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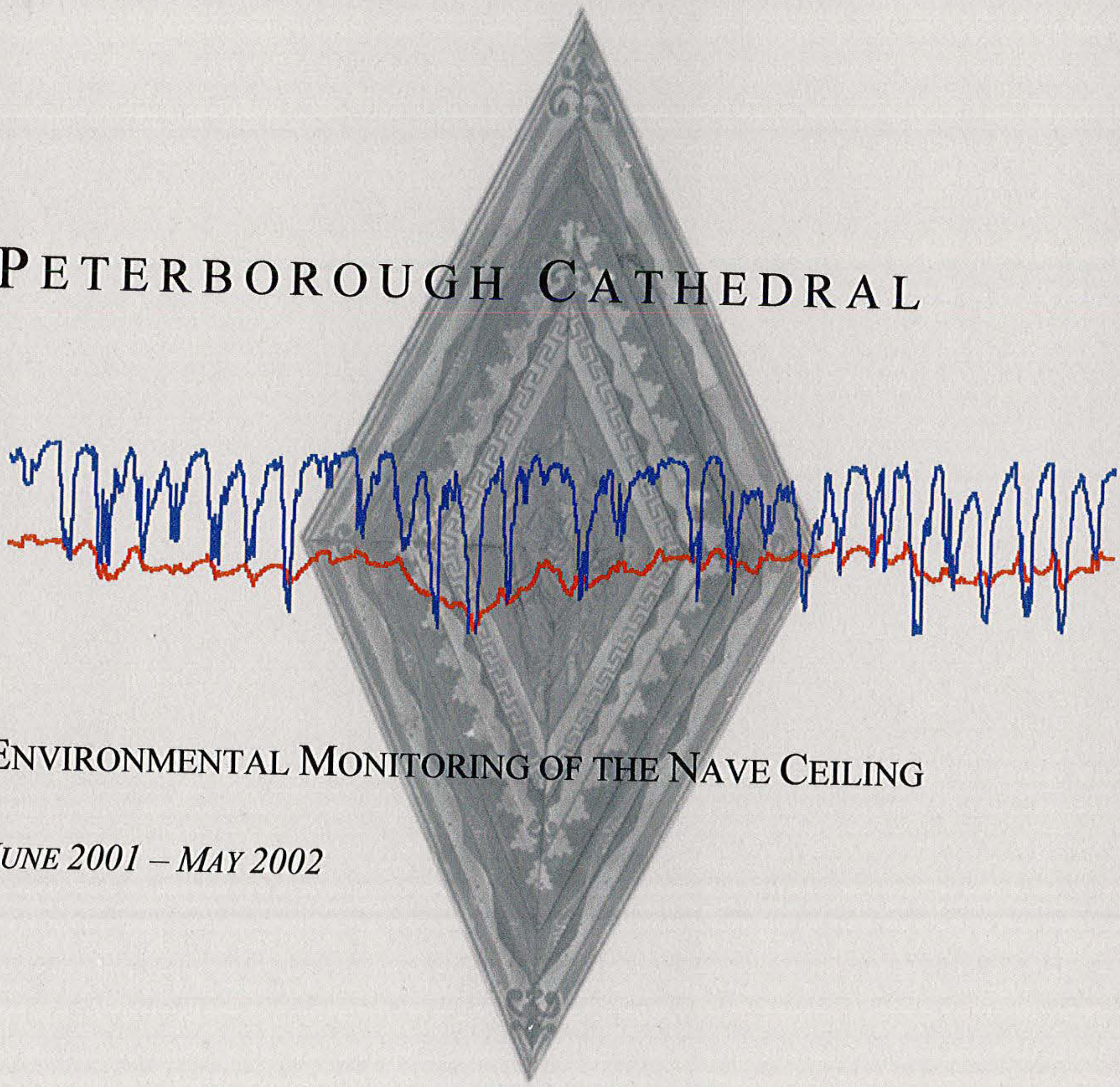
PETERBOROUGH CATHEDRAL



ENVIRONMENTAL MONITORING OF THE NAVE CEILING

JUNE 2001 – MAY 2002

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Report No: PTB01.2

Date: 20th September 2002

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Acknowledgements

I would like to express my thanks to the Dean and Chapter of Peterborough Cathedral and in particular to the head verger, Nick Drewett for his 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, Robert Gowing 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. Thanks are also due to Eltek Dataloggers Ltd for their work developing the linear measurement and light sensors.

1.0 SUMMARY

Monitoring of the microclimate in the vicinity of the 13th century ceiling has shown that there is a very significant variation between the conditions below the ceiling (in the body of the cathedral) and those above, in the roof space. This is mainly caused by the high level of ventilation combined with the low level of thermal insulation in the roof space, and the high level of heating and low level of ventilation below. Because of the resulting unstable hygro-thermal gradients across the thin oak and pine boards, there was the possibility that movement might take place, causing the paint layer to crack or delaminate. However, despite these conditions, no such deterioration has so far been observed. In order to determine why the paint layer appeared stable in conditions which are far from ideal, a system for monitoring the movement in the boards was installed in November 2002.

The data collected during the period from November 2001 to May 2003 indicated that there was indeed a small dimensional change from the boards, in direct response to changes in relative humidity. In general the movement took more than ten days to develop, although extreme diurnal fluctuations resulting from direct solar heating caused very minor short term movement. However the movement was of such a low level (between 0.1% and 0.5% across the grain of the boards) that it appeared that the compressive strength of the paint layer was sufficient to resist deformation or failure. As a result, no delamination or cracking associated with such movement has been identified.

On 22nd November 2001, there was a serious fire at the east end of the north transept. Although this caused significant damage to the surrounding masonry and the adjacent organ, the fire did not spread to the roof (although it is understood to have been very close to doing so when it was brought under control). Environmental monitoring of the ceiling was taking place throughout the fire allowing a unique opportunity to examine the effects of extreme temperatures on a historic wooden structure of this type.

2.0 INTRODUCTION

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

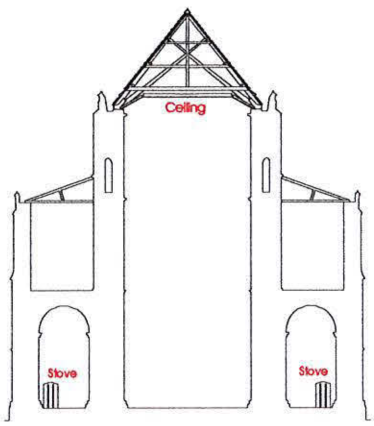


Figure 1. Structure of the nave and ceiling and location of the heating stoves.

The first report on the environmental survey was presented in August 2000.[1] The data showed there were major variations in the conditions above and below the ceiling, in particular in the winter months when the body of the cathedral is artificially heated and the ventilation levels are at their lowest. Temperature and humidity gradients across the painted ceiling boards were found to reach very high levels. In addition, the insertion of roof lights in the 19th century meant that certain areas of the upper part of the ceiling were subjected to periods of direct sunlight which caused huge fluctuations in temperature and humidity levels. However, despite the clearly unfavourable conditions, there did not appear to be significant deterioration of the paint layer of the type which might be associated with the dimensional response of the boards to the microclimatic fluctuations. In order to better understand this phenomenon a number of areas of further investigations were proposed.

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

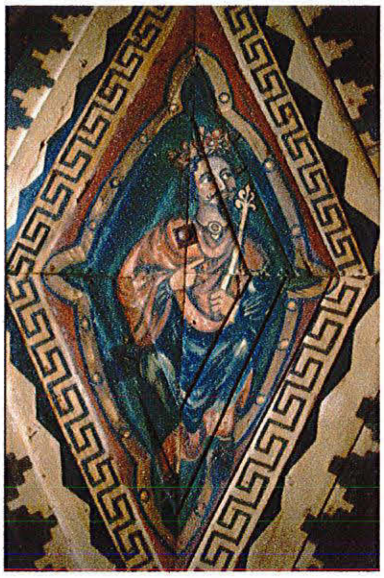


Figure 2. Detail of an area of the roof treated in Phase IV of the programme (Photo: PLP 2001).

The second report, which covered the period from June 2000 to May 2001, confirmed the general findings of year 1, and threw further light on the possible effects of variations in the conditions above and below the ceiling on the dimensional response of the boards. Calculations demonstrated that variations in conditions of between 20 and 30 days would be needed for dimensional change to take place and that diurnal fluctuations, even those associated with direct sunlight, would have almost no effect. Analysis of the data suggested that, in particular during the winter months, this could cause a slight concave deformation of the boards, resulting in the mild compression of the paint layer. A system to measure actual movement was designed in order to test the theory and to provide further information on why, despite the serious environmental conditions, paint flaking was so limited.

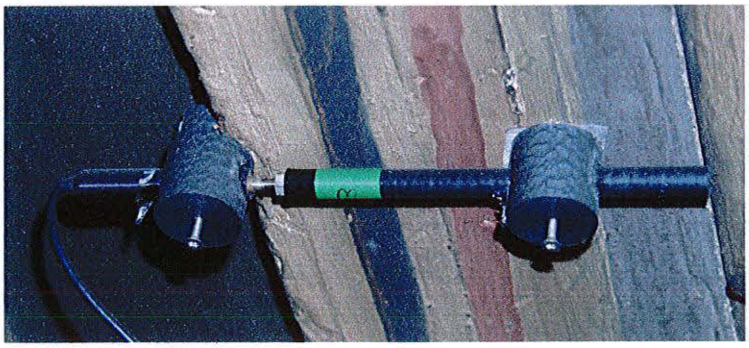
The current report, which covers the period from June 2001 to May 2002 includes the results and analysis of the first set of movement tests. It also includes data relevant to the fire which took place at the east end of the north aisle on 22nd November 2001. A probe to monitor lux and UV was also installed during this period and data will be available in 2003. Although certain information is reproduced below, for the fullest information, this report should be read in conjunction with the previous two reports.

3.0 EQUIPMENT AND PROGRAMME

3.1 MONITORING METHOD AND DATA PRESENTATION

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

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



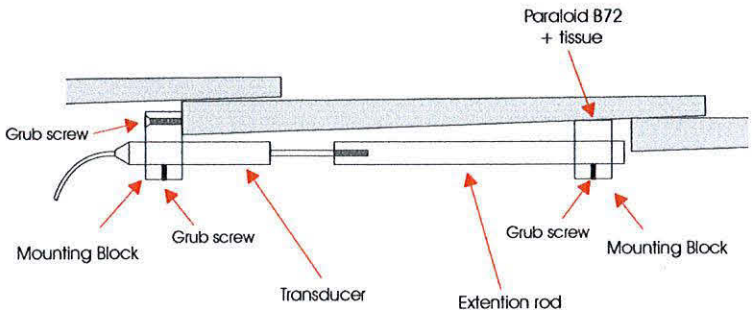


Figure 3: construction and mounting of the linear displacement transducers.

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

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

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.

Levels of movement in the boards were measured at three locations in areas 7 IV and 8 IV (an area of the ceiling exposed to direct sunlight from the windows above). Movement probes consisted of linear displacement transducers (LDTs) fixed across the grain of the board on polyester mounts.[3] The transducers had 25.4mm travel and were extended across the board with the use of a polyester rod, in order to maximise the movement recorded. Probe 6.1 was mounted on a 19th century pine board, while probes 6.2 and 6.3 were mounted on original 13th century oak boards.

The monitoring was carried out using an Eltek 1000RX1 telemetric logging system with TX7 transmitters. RH and AT were measured using Vaisala Humitter combined probes and ST was measured using EU-U-V2 thermistors.[4] The LDTs were also attached to an Eltek transmitter, so that data could be recorded at the same intervals as the other parameters, on the main datalogger. 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 2.0.16 software and processing and charting was undertaken with Microsoft Excel 97.

3.2 PROGRAMME

The environmental monitoring has taken place in three distinct stages. Between January 1995 and June 1996, periodic monitoring was undertaken by English Heritage's Mechanical and Engineering Department. Following this, from March 1998 to June 1999 a second phase of monitoring was undertaken by English Heritage's Ancient Monuments Laboratory. 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. During the present monitoring period, data was recorded on all channels at 30 minute intervals.[5]

4.0 ENVIRONMENTAL MONITORING

4.1 ARTIFICIAL INFLUENCES ON THE MICROCLIMATE

As has been discussed in the previous reports, the principal artificial influence on the microclimate is the heating system, although the levels of deliberate ventilation also have a significant influence.

Prior to the mid 19th century there was no significant heating in the cathedral. However, in the late 1860s, following the introduction of gas lighting, four coke fired Gurney stoves were installed in the nave, two in the transepts and two in the chancel. *(Diagram 2)* In 1963, the stoves were upgraded to run on oil. In 1993 they were converted for use with gas and had thermal insulation blocks added in order to increase their long term heat retention, effectively causing them to act as storage heaters.[6]

Figure 4. Windows on the south side of the nave roof. (Photo: TCA 2000)

The heaters are in use from approximately November until May. During the period that the heaters are active, they are run for twenty four hours per day usually at the full setting, although the half setting is occasionally used. The north east nave heater is not usually used, unless a

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[3] The LDTs used for the tests were Honeywell MLT 1" Linear Position Transducers.

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

[5] Some sections of data were lost as a result of electronic malfunctions.

[6] 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.

particularly cold period occurs. Of the seven remaining units, all are usually used during the winter, although if the weather is mild, some are occasionally turned off. [7]

Another significant influence on the microclimate is the deliberate ventilation of the body of the cathedral and the roof space. However, as the use of deliberate ventilation in the cathedral itself is fairly restricted, the effects are limited.

As a result of the ventilation grills installed when the roof was restored in the 19th century, the level of internal/external air exchange in the roof space is extremely high. *(See Diagram 2)* Insulation of the roof is limited and so the influence of the external conditions is very significant. In addition, glass panels were installed at the base of the roof on the north and south sides, in the mistaken belief that these would disrupt the life cycle of death watch beetle. As it was concluded that the boards served no beneficial purpose, and that the heating and cooling of the roof boards caused by direct sunlight had the potential to cause damage, it was decided that those on the south side should be covered over. Rows 8 - 39 were covered in July 2002 and it is anticipated that the remaining rows will be covered in Summer 2003.

4.2 THE FIRE

On the evening of 22nd November 2001 a fire took place in the eastern bay of the nave north aisle. The fire started in a large stack of polypropylene chairs, which were located on the south side of the aisle behind the organ. The fire was identified quickly after it was started, by a verger who alerted the fire service. The growing fire caused the lead in the adjacent north window to melt allowing it to vent via the opening.

The fire brigade arrived on the scene some time after 18:00. Because of the level of smoke caused by the thermal decomposition as well as the burning of the polypropylene, visual location was hampered, but the damage to the window and thermal imaging equipment allowed the source to be quickly identified. The fire crews then brought the fire under control in less than ten minutes, using water (with no additives) from on board high pressure hose reels. It is understood that the fire was at a point where a delay of more than a few minutes would have allowed it to spread to the roof, when it would have been beyond control.[8]

Although no areas of the painted ceiling caught fire, the heat caused short term but very dramatic fluctuations in the immediate microclimate. More seriously, the decomposition and burning of the polypropylene caused severe soot damage to the whole of the interior of the cathedral. By far the worst damage was to the 12th century stone arcade in the aisle which suffered severe structural damage as did the organ, which was badly burned.

[7] *Pers Comm.* Nick Drewett

[8] I am most grateful to Station Commander Ray McDonald of the Cambridgeshire and Peterborough Fire Service for this information.

4.3 *Monitoring Results*

The microclimatic data collected during the current period of monitoring was similar to that recorded in previous years. On the lower side of the ceiling the annual average values for RH and AT were 56.6% and 17.1°C (in the shade). The extremes for RH were 82% and 33% while those for AT were 11°C and 29°C. (Excluding fire conditions). Summer averages were 61% and 21°C with diurnal fluctuations of 8% and 3°C. Winter averages were 53.3% and 15.2°C with diurnal fluctuations of 4% and 1.5°C.[9]

The equivalent annual conditions in the roof space were 65% and 14°C. Extremes for RH were 91% and 32% while those for AT were 32°C and 3.5°C. Summer averages were 58.7% and 20.9°C with diurnal fluctuations of 18% and 6°C. Winter averages were 66.4% and 10.5°C with diurnal fluctuations of 9% and 3°C.

Humidity and temperature gradients between the upper and lower sides of the roof had a similar pattern to previous years. In the shade (Bay 33 III) the RH was consistently higher in the roof space than in the nave, throughout the winter months, while the AT and ST remained lower. In areas subjected to sunlight (Bay 36 III) a similar pattern was observed but the differences between upper and lower areas were considerably less.

As in previous years, the external conditions had a very different impact on the microclimate above and below the ceiling.[10] In the roof space the high level of deliberate ventilation and the low level of thermal insulation meant that the conditions followed the external environment closely and, as a result, the microclimate underwent regular and severe fluctuations. On the north and south sides of the ceiling (the lower sections of columns I and IV), the roof is exposed to direct sunlight through the glass panels and high levels of ventilation from the grills above and below the windows. As a result, the conditions in these areas are particularly extreme. As most of the windows have recently been boarded over, the effects of solar gain should have ceased, and so in the future the only difference in this area will be the higher than average level of ventilation. The results of this change should become apparent during the coming twelve months.

The conditions below the ceiling vary significantly from those above. The far lower level of ventilation and the thermal buffering afforded by the building structure means that the influence of the external conditions is significantly reduced. Natural ventilation (building porosity) means that the internal conditions are to some degree influenced by the external values (the influence of the external AH is particularly visible during some periods), but in general this is limited. The thermal conditions in the roof space have a direct effect on the microclimate immediately beneath the roof (the ceiling structure itself offers little thermal insulation) so that during the winter months, heat clearly passes through the wooden boards, and when sun falls on the upper sides, the lower surface temperature rises accordingly. However, the most significant influence below the ceiling is, once again, the heating system. During the winter months when it is in operation, an AT of

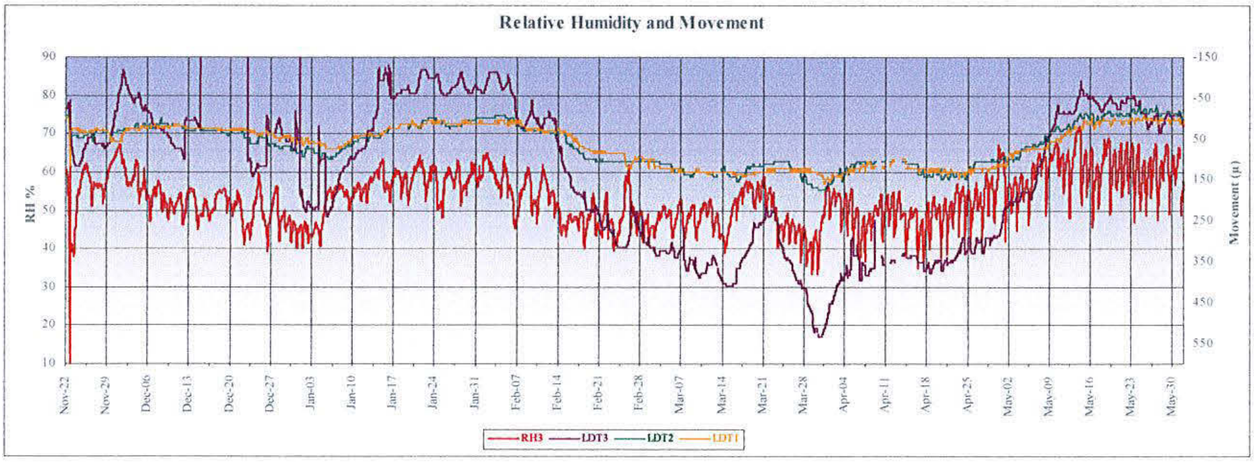

Chart 1: LDT data (from their installation in November 2001, until May 2002) plotted against RH data from probe 3 (in an area below the ceiling effected by sunlight). In order to show the correlation more clearly, the movement scale has been reversed. Therefore, when the LDT chart rises, the board is contracting and vice versa

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[9] Diurnal fluctuations are based on visual estimates.

[10] More detailed information on the influence of external conditions and the effects of the heating system can be found in the 2001 monitoring report

approximately 15C is achieved 24 hours per day, with a correspondingly low RH of approximately 53%. Heat passing through the boards can be observed by comparing the ST above the ceiling which, during cold periods, remain significantly higher that the AT.

The variations between the above and below ceiling conditions often result in extreme hygro-thermal gradients across the boards, raising concerns about their dimensional response and the implication for the paint layer. It was in order to measure their *actual* movement that Linear Displacement Transducers were installed on three separate boards (two original oak and one later pine). The data showed that in all three cases, movement took place in response to changes in Relative Humidity.

The pattern of movement indicated that when the RH increased, the surface of the board contracted, and when the RH decreased, the surface of the board expanded. During these long slow periods of movement, the RH in the roof space remained consistently above that below the ceiling, possibly suggesting that an increase in volume on the top of the board was causing a mild concave compression on its under side. This may have been exacerbated by the fact that the upper side is covered with only hessian and glue, while the lower face is covered with a non porous layer of oil paint.

However, the level of movement was extremely limited and took place over long periods of time. In general, diurnal fluctuations in hygro-thermal parameters had no observable influence on the dimensional response of the boards. The only exception to this was the sudden heating of the boards as a result of solar gain, which appeared to have a very marginal effect, although it was inconstant and irregular.

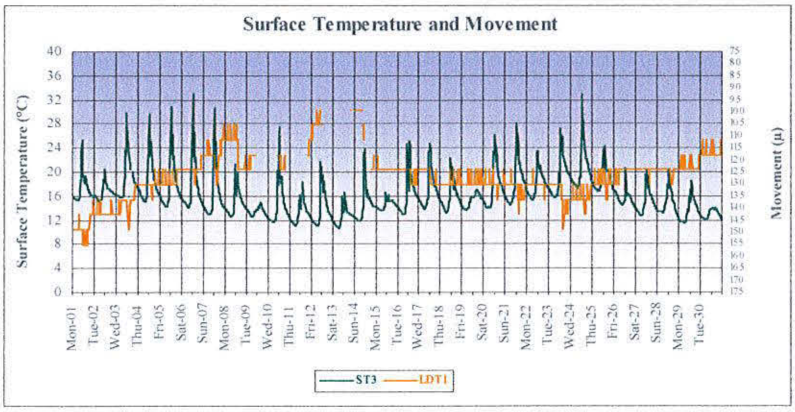


Chart 2. Detail of the surface temperature at probe 3 in April 2002, plotted against the movement of the LDT. Although there is a very minor response following extreme heating, it is irregular and inconsistent.

There was a noticeable difference in the movement recorded at probes 6.1 and 6.2 which were almost identical, and the more significant movement recorded at 6.3. Probes 6.1 and 6.3, which were mounted on an original oak and a 19th century pine board, had a movement range of up to 150µ. Probe 6.3, mounted on a second original oak board had a range of up to 700µ. The reason for this variation is not at present clear, but it may be associated with the fixings on the boards and the fact that the board was badly cracked in an area above the probe. It is hoped that when a full year of data is available, it may be possible to throw more light on these discrepancies.

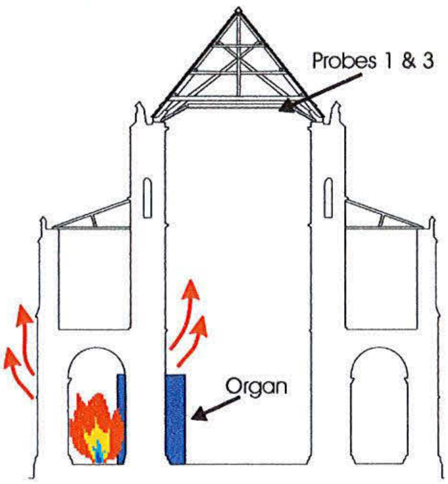
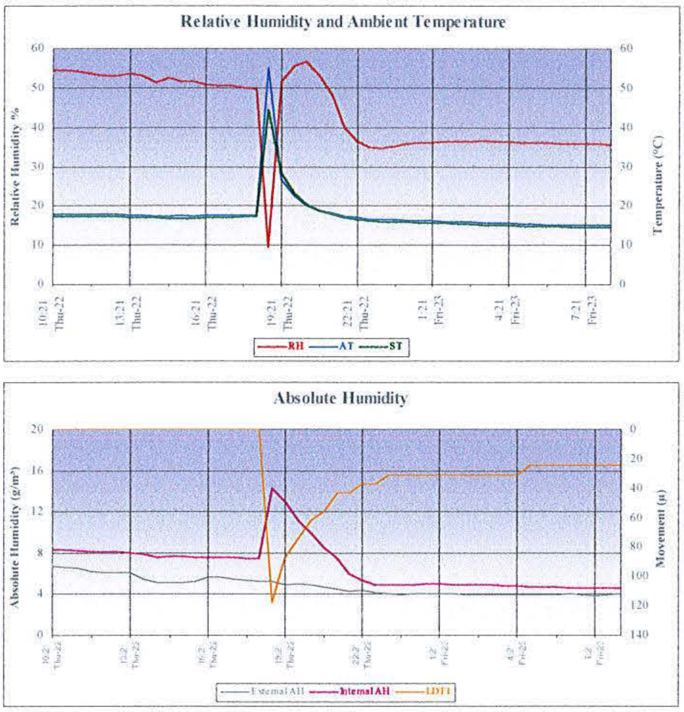


Figure 5: diagram showing the location of the fire relative to the ceiling

On 22nd November 2002, a fire broke out at the west end of the north aisle, immediately behind the organ. Although it was swiftly brought under control, structural damage to the masonry and the organ was very severe and a veil of soot was deposited over much of the interior of the cathedral.

Probe 1 was located on the nave ceiling immediately opposite the source of the fire and although the logging interval was only set at 30 minutes, the data provides an interesting insight into the microclimatic response to extreme temperature.

The sharp increase in air temperature (17°C at 18:21 and 55°C at 18:51) is reflected in the decrease in RH to just over 9%. It is interesting to note that the ST remained below the AT, as a result of the cooling effect of the conditions in the roof space. The increase in temperature caused a high level of desorption or evaporation of moisture from the surface of the wood, resulting in a sharp increase in AH. It is understood that a relatively limited amount of water was used to control the fire and this may well have caused an additional increase in the AH.



Charts 3 & 4. The conditions on the evening of 22nd November 2002 during the fire. Note the increase in AH as a response to the increase in temperature. LDT1, situated some distance to the west, also shows a considerable level of movement.

The more gentle decrease in the AT which followed the fire being brought under control was immediately reflected in an increase in RH, which, because of the increase in AH, rose above the level where it stood before the fire began. Following the reduction of the AT to its normal level, the RH decreased in accordance with the prevailing AH.[11] At the height of the fire, the LDT's, which are located approximately 45m from the source of the fire, recorded an increase of up to 120µ. However, it is possible that the change in dimensions was caused by the effect of the heat on the mountings rather than on the board itself.

[11] The accuracy of the Humitter probe may have varied by up to an additional 1.5% at 55°C

4.0 DISCUSSION AND CONCLUSIONS

The data for the current year confirmed the general background environmental conditions seen in previous years, and in particular the variations between the conditions on the lower side of the ceiling and those in the roof space. It is hoped that the covering of the windows will reduce the extremes of temperature caused by direct sunlight, but will have little effect on the general conditions which are caused by the high level of ventilation and low level of thermal insulation in the roof space.

The data from the Linear Displacement Transducers showed that a low level of movement was taking place in the boards, but, as had been anticipated, it took some considerable time for a dimensional response to changing microclimate, to develop. As a result, the movement shadowed the RH fairly crudely, with dimensional change taking place over periods of ten days or more. Some very minor response was detected when the boards were exposed to direct sunlight, but this was irregular and erratic.

It will be necessary to have a full year of data before it is possible to say precisely how the movement patterns reflect seasonal change. But, on the basis of the current data it can be seen that the long term increases in RH (both above an below the ceiling), caused the lower surface of the board to contract. The level of deformation will inevitably vary depending on the cut and the dimensions of the board as well as the way in which it is fixed to the surrounding structure. It is likely that it is factors such as these which caused the variation in readings between the three different probes. However, it is notable that although there were variations in the *level* of dimensional response, the patterns of movement were very close.

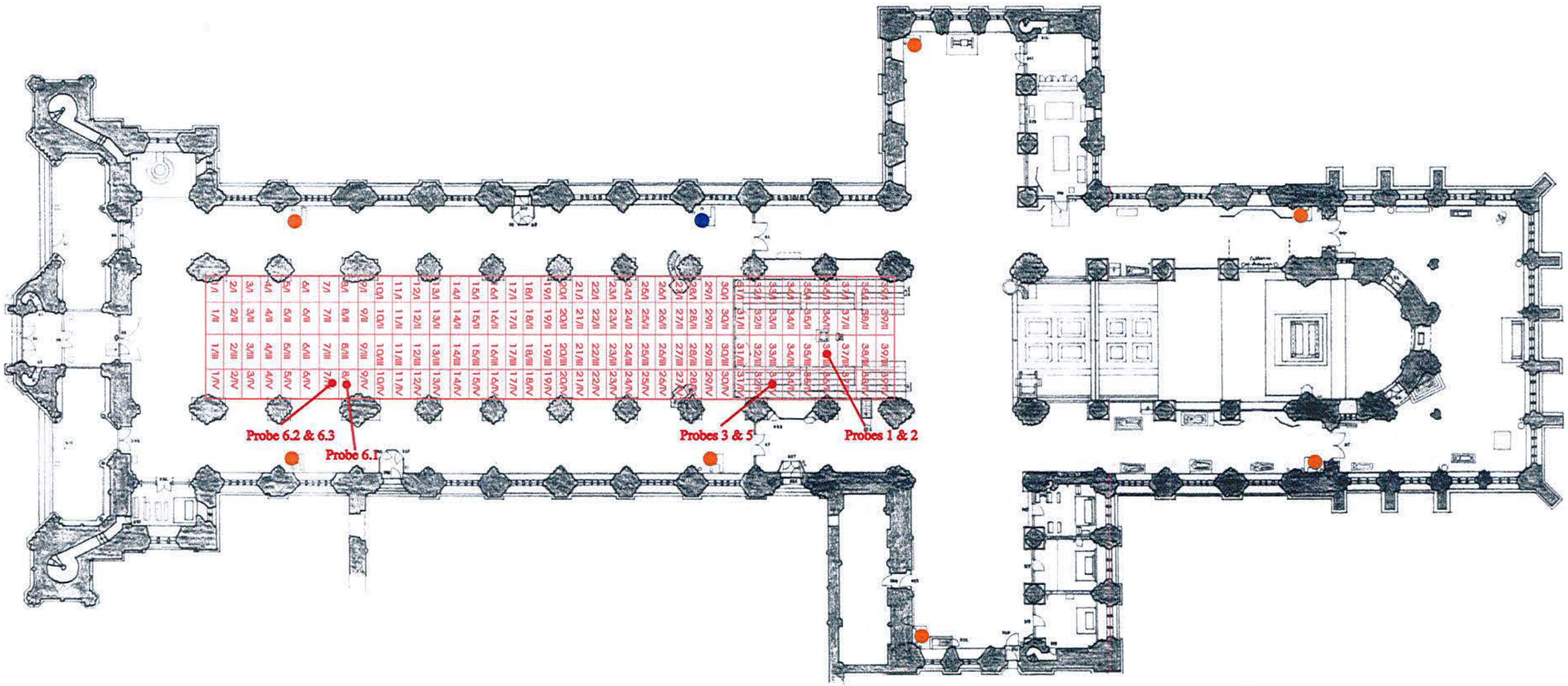
Because, over long periods, the average RH in the roof space was considerably higher than that in the body of the cathedral, and an increase in RH appears to cause the lower side of the board to contract, it is possible that the difference between the upper an lower RH causes a mild concave deformation of the lower surface of the board. (The level of such a distortion will inevitably be effected by the structure of the board as well as its surface treatment and the method by which it is fixed.)

The investigation into the level of movement was prompted by the concern that significant movement would cause cracking or flaking of the paint layer. It appears from the data so far available that the lack of this type of damage is due to the compressive strength of the paint layer allowing it to adsorb the low levels of movement generated by the variations in the microclimate conditions. (Maximum movement appears to be in the order of 0.1% to 0.5% across the grain) When a full year of data is available it will be possible to examine the deformation of the boards more accurately and this may throw further light on the reason for the low level of deterioration in the paint layer. It is interesting to note that as the average difference between the upper and lower levels of RH is more significant in shade (see the comparative gradient charts) the covering of the windows may marginally increase the level of movement in the boards.

Although it was both unwelcome and unexpected, the fire provided a unique opportunity to examine how an historic wooden structure reacts to extreme heat. Regrettably, as the data logging interval was set at 30 minutes, it was not possible to examine, in detail, the response of the wood as the temperature rose and fell. However, from the data that we have, it was possible to see that the sudden rise in temperature caused a sharp decrease in the RH, despite the evaporation of so much moisture from the wood, resulting in a sharp increase in the AH. The LDTs all recorded a short, but noticeable period of movement during the fire, but this appears to have been short term. With the 30 minute logging intervals, it was not possible to tell whether the temperature recorded was the highest reached during the fire and so the actual effect may have been more dramatic. However, the condition examination undertaken after the fire revealed that, despite the layer of deposited soot, no structural damage to the paint layer appeared to have been caused.

