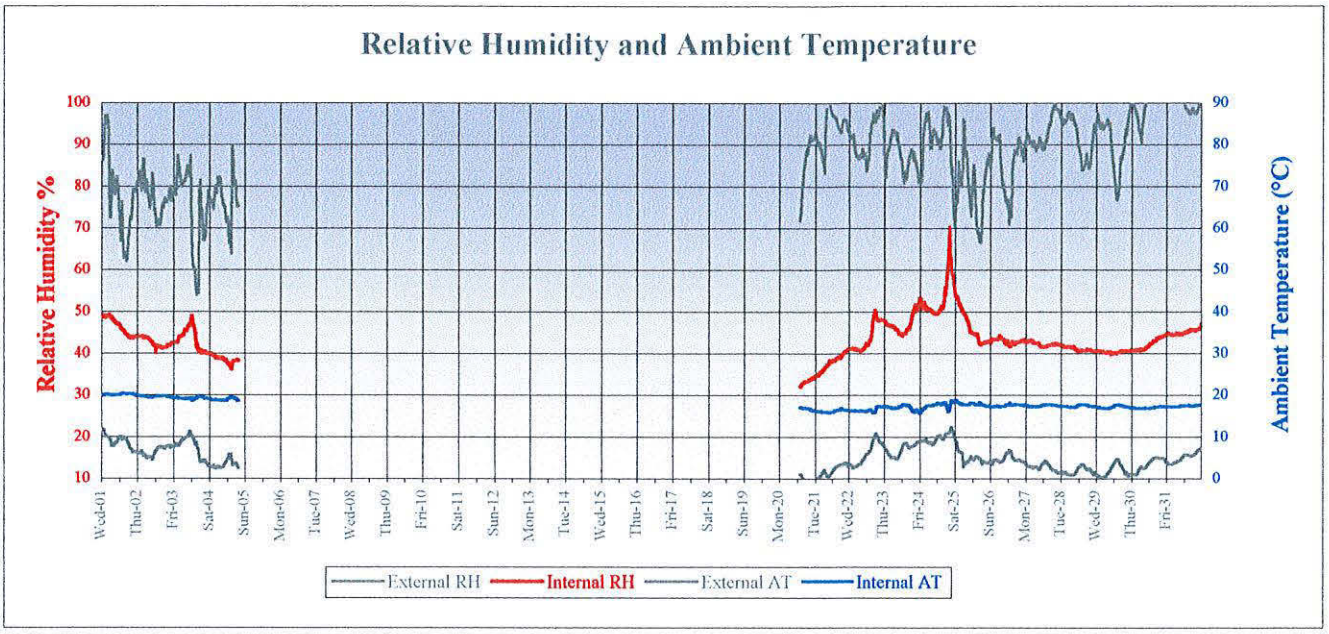


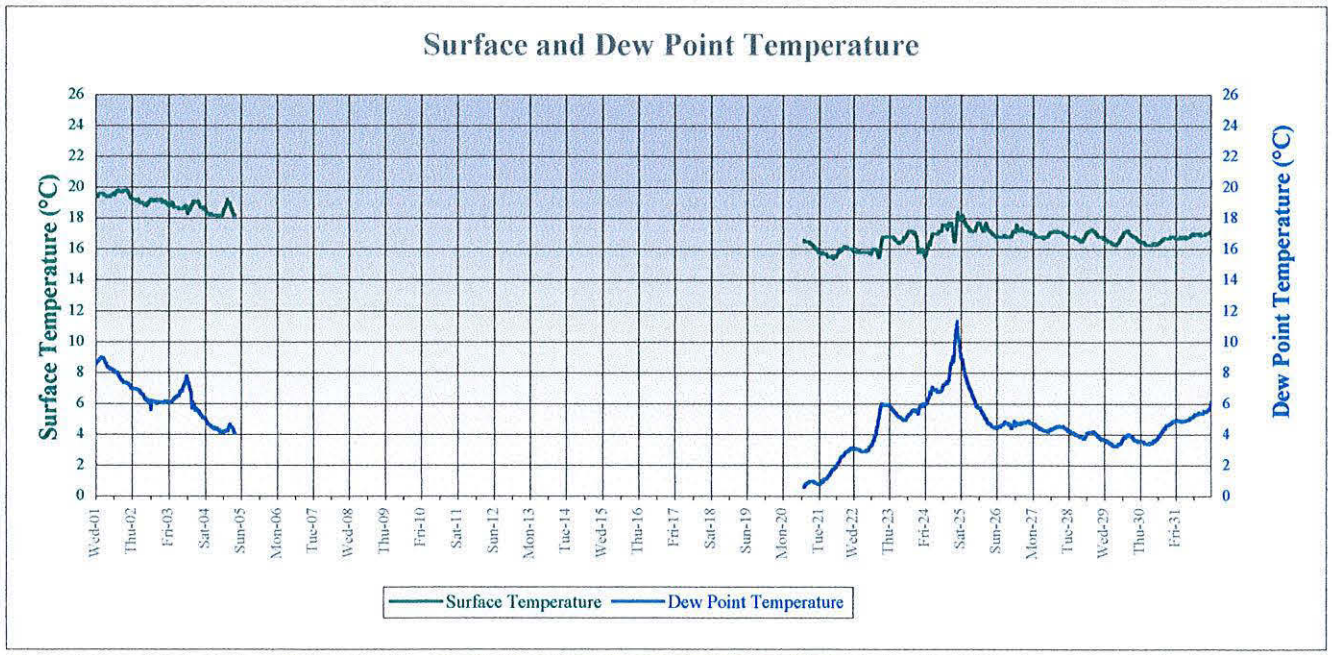


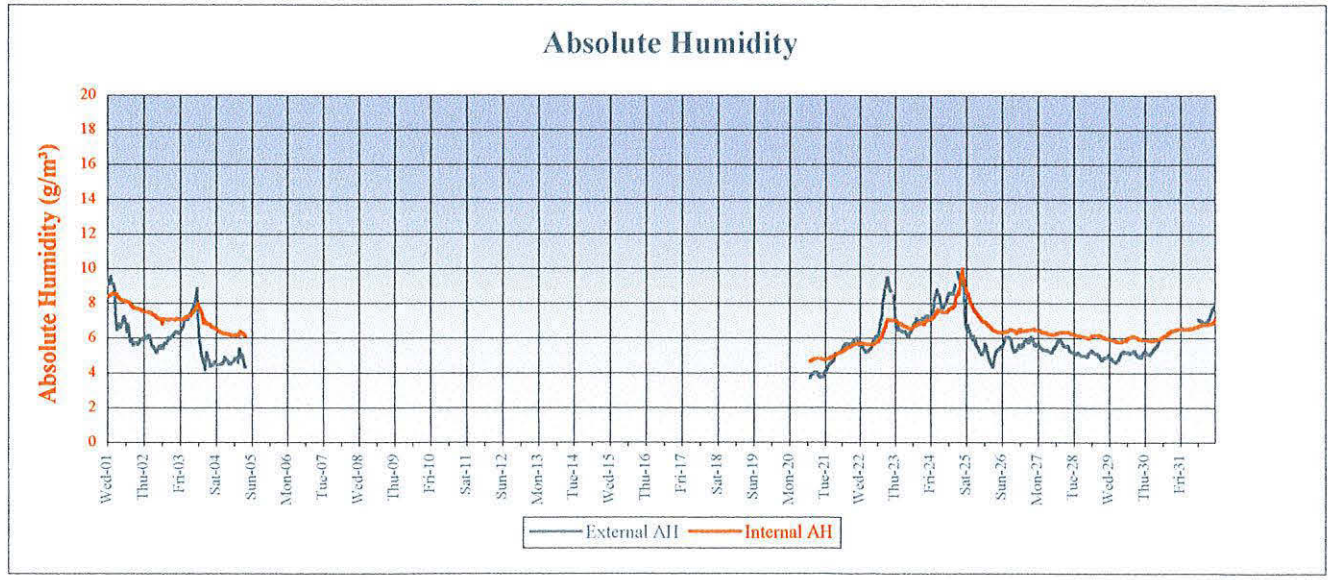
Peterborough Cathedral Nave Ceiling

December 1999

Probe 1: Bay 36 III lower side (shade)



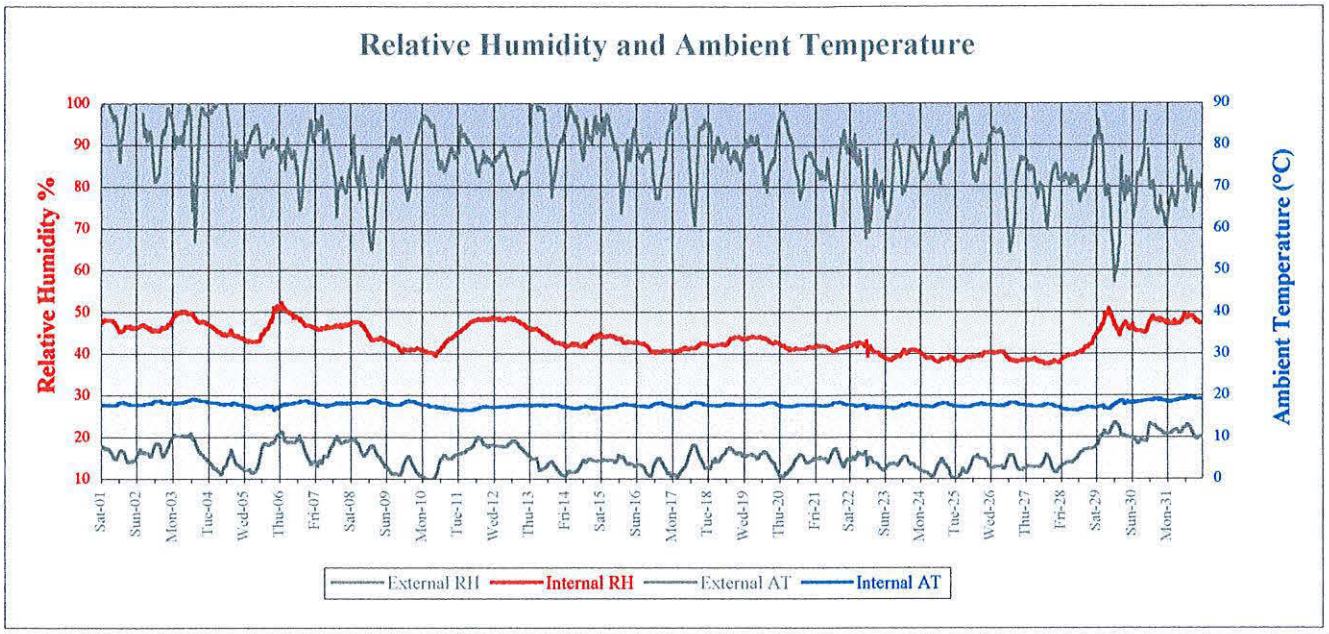


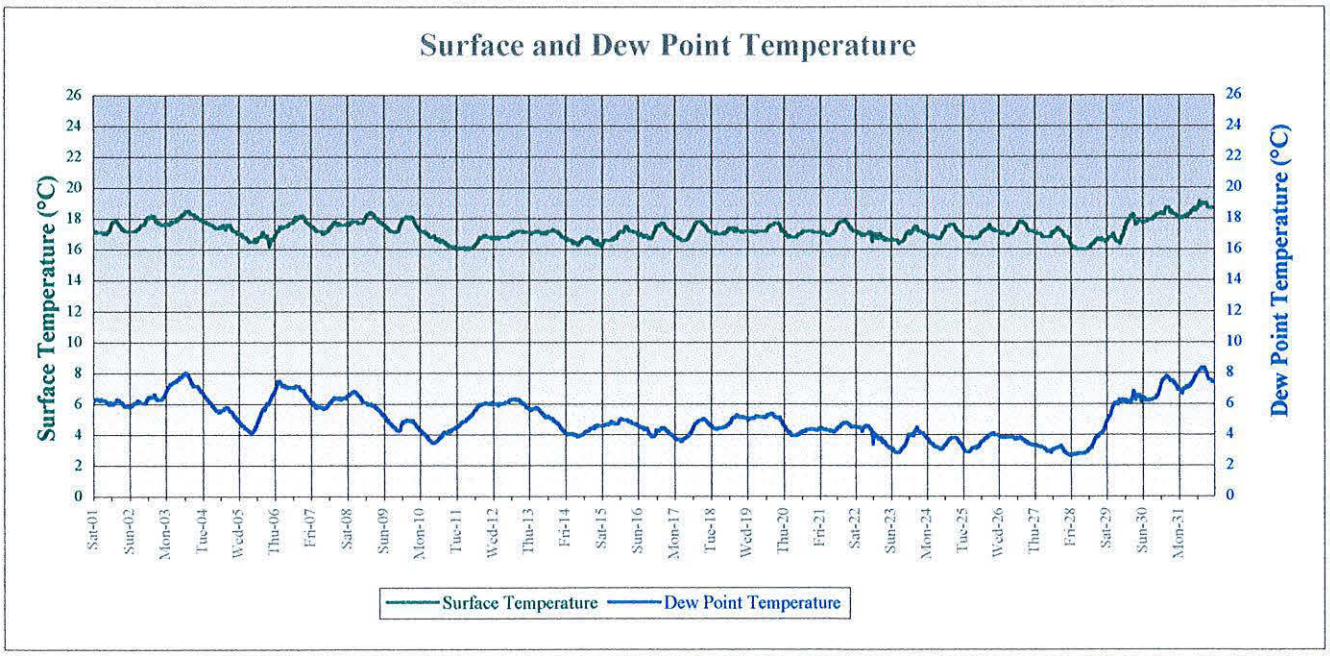


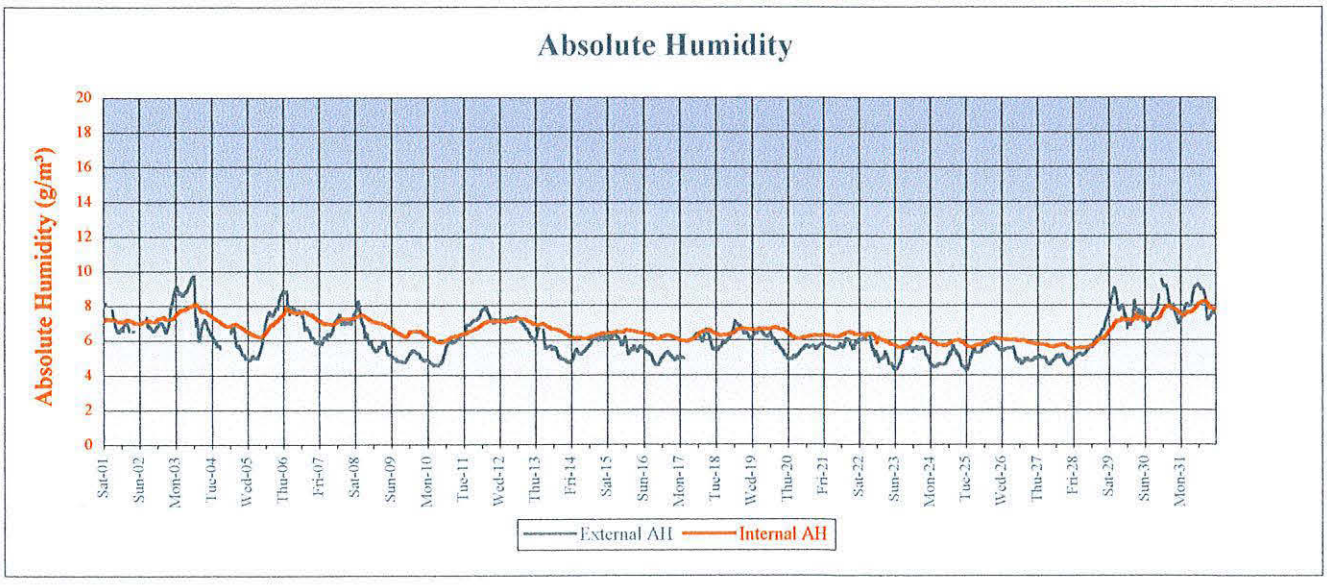
Peterborough Cathedral Nave Ceiling

January 2000

Probe 1: Bay 36 III lower side (shade)



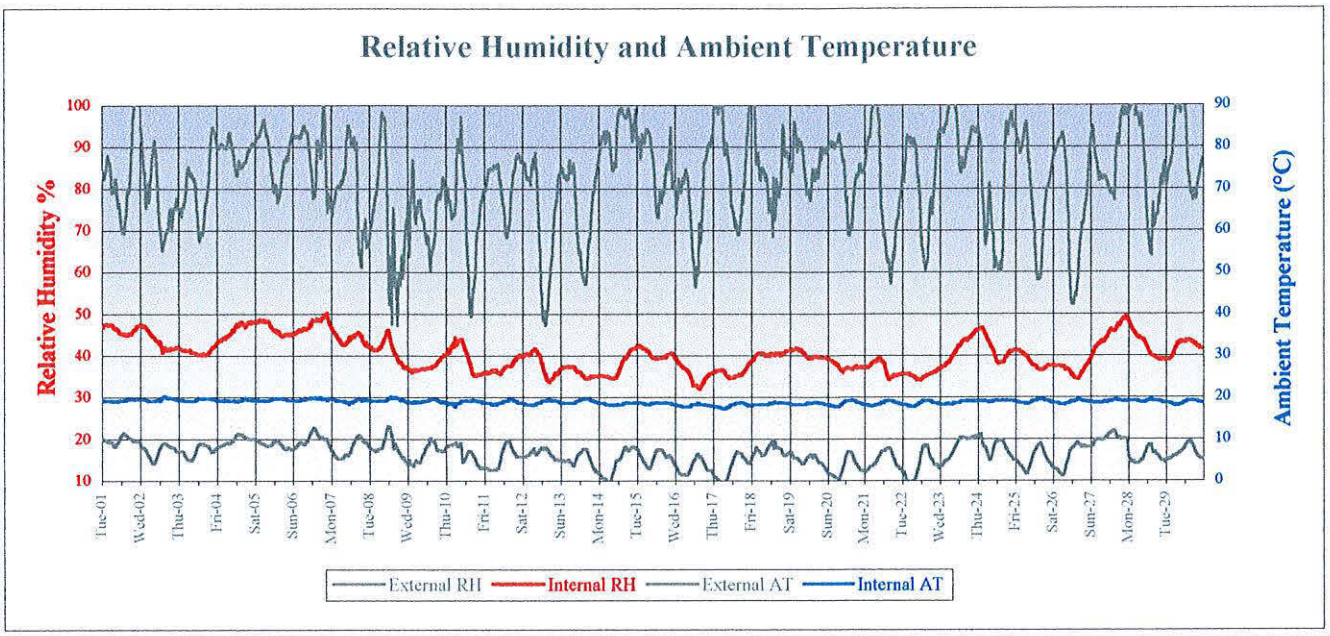


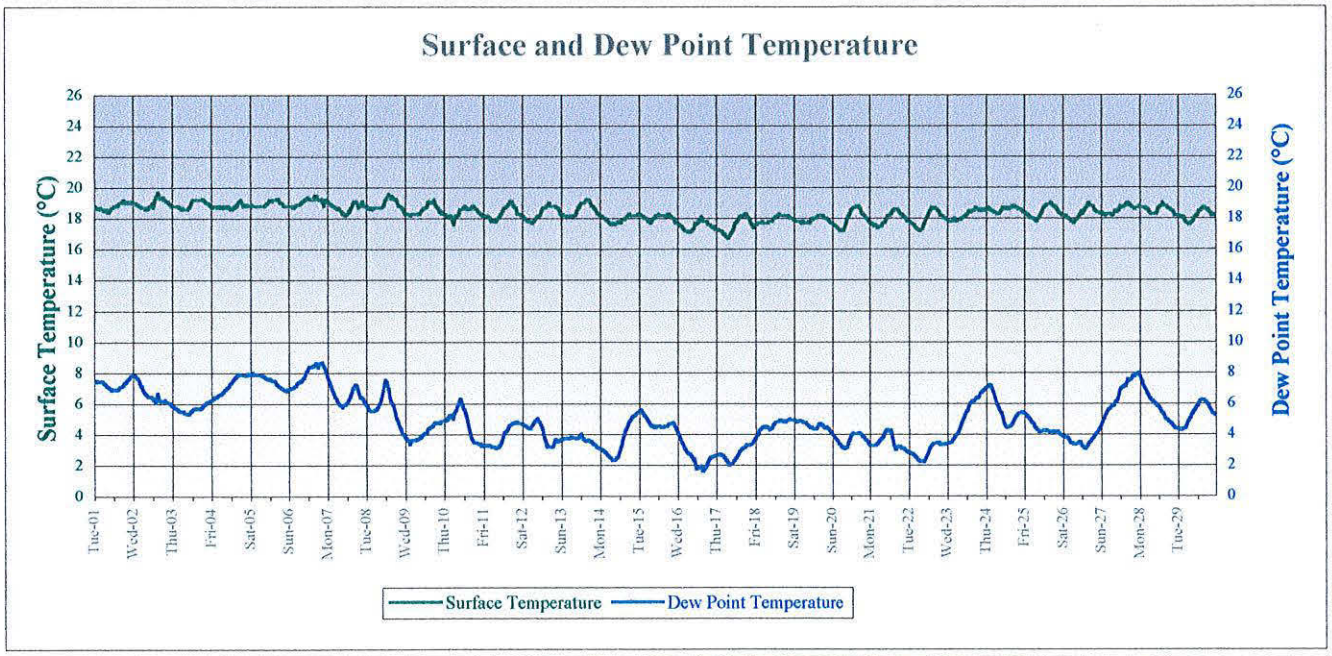


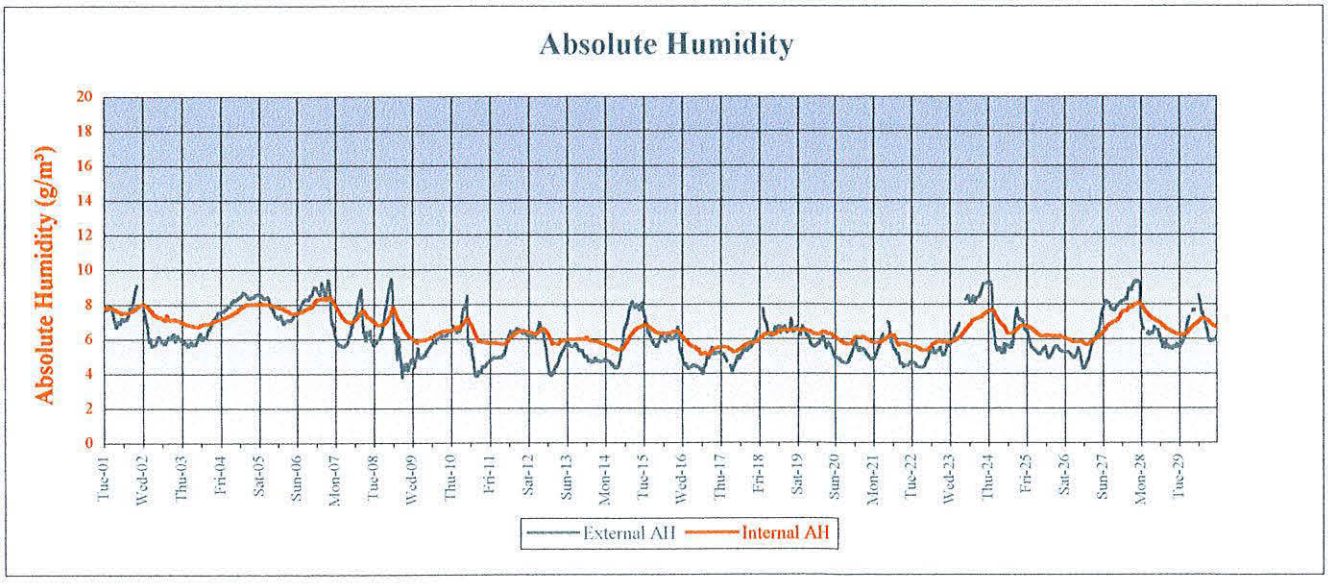
Peterborough Cathedral Nave Ceiling

February 2000

Probe 1: Bay 36 III lower side (shade)



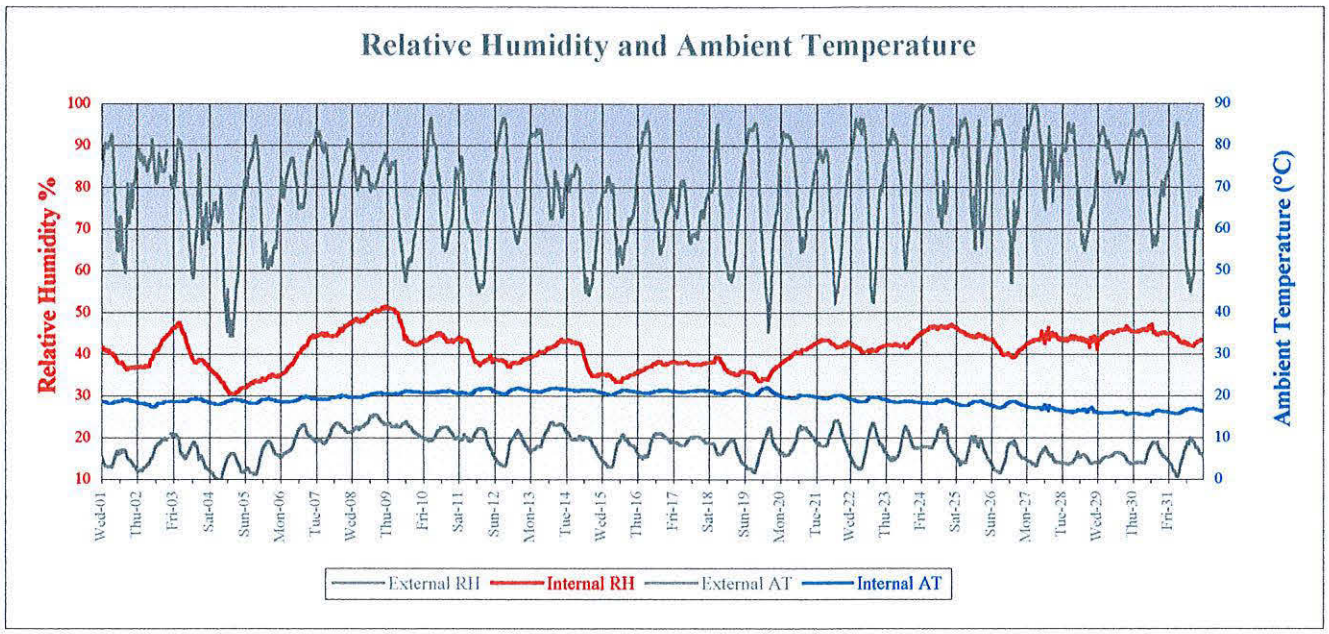


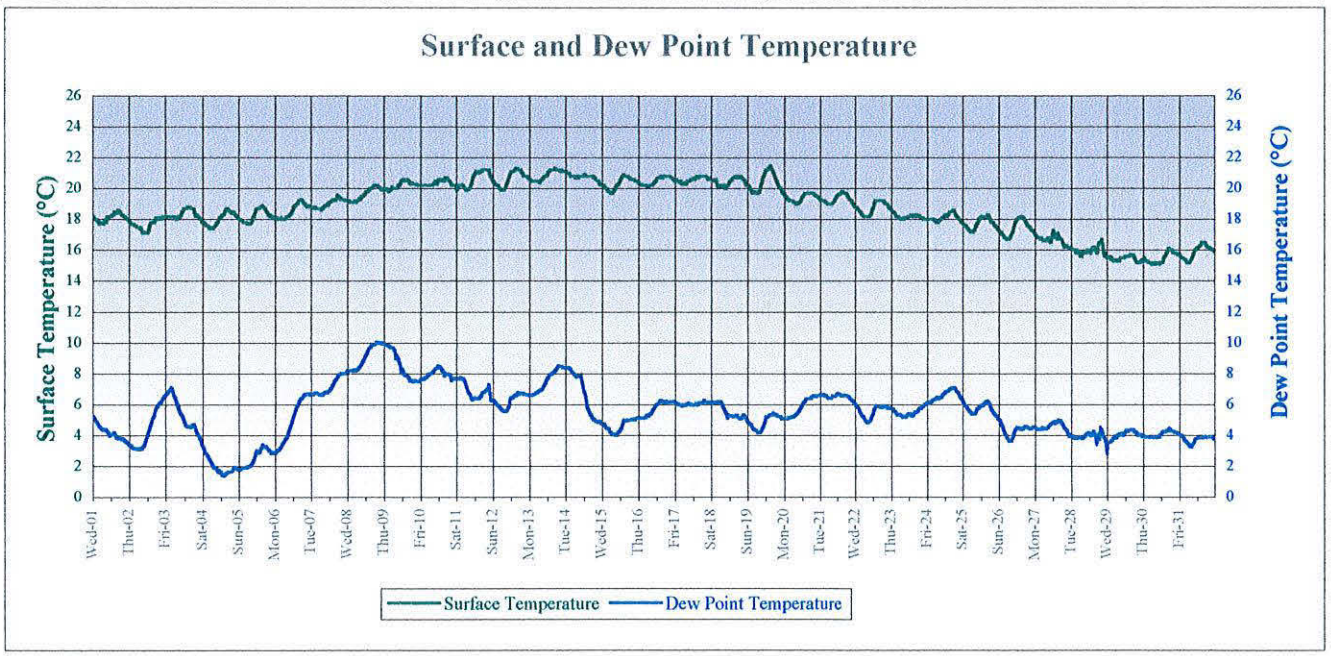


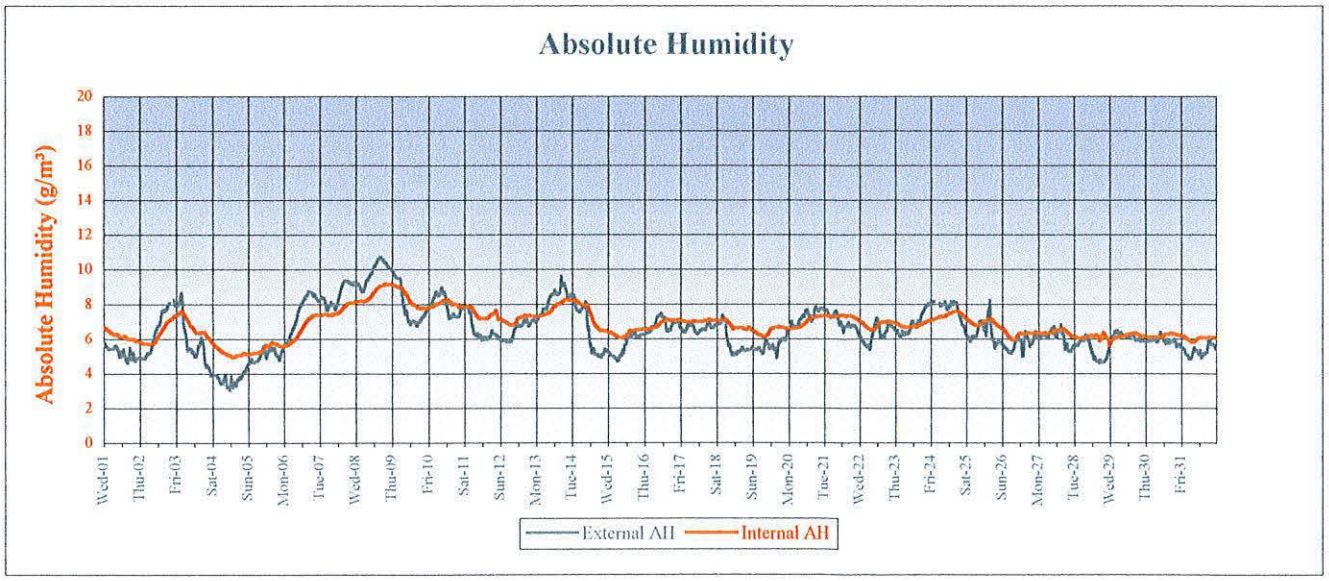
Peterborough Cathedral Nave Ceiling

March 2000

Probe 1: Bay 36 III lower side (shade)



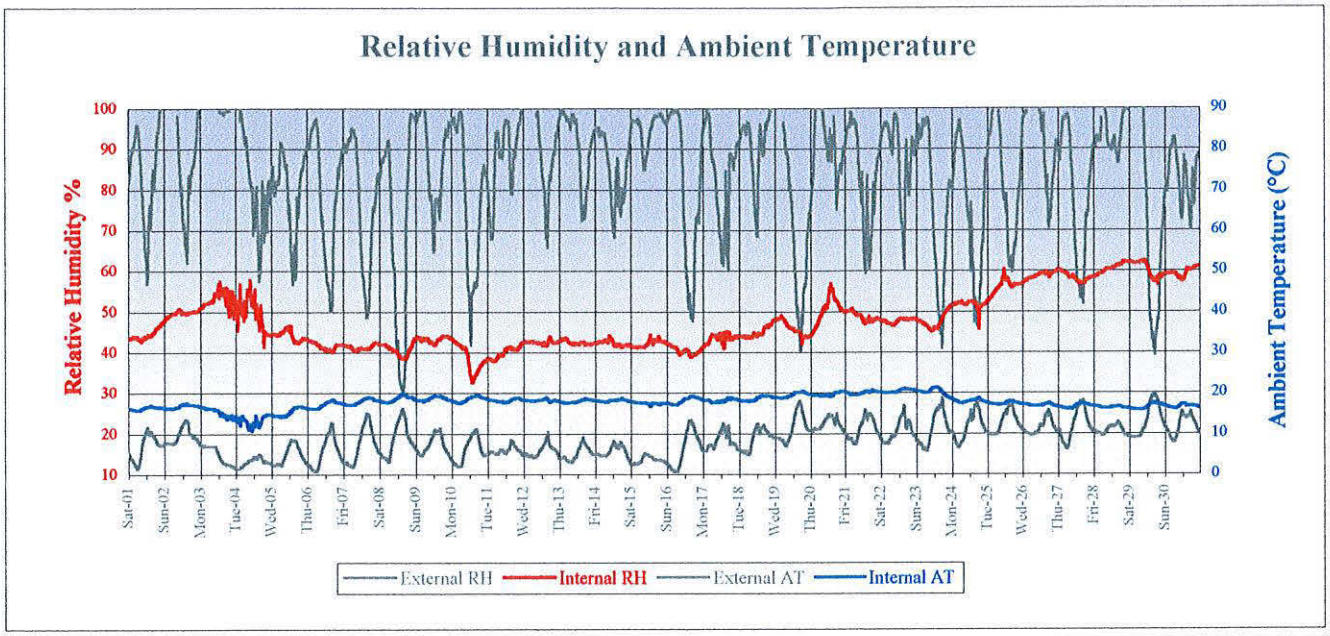


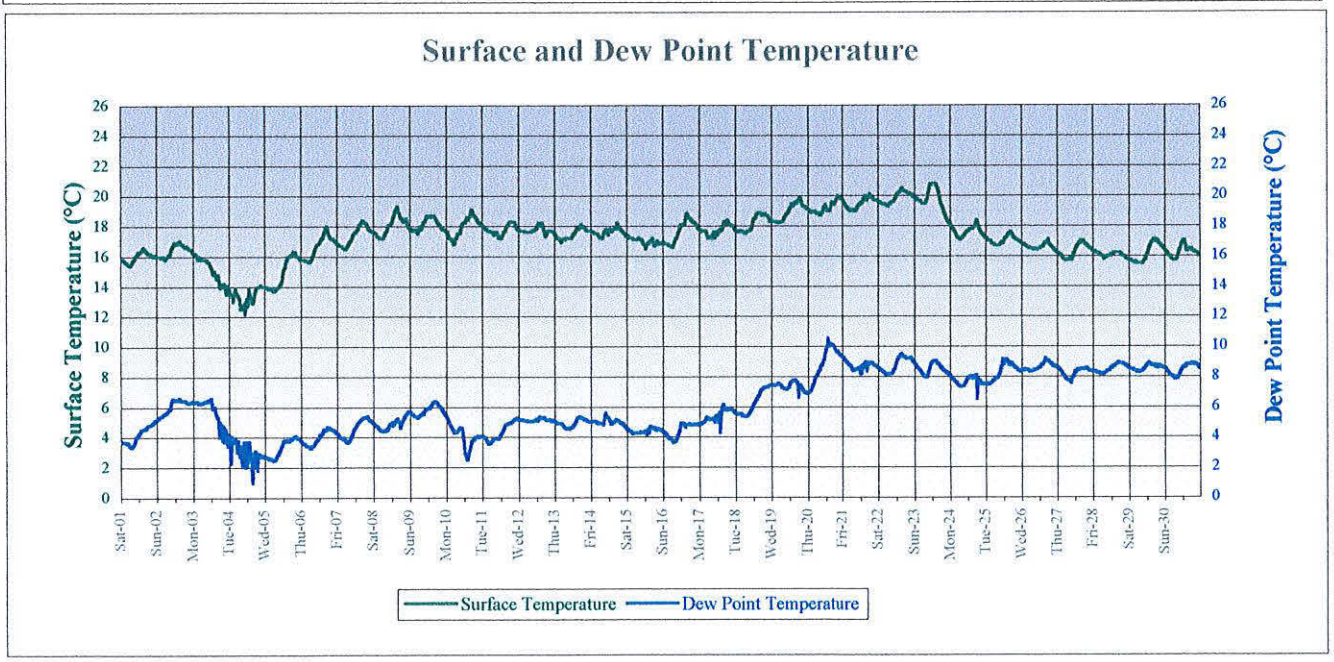


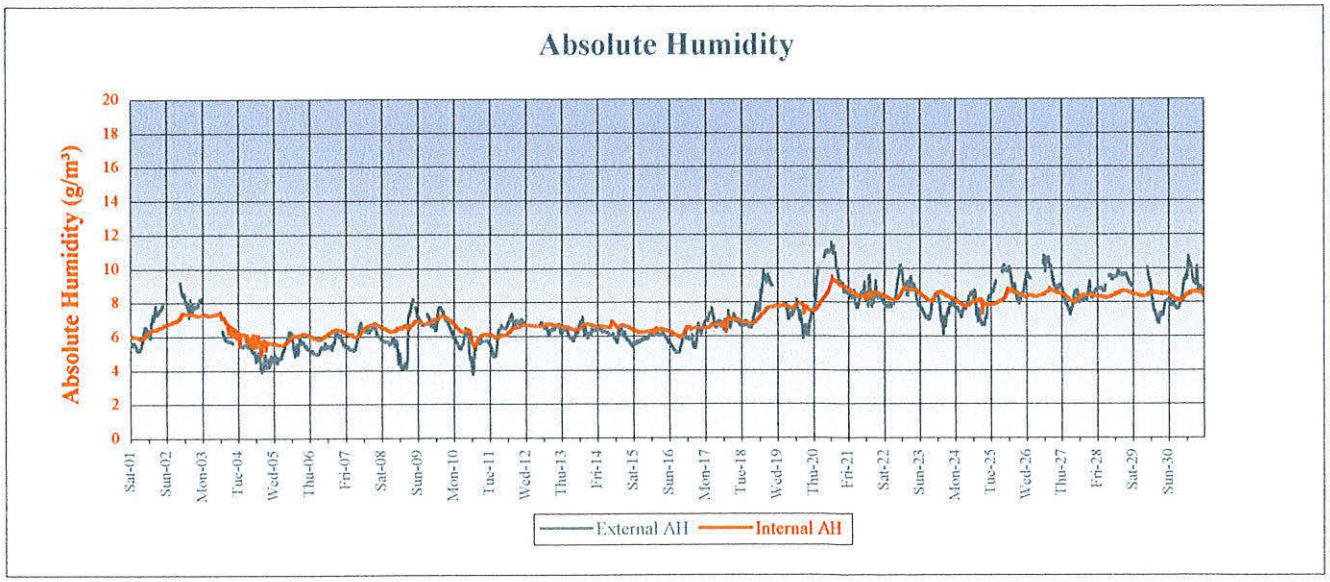
Peterborough Cathedral Nave Ceiling

April 2000

Probe 1: Bay 36 III lower side (shade)



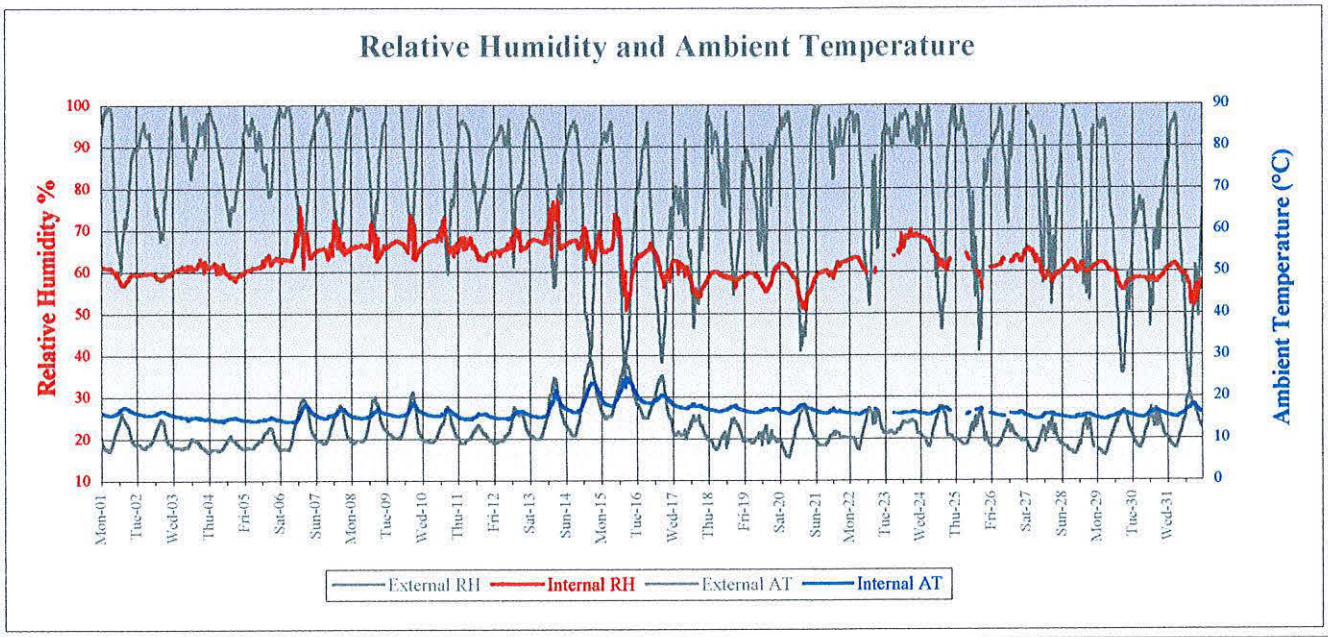


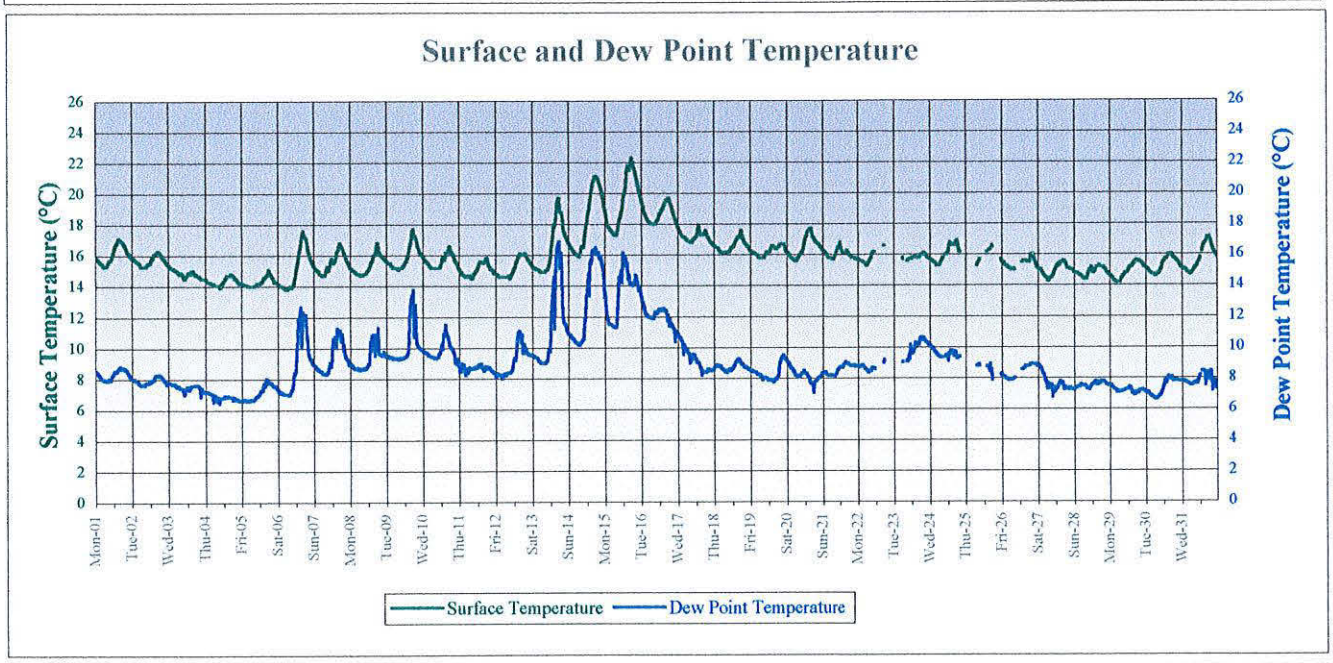


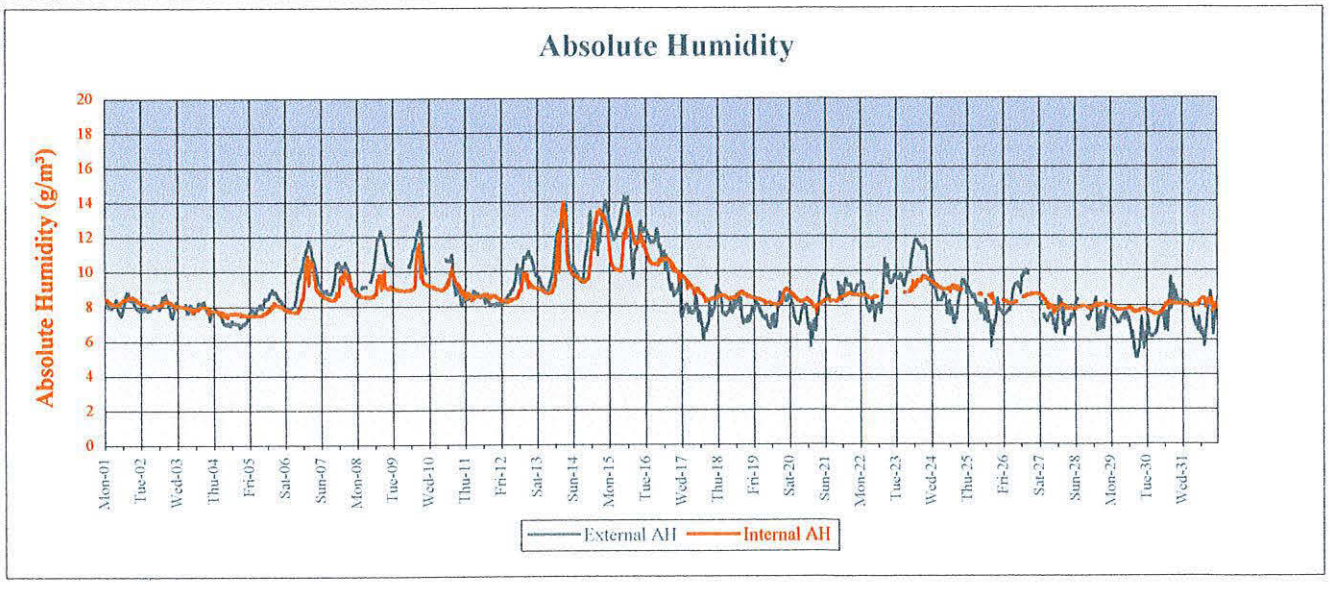
Peterborough Cathedral Nave Ceiling

May 2000

Probe 1: Bay 36 III lower side (shade)



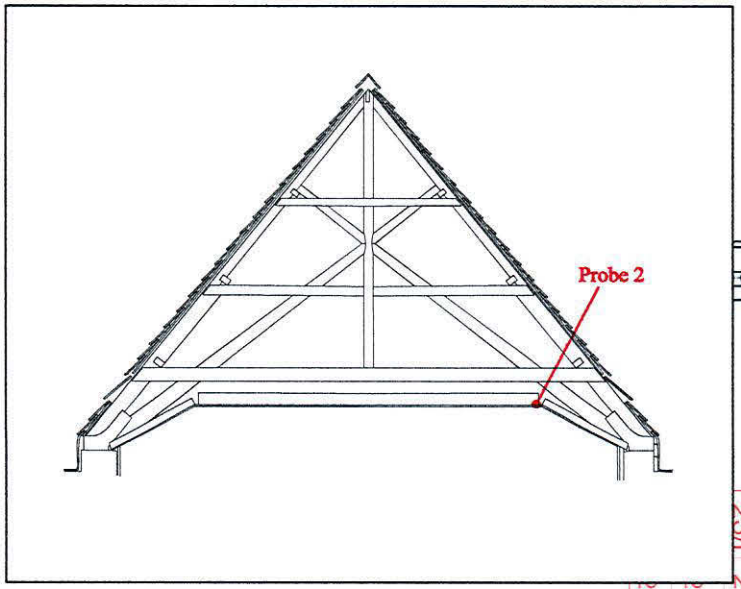


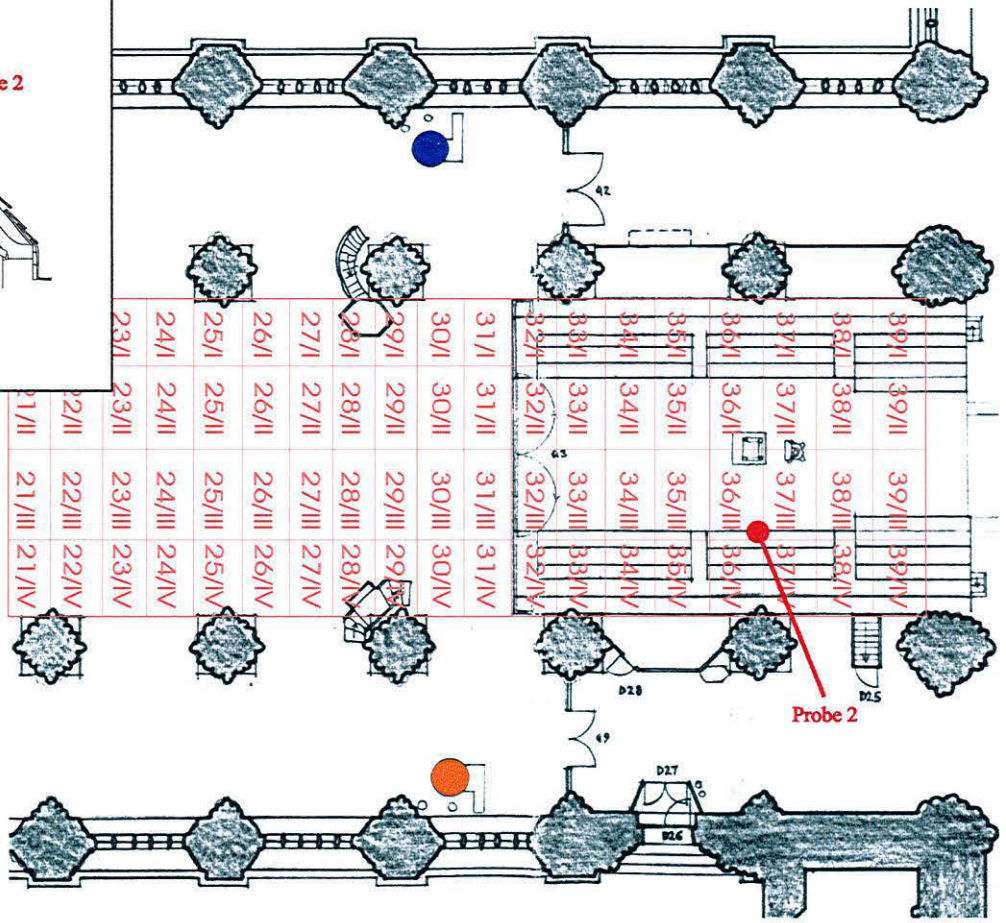


PROBE 2

BAY 36 III UPPER SIDE (SHADE)

DIAGRAM 4





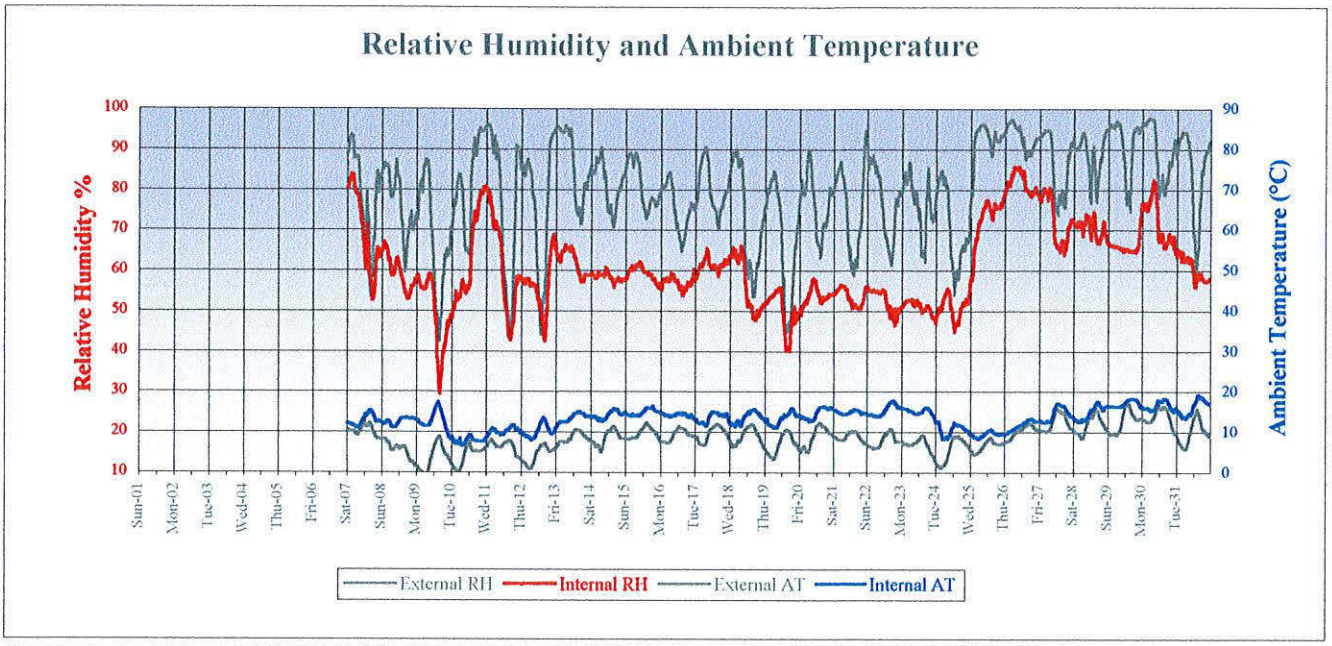
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove Occasional use stove Probe sites
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	

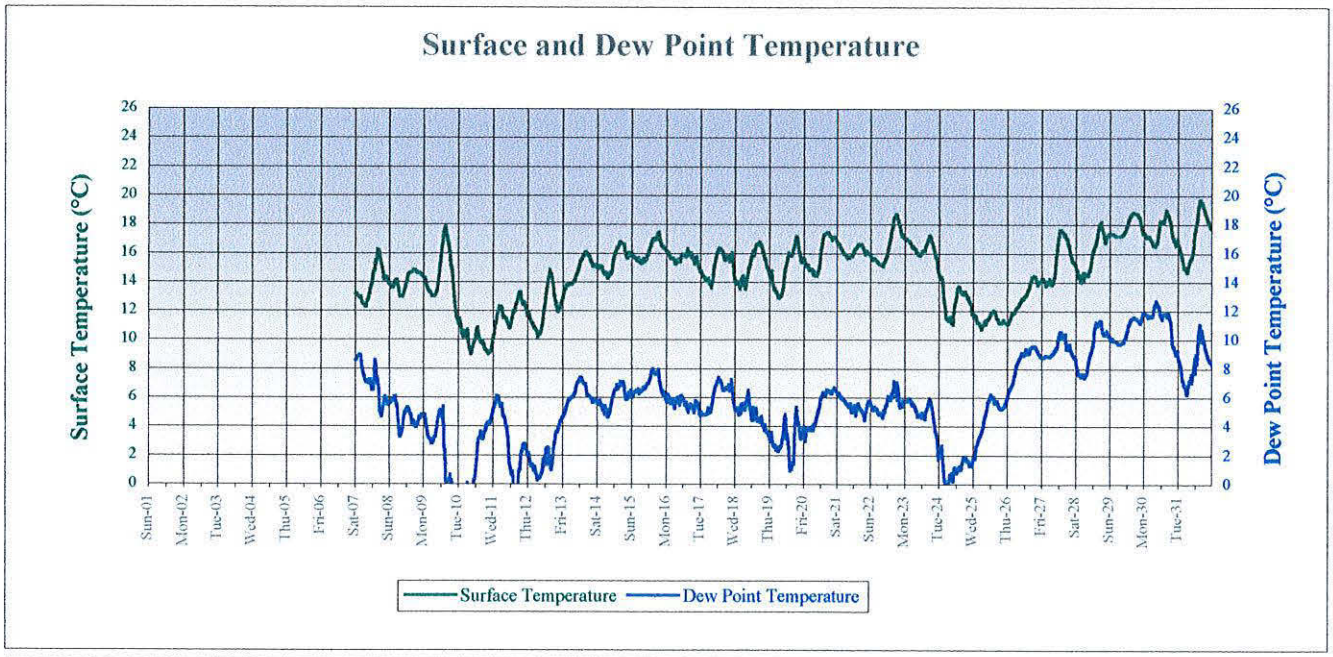
THIS PAGE IS INTENTIONALLY BLANK

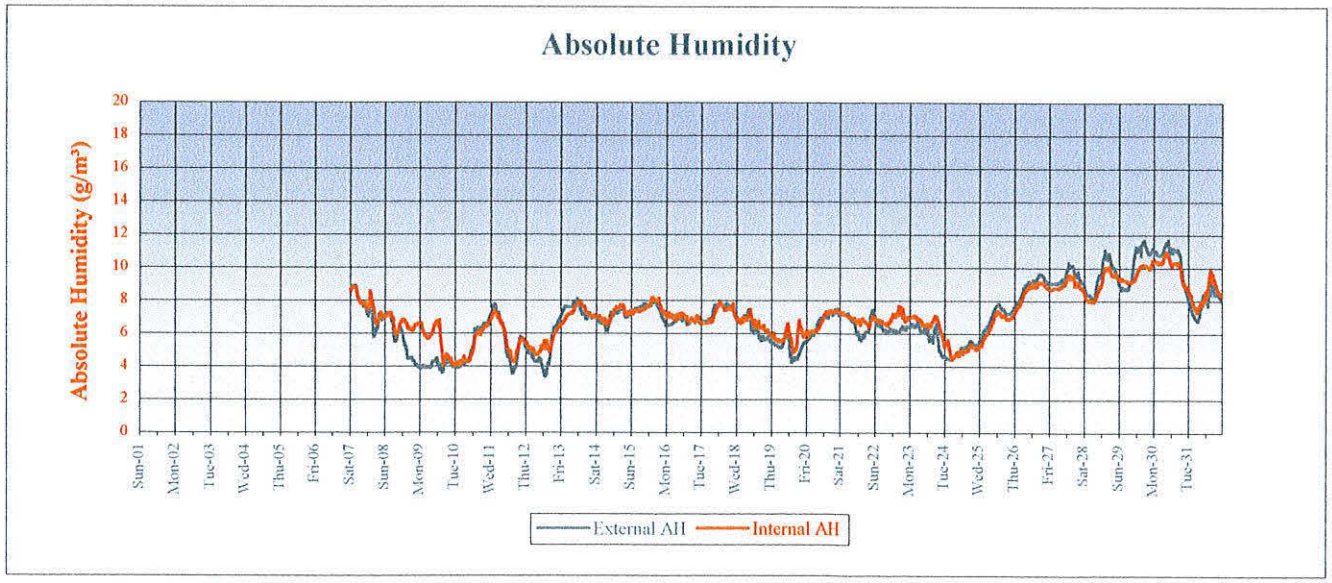
Peterborough Cathedral Nave Ceiling

March 1998

Probe 2: Bay 36 III upper side (shade)



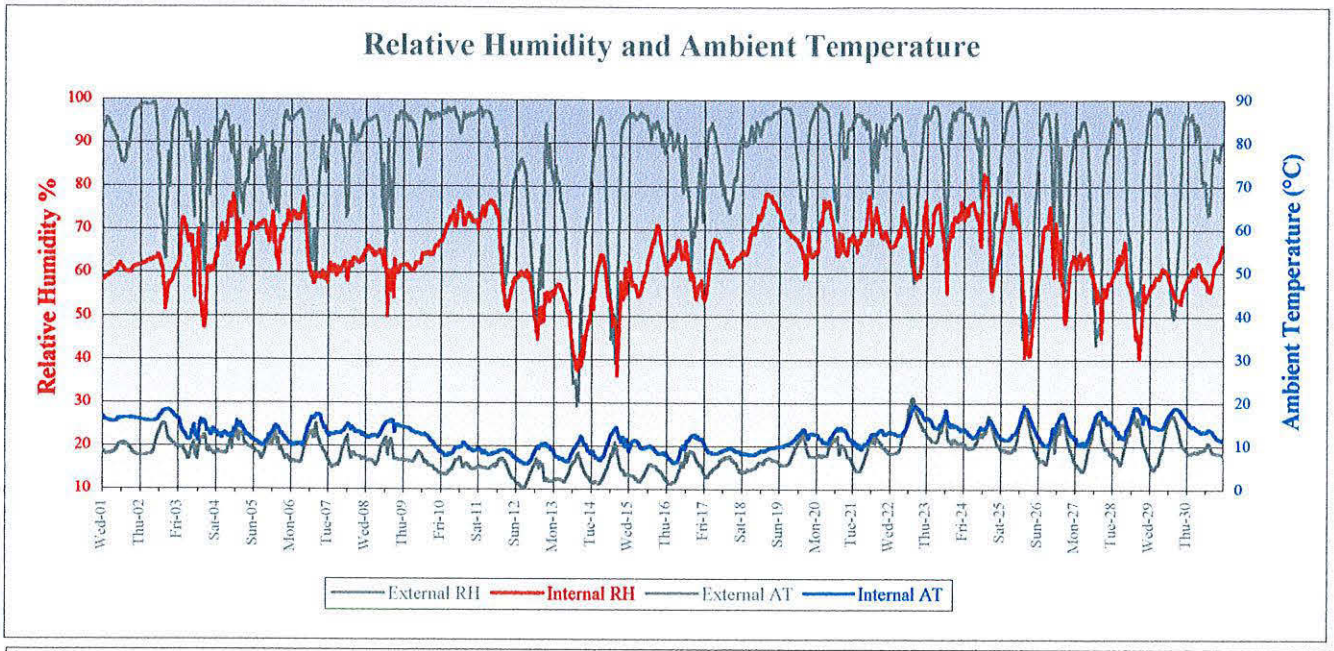


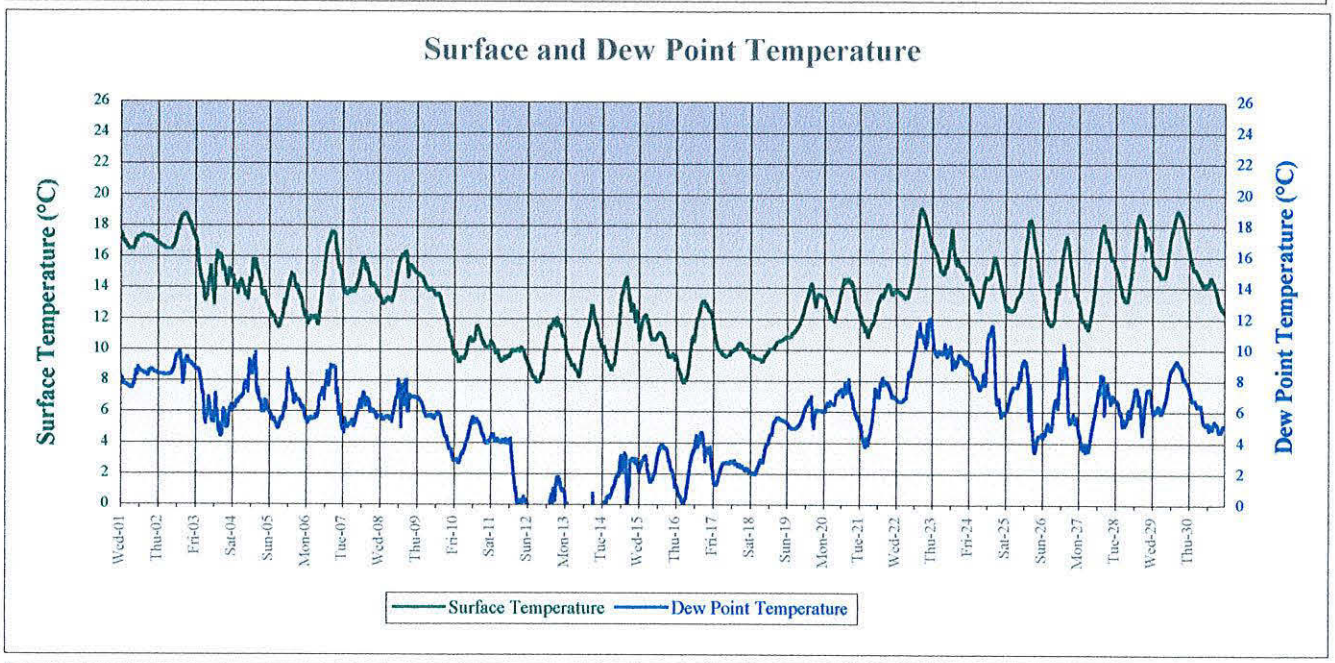


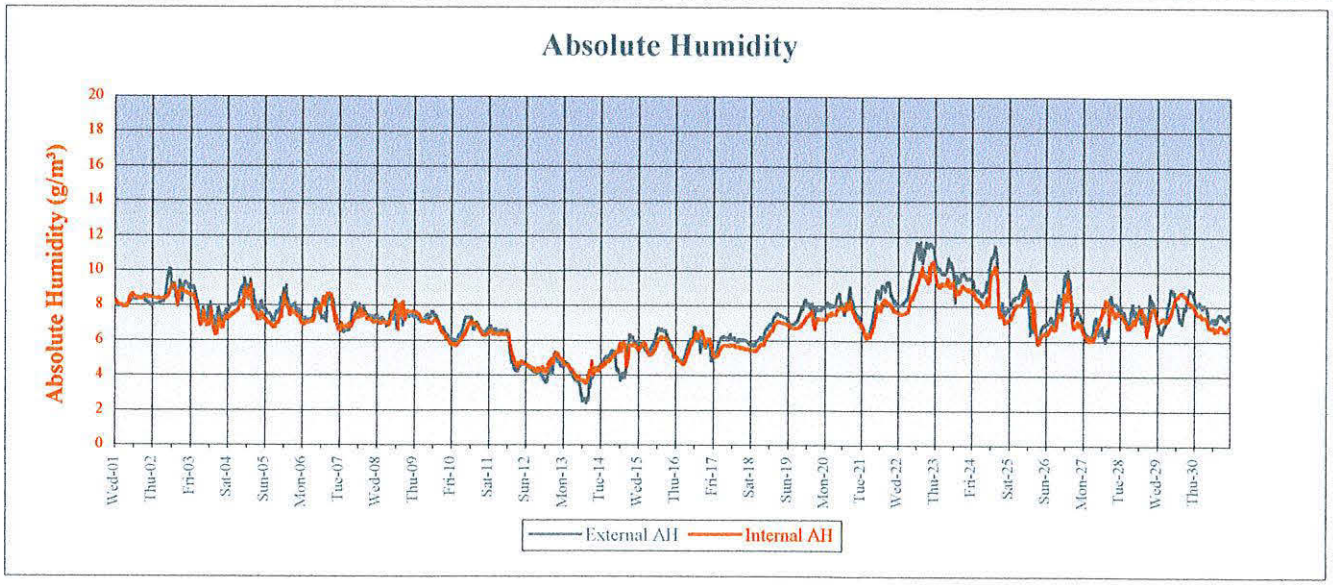
Peterborough Cathedral Nave Ceiling

April 1998

Probe 2: Bay 36 III upper side (shade)