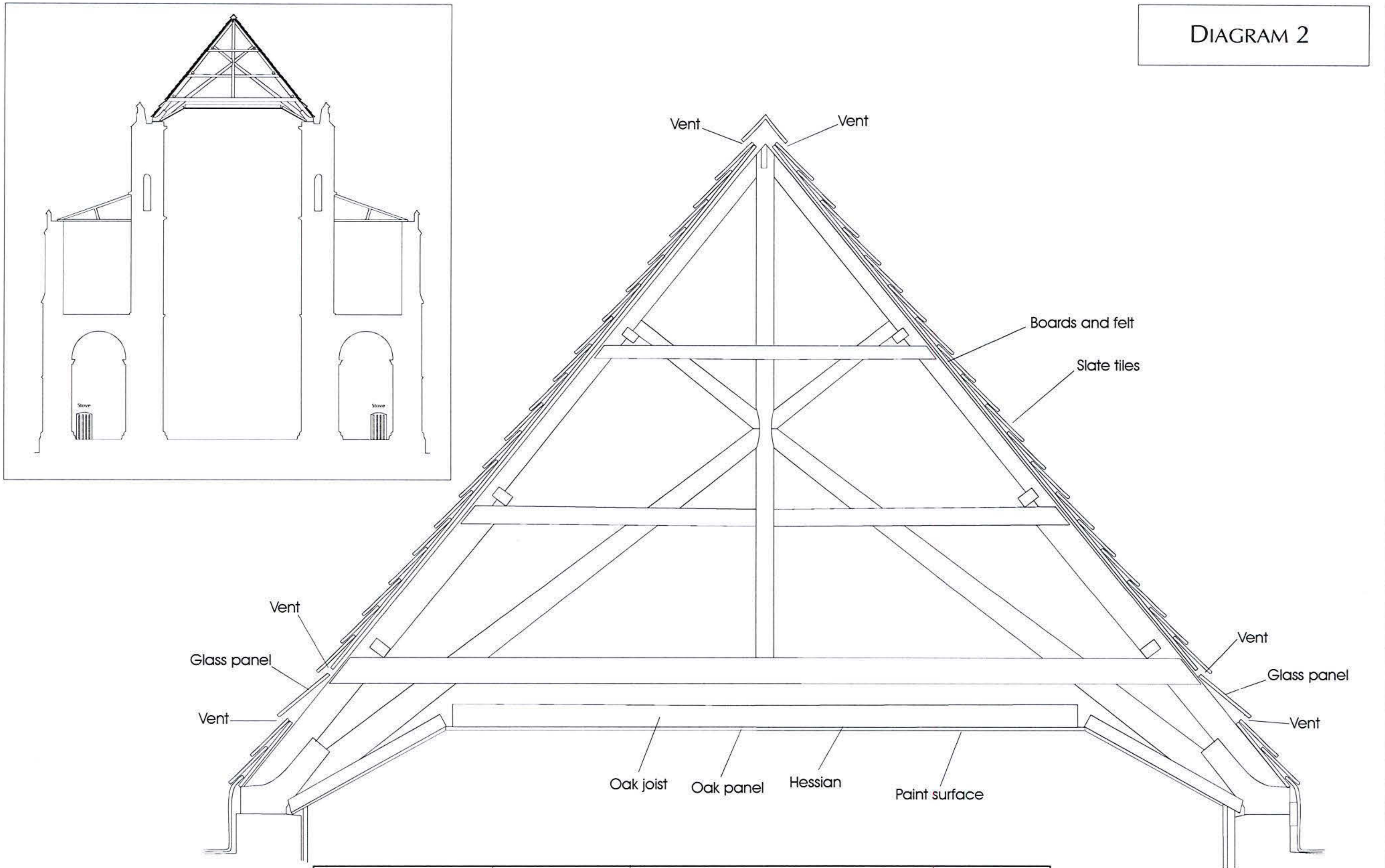
COMPARATIVE CHARTS

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

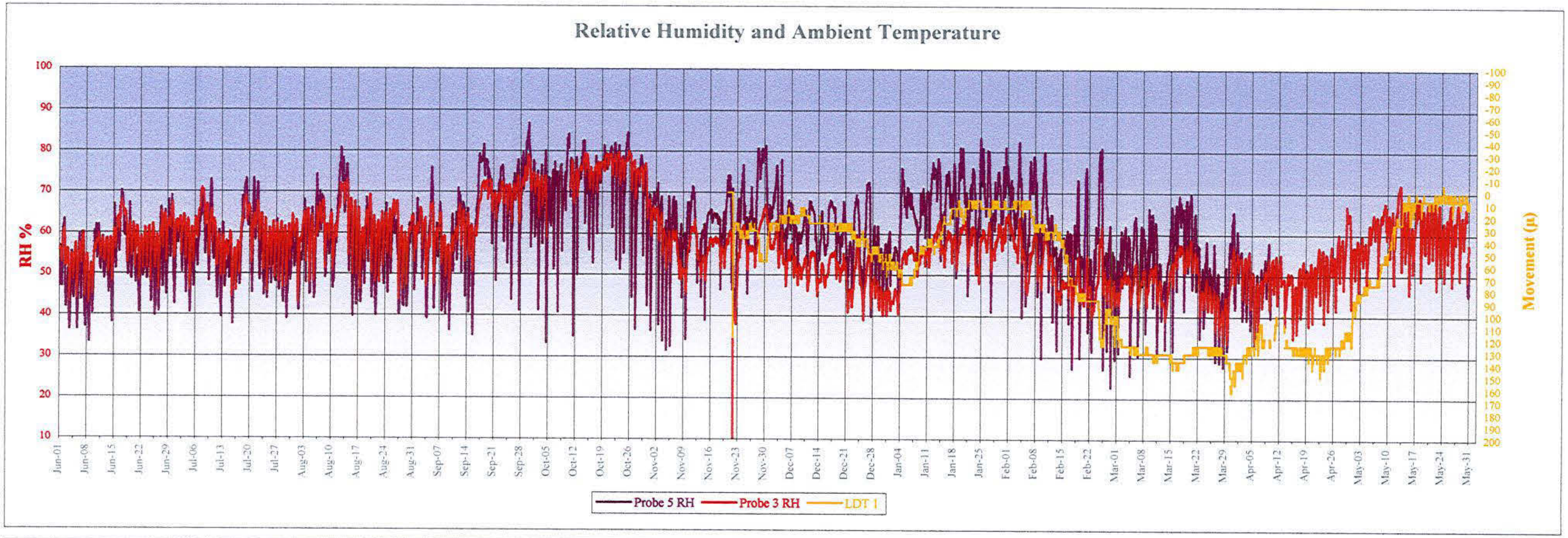


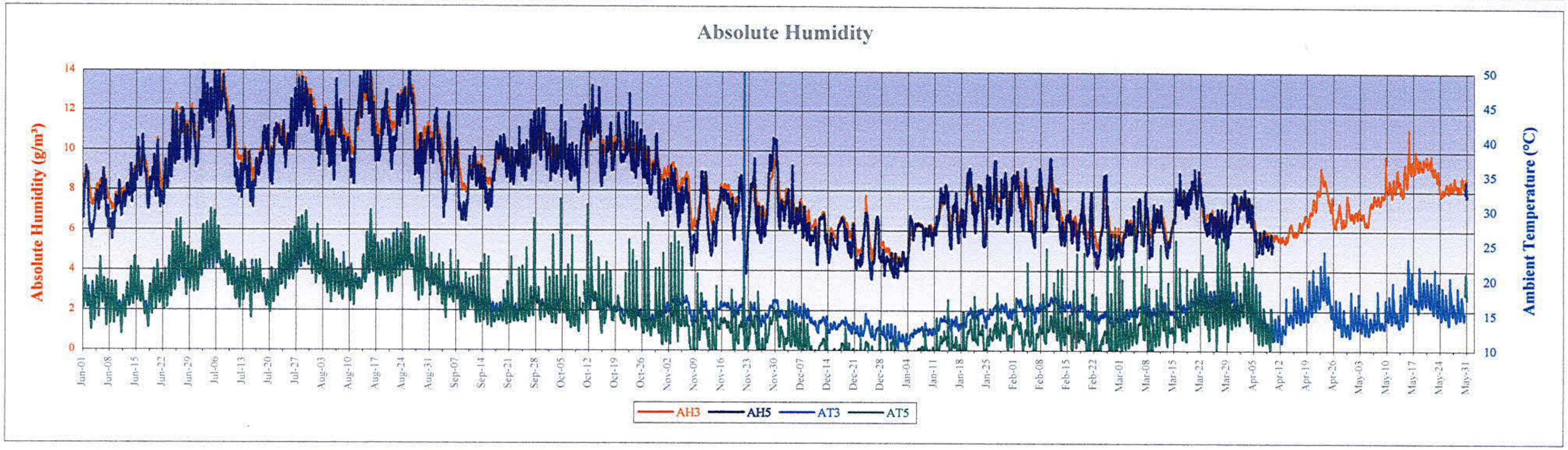
Site: Peterborough Cathedral	Type: Probe and stove locations	
Area: Plan (Base plan drawn by Julian Limentani)	Date: July 2000	Tobit Curteis Associates 36 Abbey Road, Cambridge, CB5 8HQ

Peterborough Cathedral Nave Ceiling

June 2001 - May 2002

LDT movement with RH and AT for Probes 3 & 5 (Bay 33 IV lower upper side: sun)

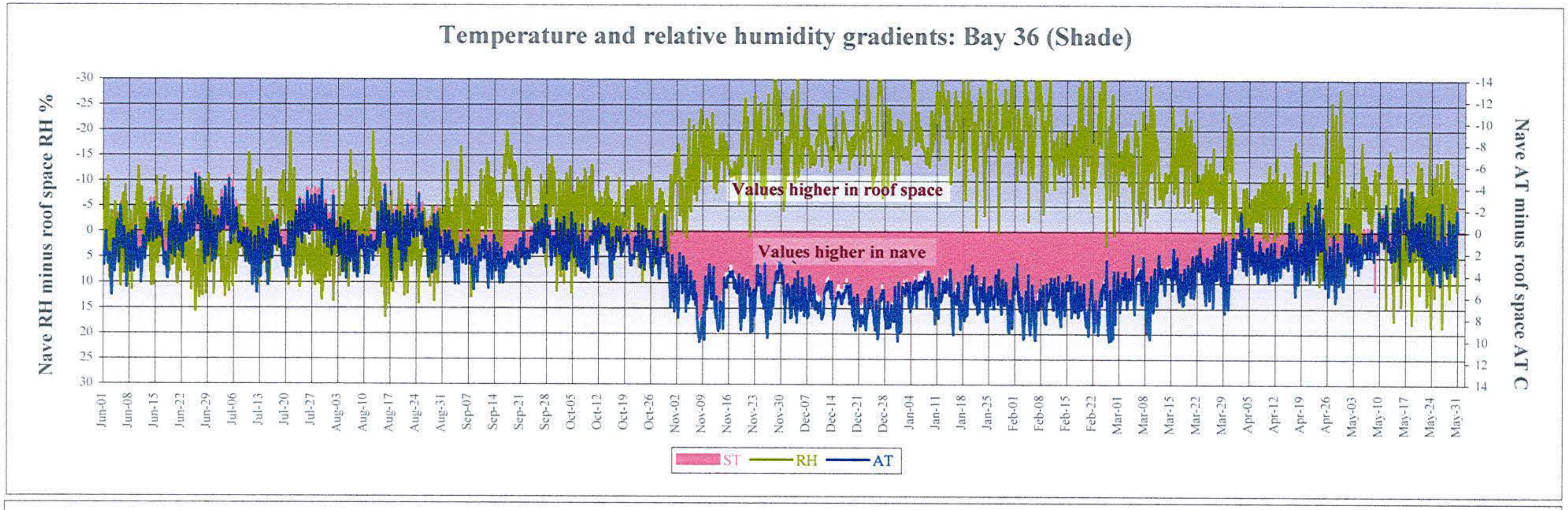


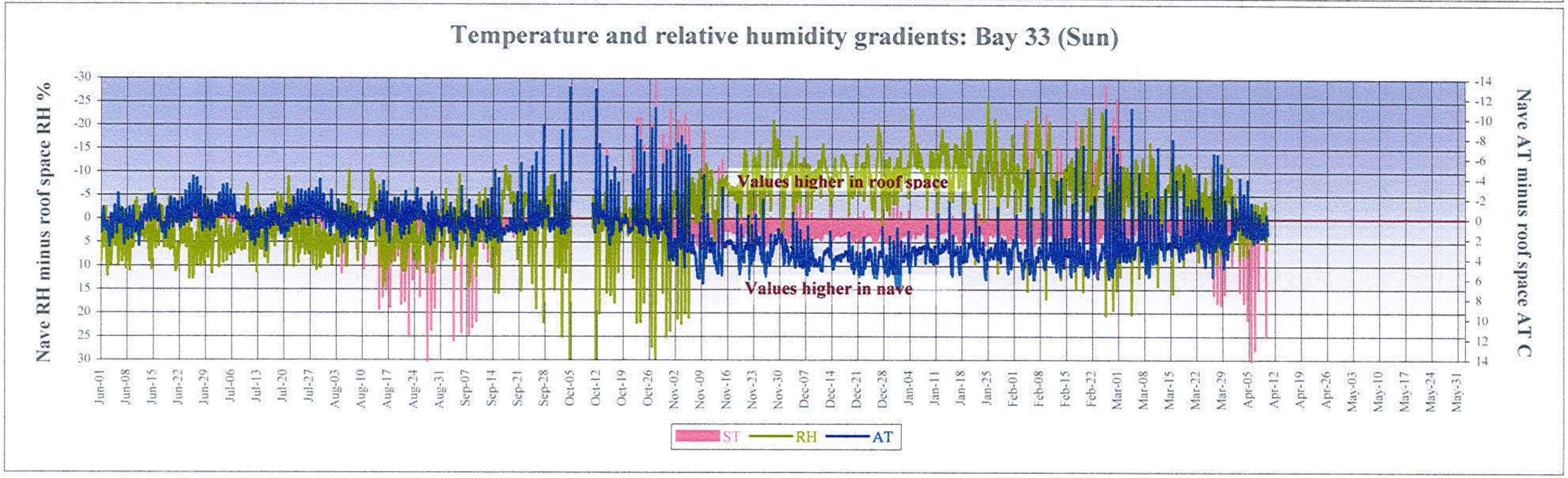


Peterborough Cathedral Nave Ceiling

Temperature and Relative Humidity gradients

June 2001 - May 2002



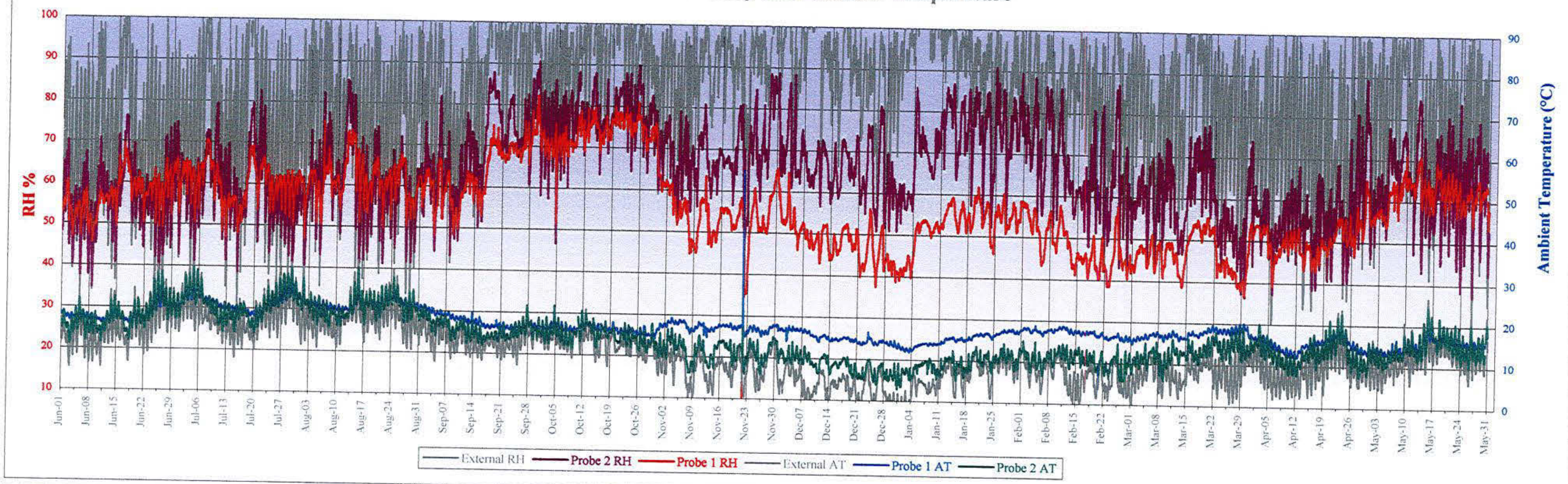


Peterborough Cathedral Nave Ceiling

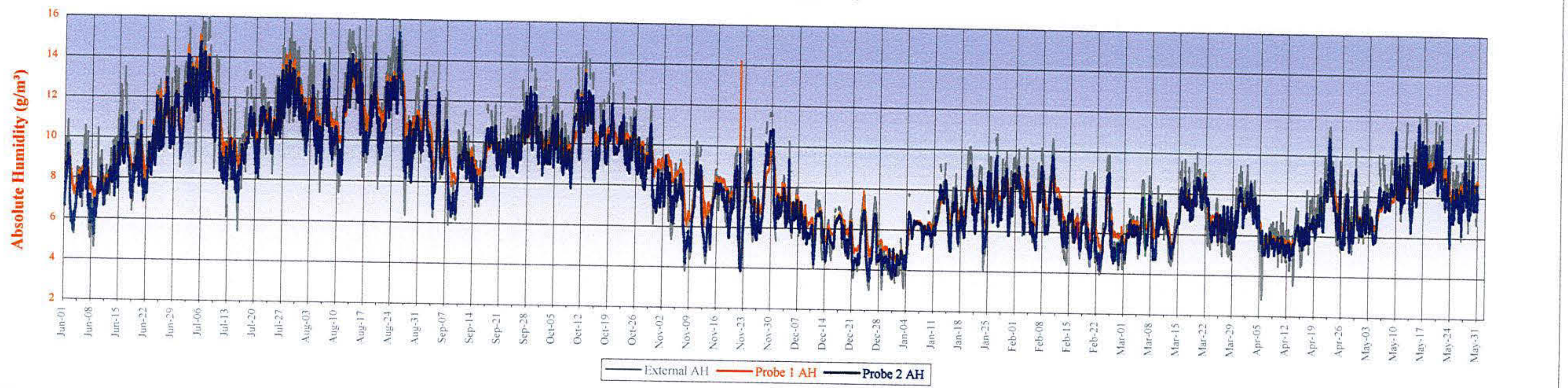
Probe 1: Bay 36 III lower side & Probe 2: Bay 36 III upper side (shade)

June 2001 - May 2002

Relative Humidity and Ambient Temperature



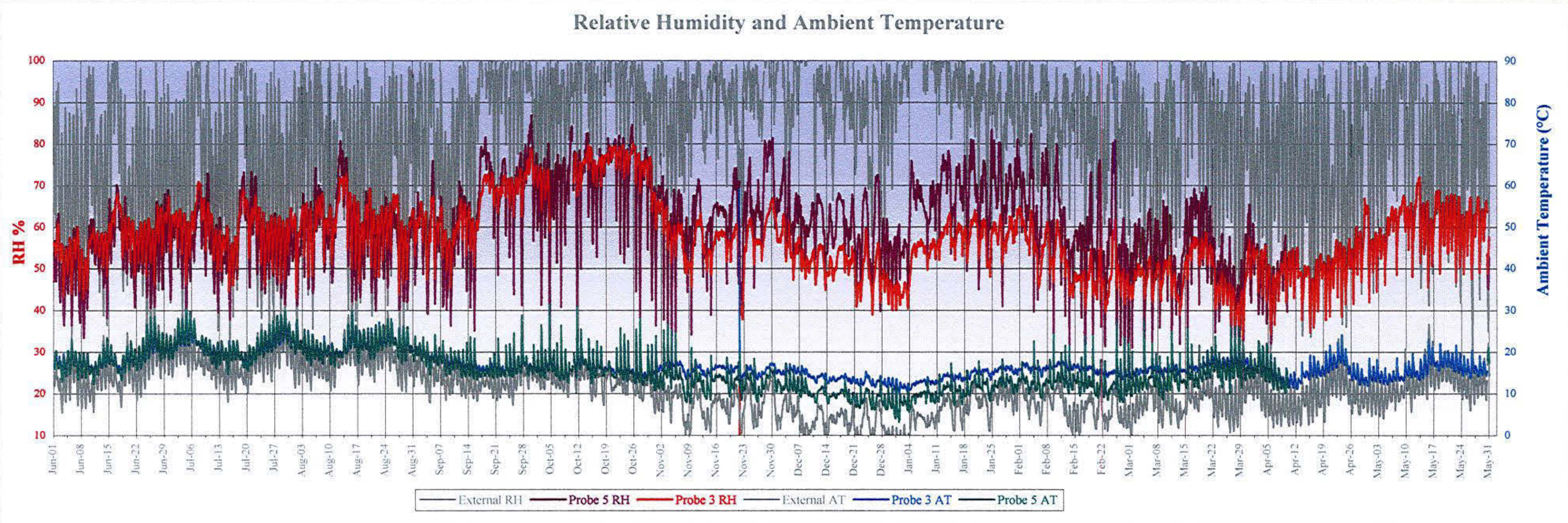
Absolute Humidity

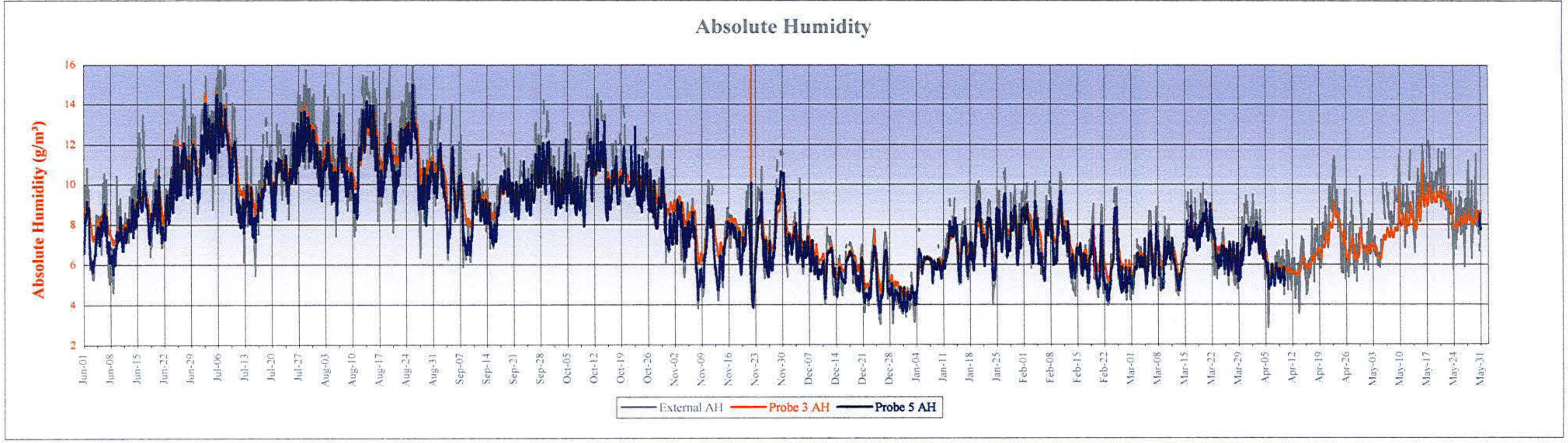


Peterborough Cathedral Nave Ceiling

June 2001 - May 2002

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

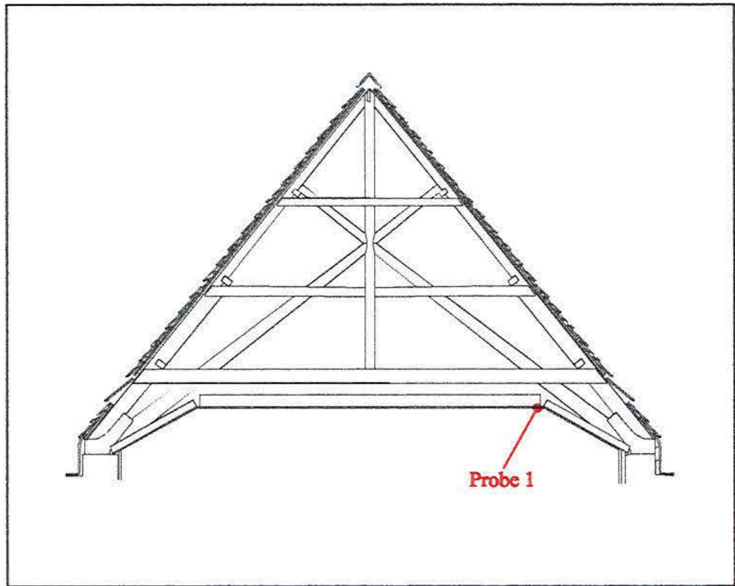


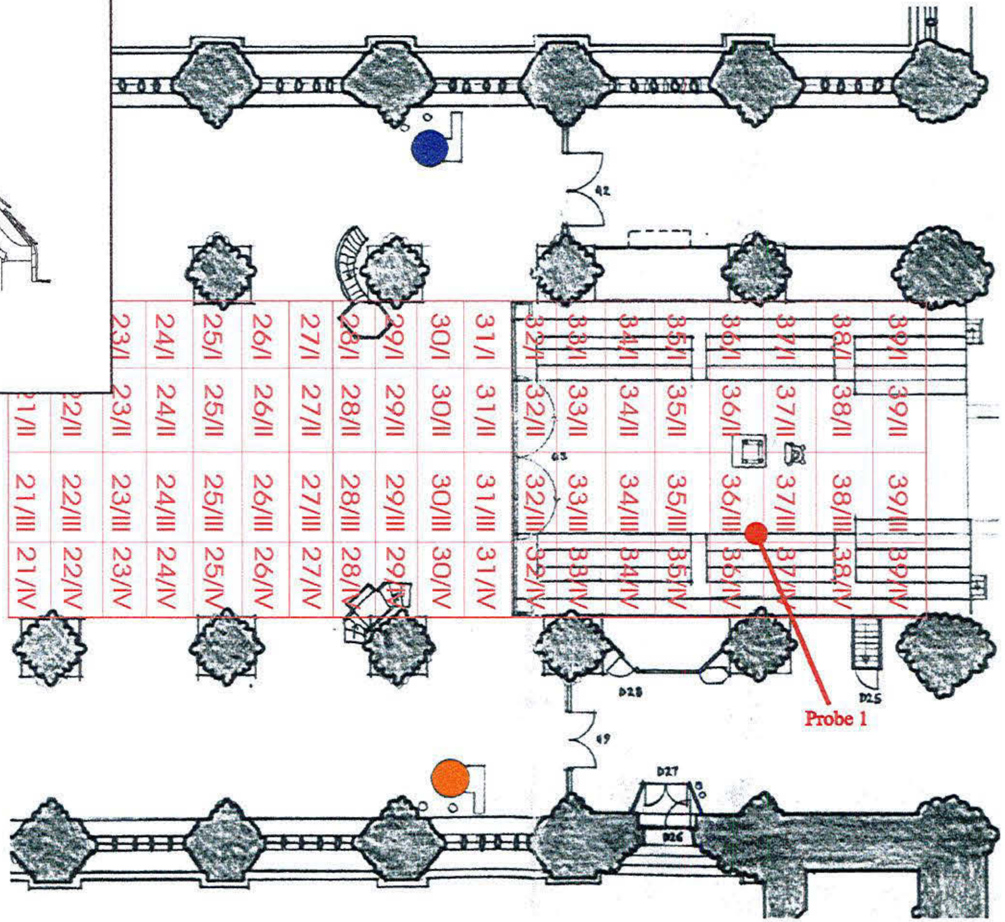


PROBE 1

BAY 36 III LOWER SIDE (SHADE)

DIAGRAM 3



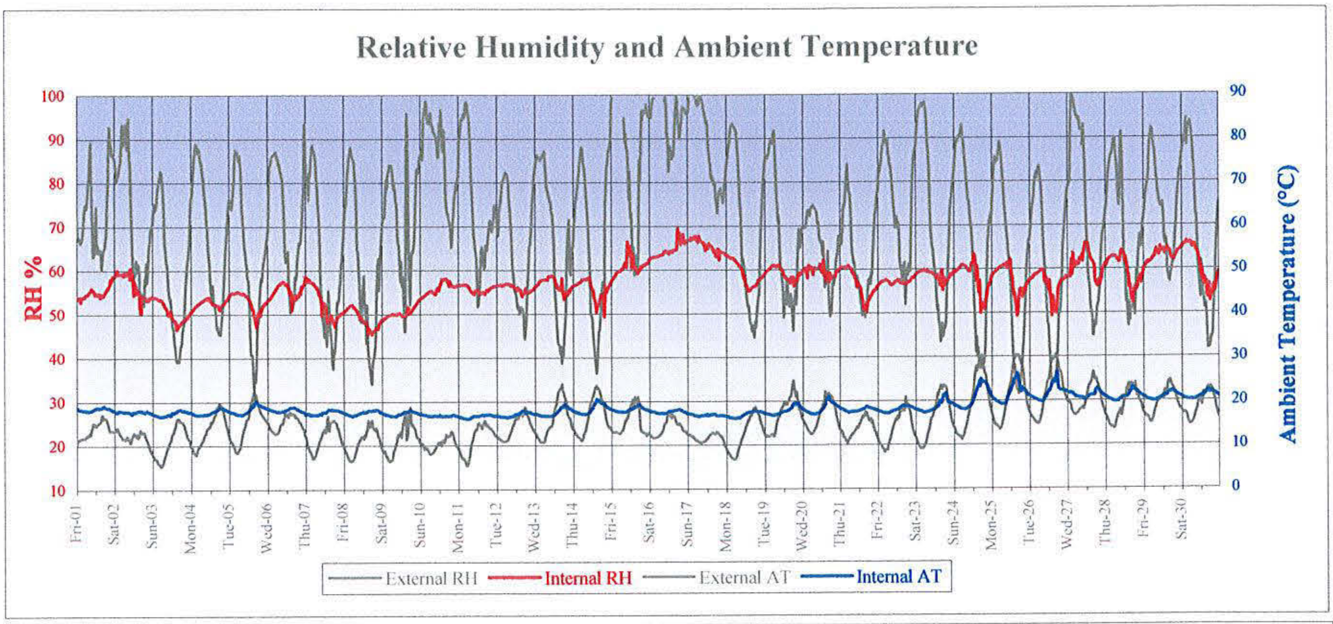


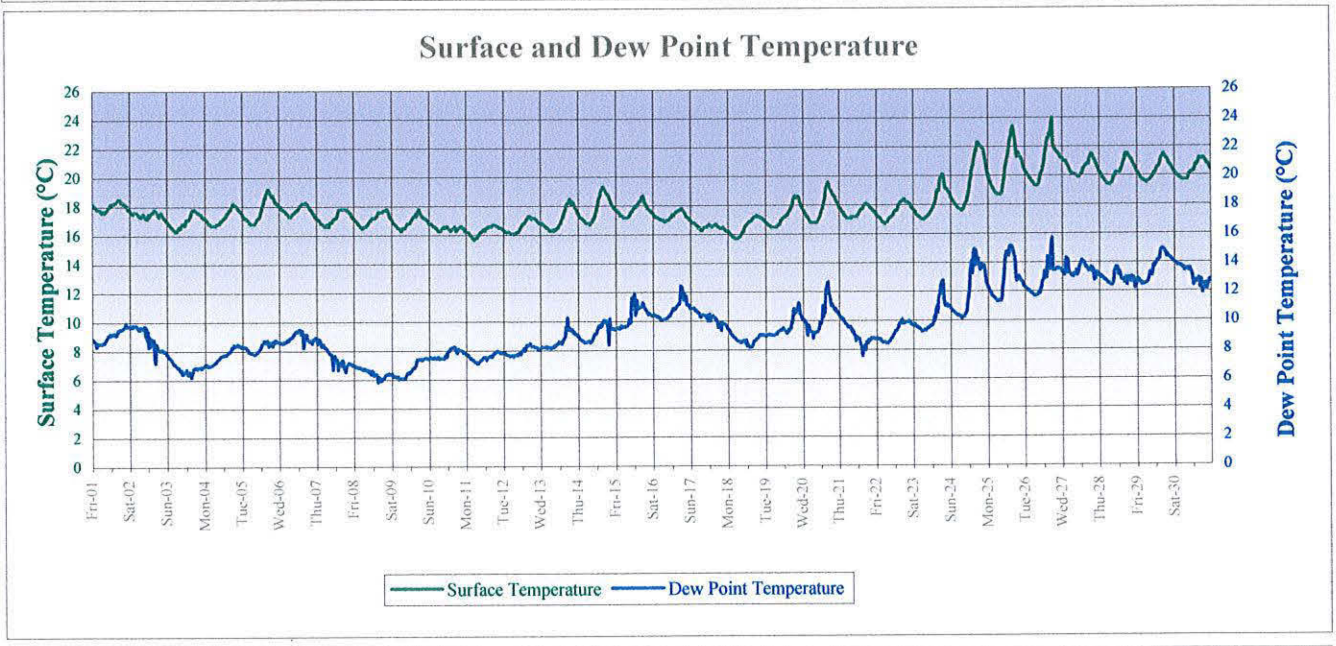
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 10m 20m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

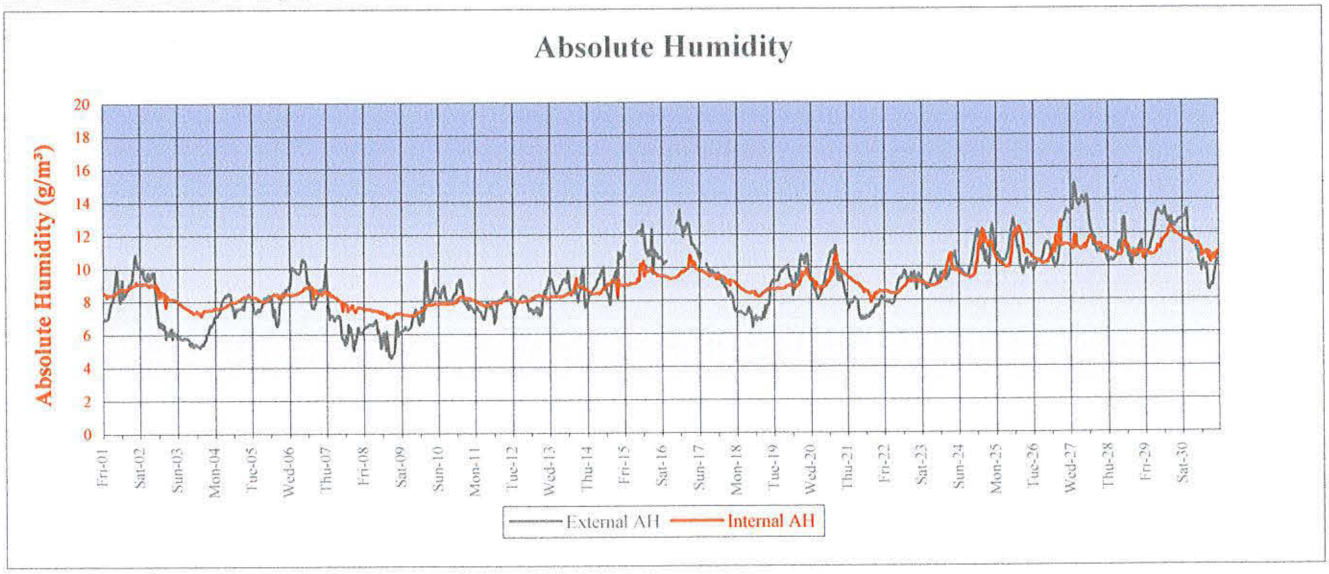
Peterborough Cathedral Nave Ceiling

June 2001

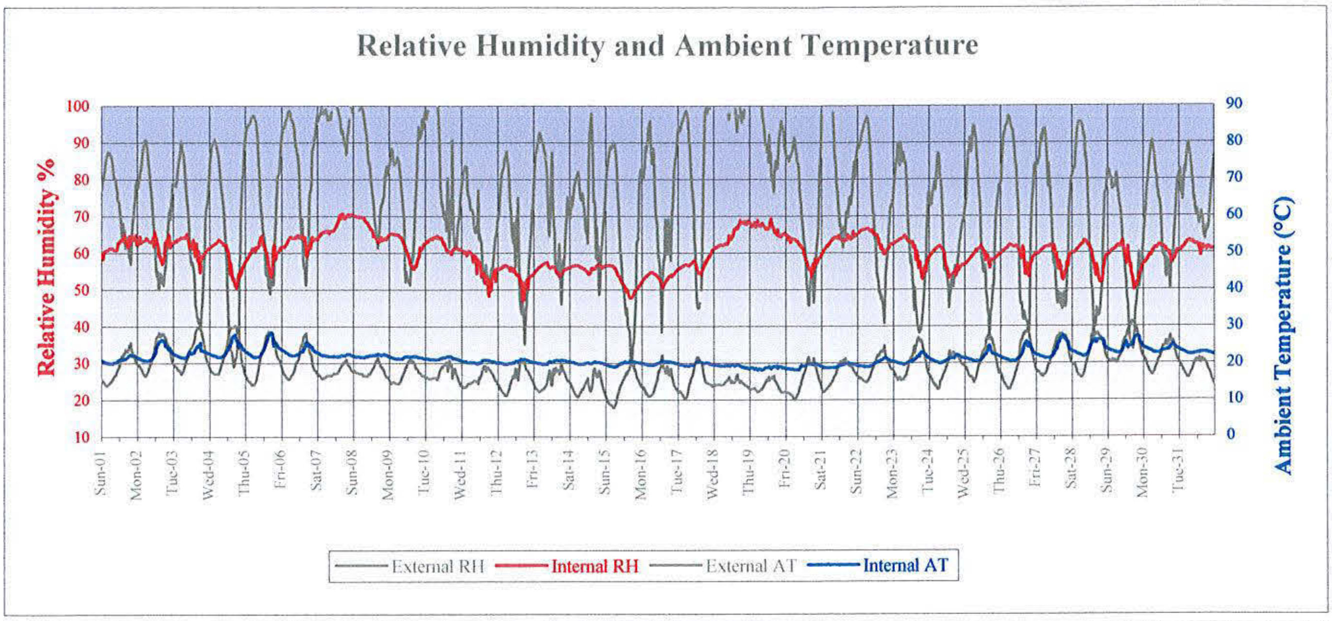
Probe 1: Bay 36 III lower side (shade)

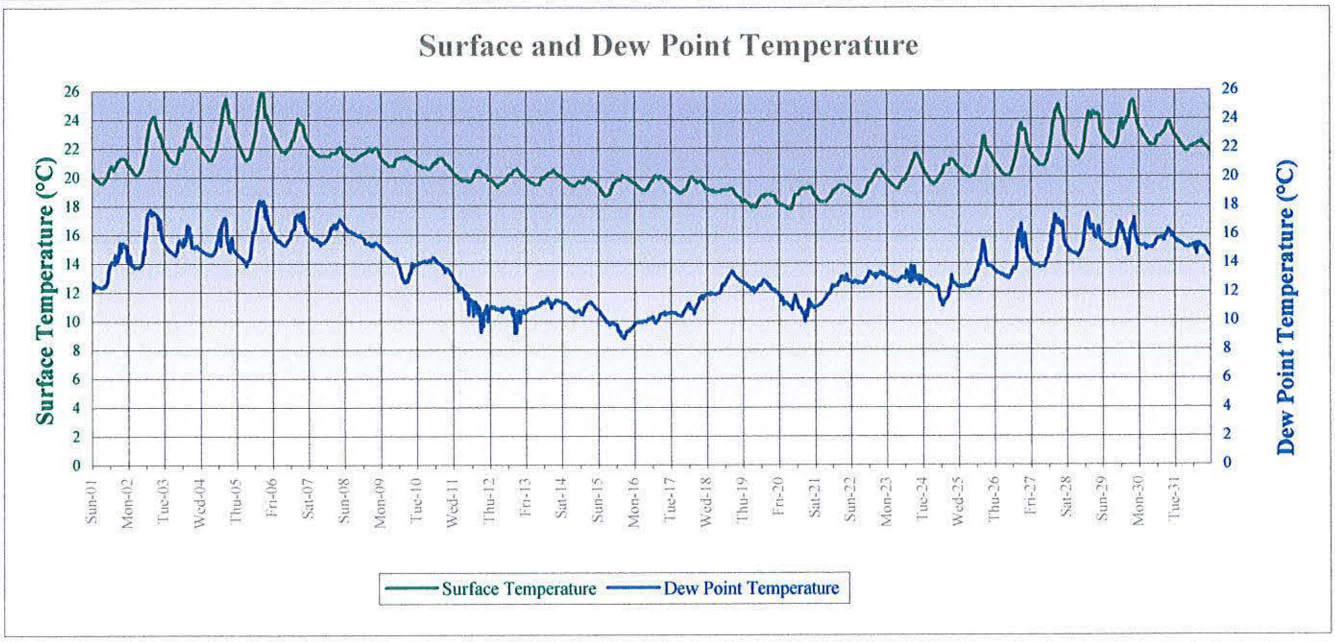


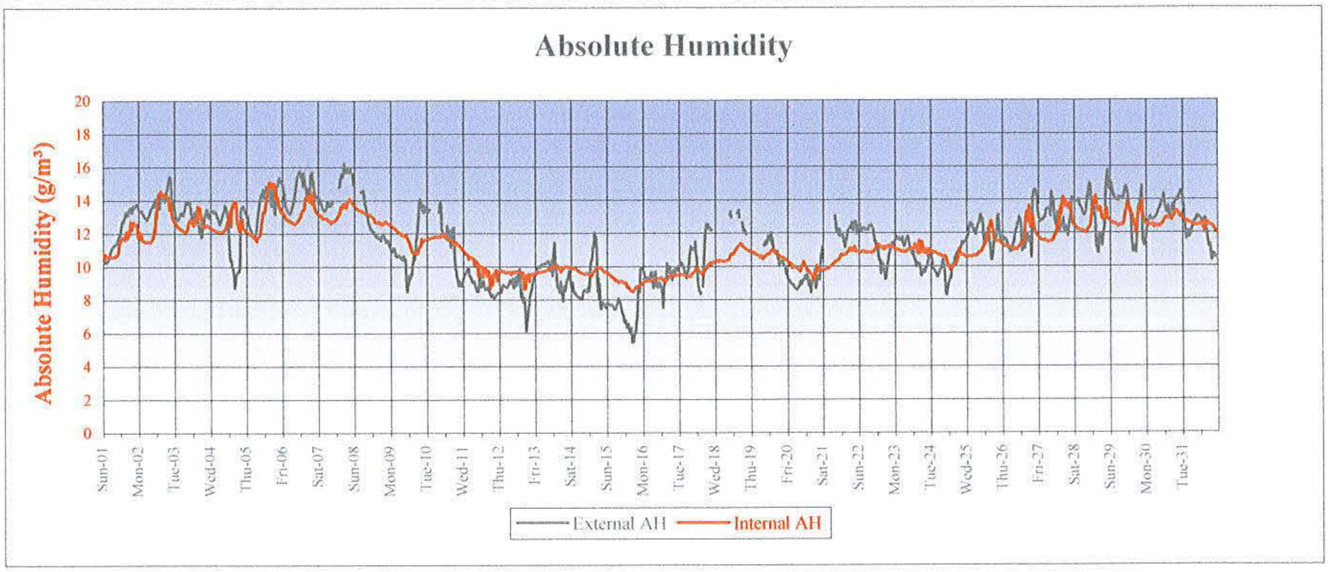




Probe 1: Bay 36 III lower side (shade)



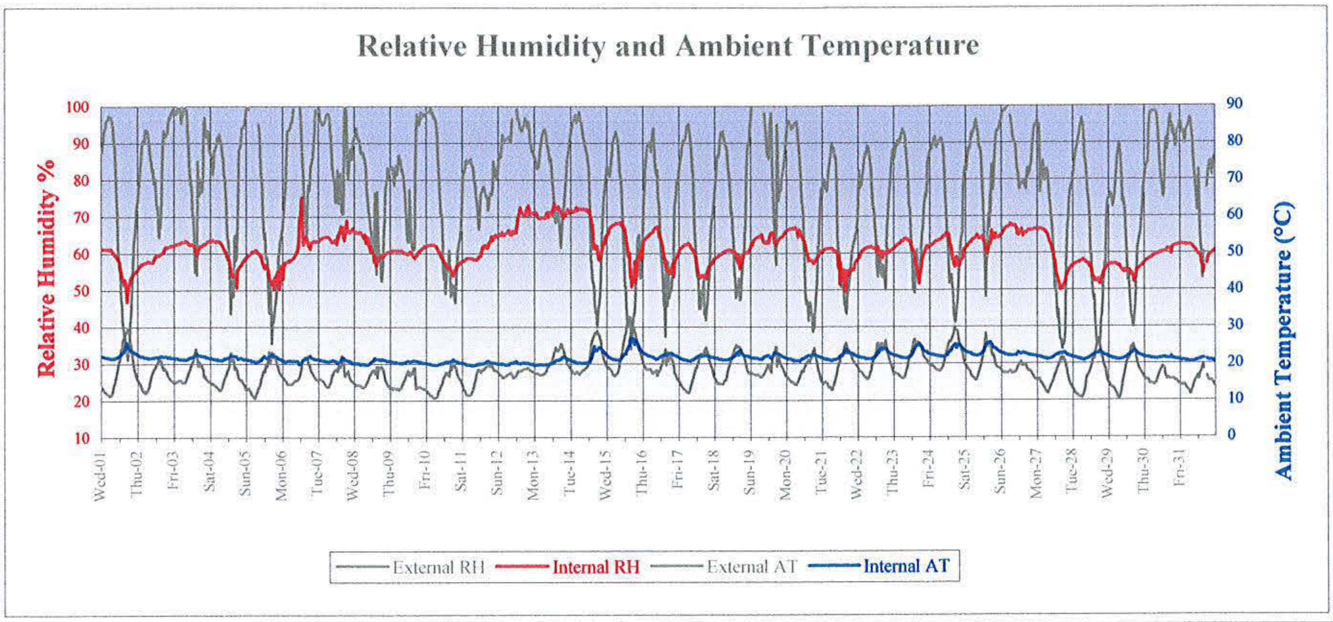


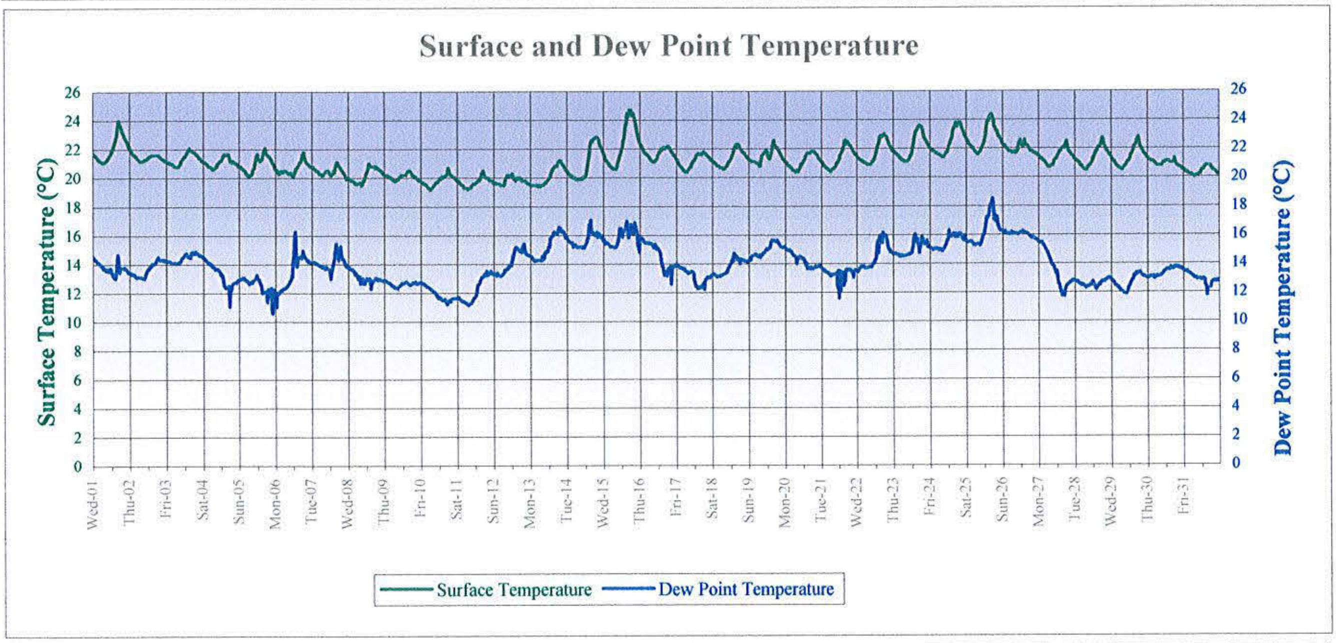


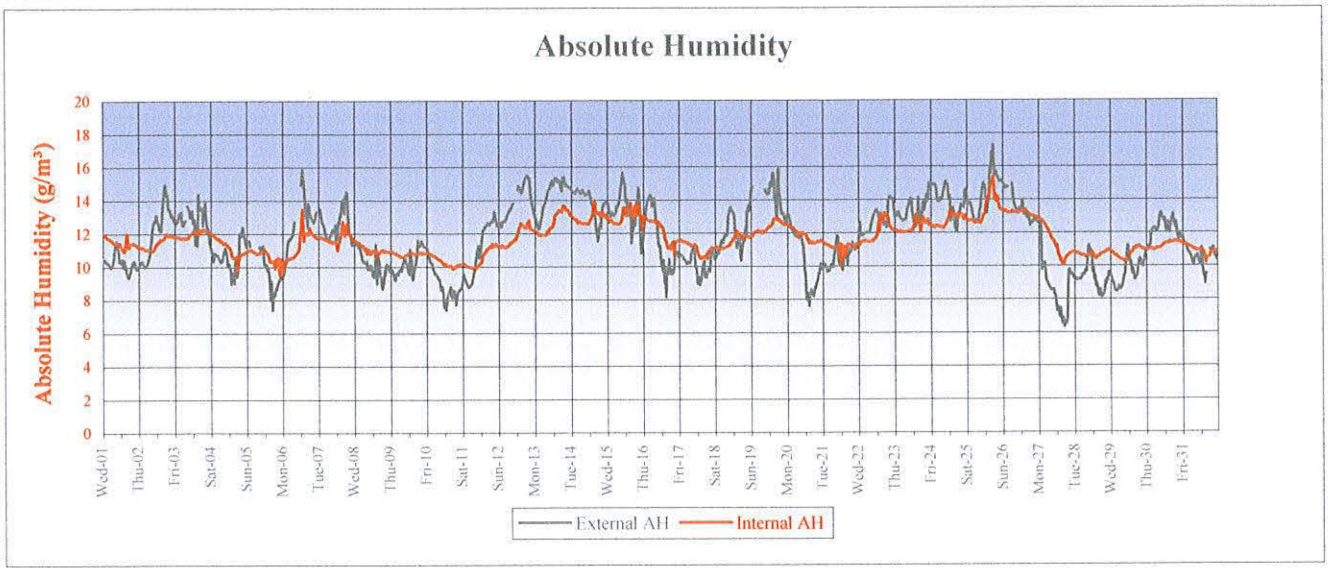
Peterborough Cathedral Nave Ceiling

August 2001

Probe 1: Bay 36 III lower side (shade)



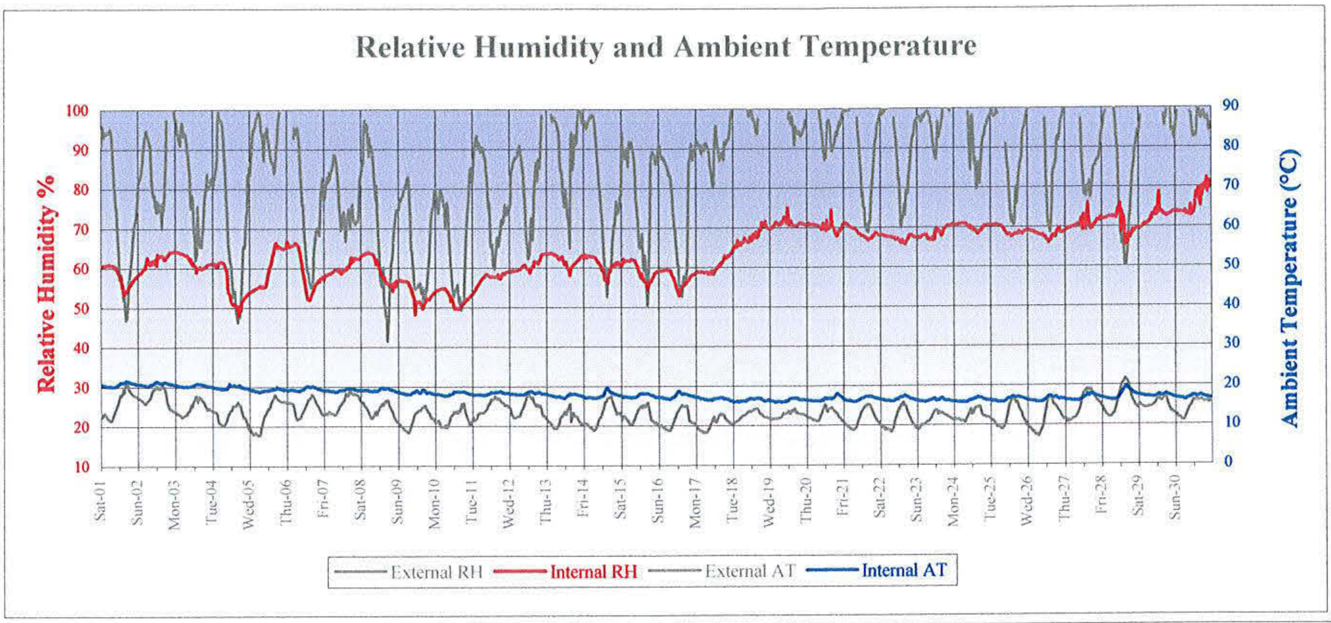


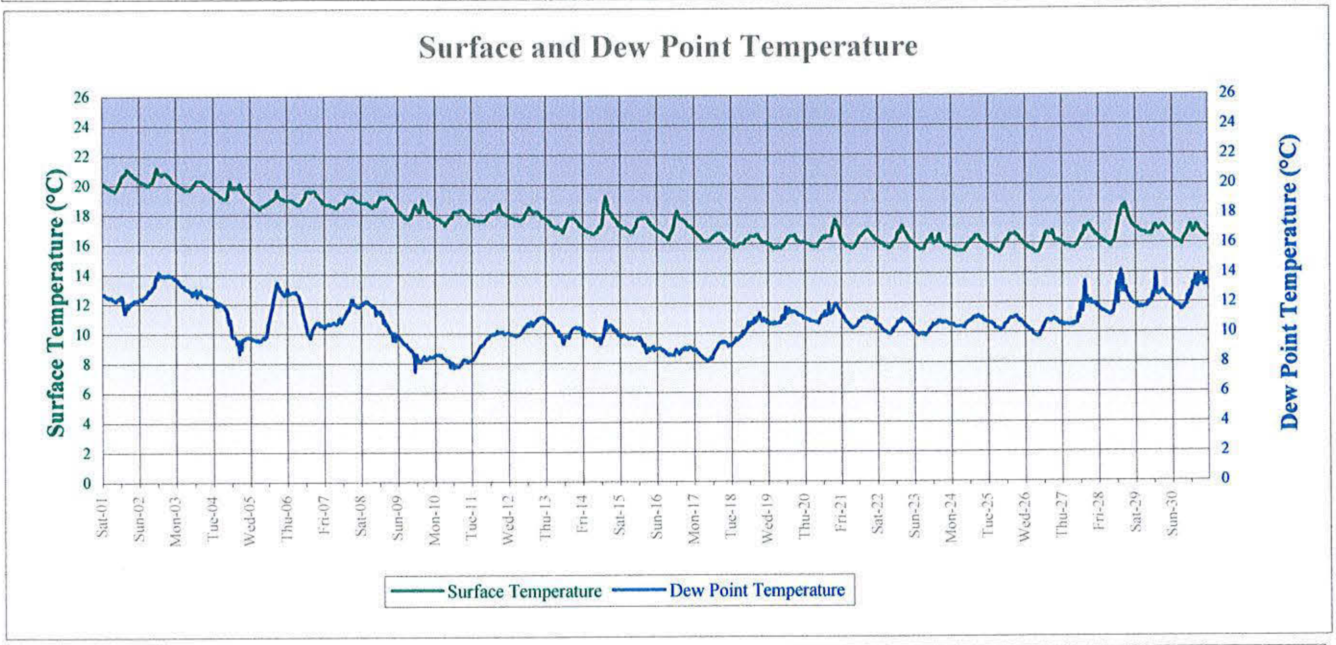


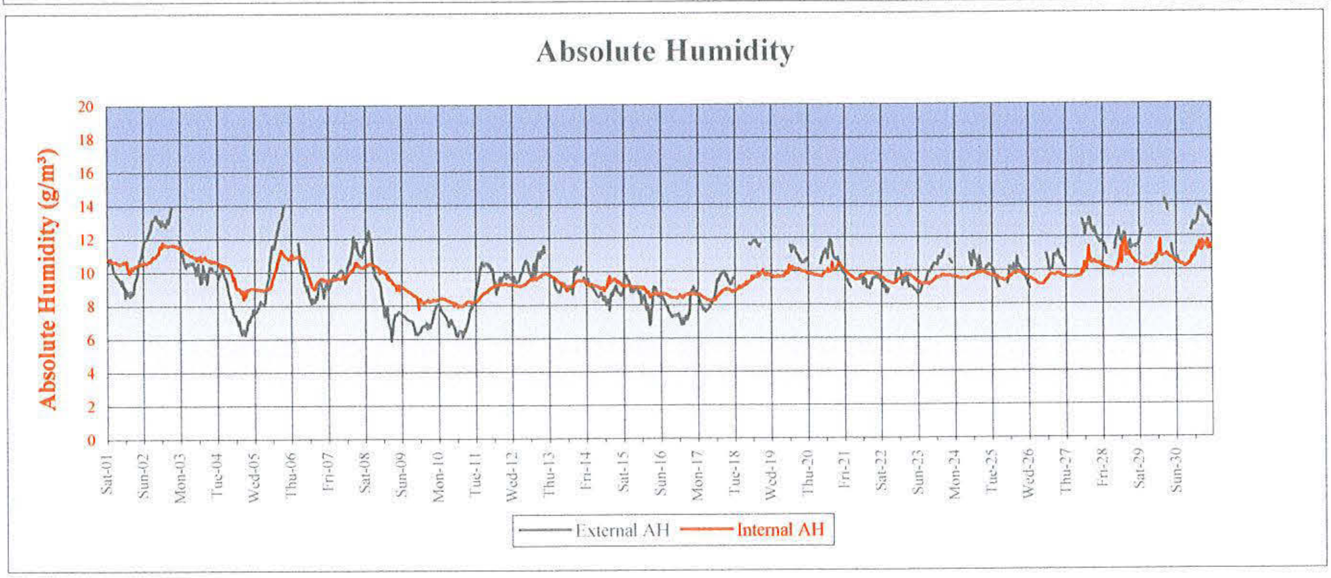
Peterborough Cathedral Nave Ceiling

September 2001

Probe 1: Bay 36 III lower side (shade)



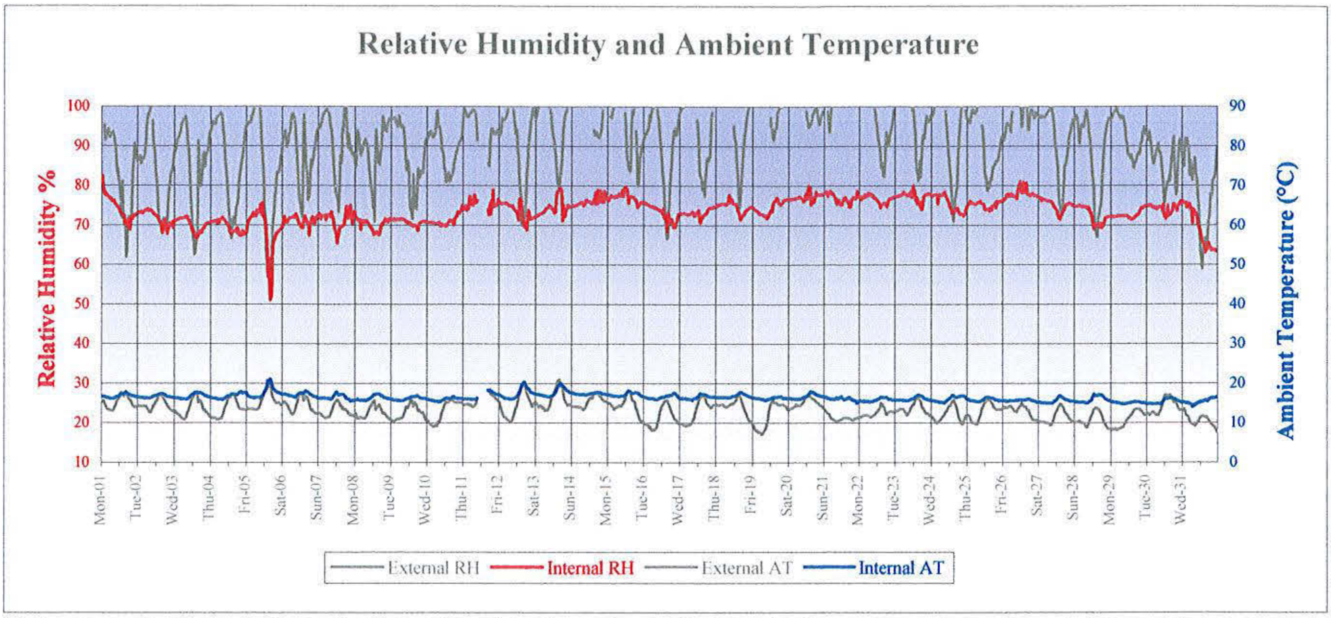


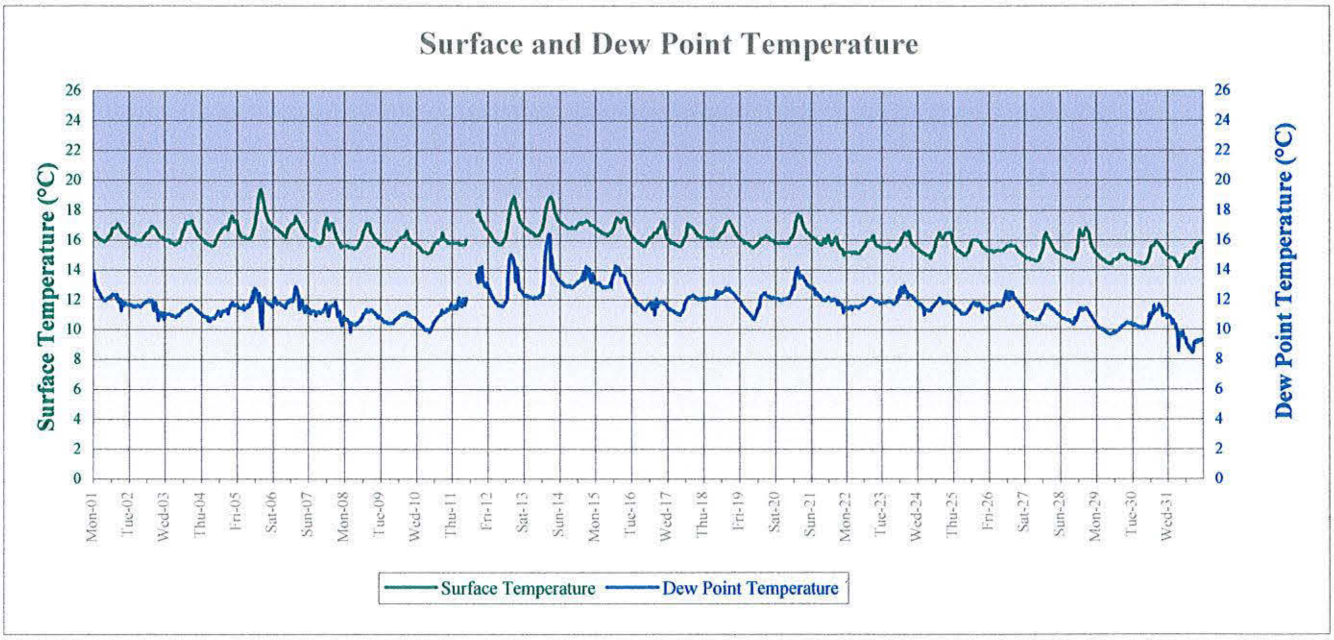


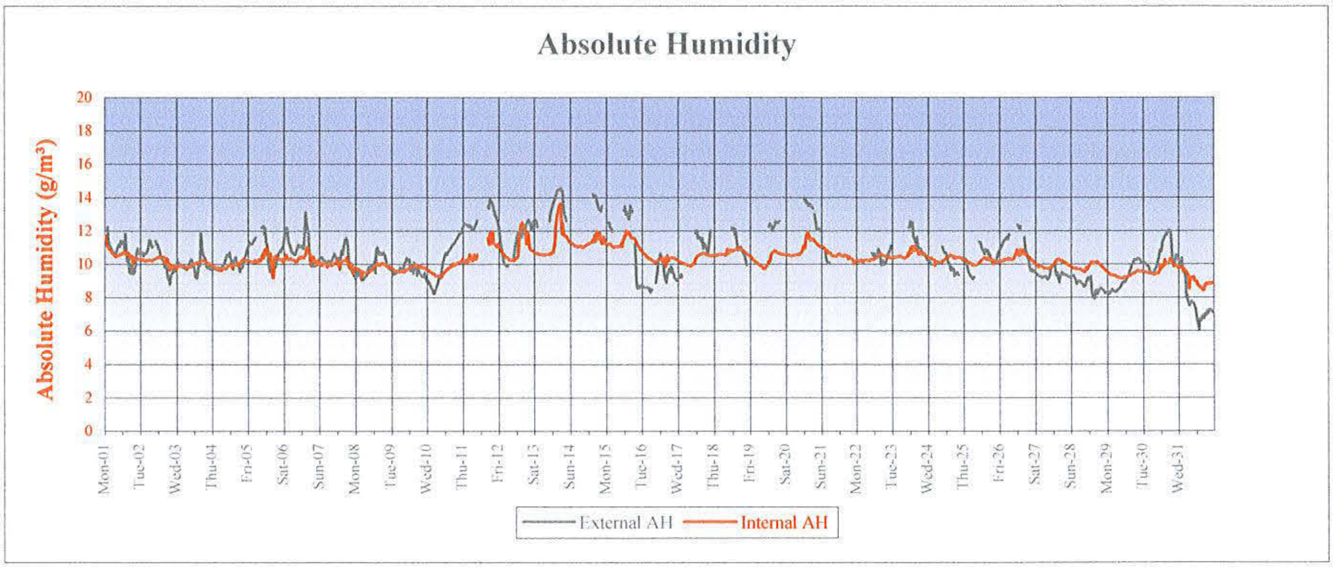
Peterborough Cathedral Nave Ceiling

October 2001

Probe 1: Bay 36 III lower side (shade)

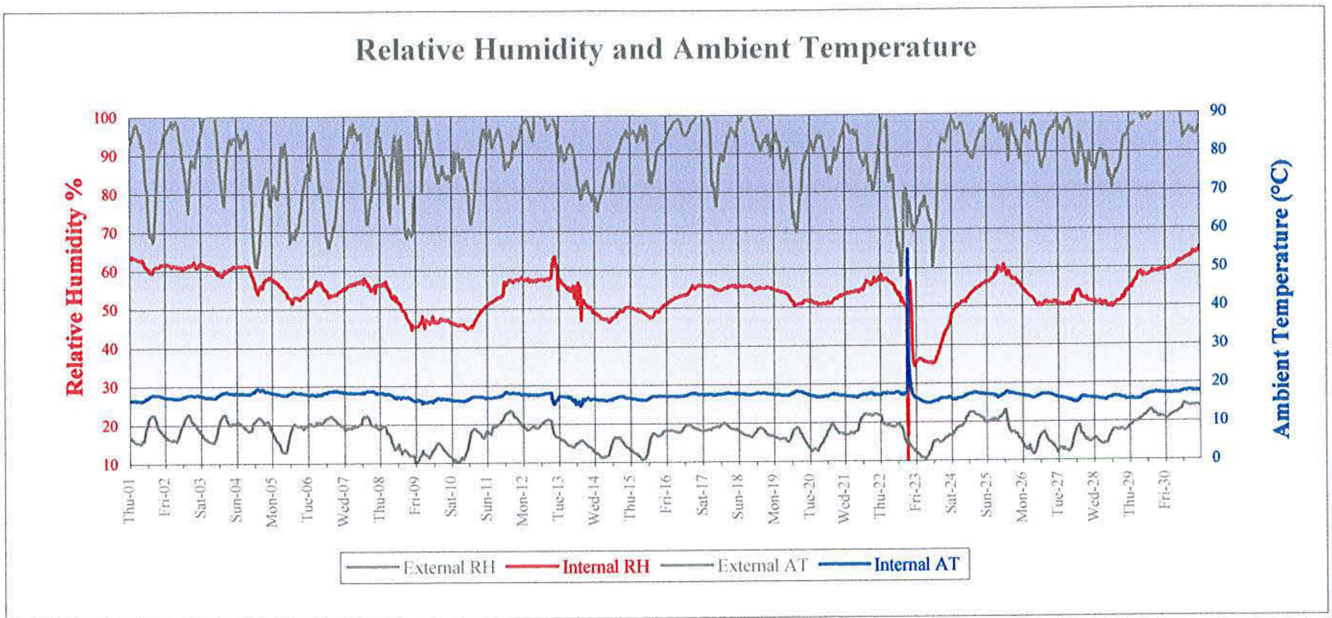


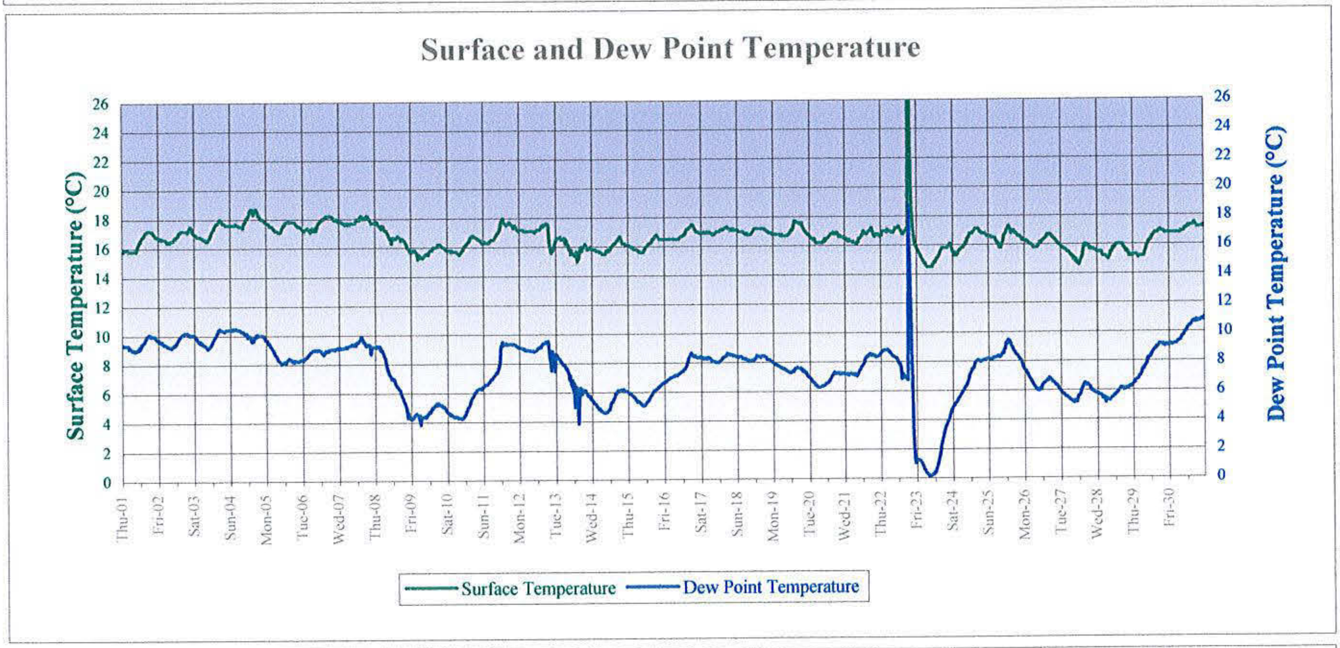


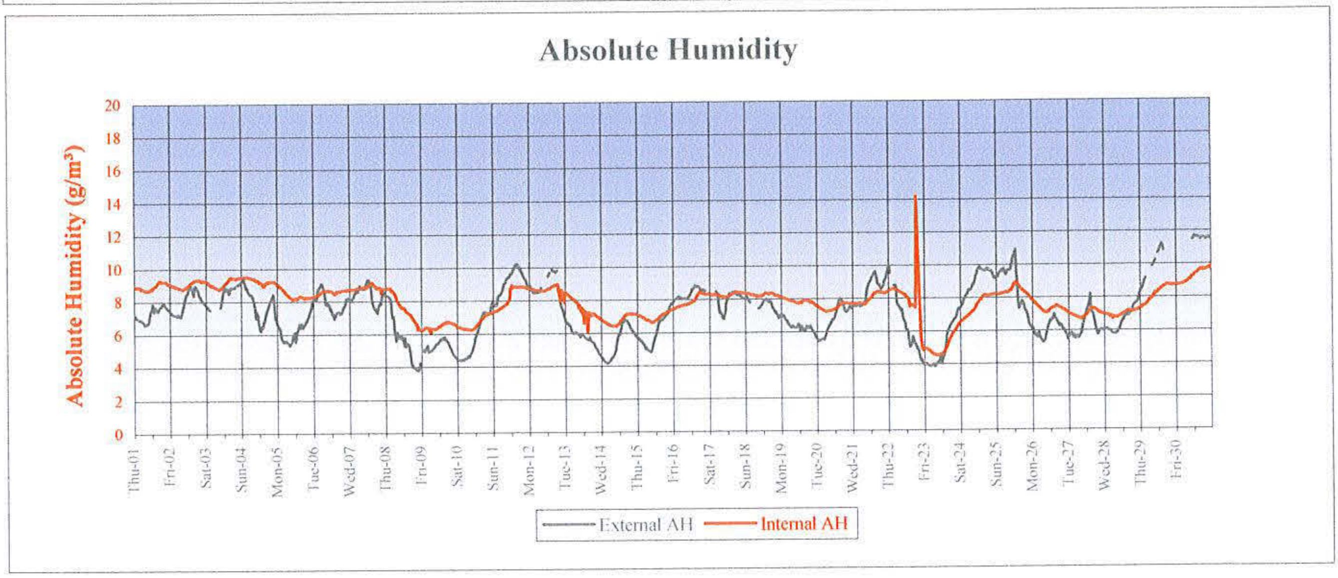


Peterborough Cathedral Nave Ceiling

Probe 1: Bay 36 III lower side (shade)



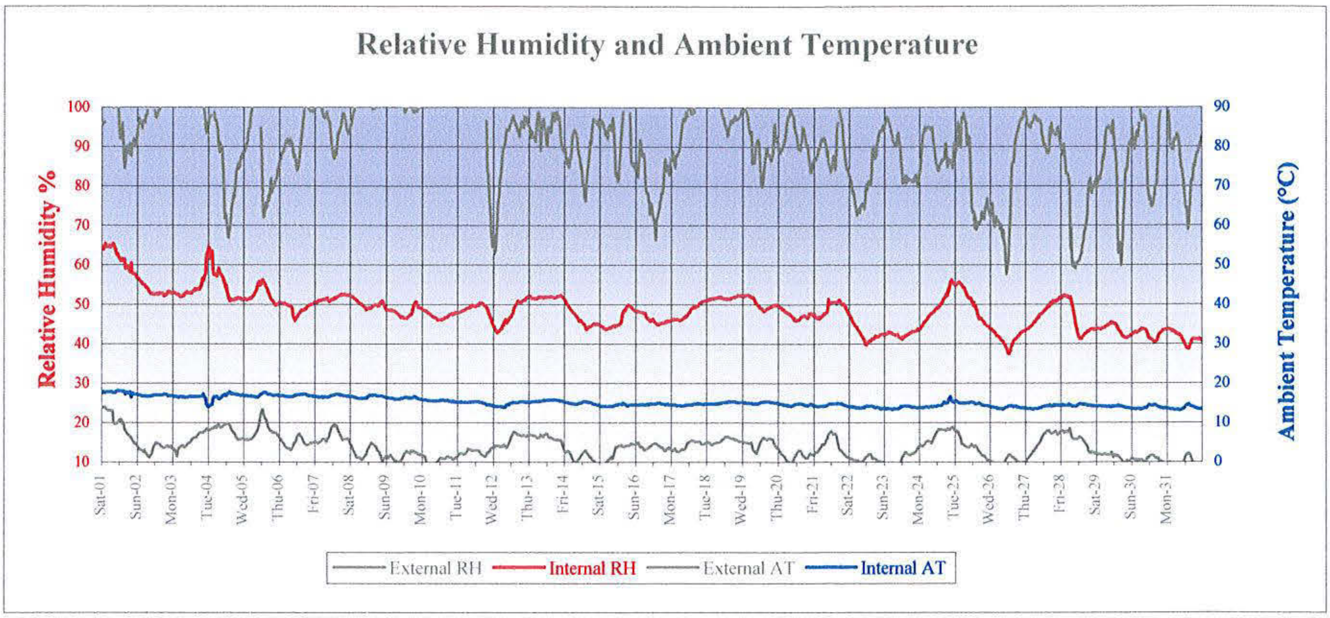


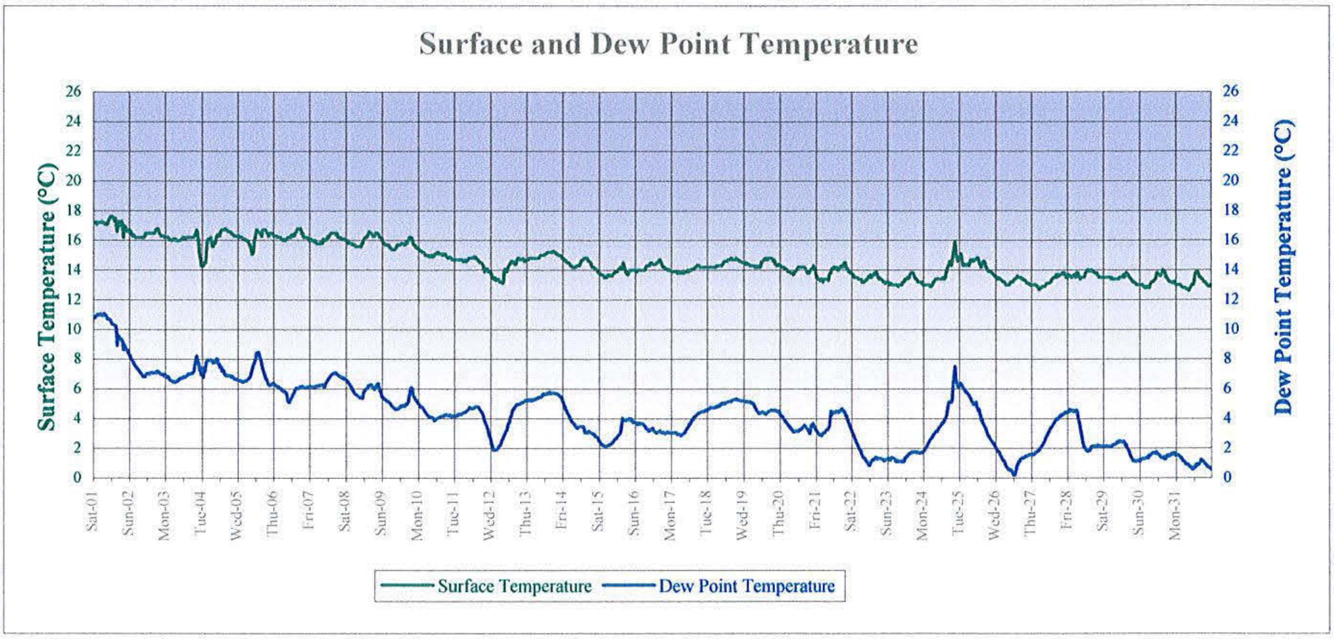


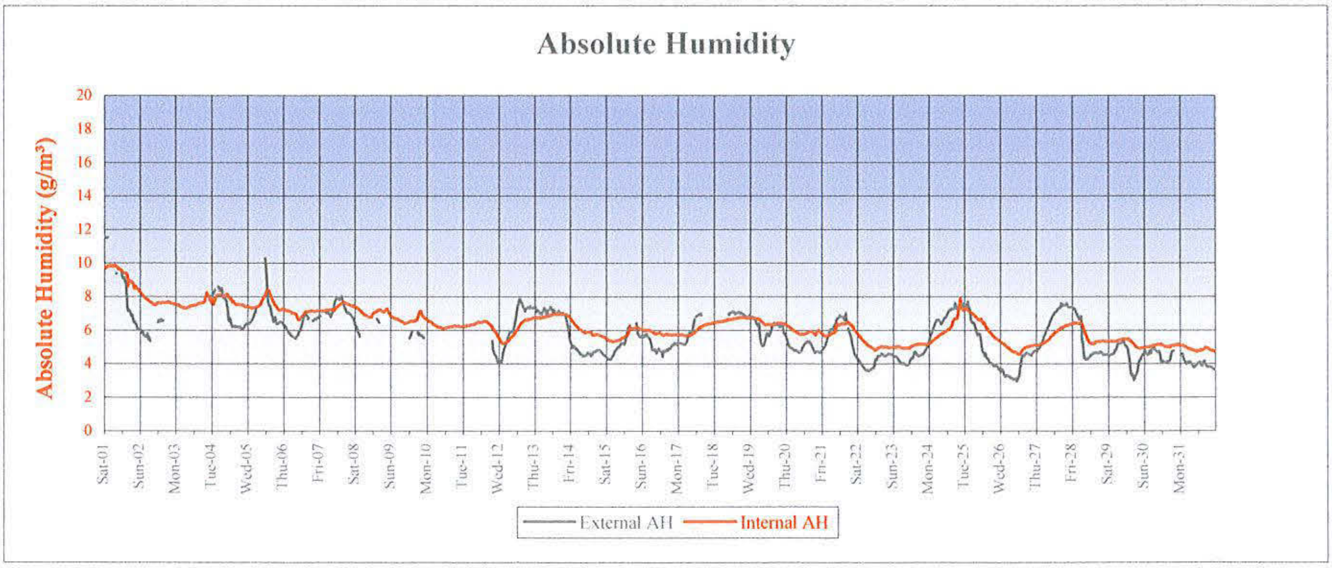
Peterborough Cathedral Nave Ceiling

December 2001

Probe 1: Bay 36 III lower side (shade)