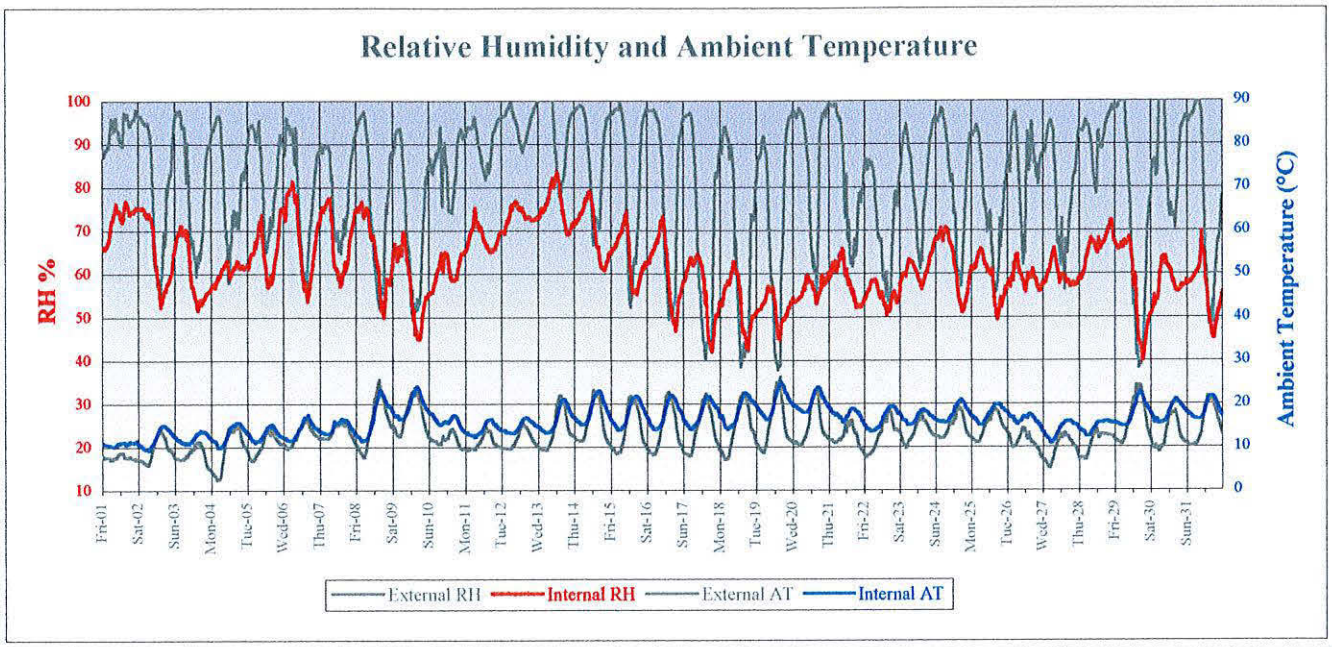


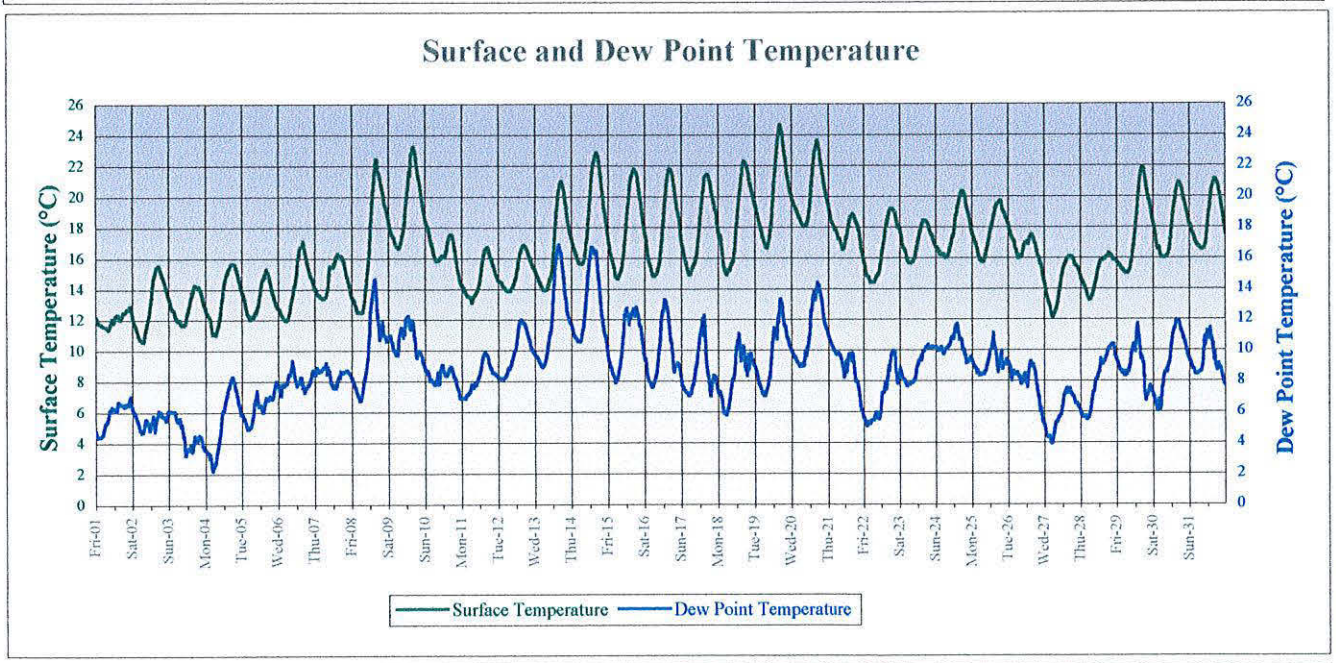


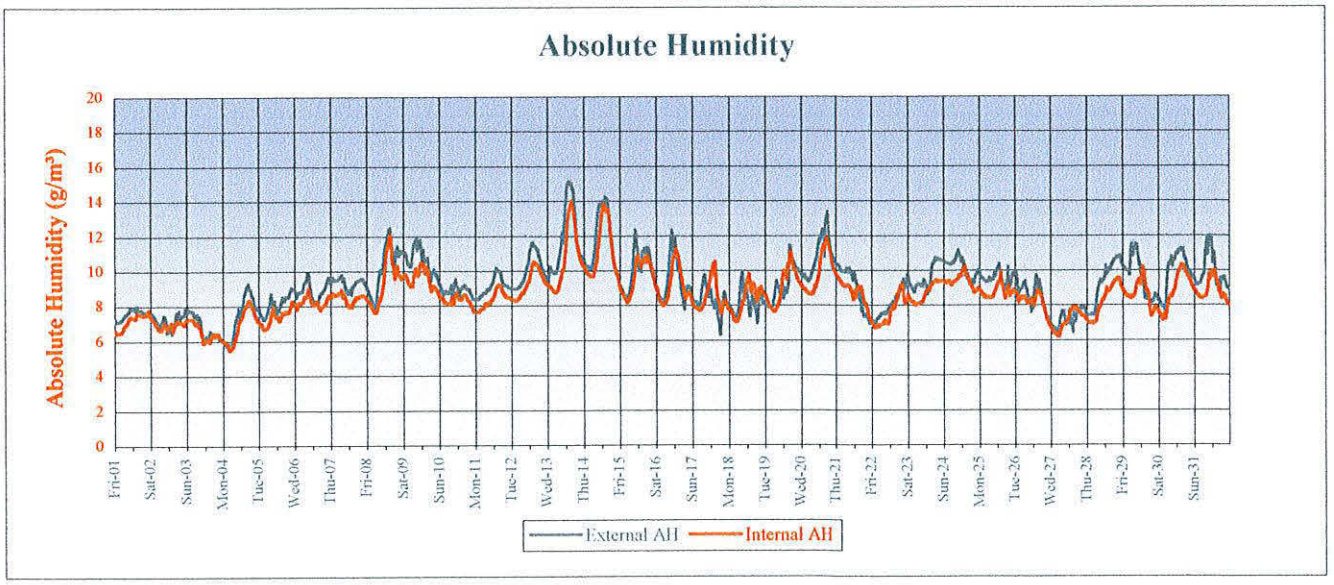
Peterborough Cathedral Nave Ceiling

May 1998

Probe 2: Bay 36 III upper side (shade)



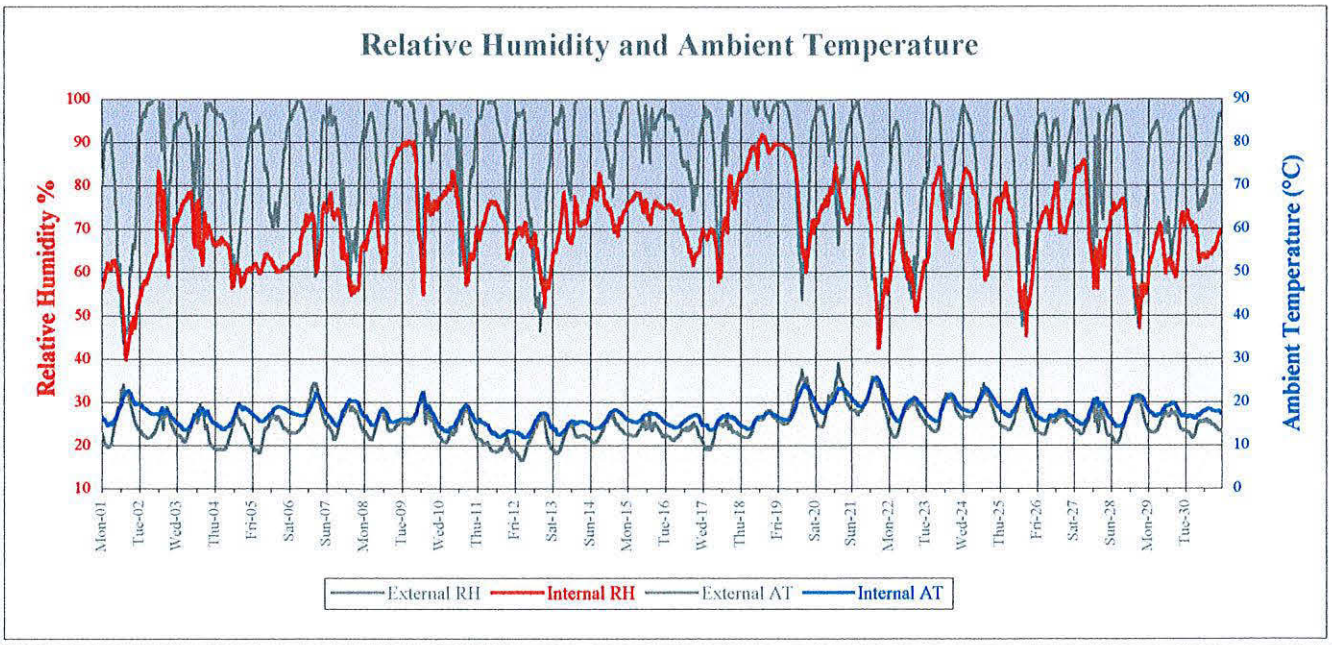


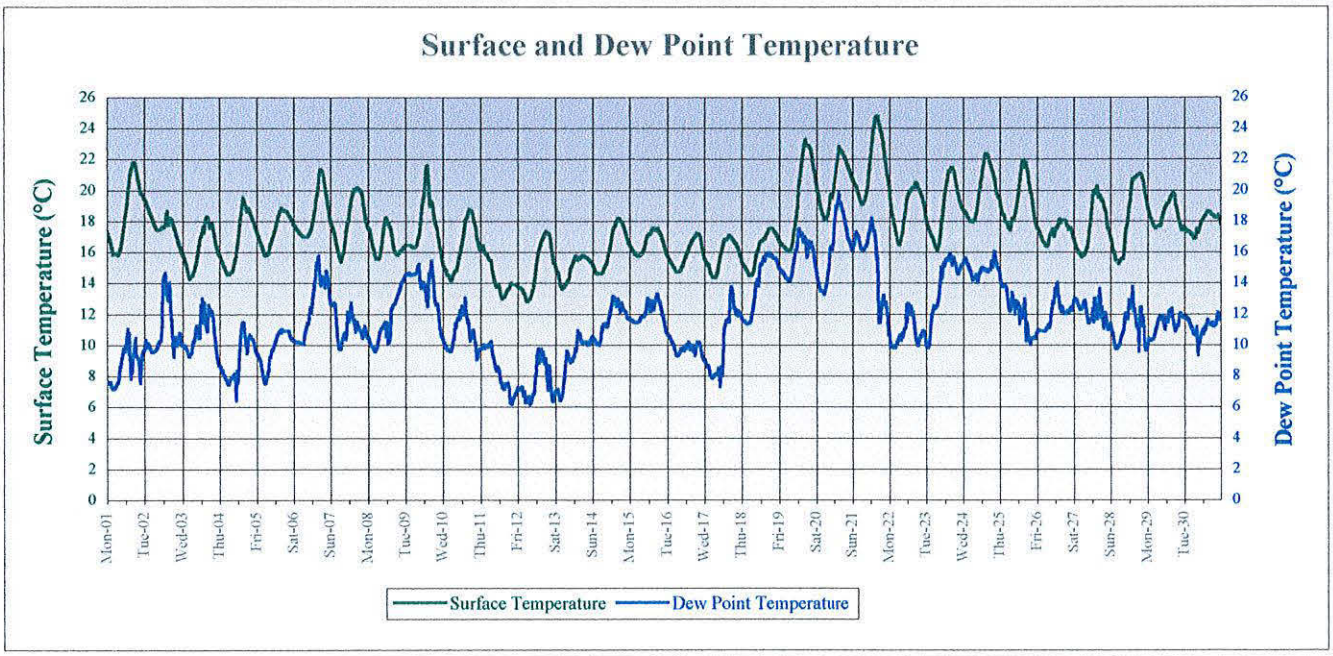


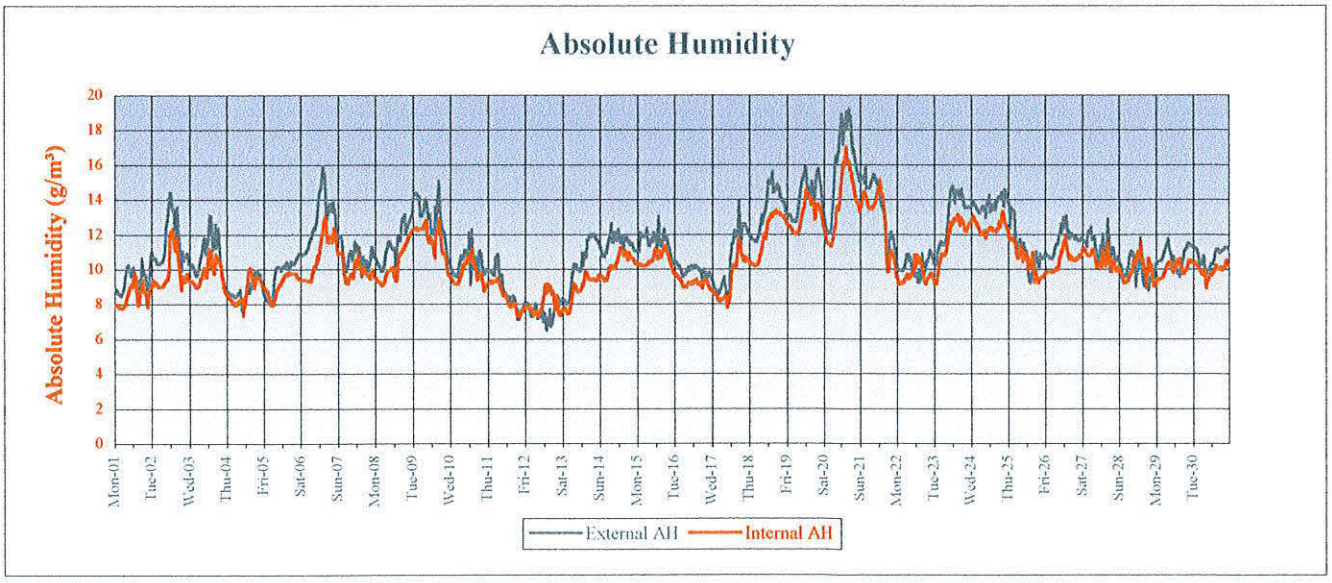
Peterborough Cathedral Nave Ceiling

June 1998

Probe 2: Bay 36 III upper side (shade)



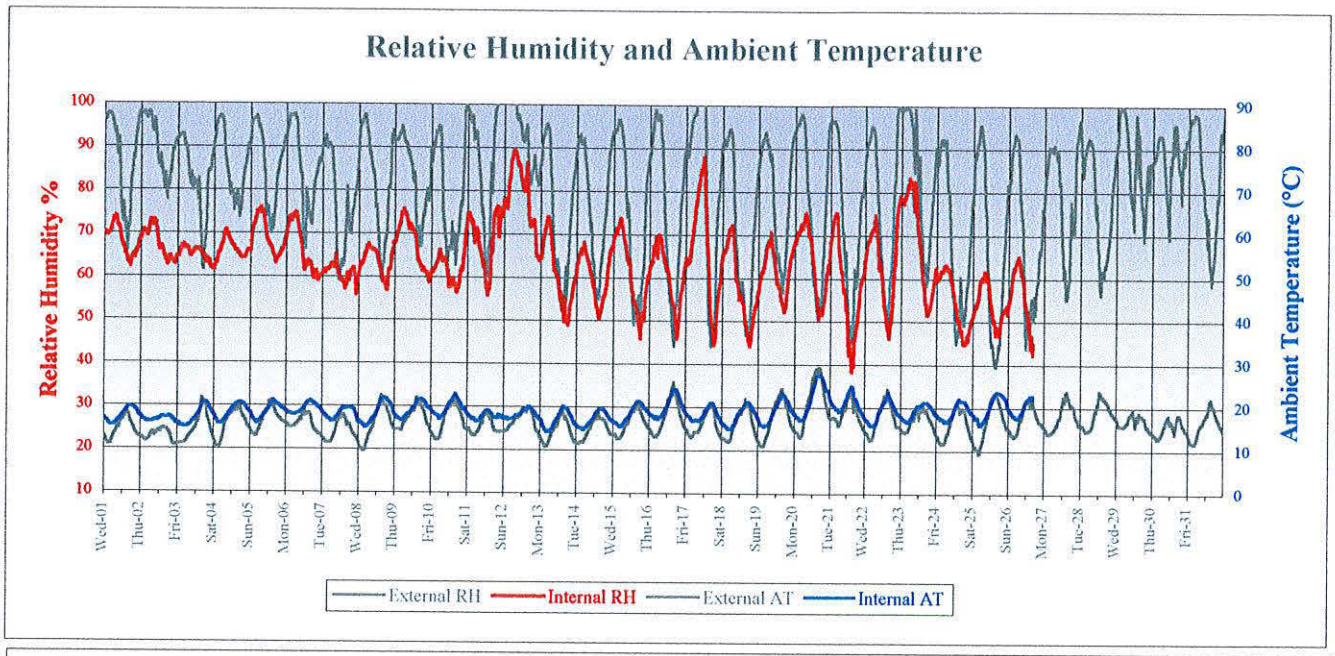


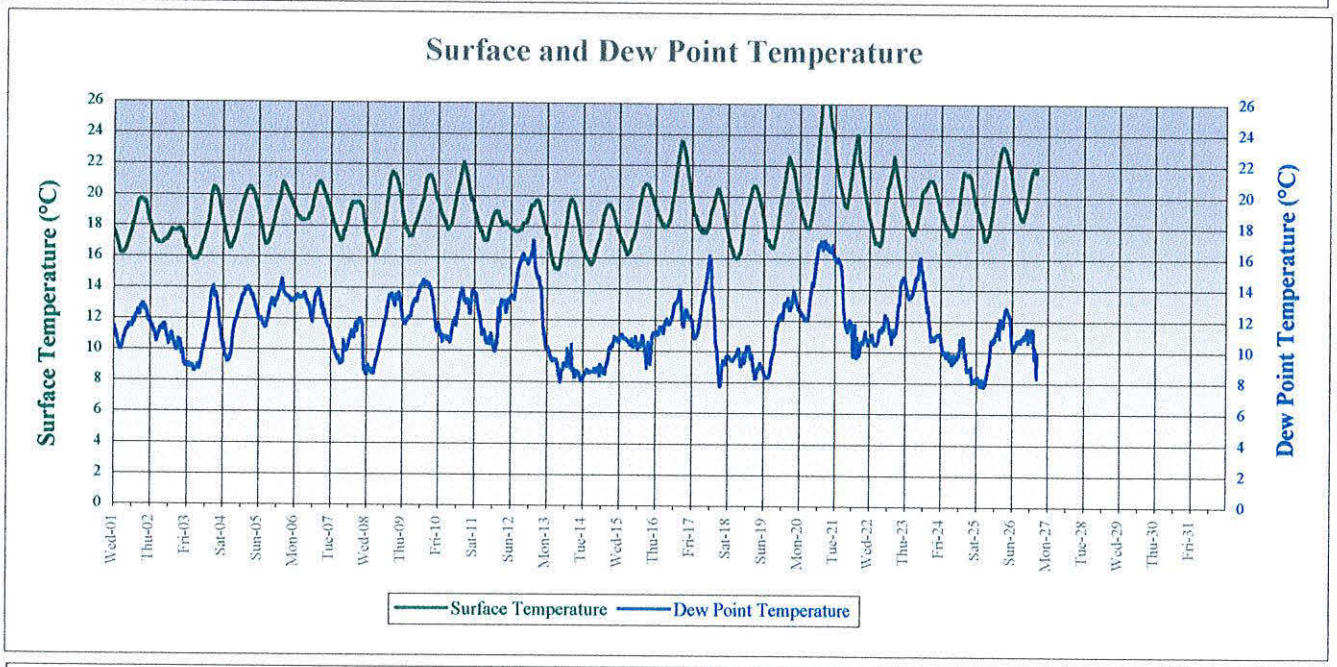


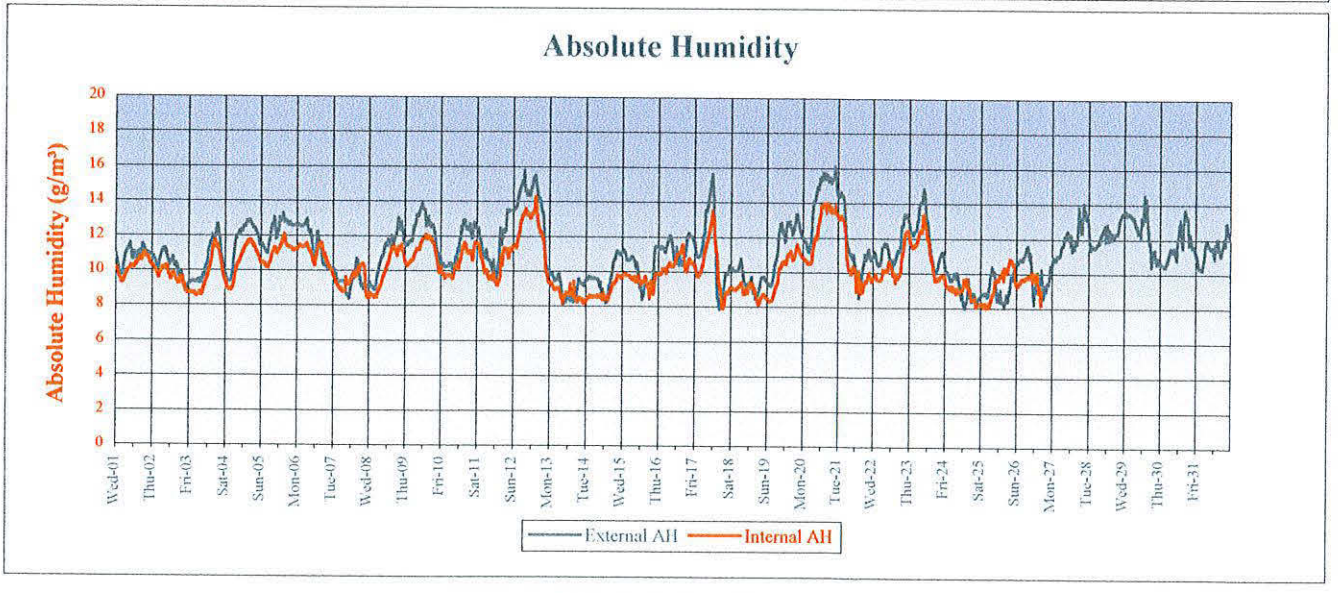
Peterborough Cathedral Nave Ceiling

July 1998

Probe 2: Bay 36 III upper side (shade)



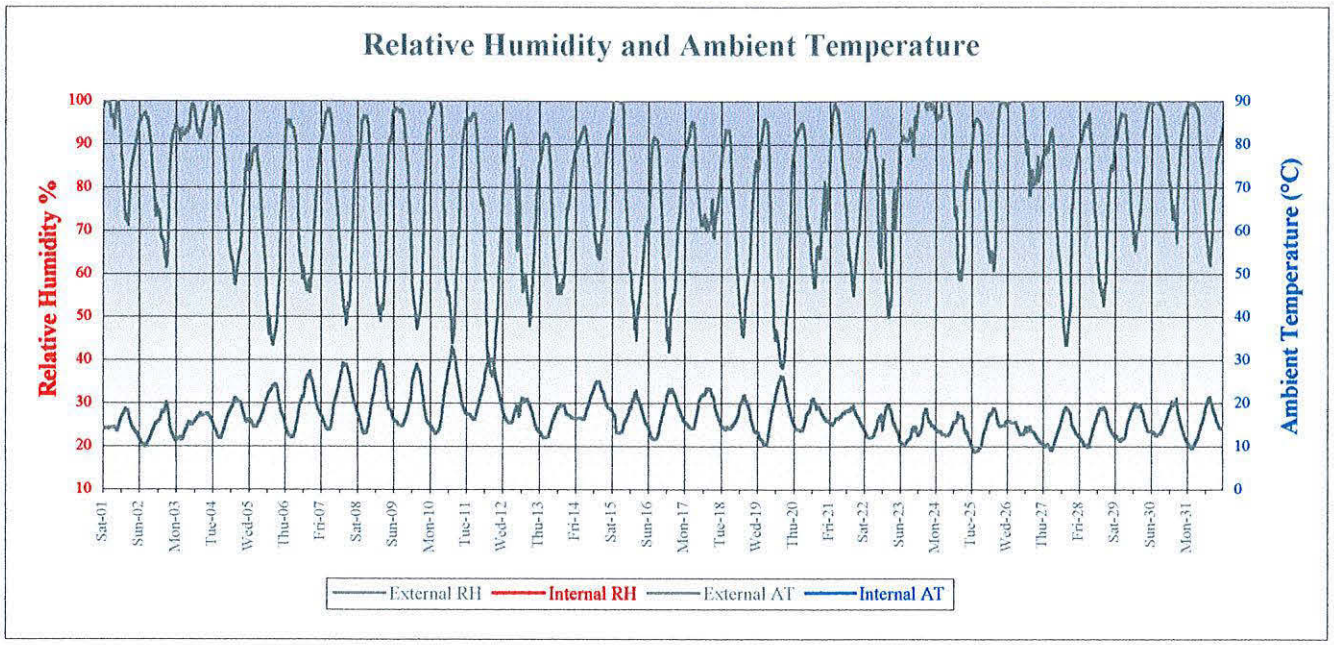


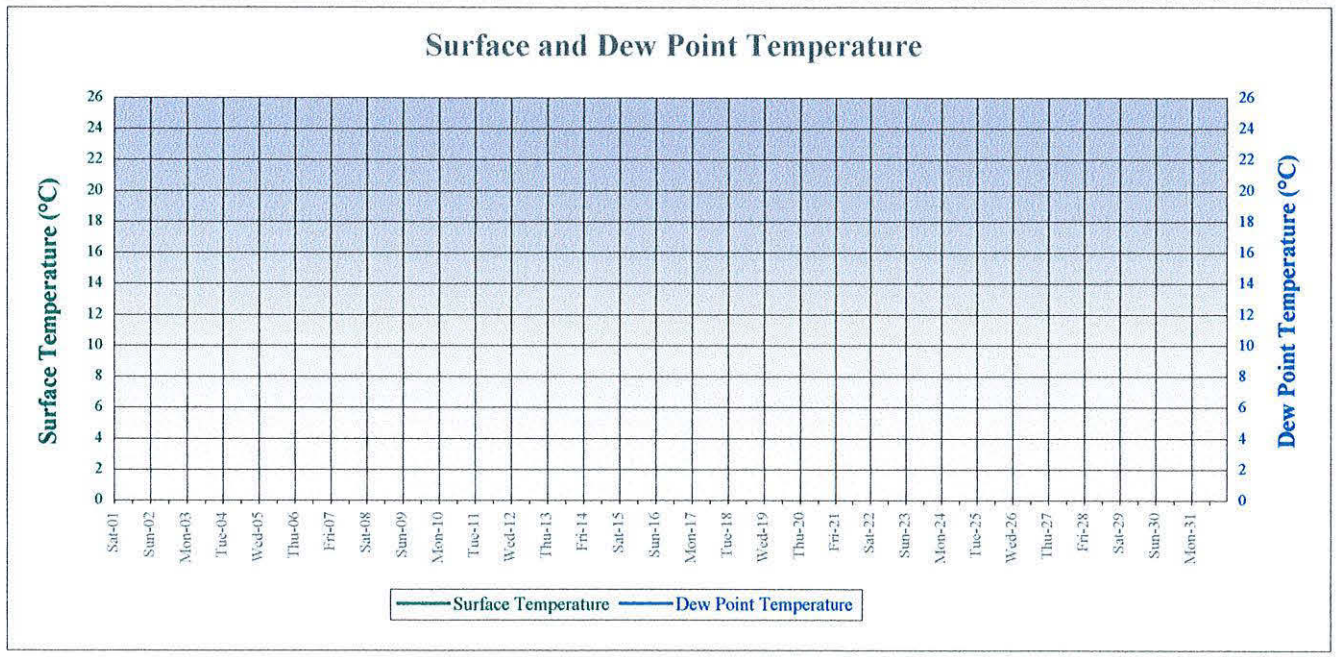


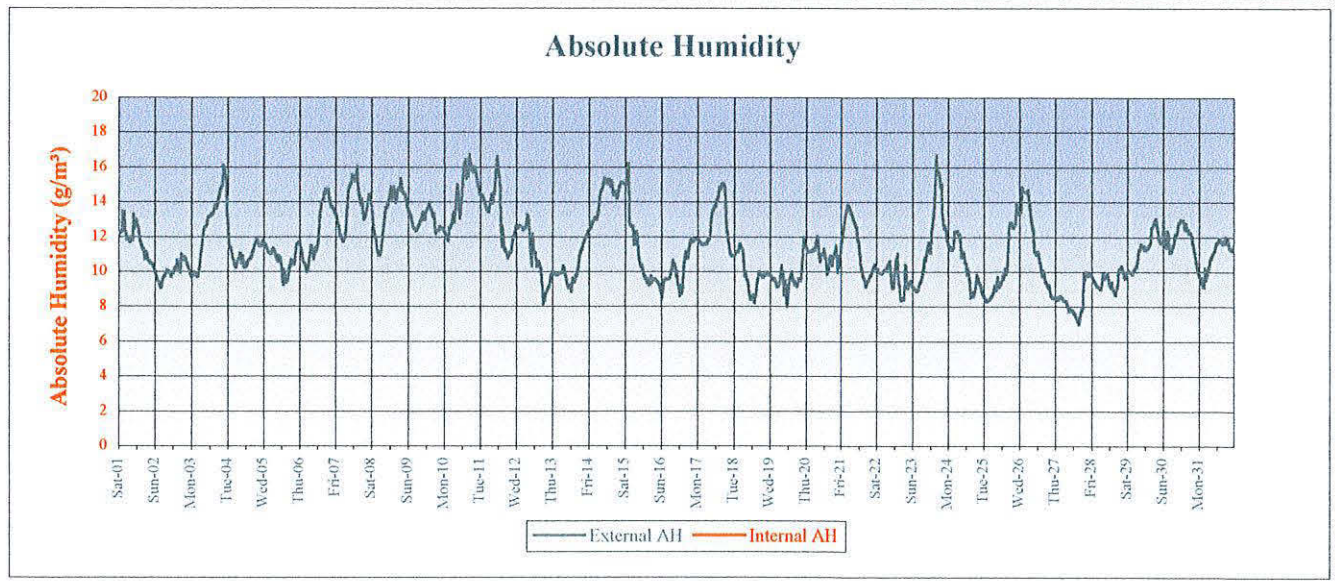
Peterborough Cathedral Nave Ceiling

August 1998

Probe 2: Bay 36 III upper side (shade)



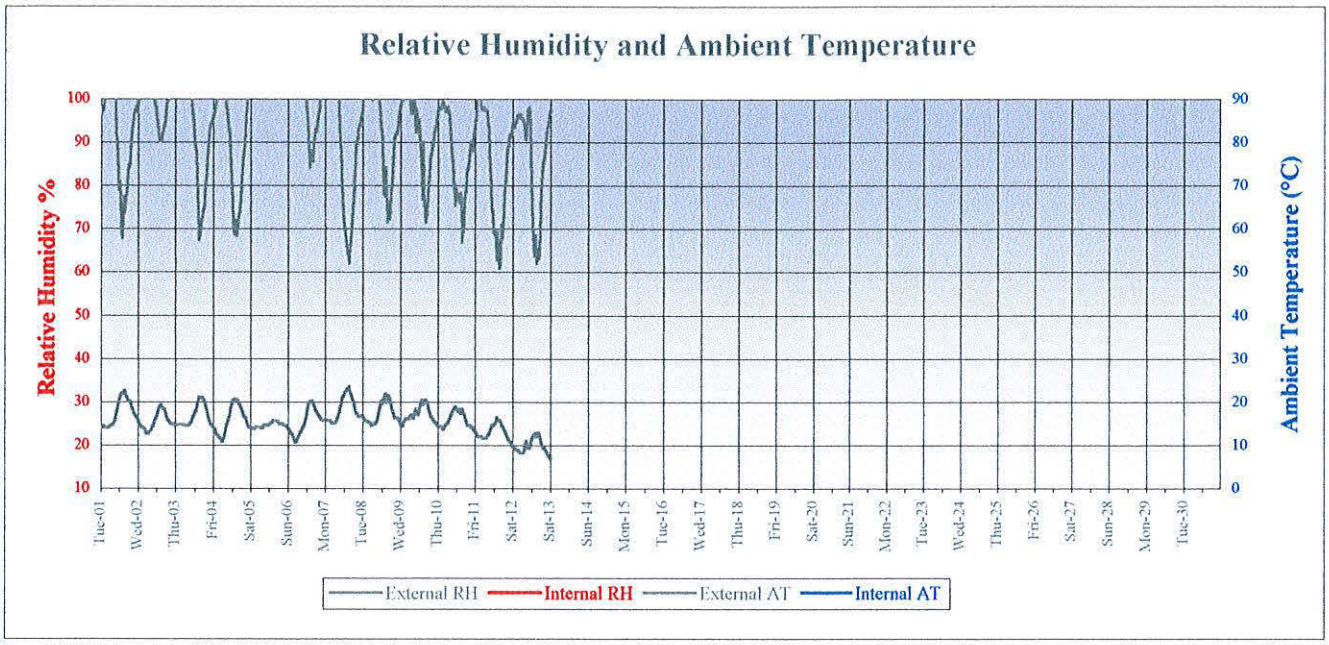


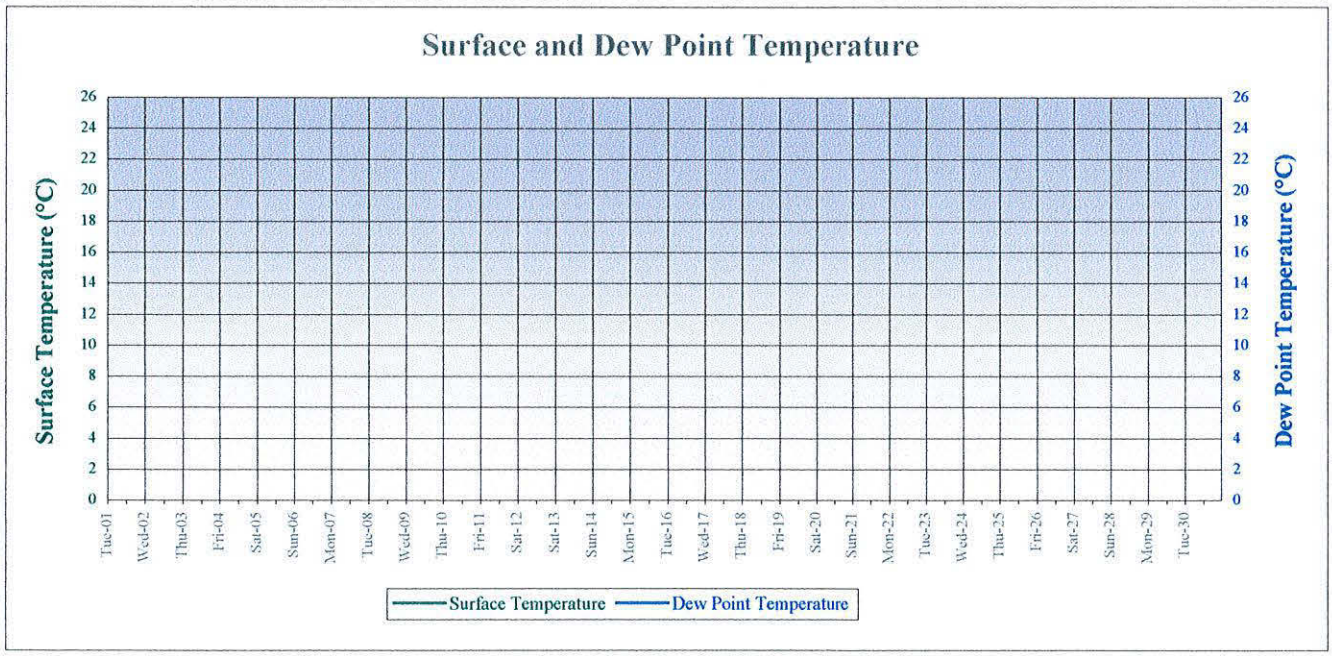


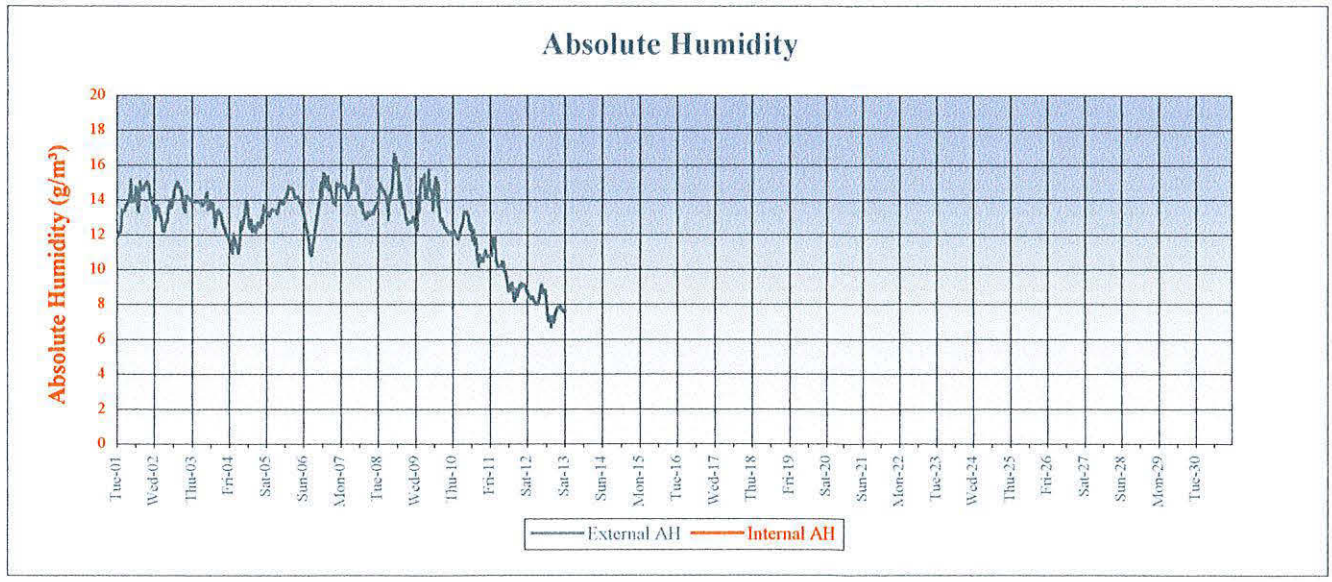
Peterborough Cathedral Nave Ceiling

September 1998

Probe 2: Bay 36 III upper side (shade)



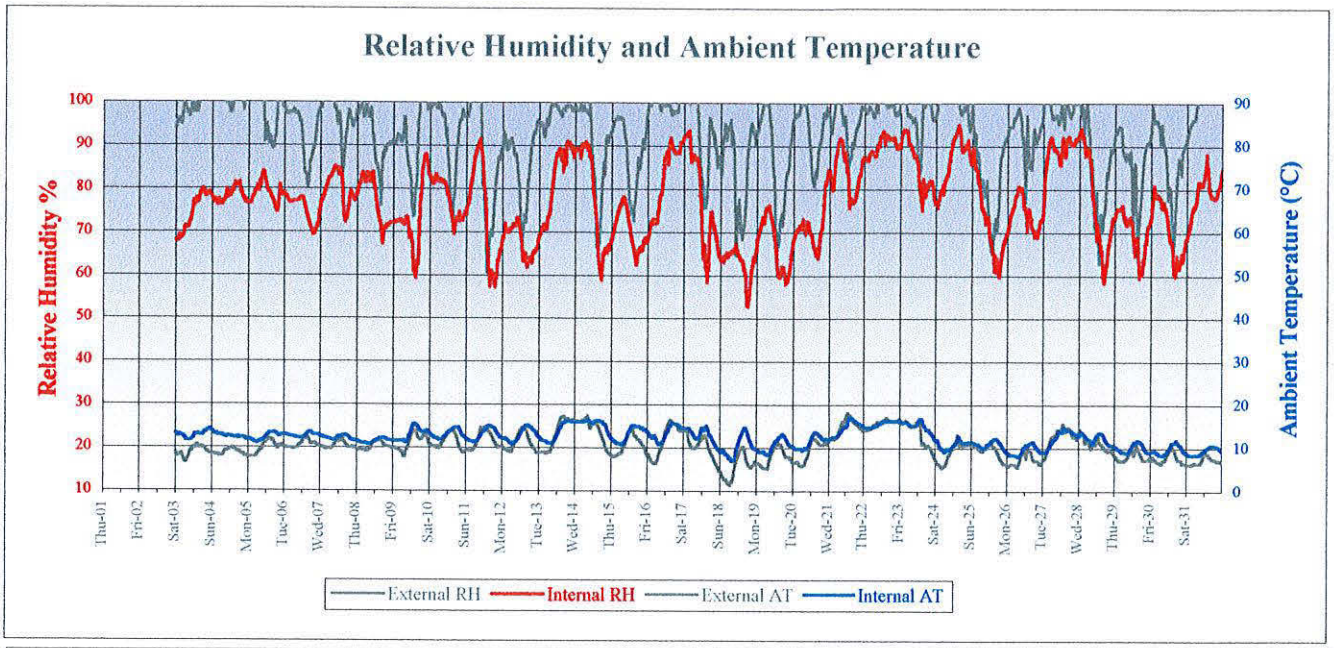


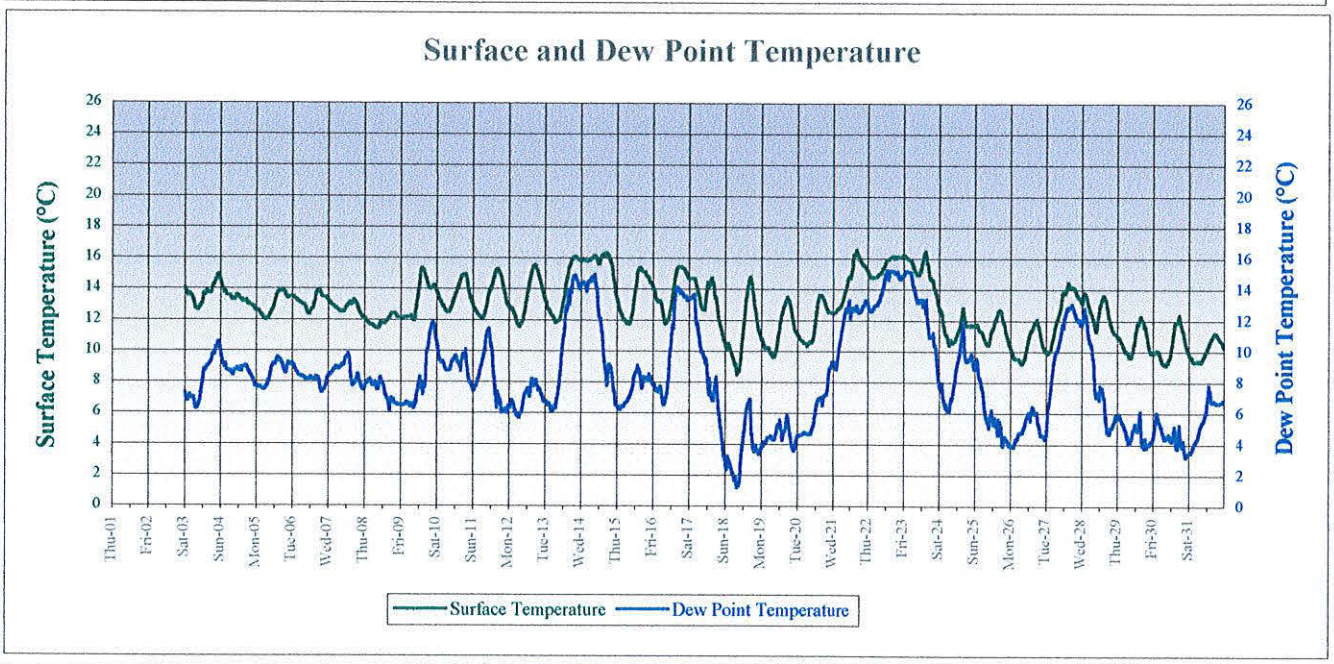


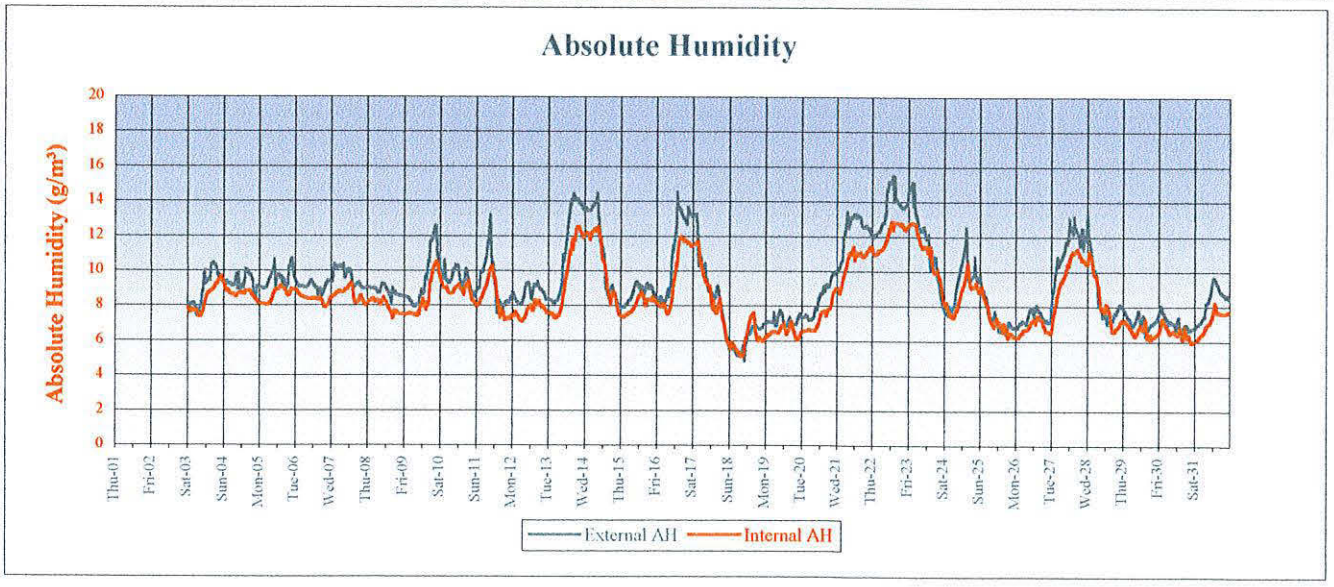
Peterborough Cathedral Nave Ceiling

October 1998

Probe 2: Bay 36 III upper side (shade)



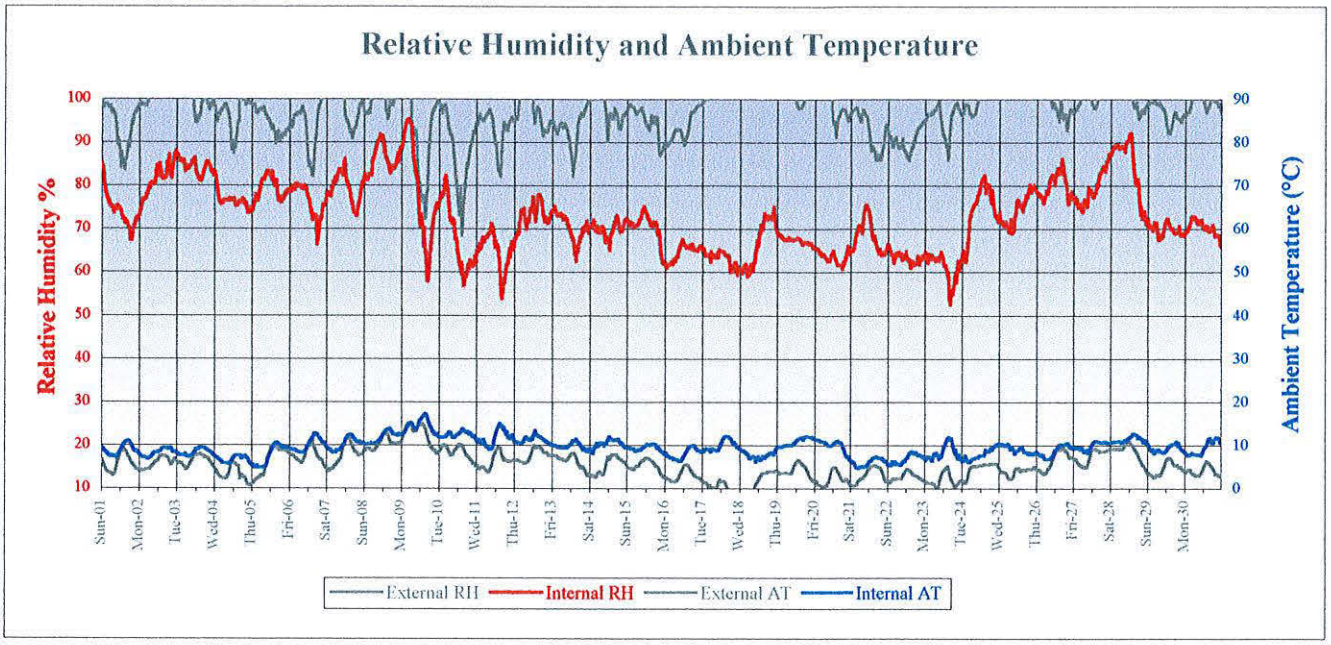


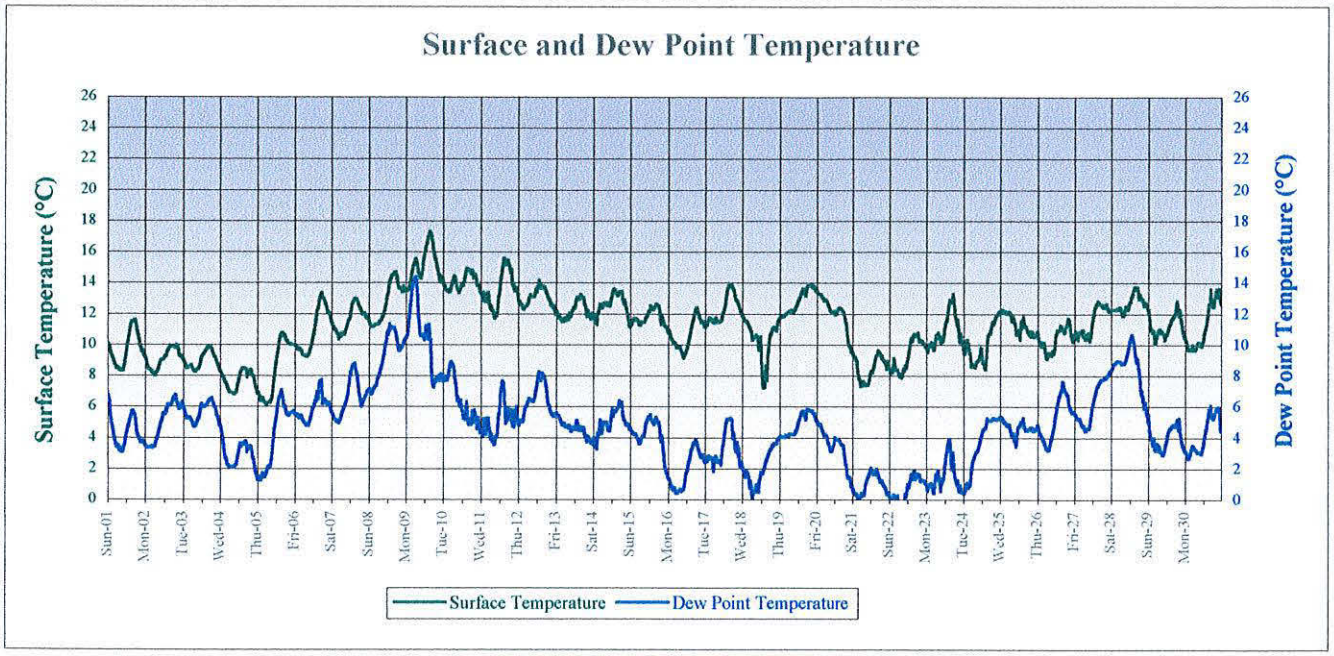


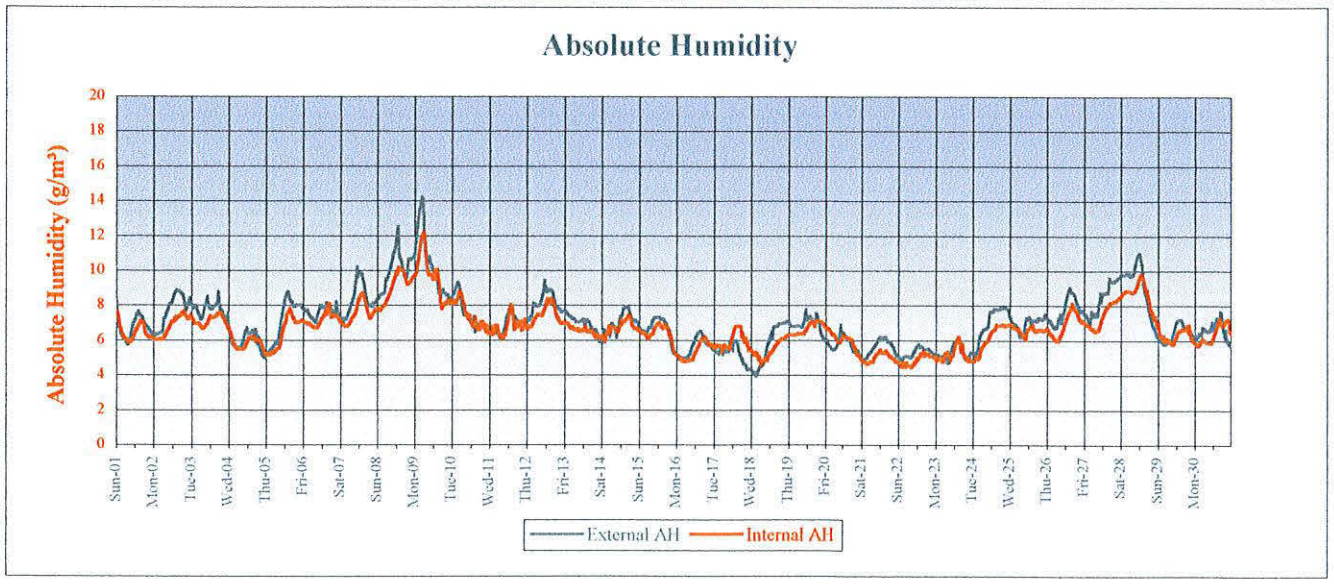
Peterborough Cathedral Nave Ceiling

November 1998

Probe 2: Bay 36 III upper side (shade)



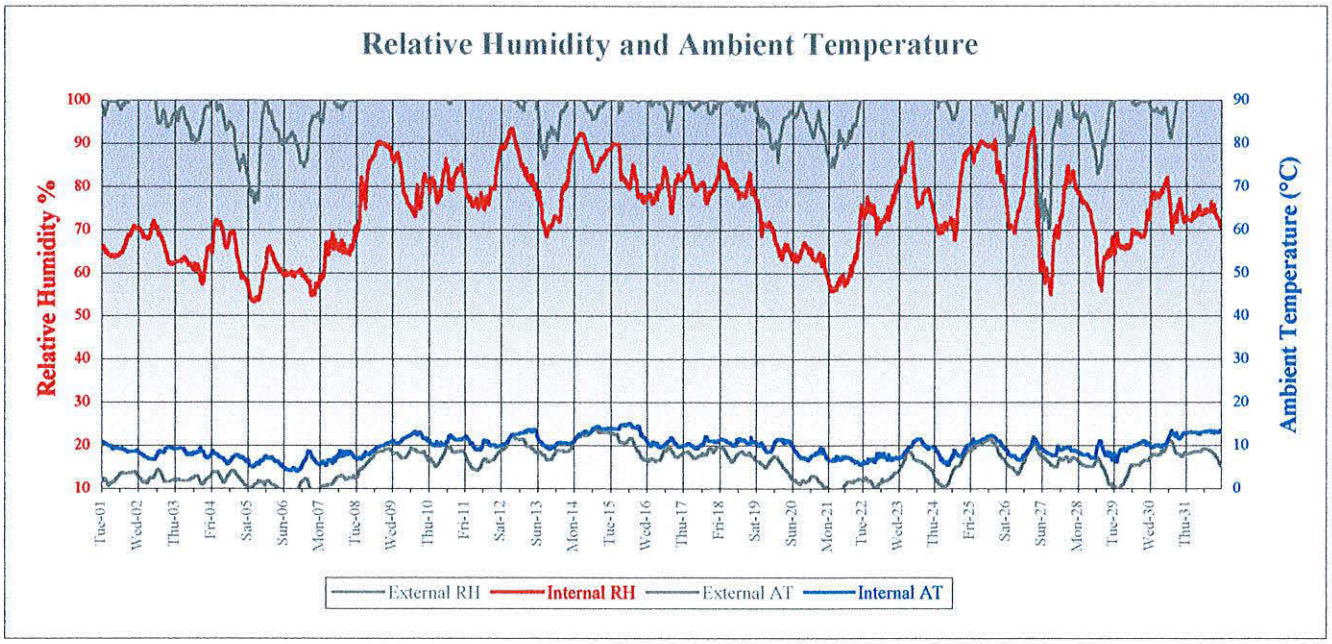


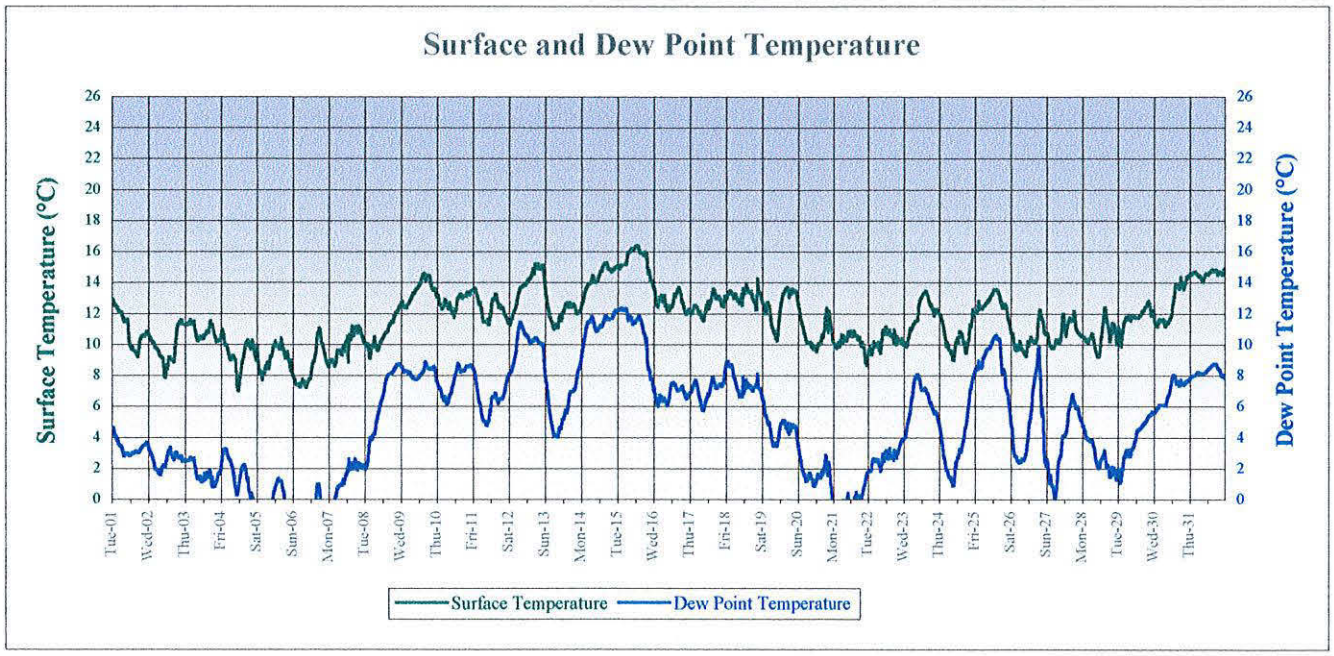


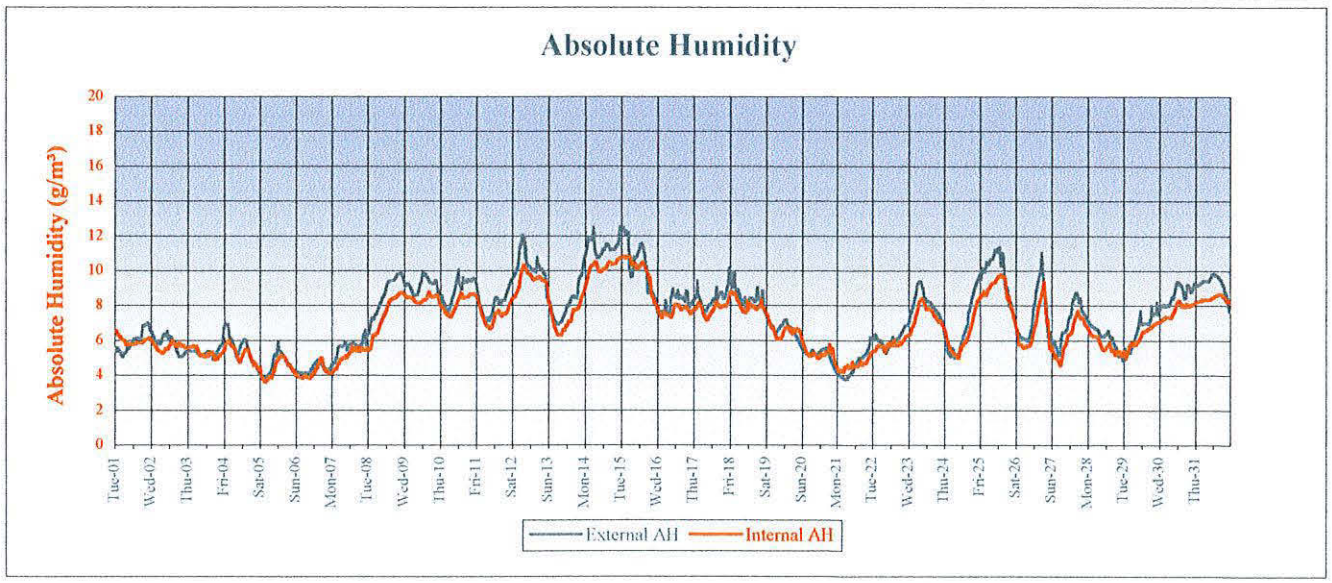
Peterborough Cathedral Nave Ceiling

December 1998

Probe 2: Bay 36 III upper side (shade)