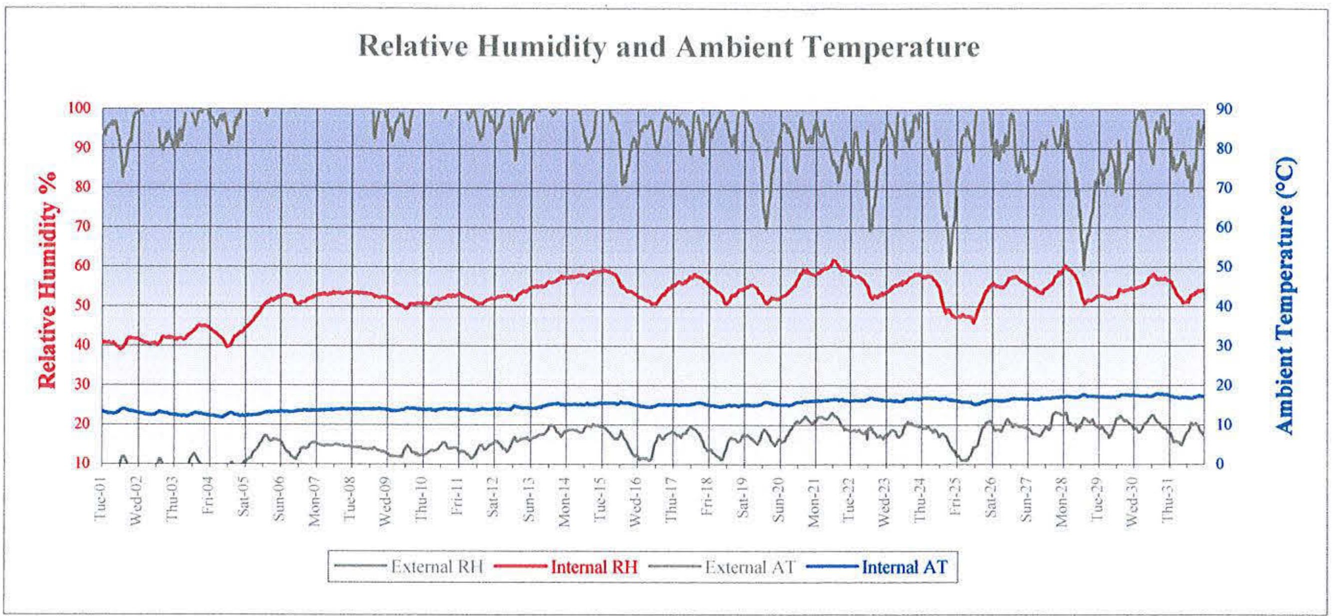


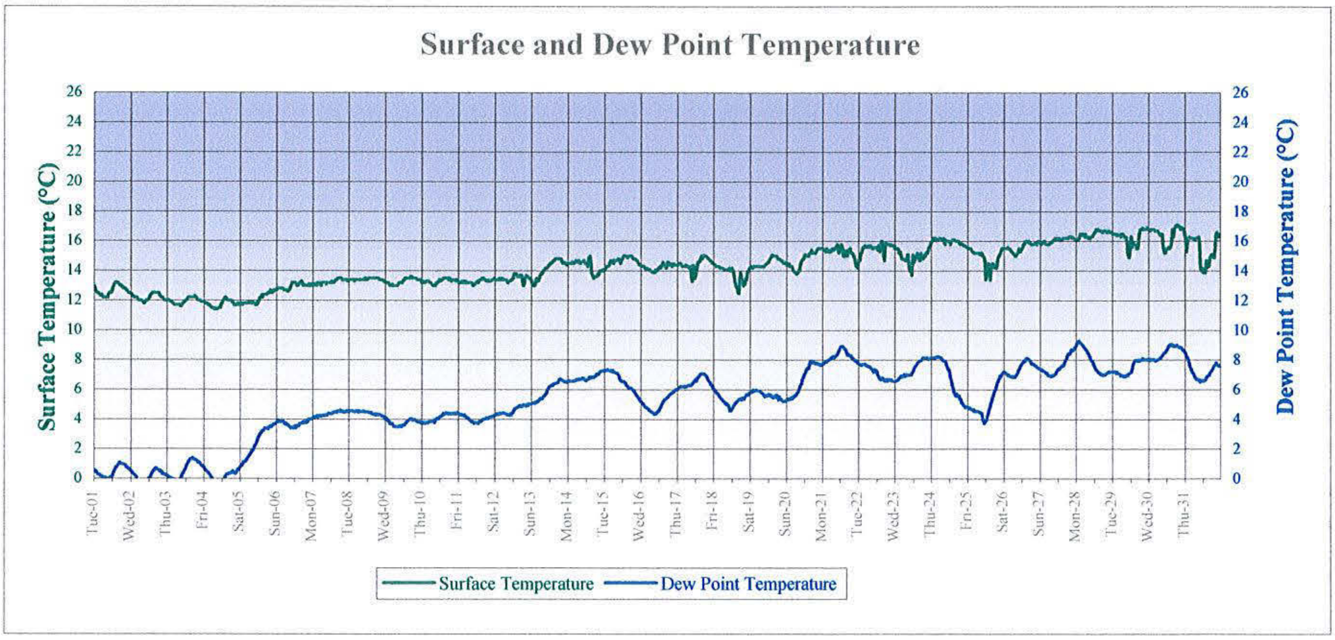


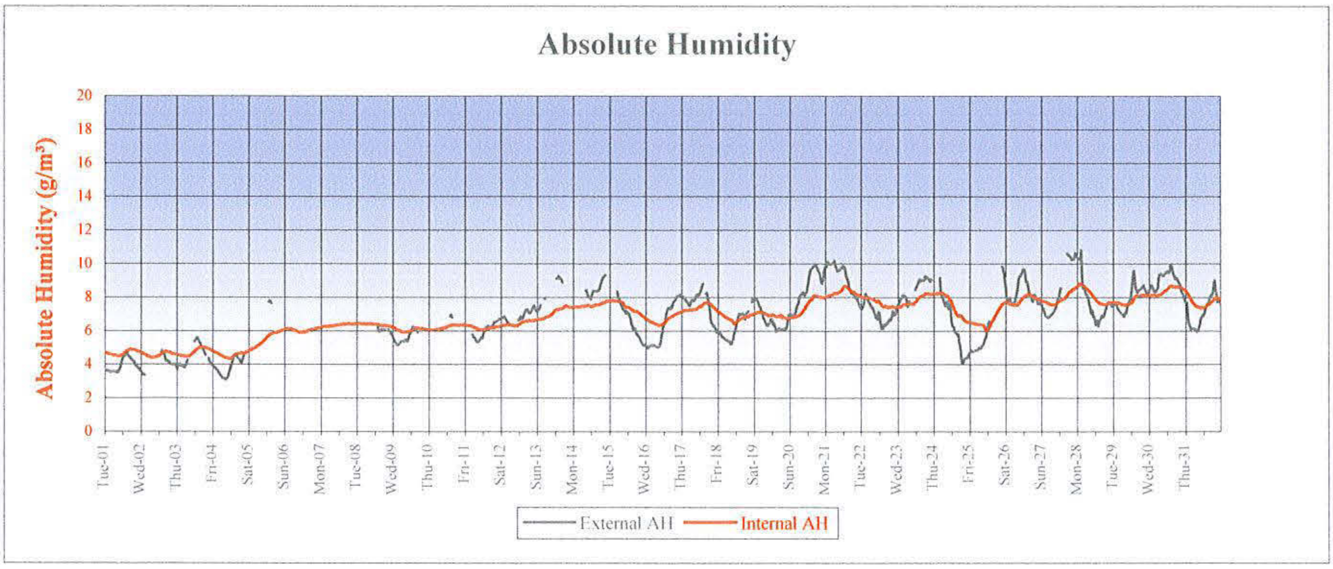
Peterborough Cathedral Nave Ceiling

January 2002

Probe 1: Bay 36 III lower side (shade)

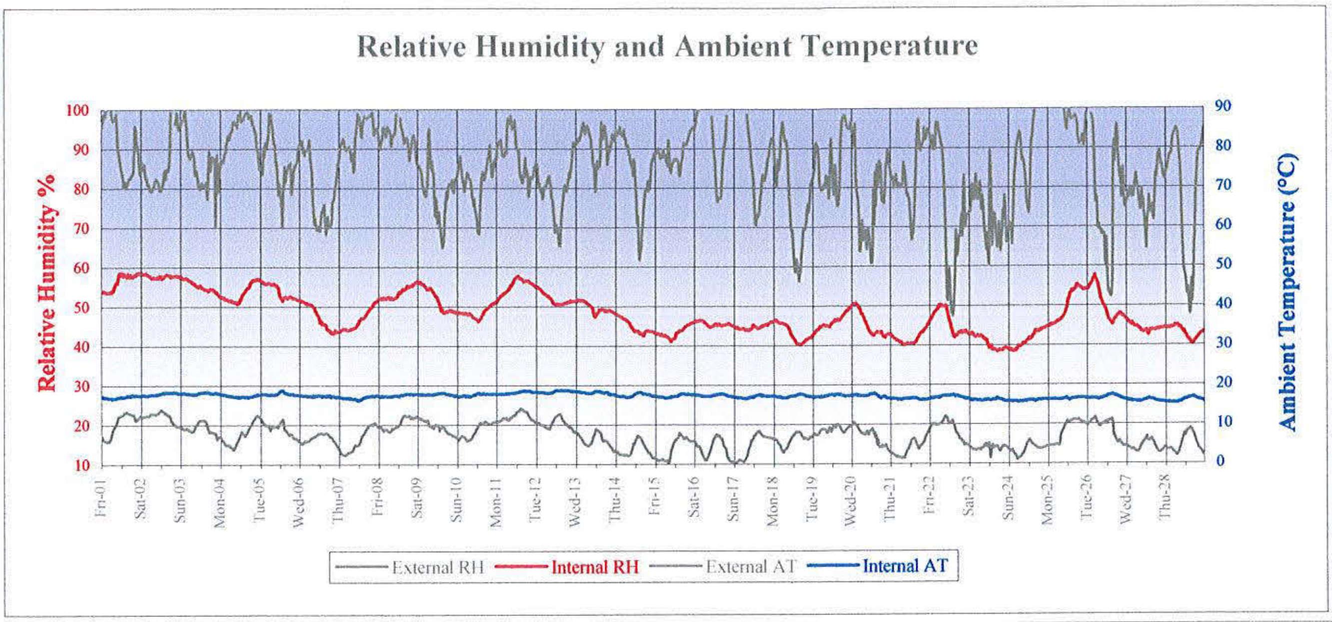


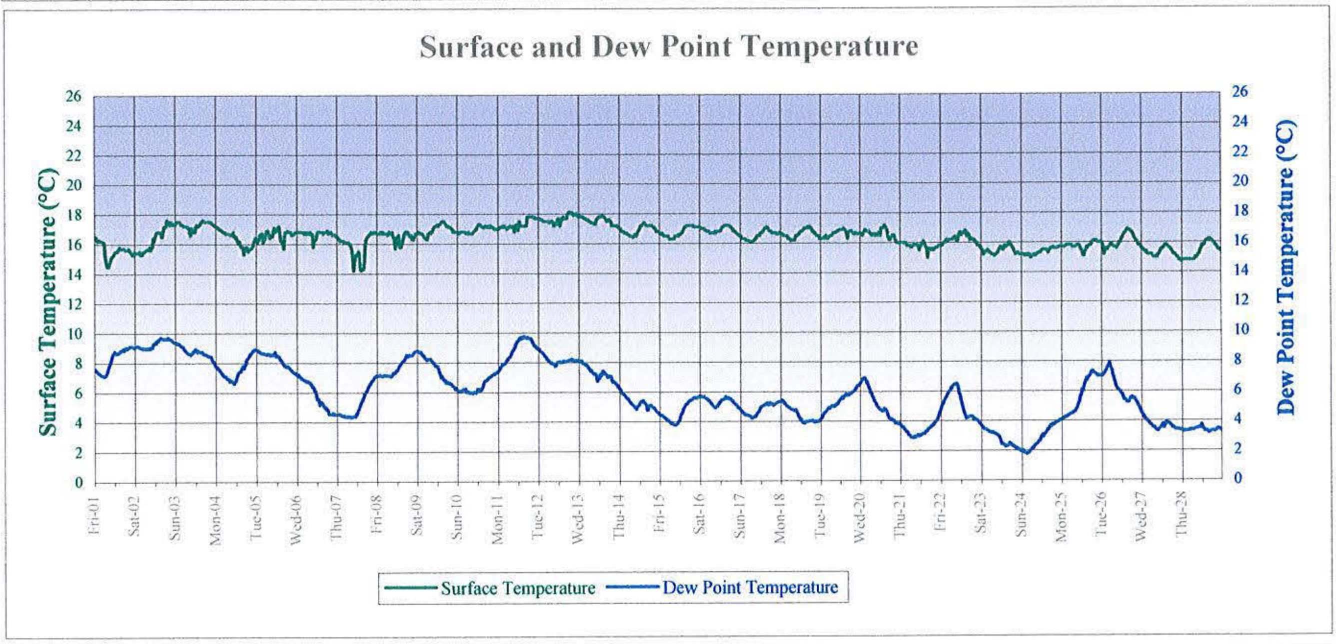


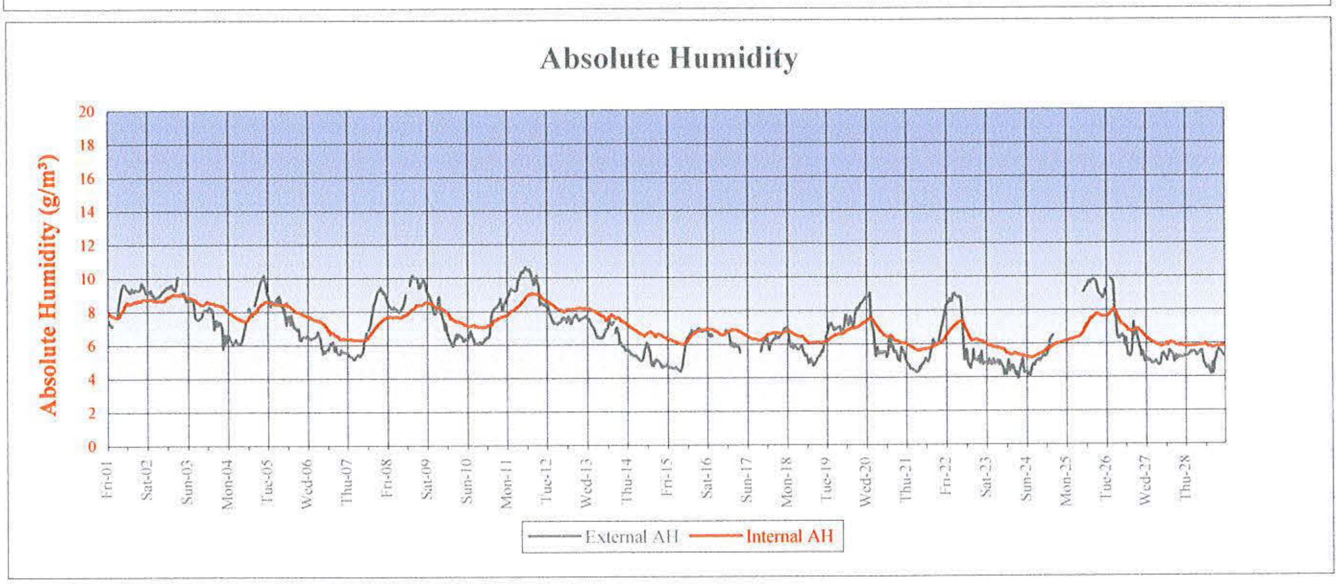


Peterborough Cathedral Nave Ceiling

Probe 1: Bay 36 III lower side (shade)



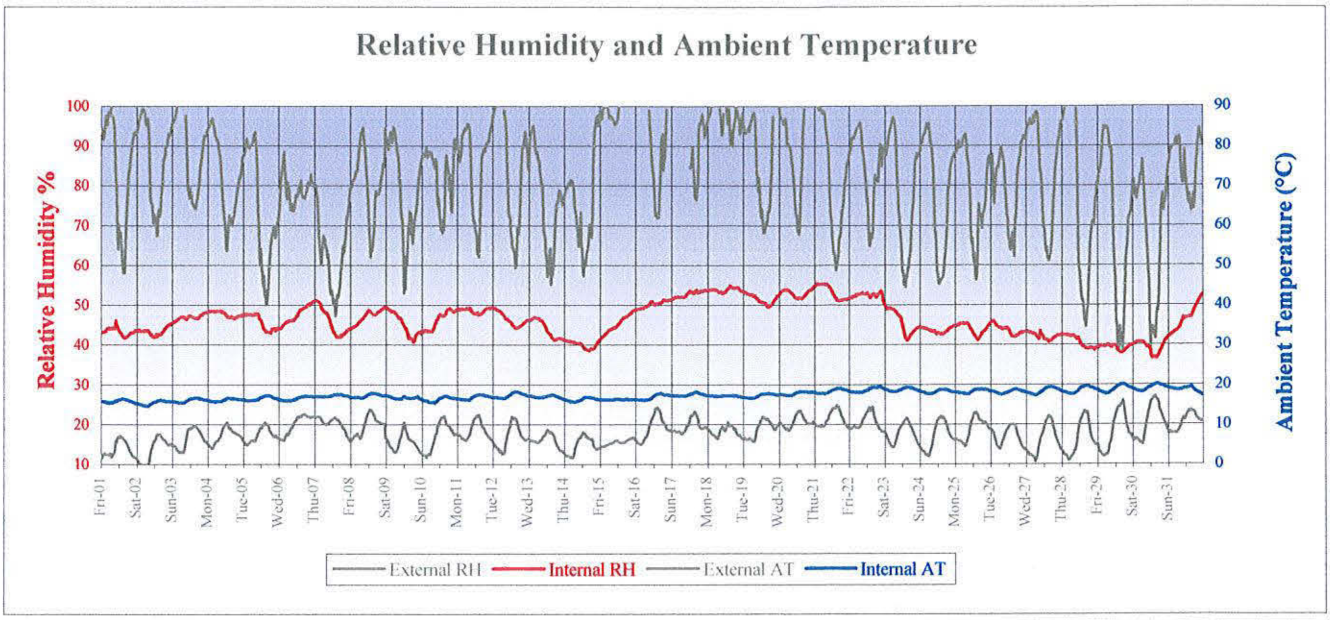


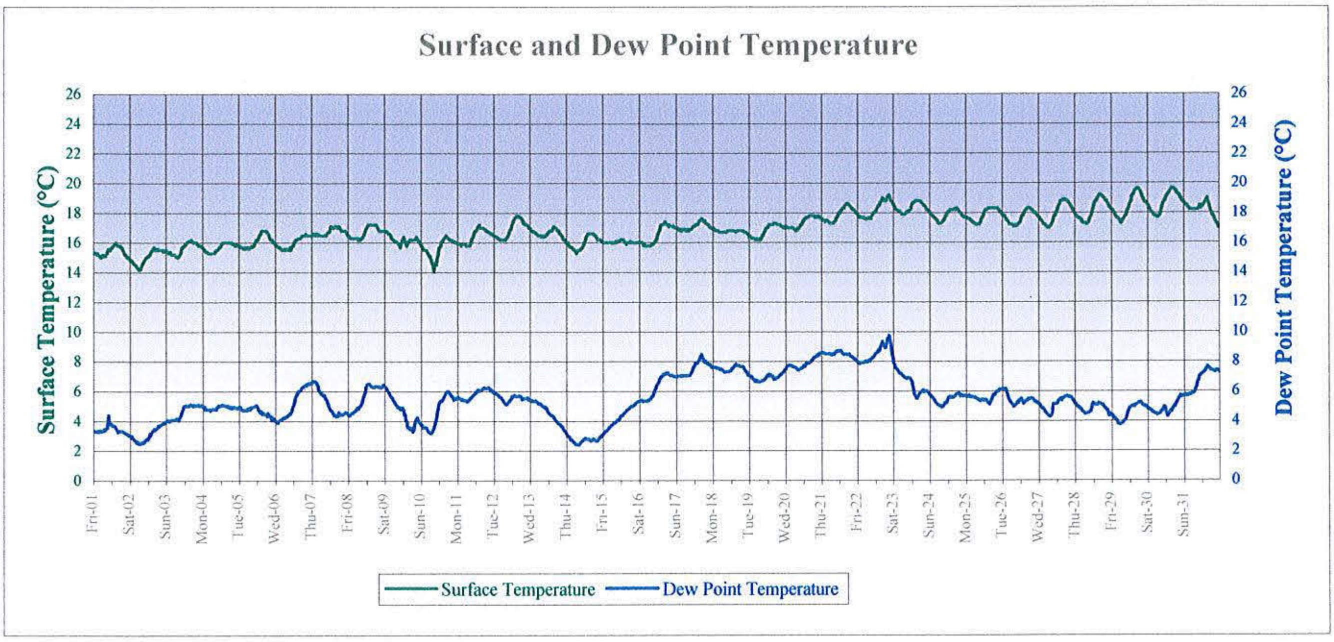


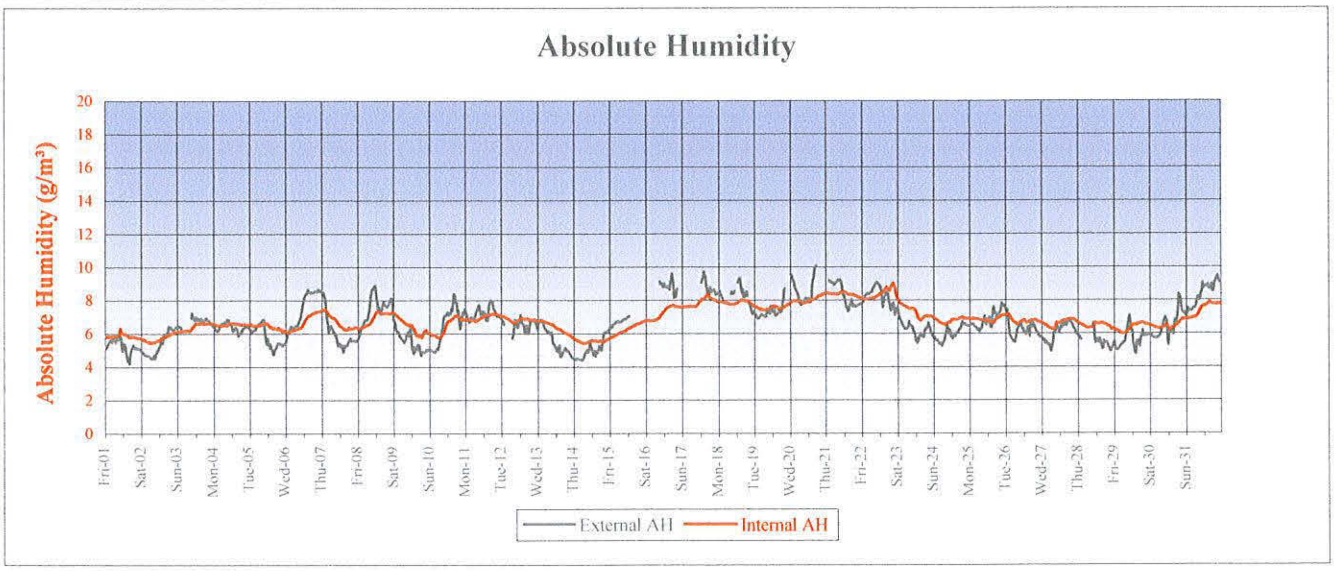
Peterborough Cathedral Nave Ceiling

March 2002

Probe 1: Bay 36 III lower side (shade)

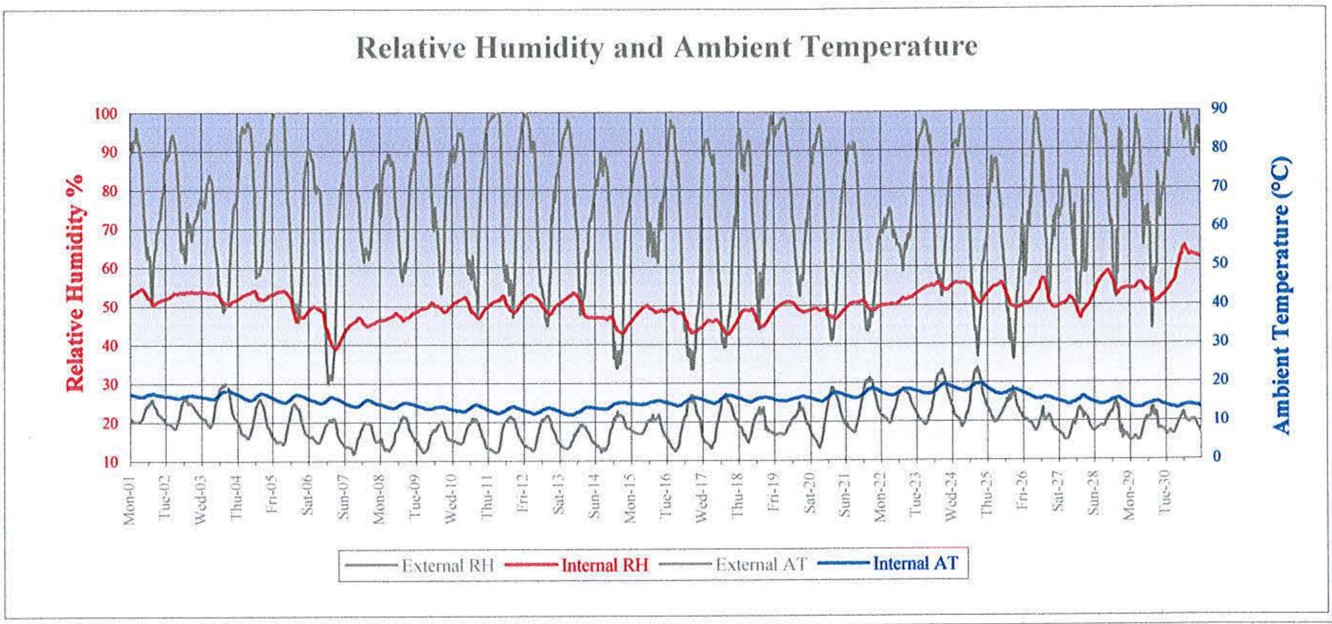


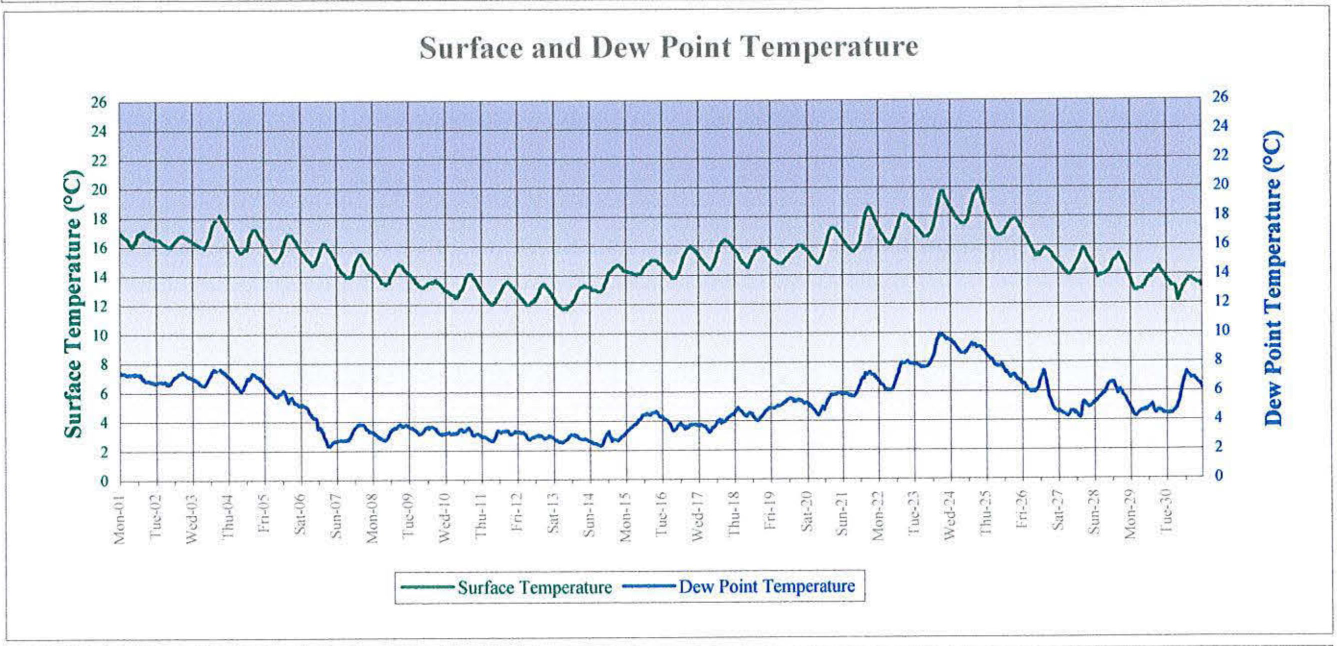


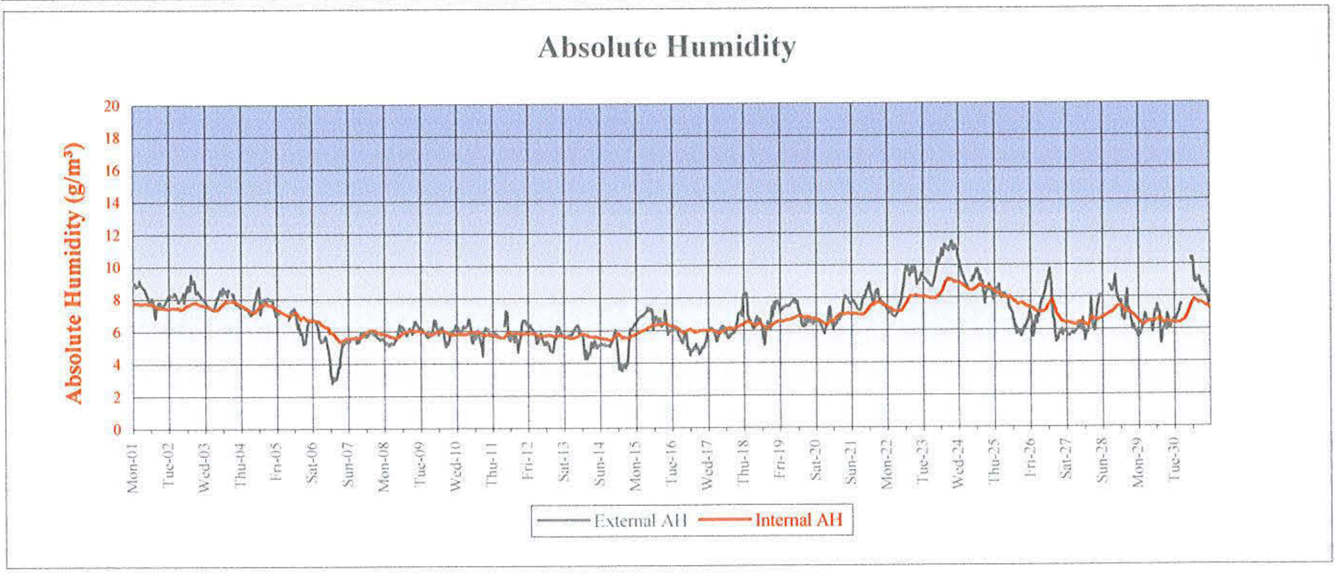


Peterborough Cathedral Nave Ceiling

Probe 1: Bay 36 III lower side (shade)



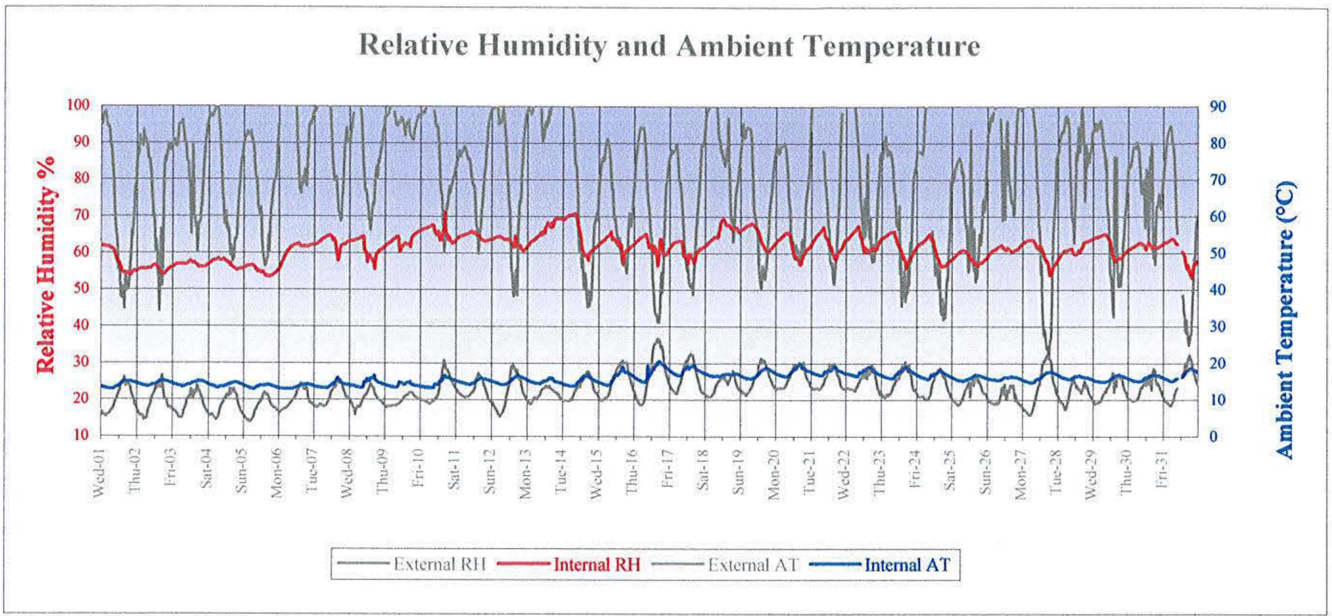


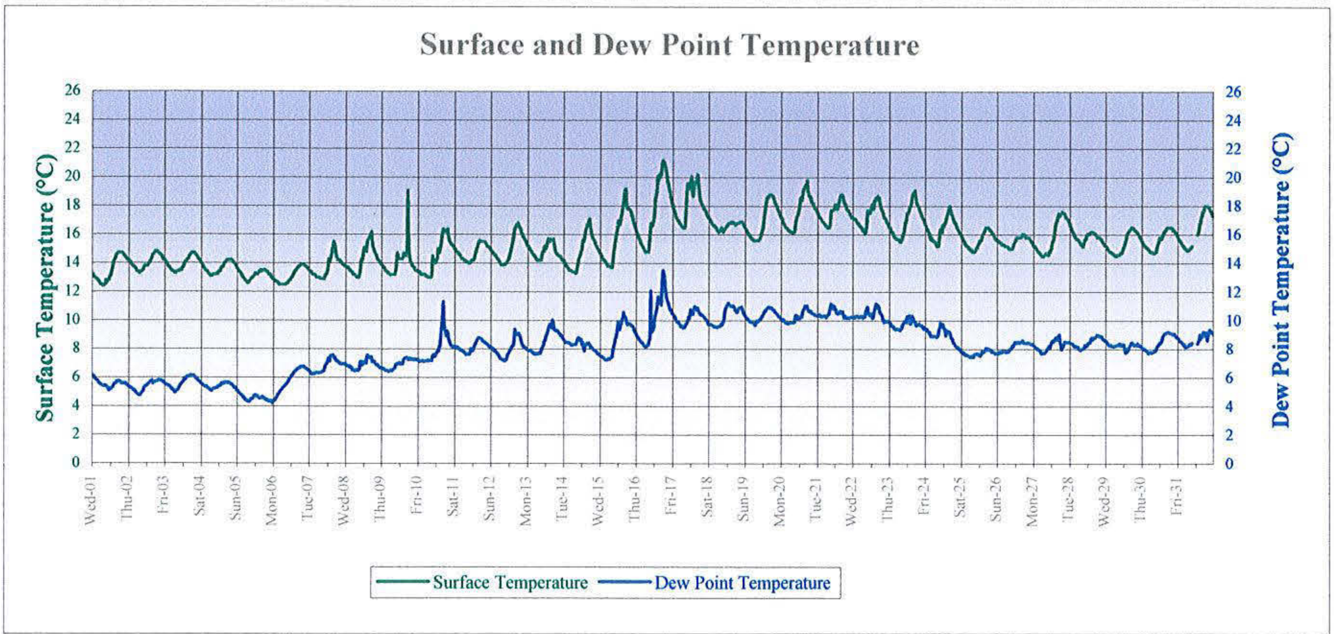


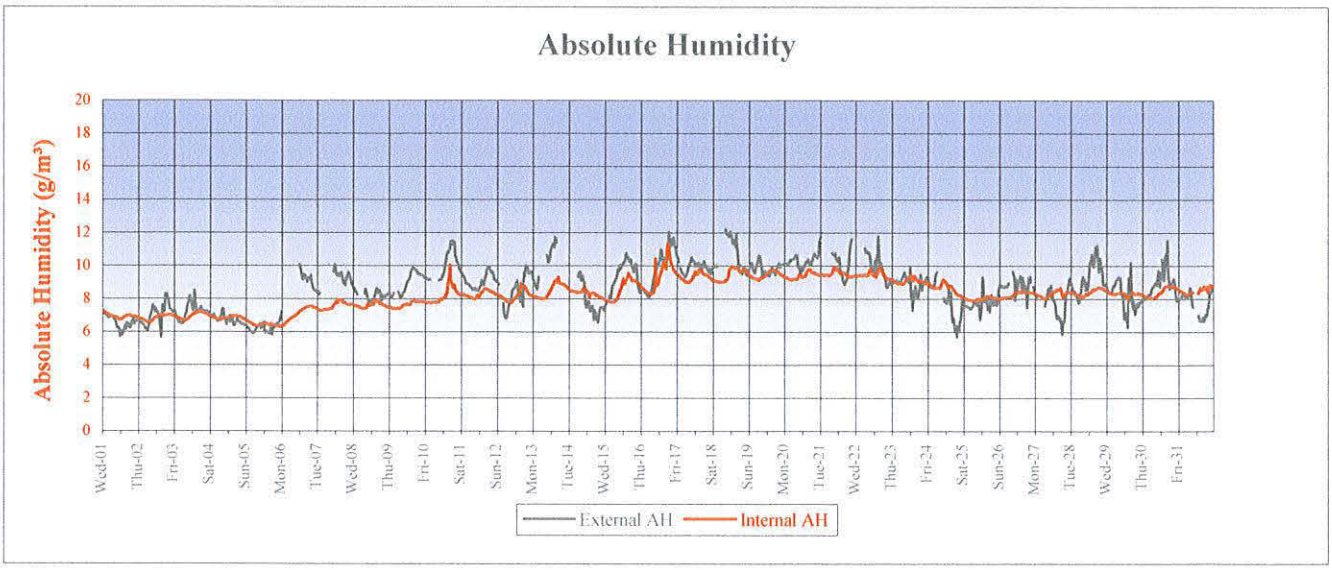
Peterborough Cathedral Nave Ceiling

May 2002

Probe 1: Bay 36 III lower side (shade)



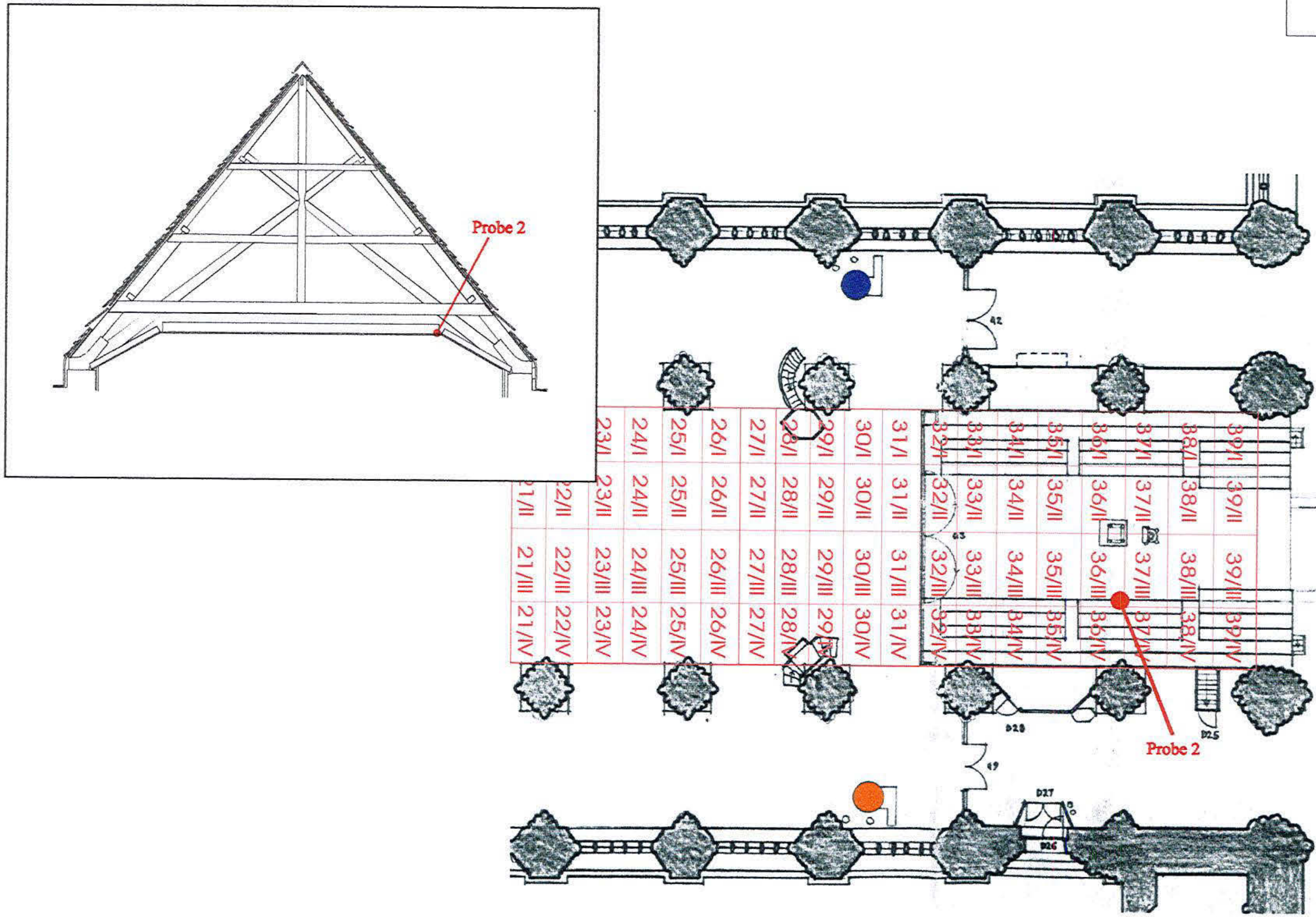




PROBE 2

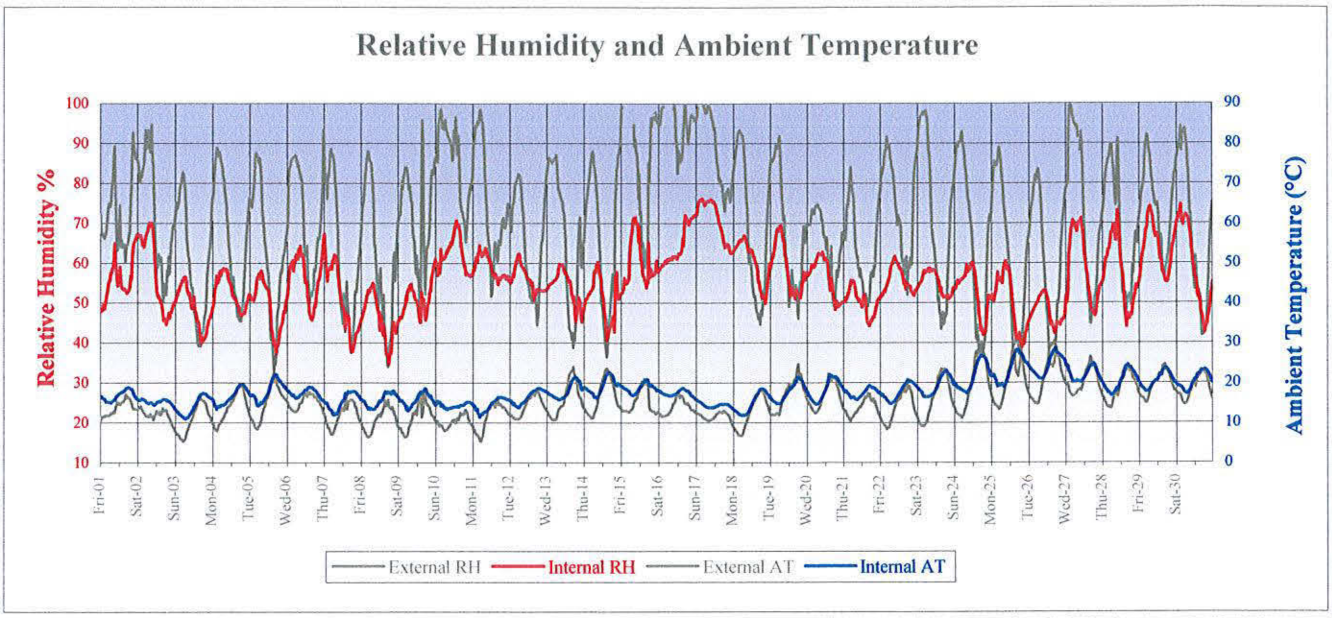
BAY 36 III UPPER SIDE (SHADE)

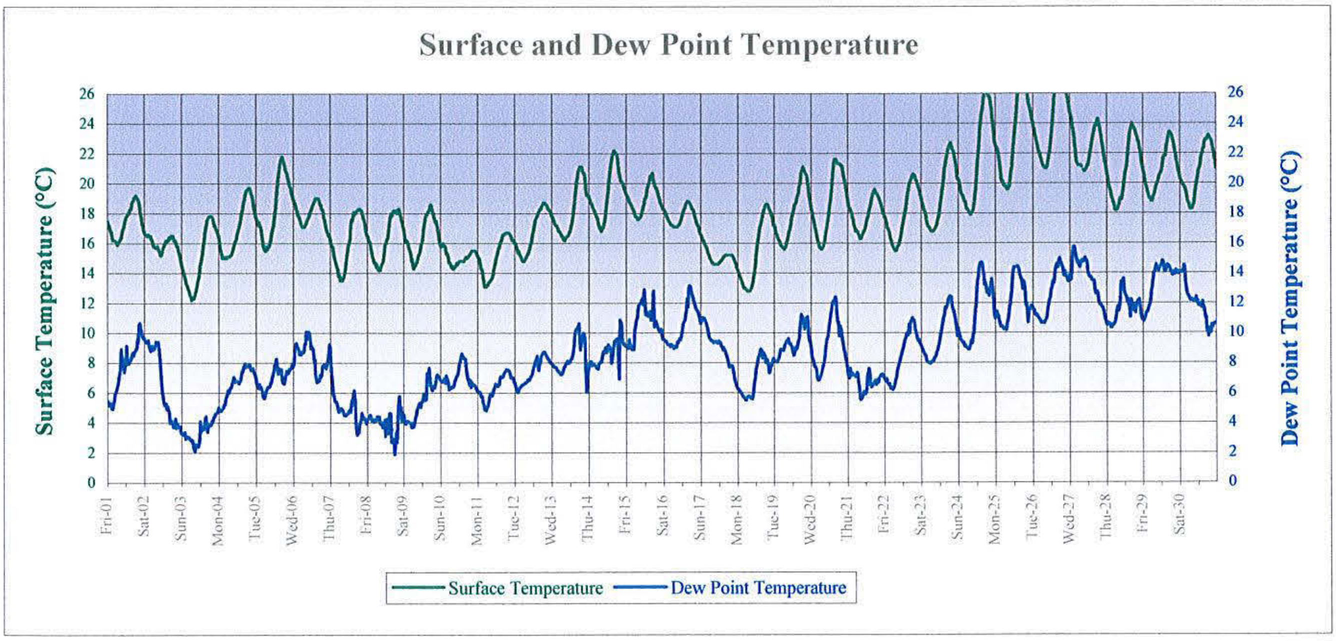
Diagram 4

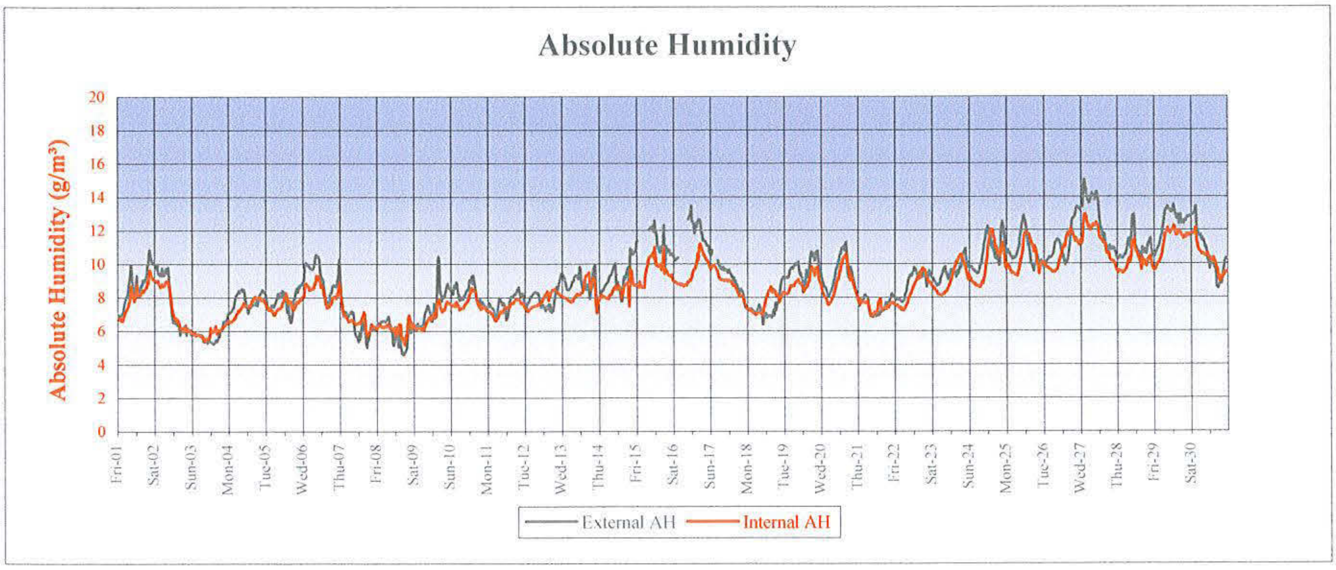


Site: Peterborough Cathedral	Type: Probe and stove locations	0m 5m 10m	Full use stove
Area: Plan (Base plan drawn by Julian Limentani)	Date: July 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

Probe 2: Bay 36 III upper side (shade)



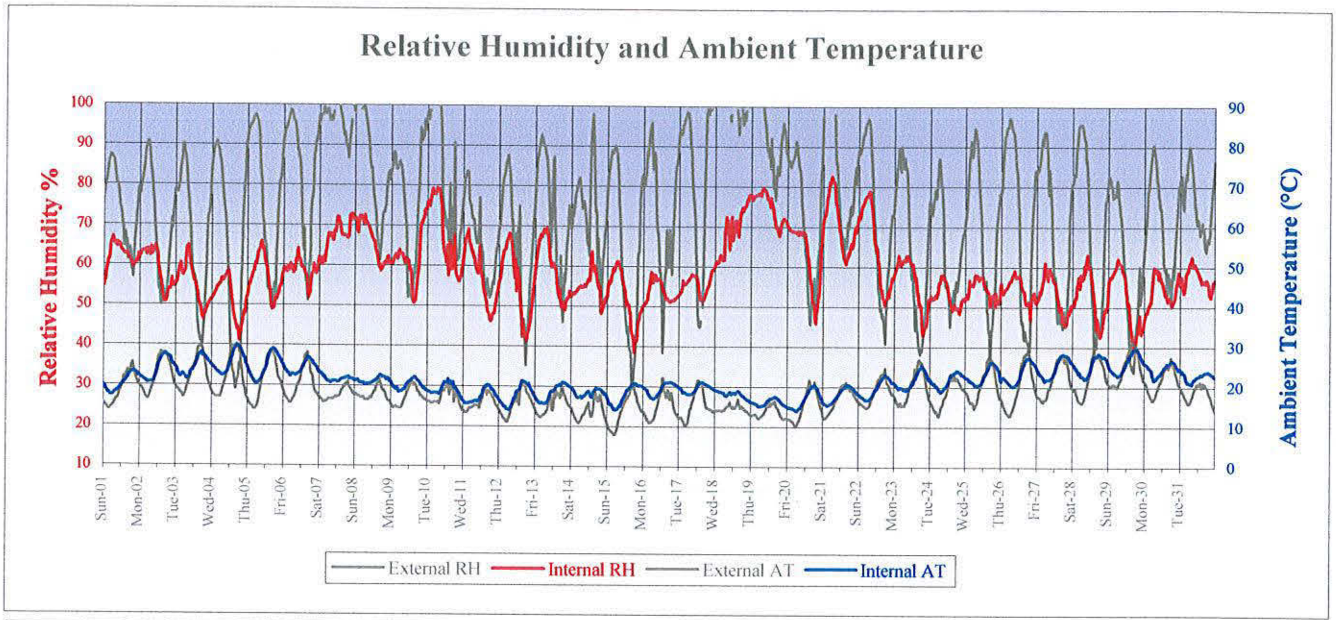


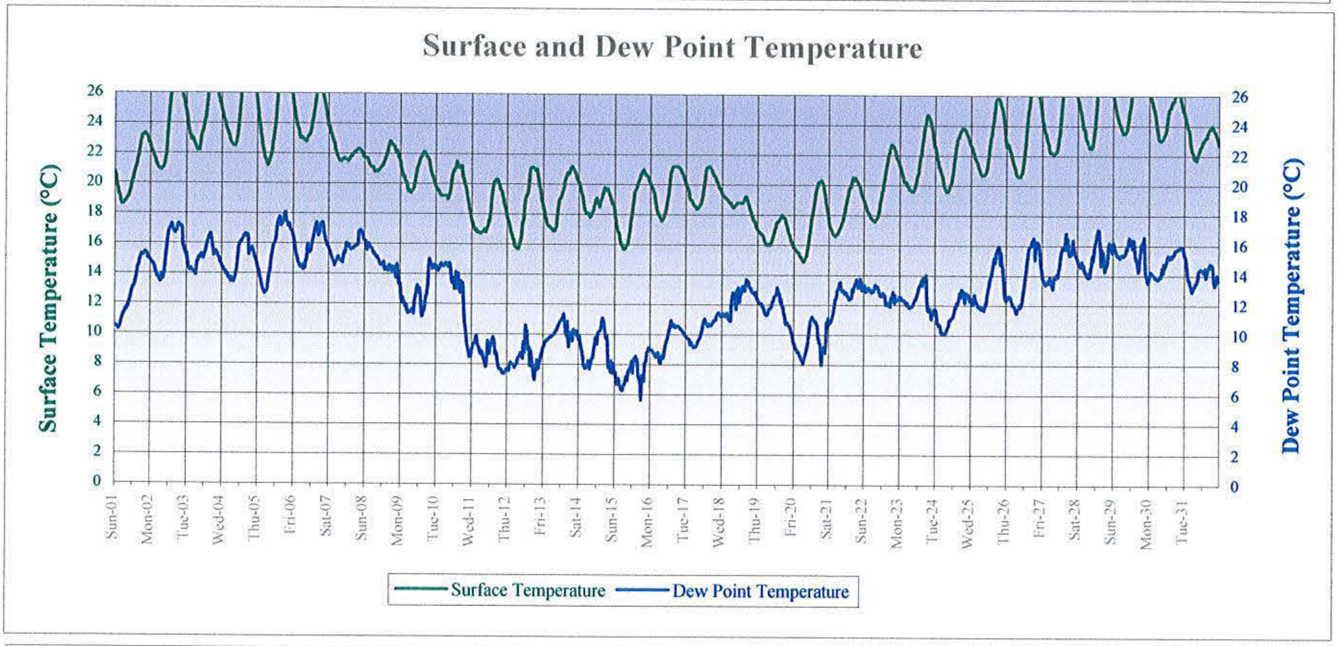


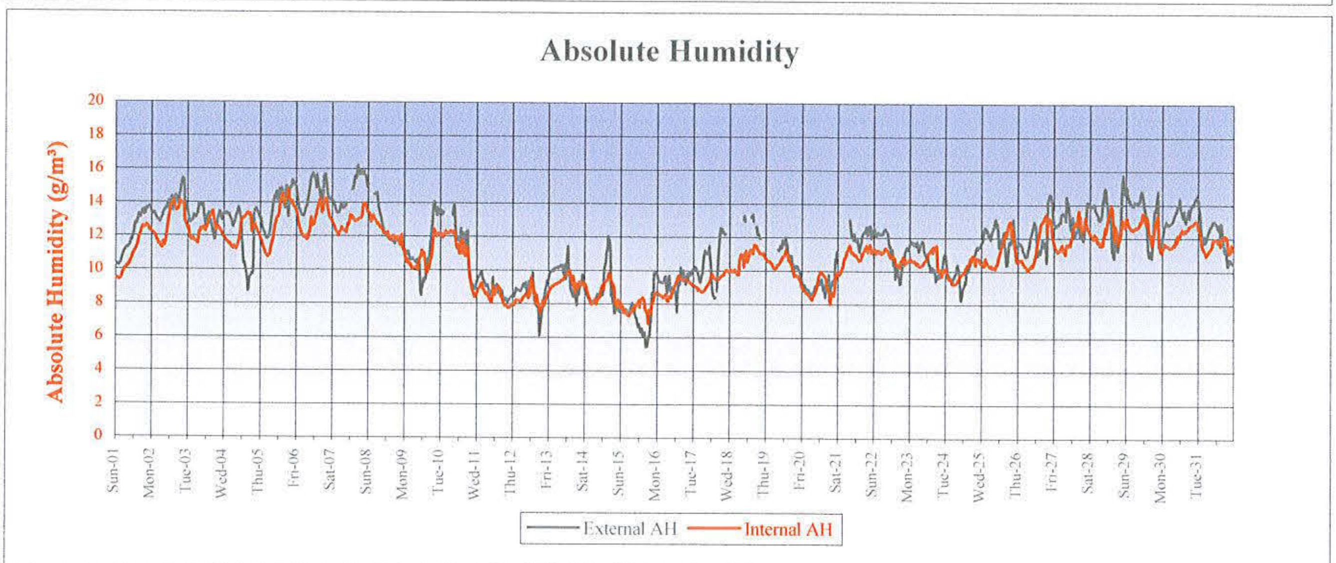
Peterborough Cathedral Nave Ceiling

July 2001

Probe 2: Bay 36 III upper side (shade)

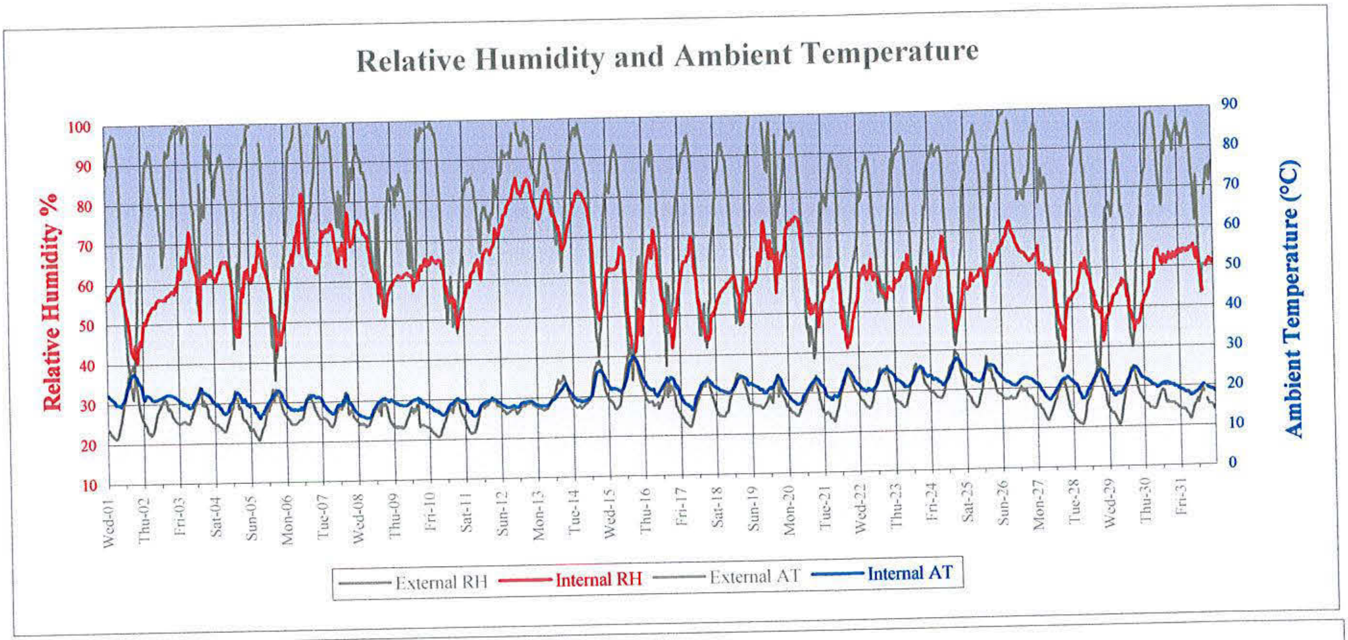


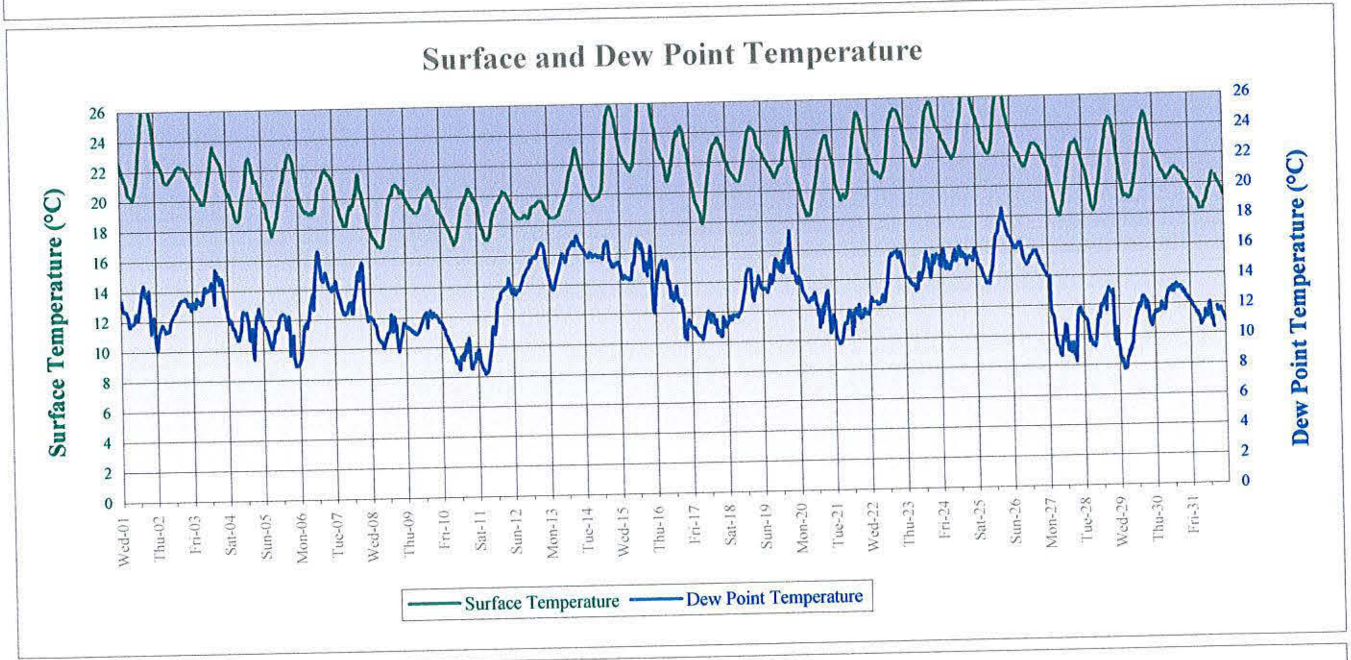


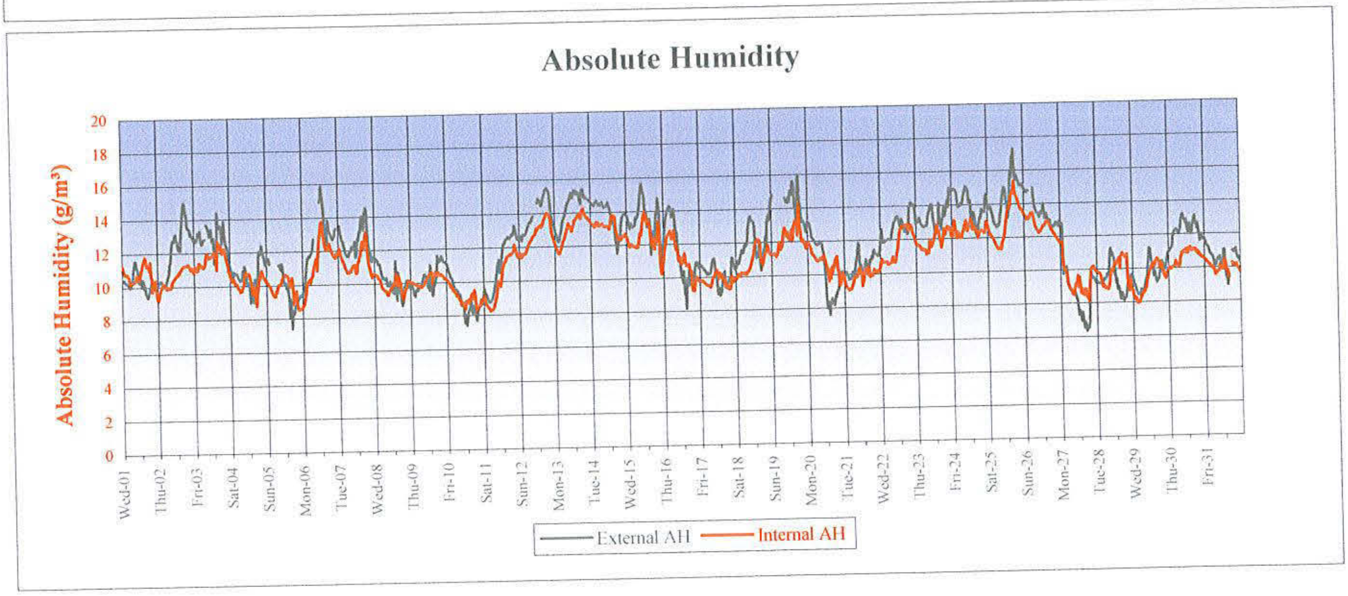


Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)

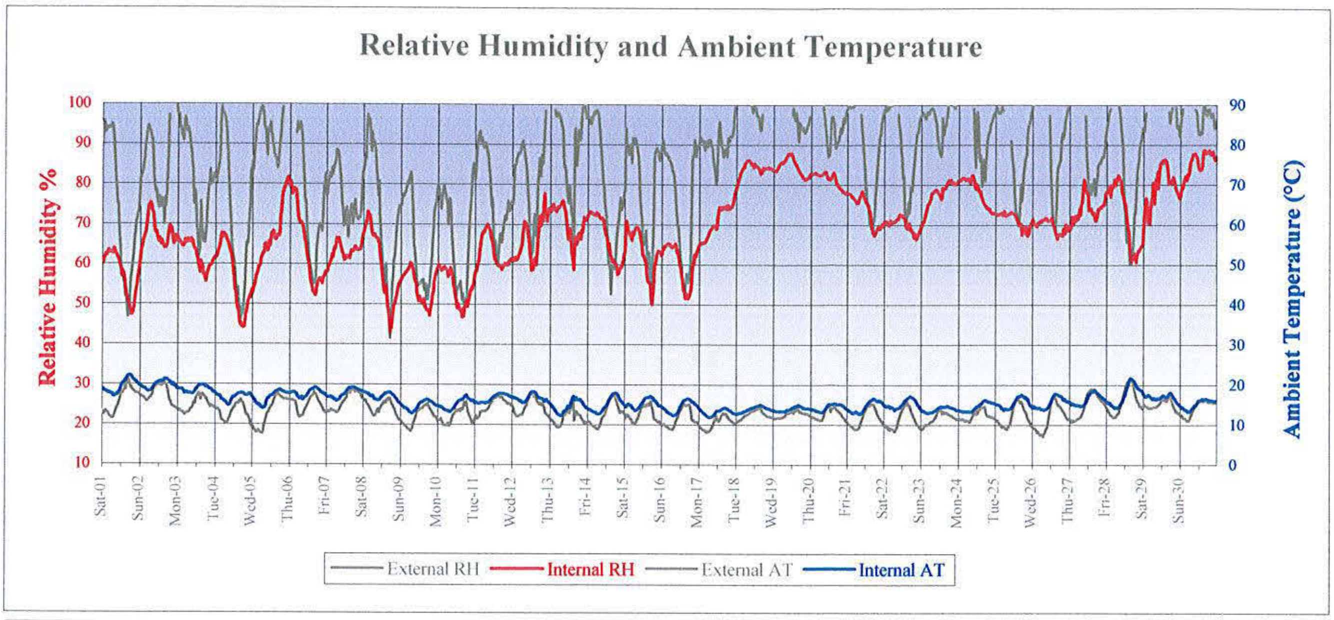


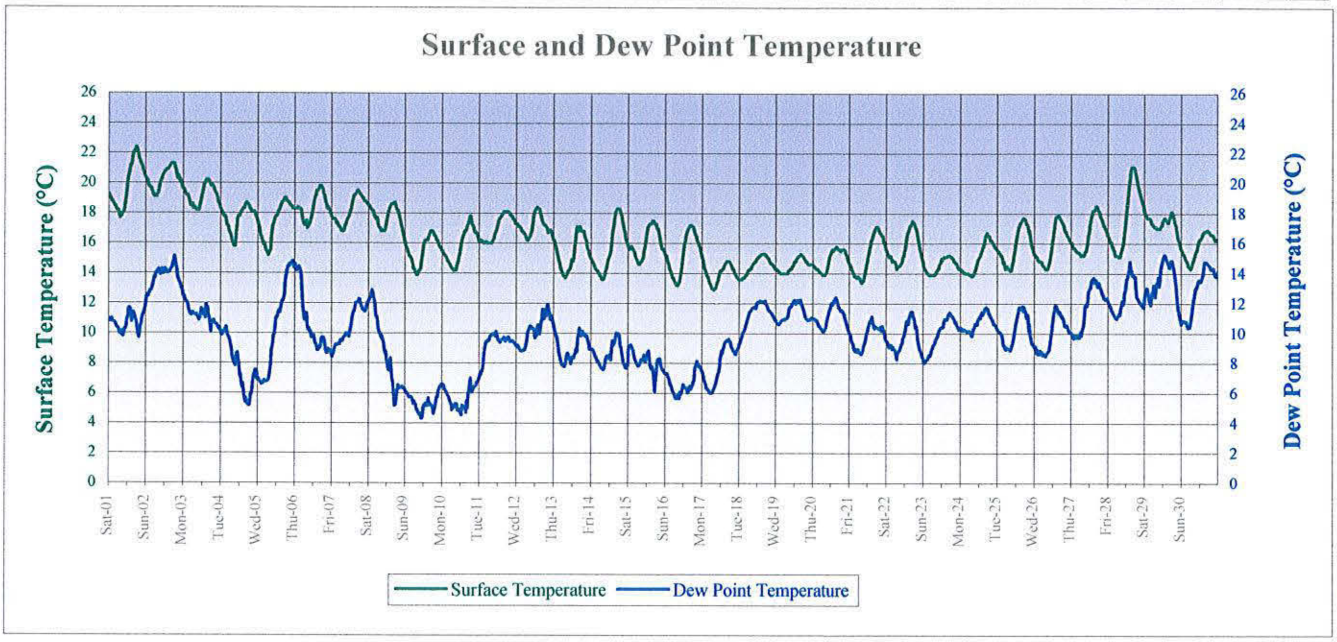


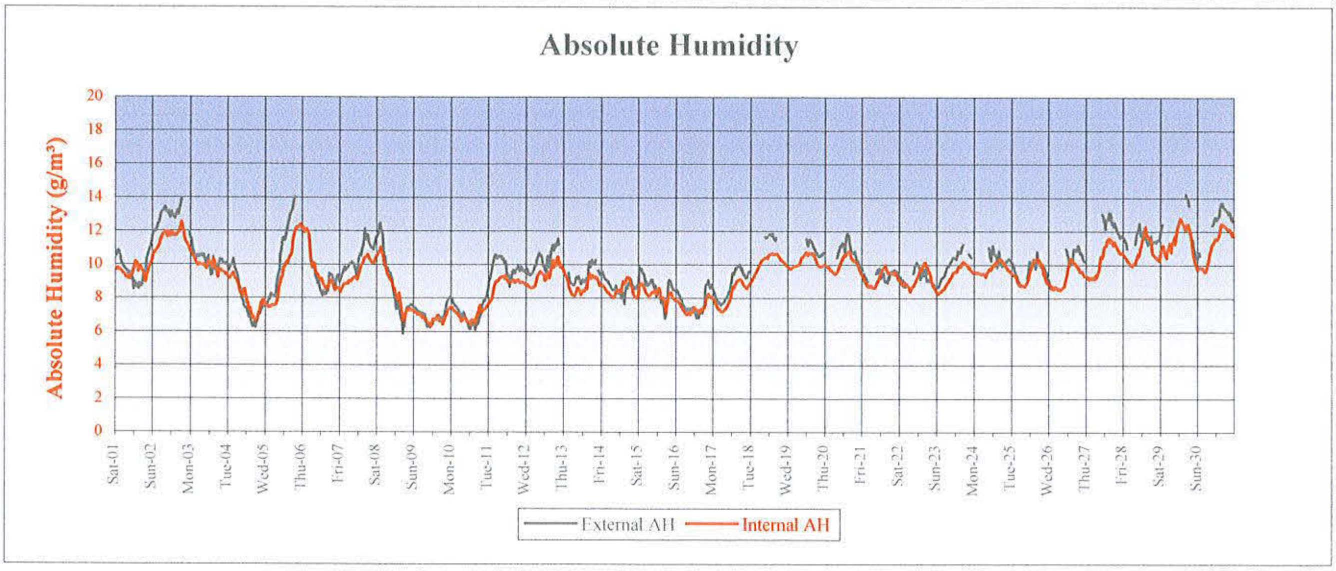


Peterborough Cathedral Nave Ceiling

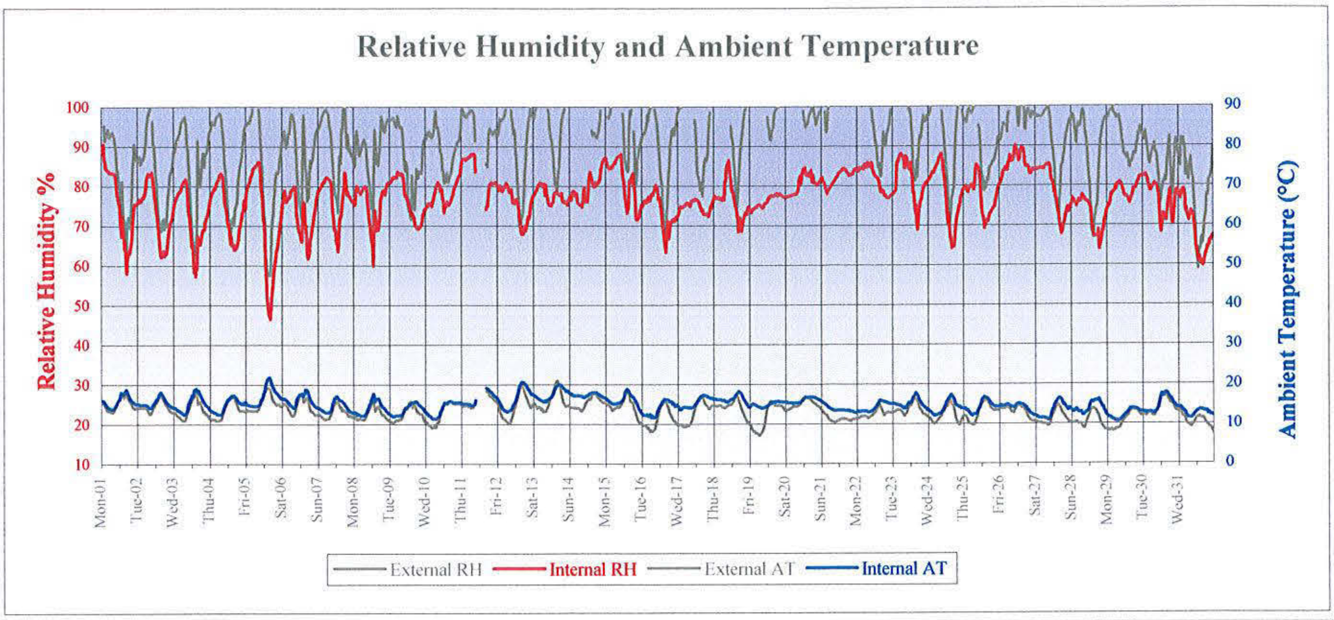
Probe 2: Bay 36 III upper side (shade)