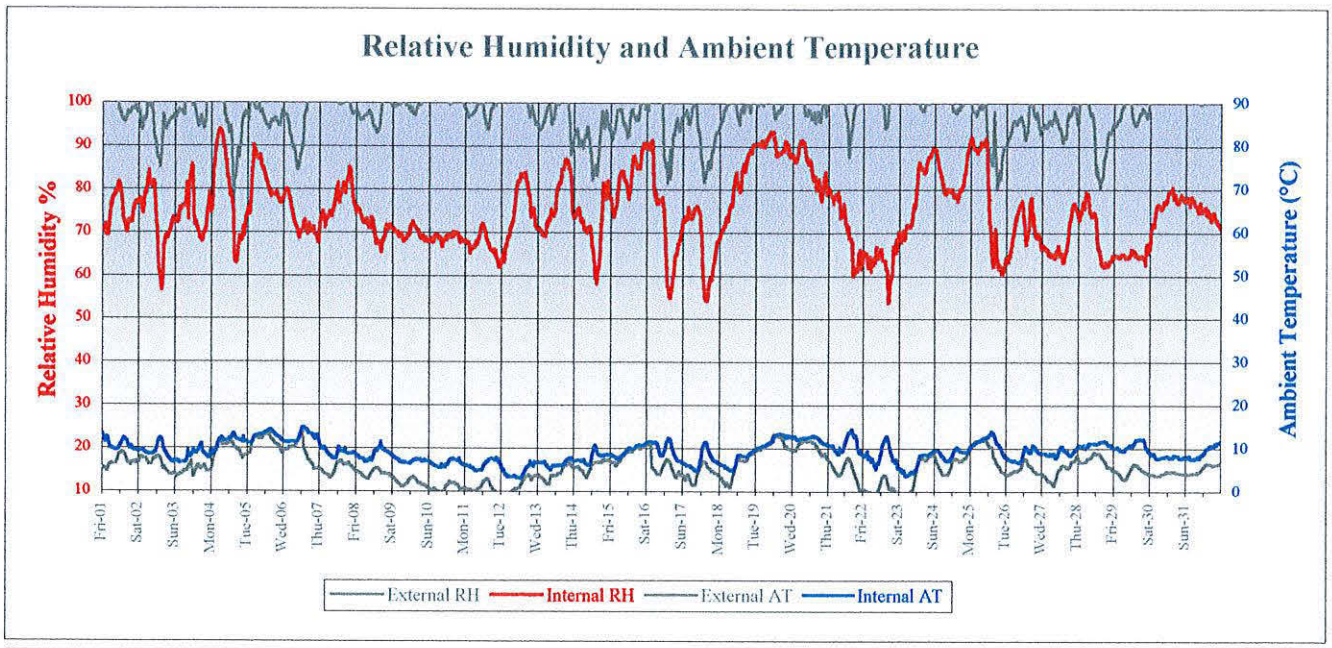


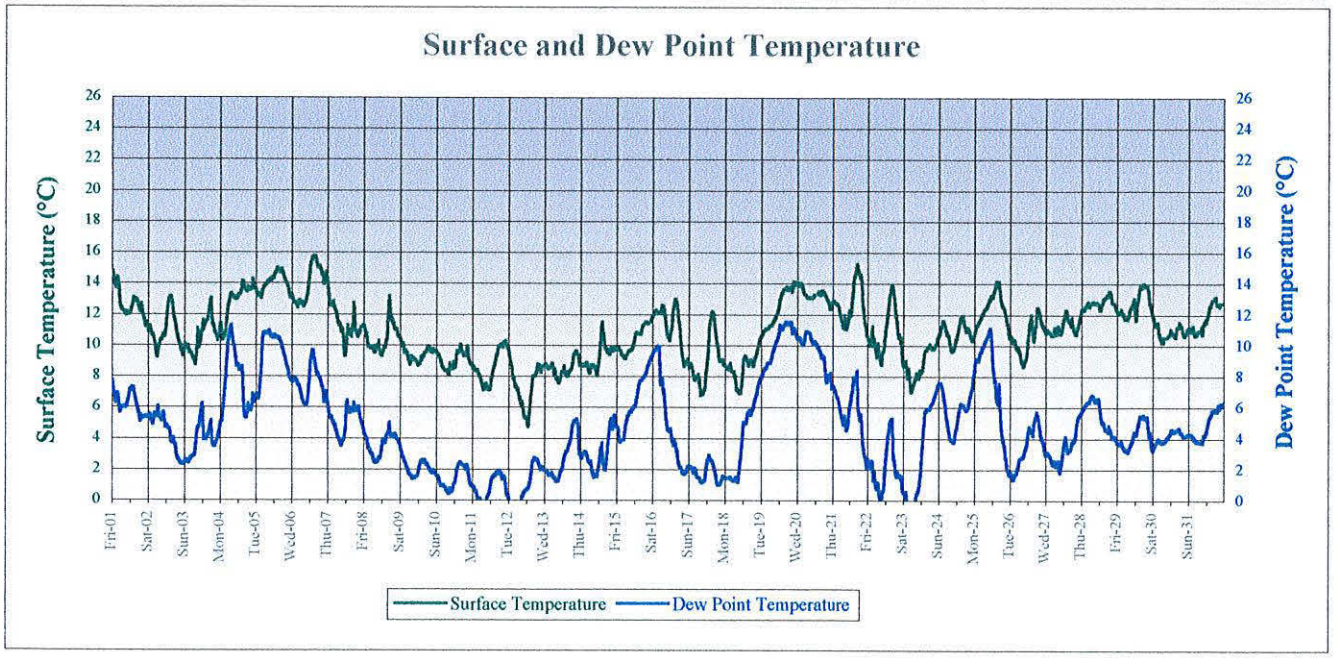


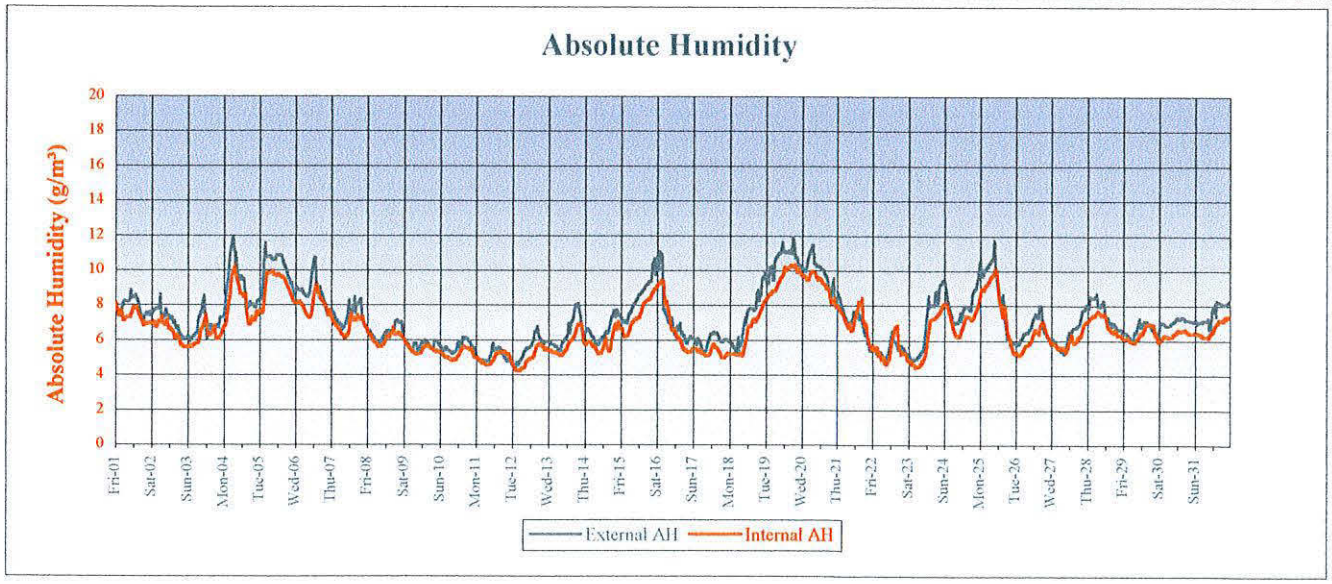
Peterborough Cathedral Nave Ceiling

January 1999

Probe 2: Bay 36 III upper side (shade)



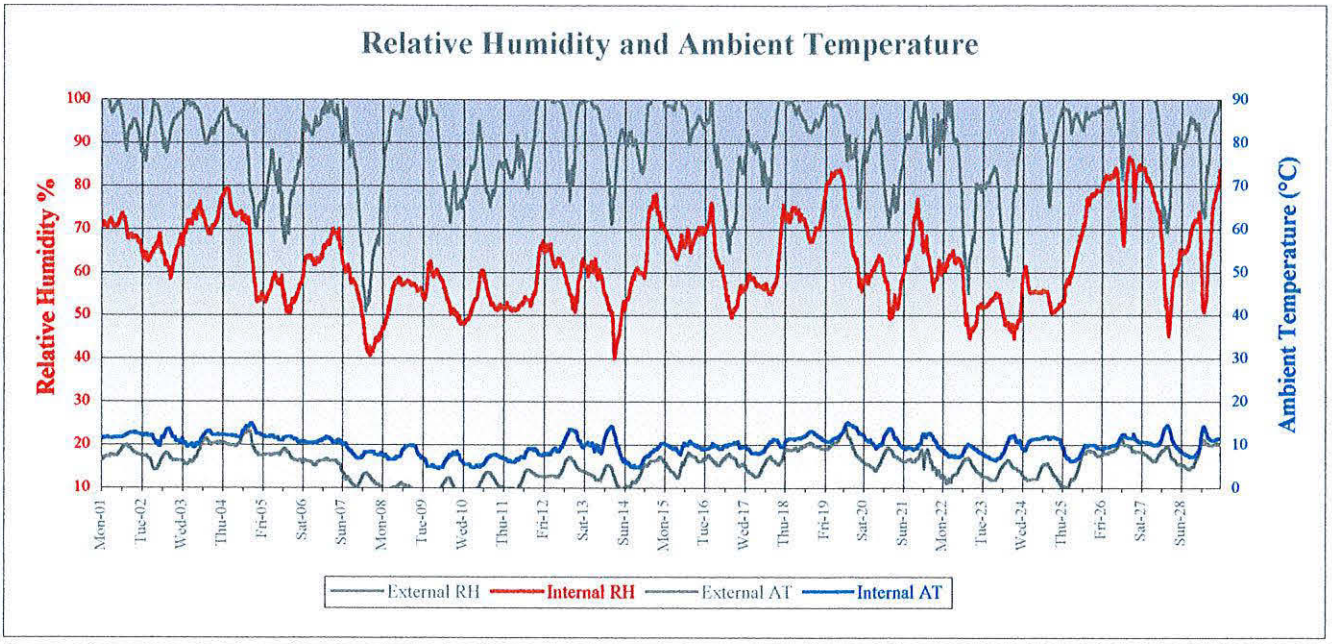


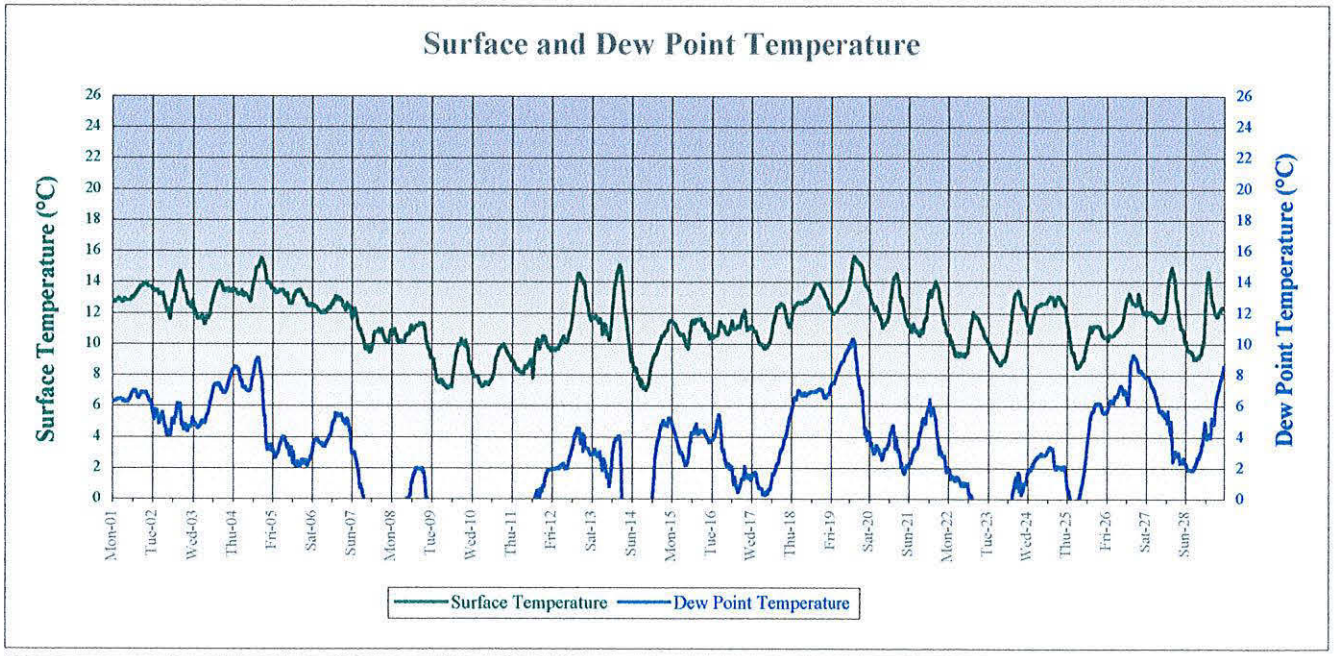


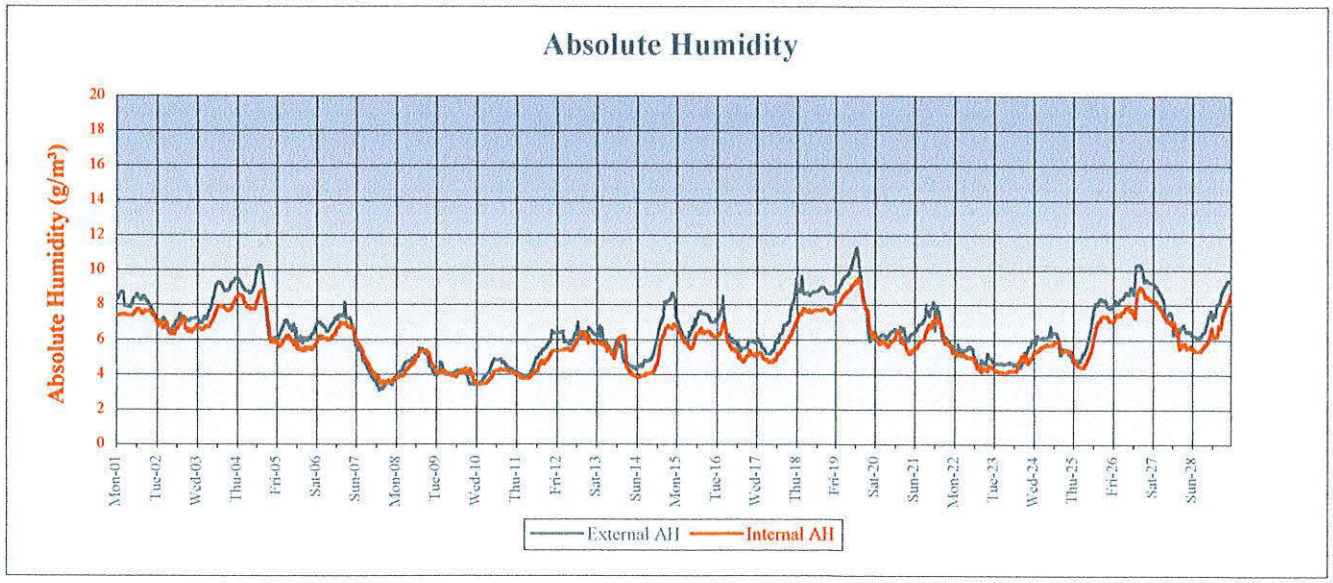
Peterborough Cathedral Nave Ceiling

February 1999

Probe 2: Bay 36 III upper side (shade)



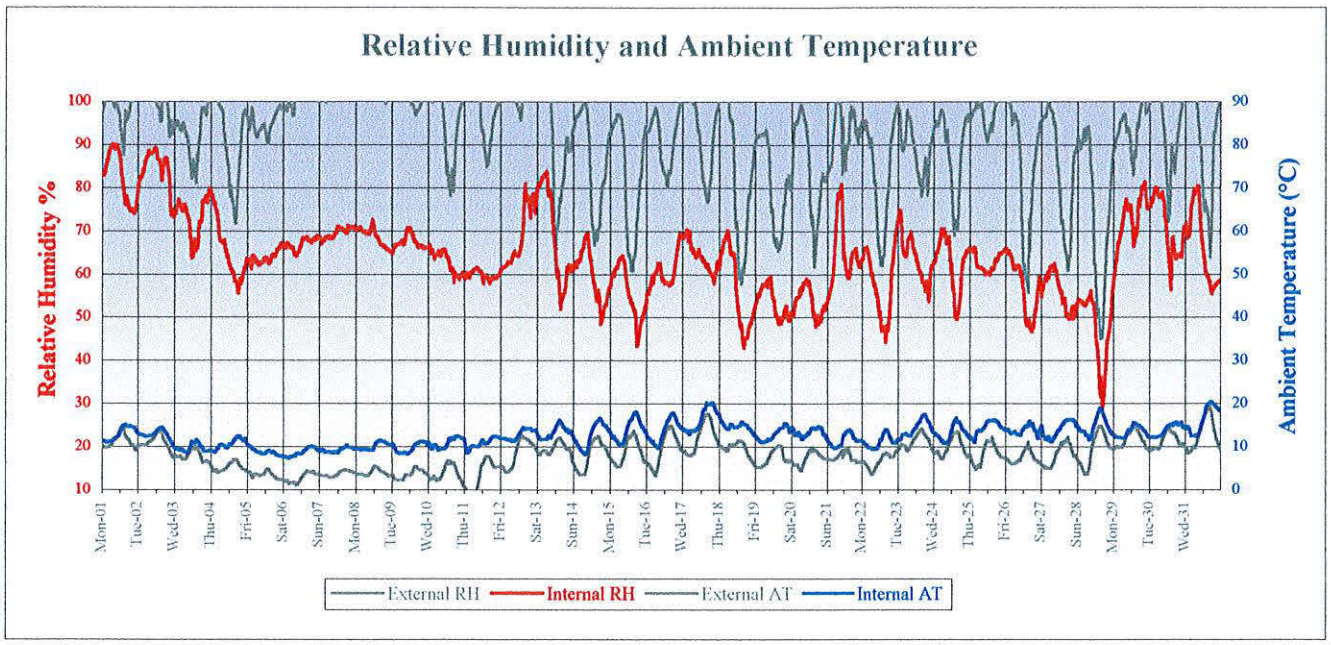


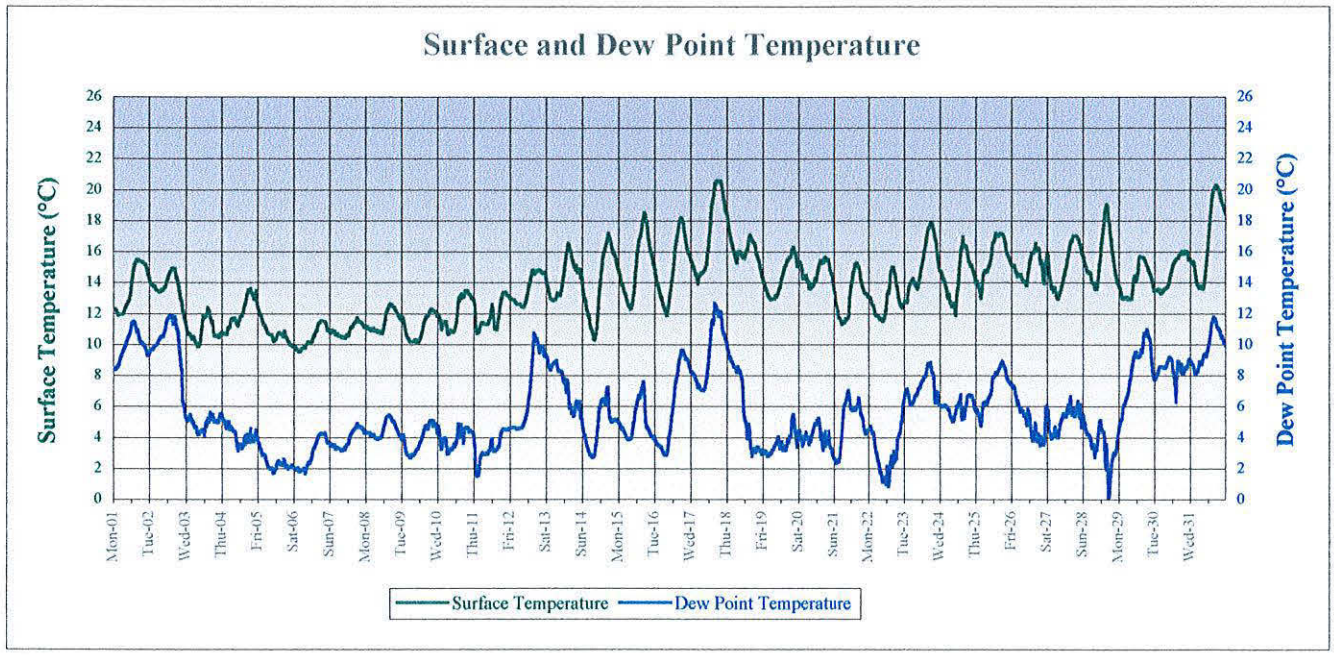


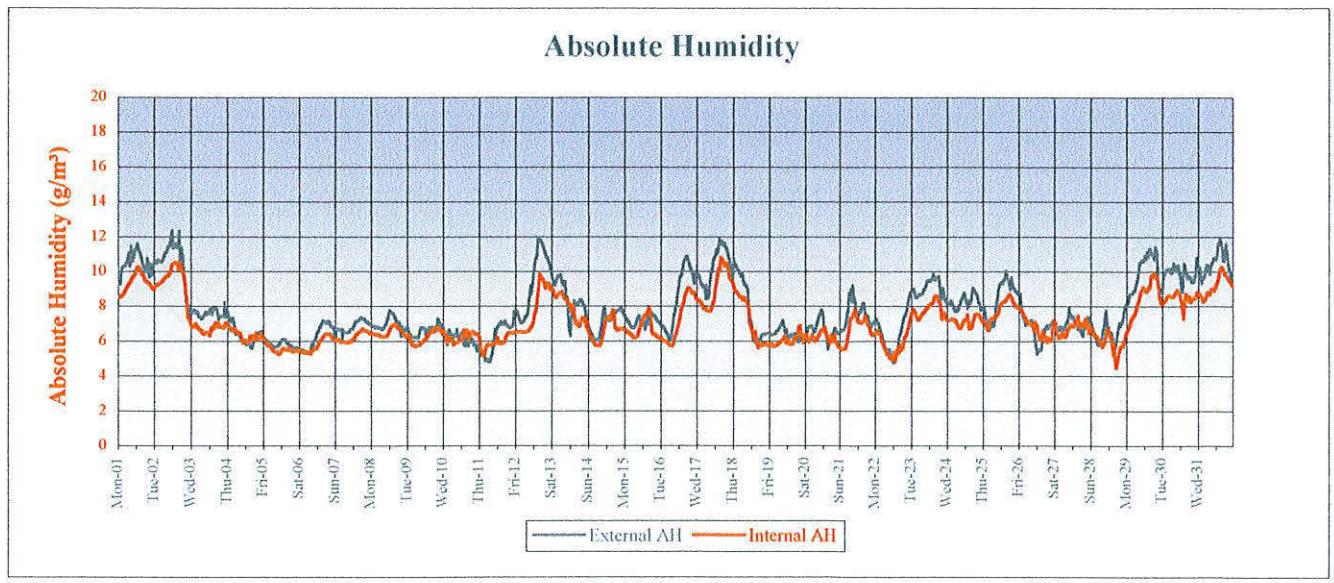
Peterborough Cathedral Nave Ceiling

March 1999

Probe 2: Bay 36 III upper side (shade)



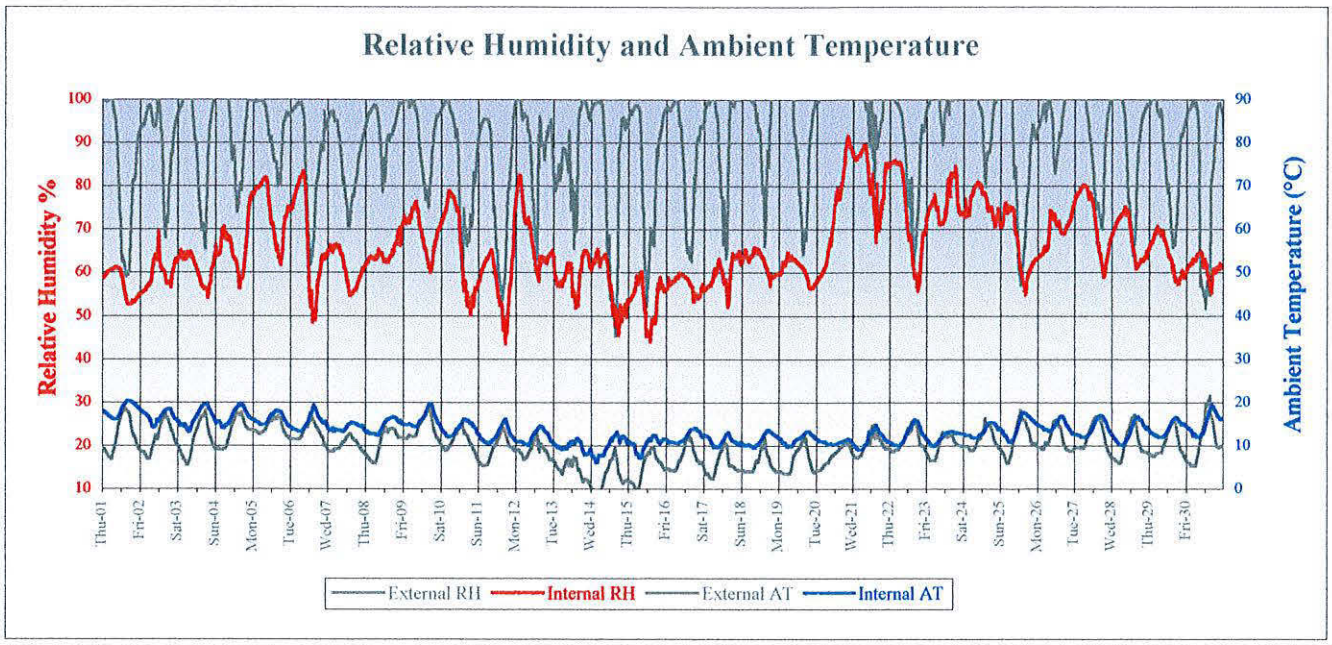


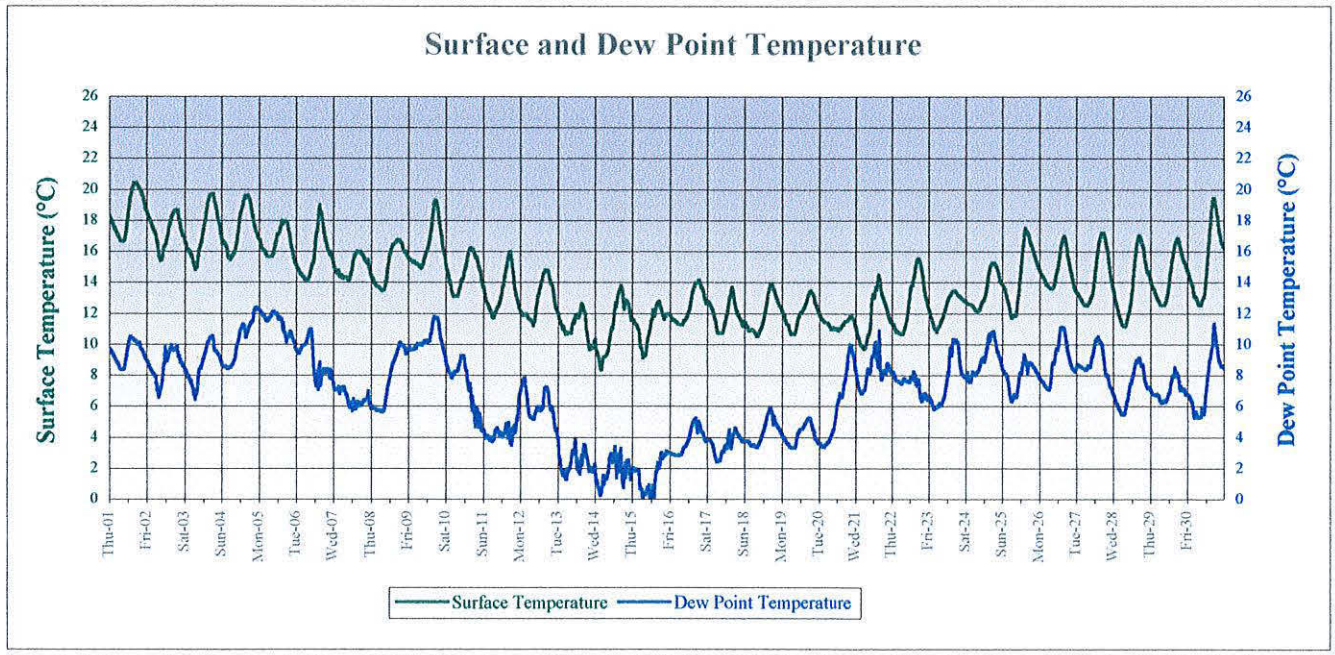


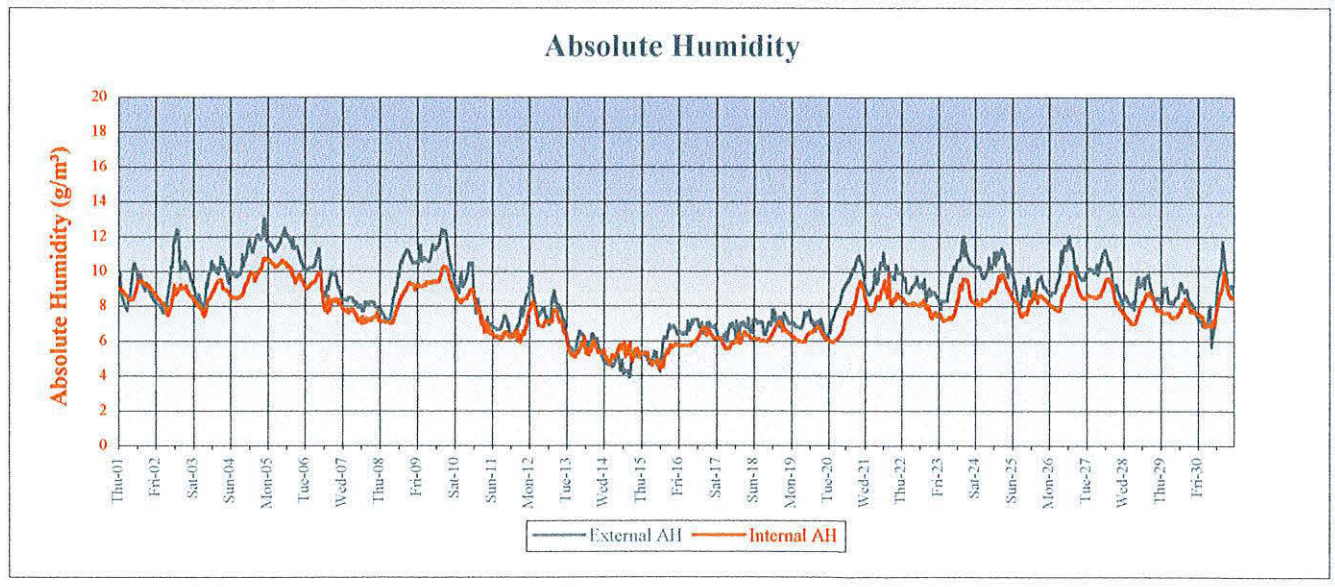
Peterborough Cathedral Nave Ceiling

April 1999

Probe 2: Bay 36 III upper side (shade)



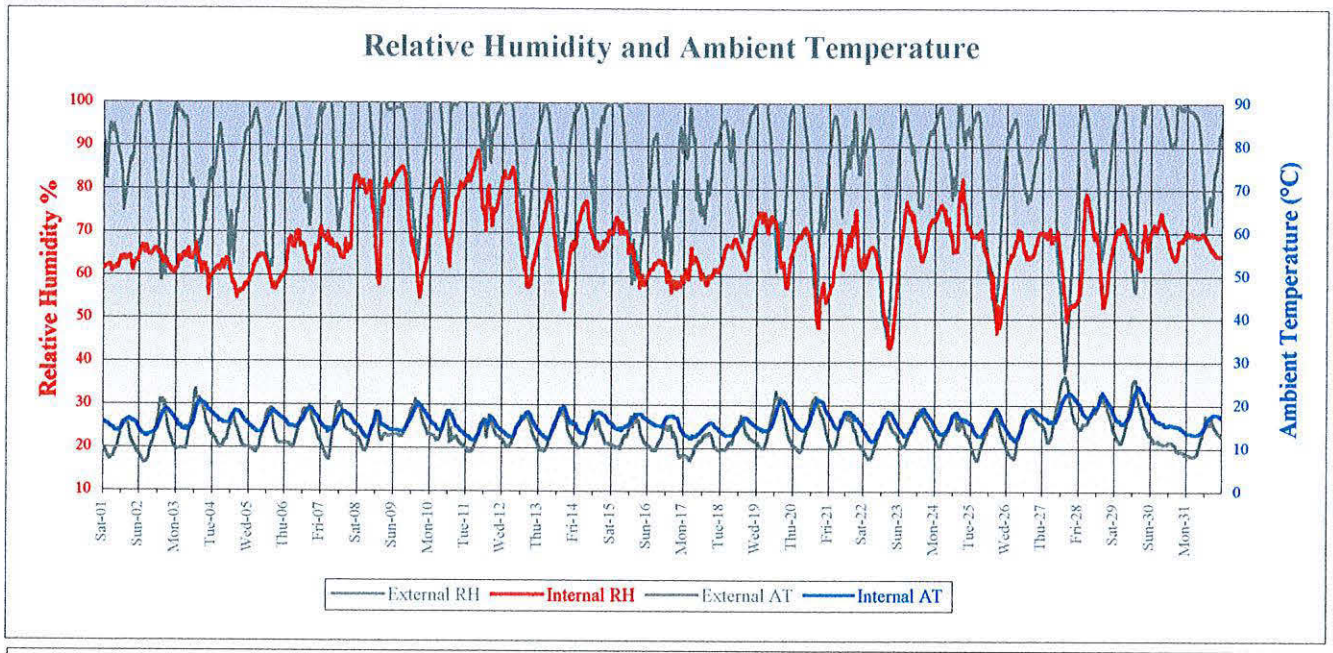


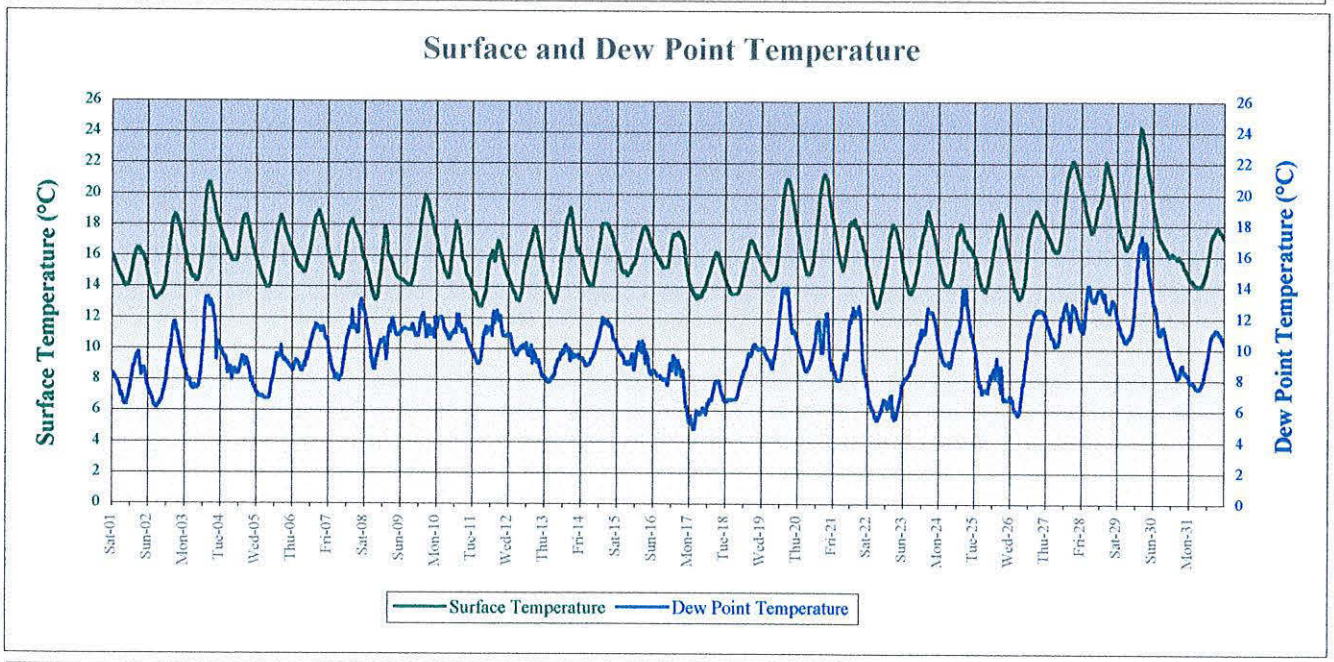


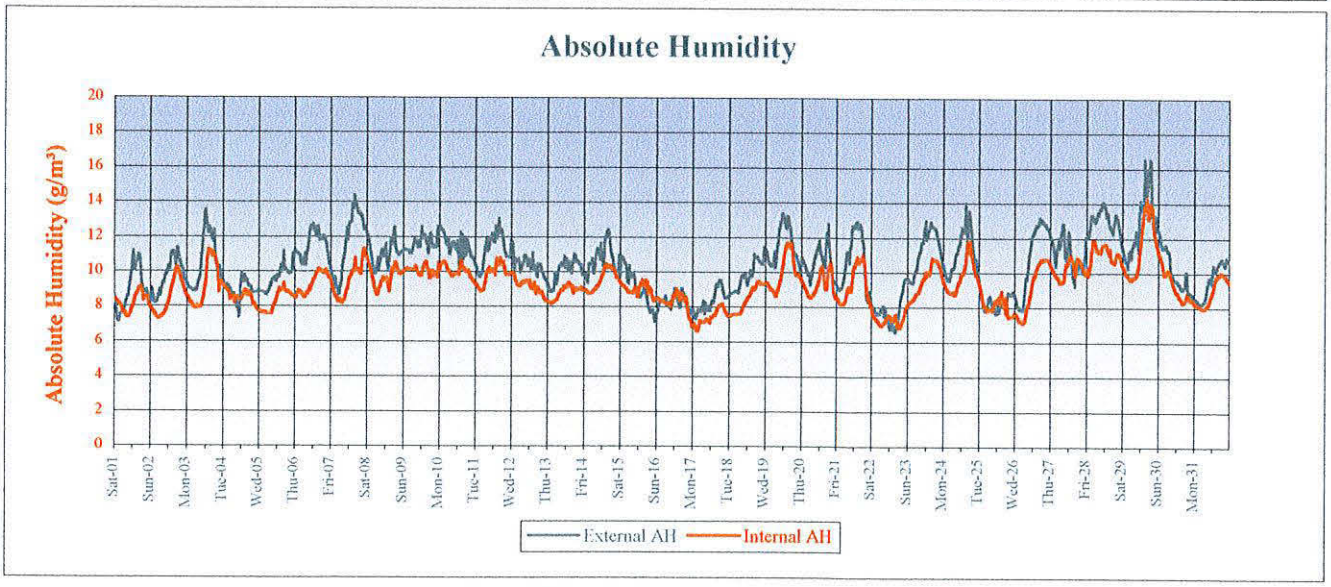
Peterborough Cathedral Nave Ceiling

May 1999

Probe 2: Bay 36 III upper side (shade)



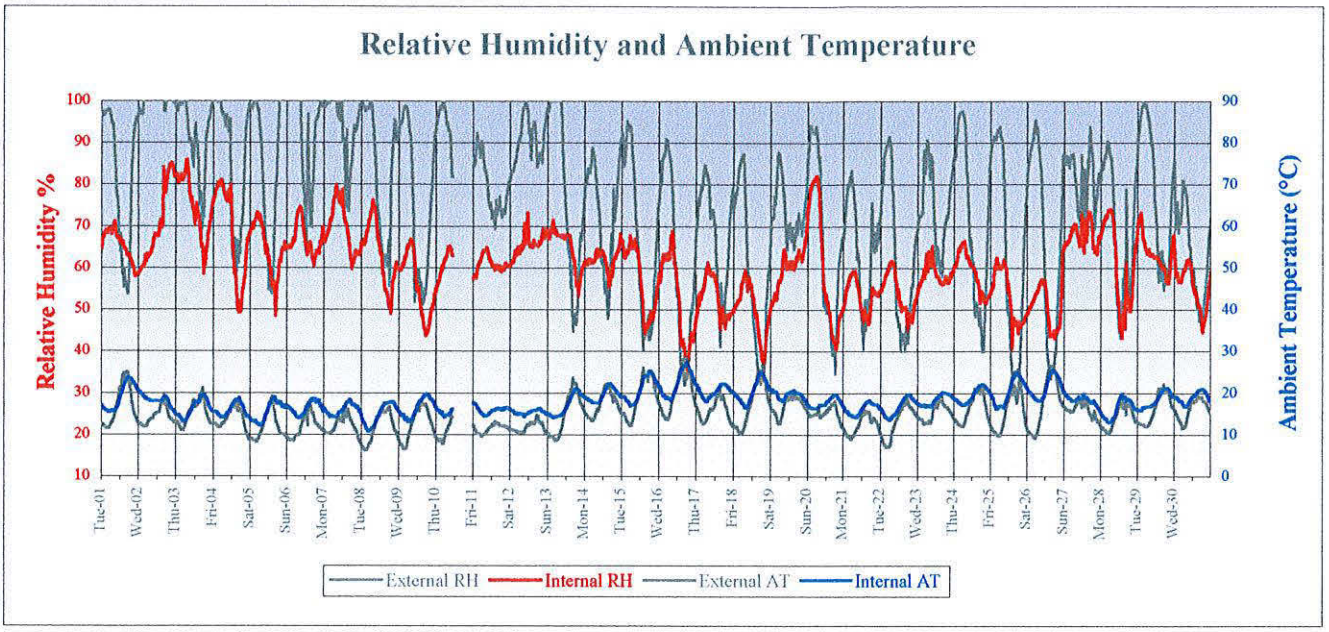


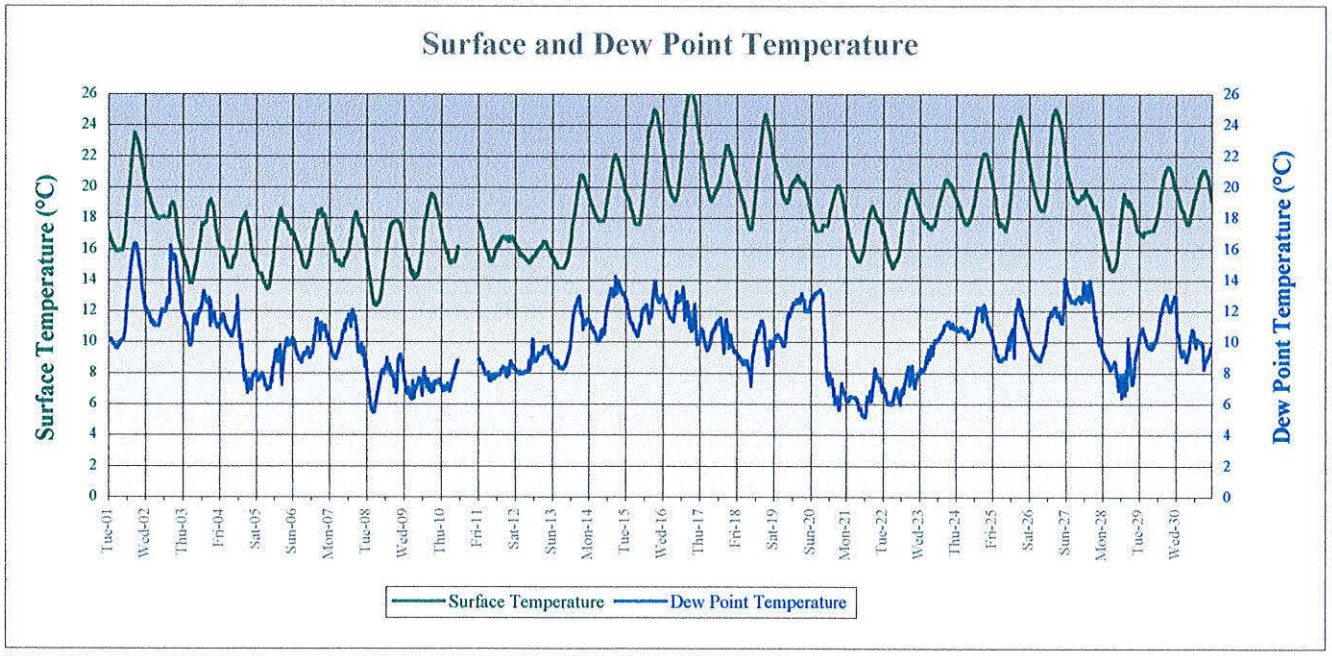


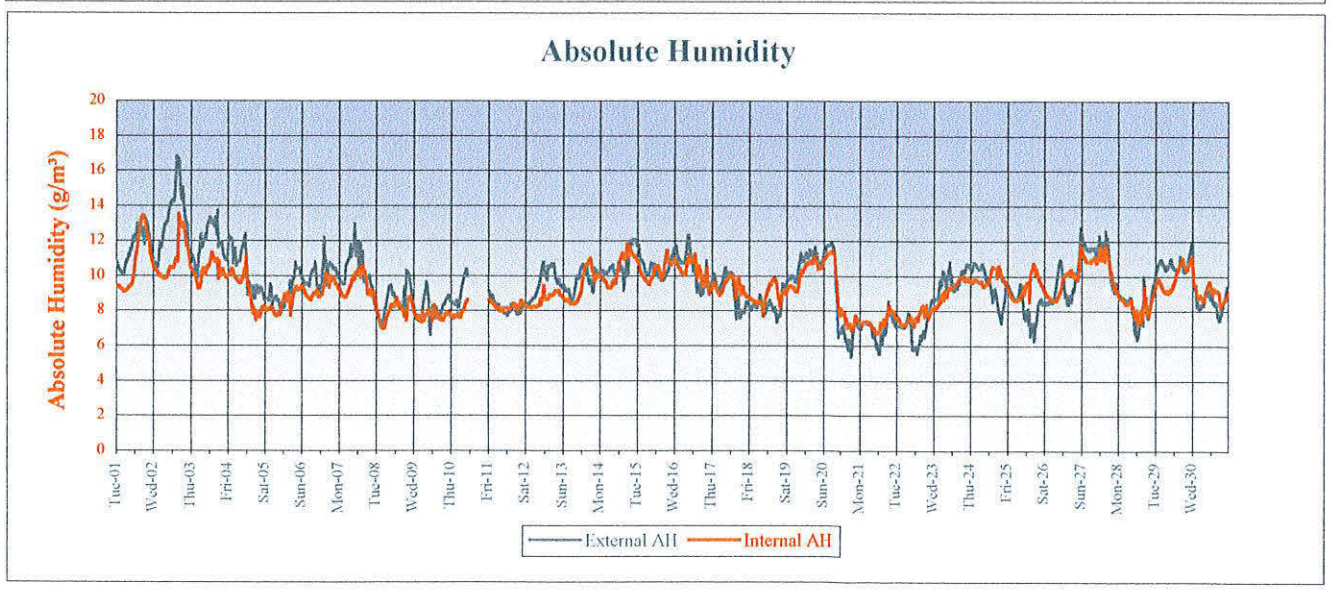
Peterborough Cathedral Nave Ceiling

June 1999

Probe 2: Bay 36 III upper side (shade)



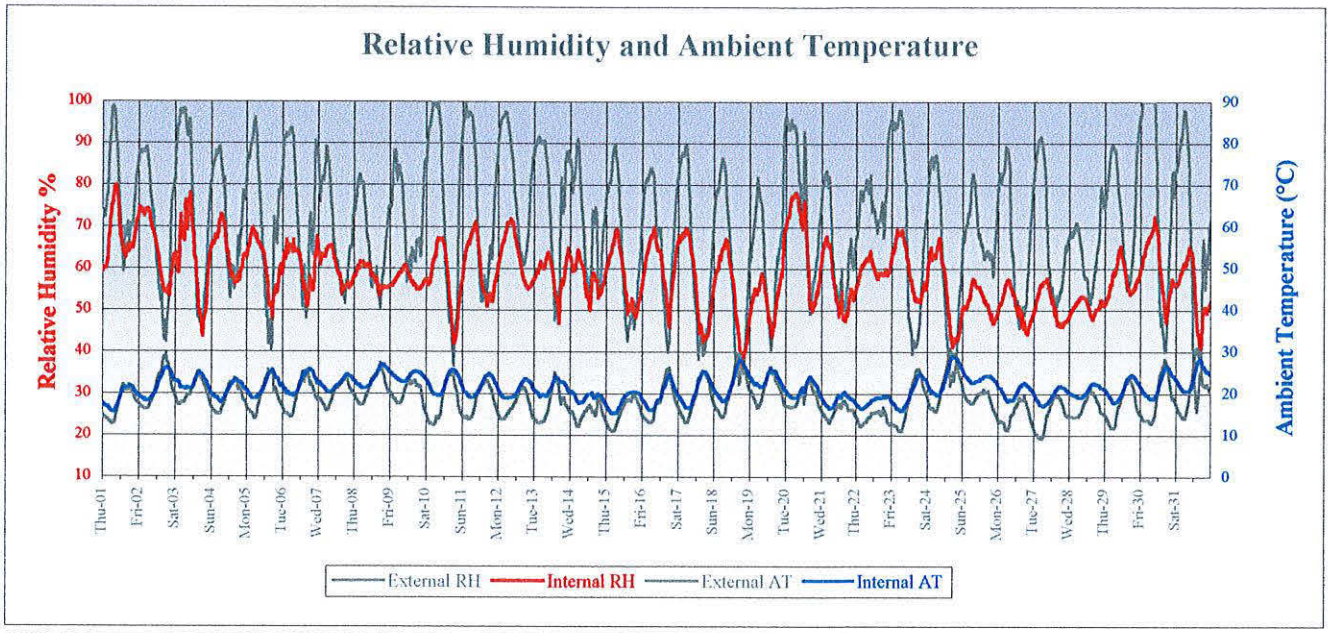


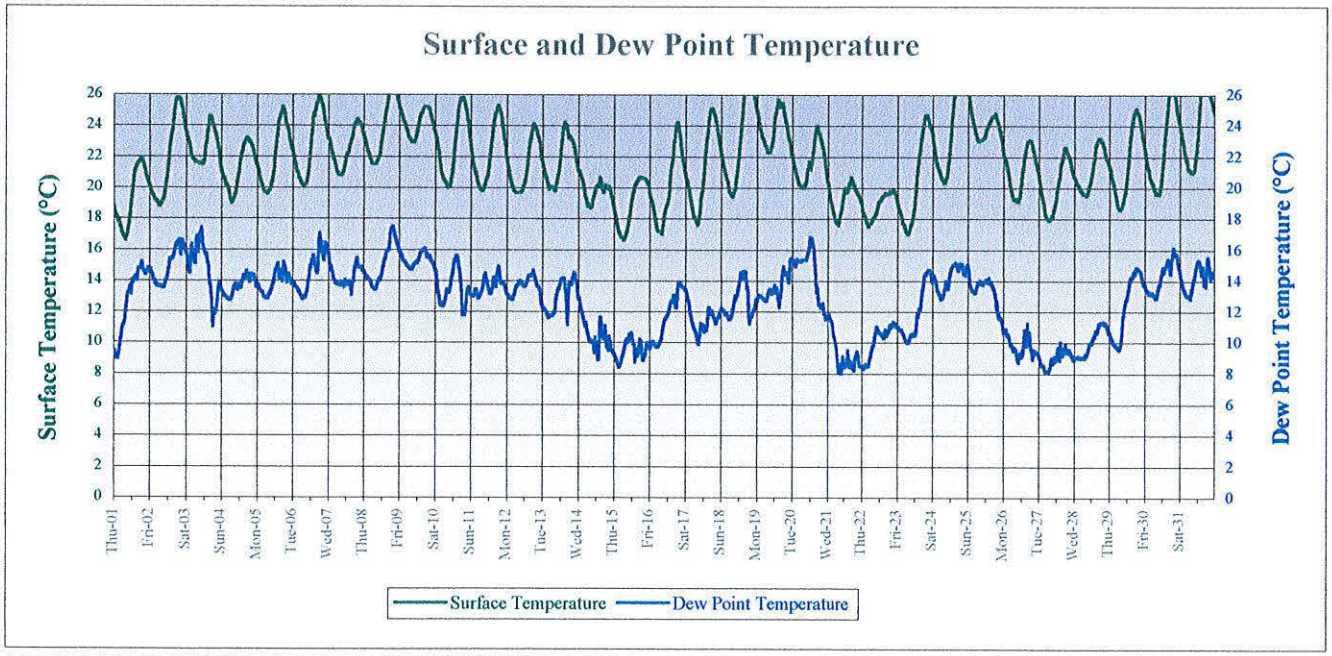


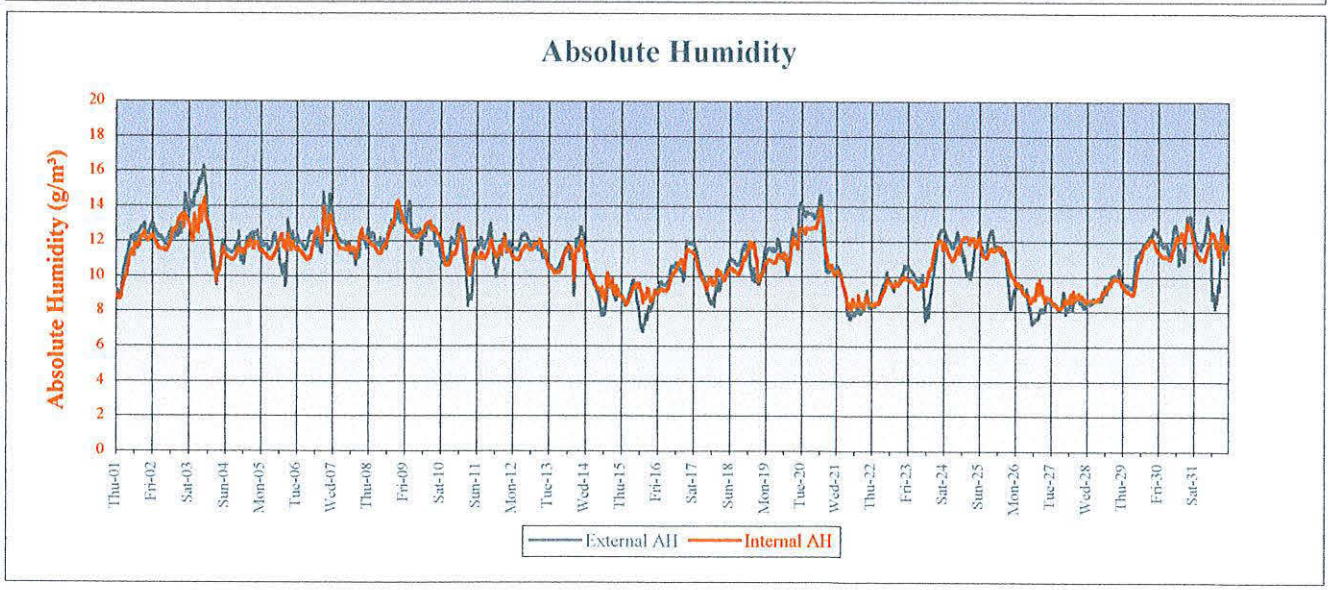
Peterborough Cathedral Nave Ceiling

July 1999

Probe 2: Bay 36 III upper side (shade)



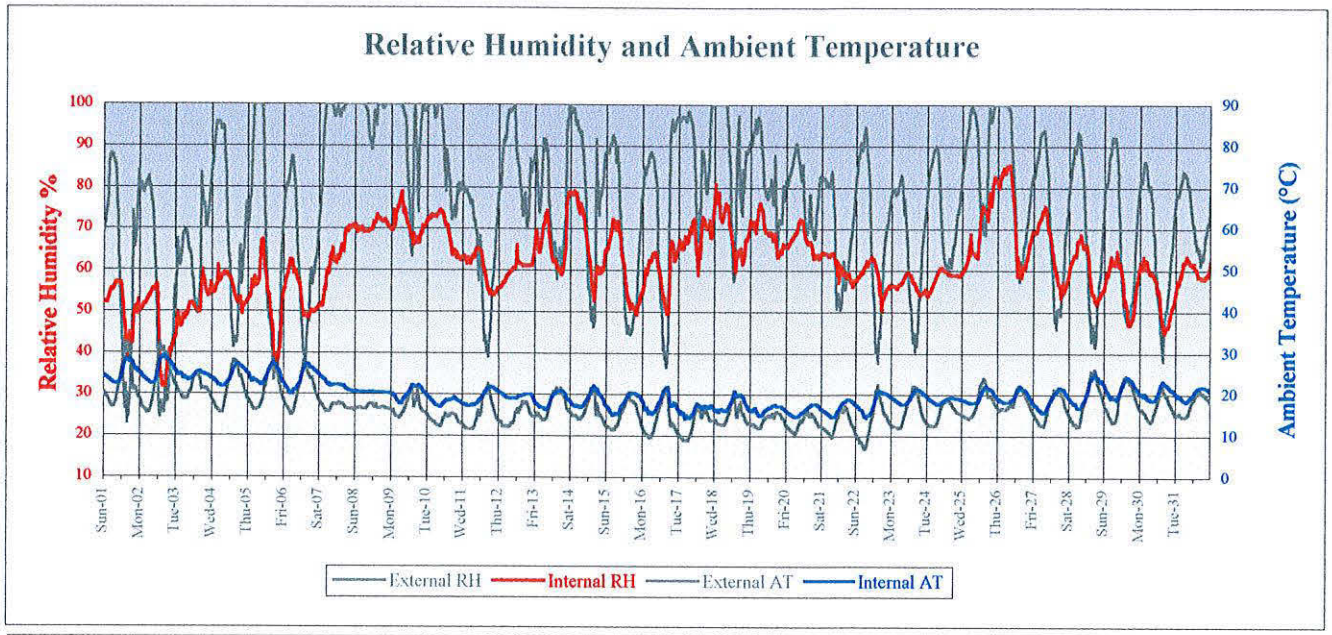


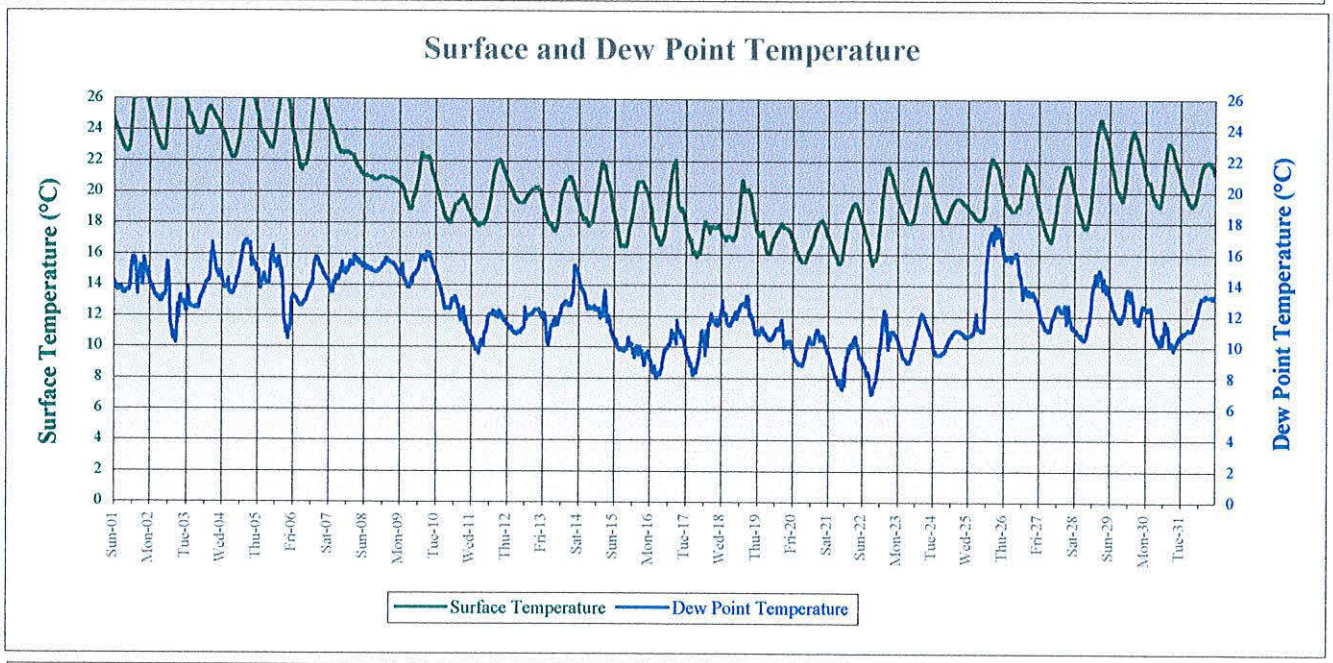


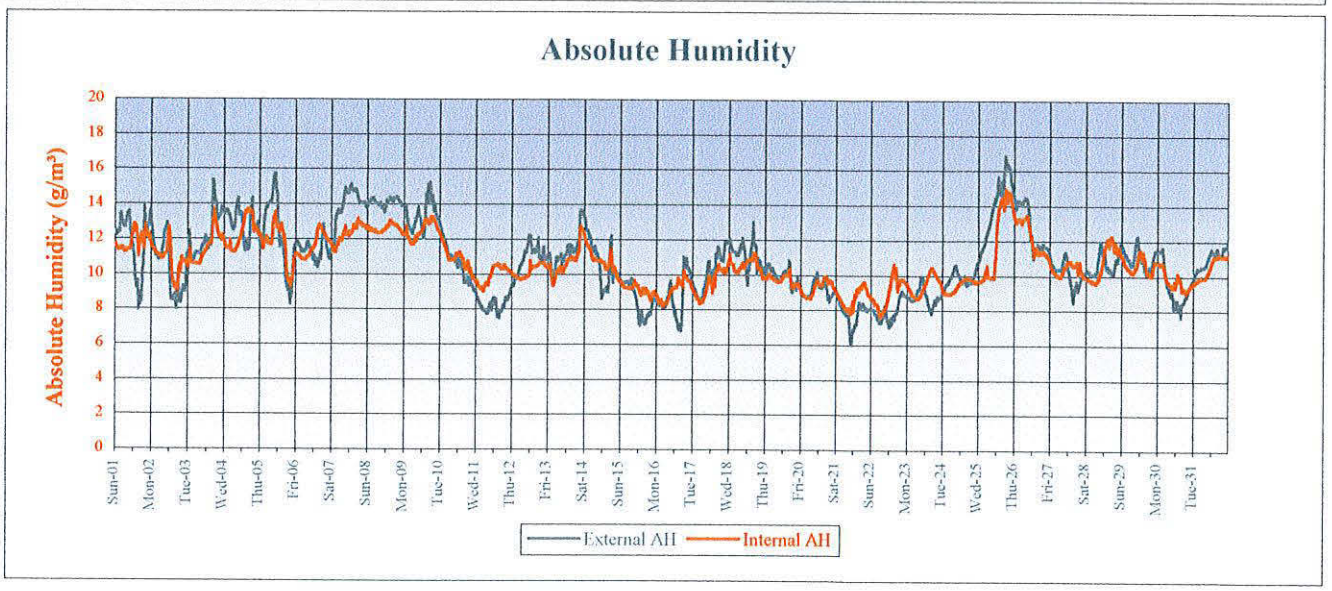
Peterborough Cathedral Nave Ceiling

August 1999

Probe 2: Bay 36 III upper side (shade)



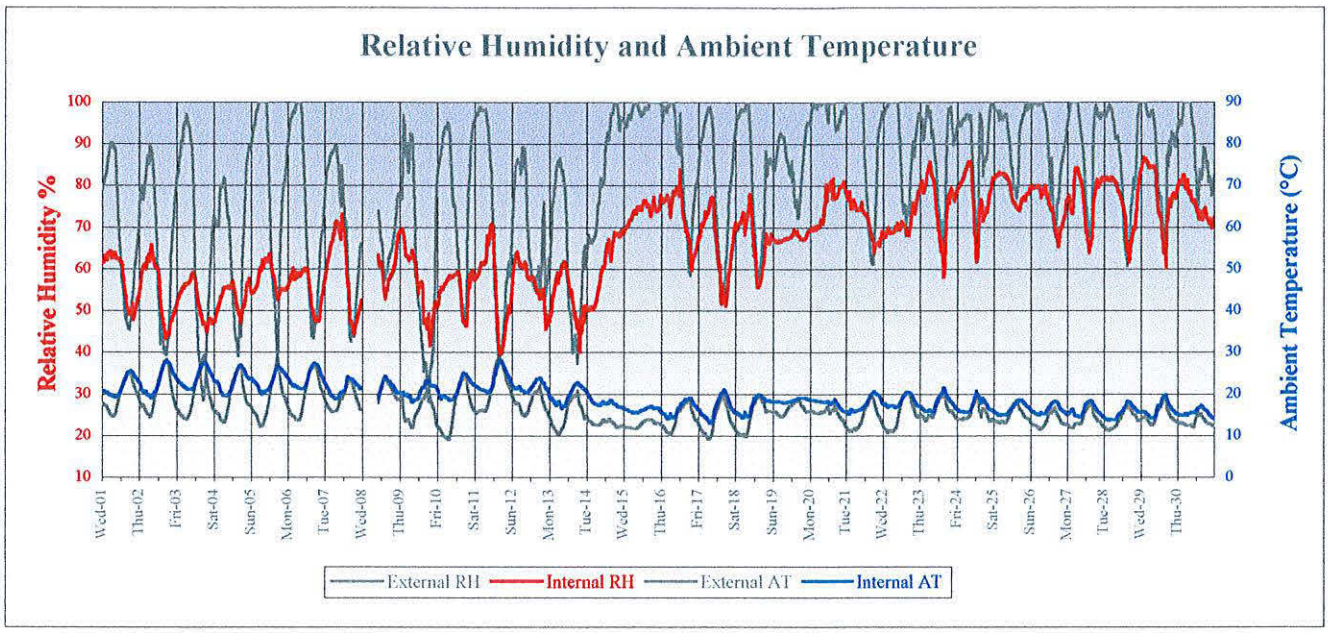


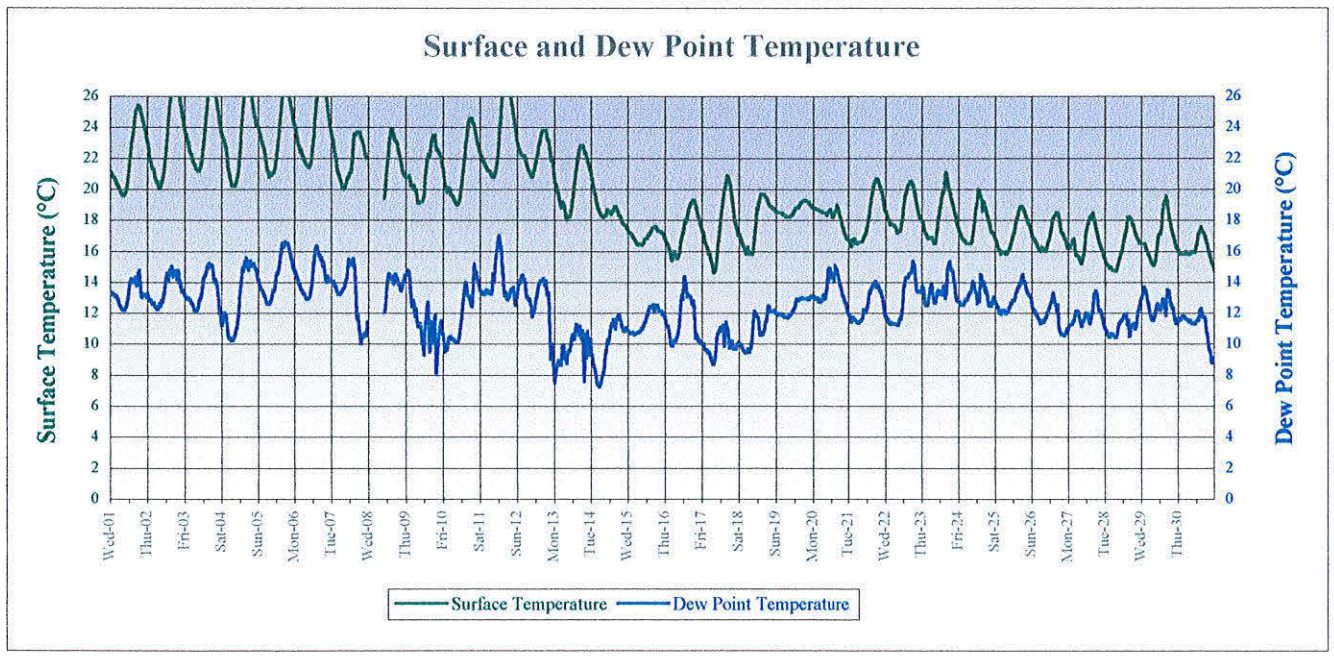


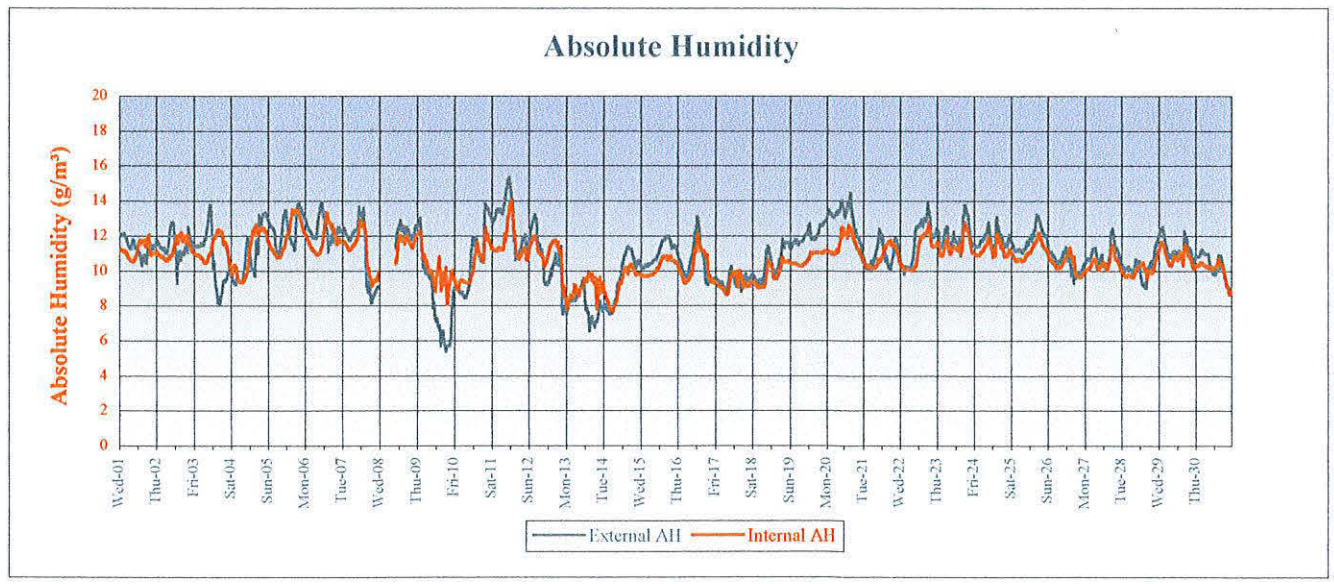
Peterborough Cathedral Nave Ceiling

September 1999

Probe 2: Bay 36 III upper side (shade)



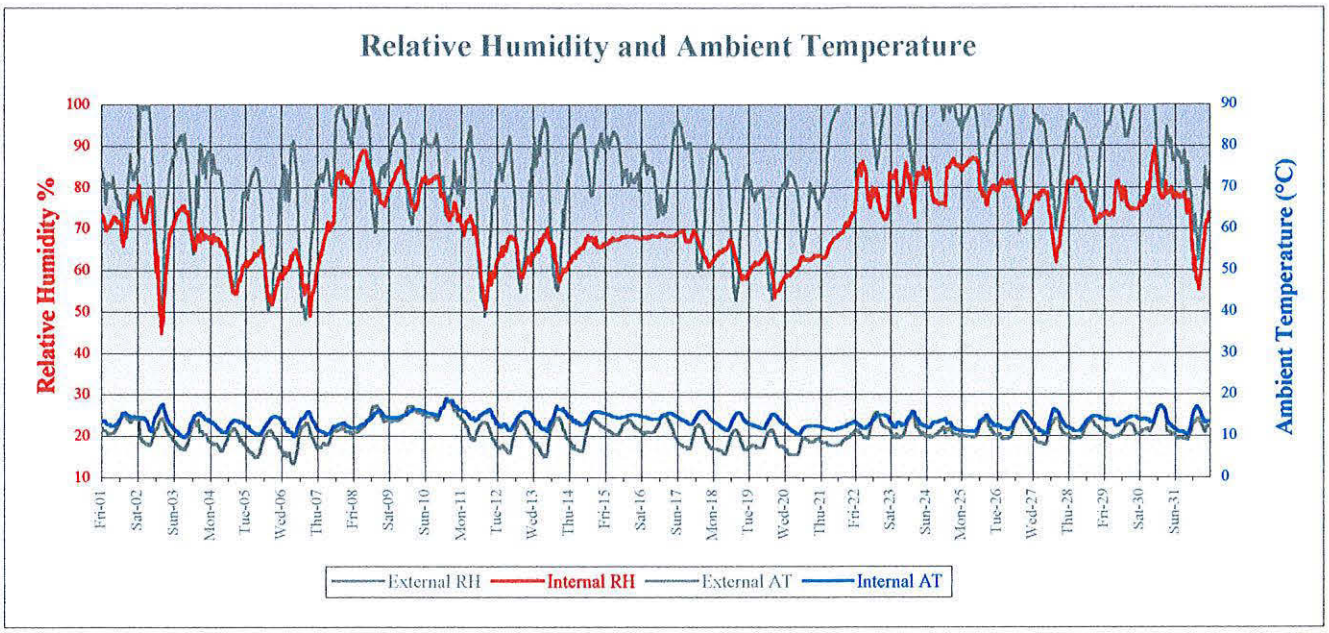


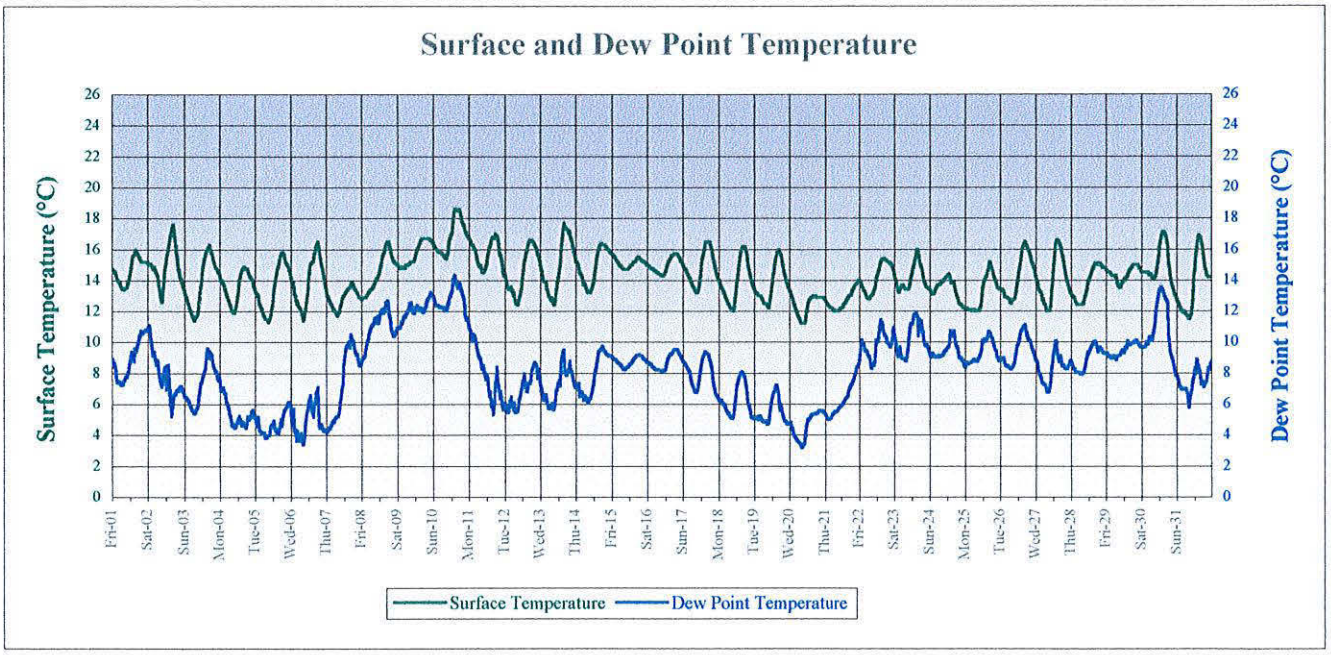


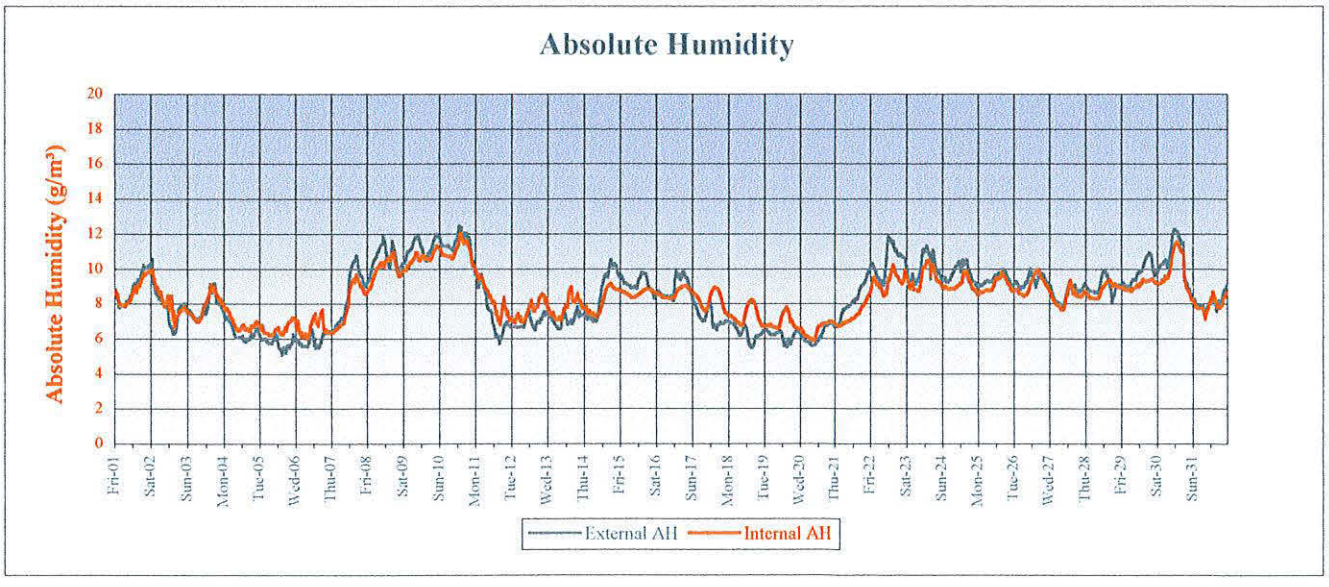
Peterborough Cathedral Nave Ceiling

October 1999

Probe 2: Bay 36 III upper side (shade)



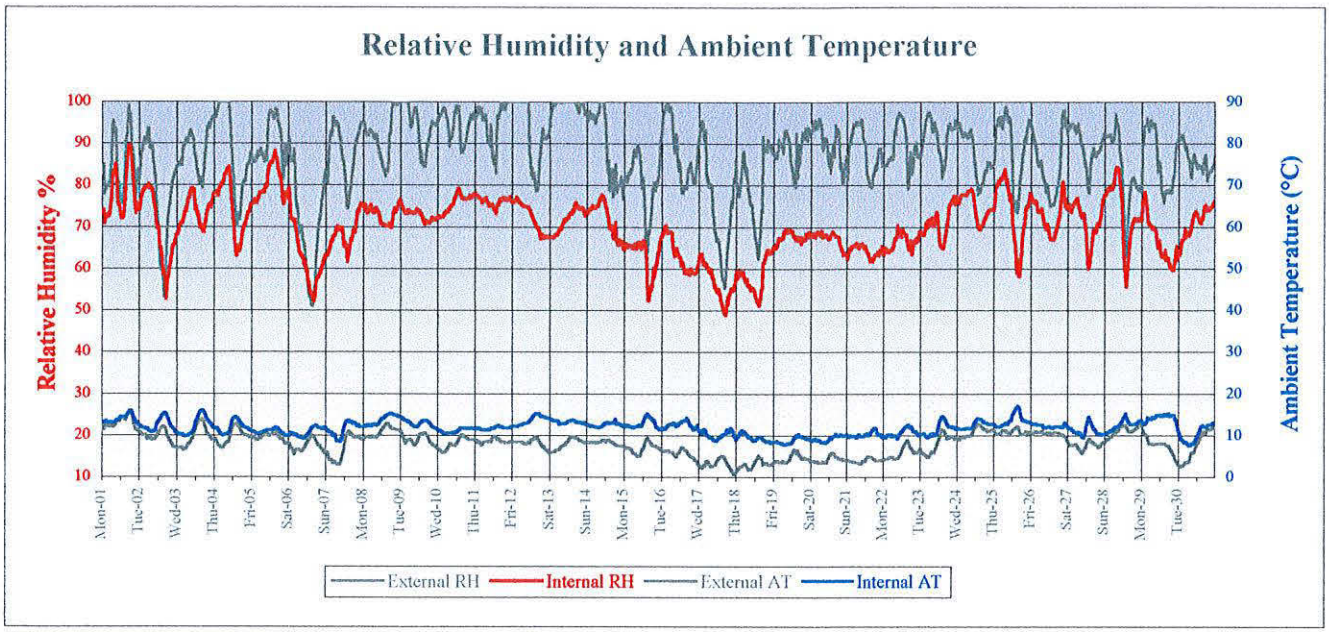


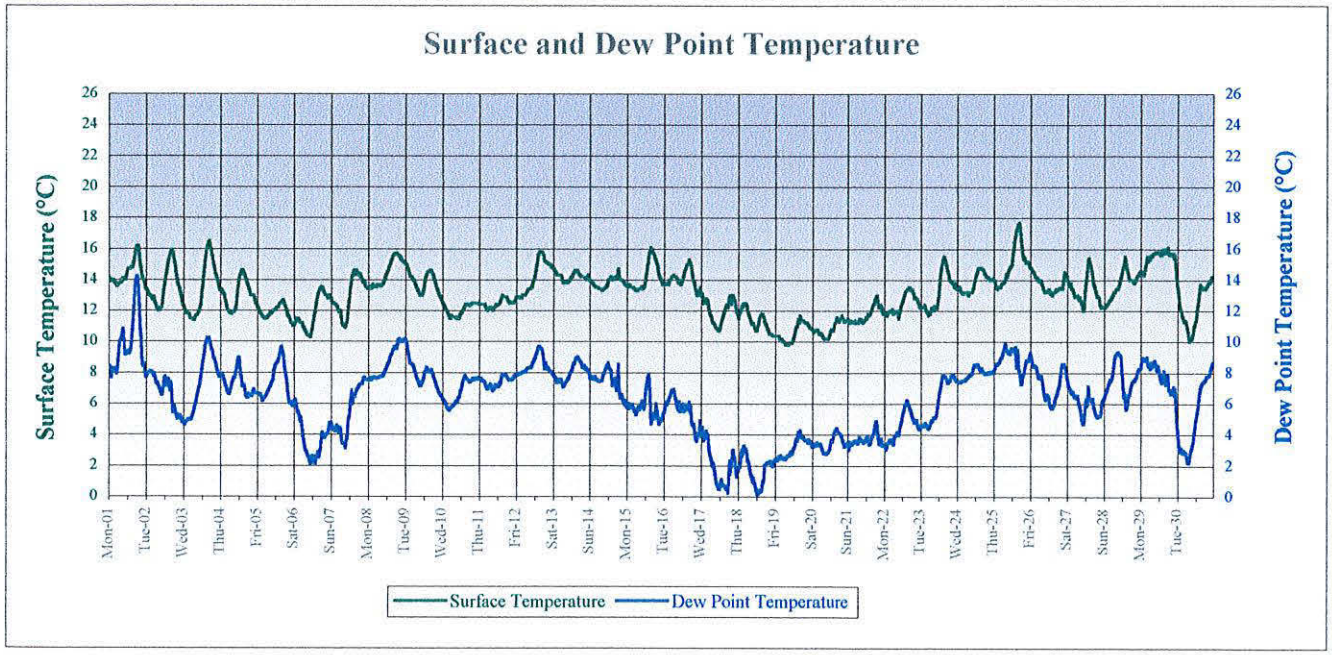


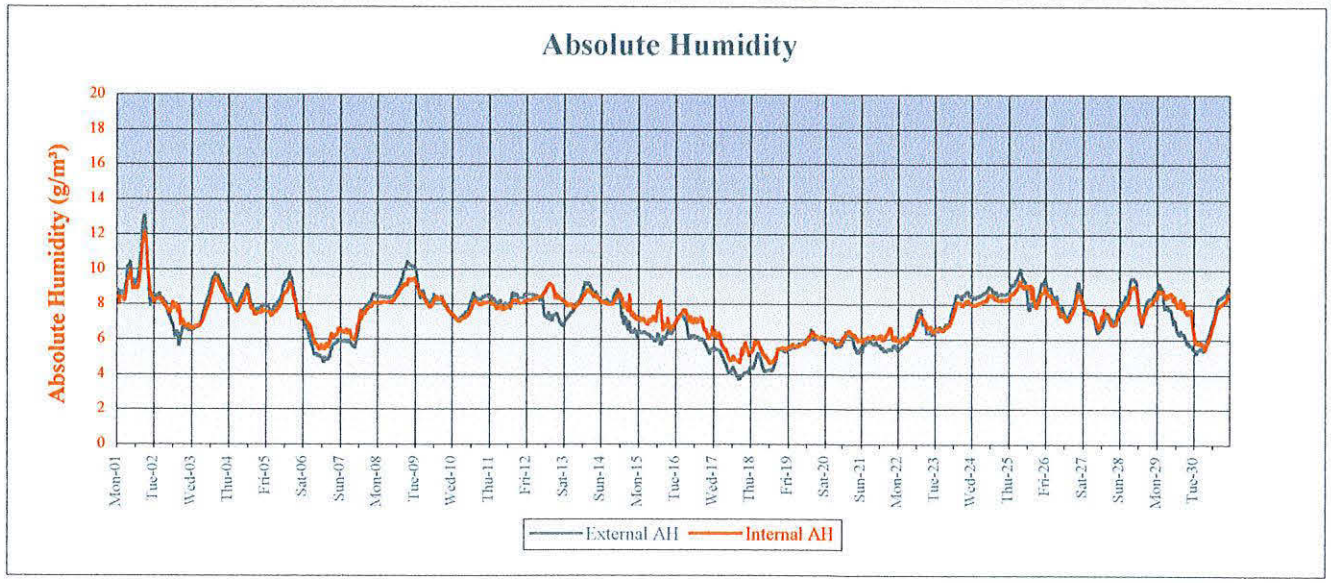
Peterborough Cathedral Nave Ceiling

November 1999

Probe 2: Bay 36 III upper side (shade)



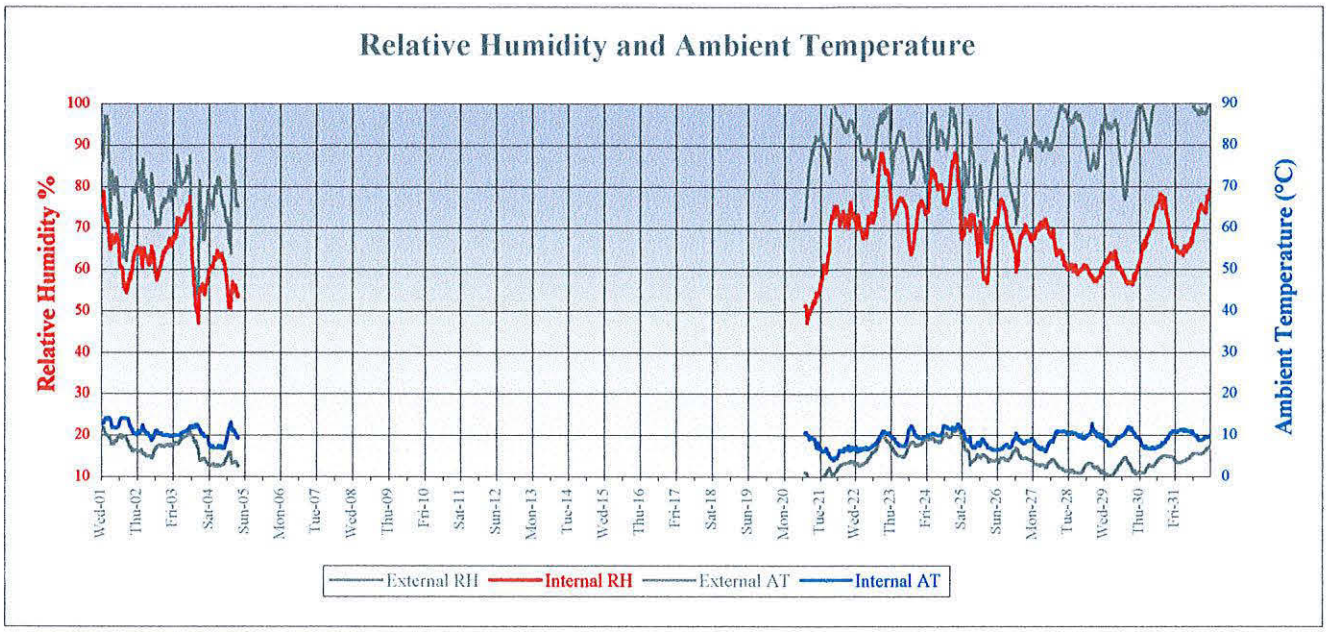


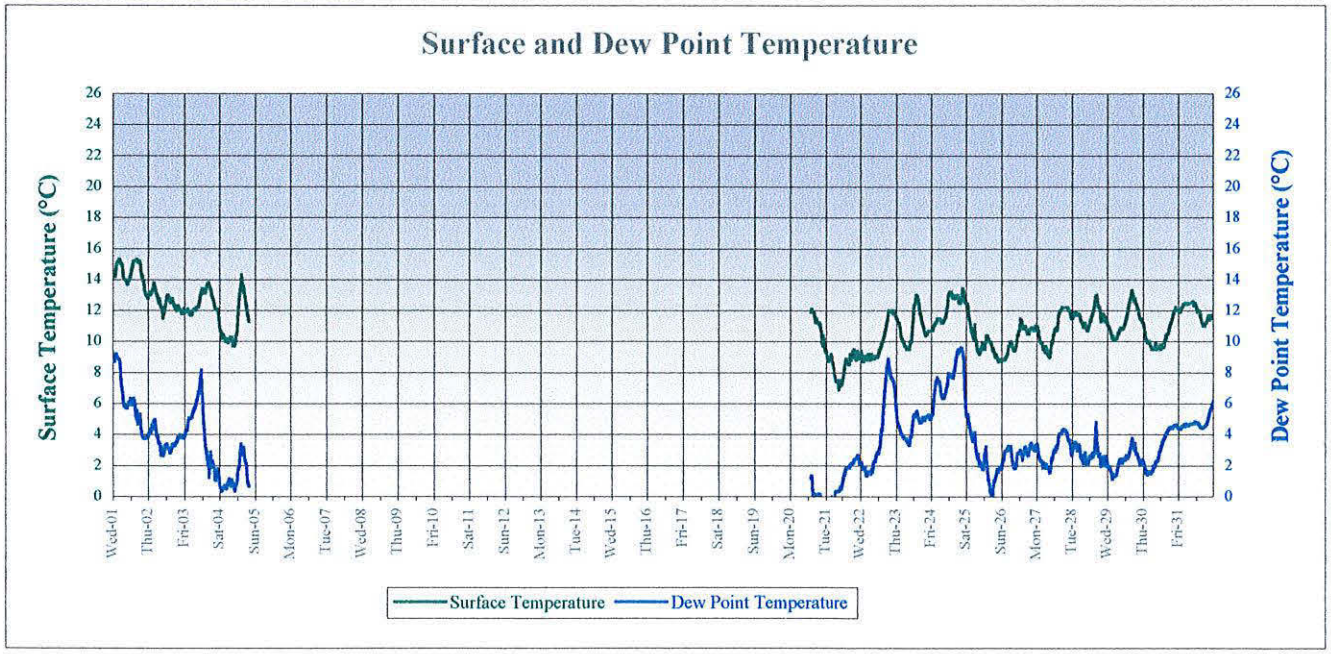


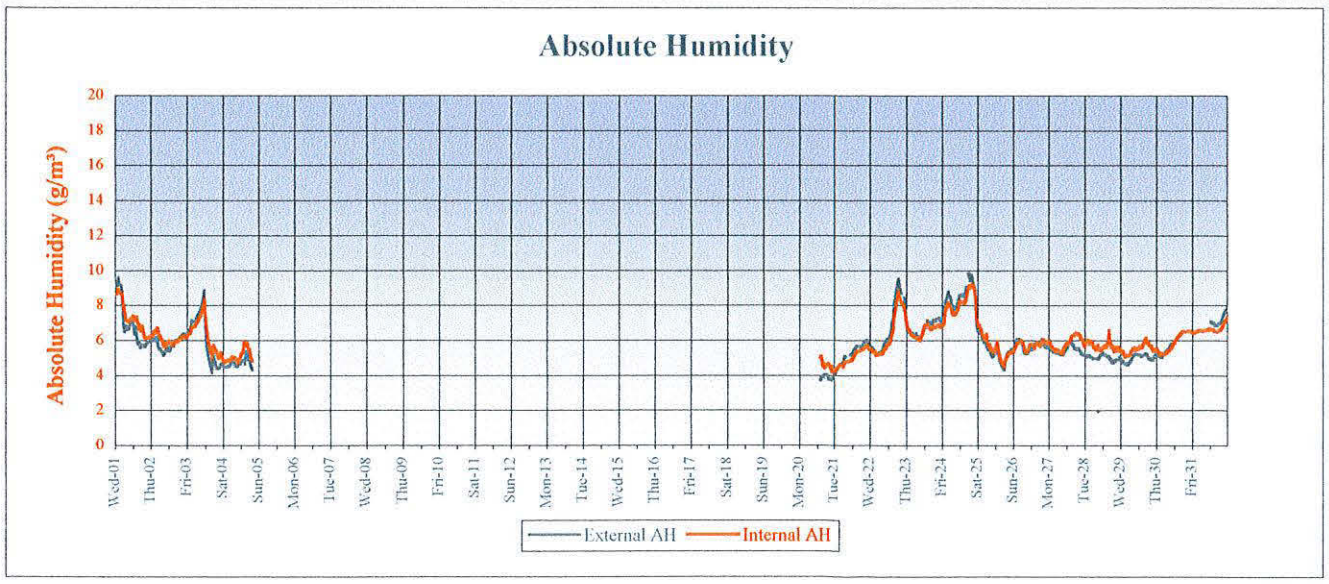
Peterborough Cathedral Nave Ceiling

December 1999

Probe 2: Bay 36 III upper side (shade)



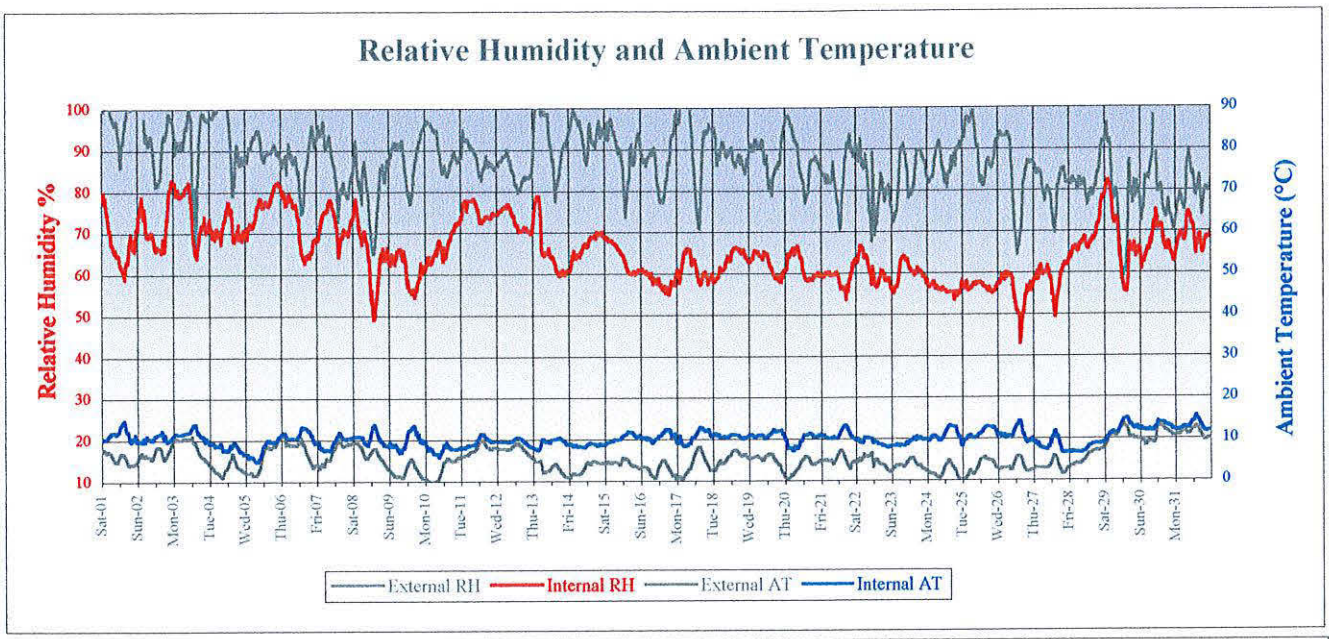


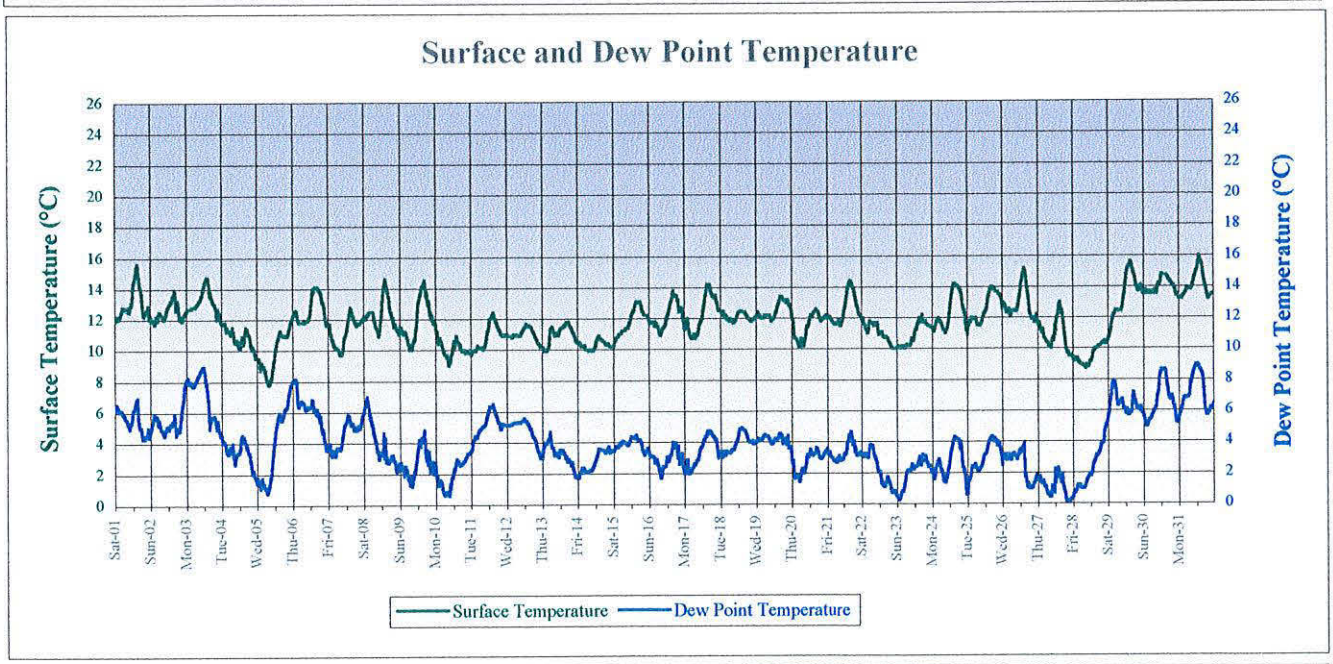


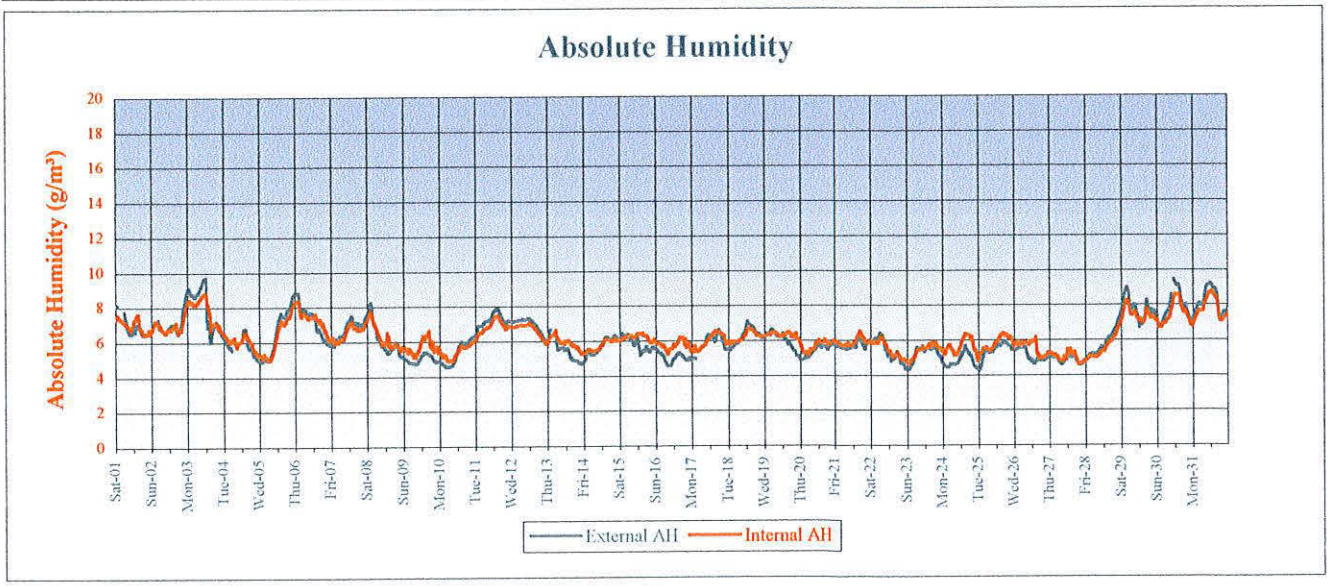
Peterborough Cathedral Nave Ceiling

January 2000

Probe 2: Bay 36 III upper side (shade)



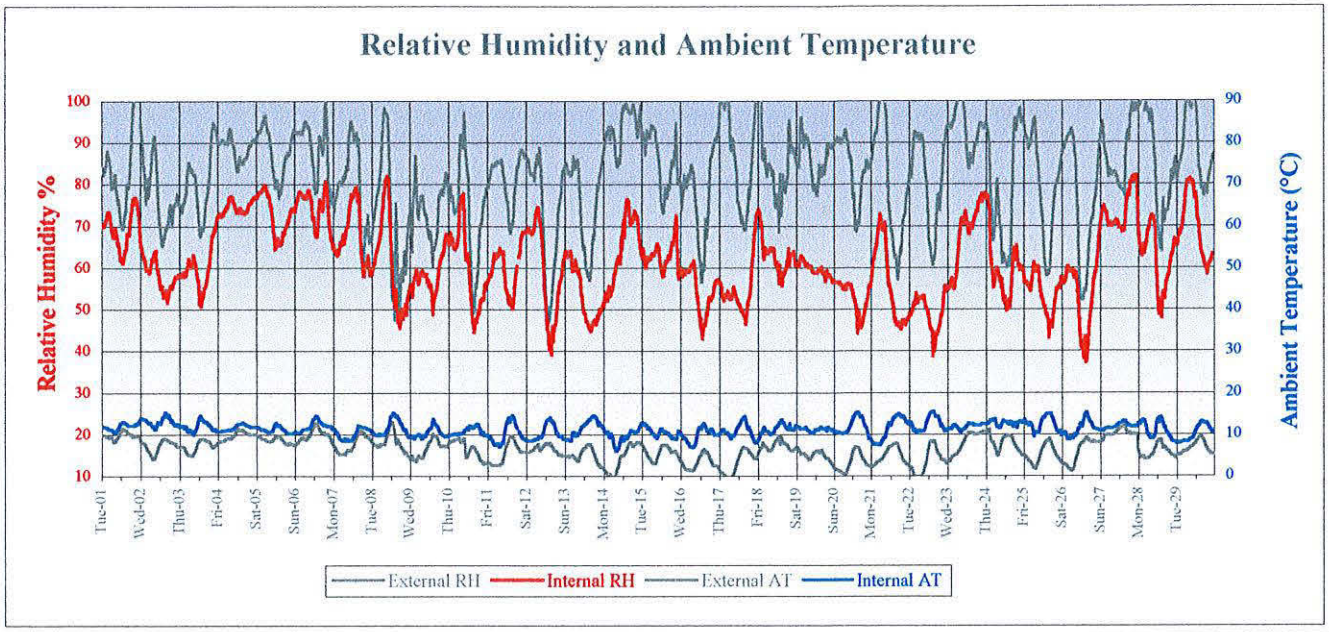


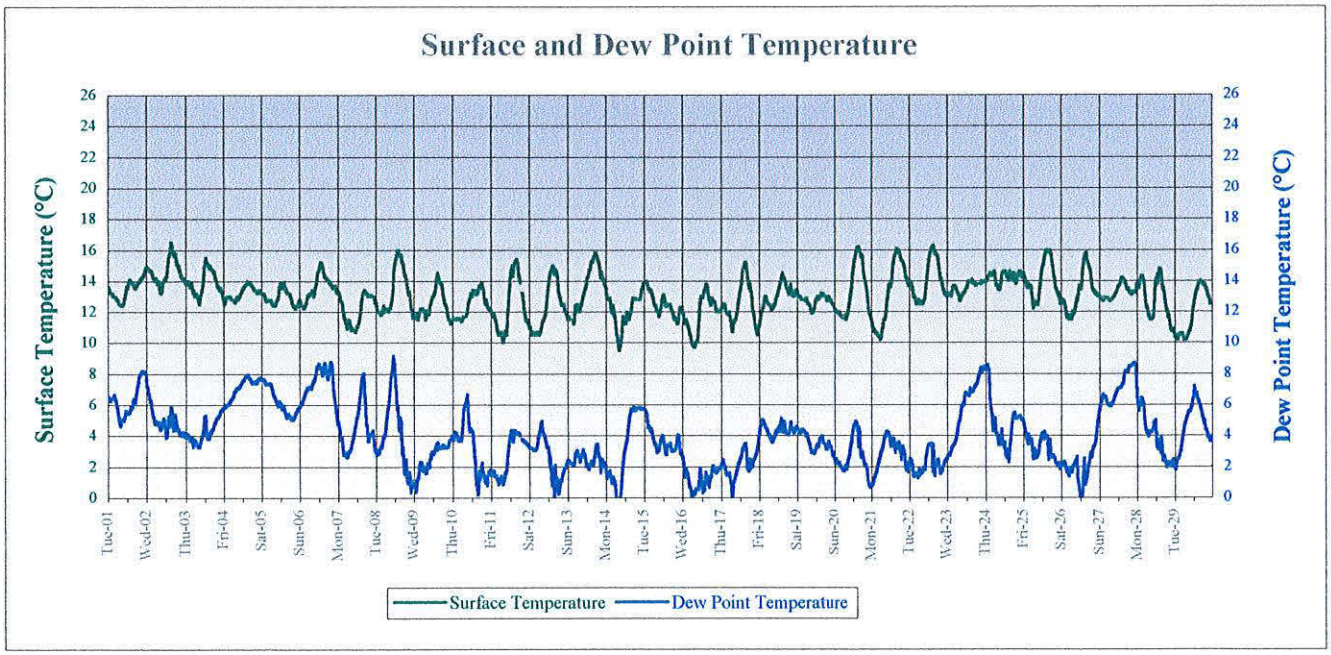


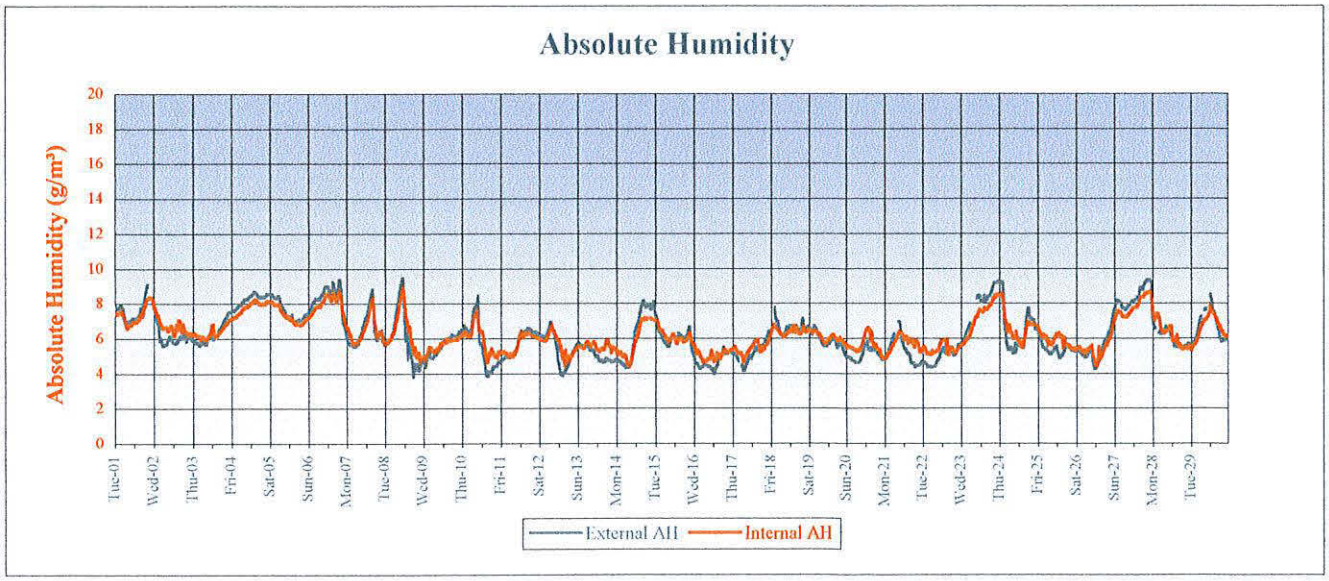
Peterborough Cathedral Nave Ceiling

February 2000

Probe 2: Bay 36 III upper side (shade)



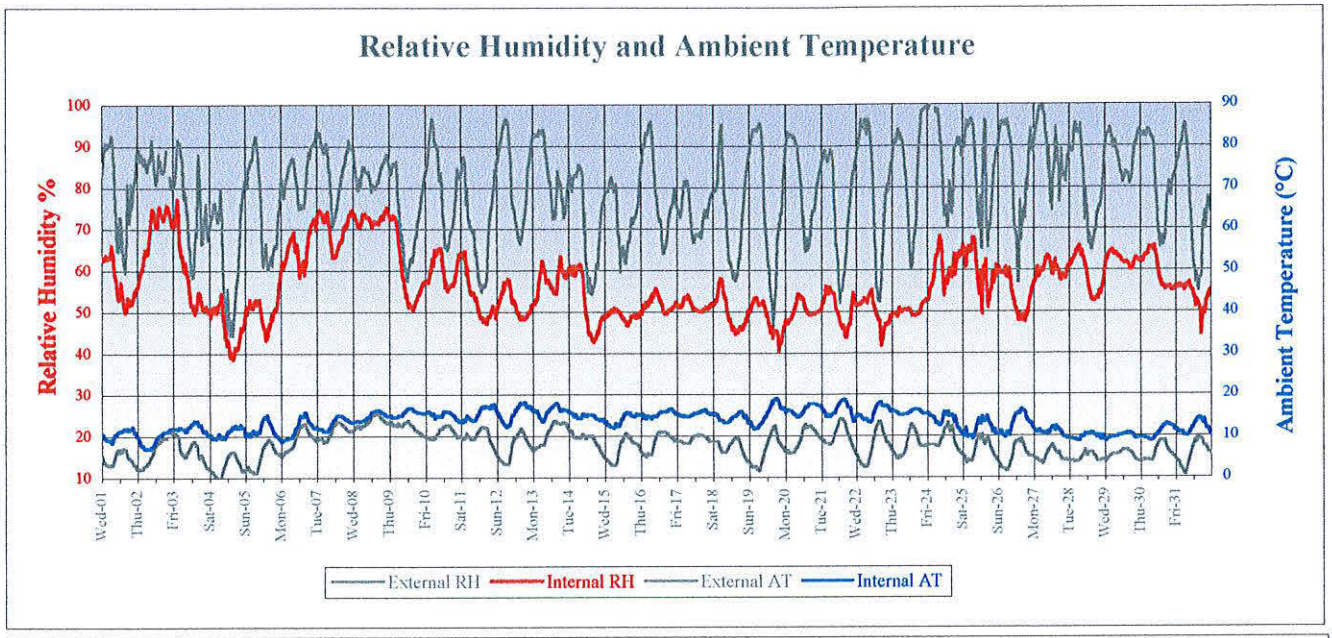


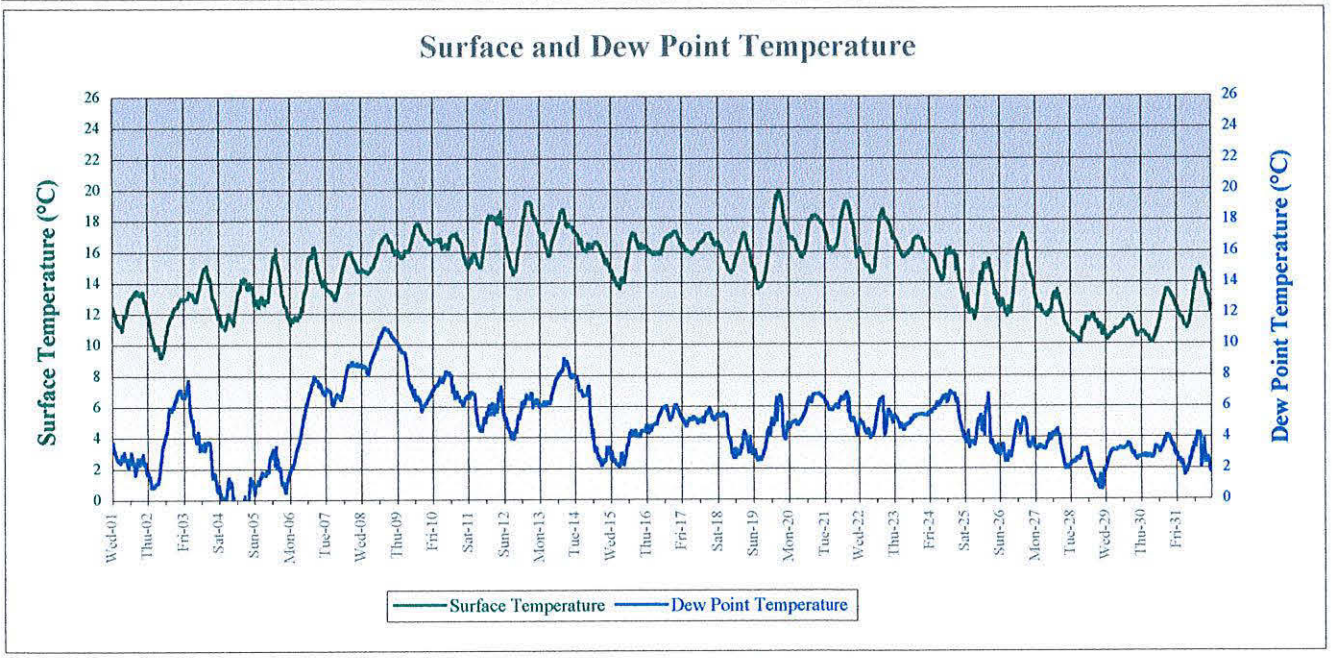


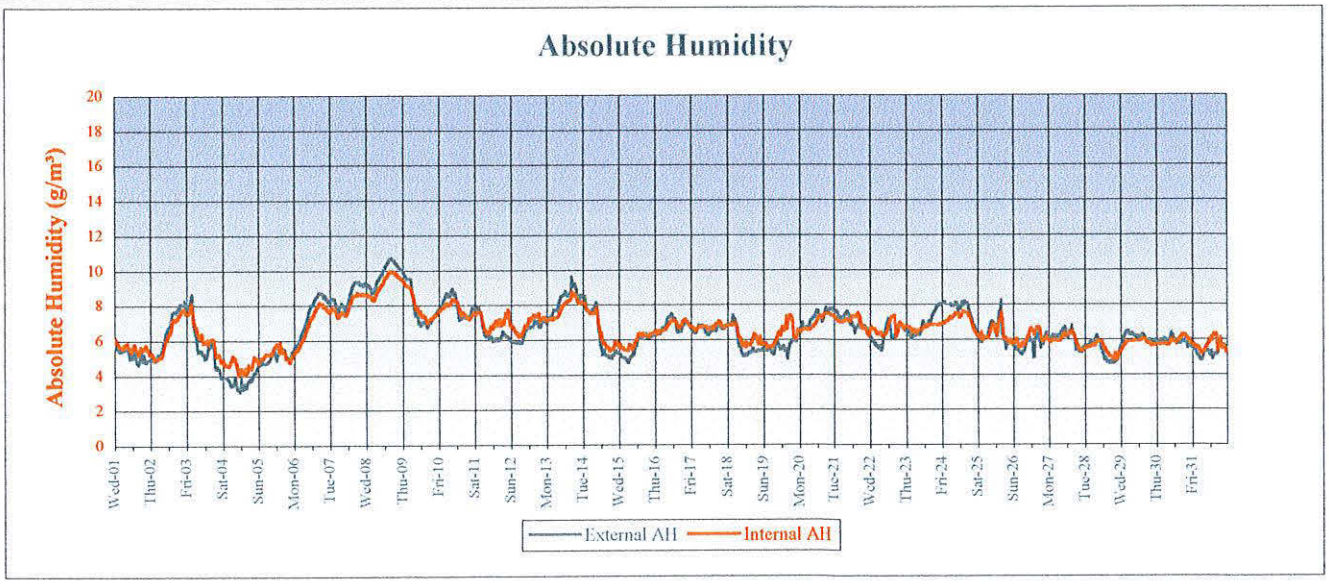
Peterborough Cathedral Nave Ceiling

March 2000

Probe 2: Bay 36 III upper side (shade)



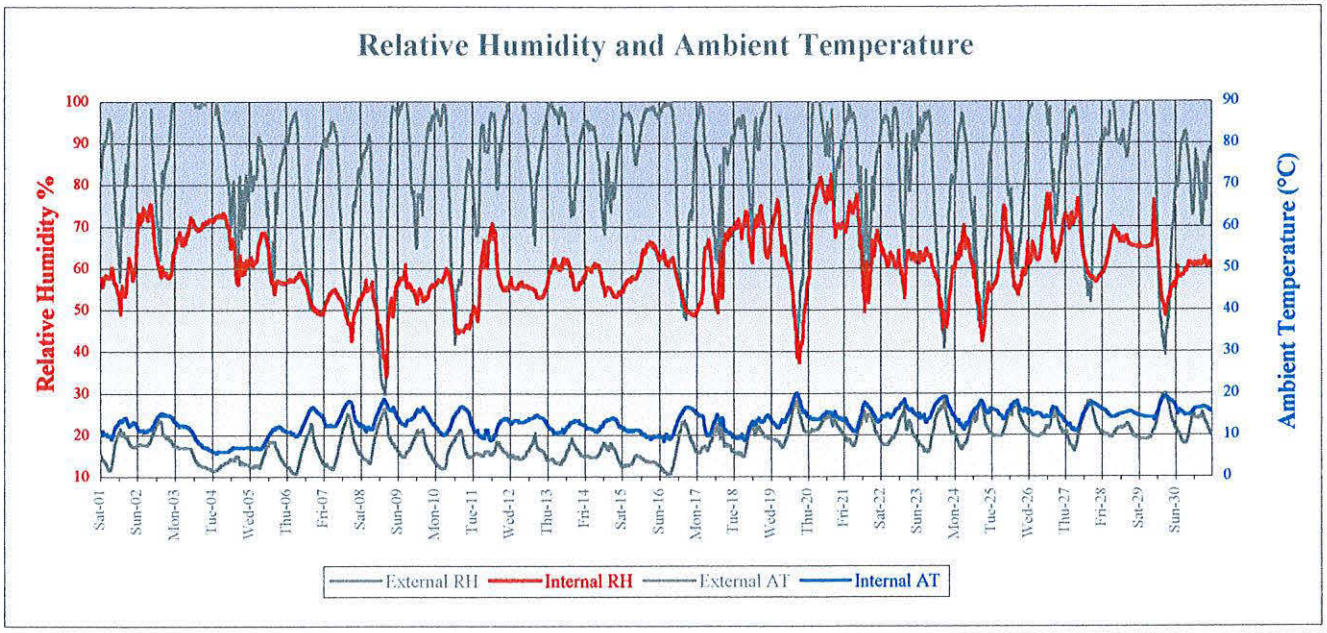


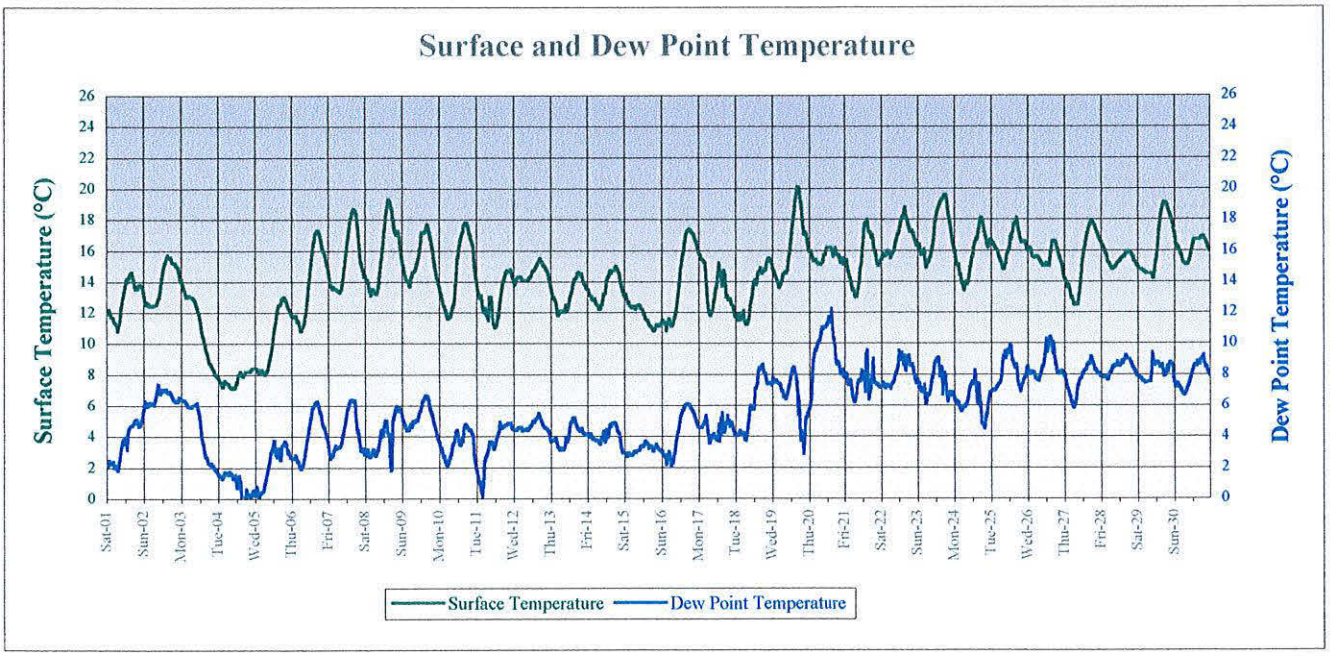


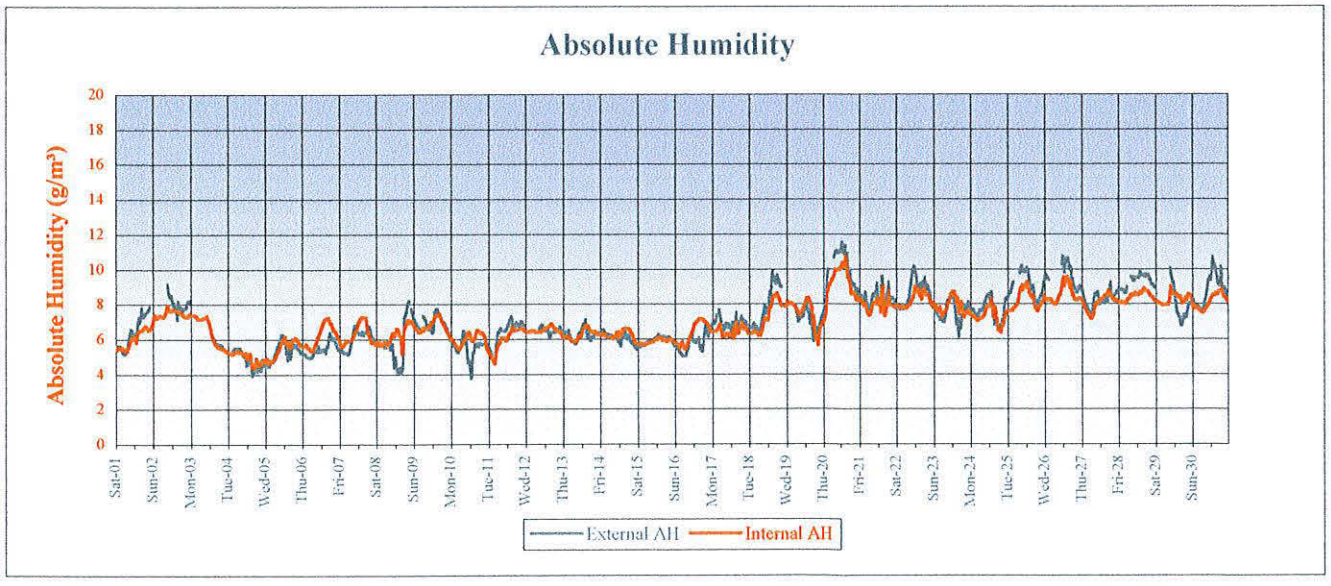
Peterborough Cathedral Nave Ceiling

April 2000

Probe 2: Bay 36 III upper side (shade)