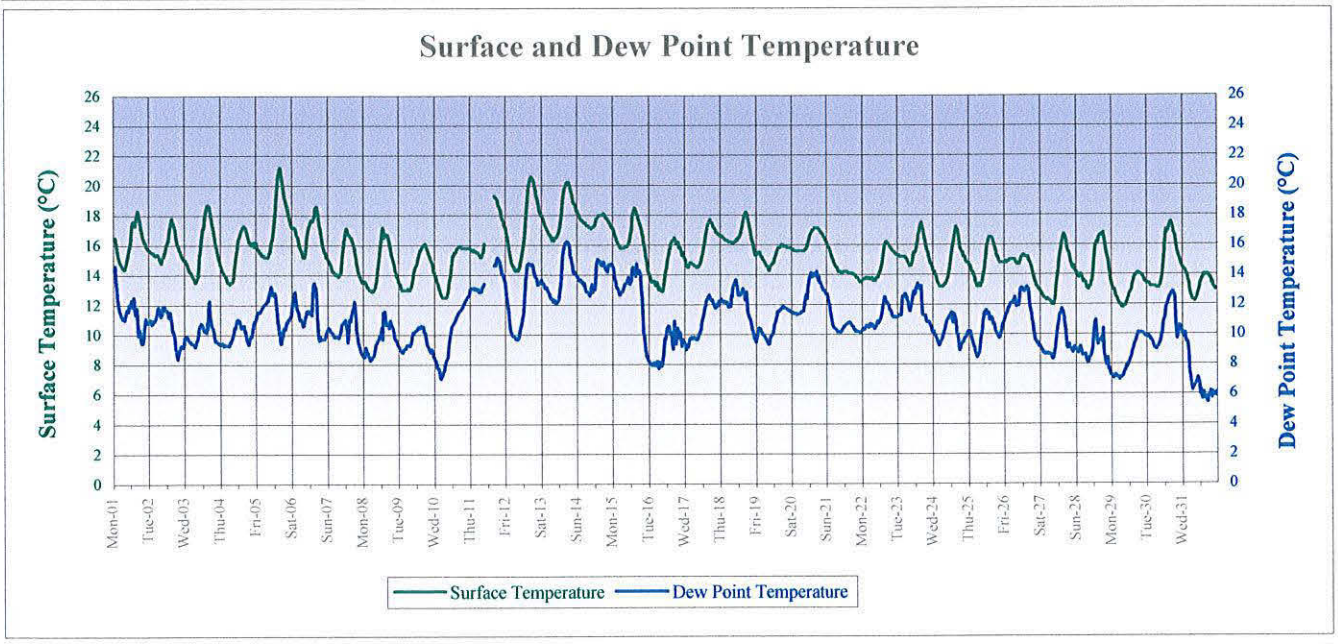


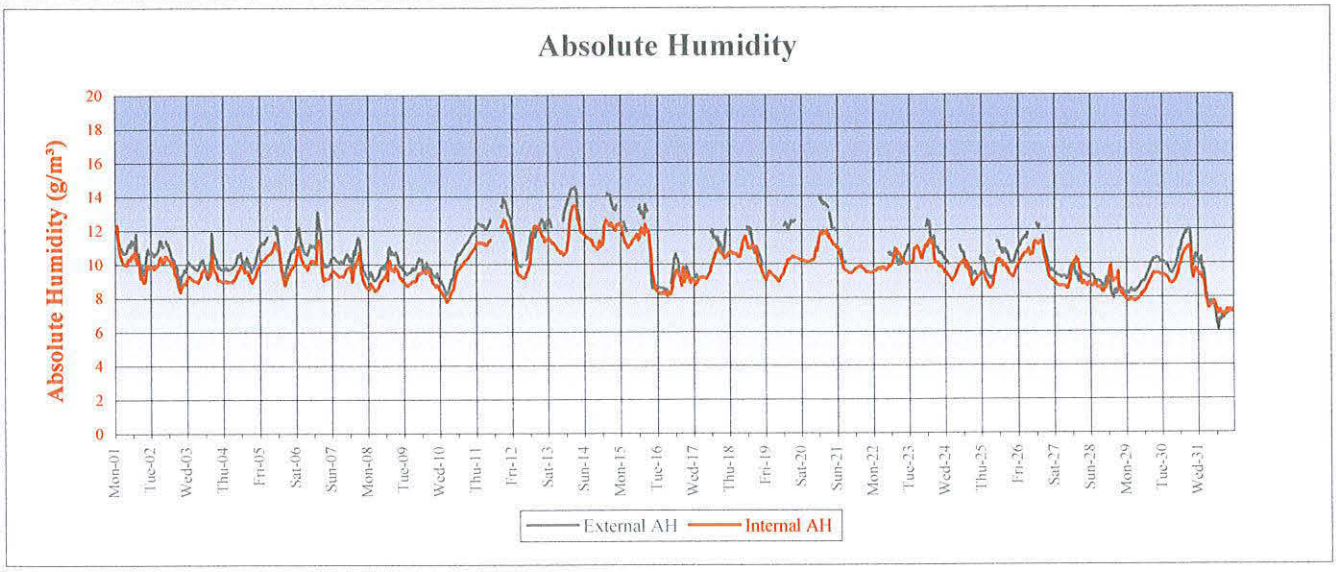




Probe 2: Bay 36 III upper side (shade)

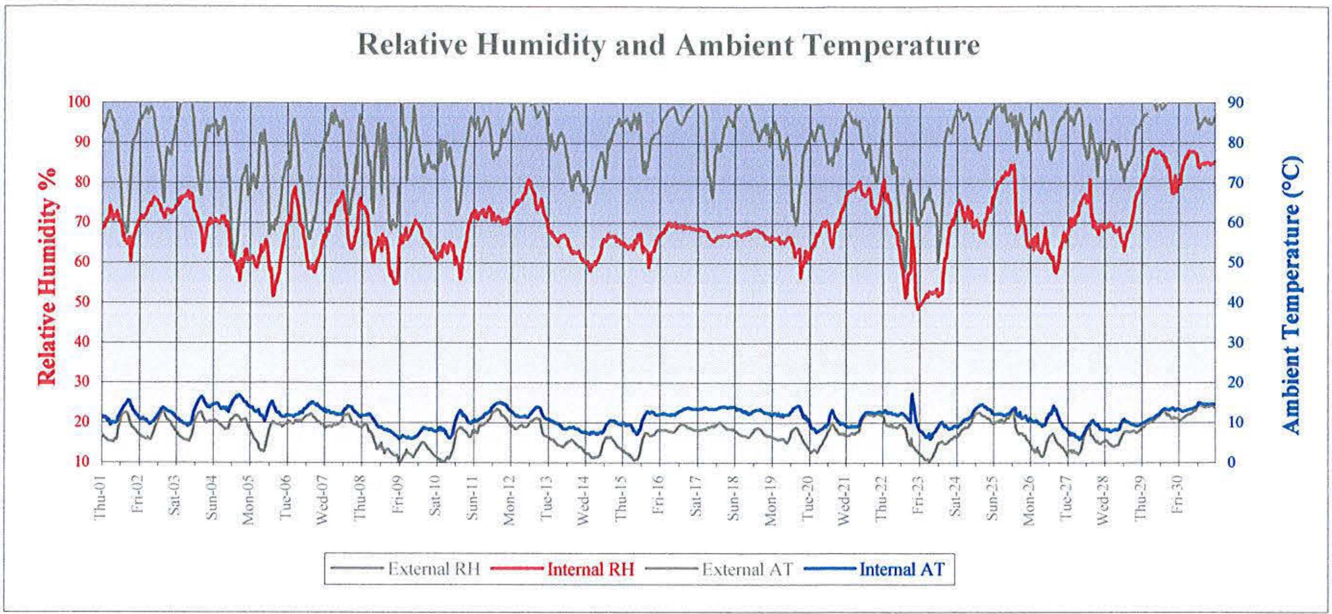


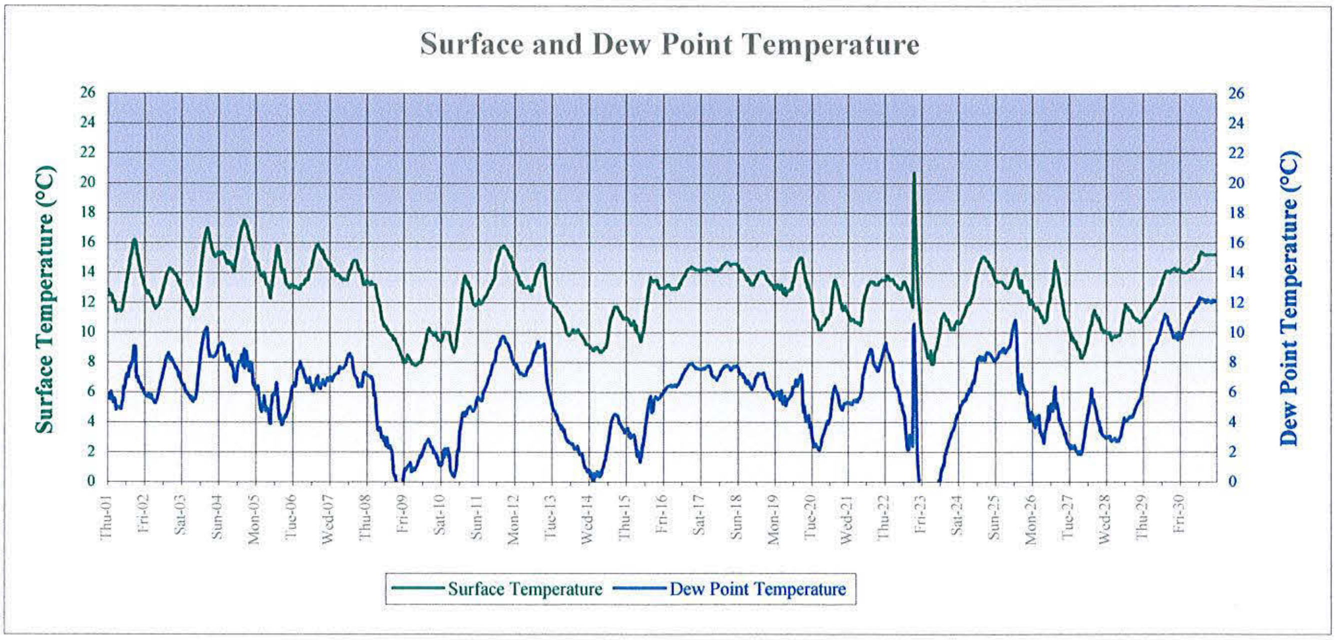


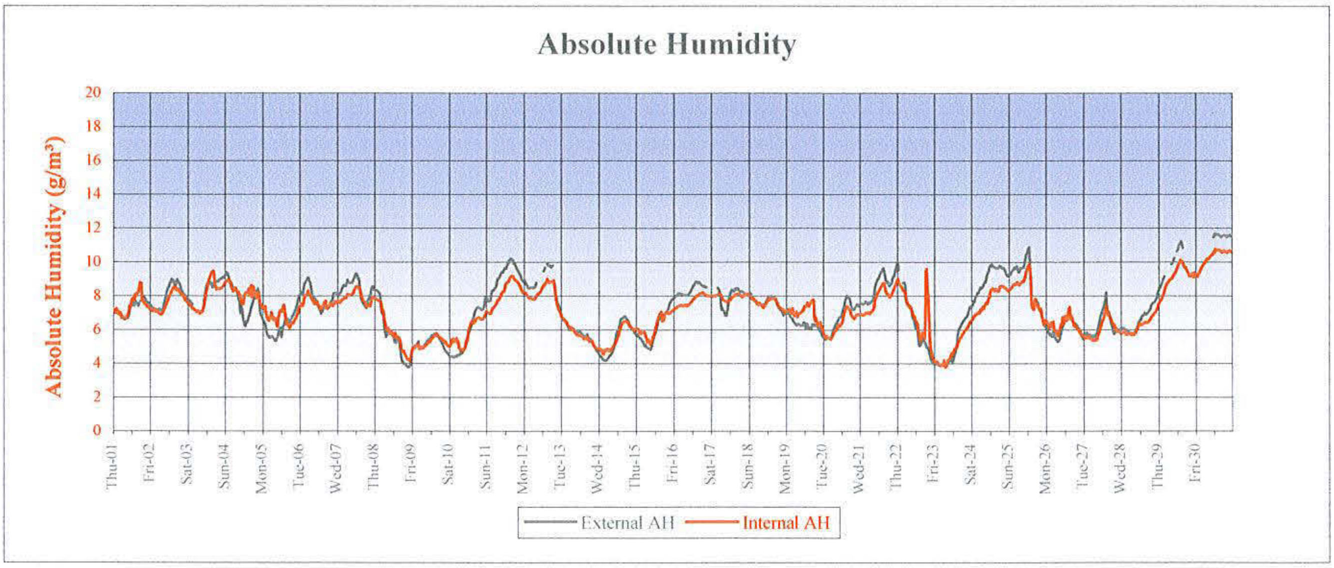


Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)

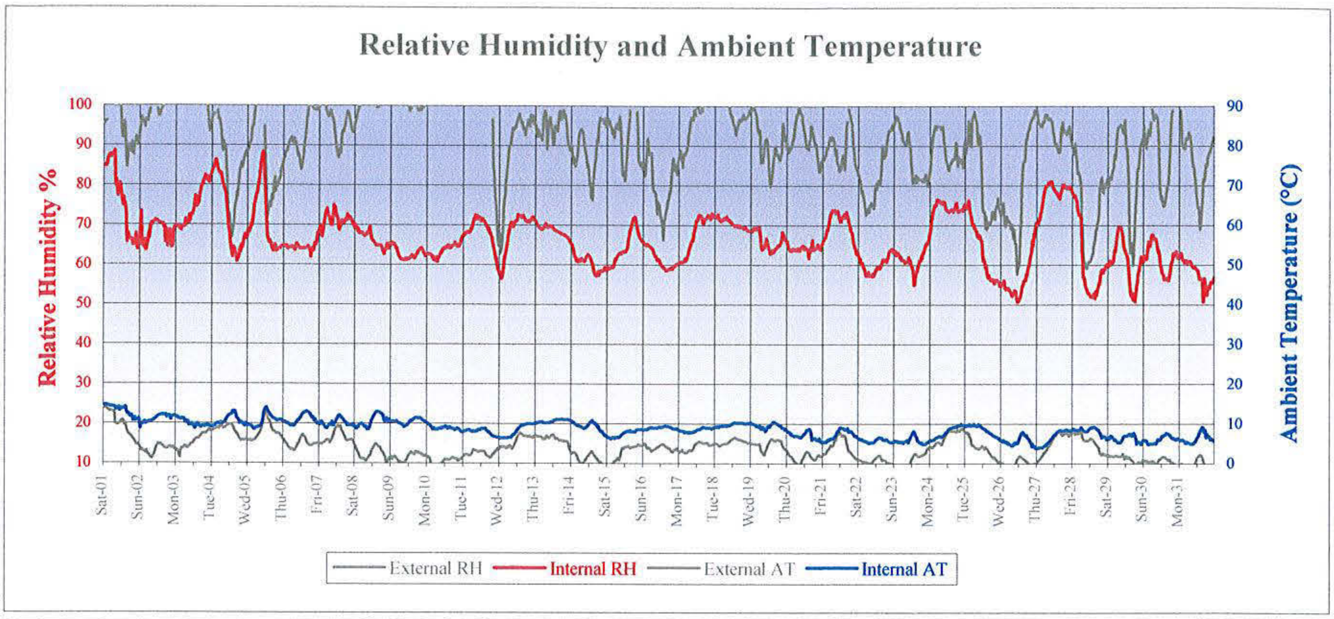


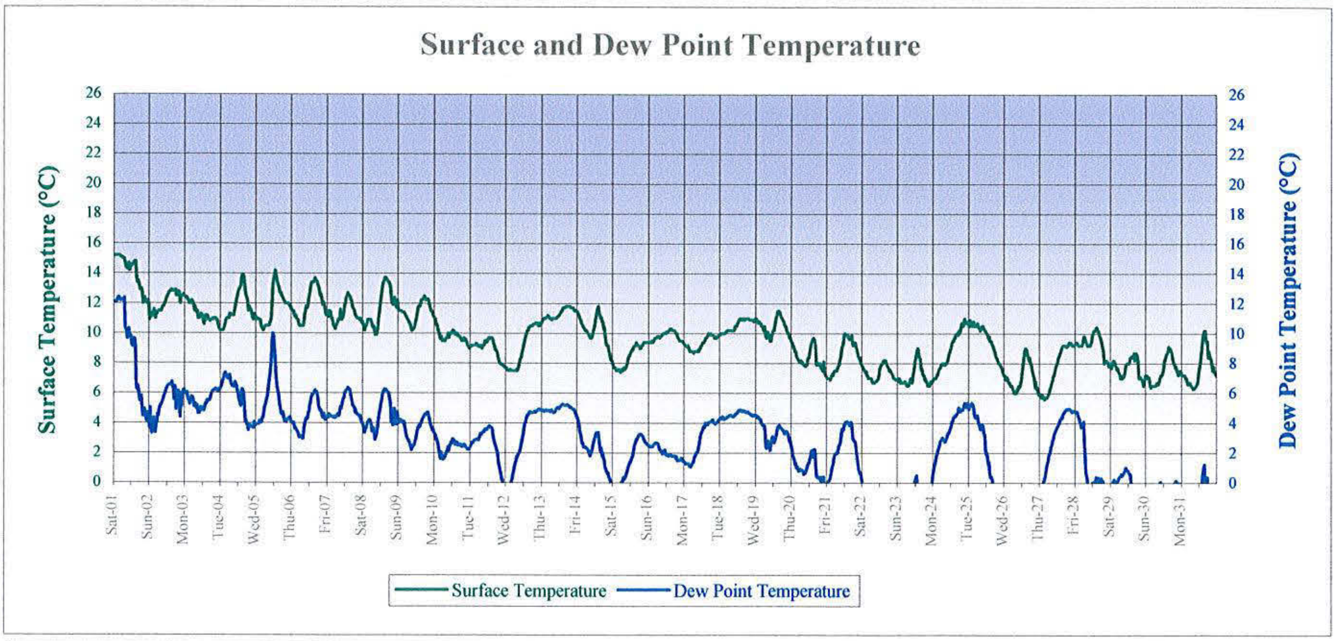


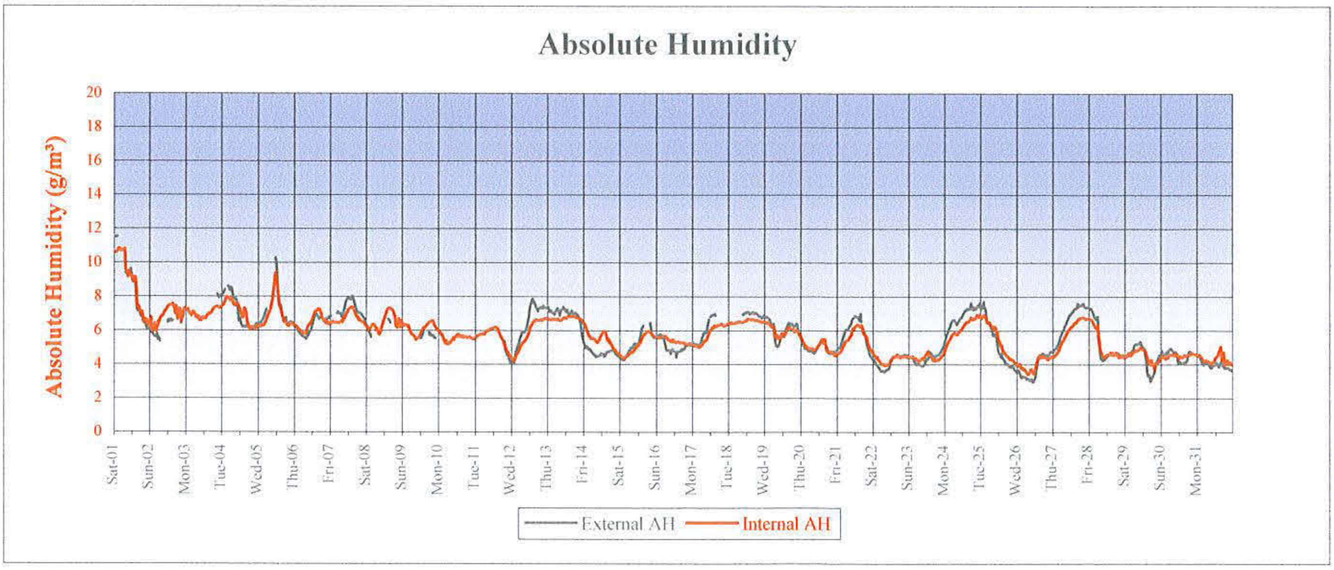


Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)

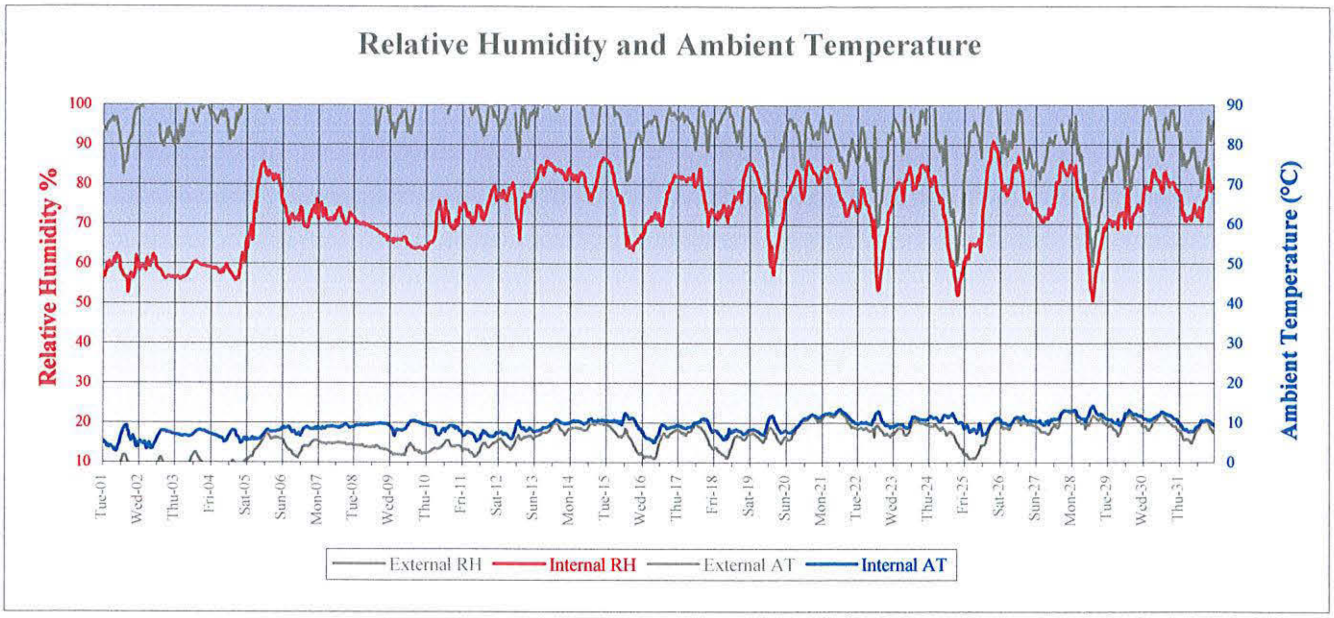


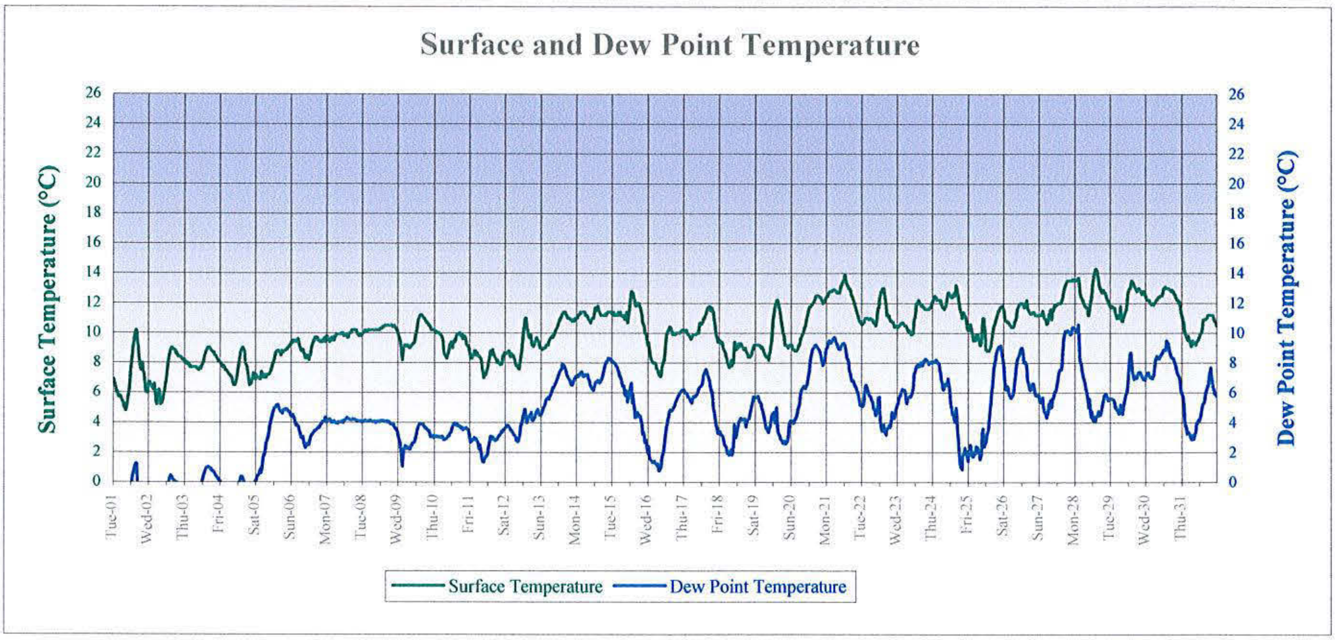


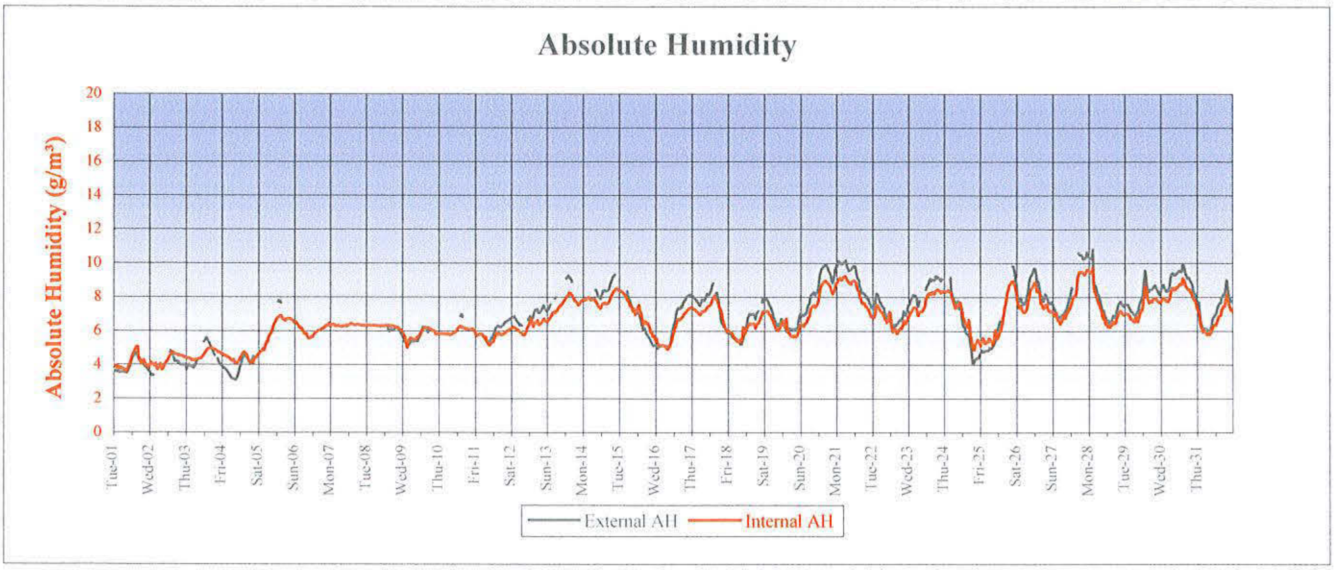


Peterborough Cathedral Nave Ceiling

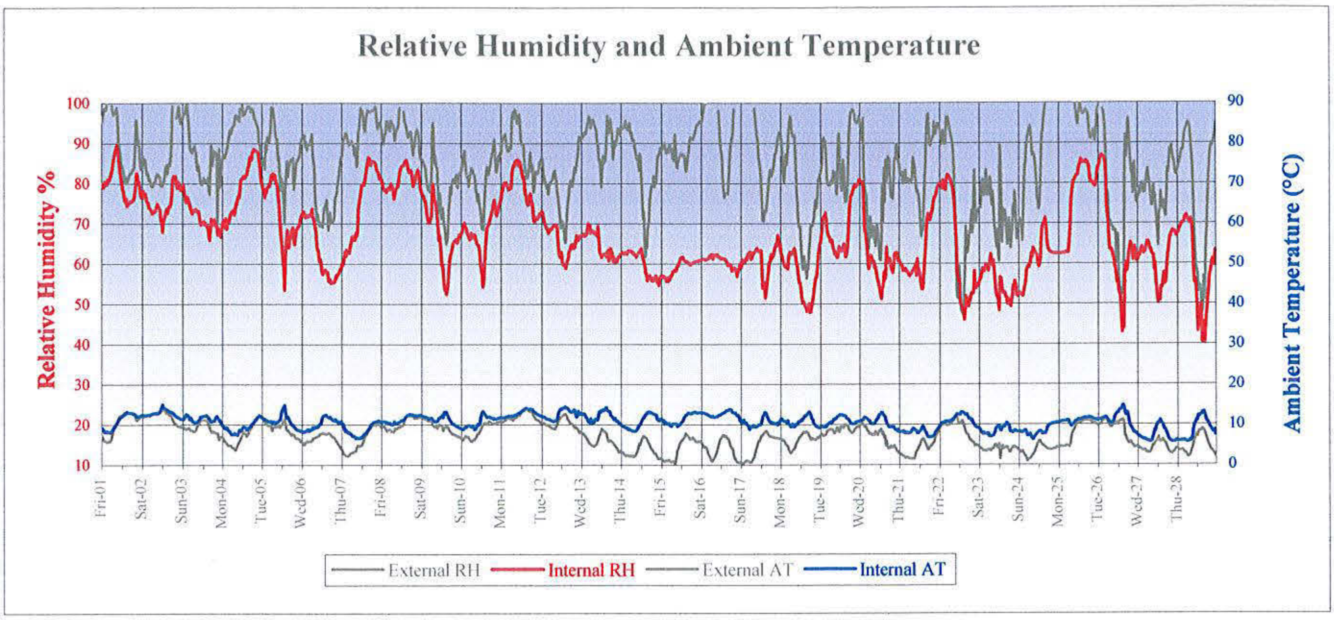
Probe 2: Bay 36 III upper side (shade)

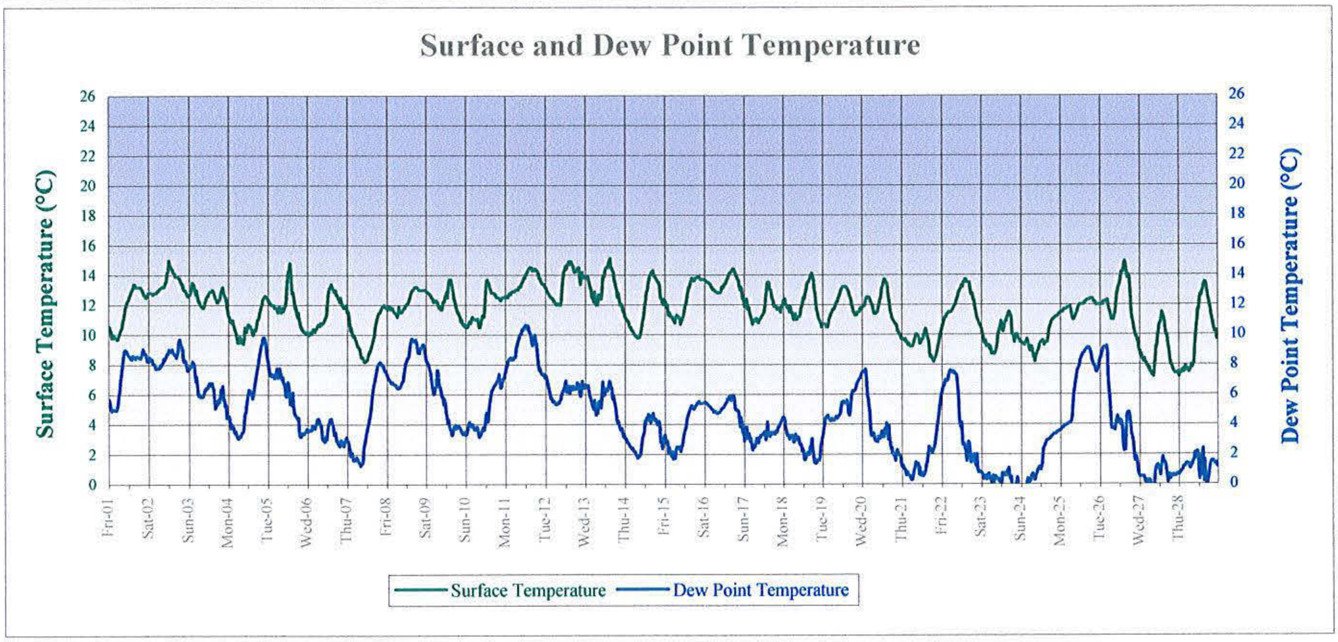


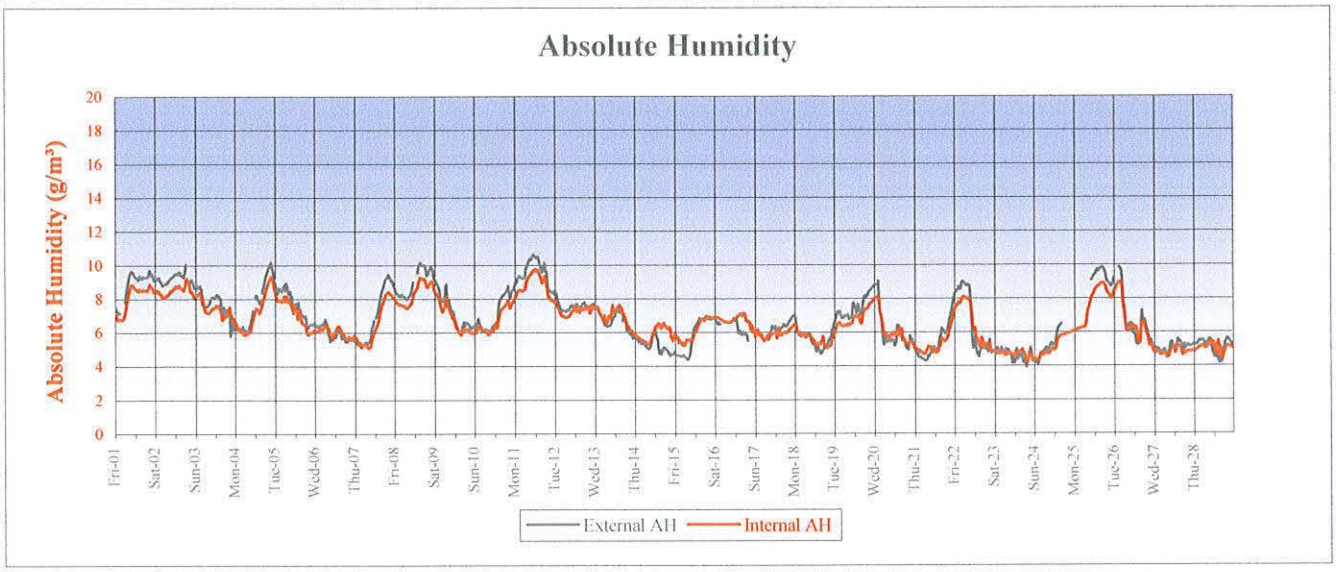




Probe 2: Bay 36 III upper side (shade)