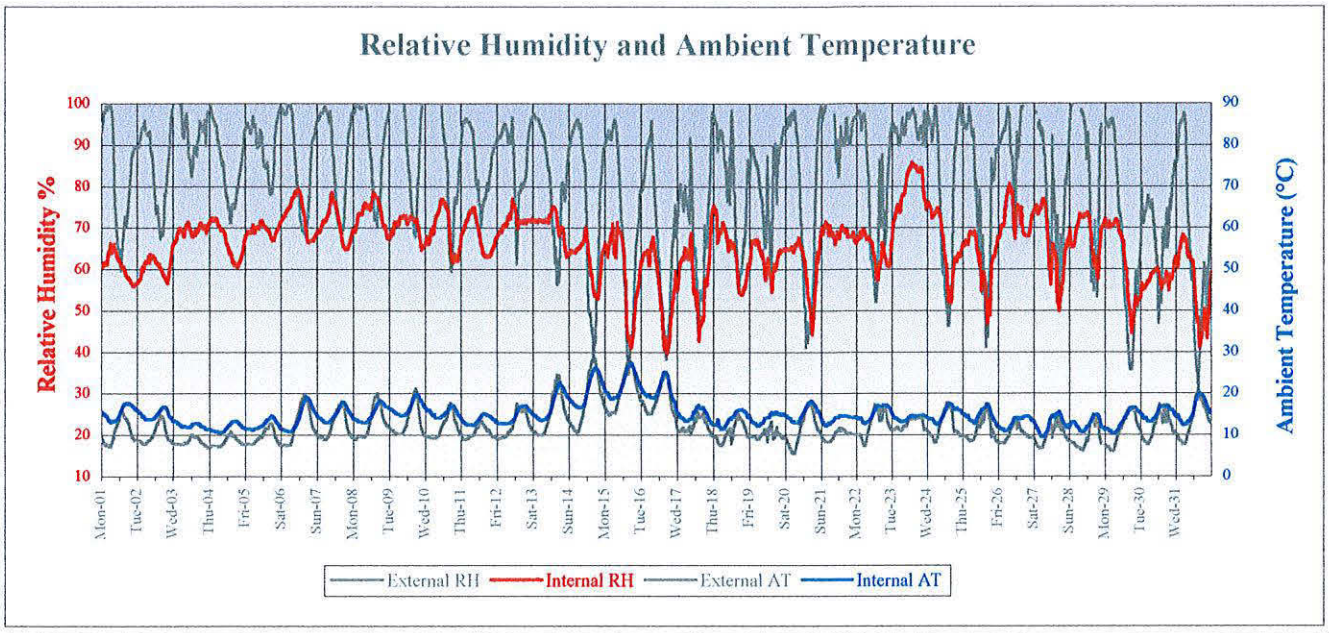


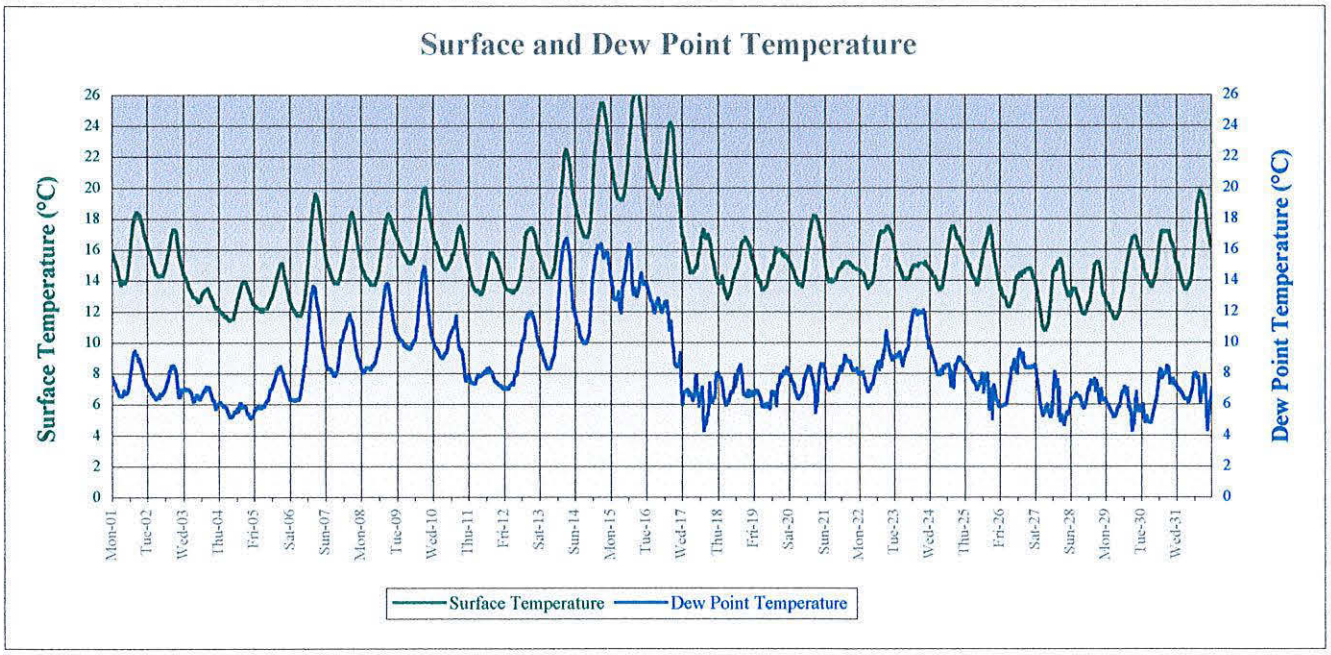


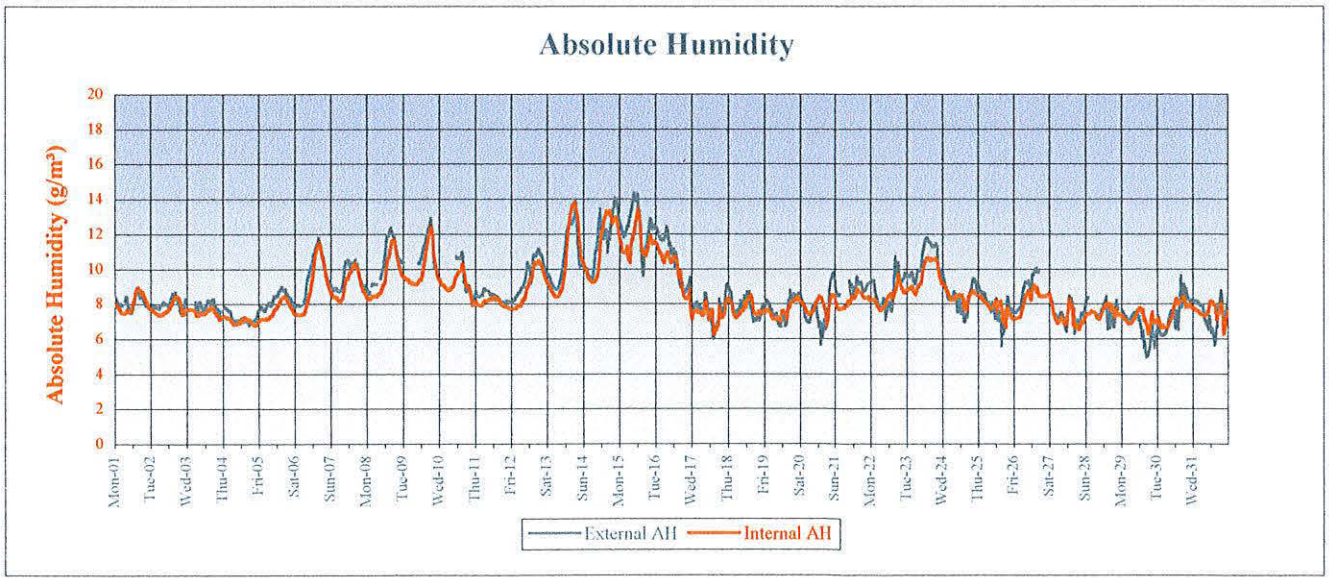
Peterborough Cathedral Nave Ceiling

May 2000

Probe 2: Bay 36 III upper side (shade)



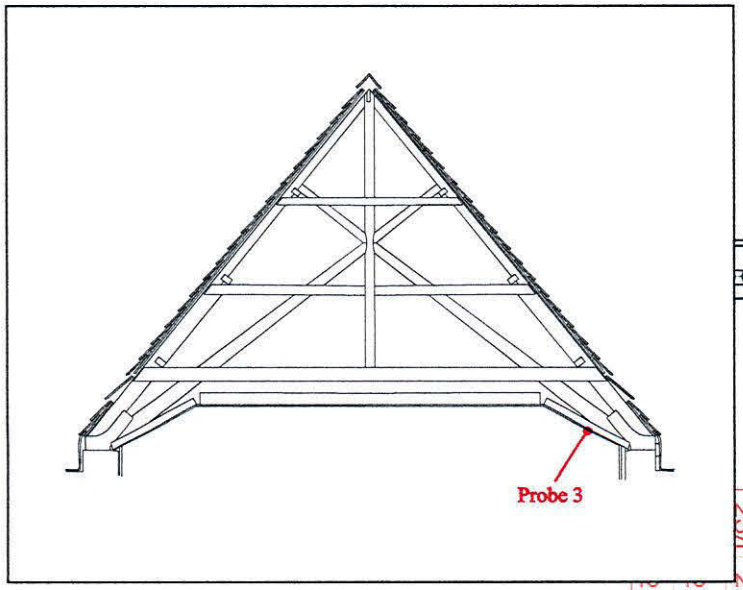


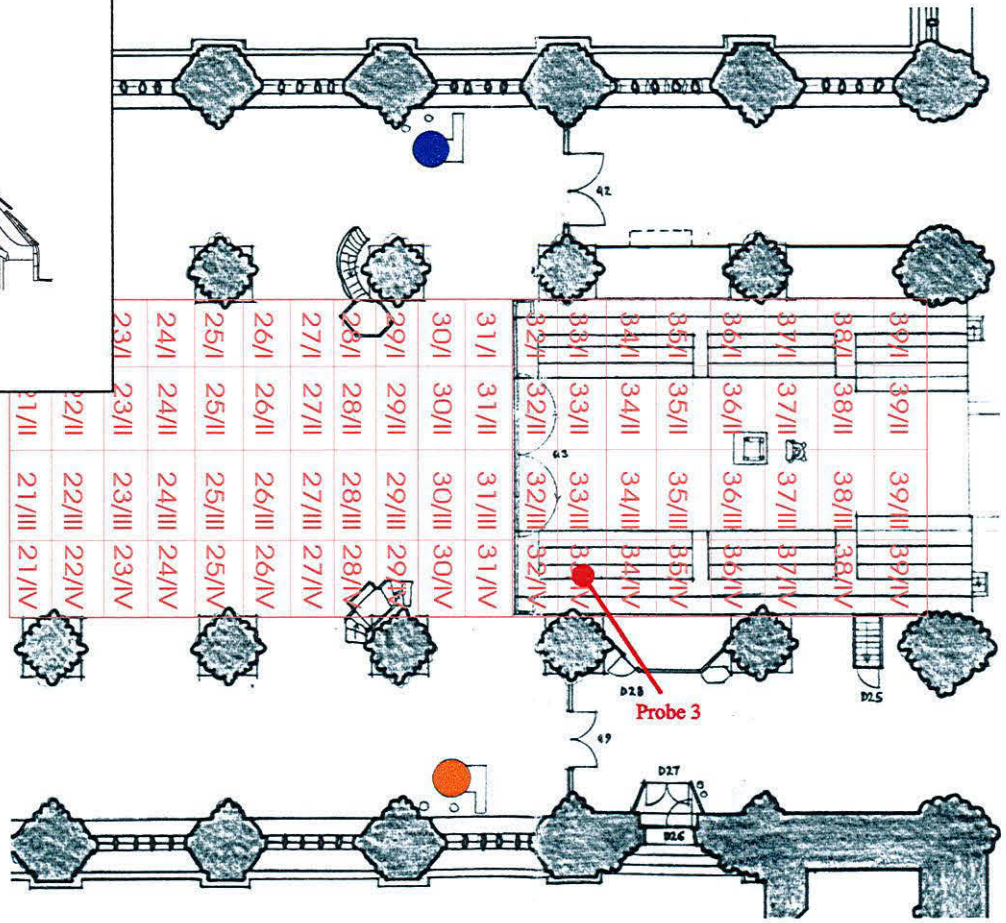


PROBE 3

BAY 33 IV LOWER SIDE (SUN)

DIAGRAM 5



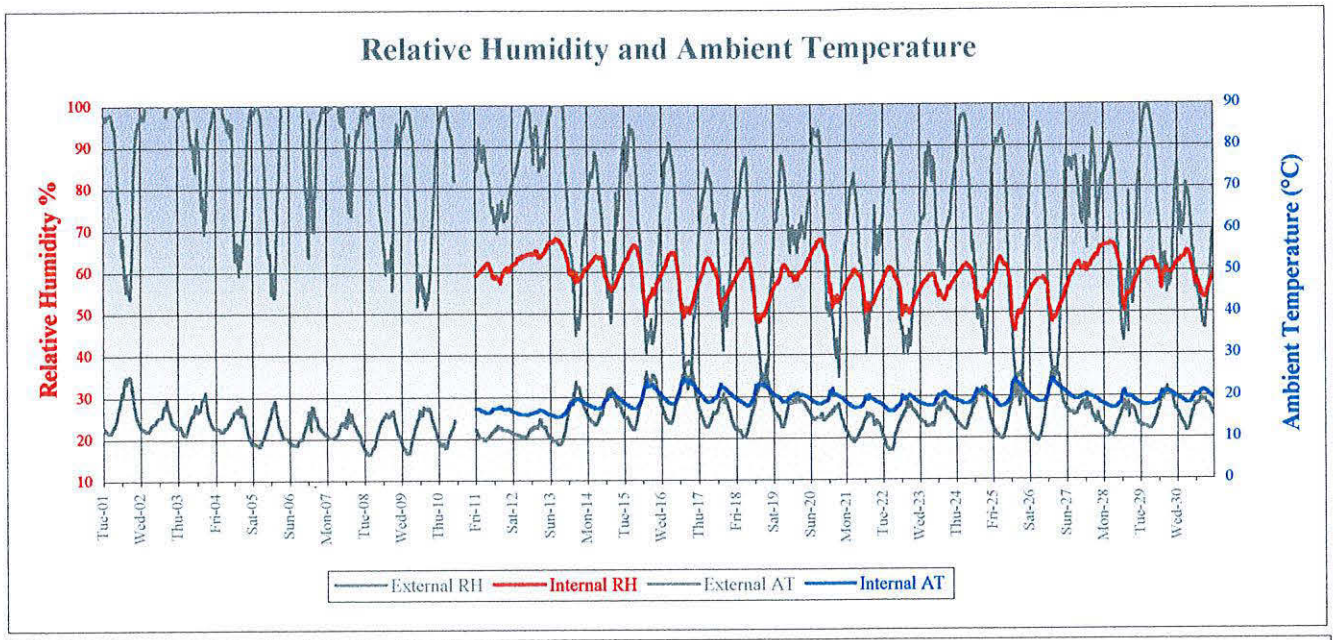


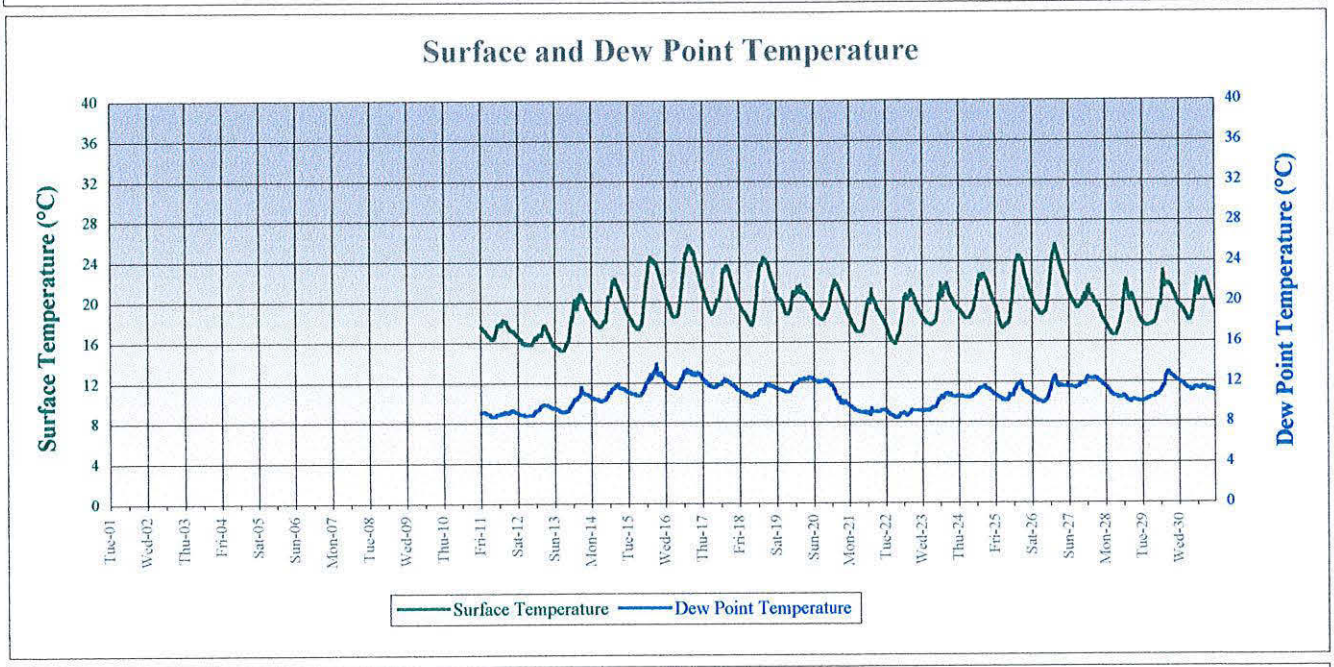
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

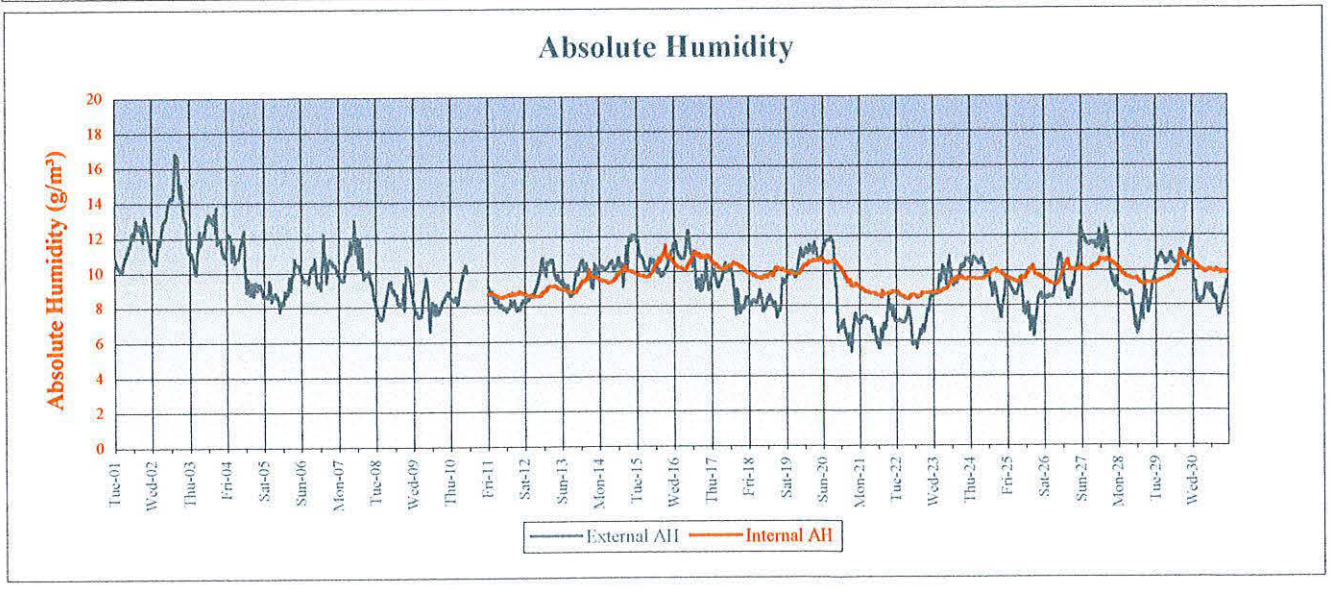
Peterborough Cathedral Nave Ceiling

June 1999

Probe 3: Bay 33 III lower side (sun)



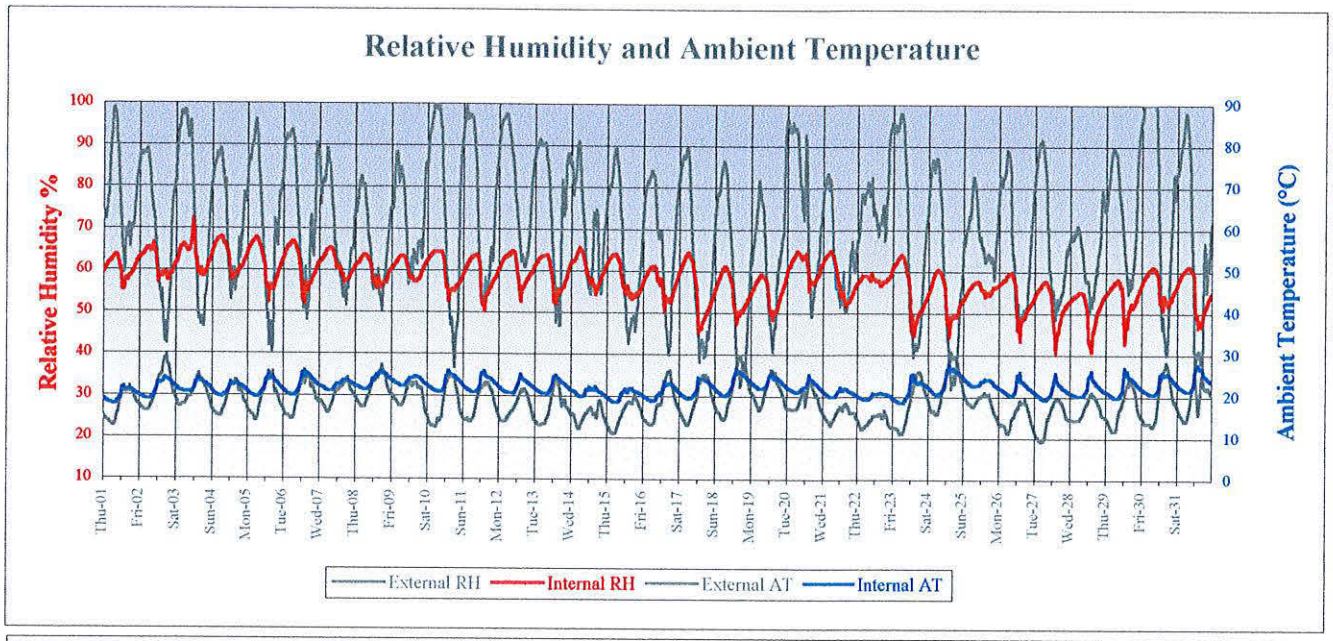


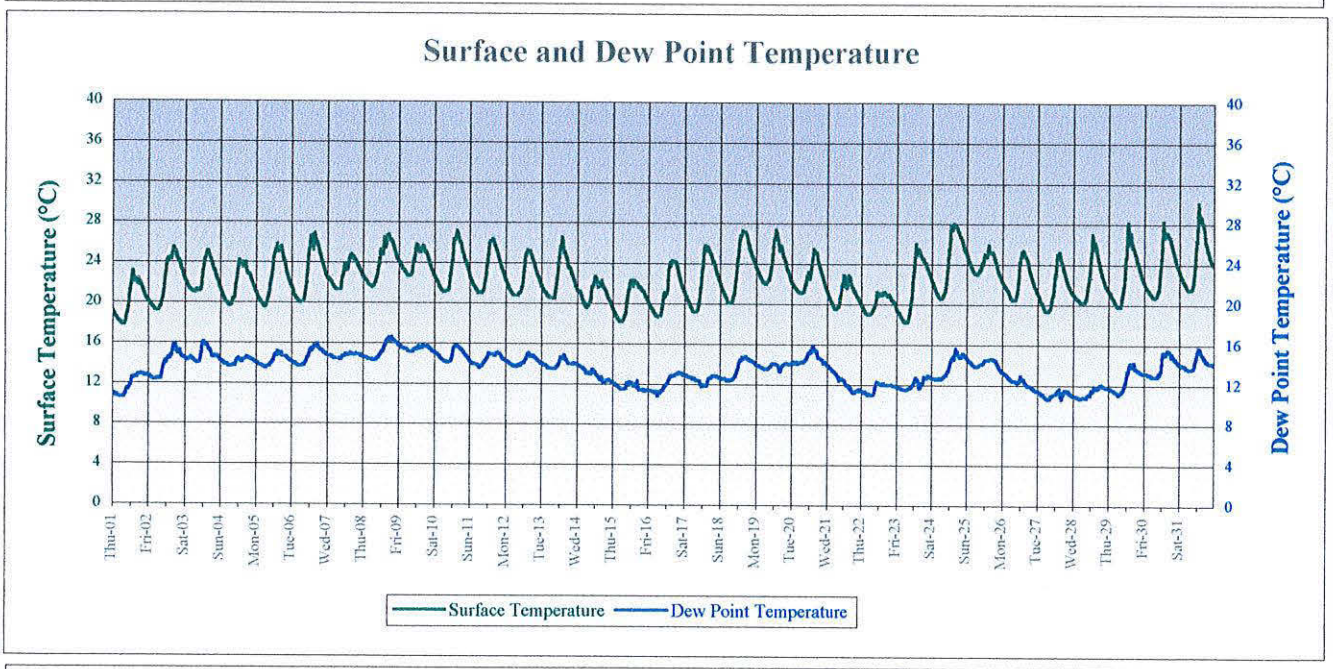


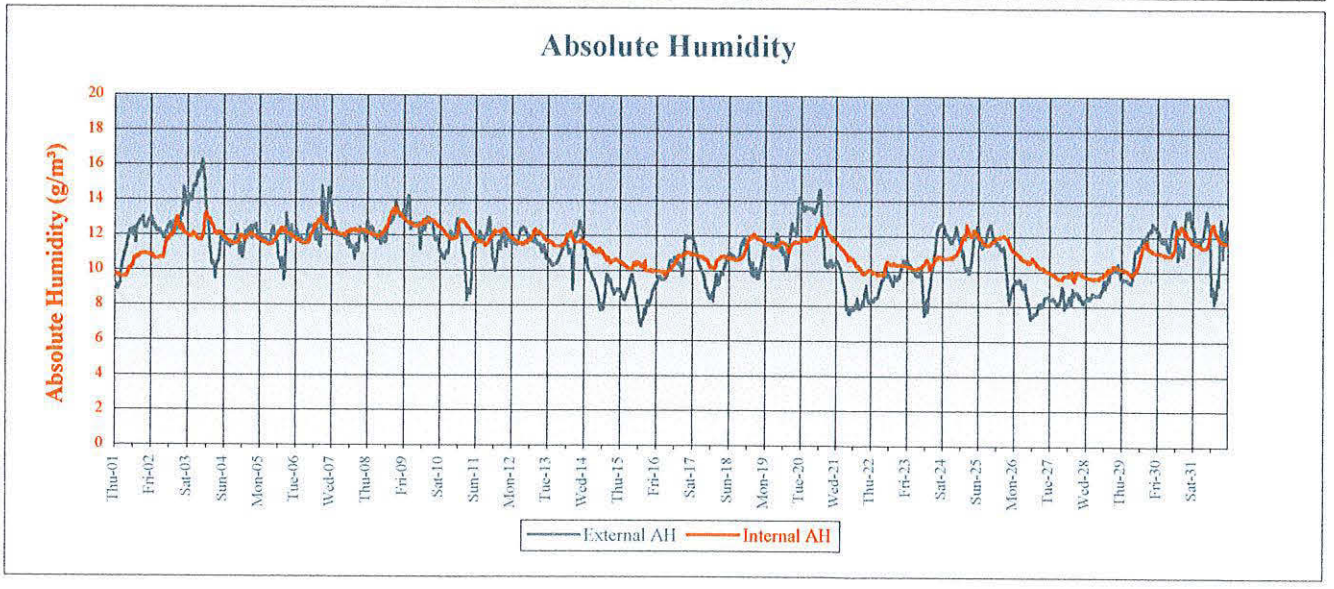
Peterborough Cathedral Nave Ceiling

July 1999

Probe 3: Bay 33 III lower side (sun)



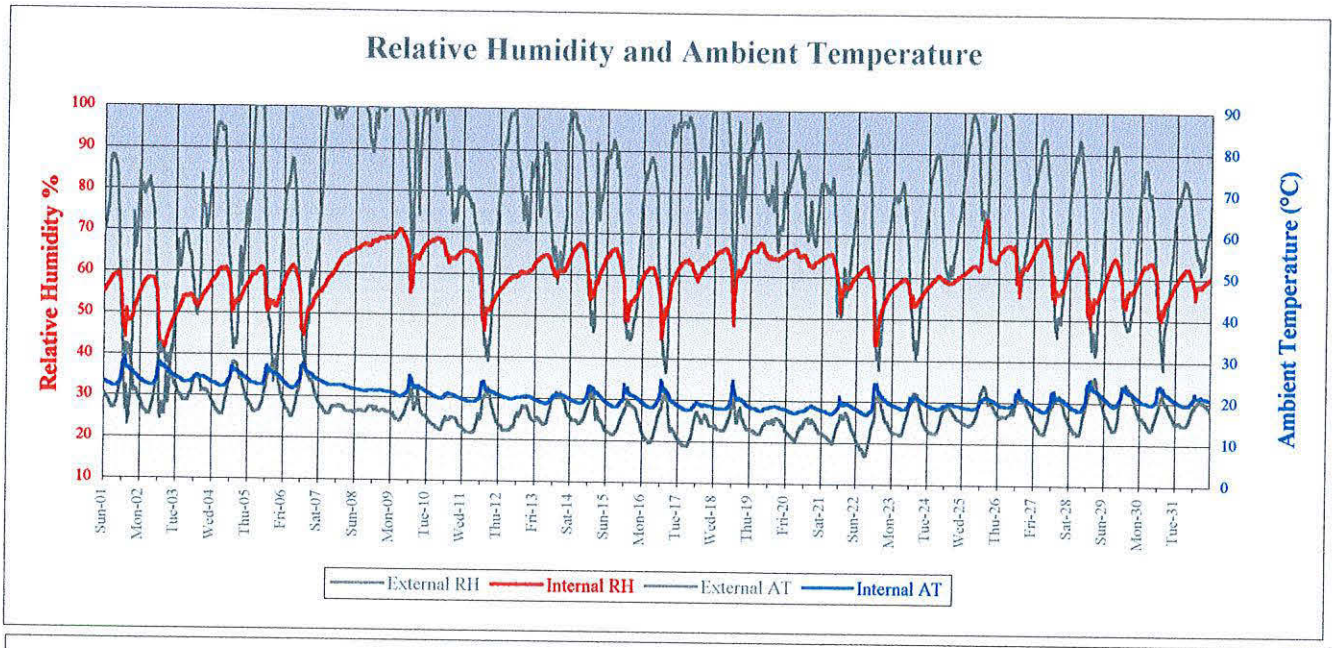


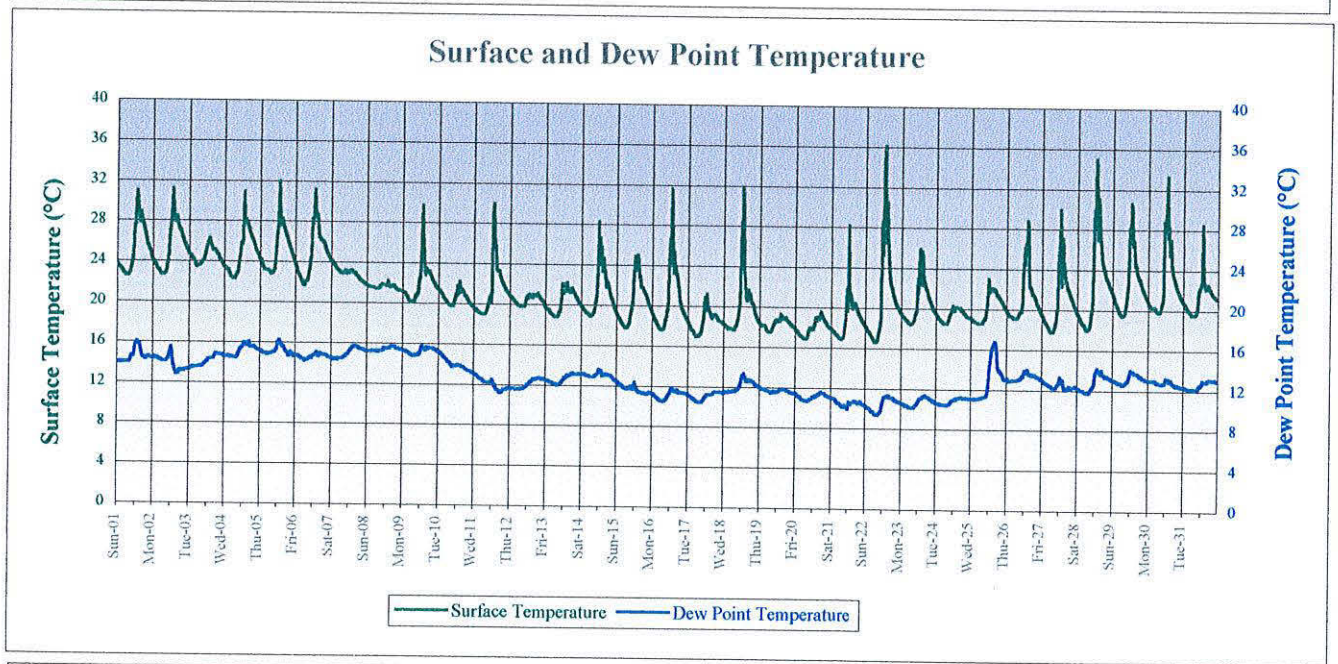


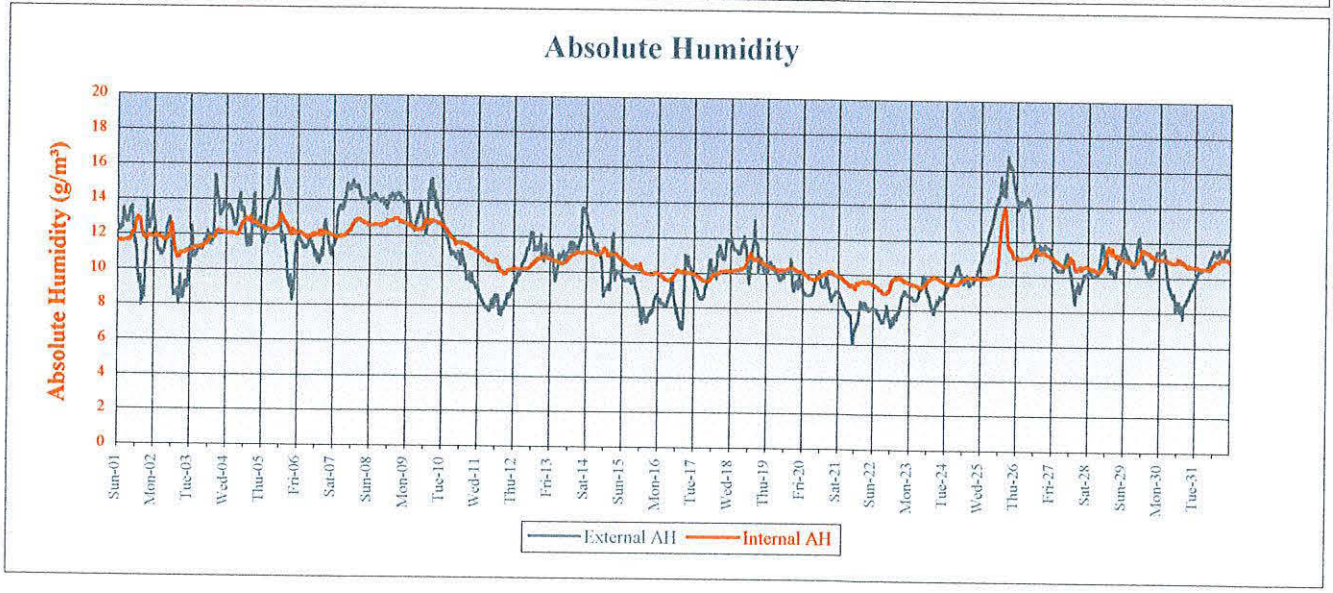
Peterborough Cathedral Nave Ceiling

August 1999

Probe 3: Bay 33 III lower side (sun)



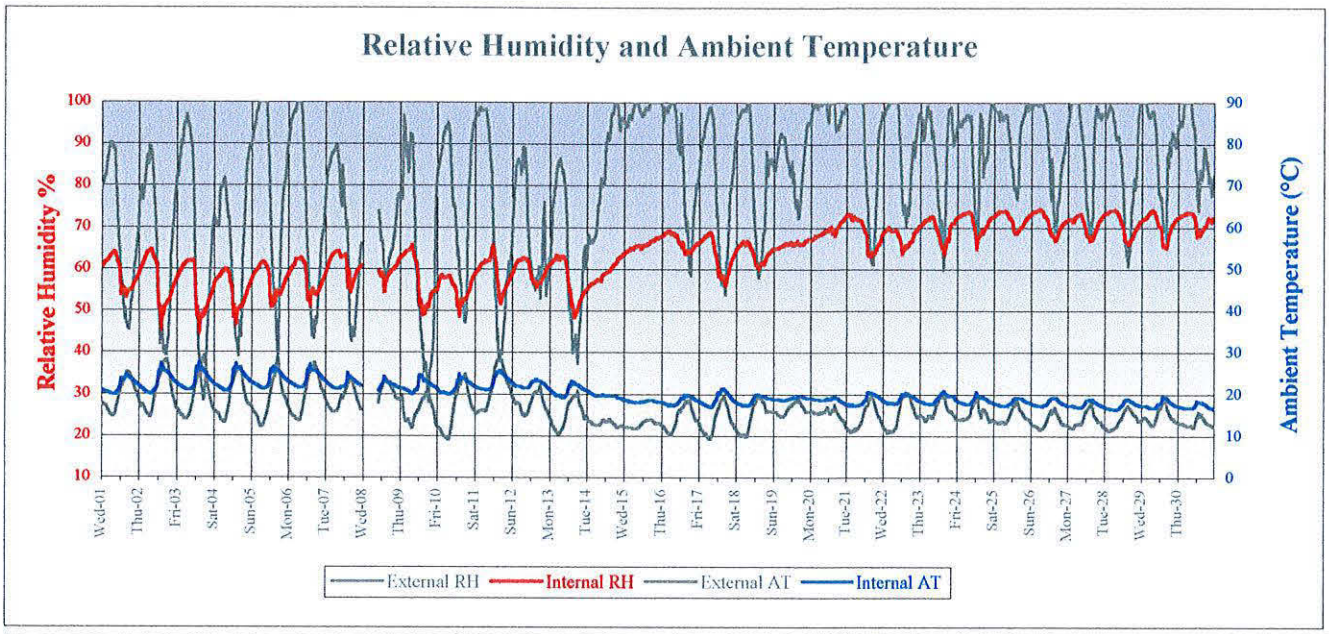


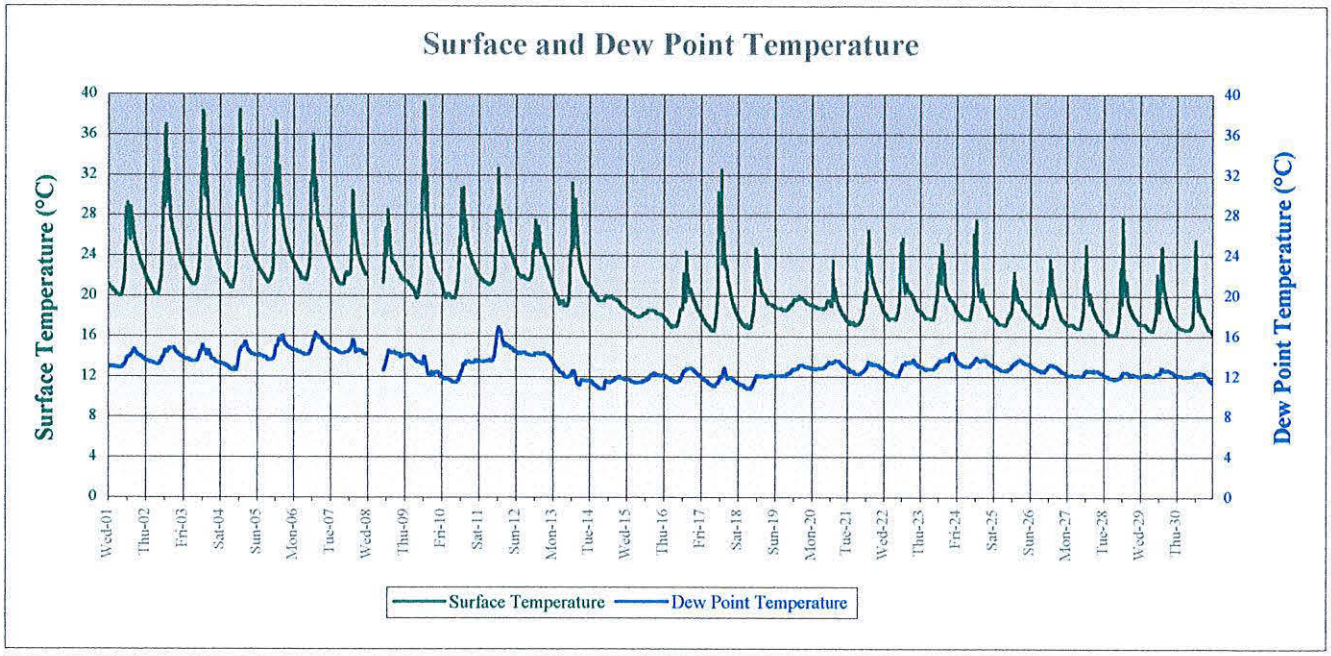


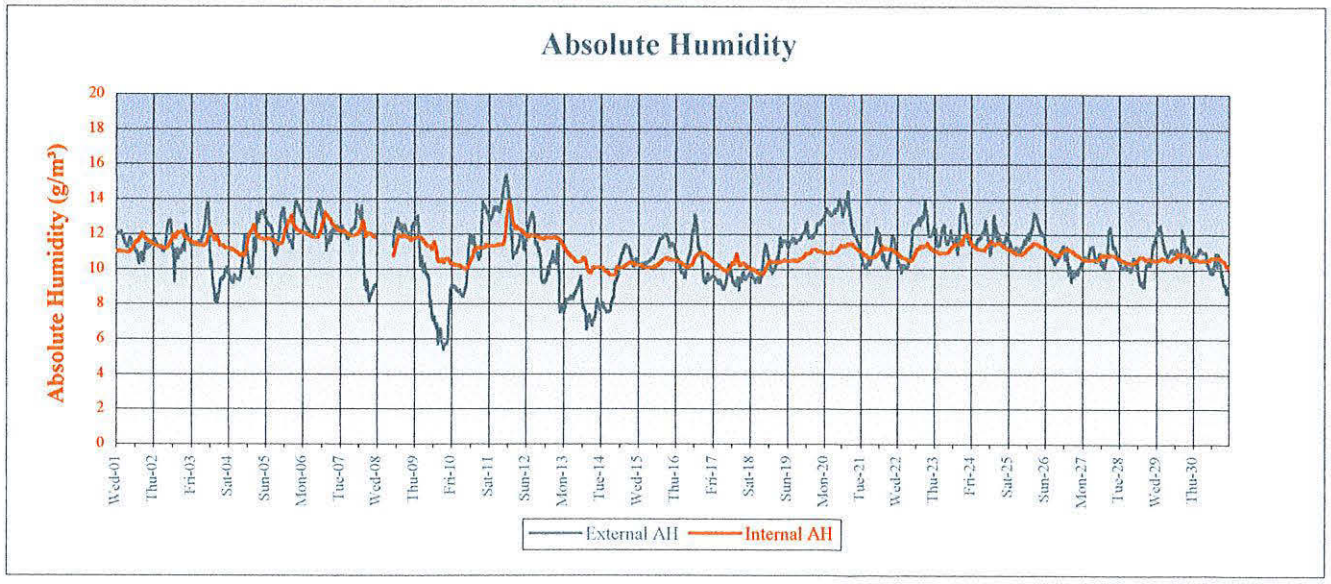
Peterborough Cathedral Nave Ceiling

September 1999

Probe 3: Bay 33 III lower side (sun)



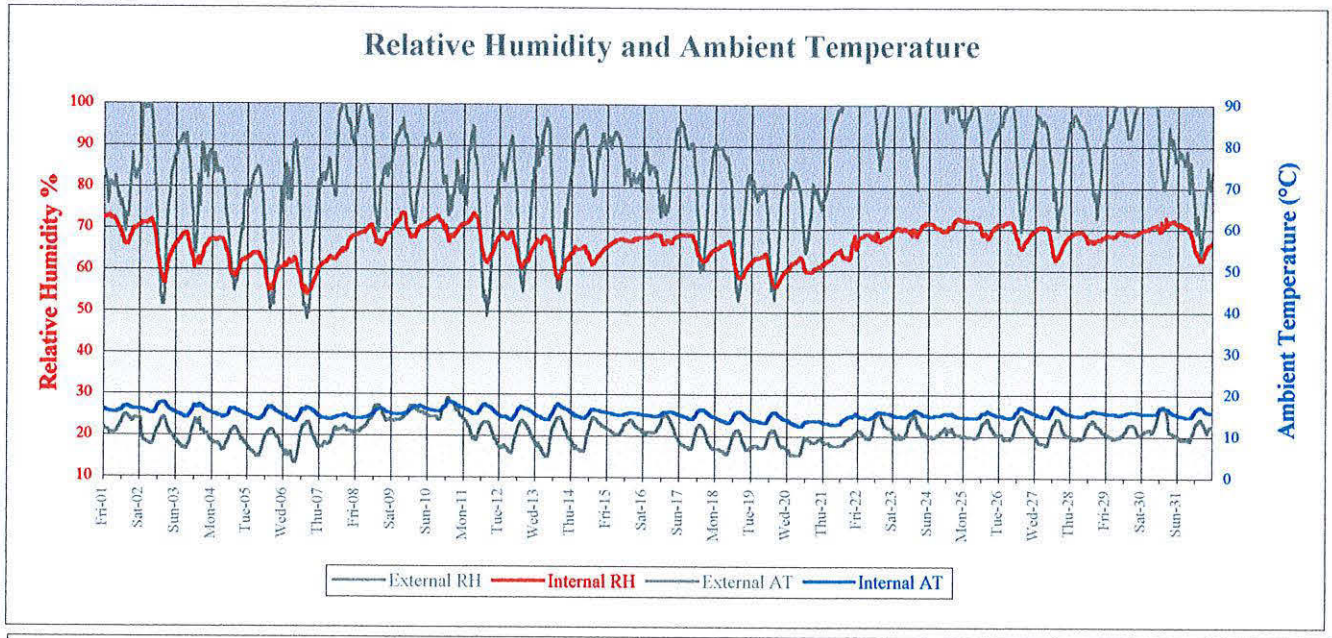


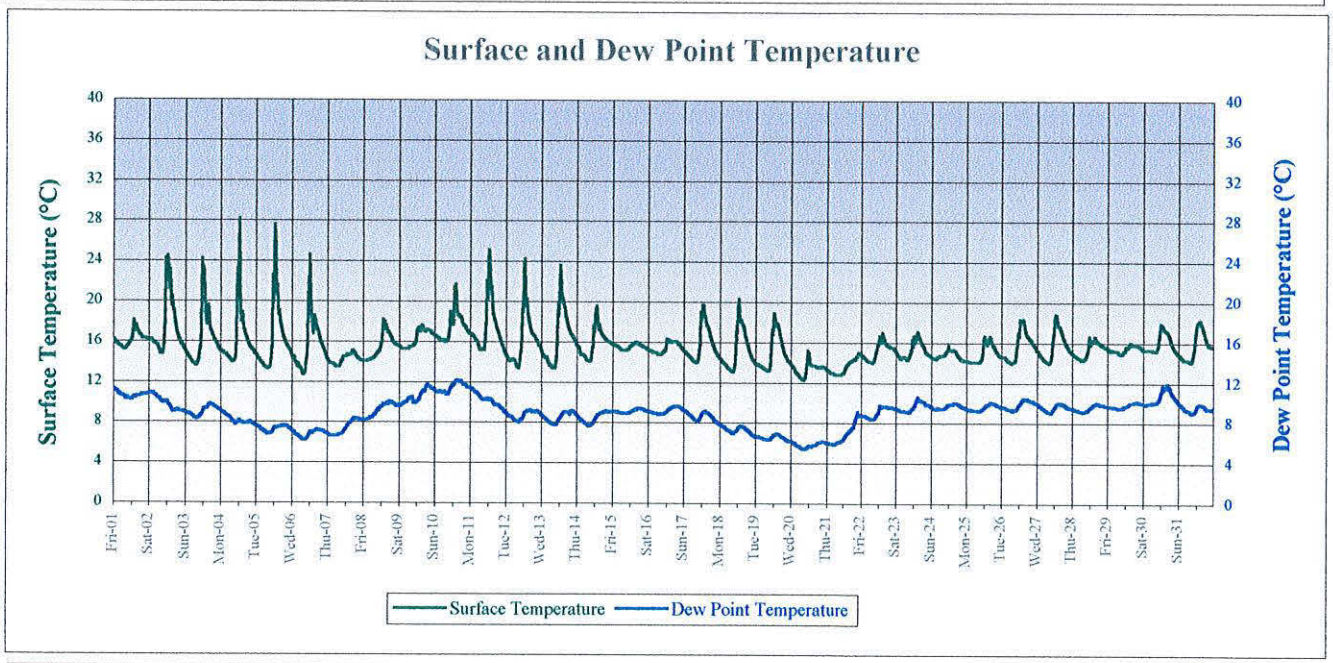


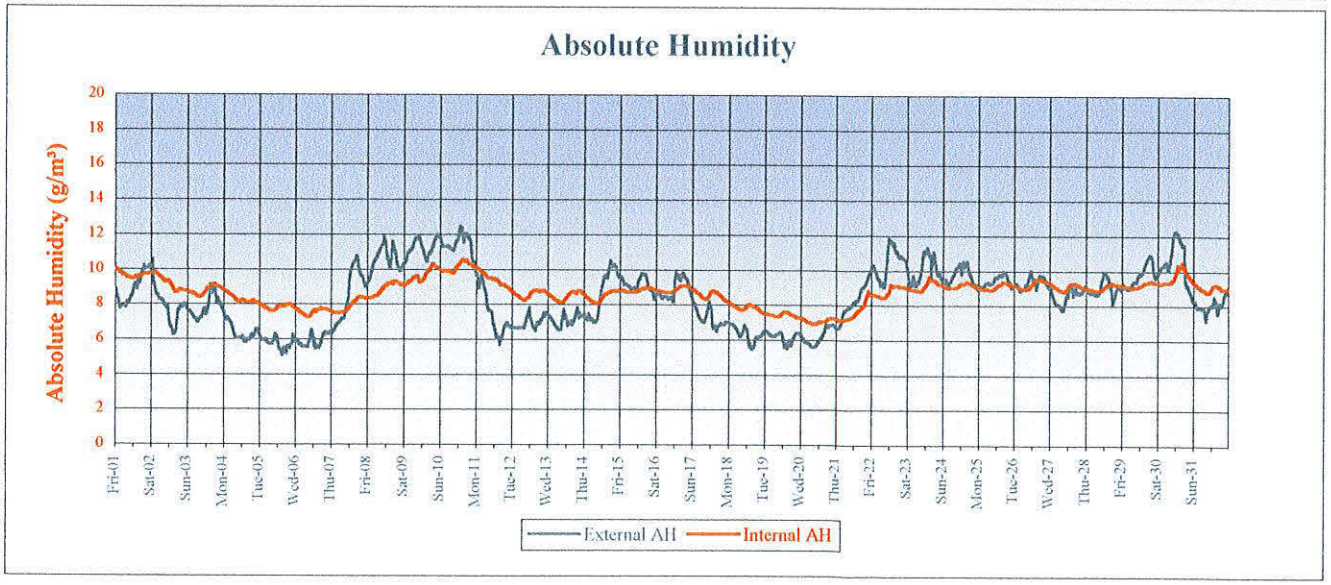
Peterborough Cathedral Nave Ceiling

October 1999

Probe 3: Bay 33 III lower side (sun)



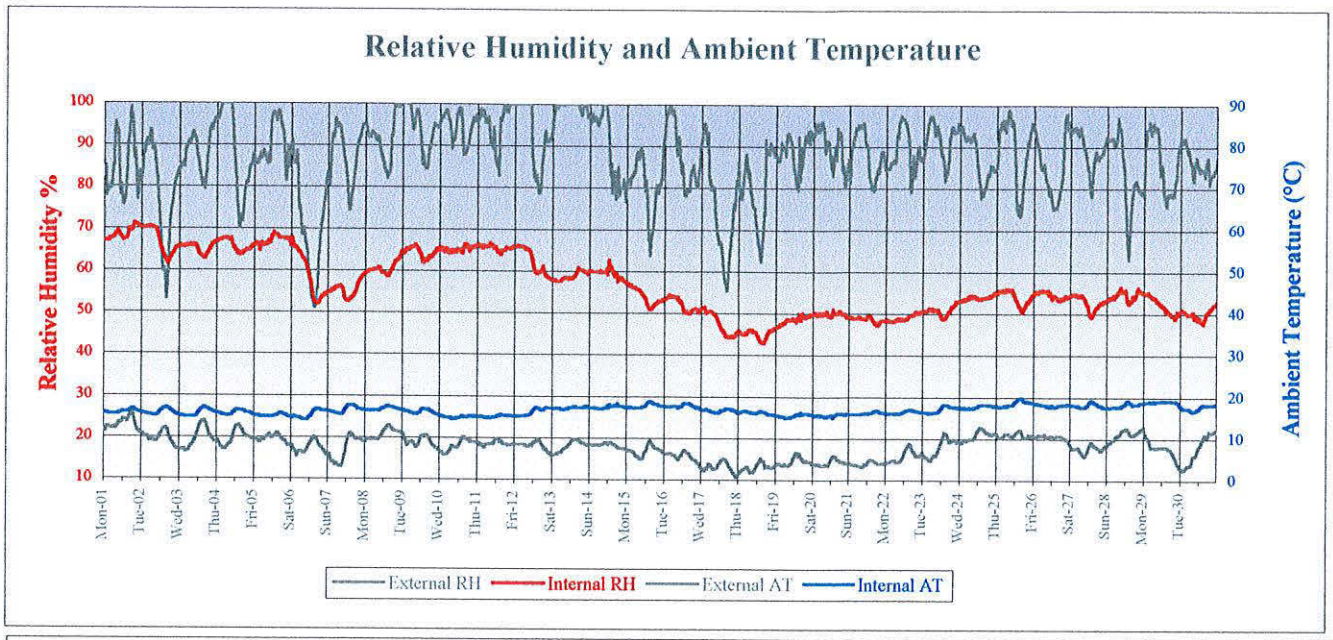


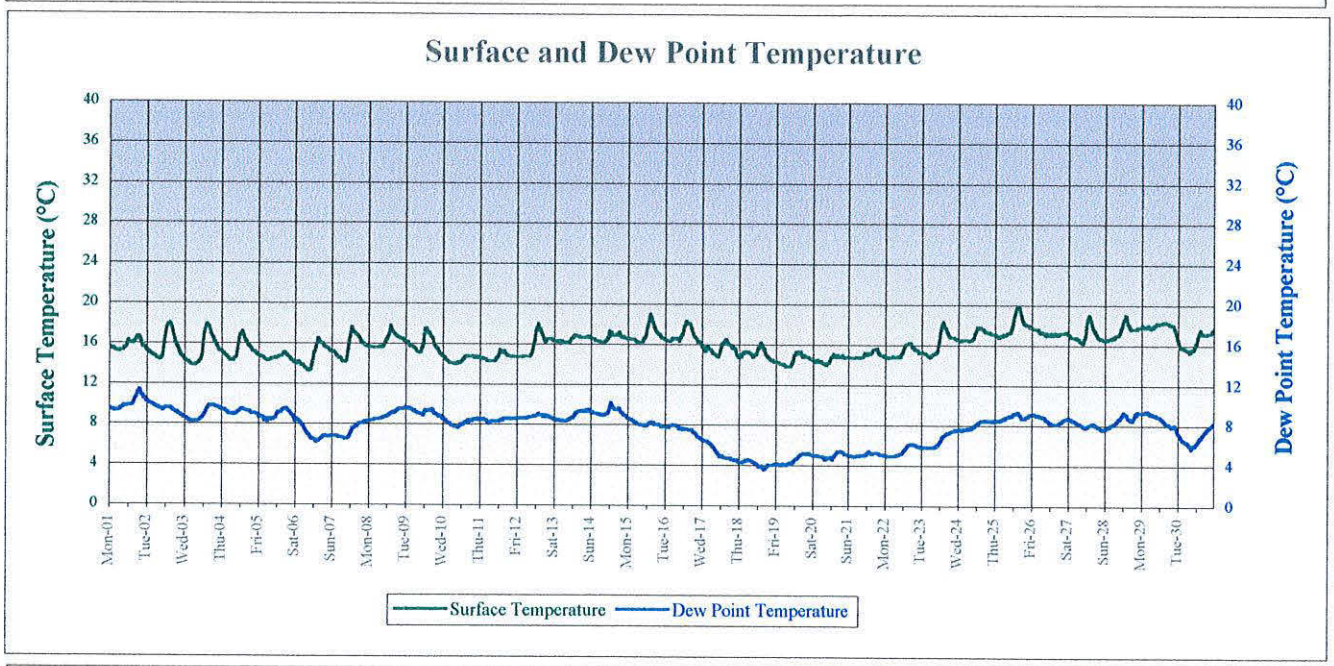


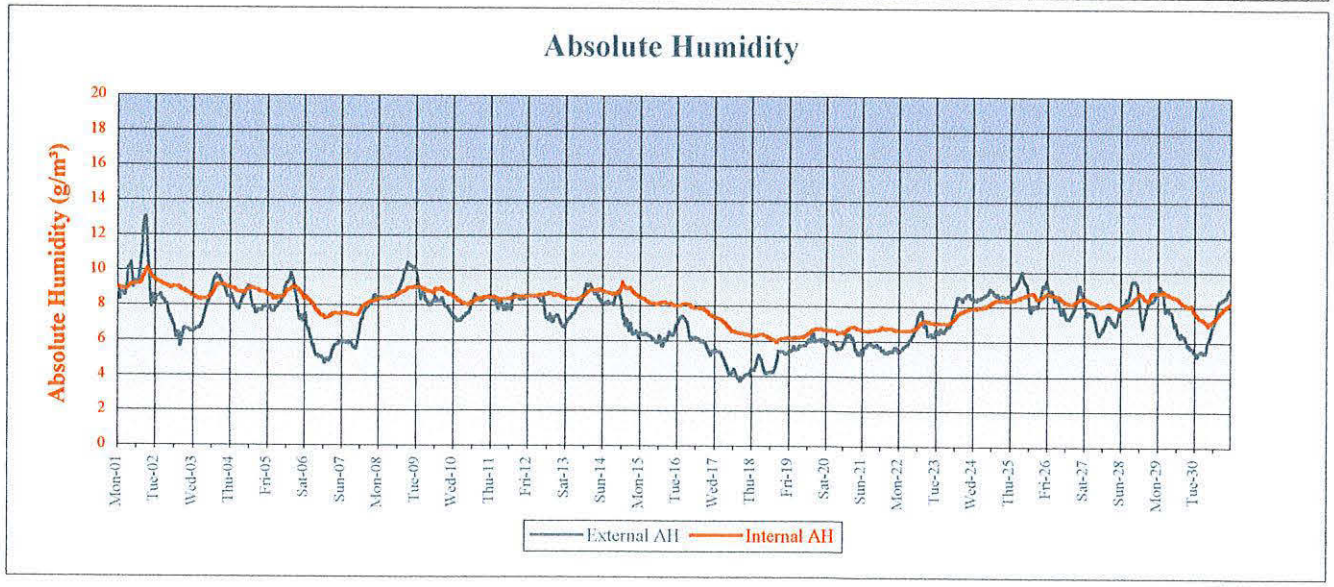
Peterborough Cathedral Nave Ceiling

November 1999

Probe 3: Bay 33 III lower side (sun)



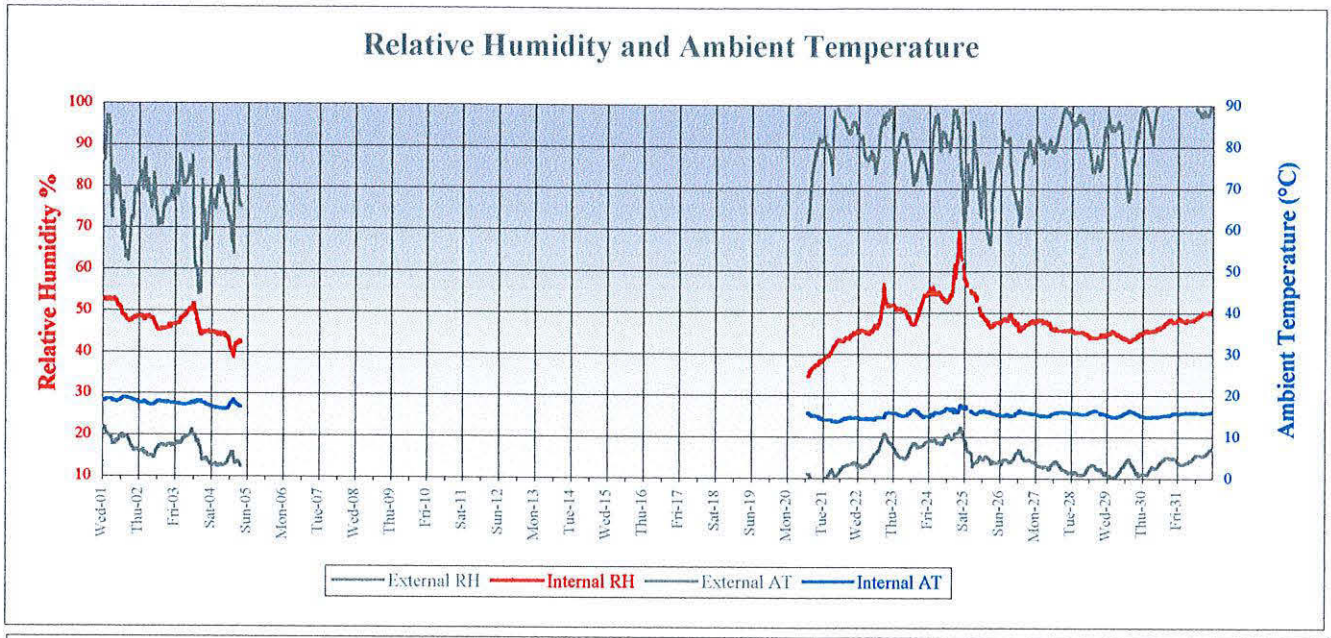


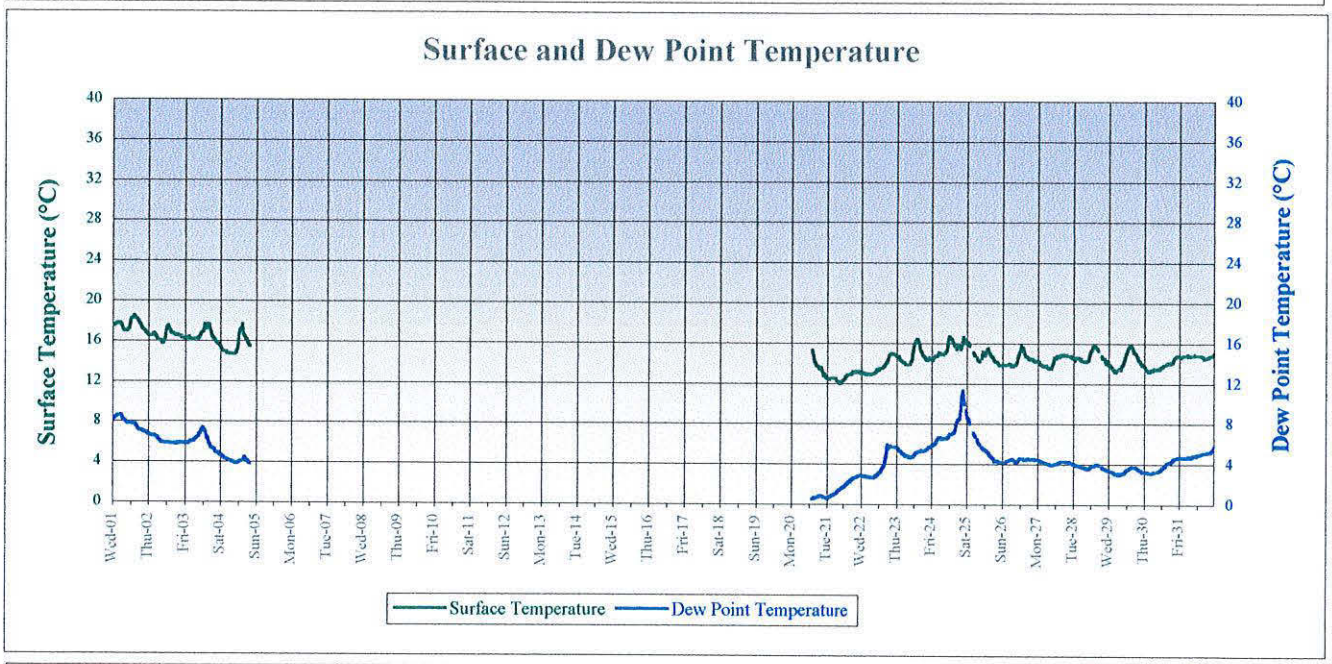


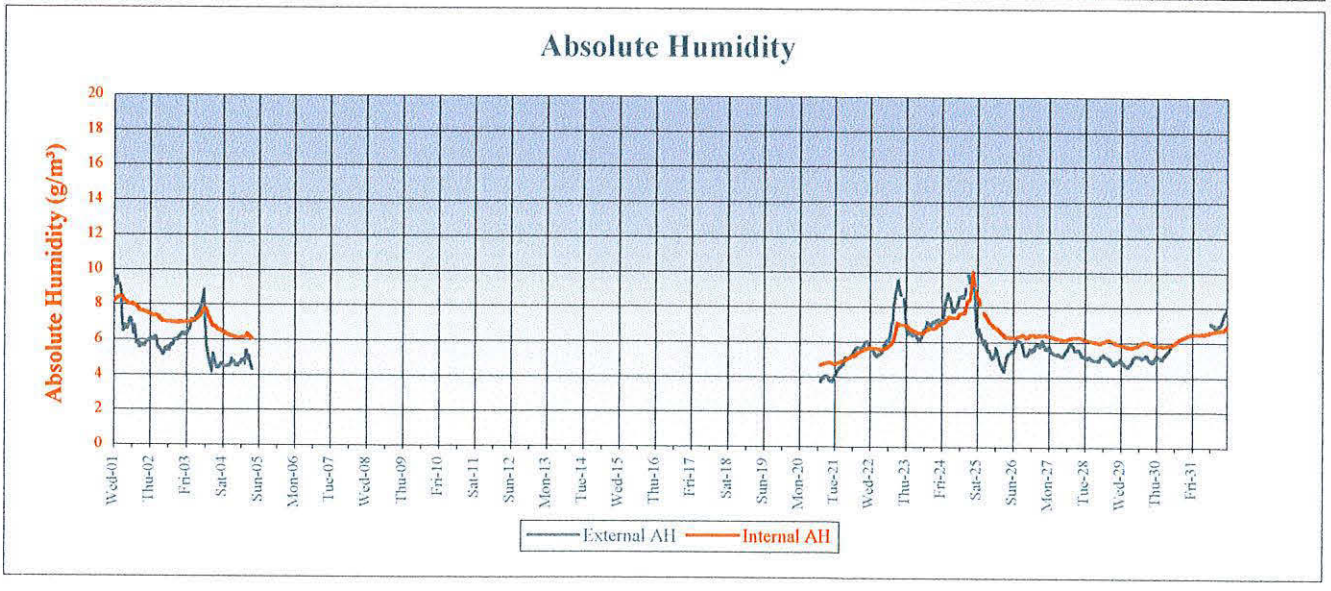
Peterborough Cathedral Nave Ceiling

December 1999

Probe 3: Bay 33 III lower side (sun)



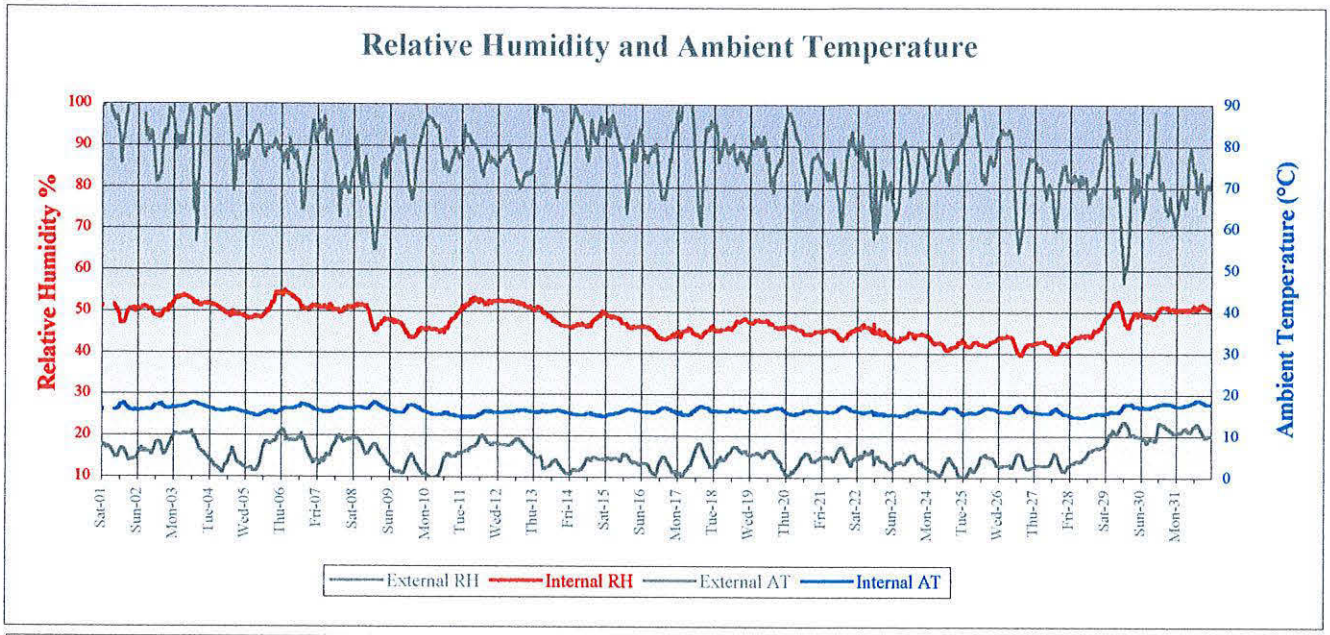


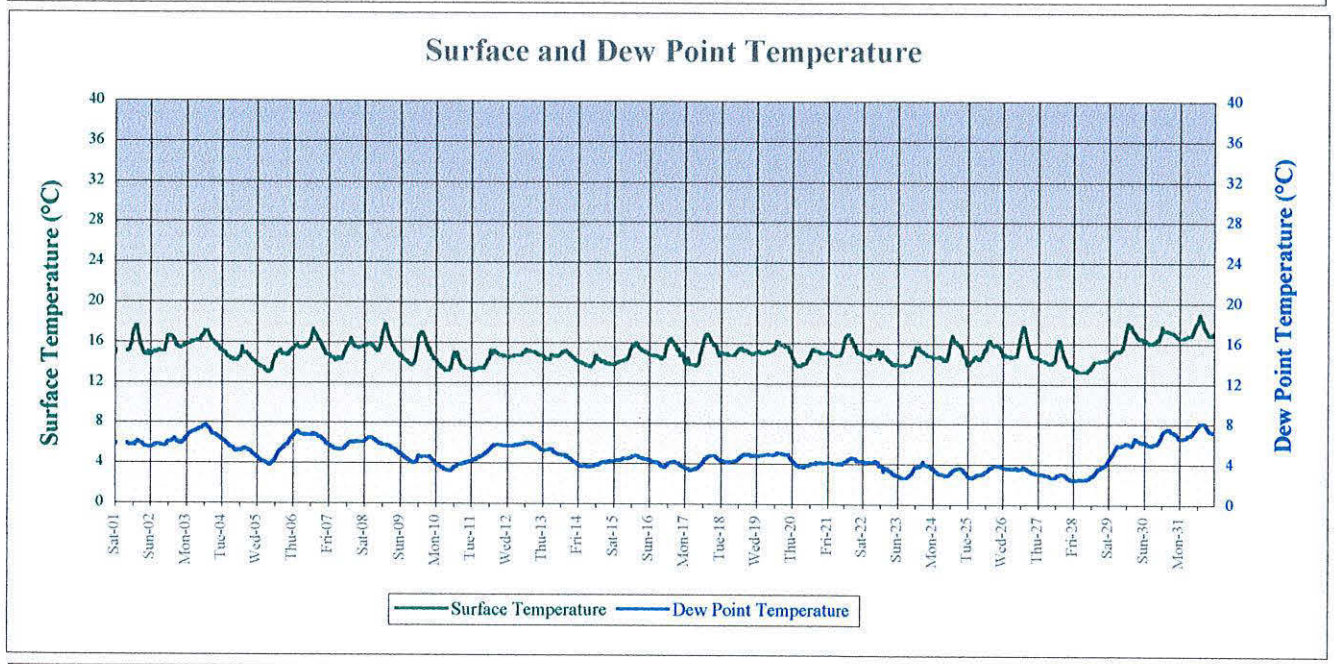


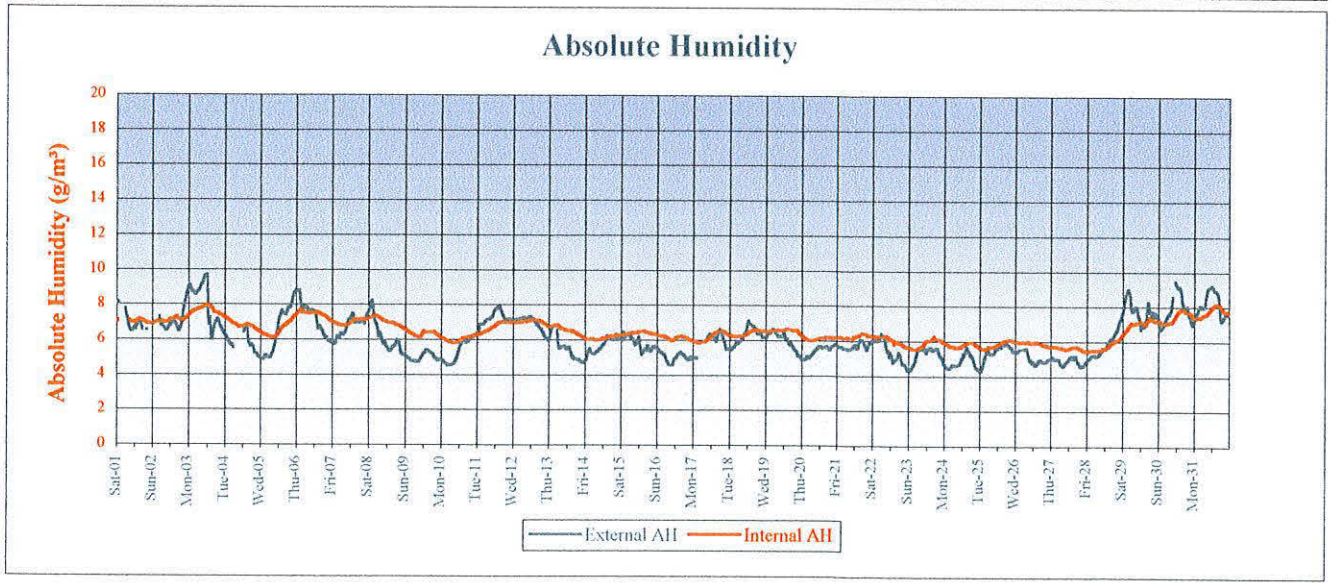
Peterborough Cathedral Nave Ceiling

January 2000

Probe 3: Bay 33 III lower side (sun)



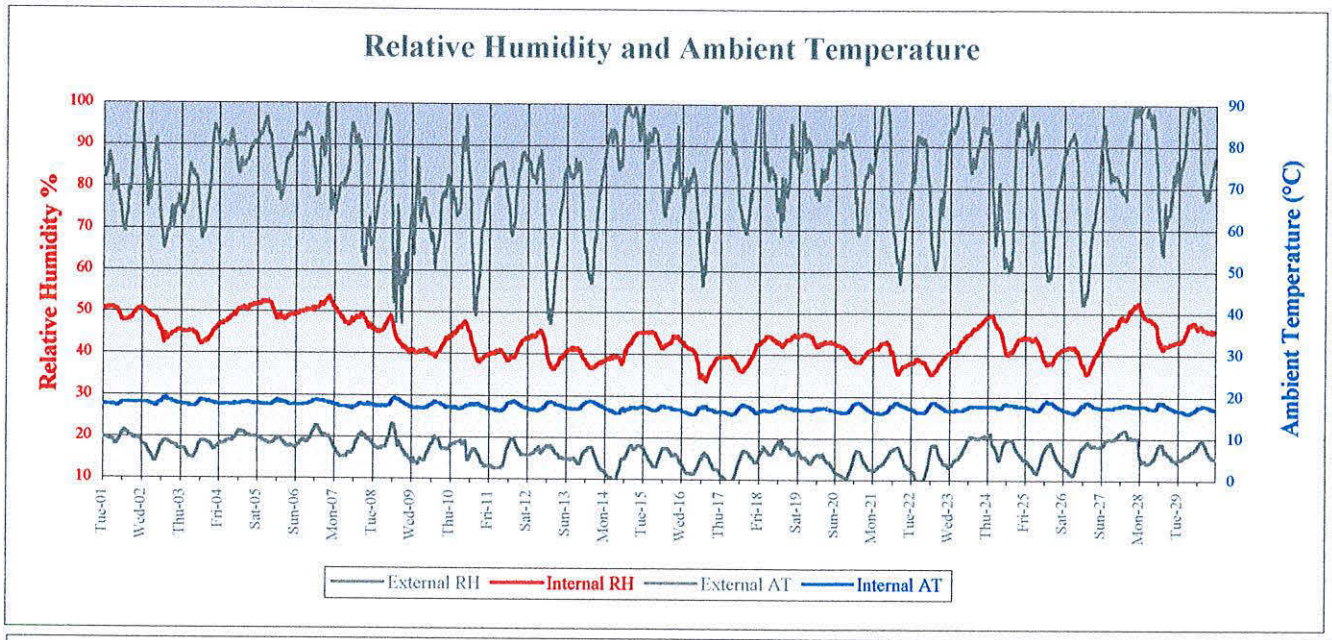


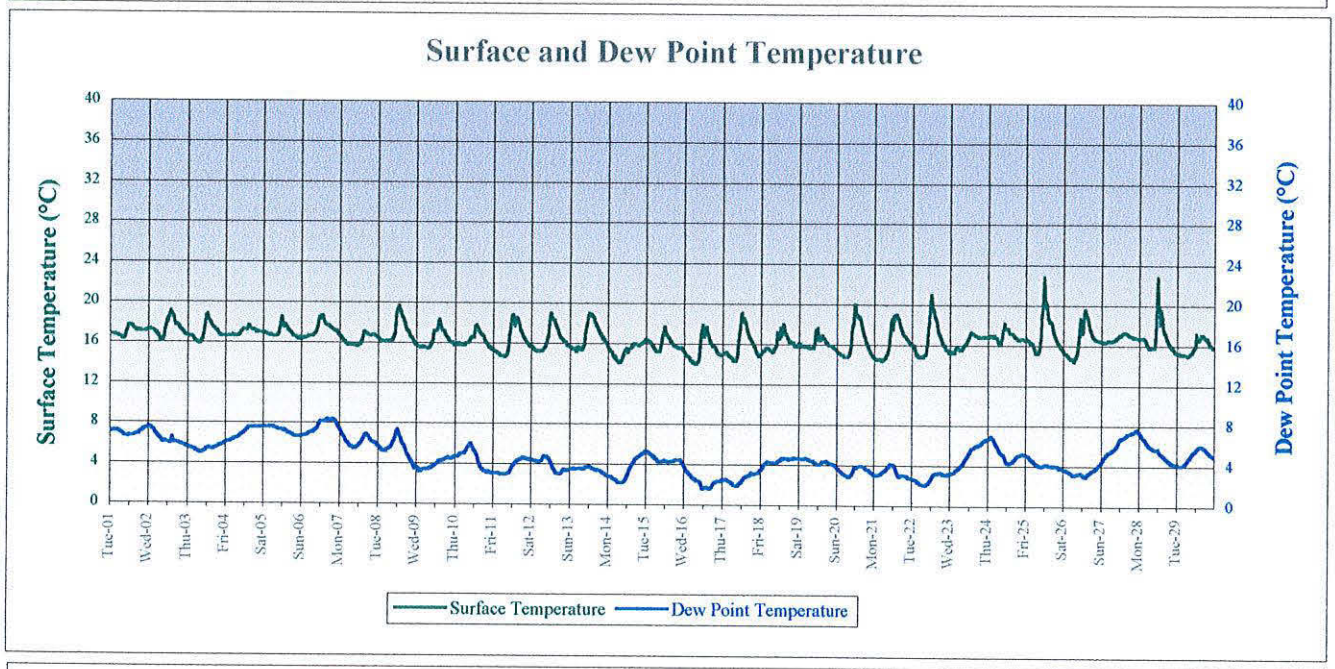


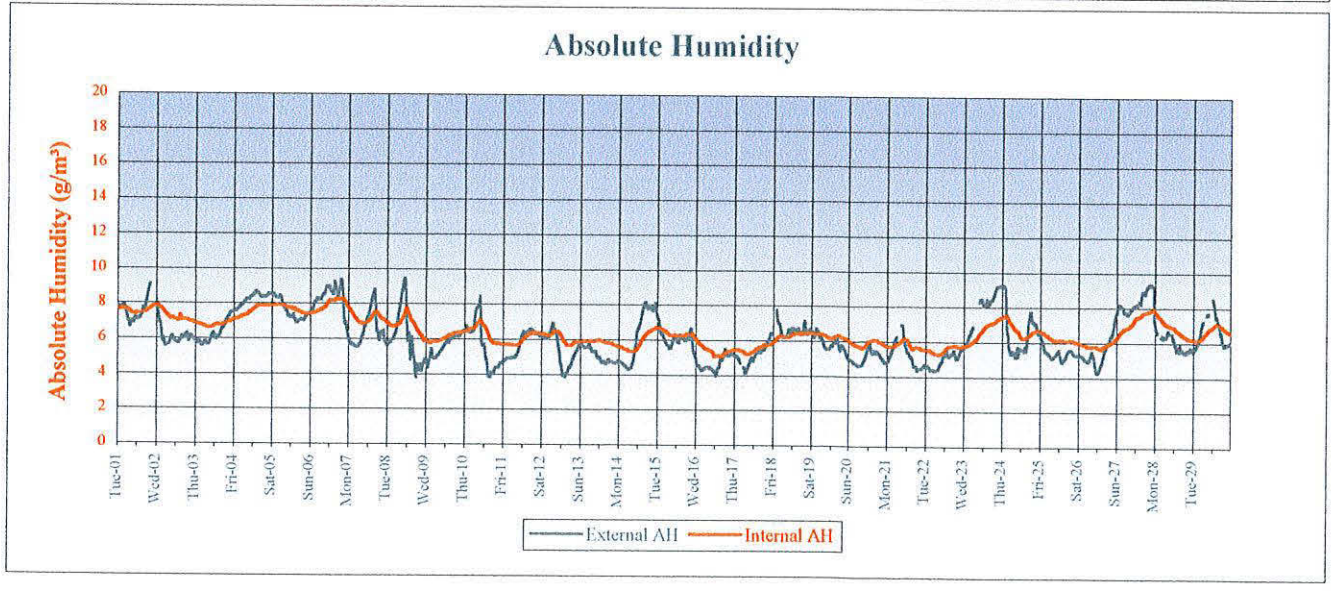
Peterborough Cathedral Nave Ceiling

February 2000

Probe 3: Bay 33 III lower side (sun)



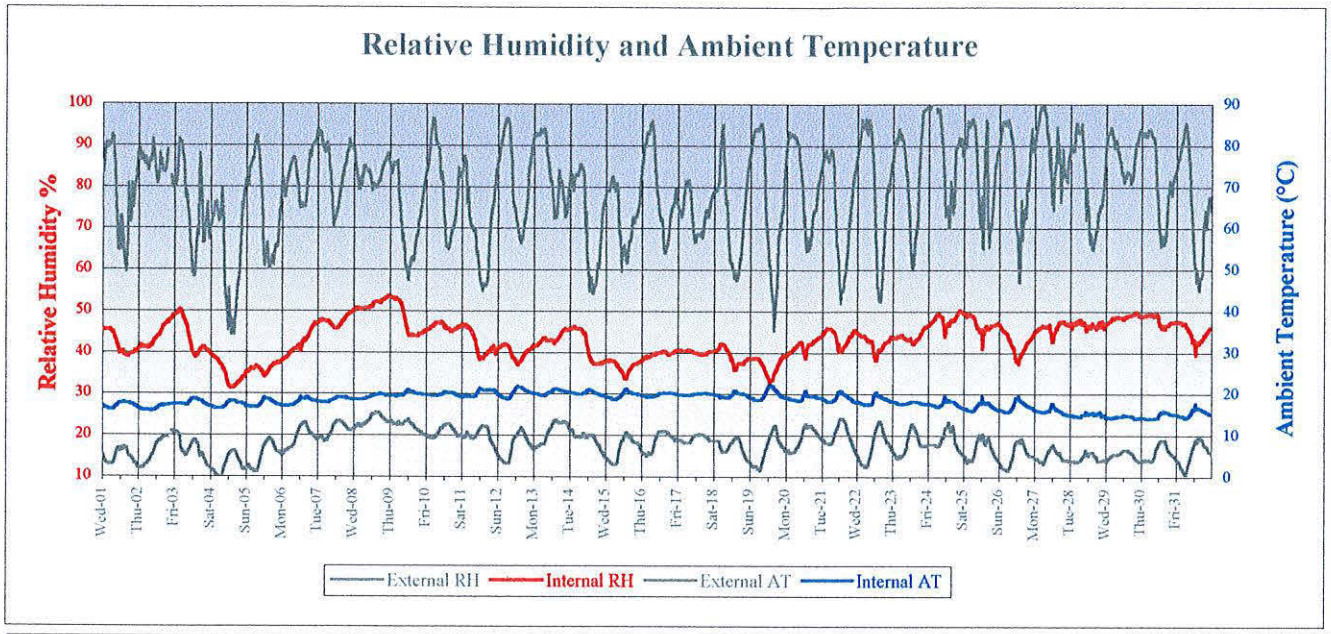


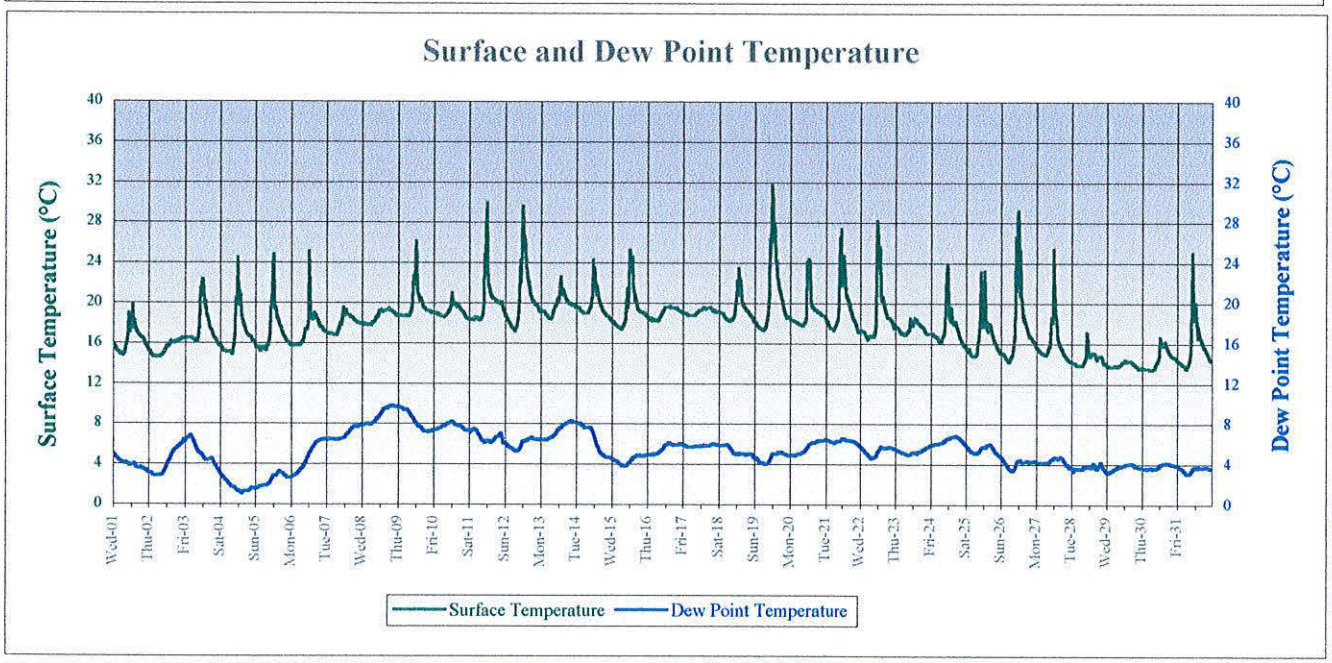


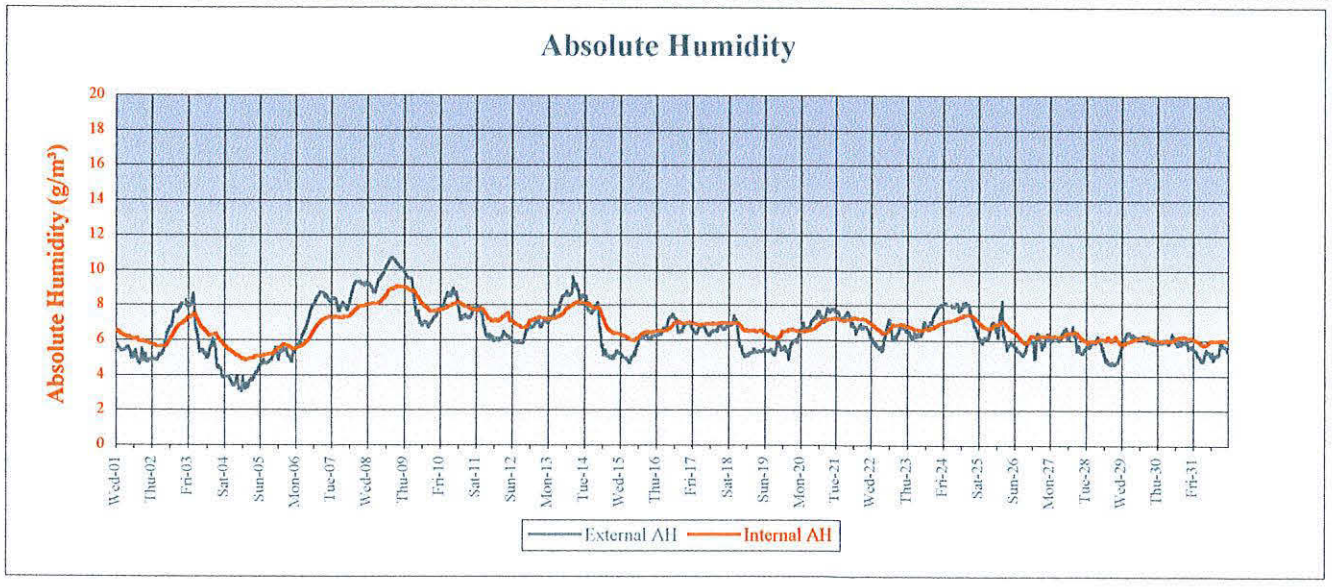
Peterborough Cathedral Nave Ceiling

March 2000

Probe 3: Bay 33 III lower side (sun)



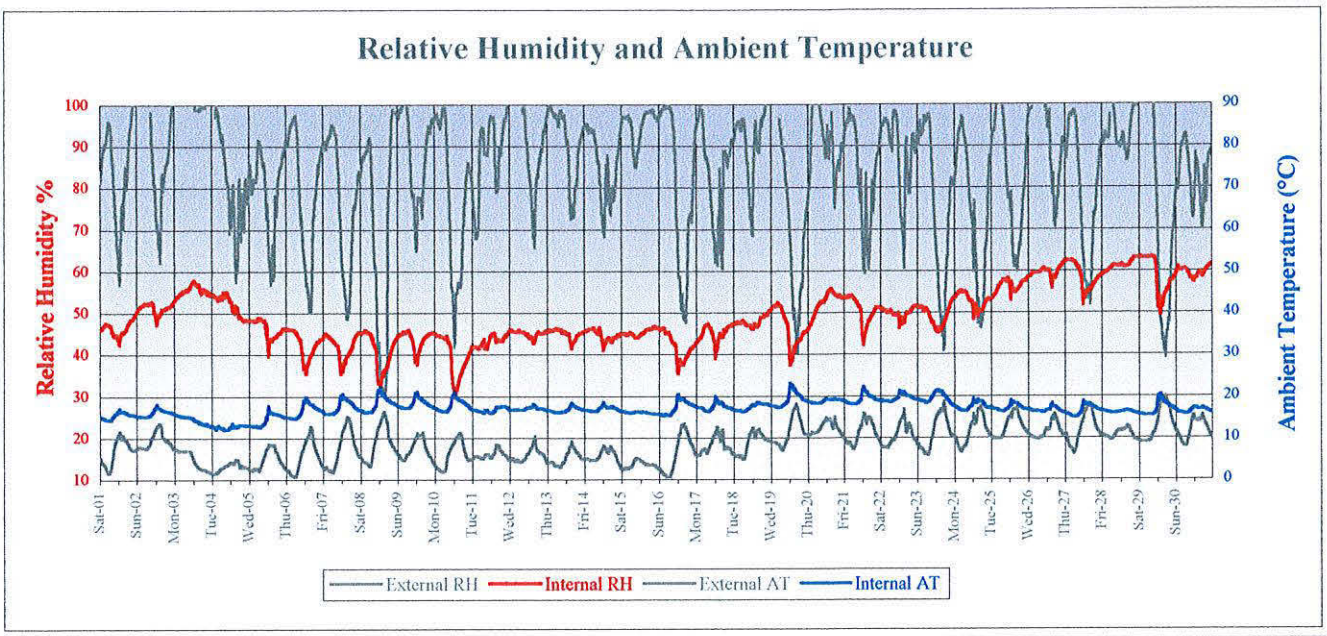


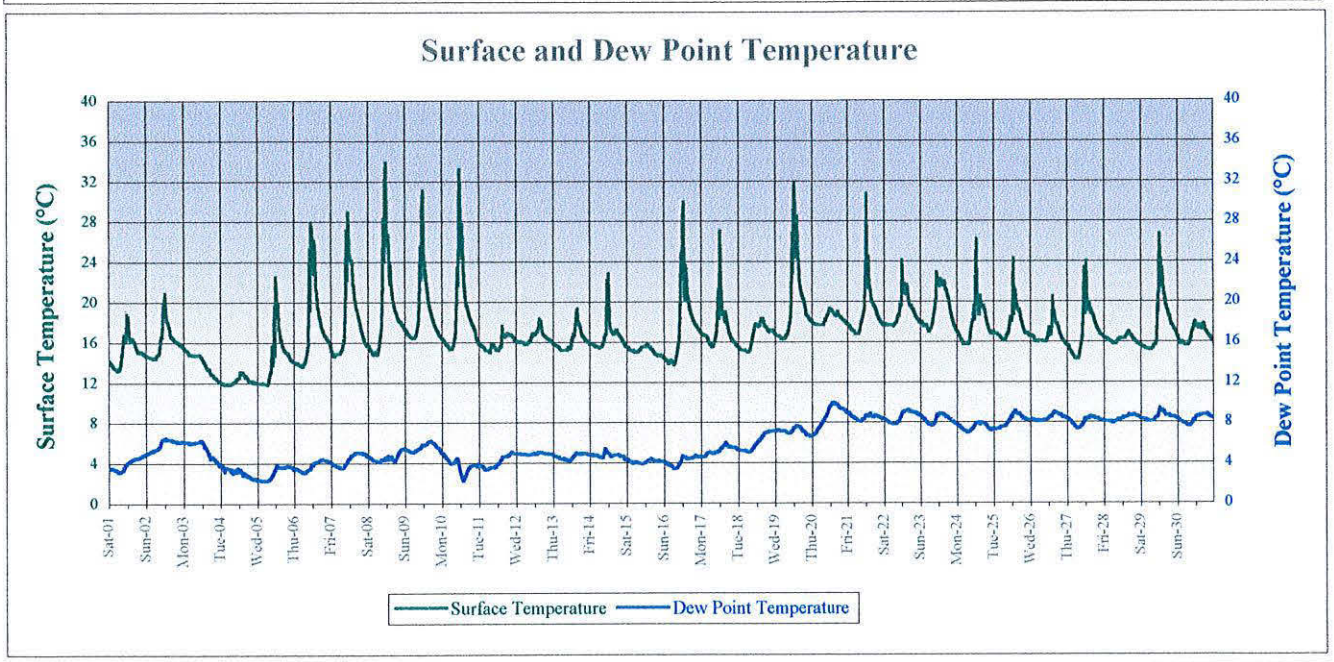


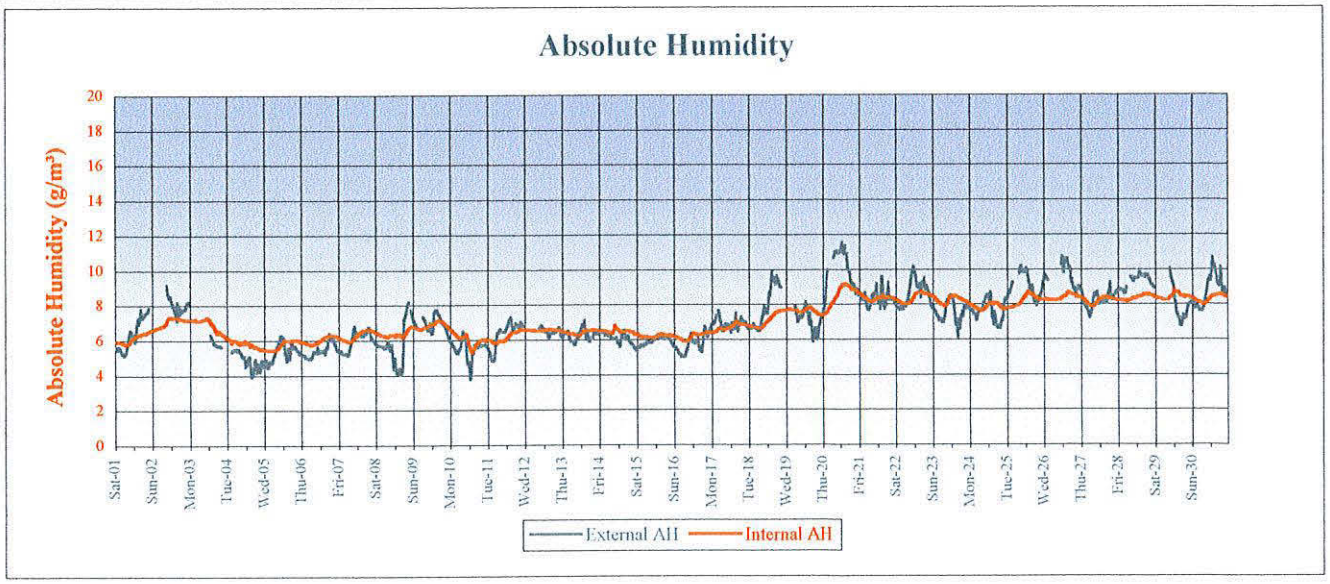
Peterborough Cathedral Nave Ceiling

April 2000

Probe 3: Bay 33 III lower side (sun)



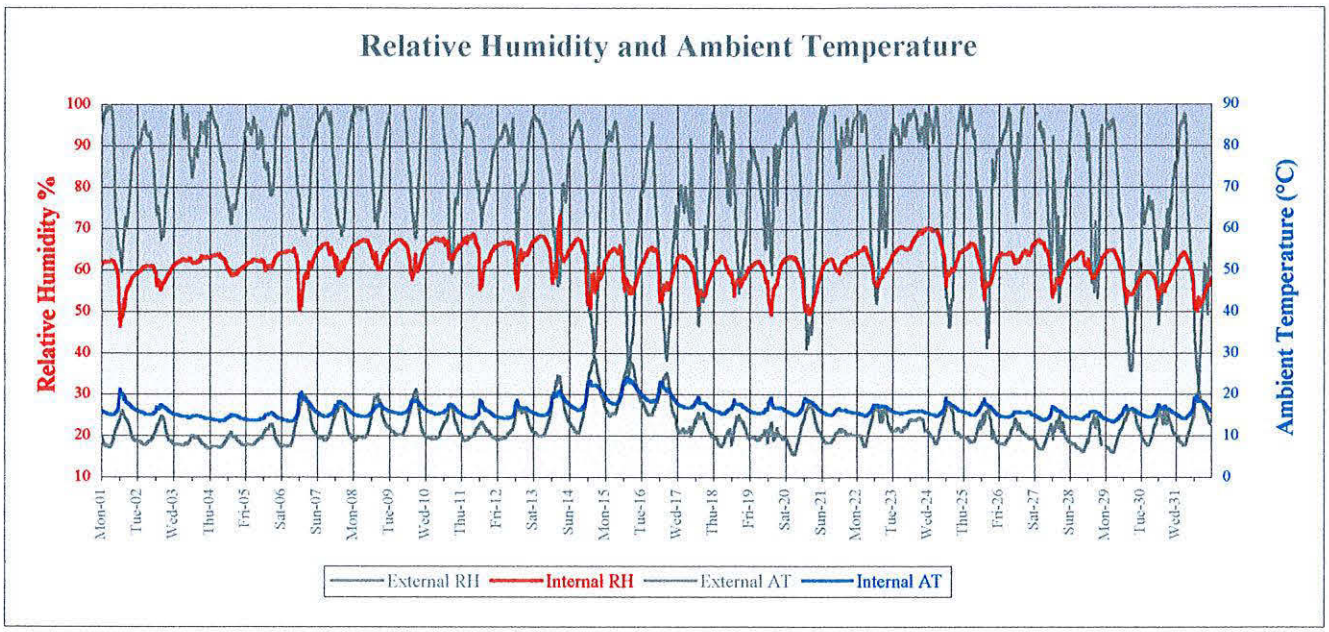


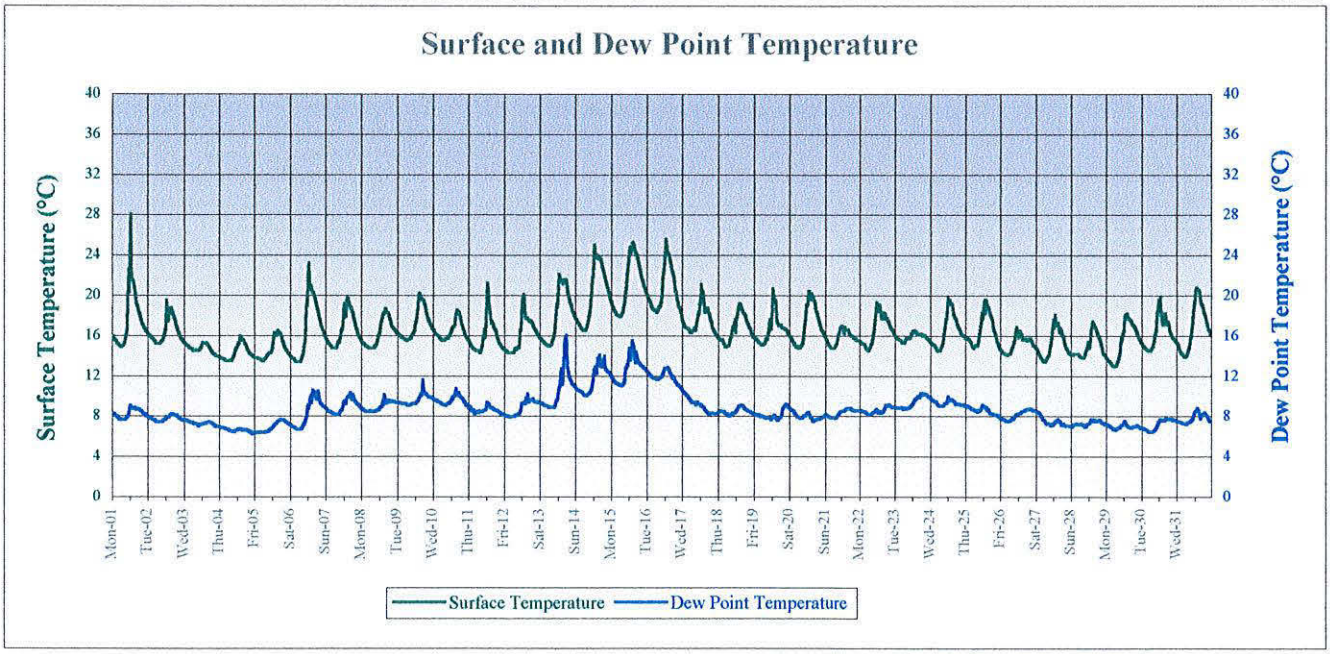


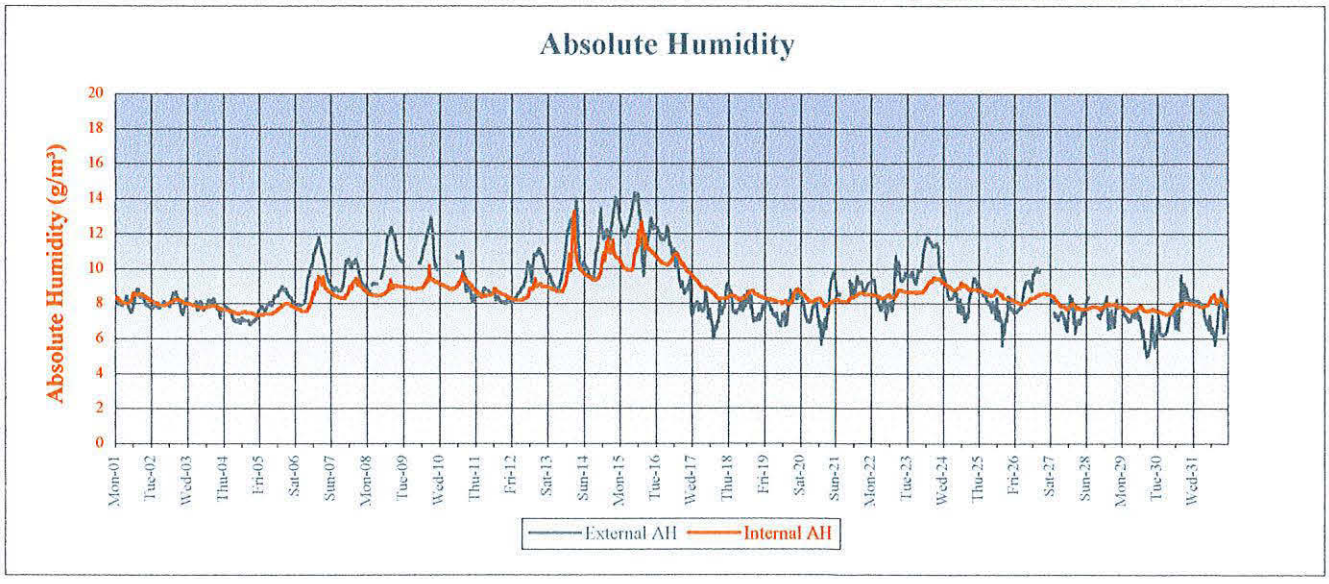
Peterborough Cathedral Nave Ceiling

May 2000

Probe 3: Bay 33 III lower side (sun)



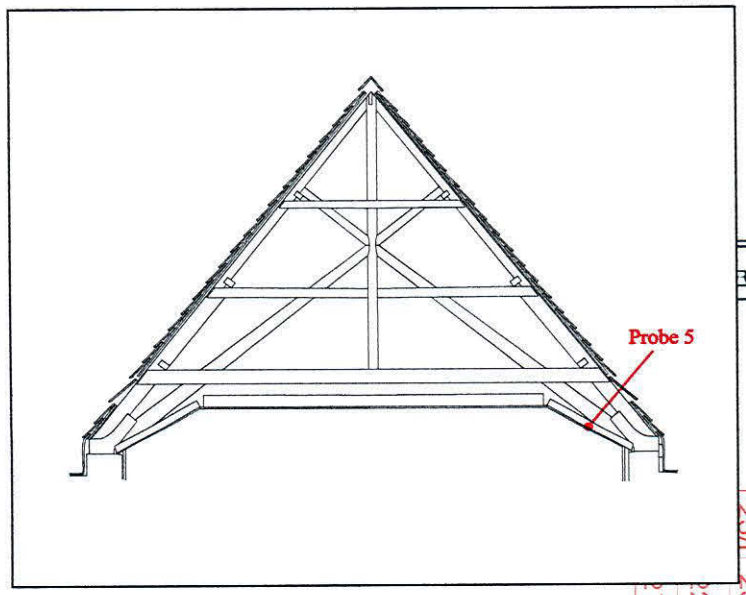


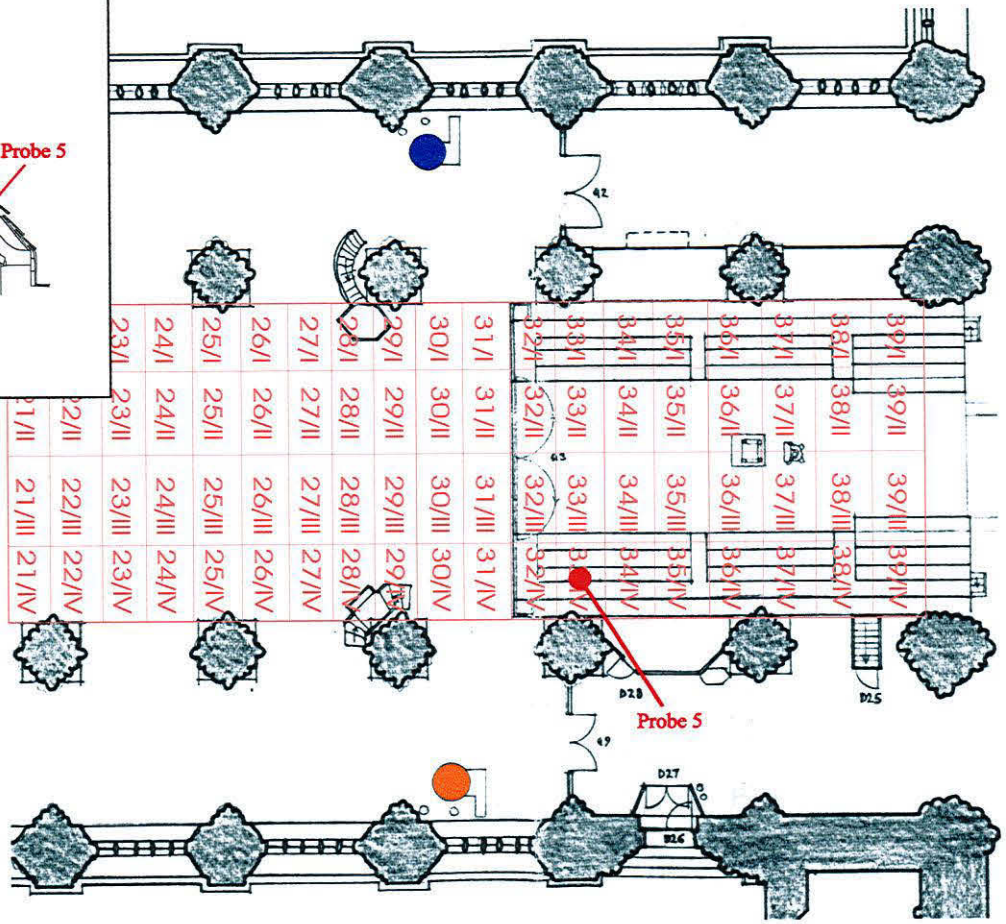


PROBE 5

BAY 33 IV UPPER SIDE (SUN)

DIAGRAM 6



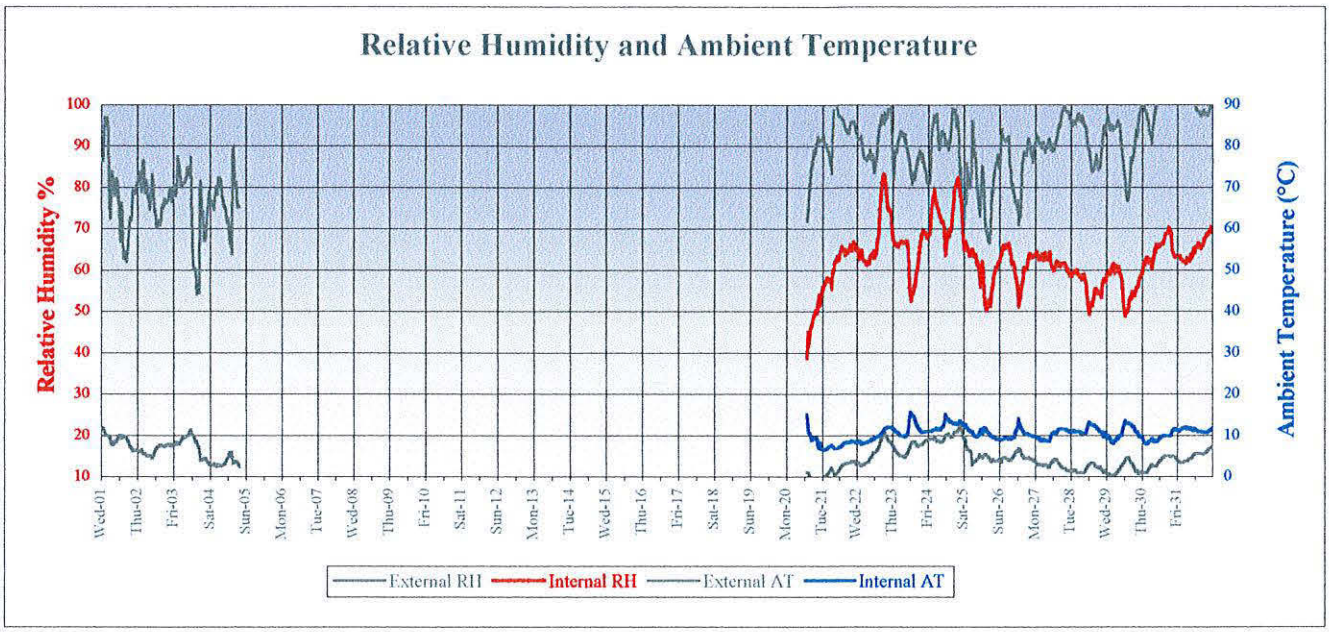


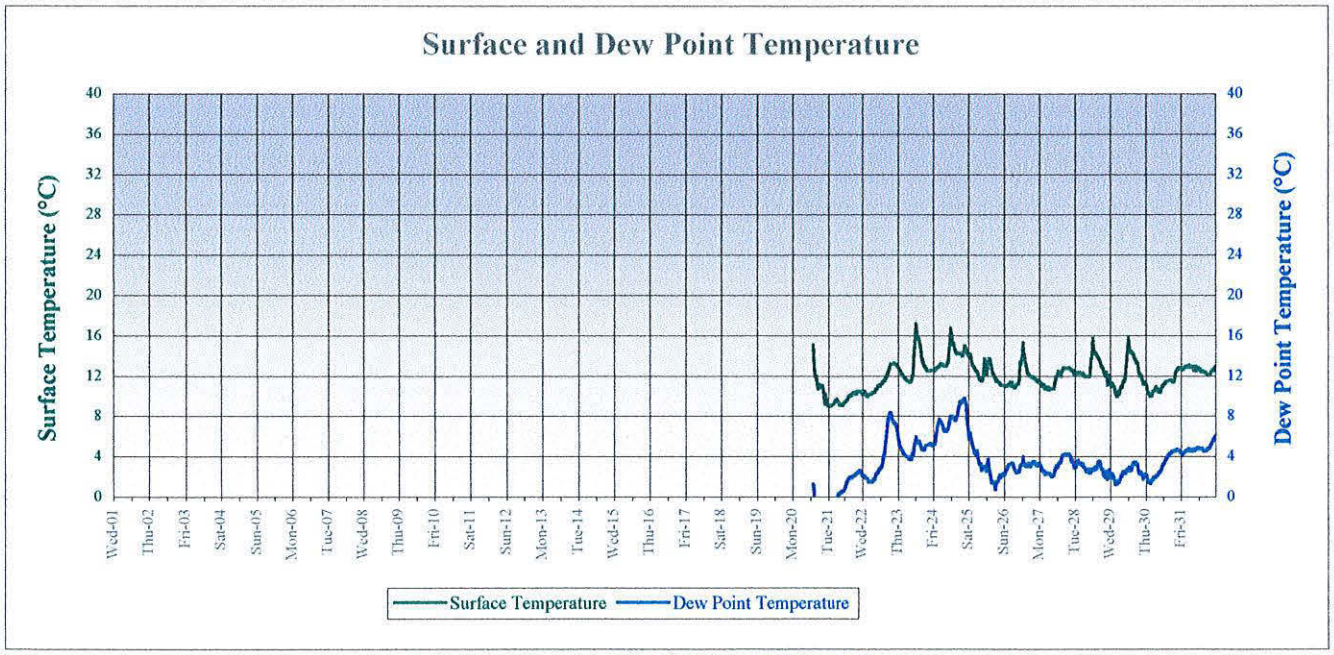
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove Occasional use stove Probe sites
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	

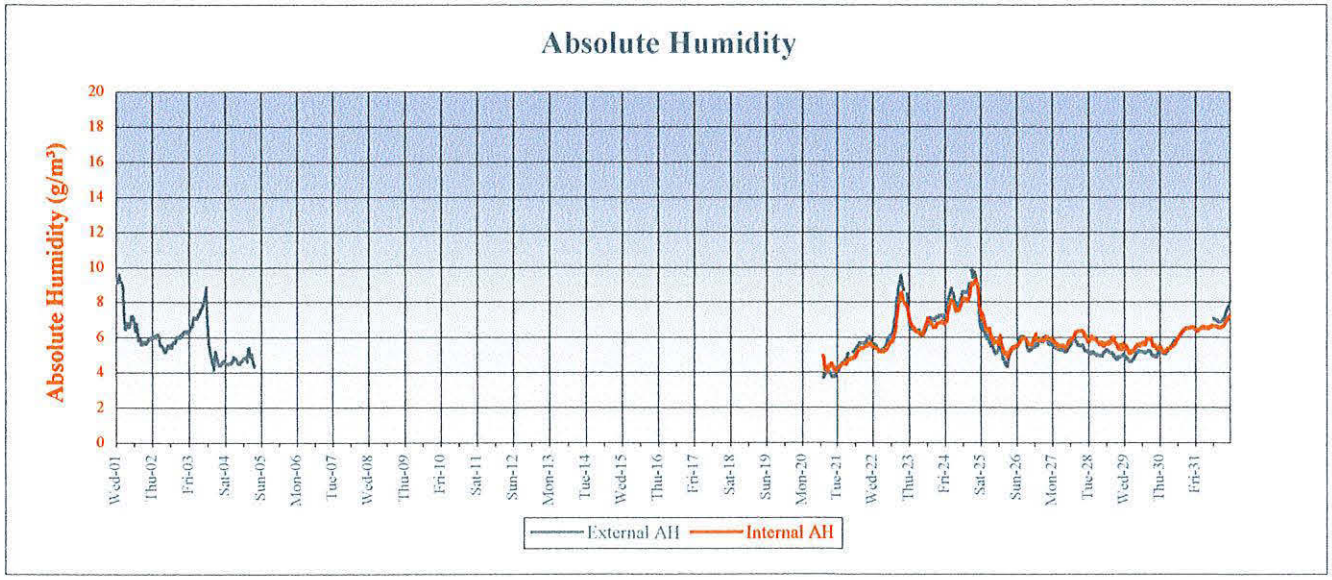
Peterborough Cathedral Nave Ceiling

December 1999

Probe 5: Bay 33 III upper side (sun)



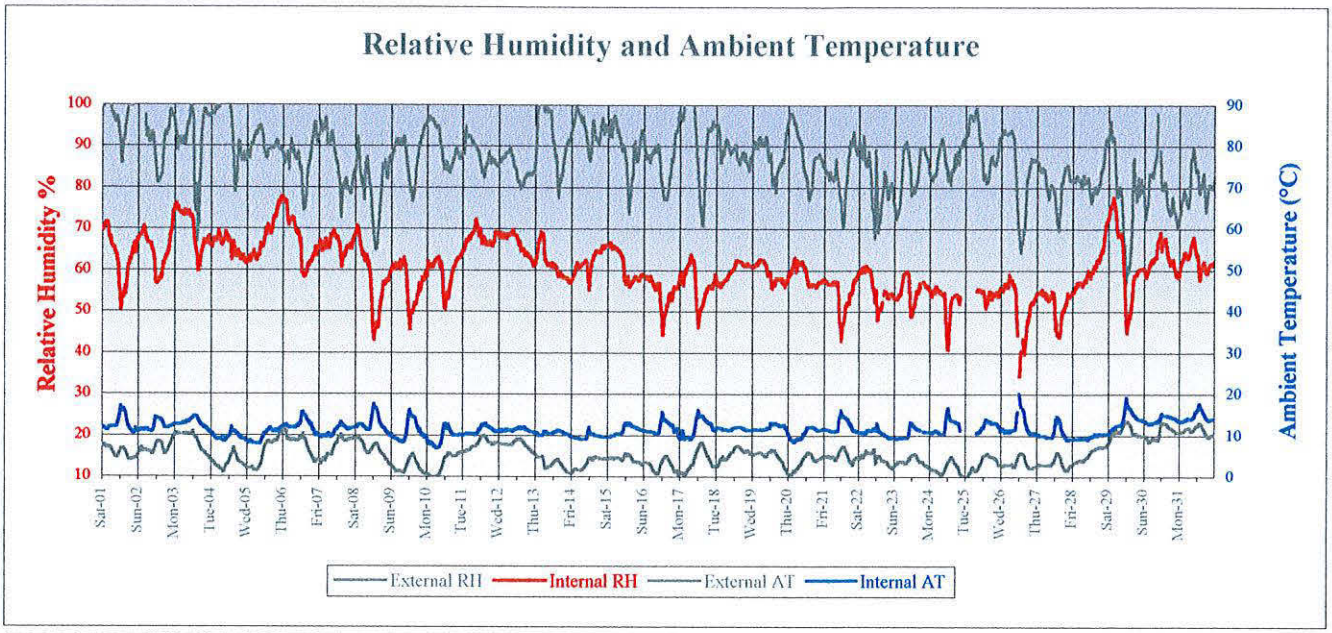


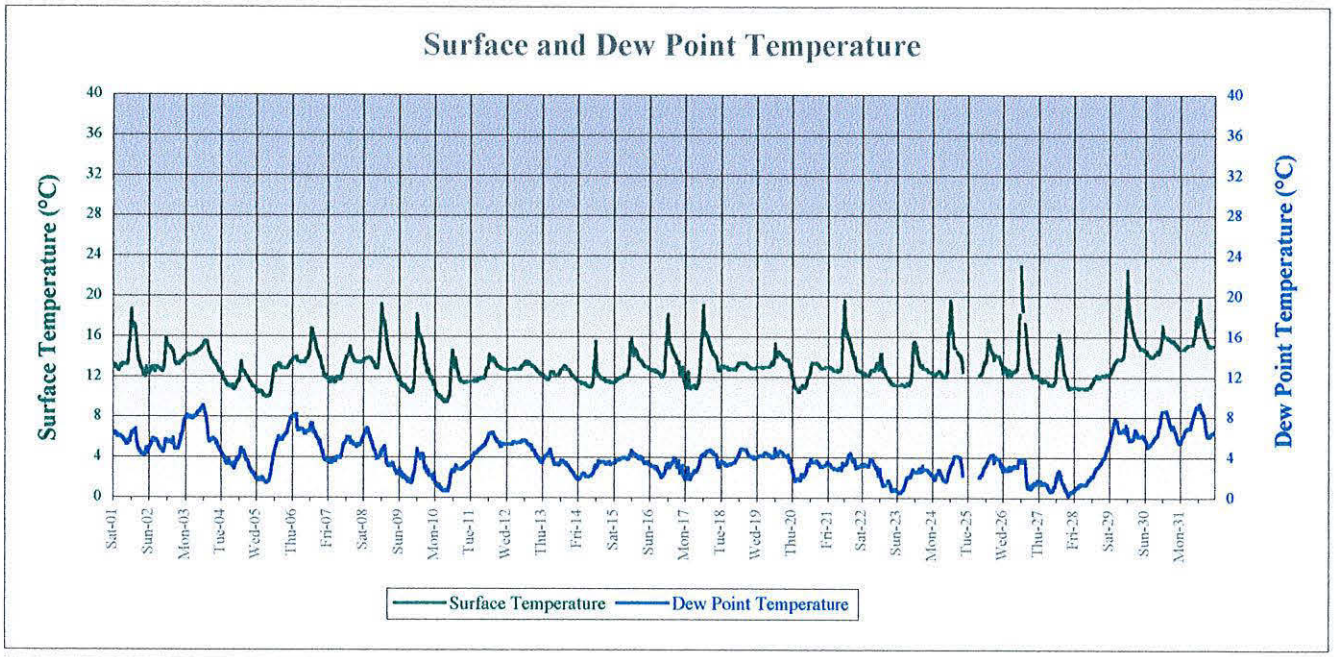


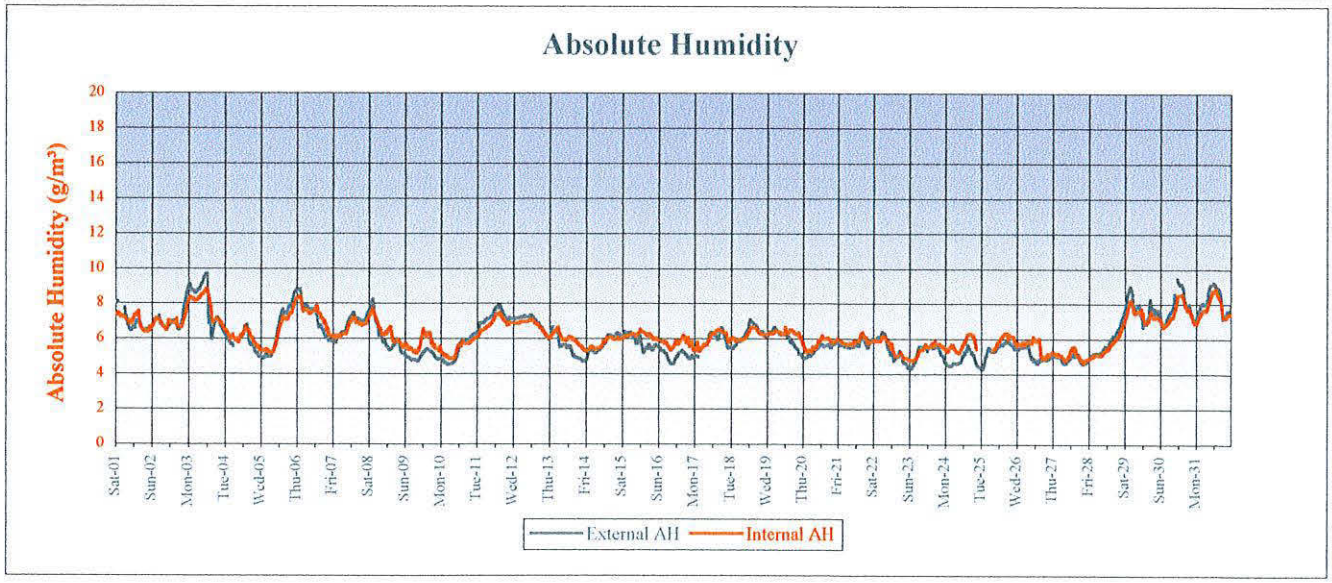
Peterborough Cathedral Nave Ceiling

January 2000

Probe 5: Bay 33 III upper side (sun)



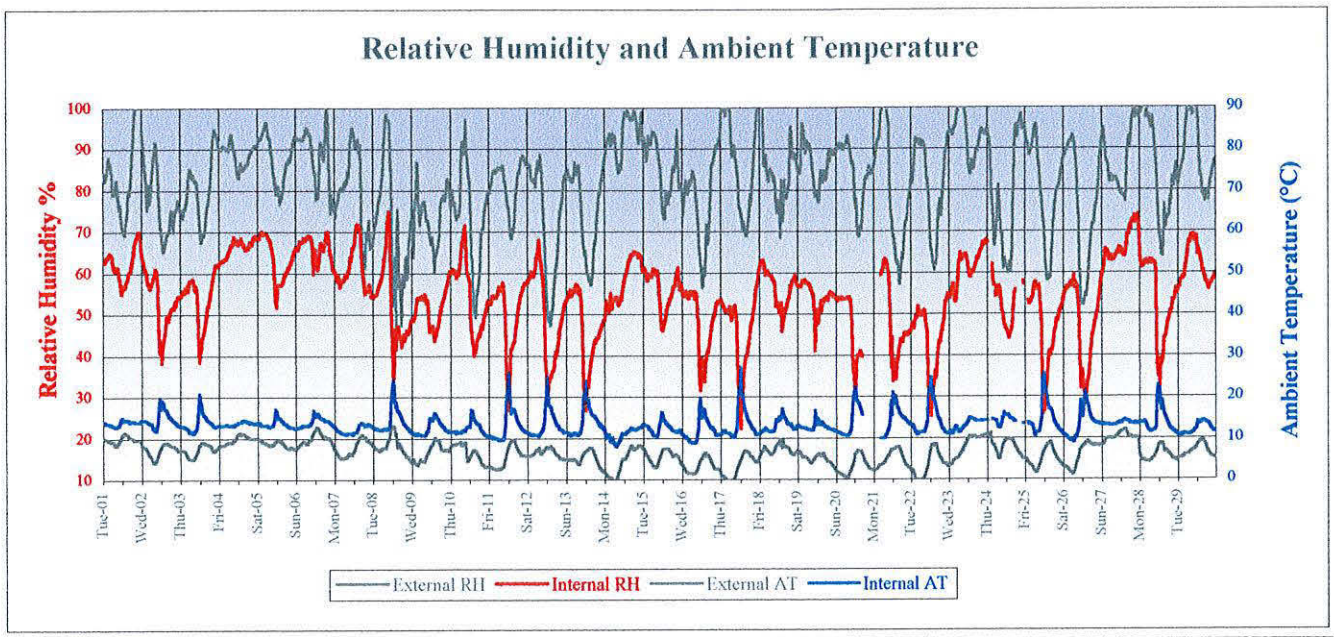


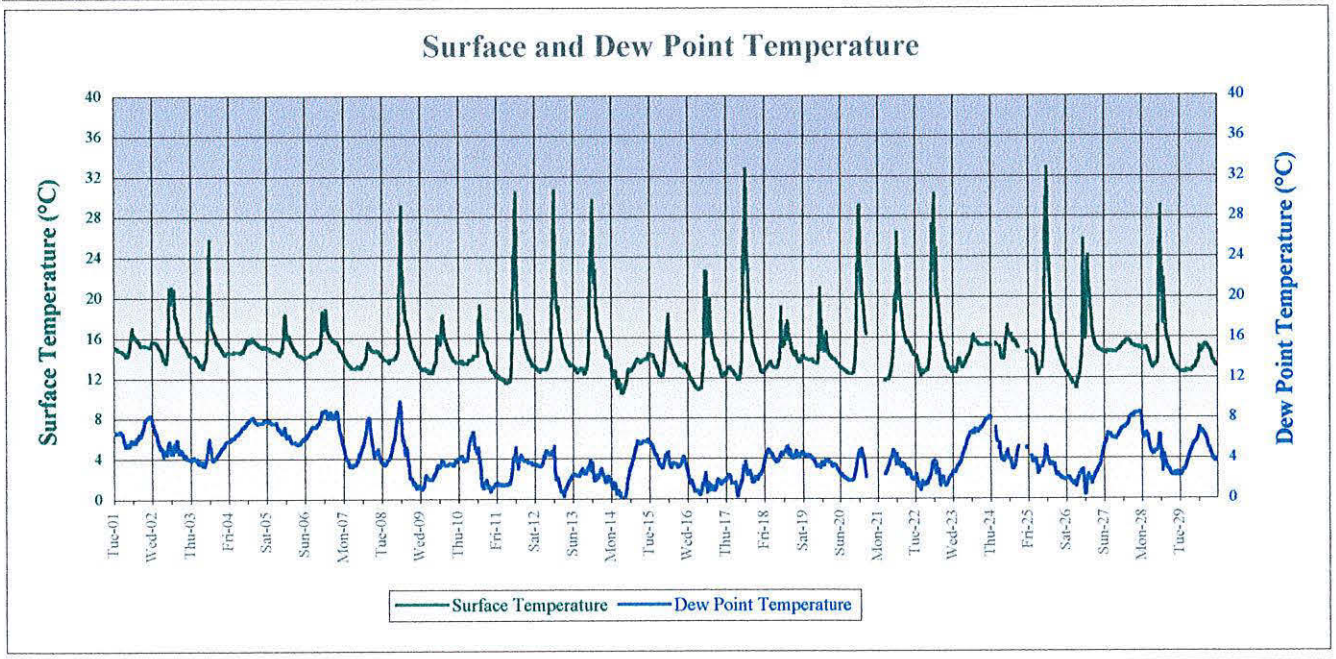


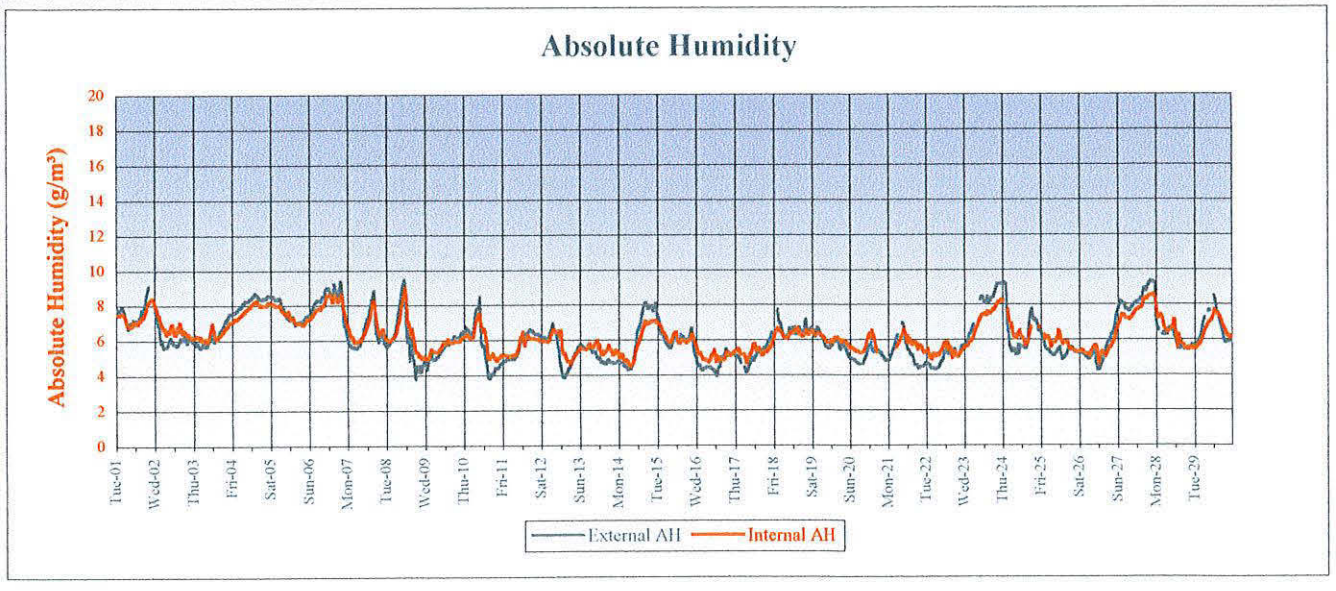
Peterborough Cathedral Nave Ceiling

February 2000

Probe 5: Bay 33 III upper side (sun)