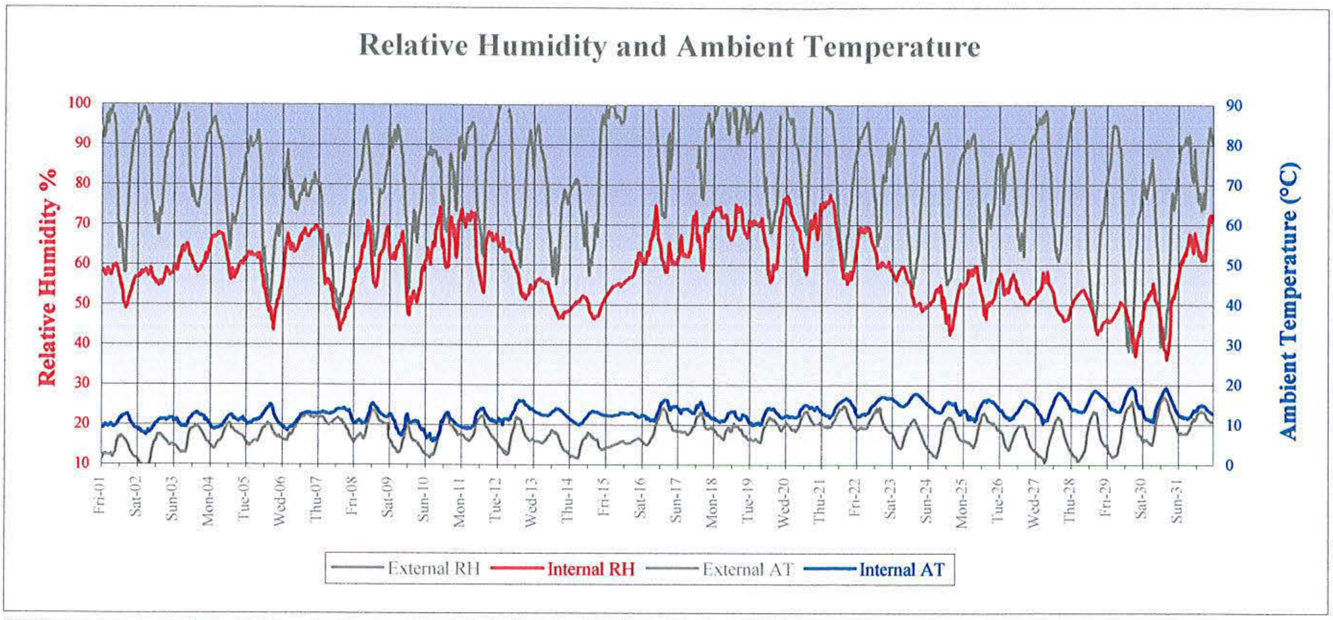


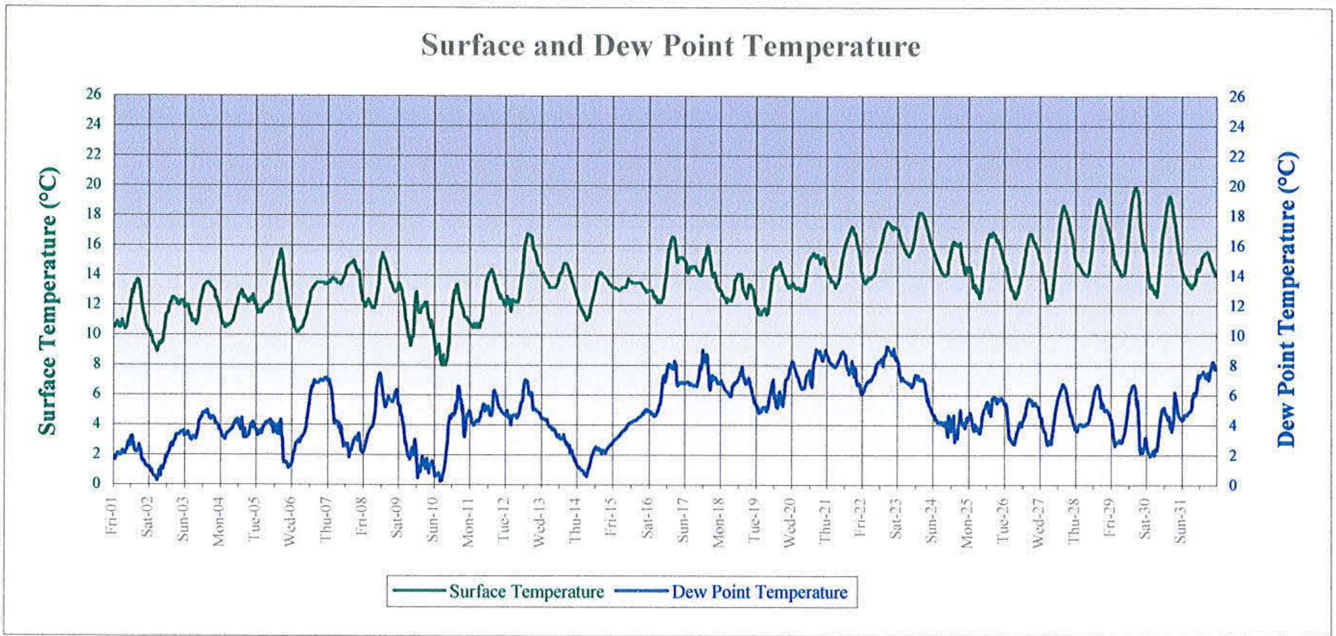


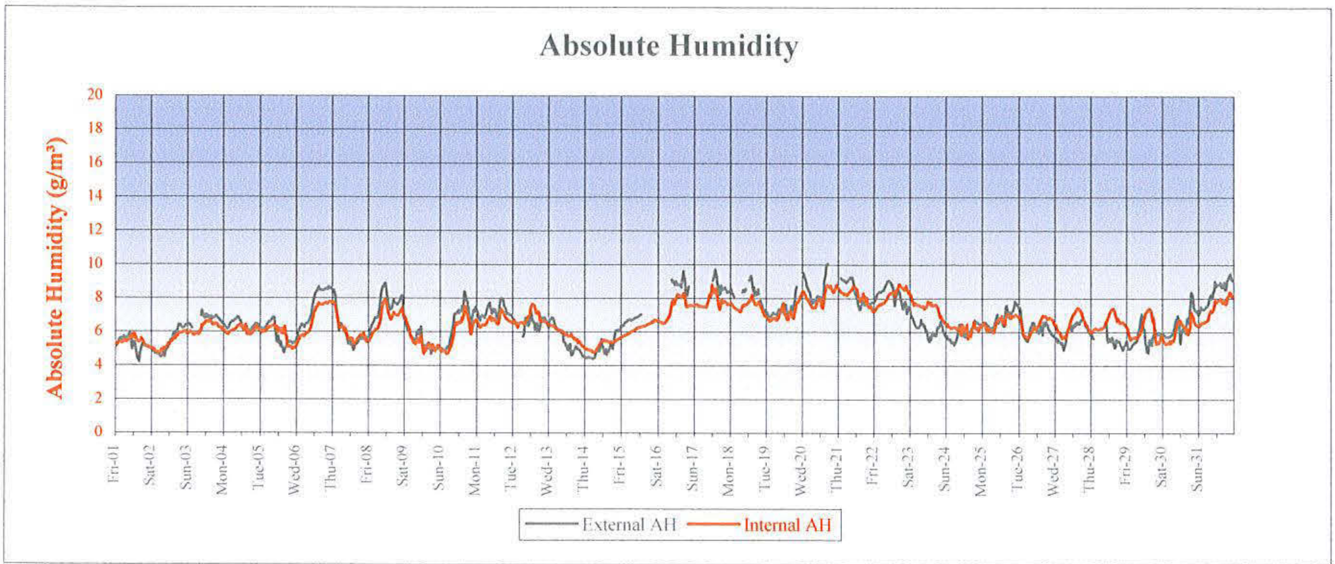
Peterborough Cathedral Nave Ceiling

March 2002

Probe 2: Bay 36 III upper side (shade)

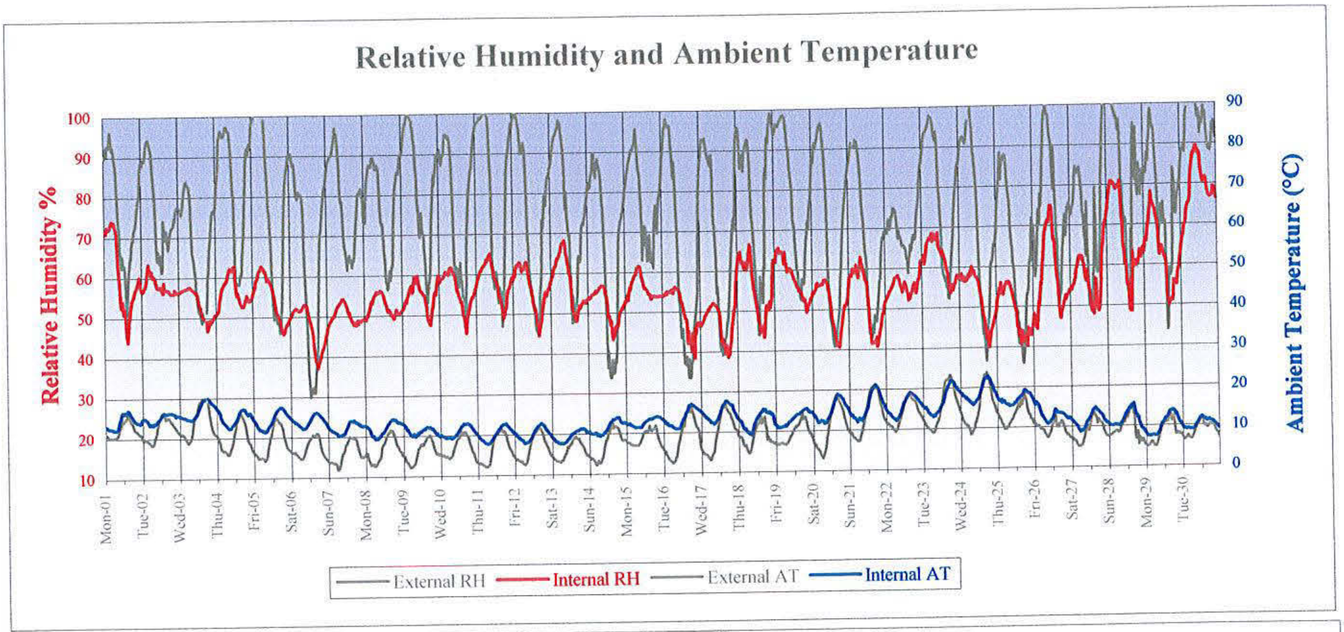


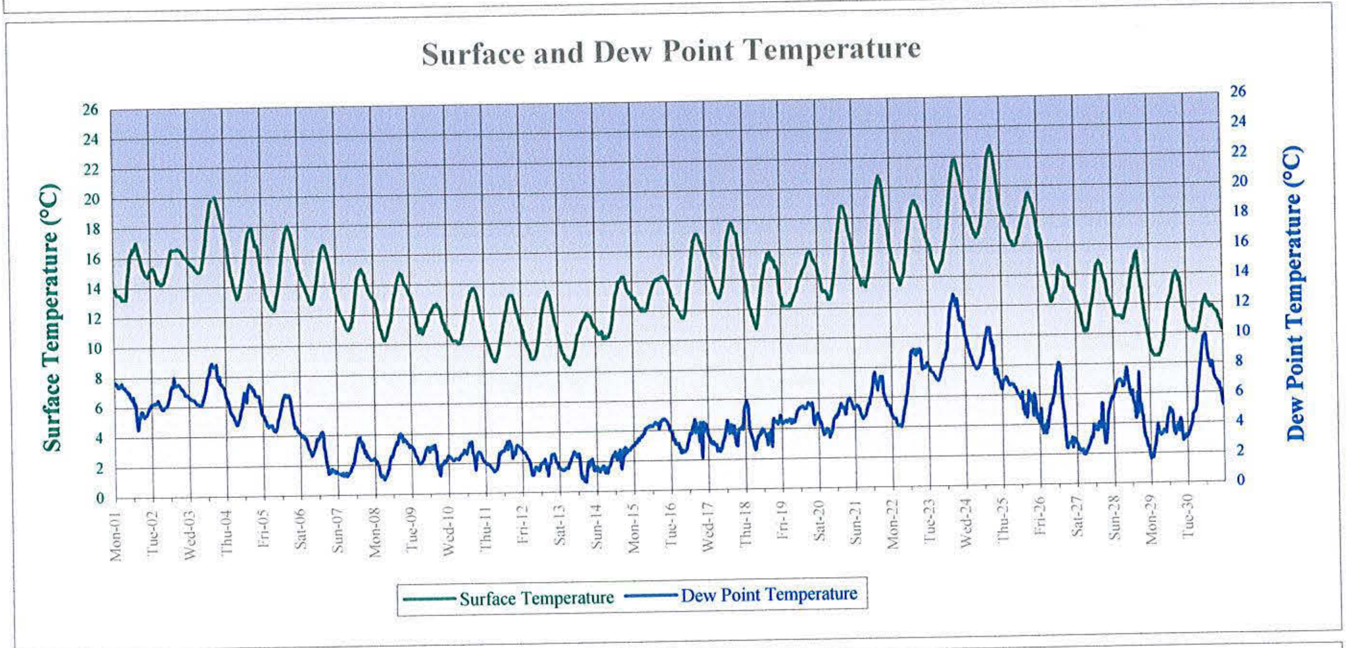


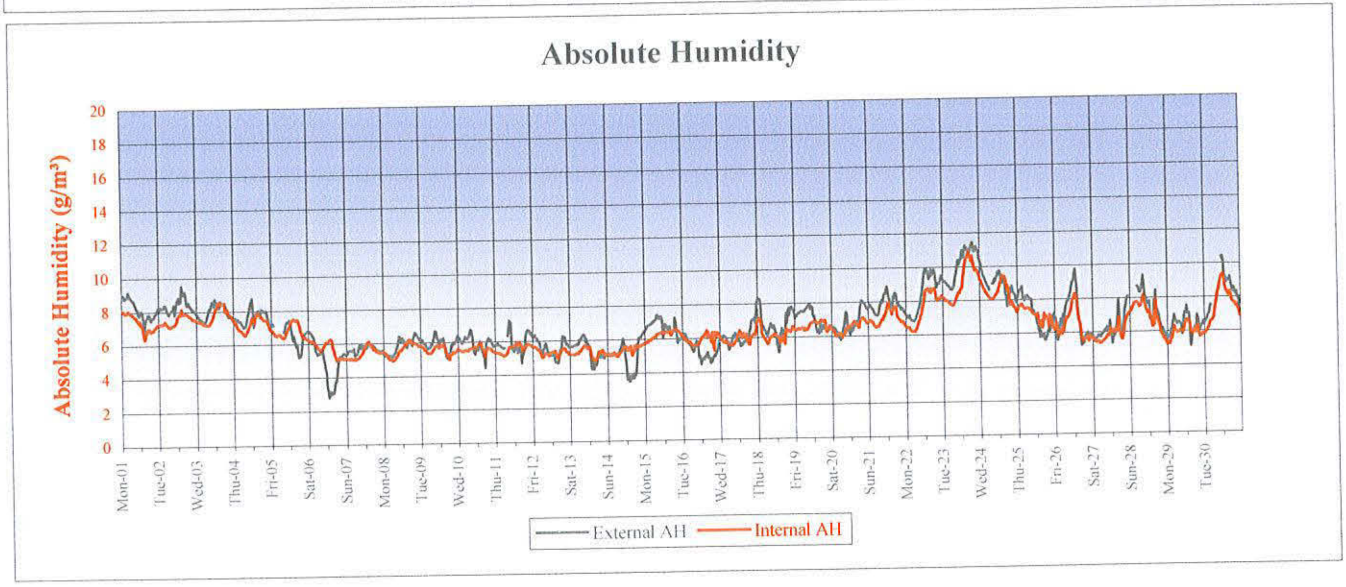


Peterborough Cathedral Nave Ceiling

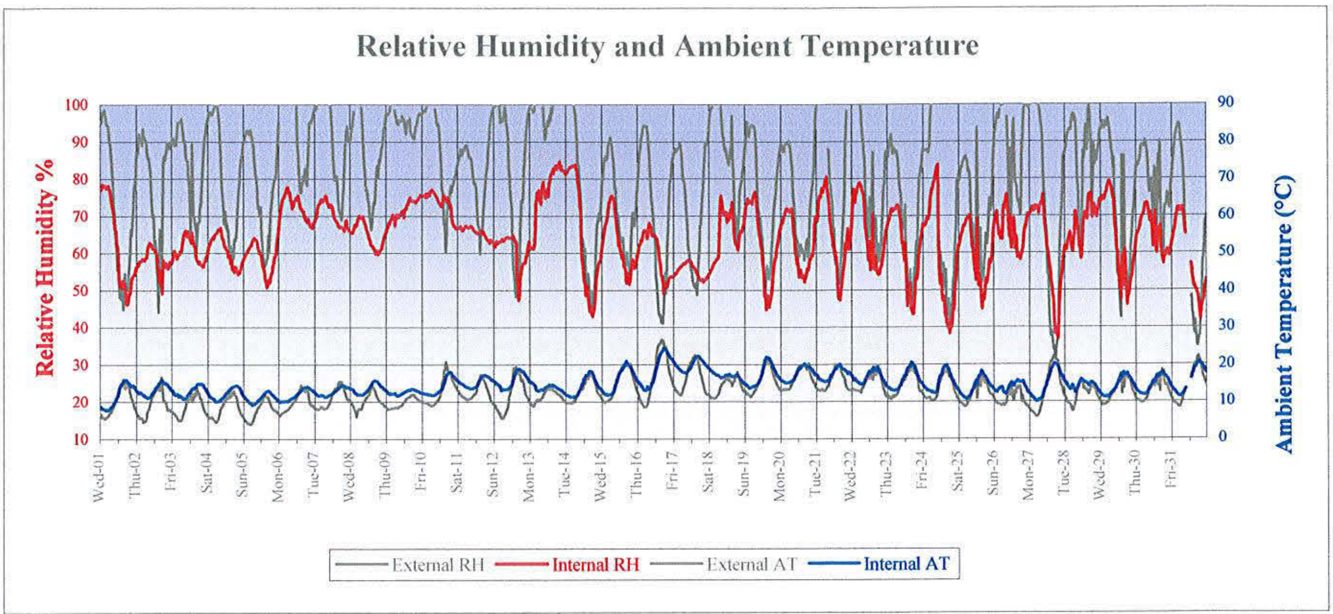
Probe 2: Bay 36 III upper side (shade)

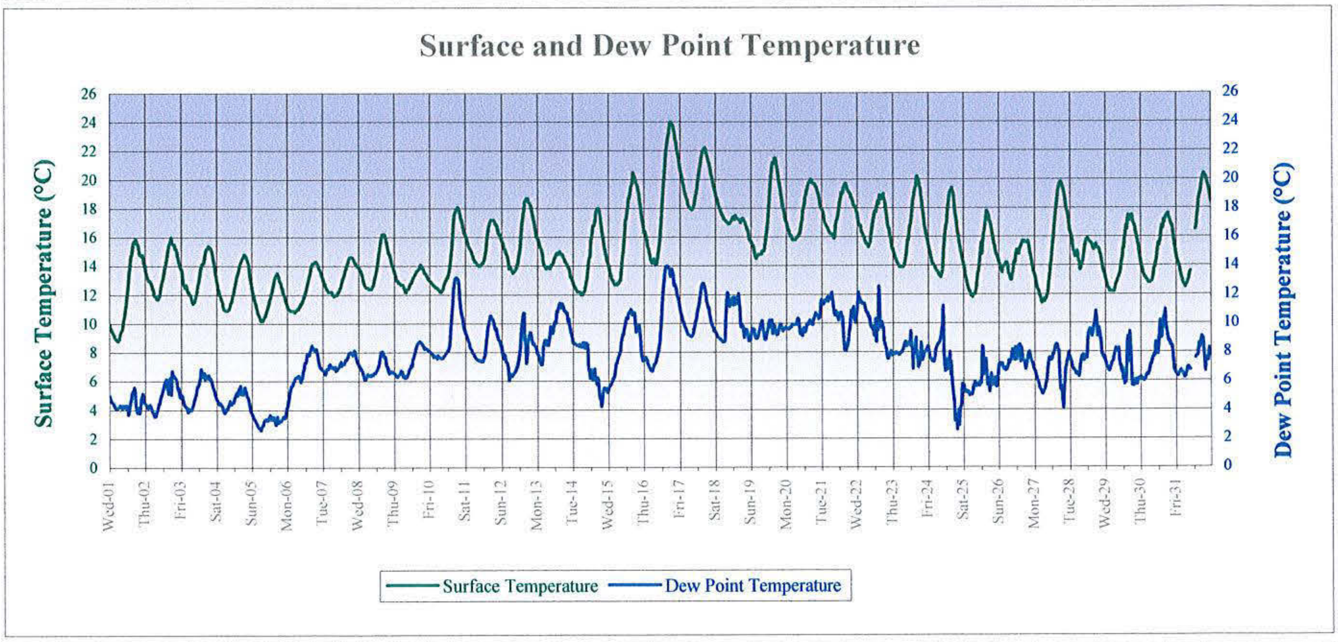


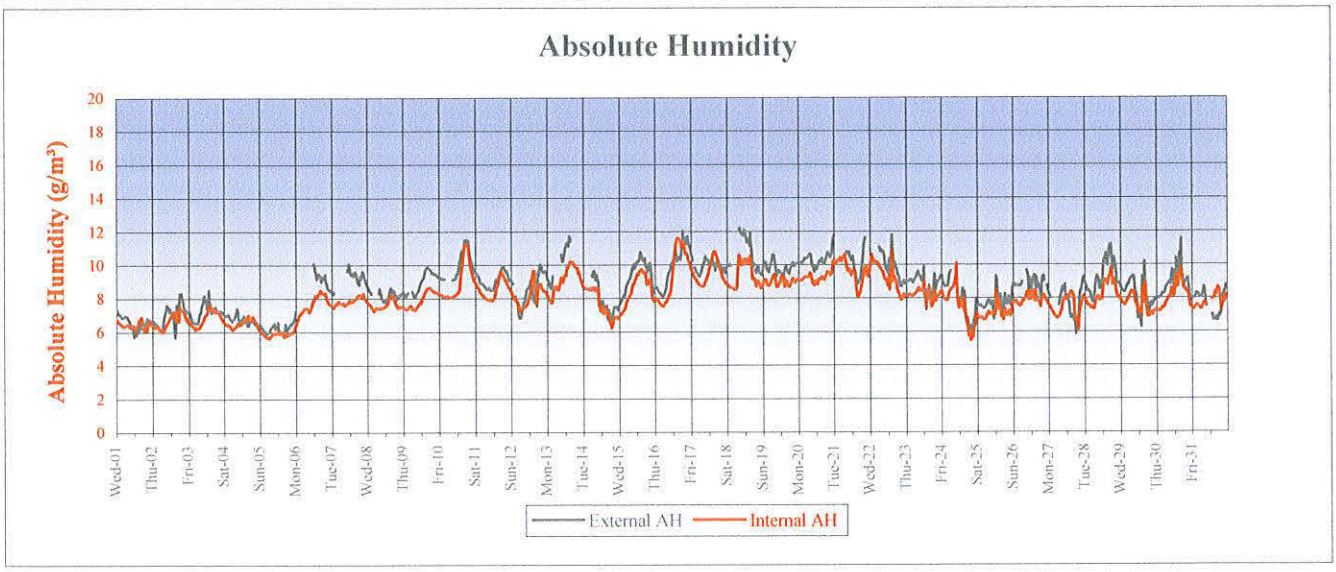




Probe 2: Bay 36 III upper side (shade)



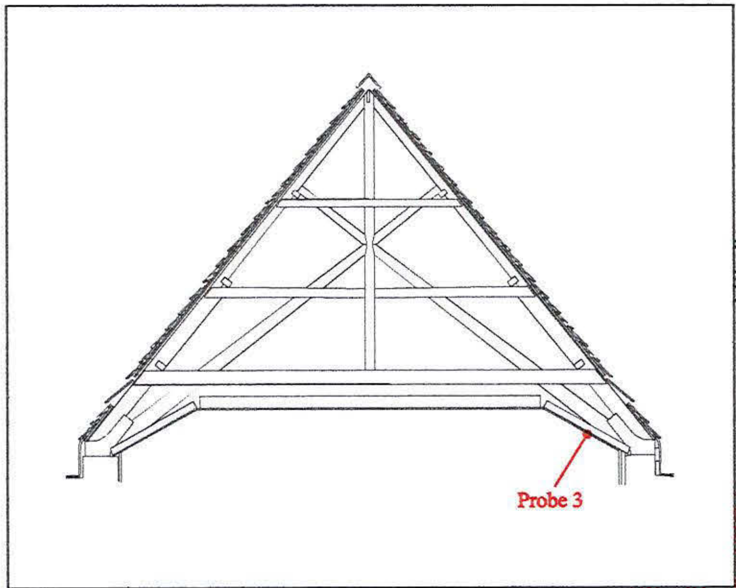


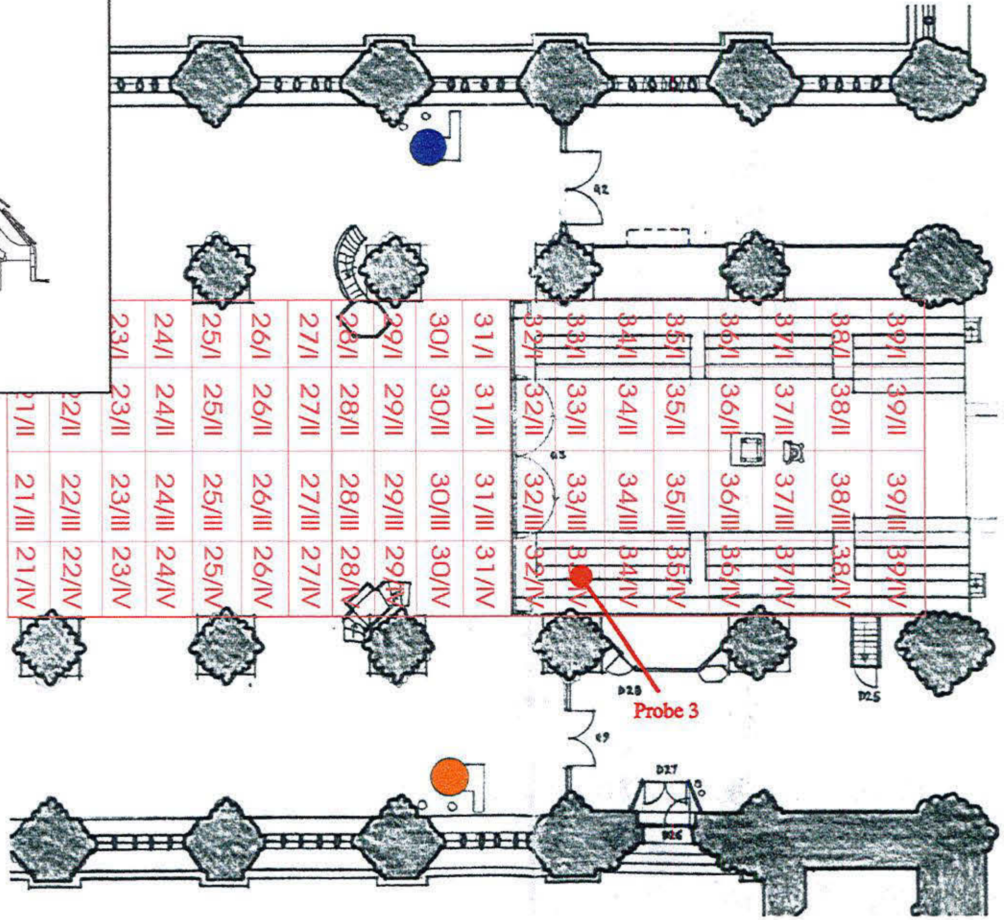


PROBE 3

BAY 33 IV LOWER SIDE (SUN)

Diagram 5



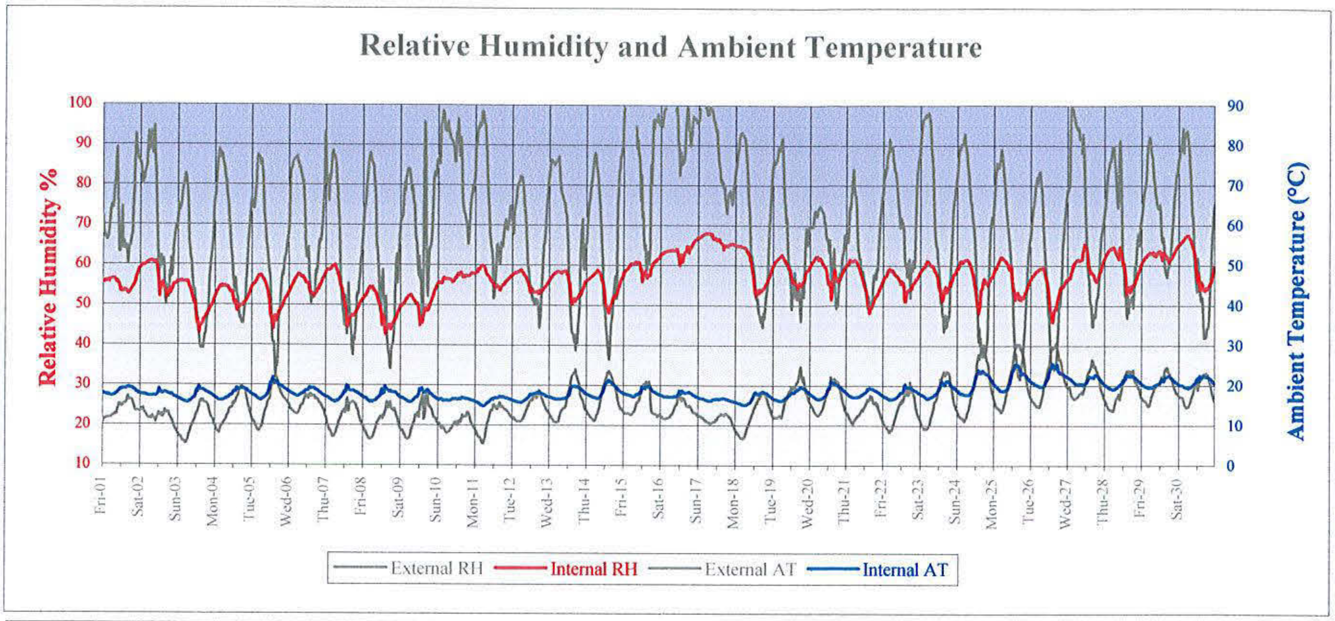


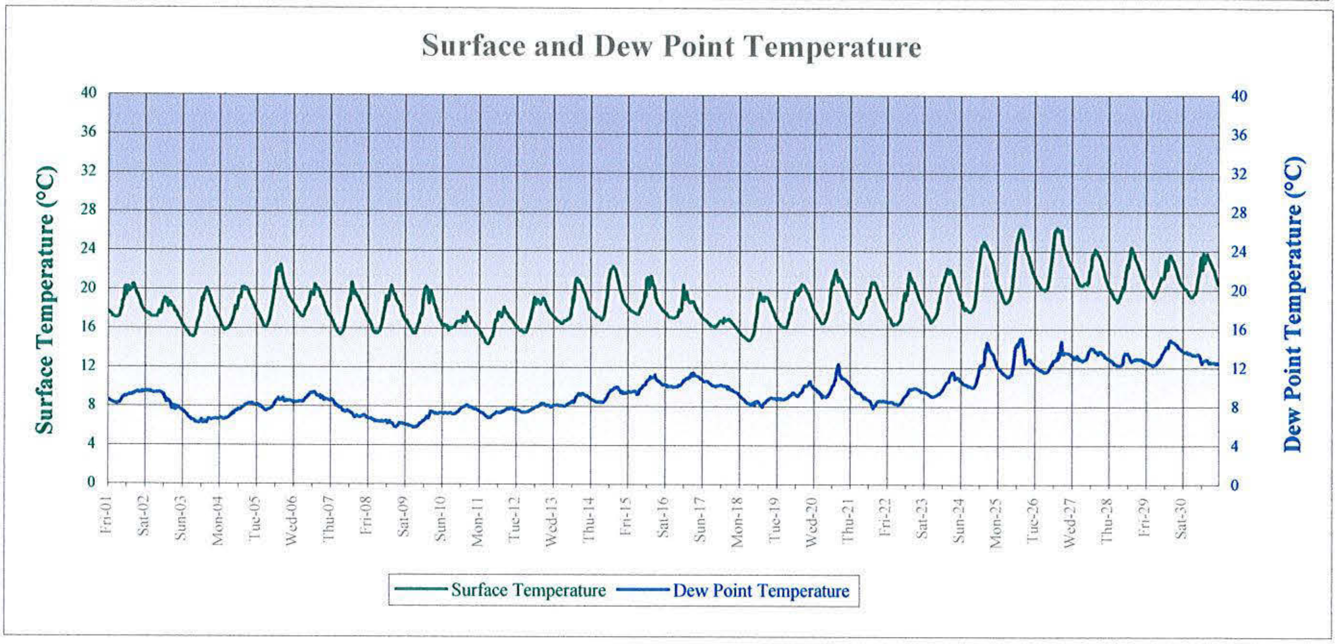
Site: Peterborough Cathedral	Type: Probe and stove locations	0m 5m 10m	Full use stove
Area: Plan (Base plan drawn by Julian Limentani)	Date: July 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

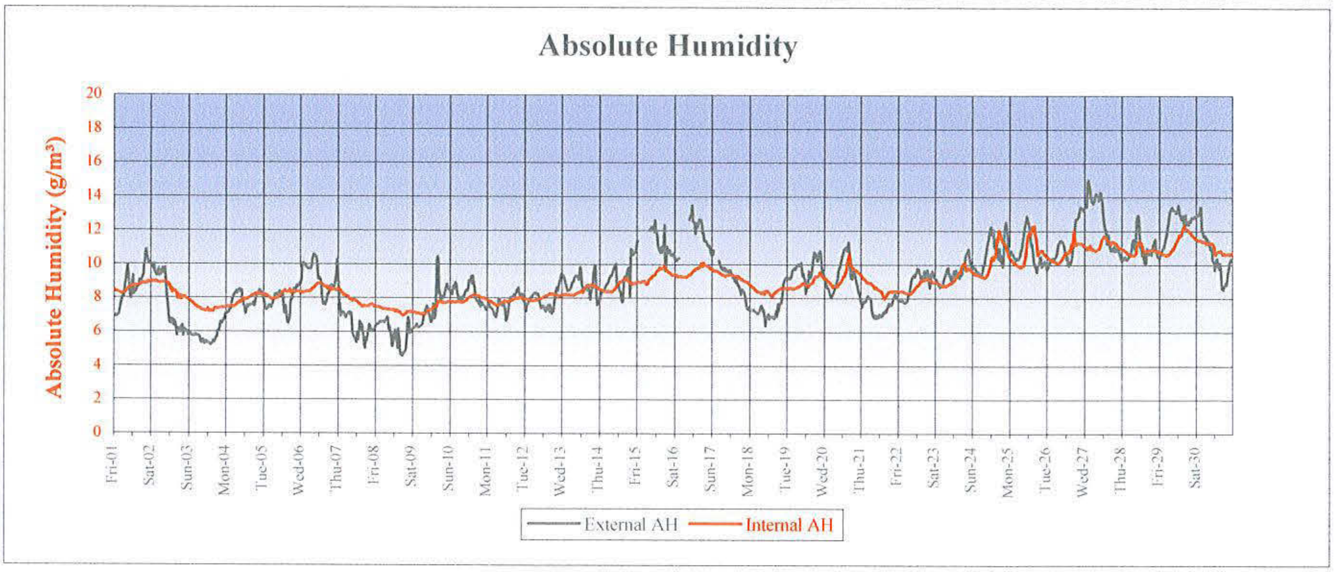
Peterborough Cathedral Nave Ceiling

June 2001

Probe 3: Bay 33 III lower side (sun)