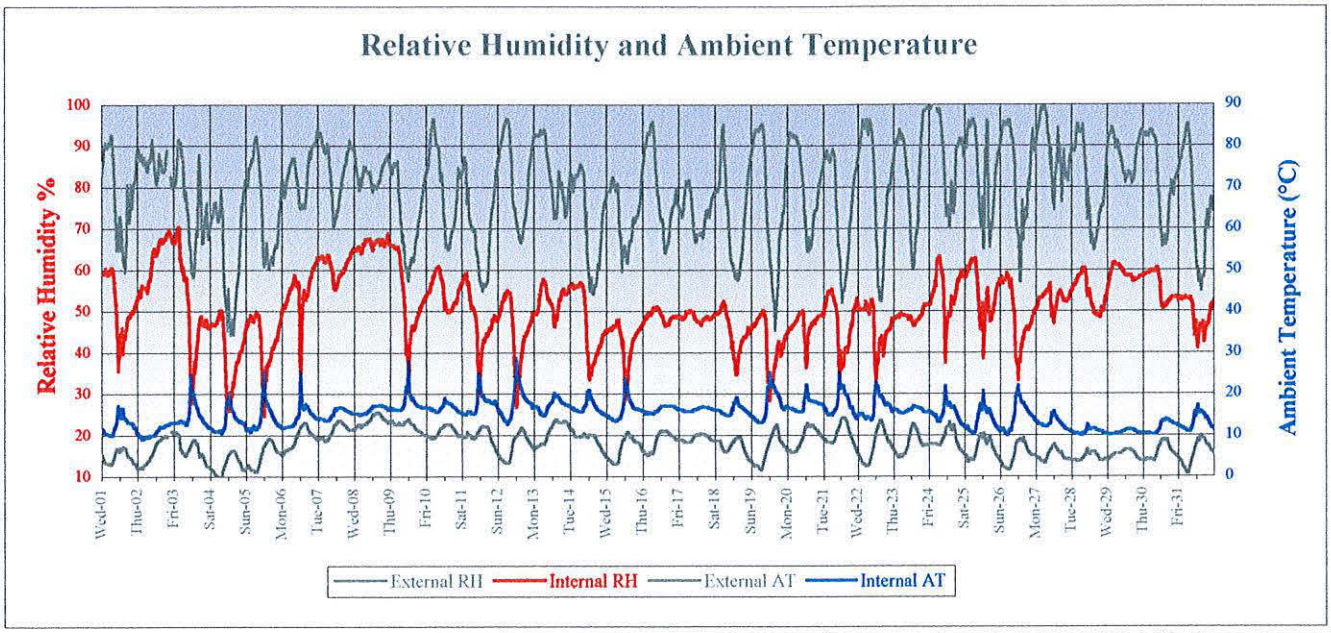


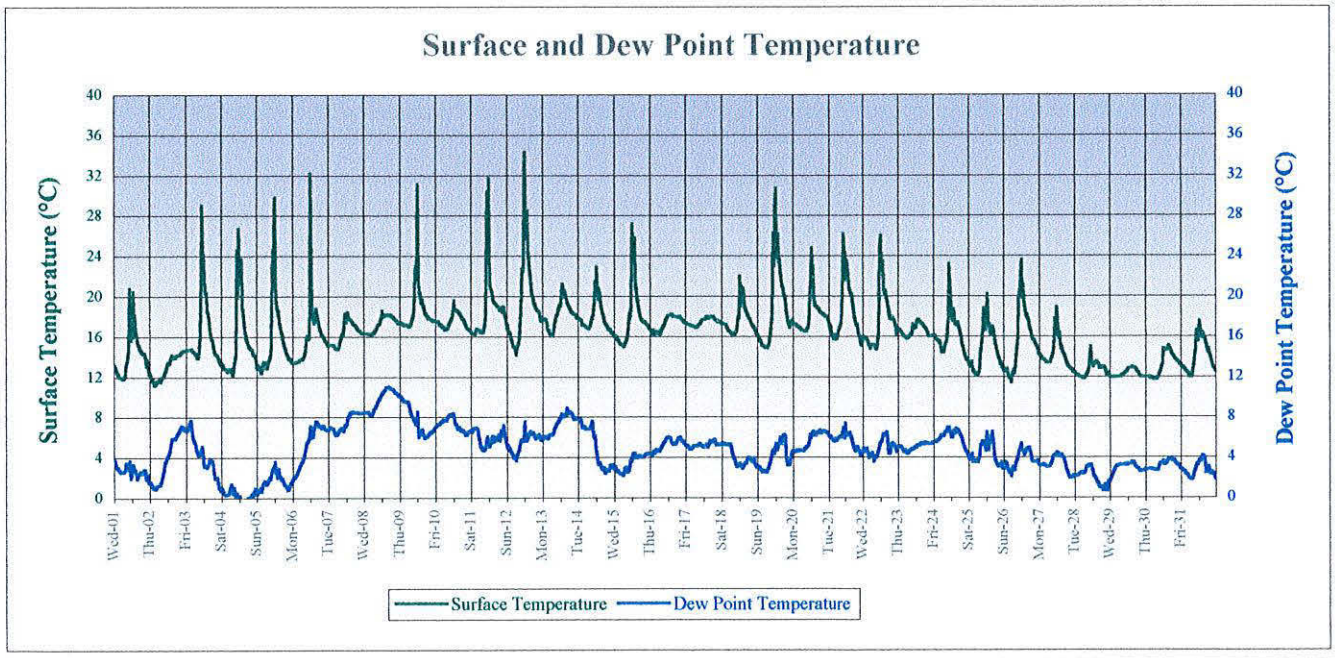


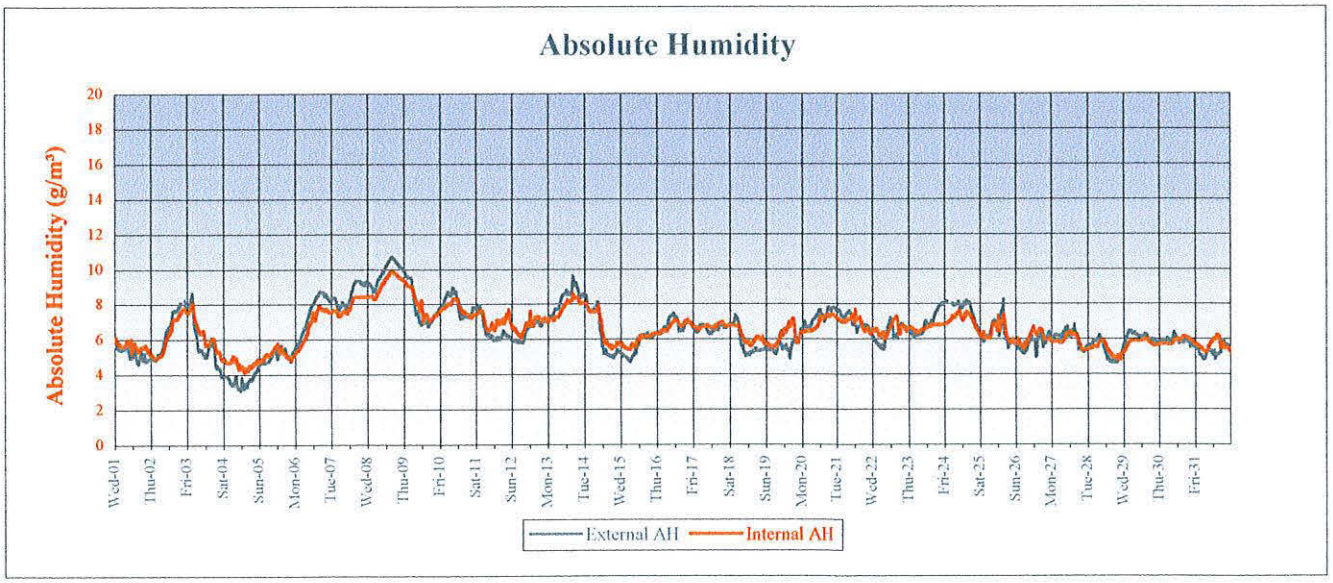
Peterborough Cathedral Nave Ceiling

March 2000

Probe 5: Bay 33 III upper side (sun)



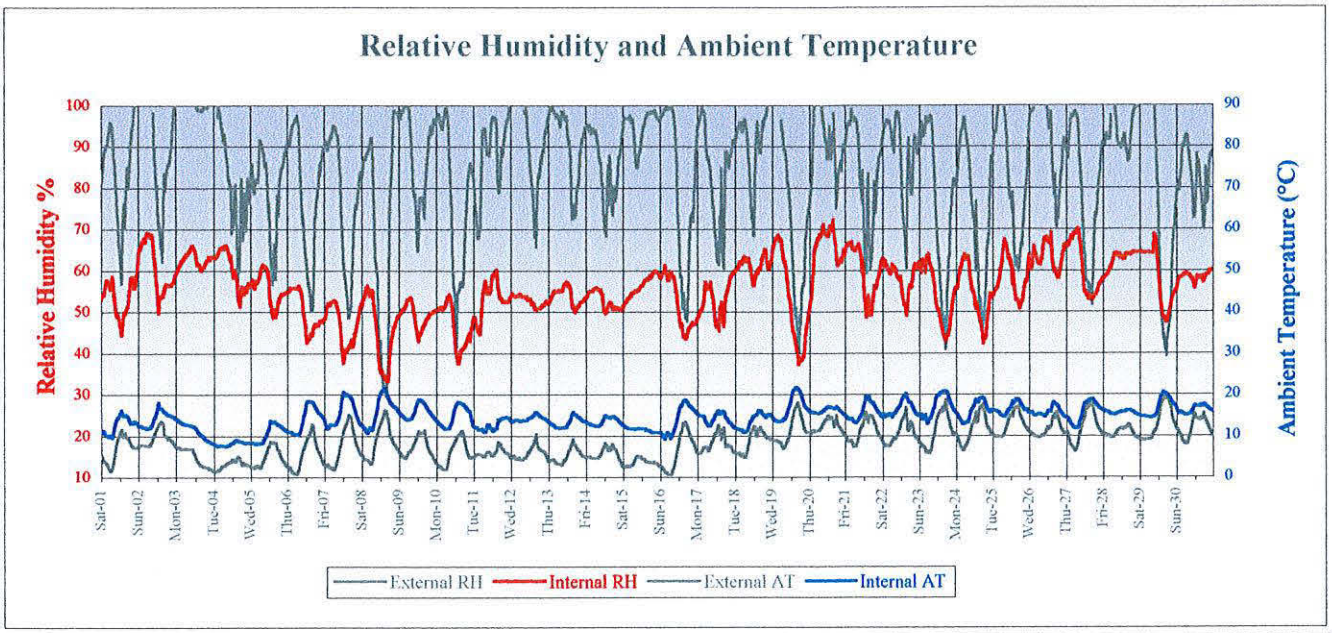


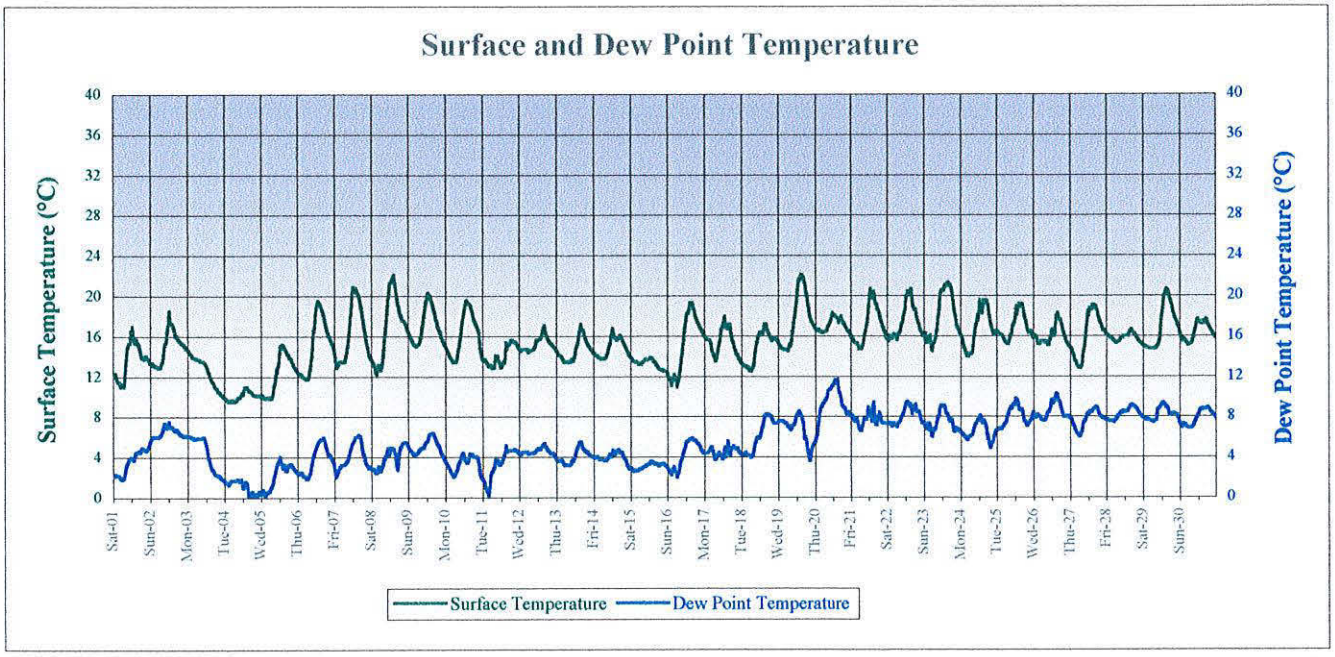


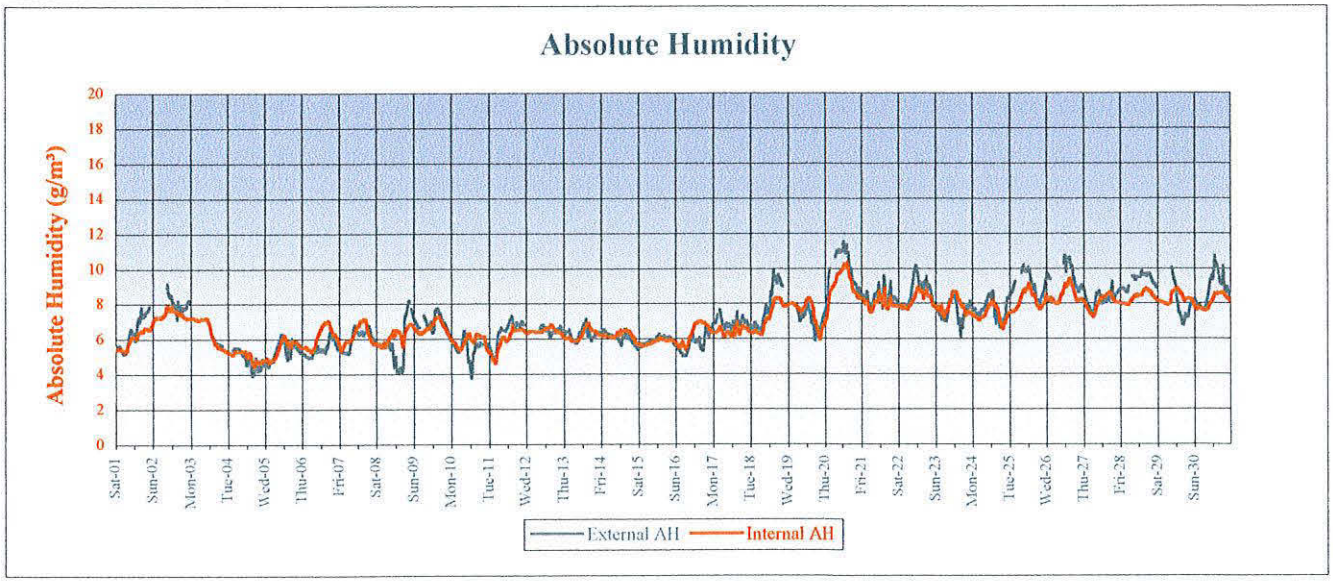
Peterborough Cathedral Nave Ceiling

April 2000

Probe 5: Bay 33 III upper side (sun)



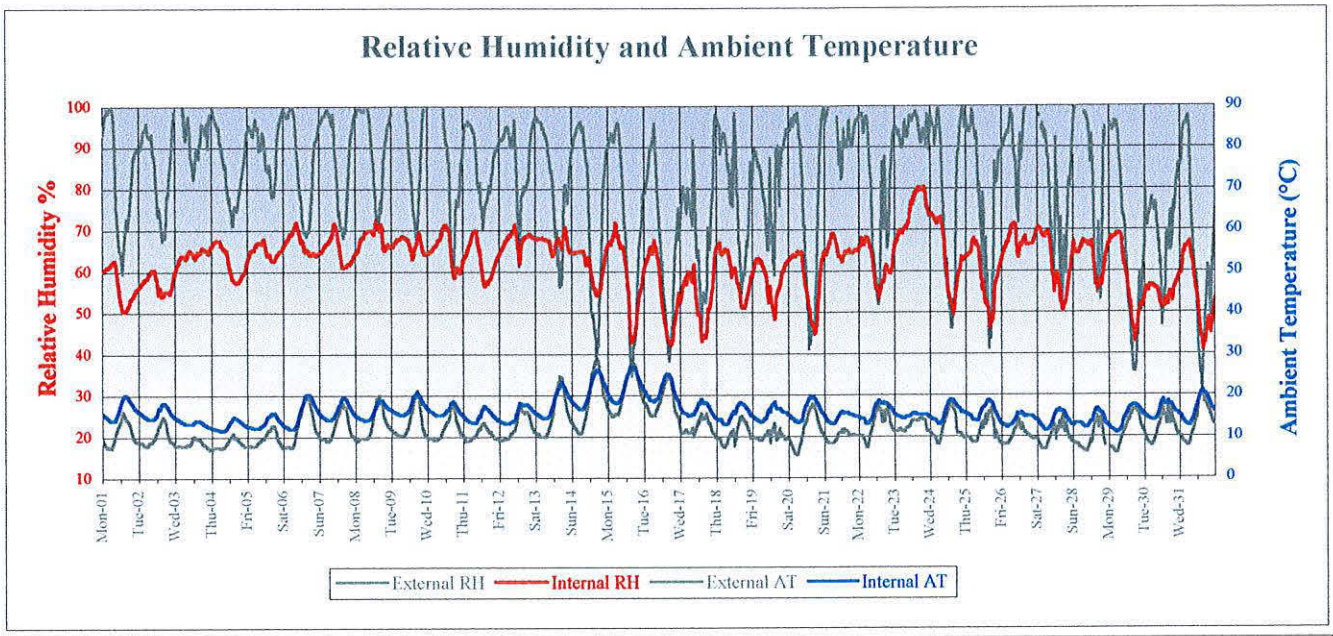


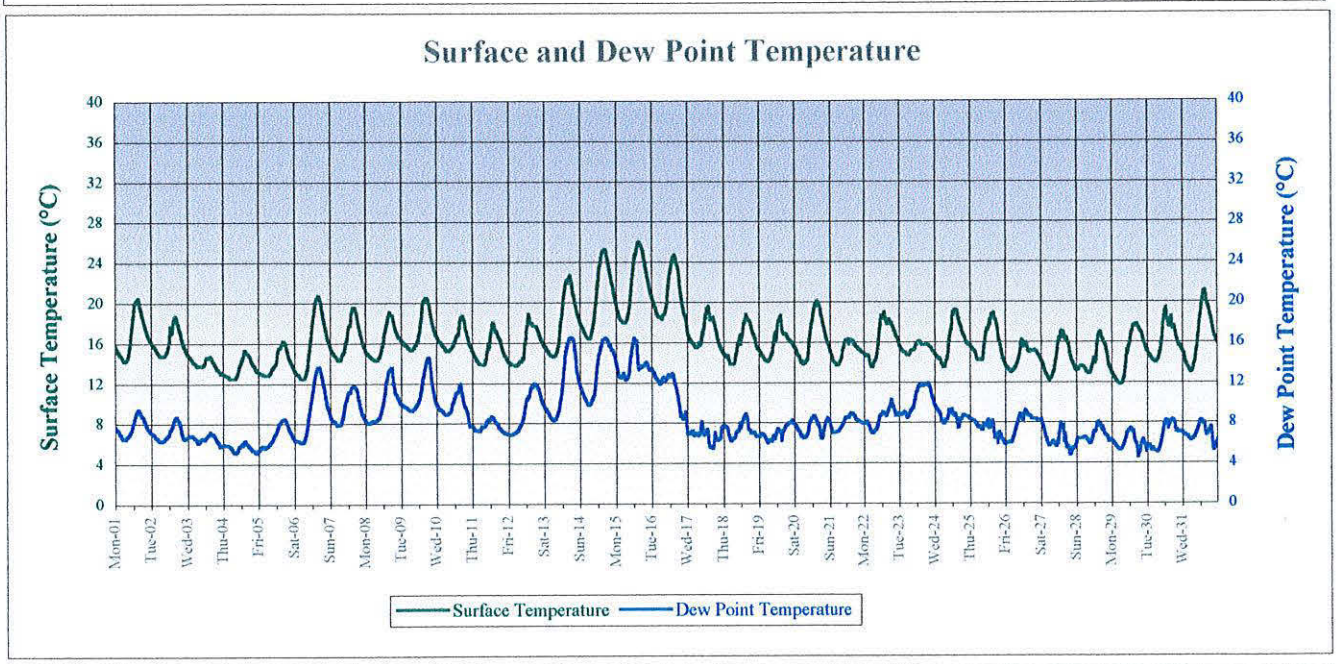


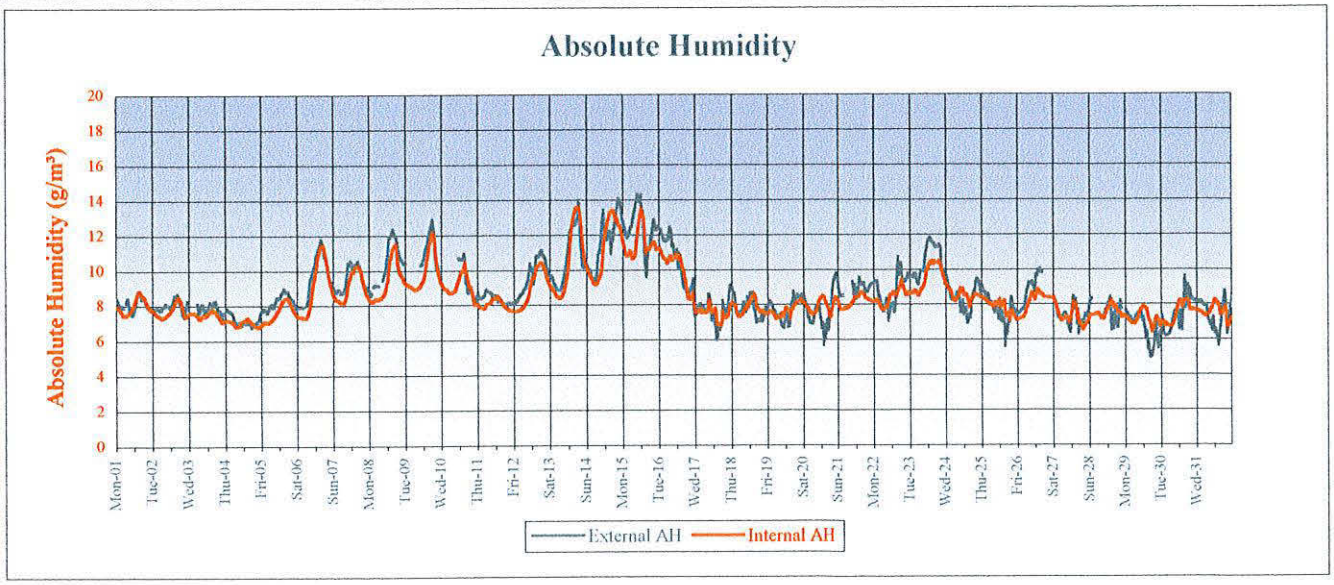
Peterborough Cathedral Nave Ceiling

May 2000

Probe 5: Bay 33 III upper side (sun)

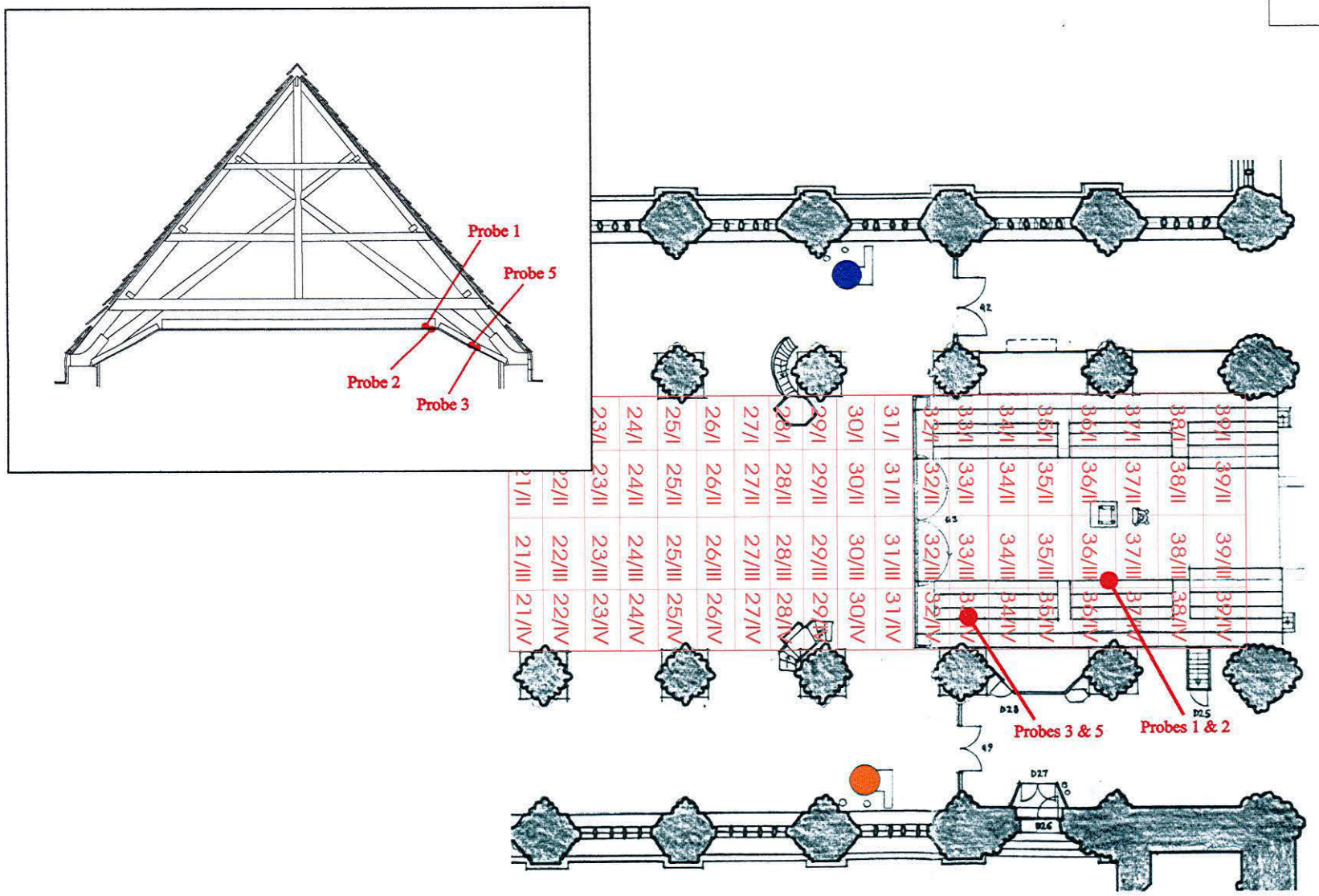






COMPARATIVE CHARTS

DIAGRAM 7

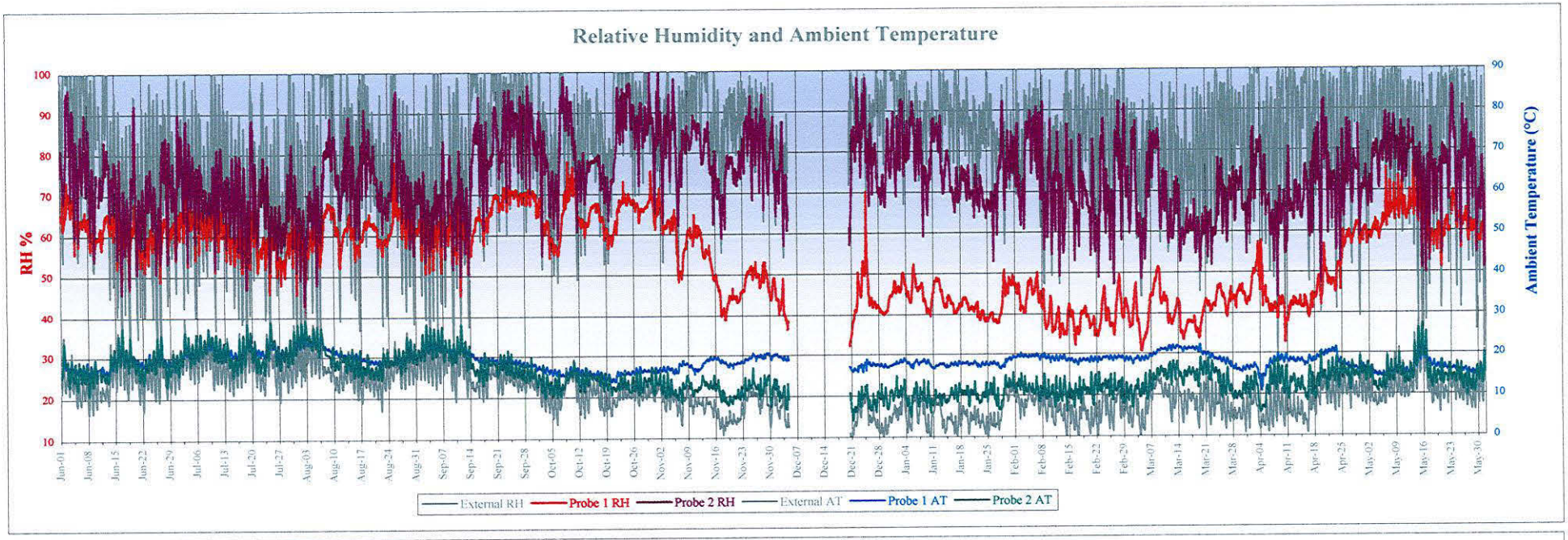


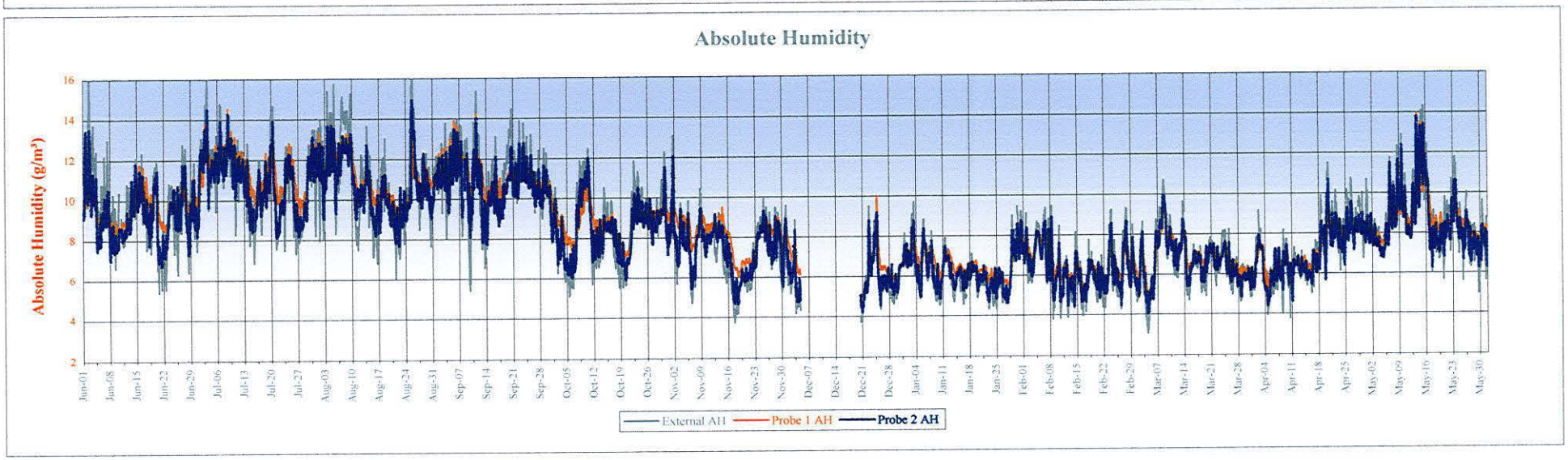
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove Occasional use stove Probe sites
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	

Peterborough Cathedral Nave Ceiling

June 1999 - May 2000

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

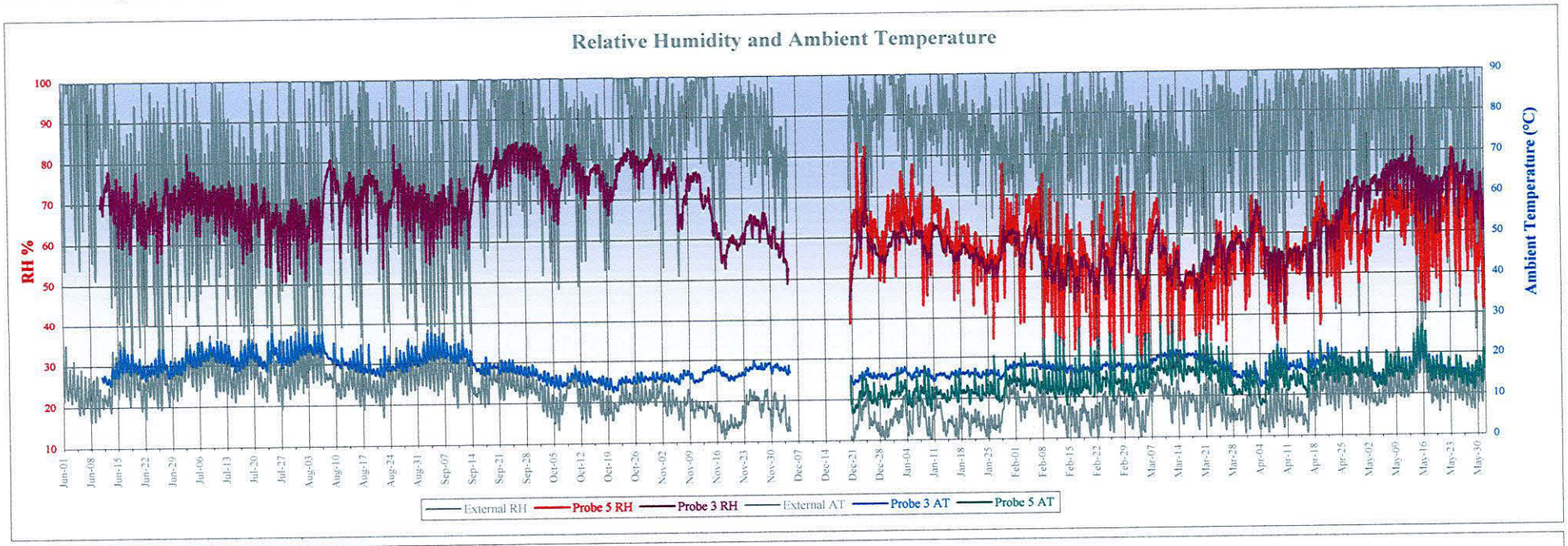


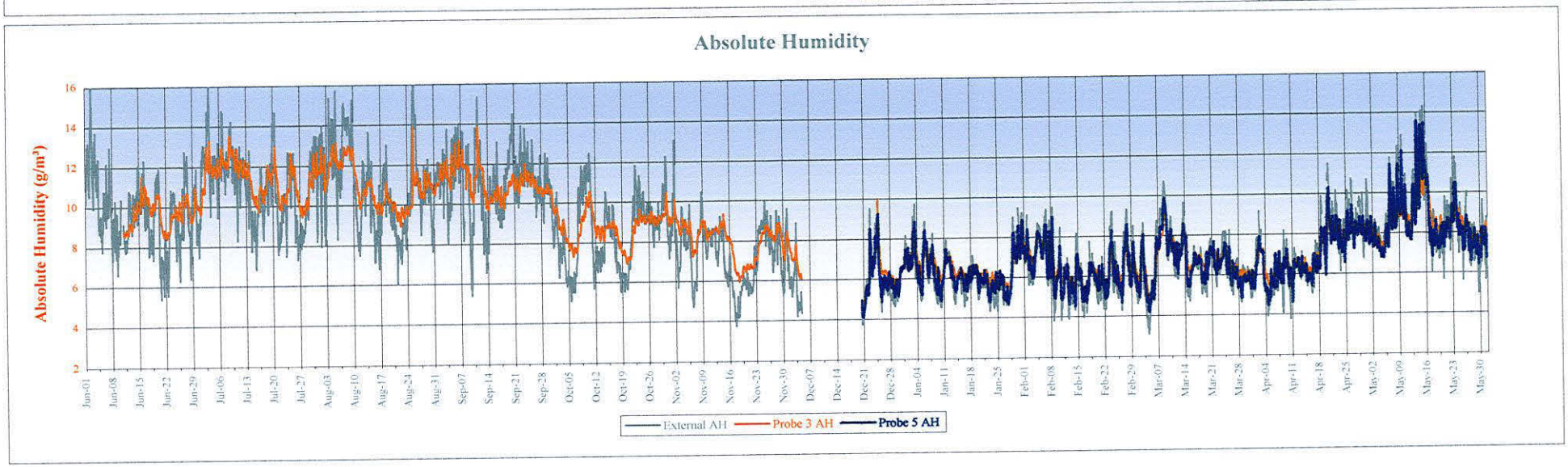


Peterborough Cathedral Nave Ceiling

June 1999 - May 2000

Probe 3: Bay 33 IV lower side & Probe 2: Bay 33 IV upper side (sun)

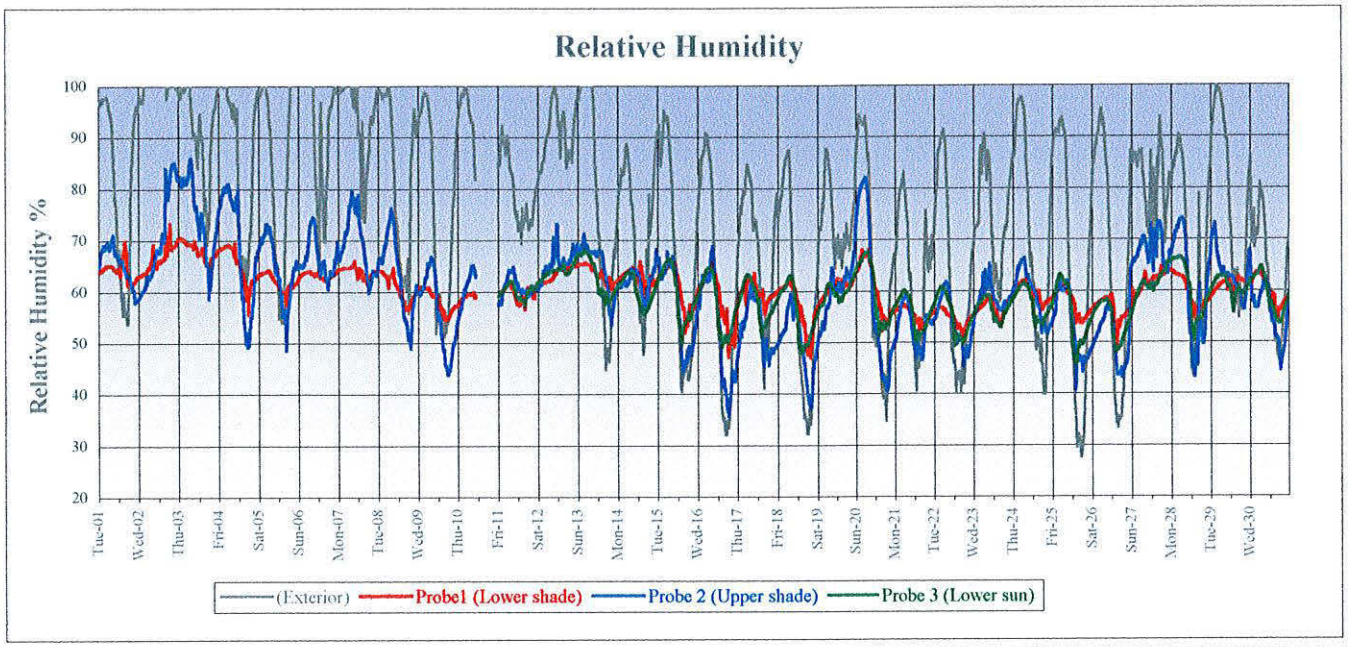


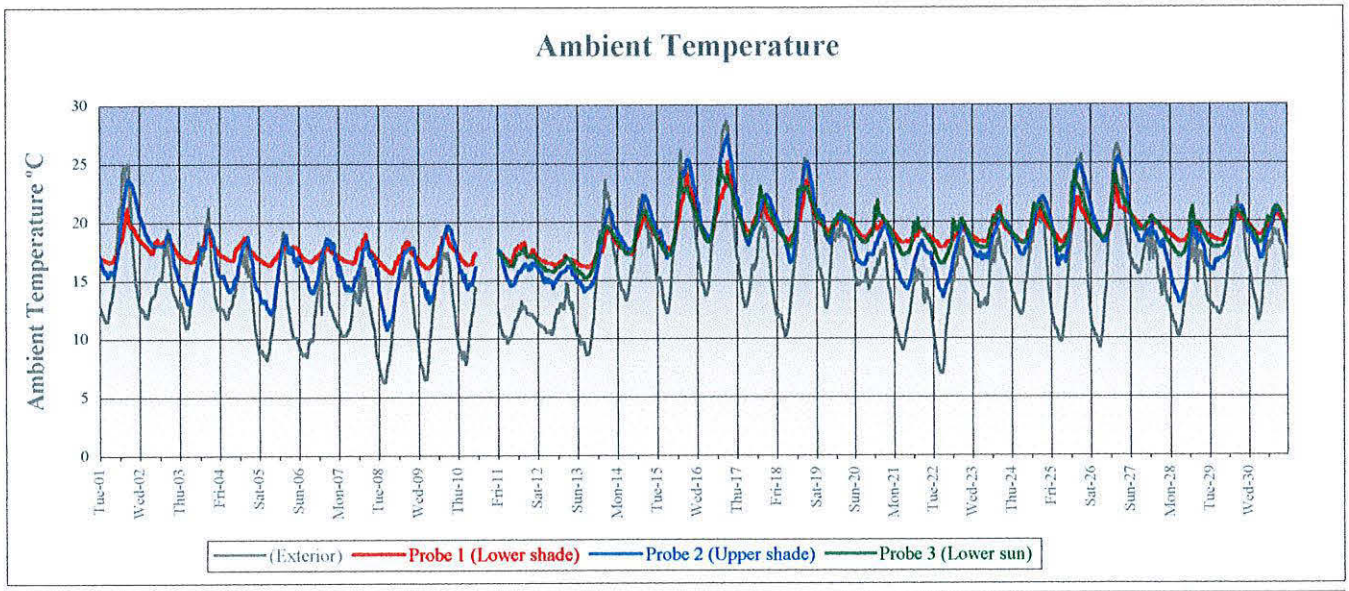


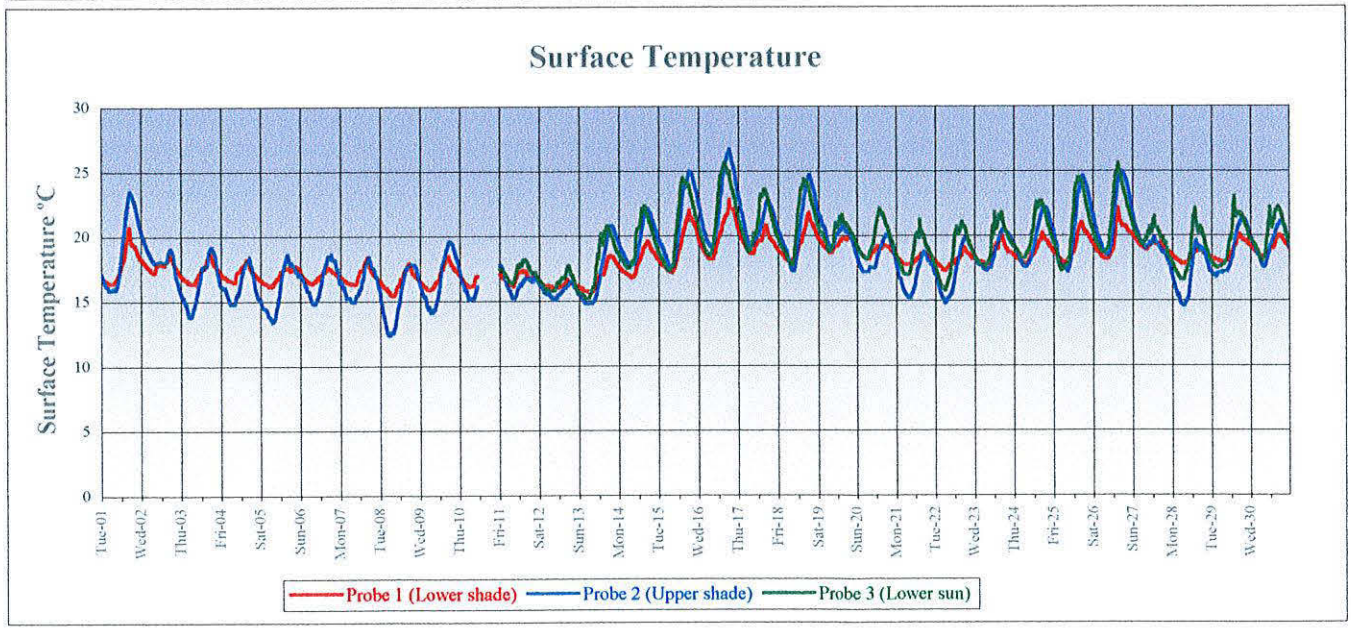
Peterborough Cathedral Nave Ceiling

June 1999

Comparative data



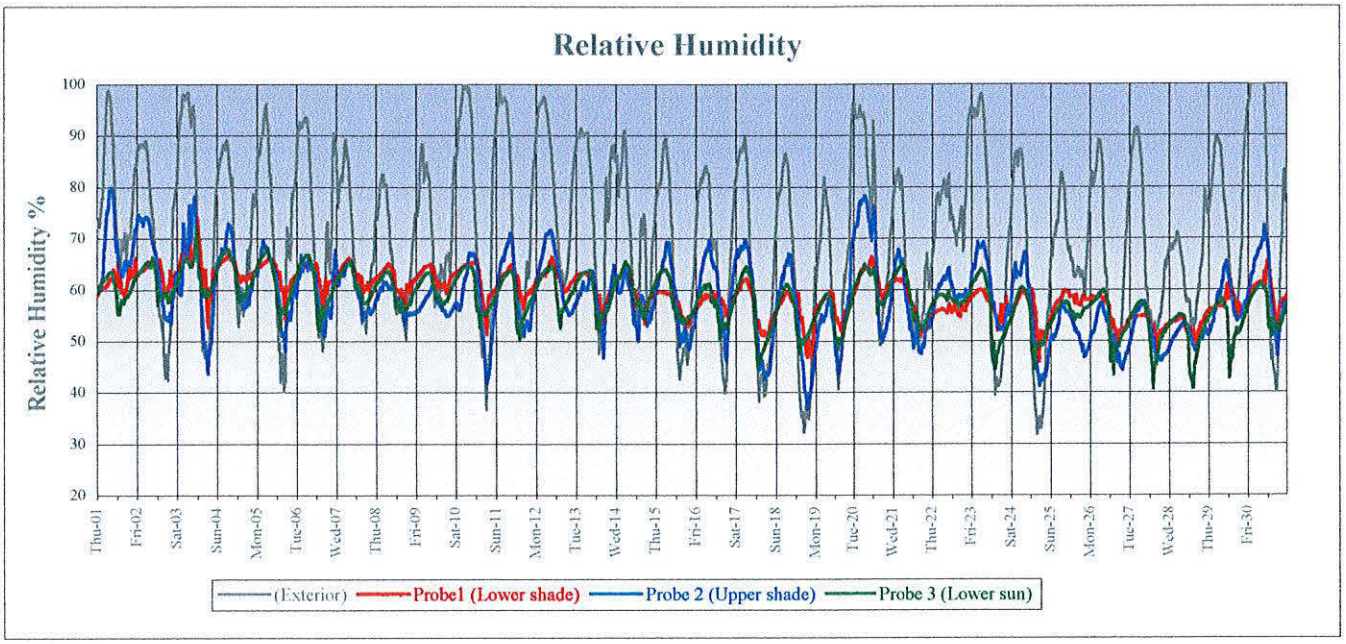


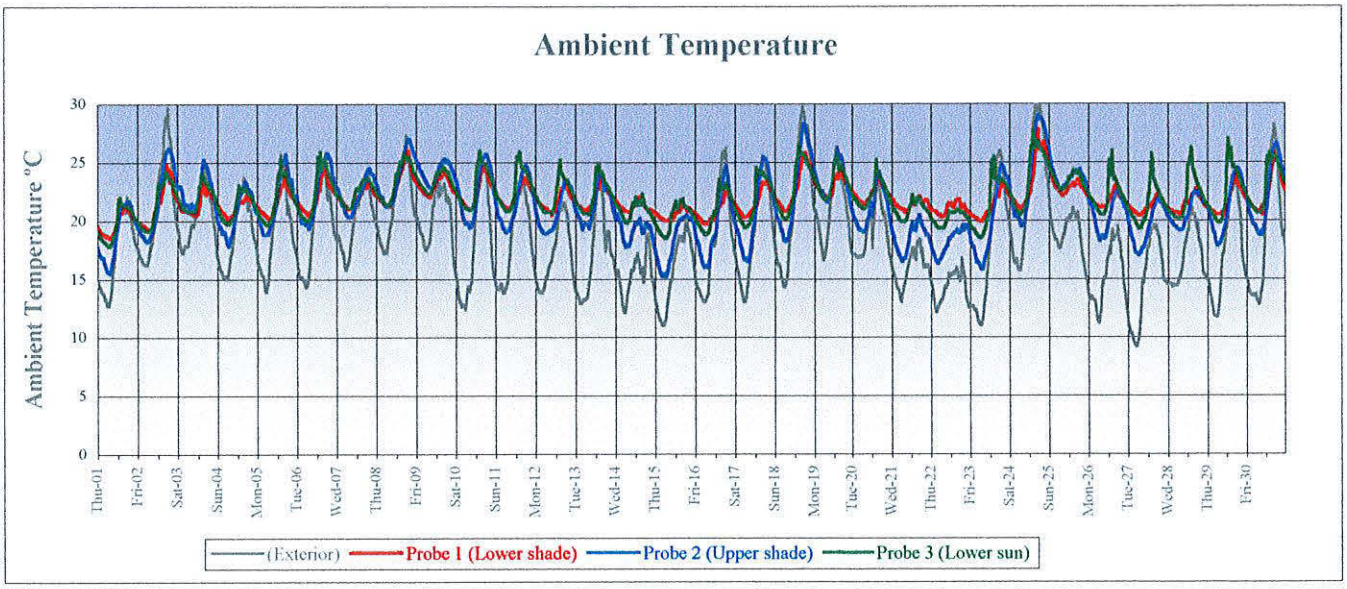


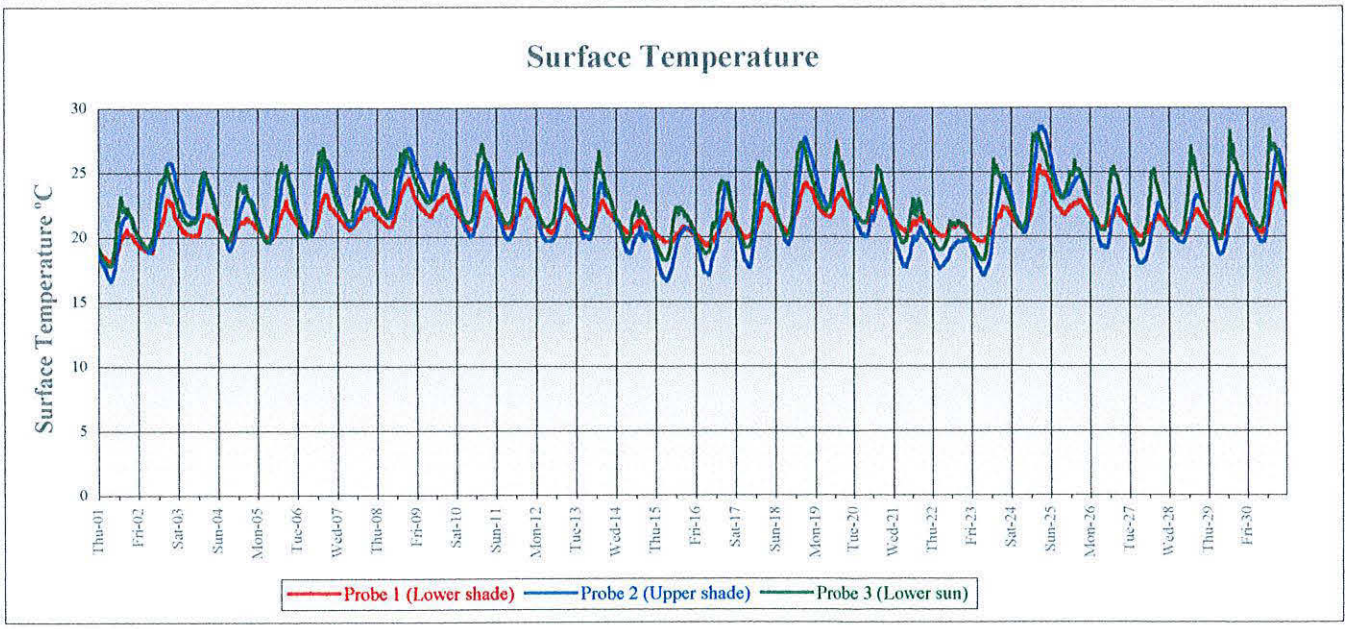
Peterborough Cathedral Nave Ceiling

July 1999

Comparative data



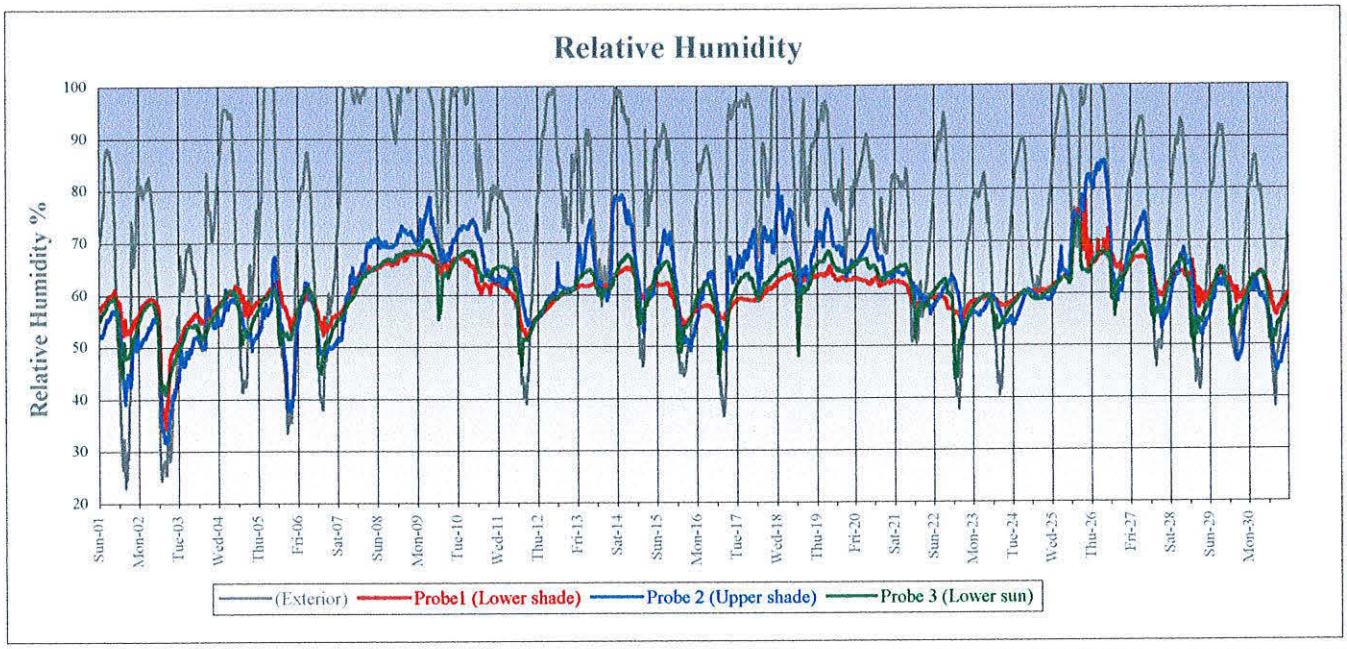


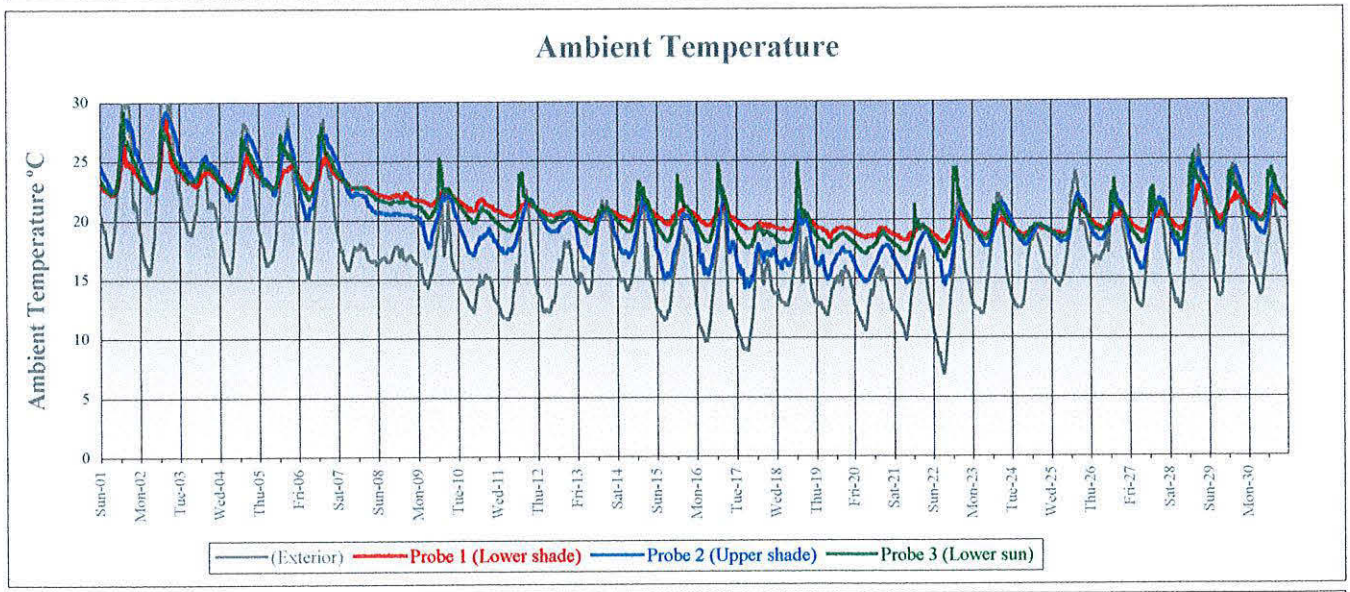


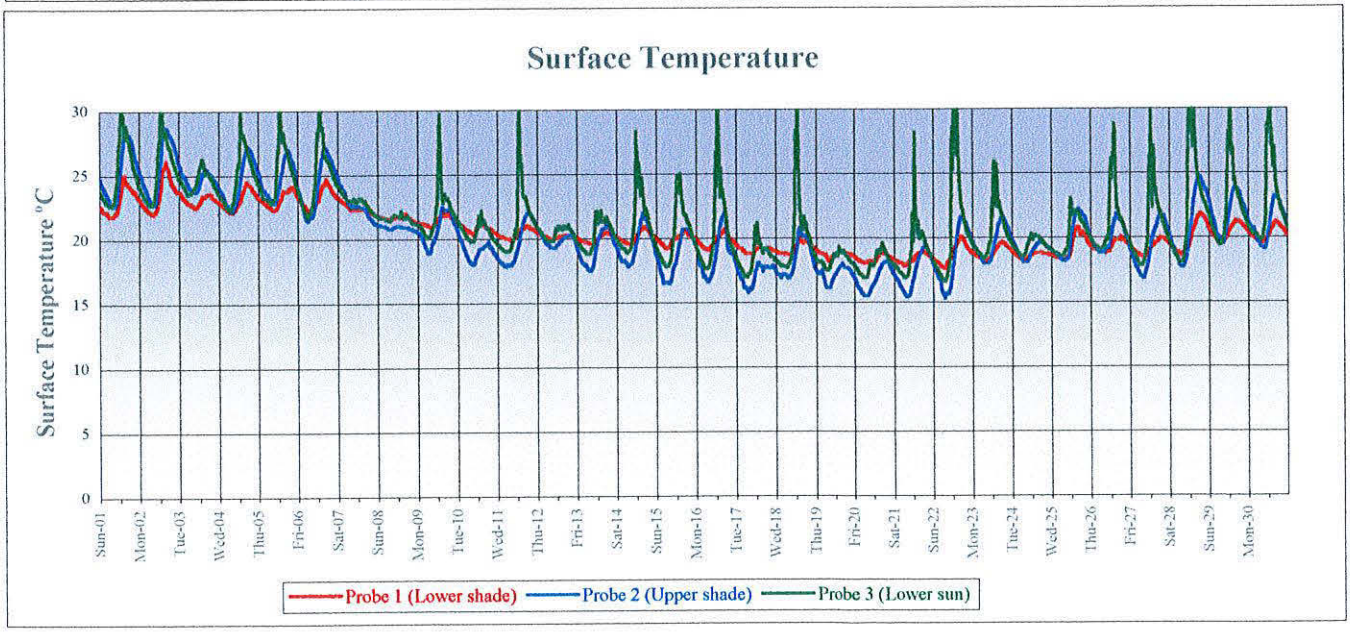
Peterborough Cathedral Nave Ceiling

August 1999

Comparative data



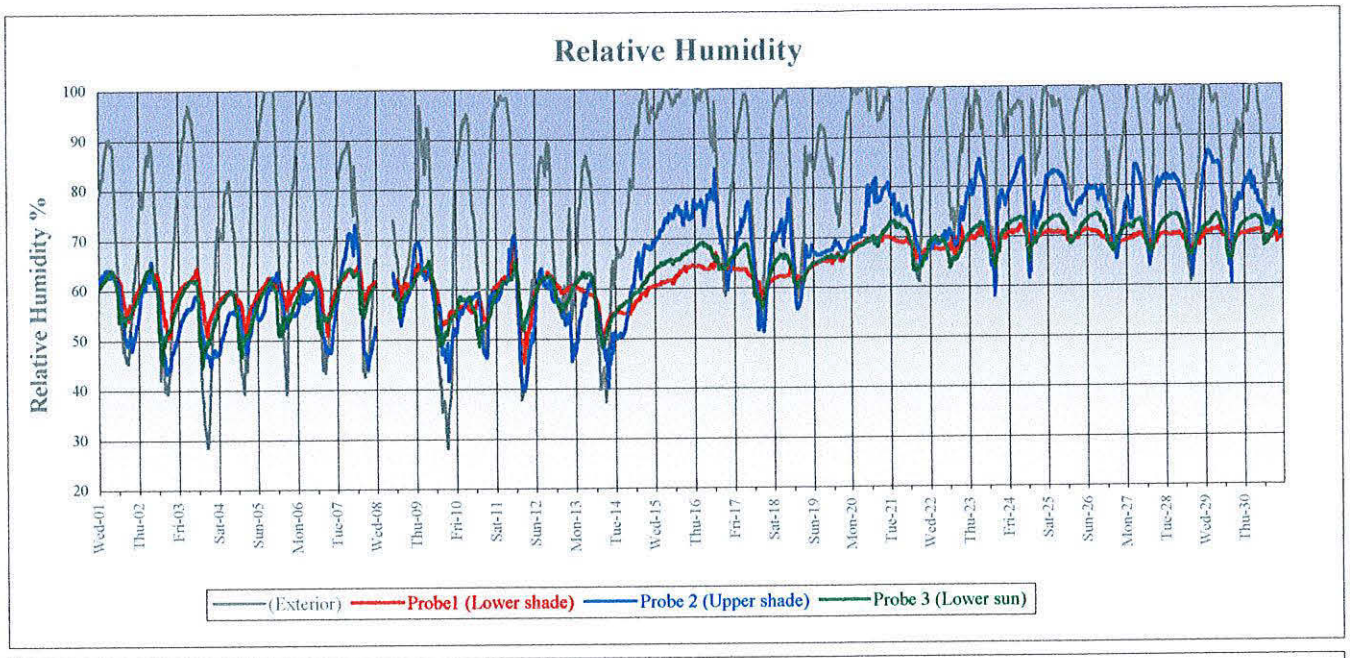


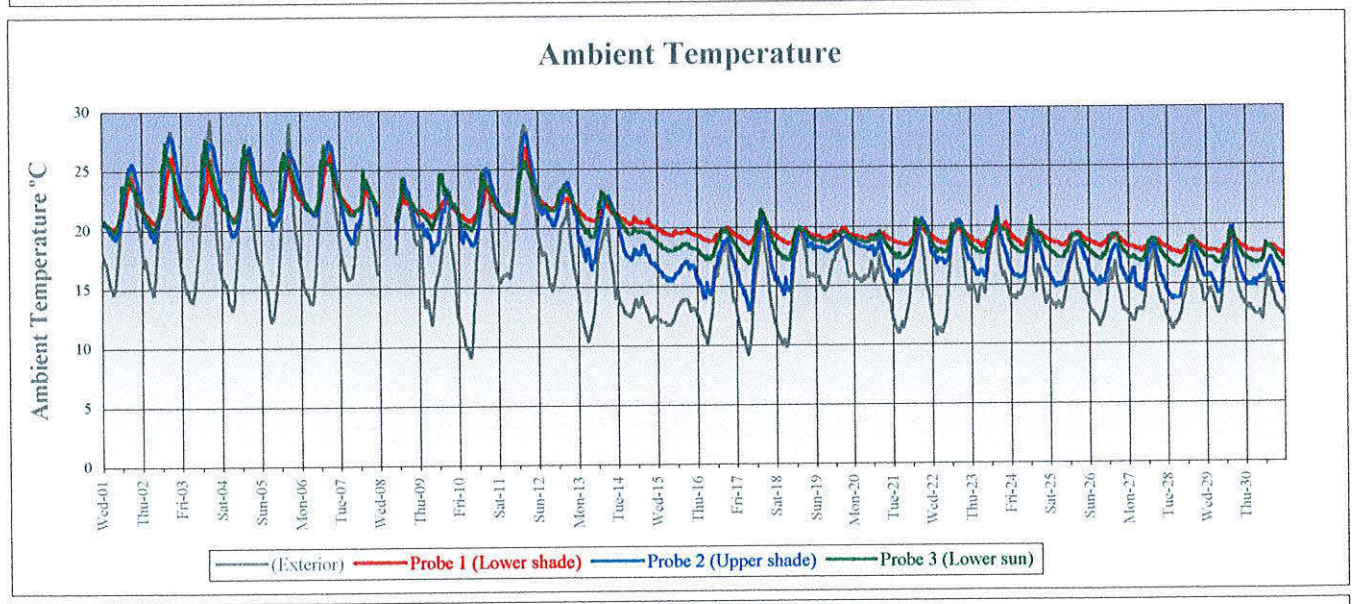


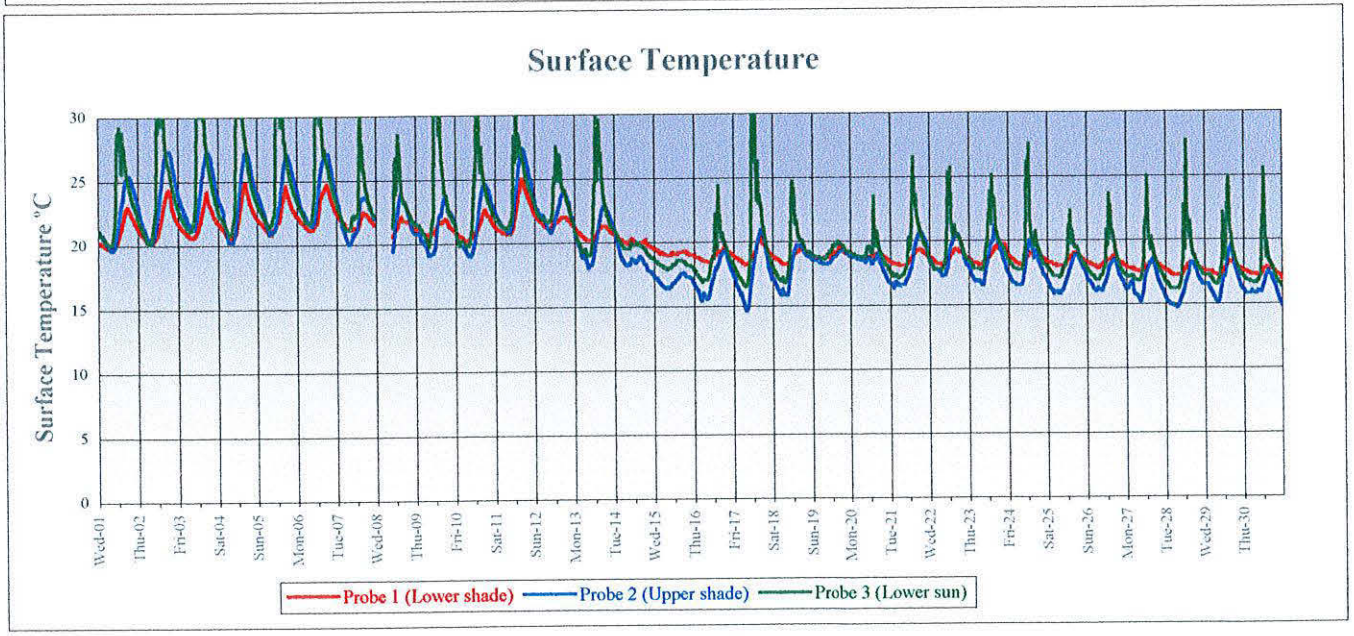
Peterborough Cathedral Nave Ceiling

September 1999

Comparative data



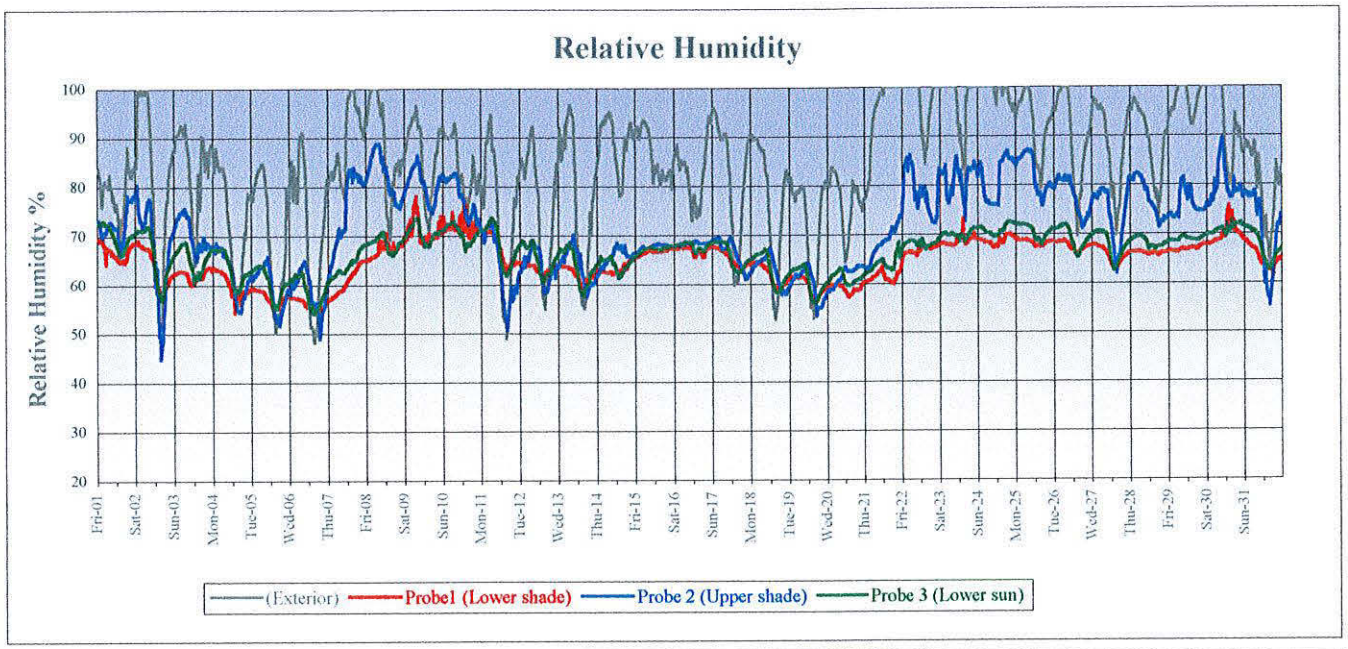


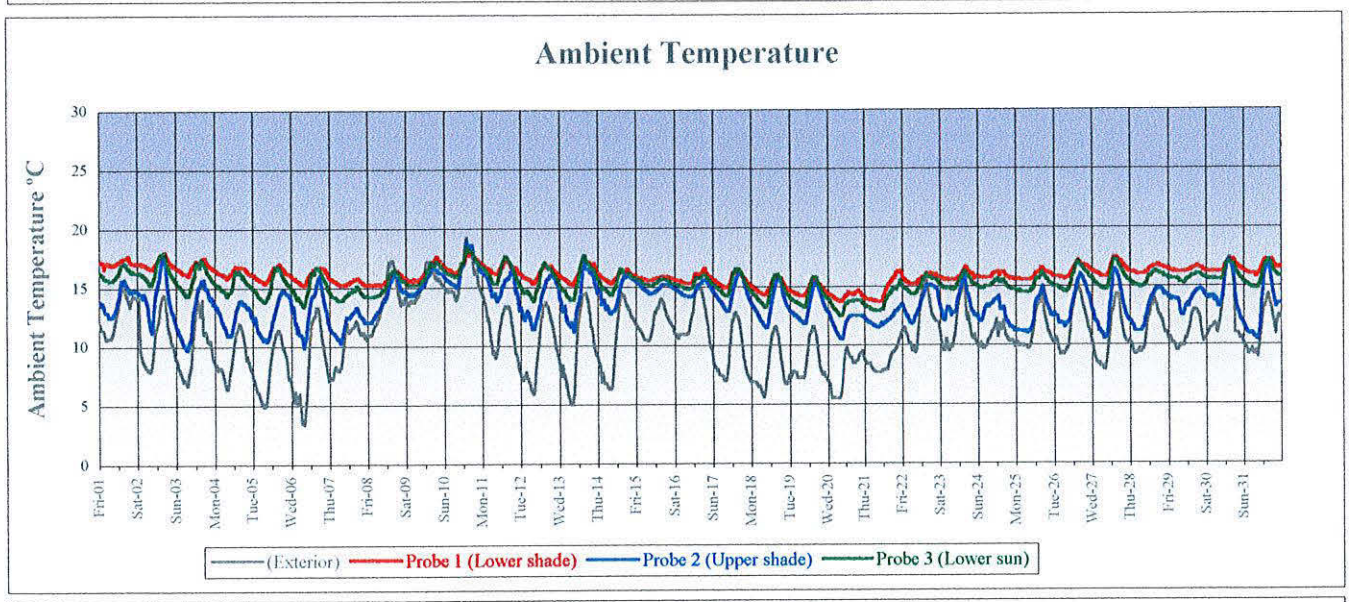


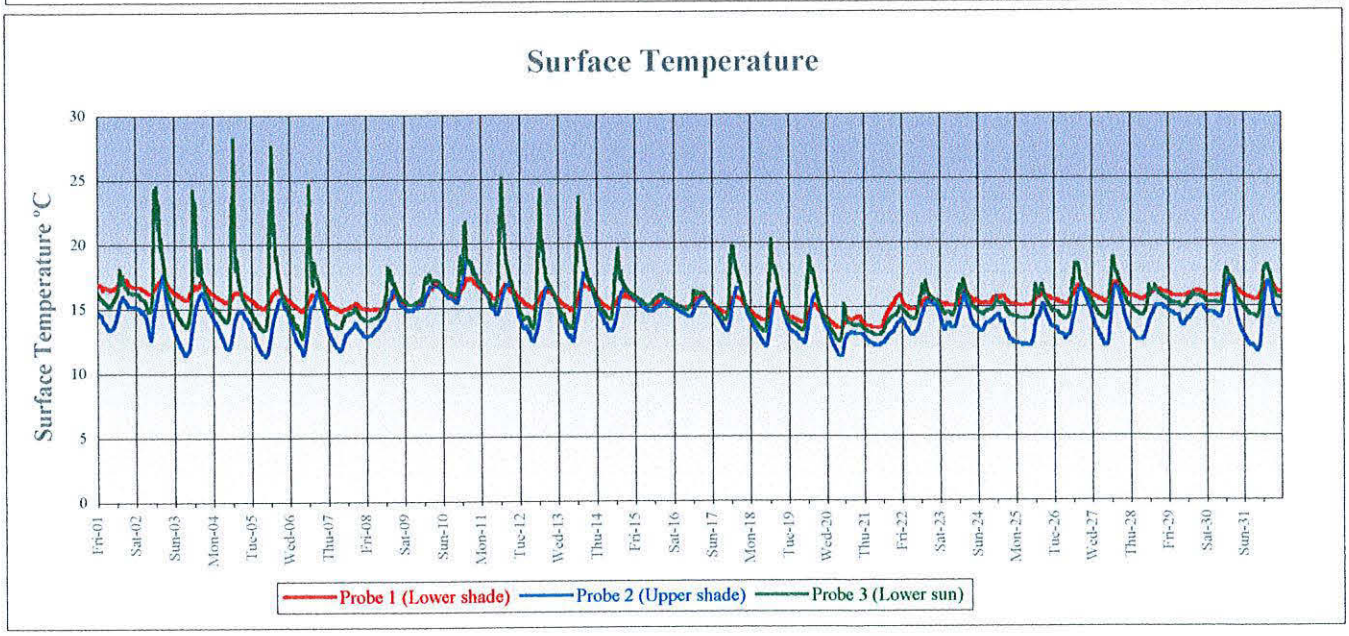
Peterborough Cathedral Nave Ceiling

October 1999

Comparative data



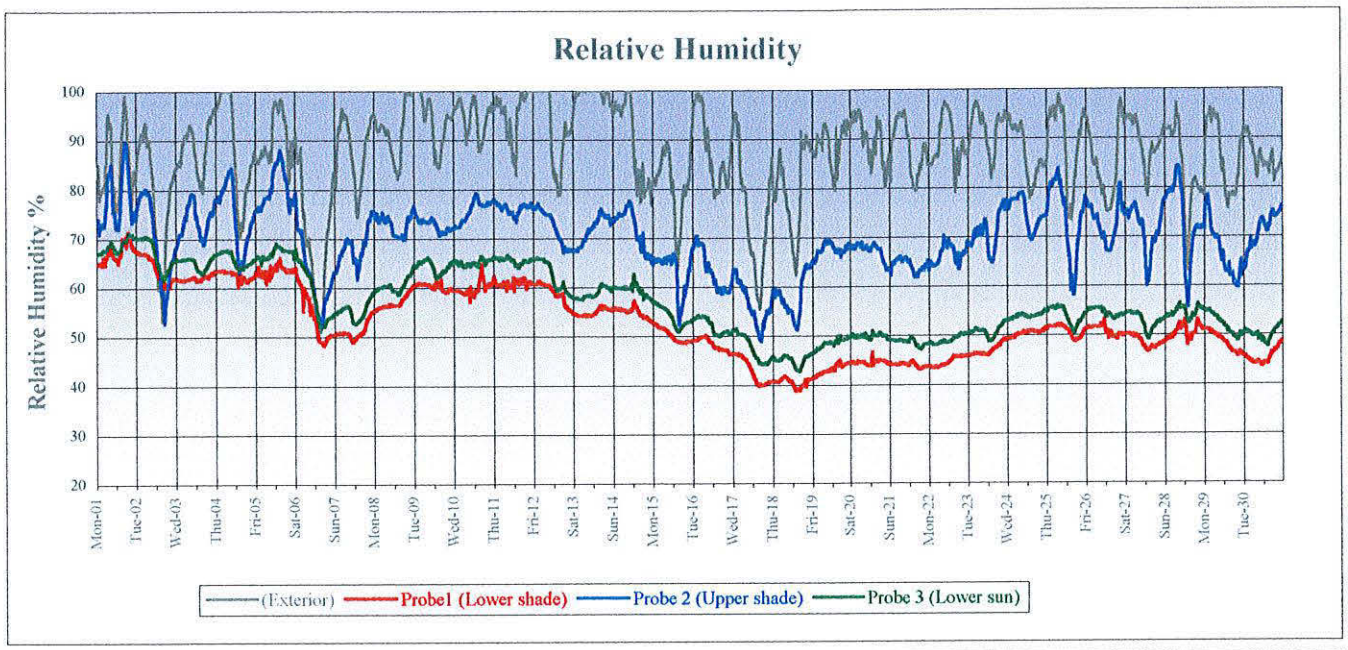


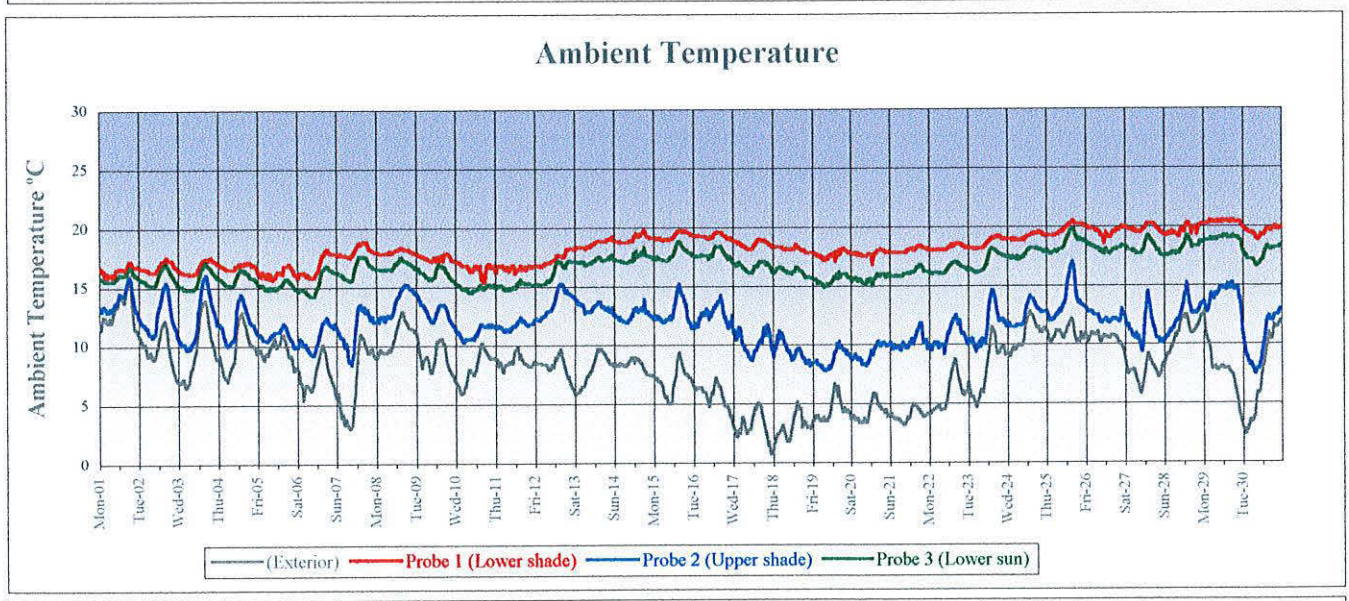


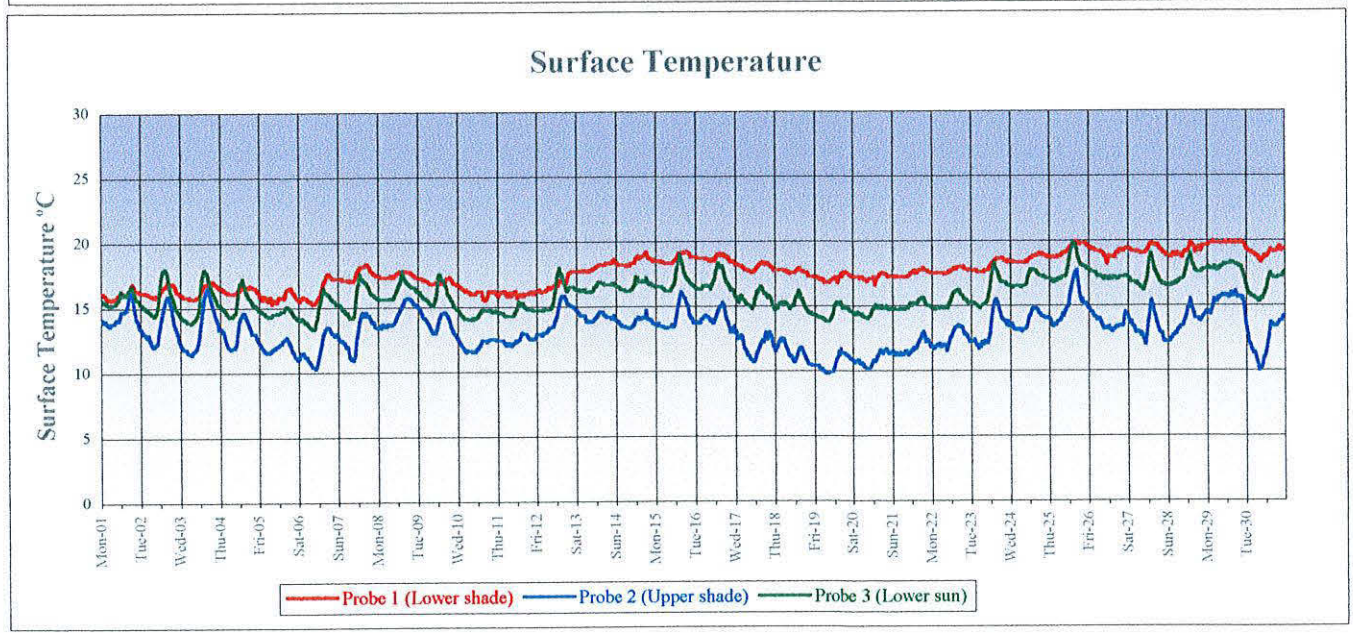
Peterborough Cathedral Nave Ceiling

November 1999

Comparative data



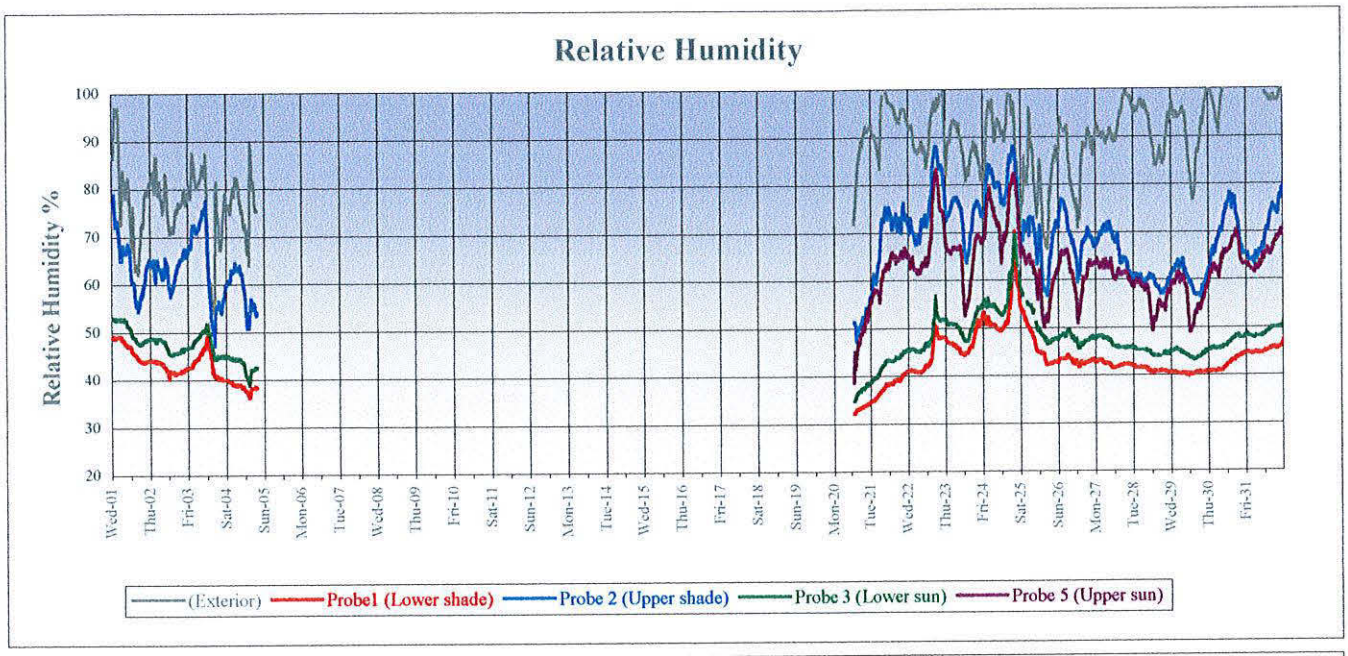


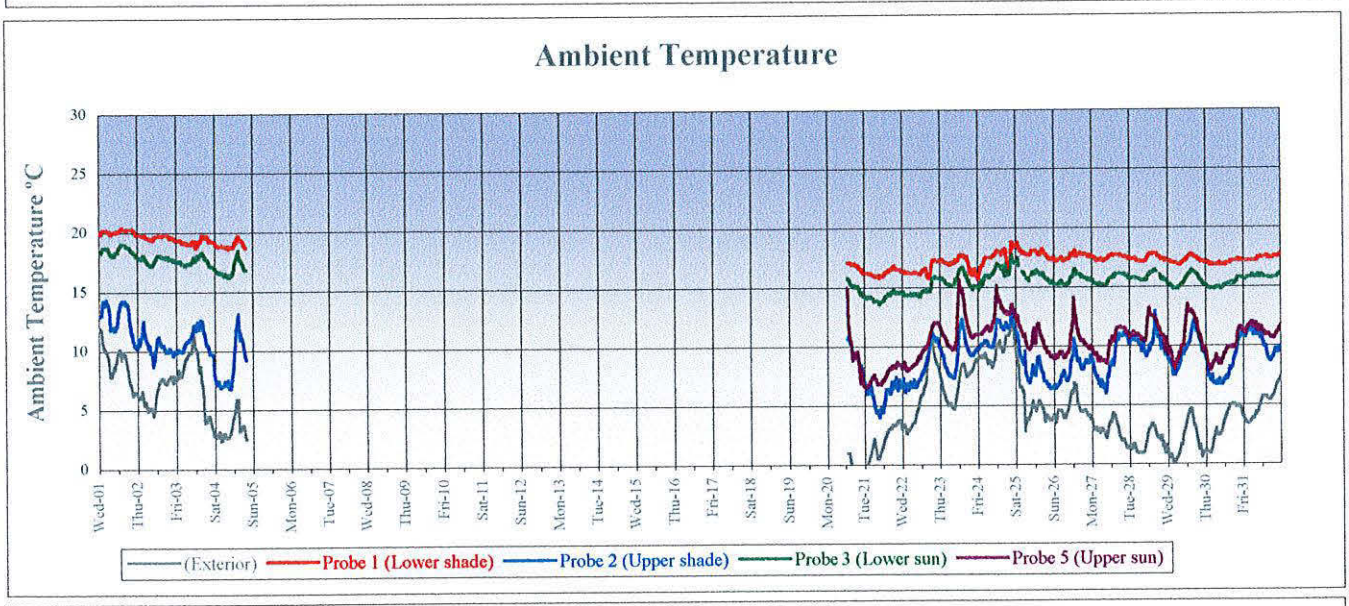


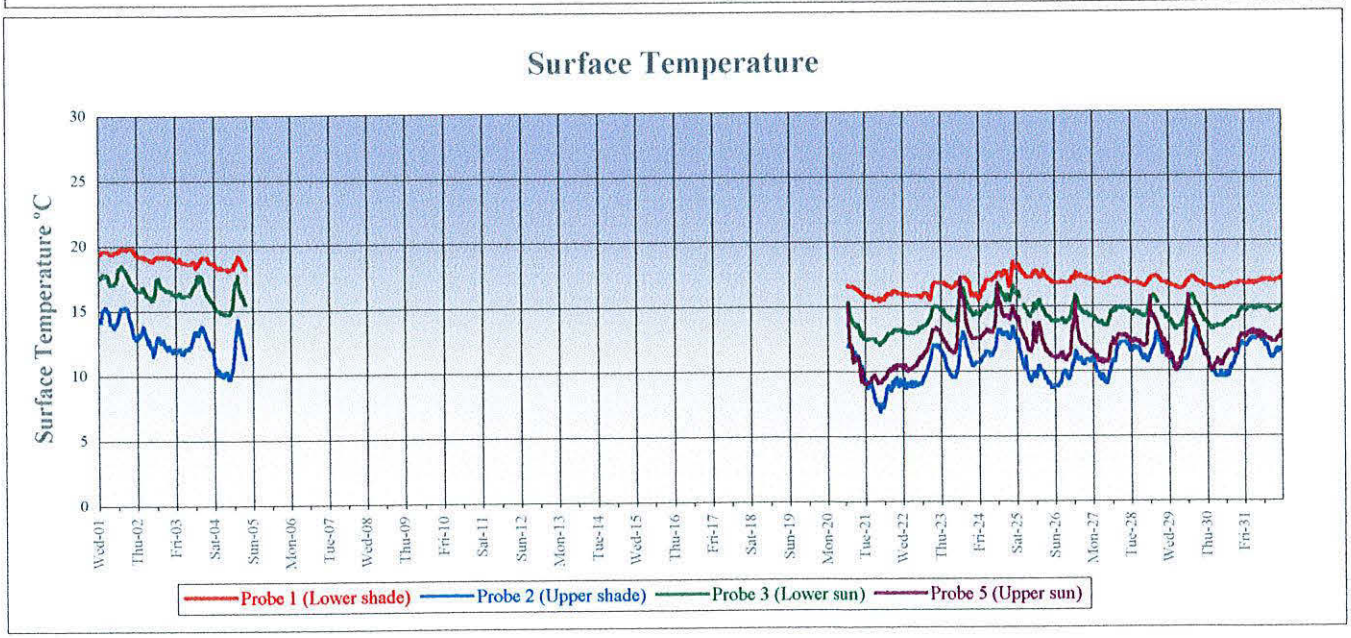
Peterborough Cathedral Nave Ceiling

December 1999

Comparative data



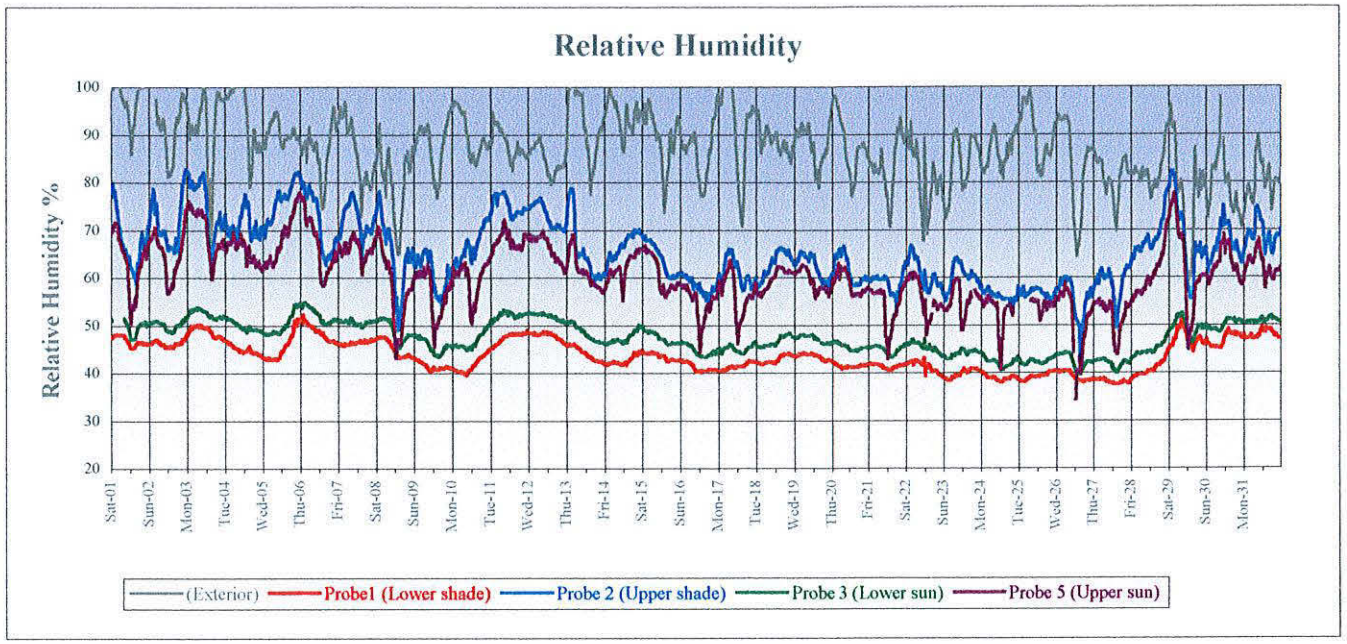


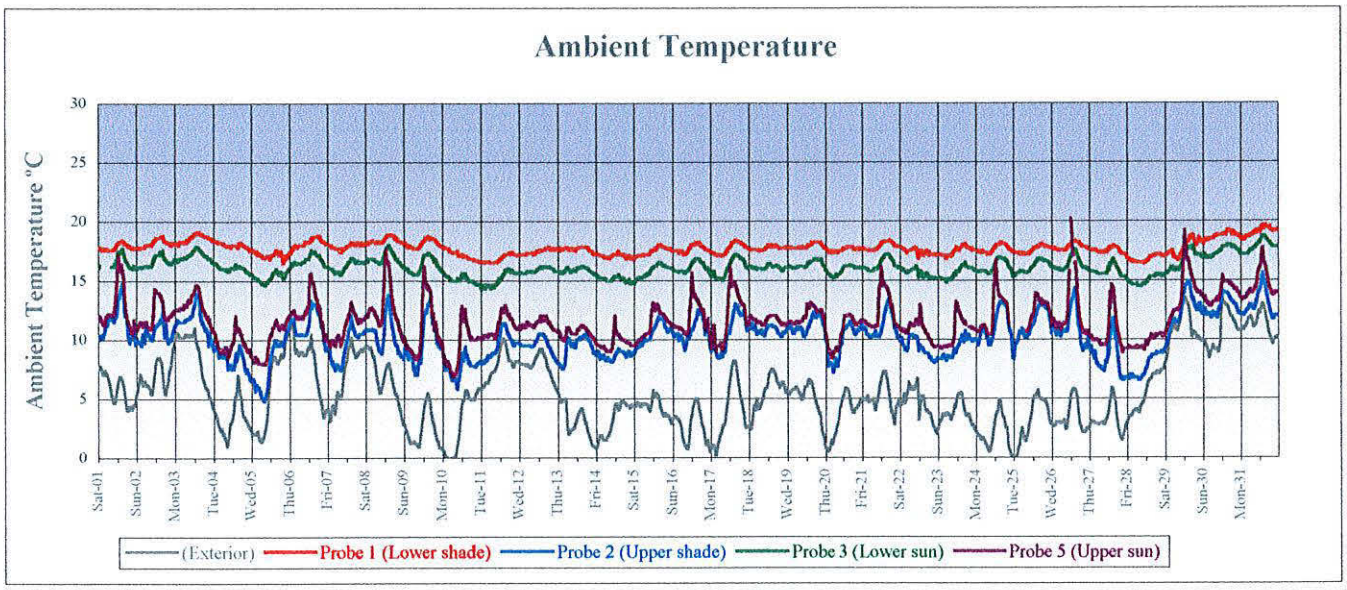


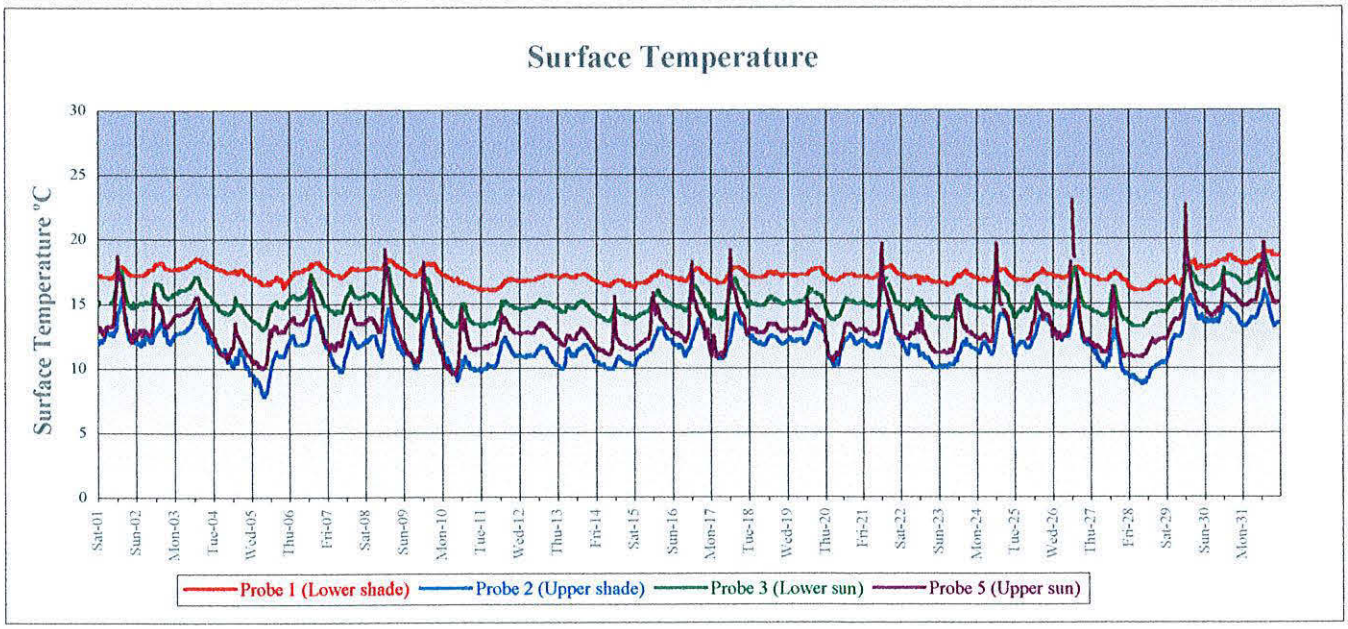
Peterborough Cathedral Nave Ceiling

January 2000

Comparative data



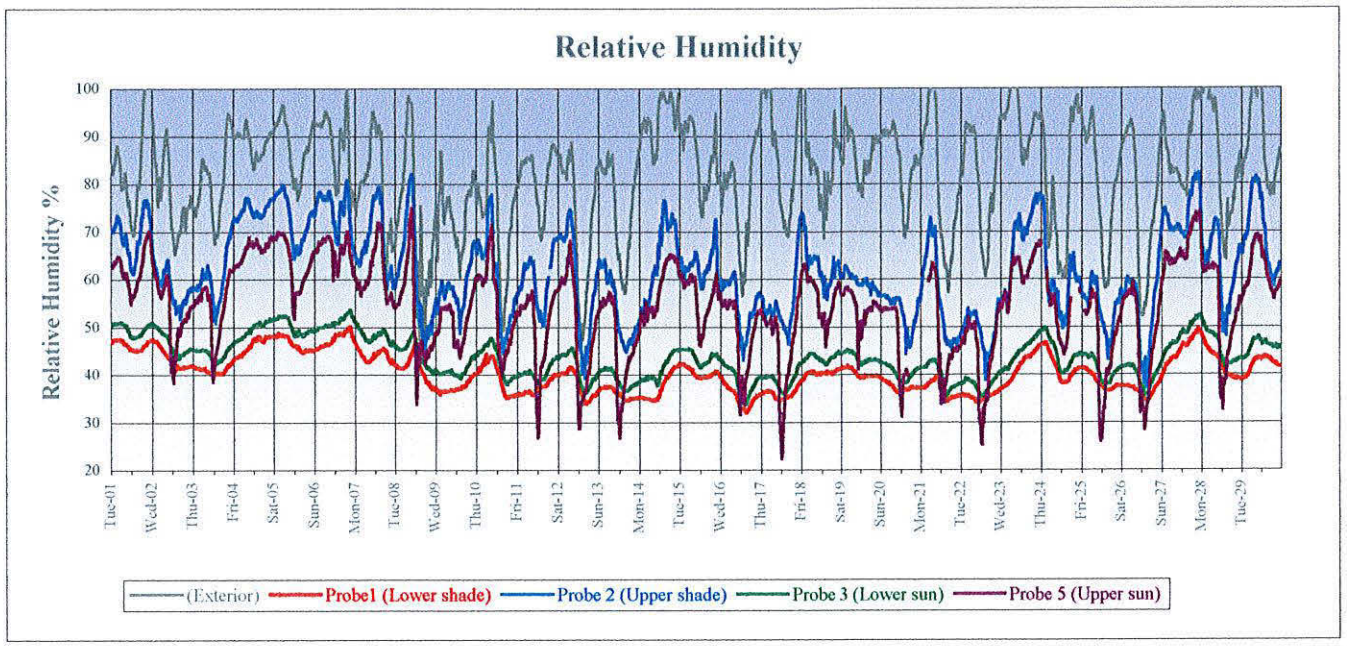


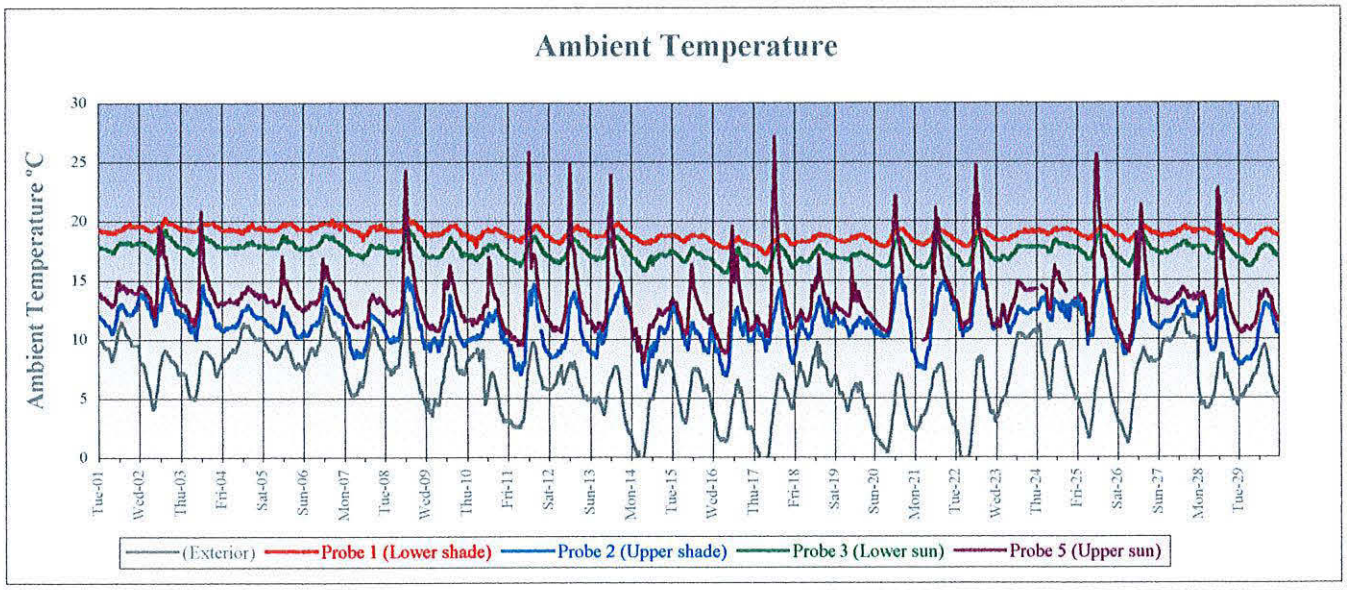


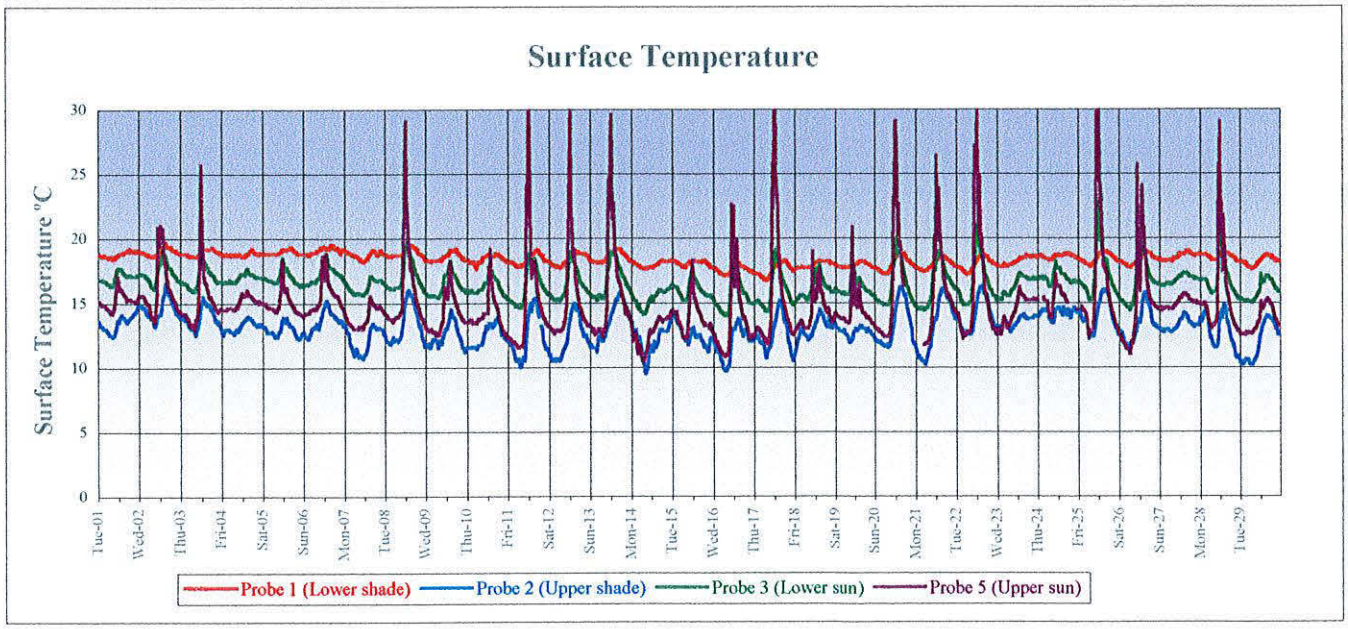
Peterborough Cathedral Nave Ceiling

February 2000

Comparative data



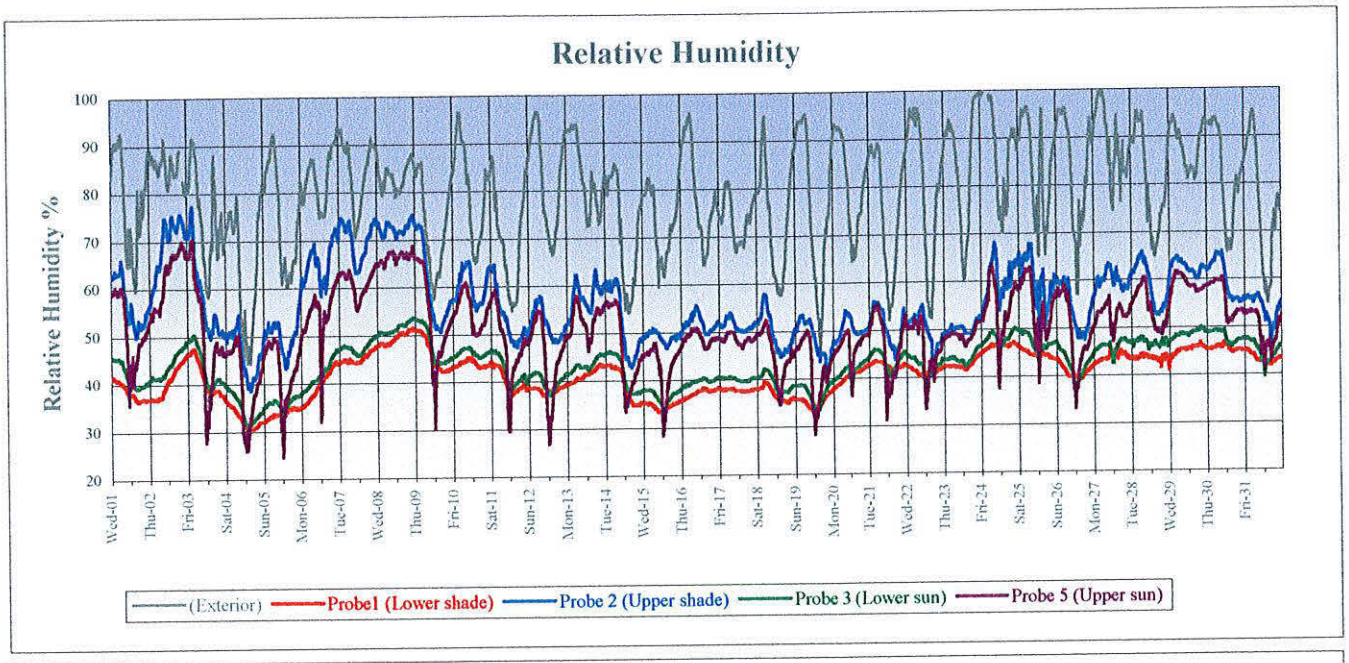


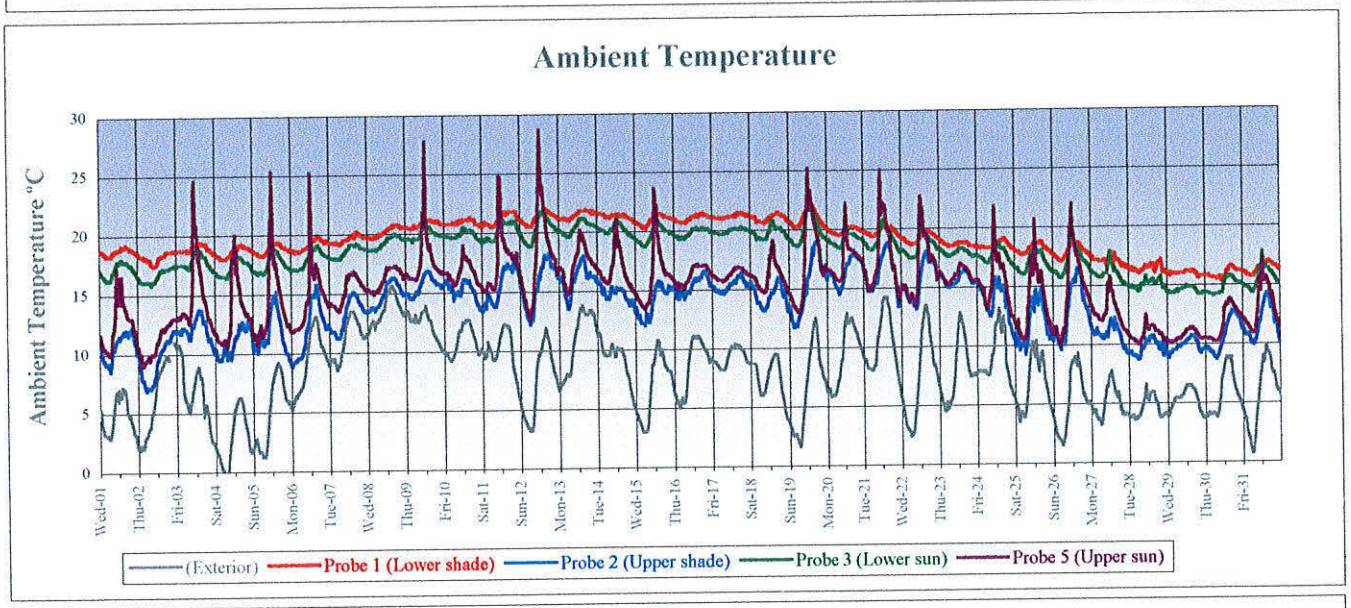


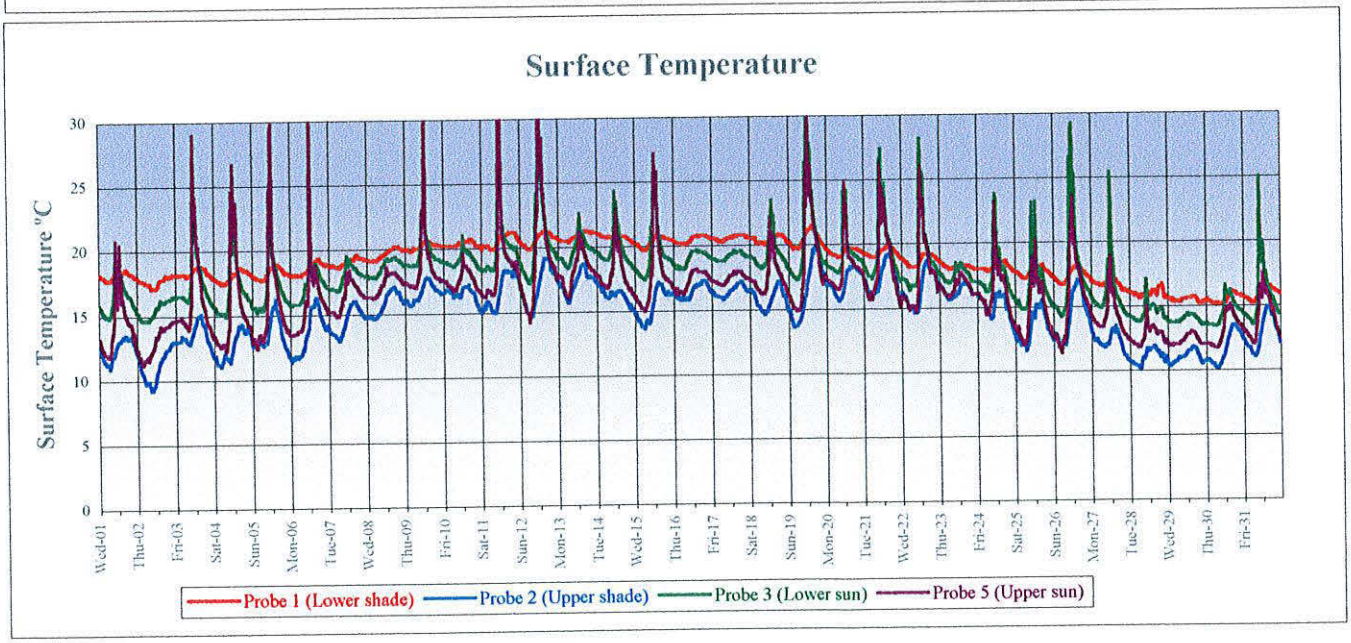
Peterborough Cathedral Nave Ceiling

March 2000

Comparative data



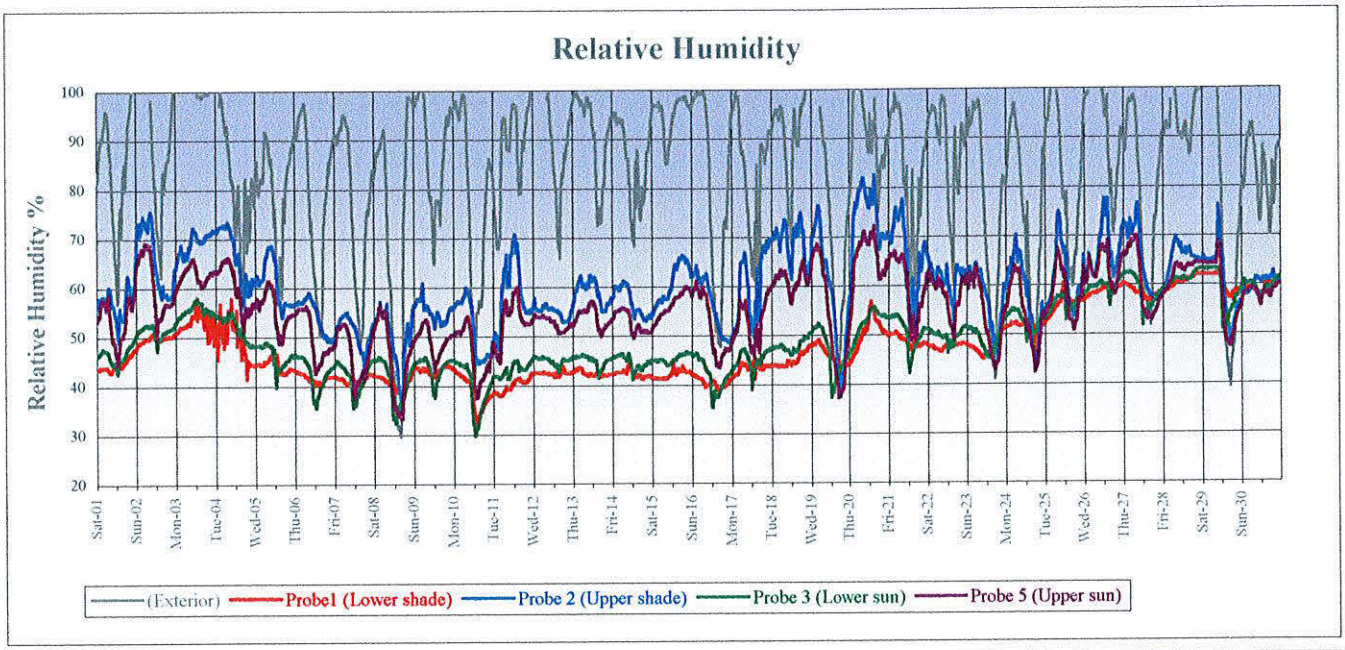


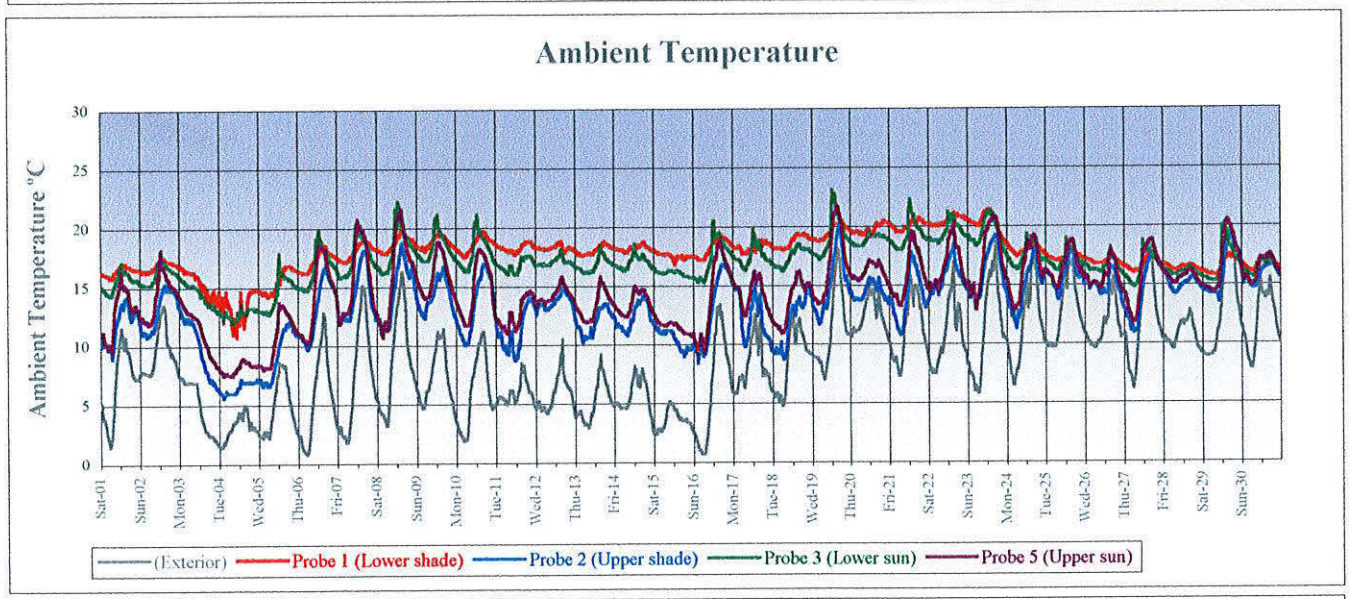


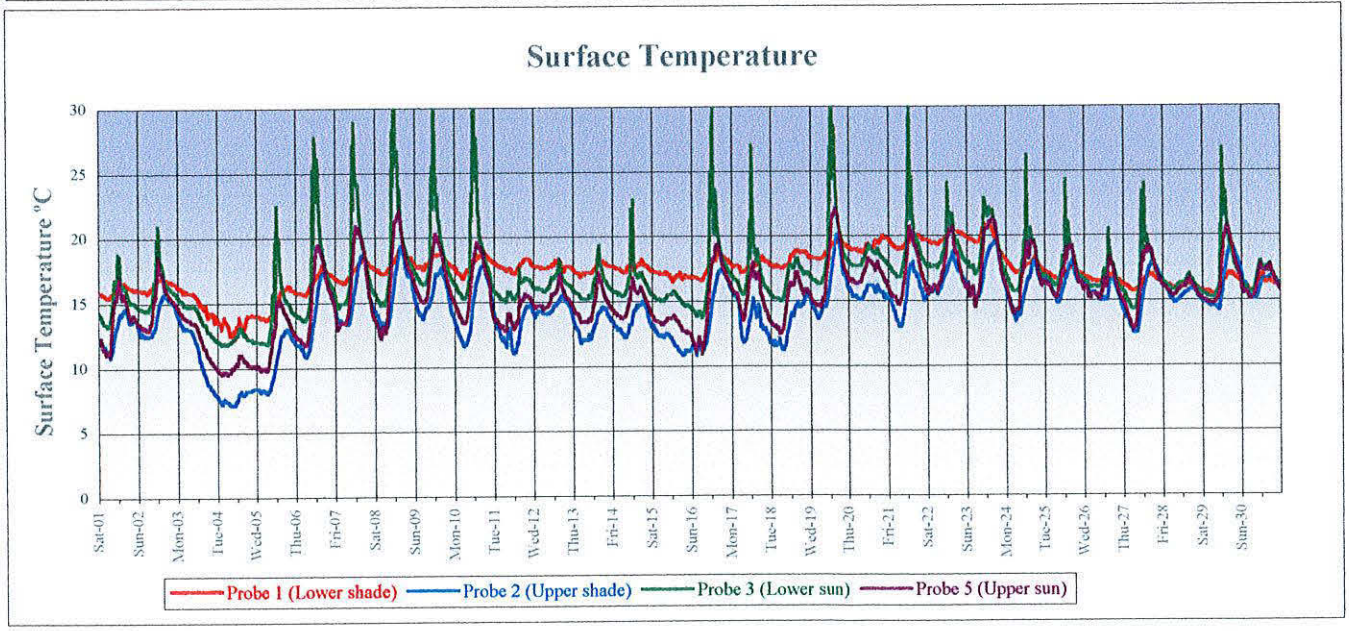
Peterborough Cathedral Nave Ceiling

April 2000

Comparative data







Peterborough Cathedral Nave Ceiling

May 2000

Comparative data