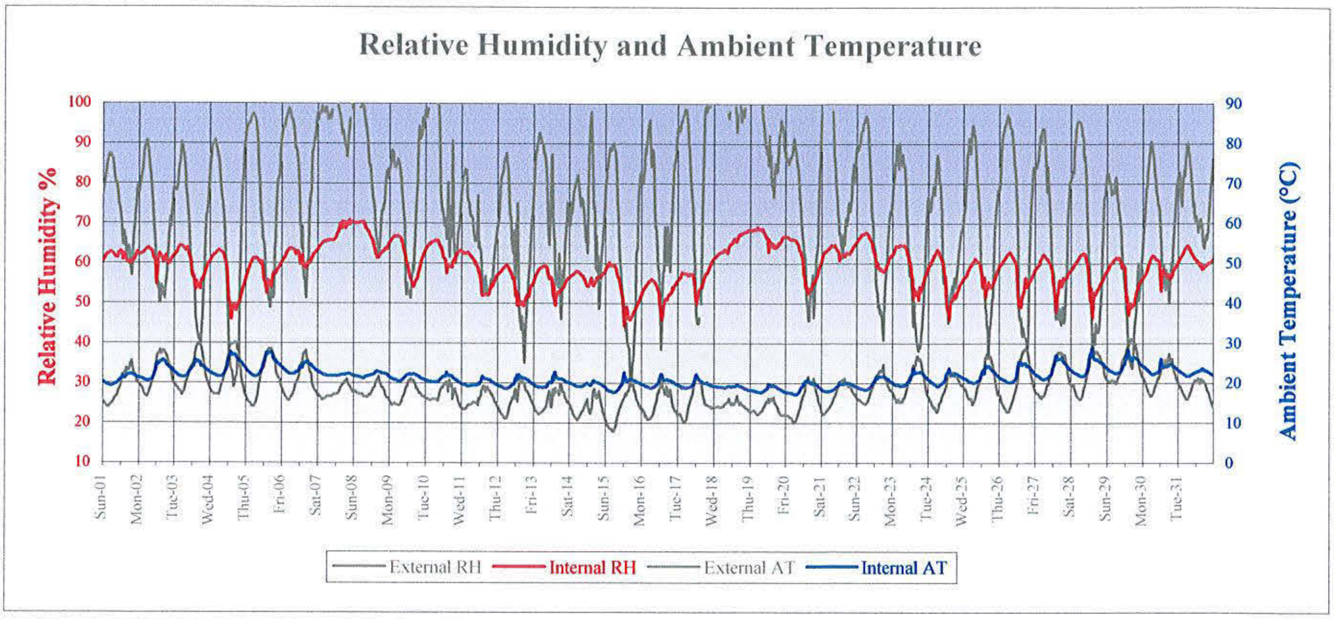


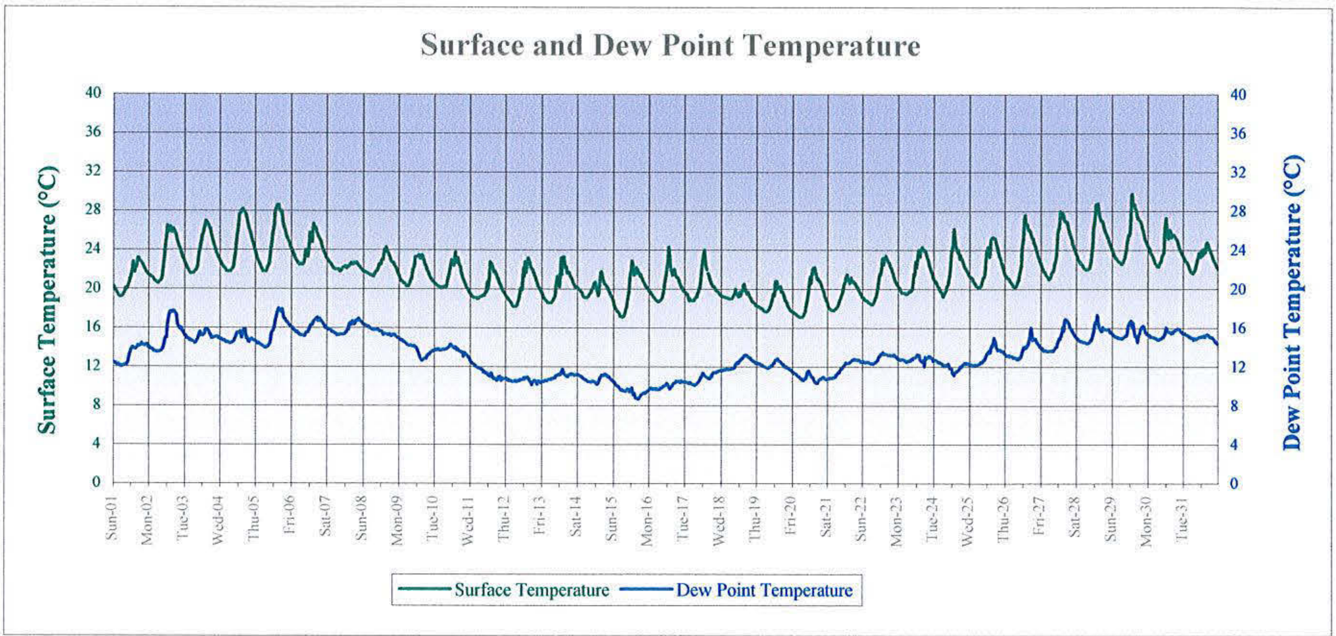


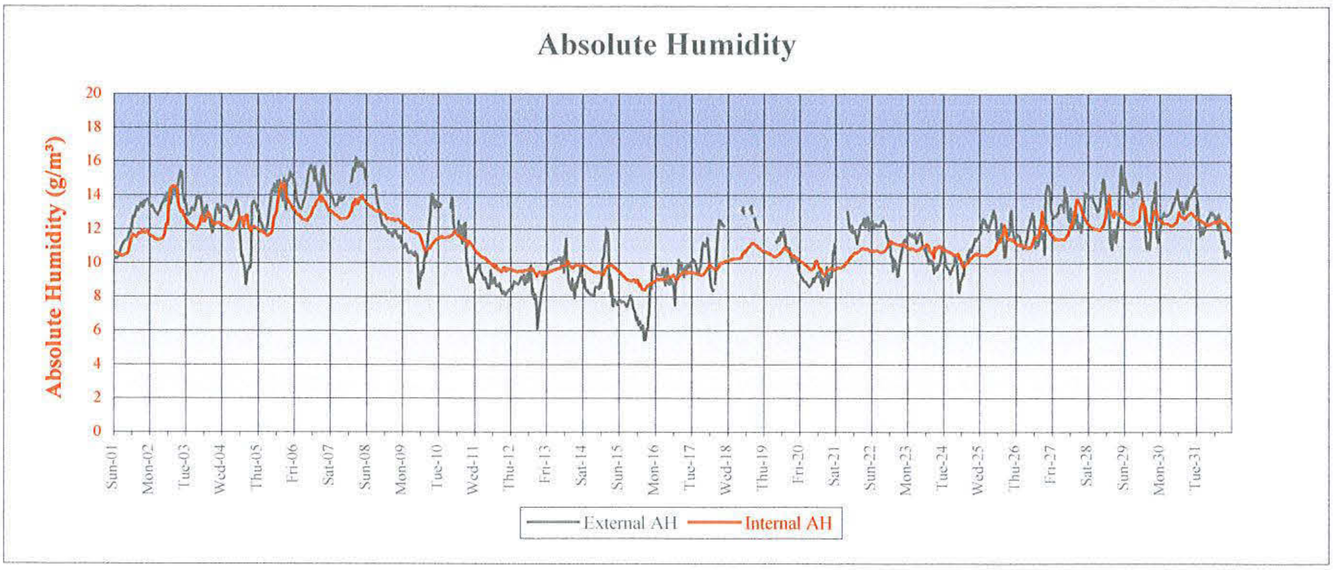


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)

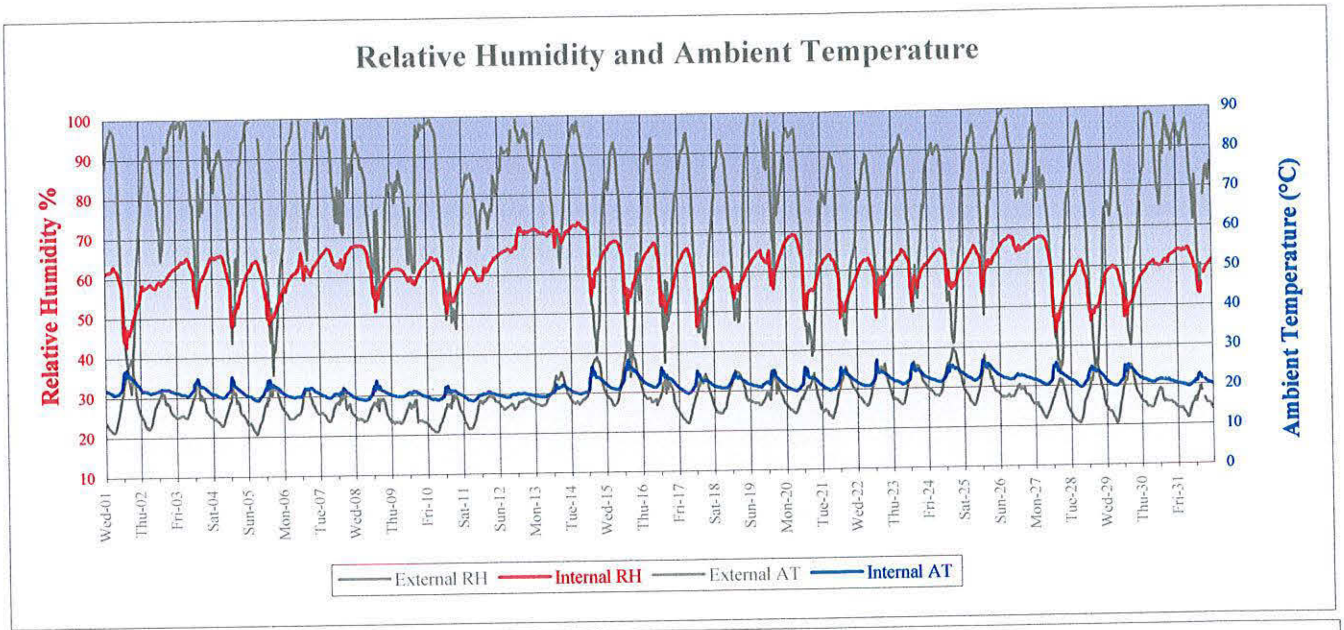


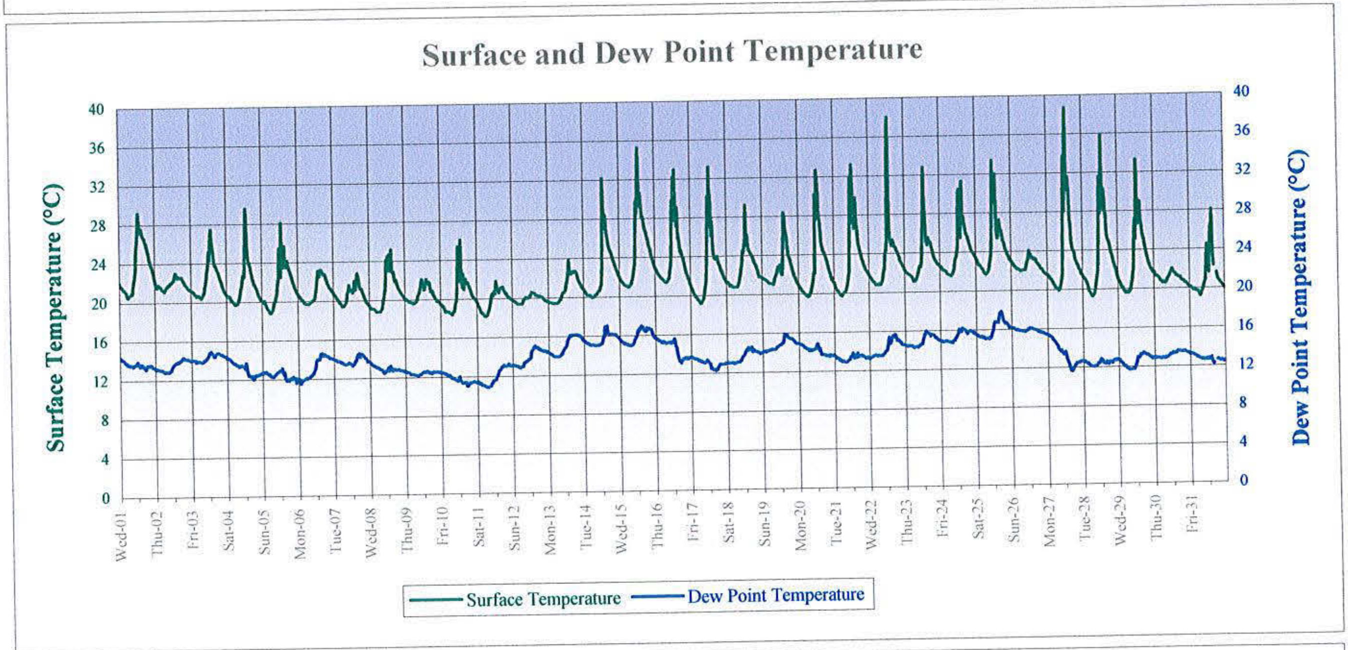


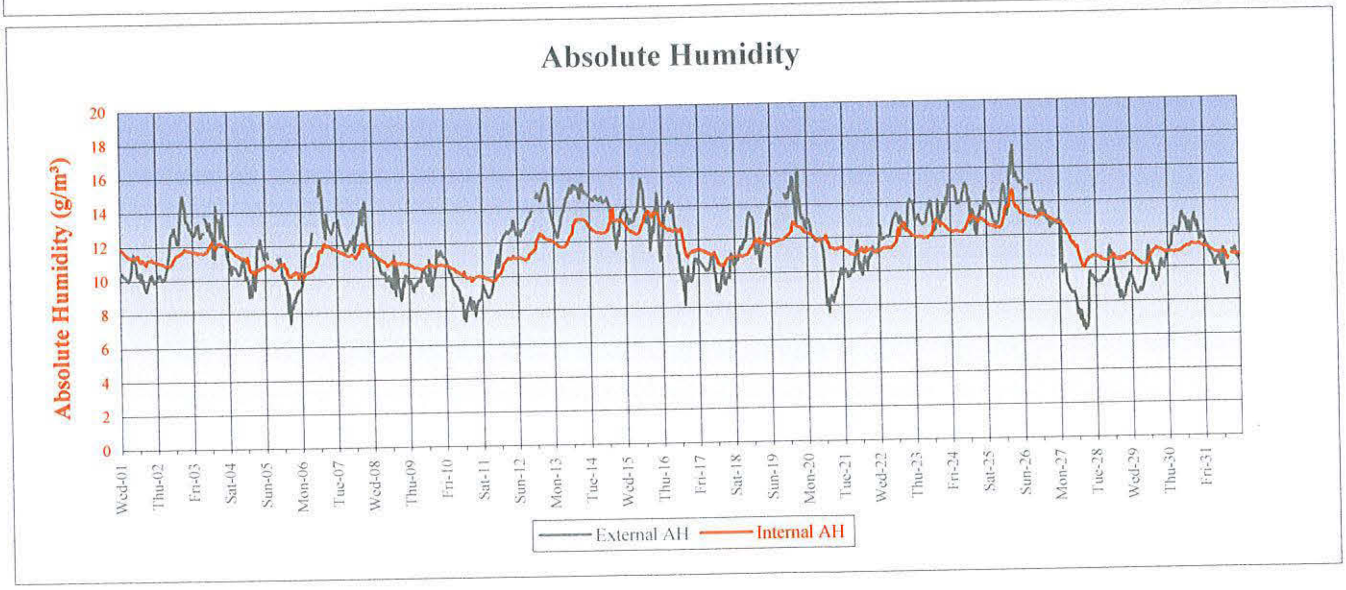


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)

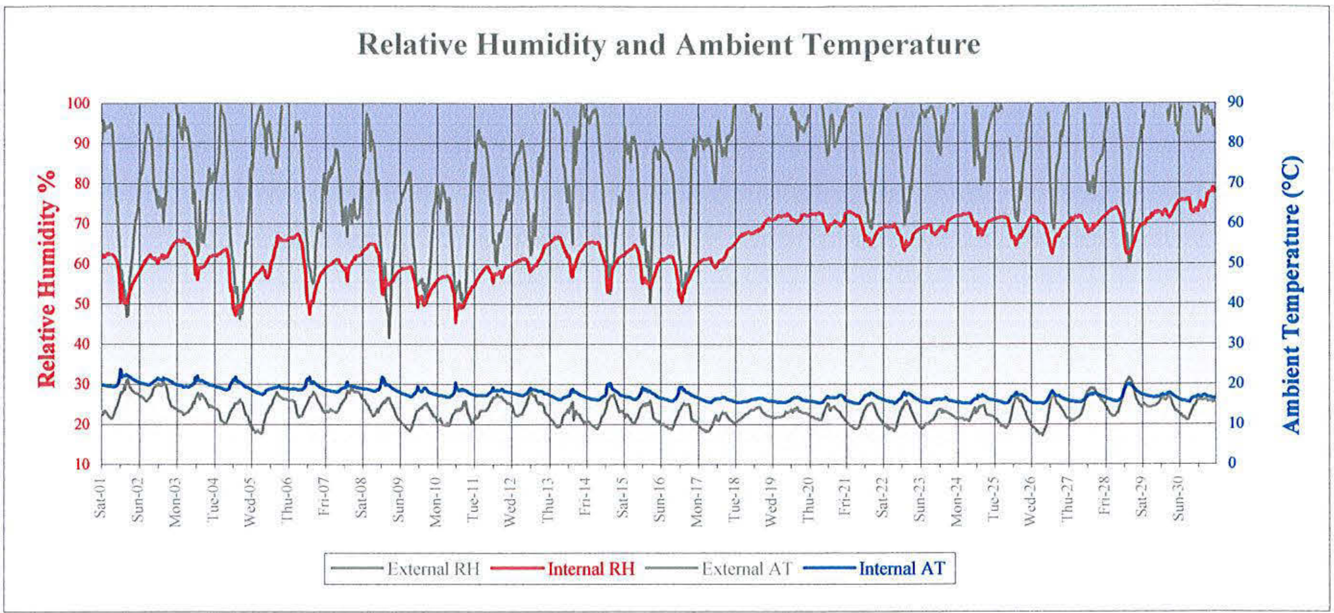


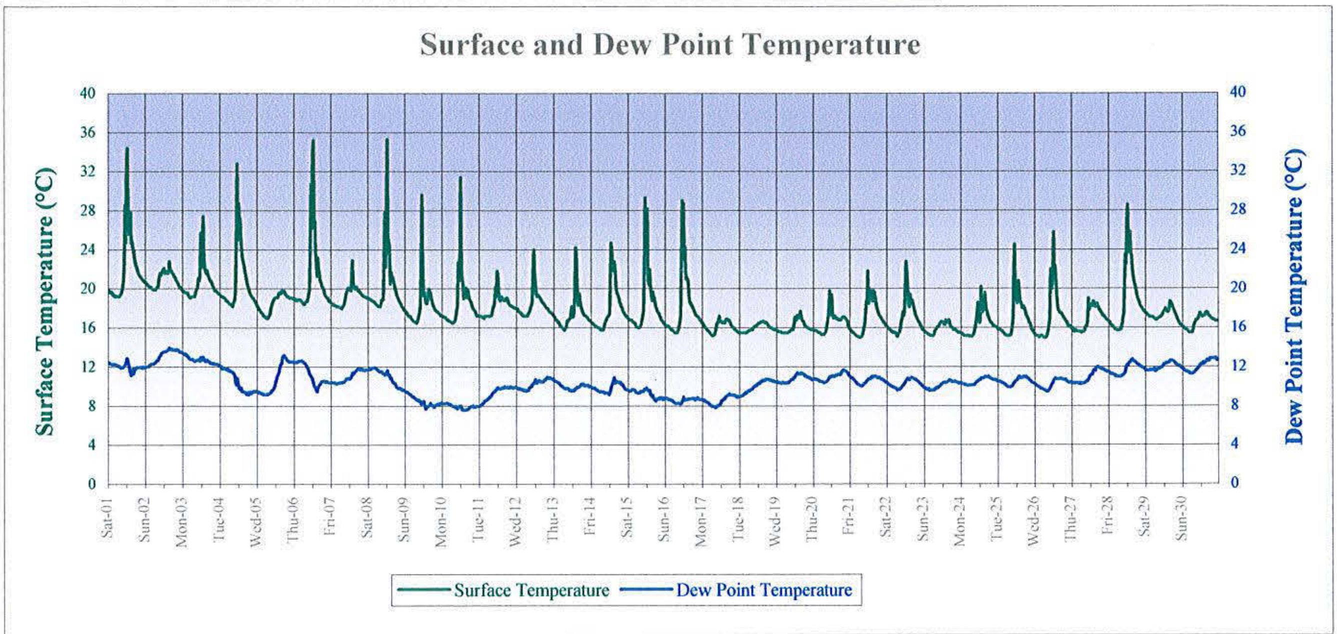


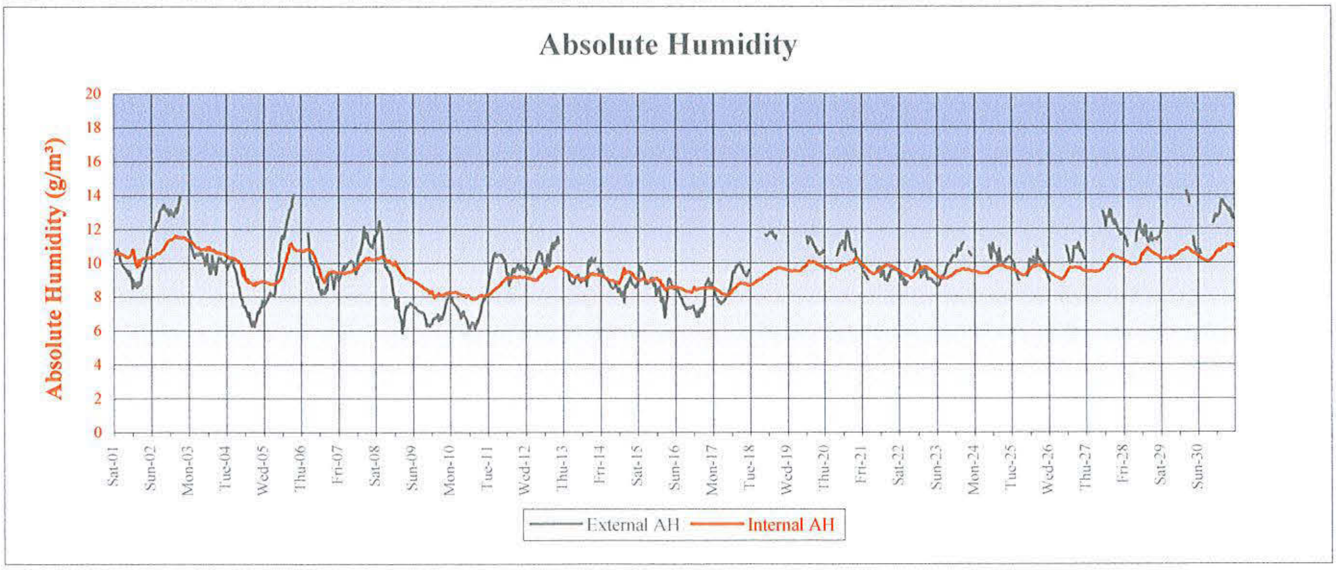


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)

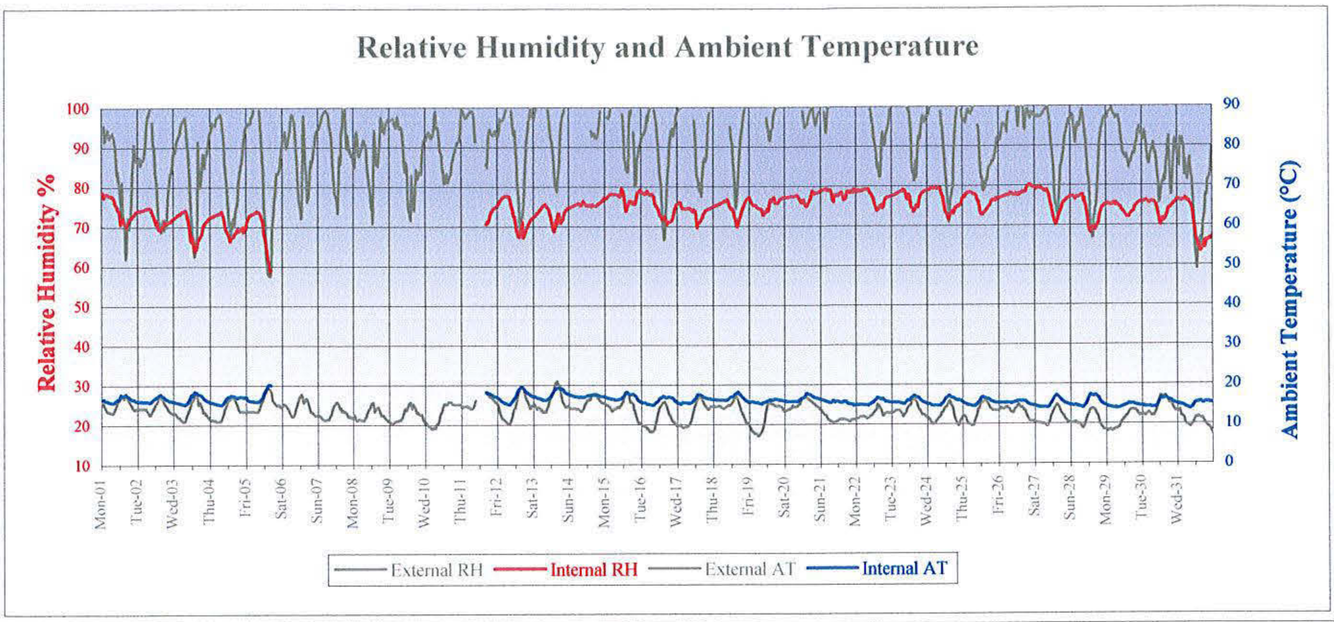


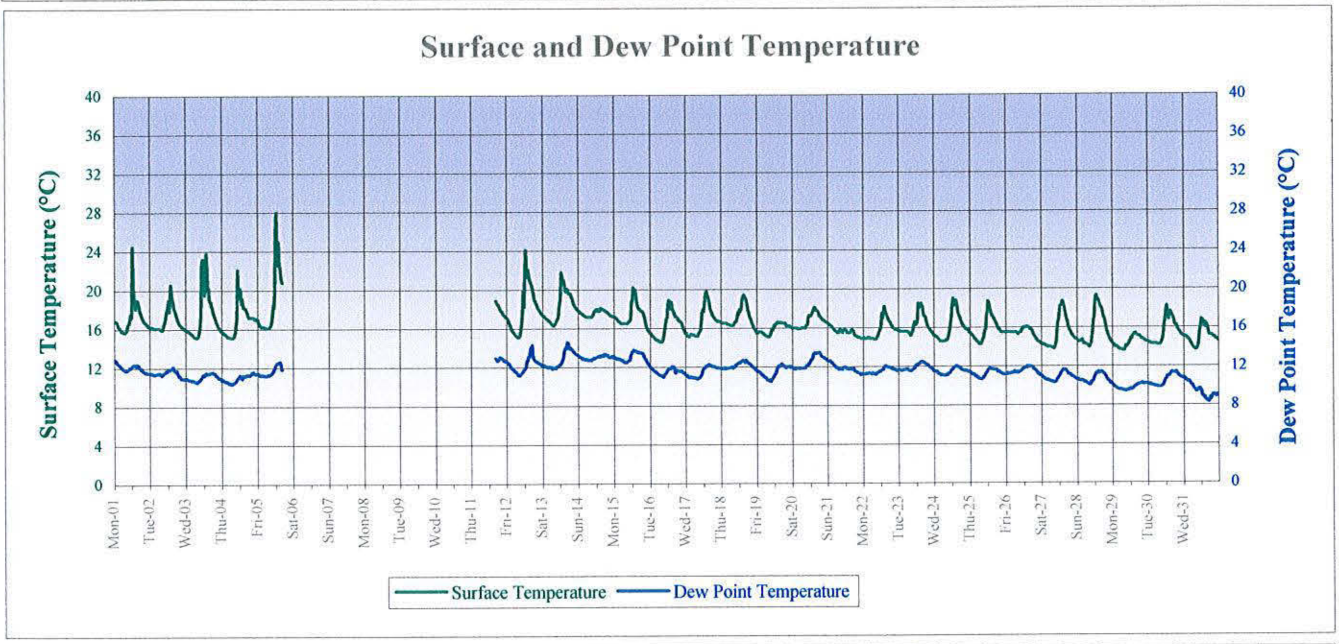


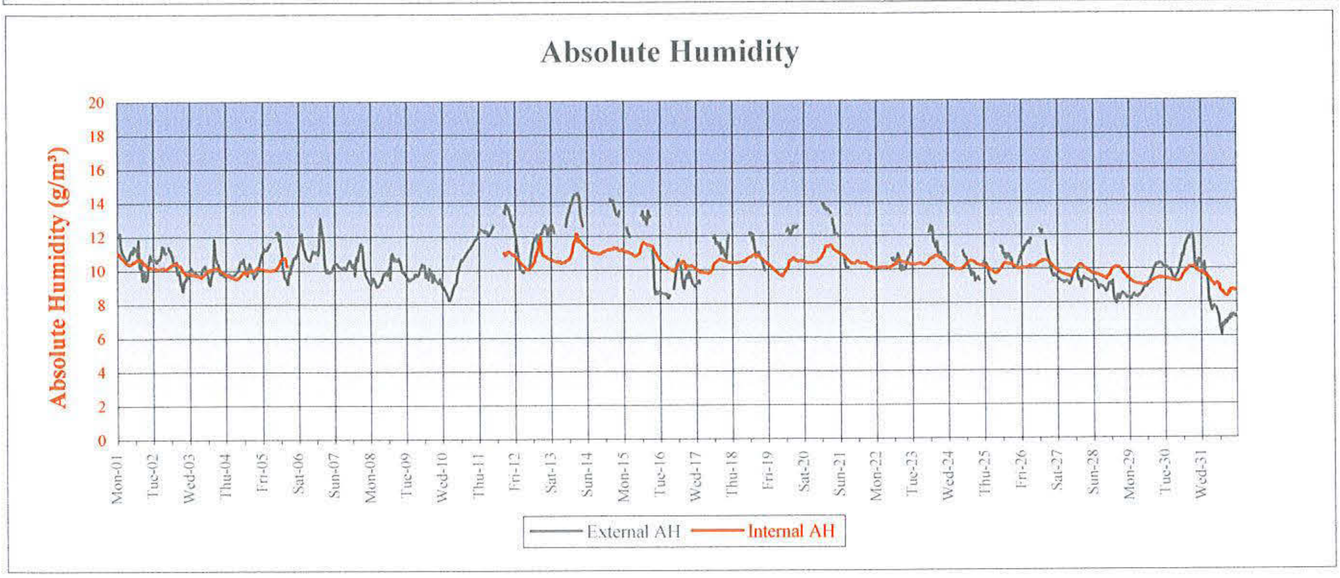


Peterborough Cathedral Nave Ceiling

Probe 3: Bay 33 III lower side (sun)



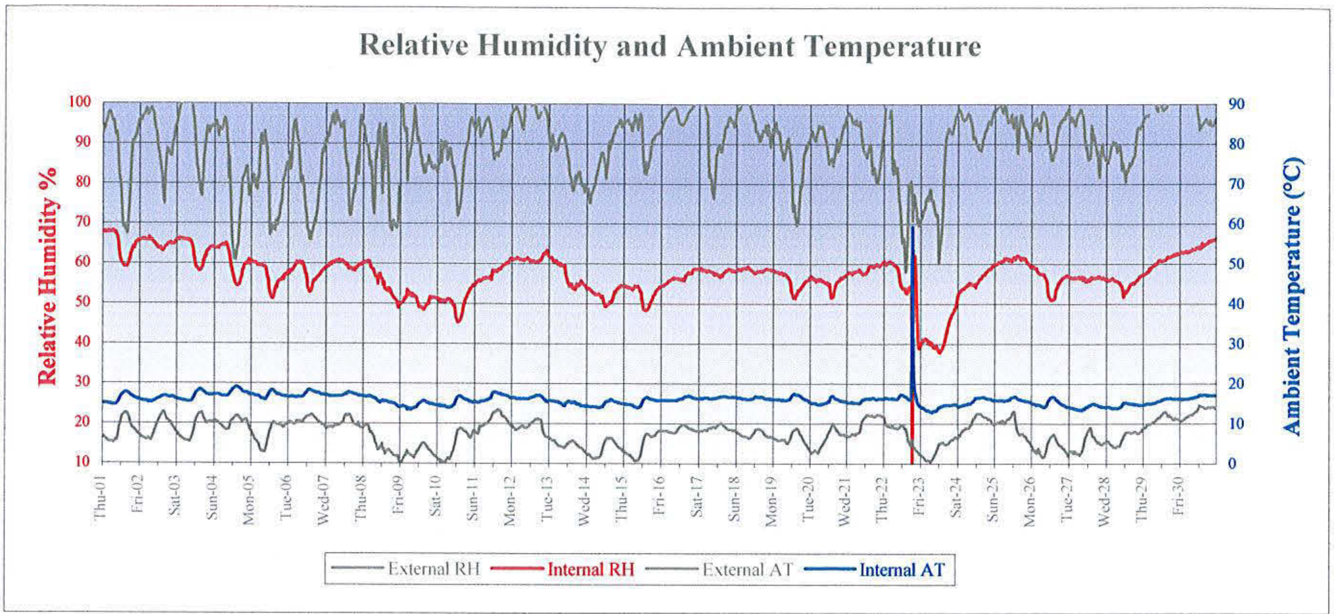


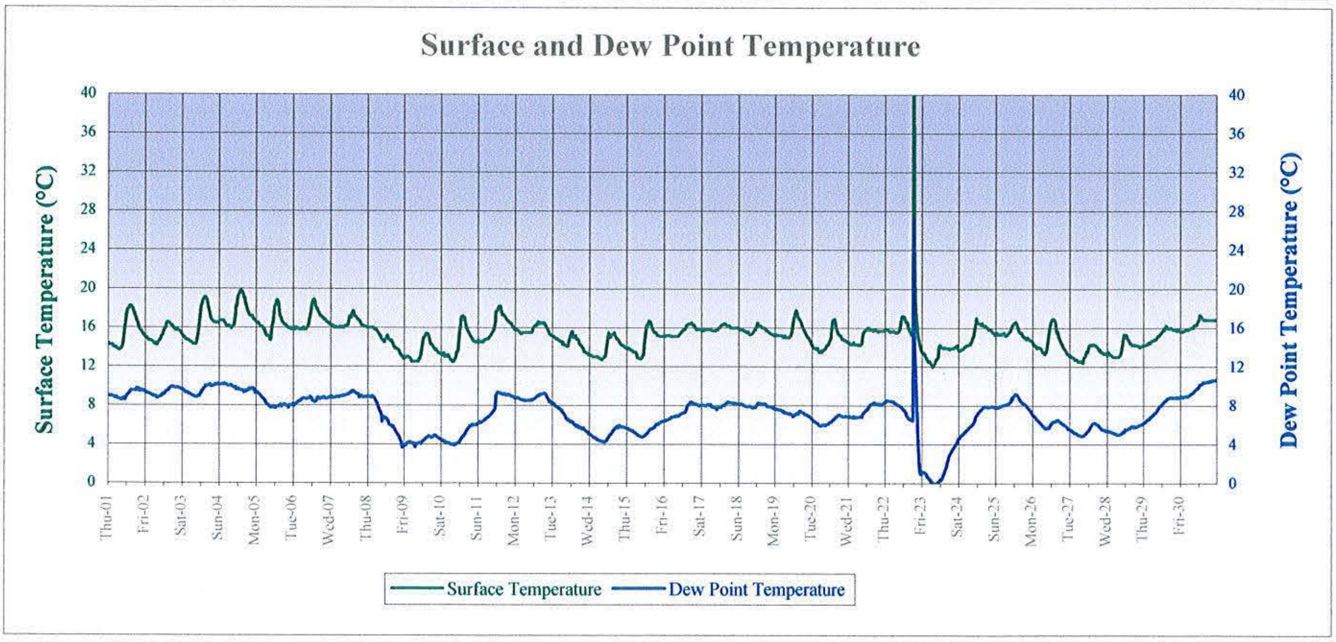


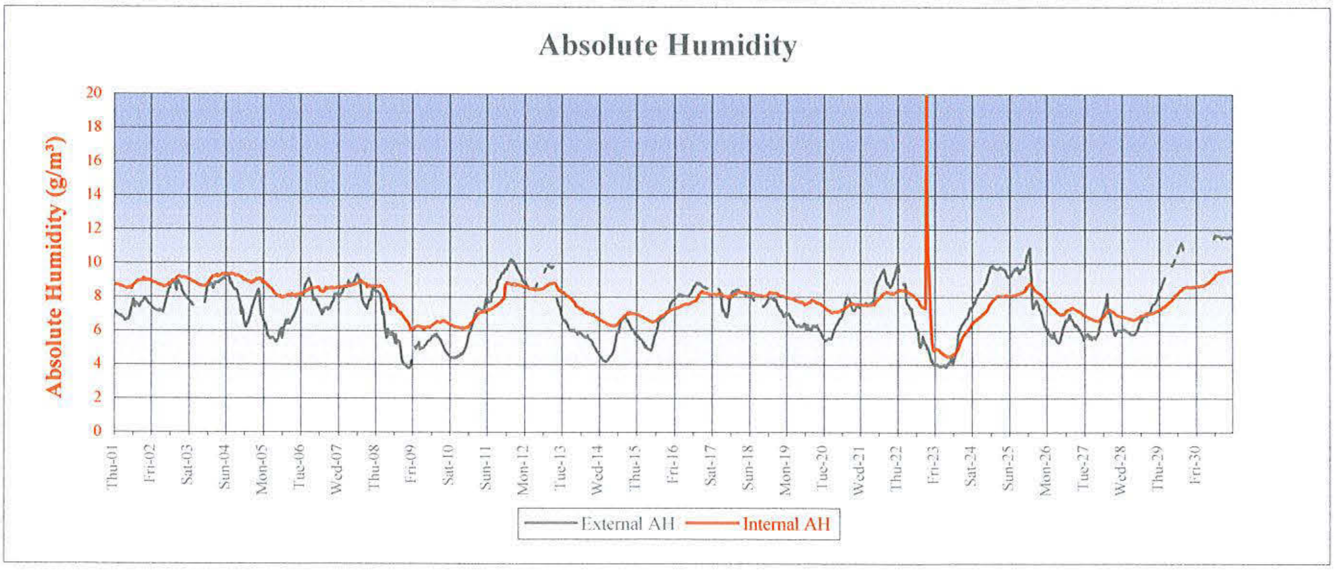
Peterborough Cathedral Nave Ceiling

November 2001

Probe 3: Bay 33 III lower side (sun)



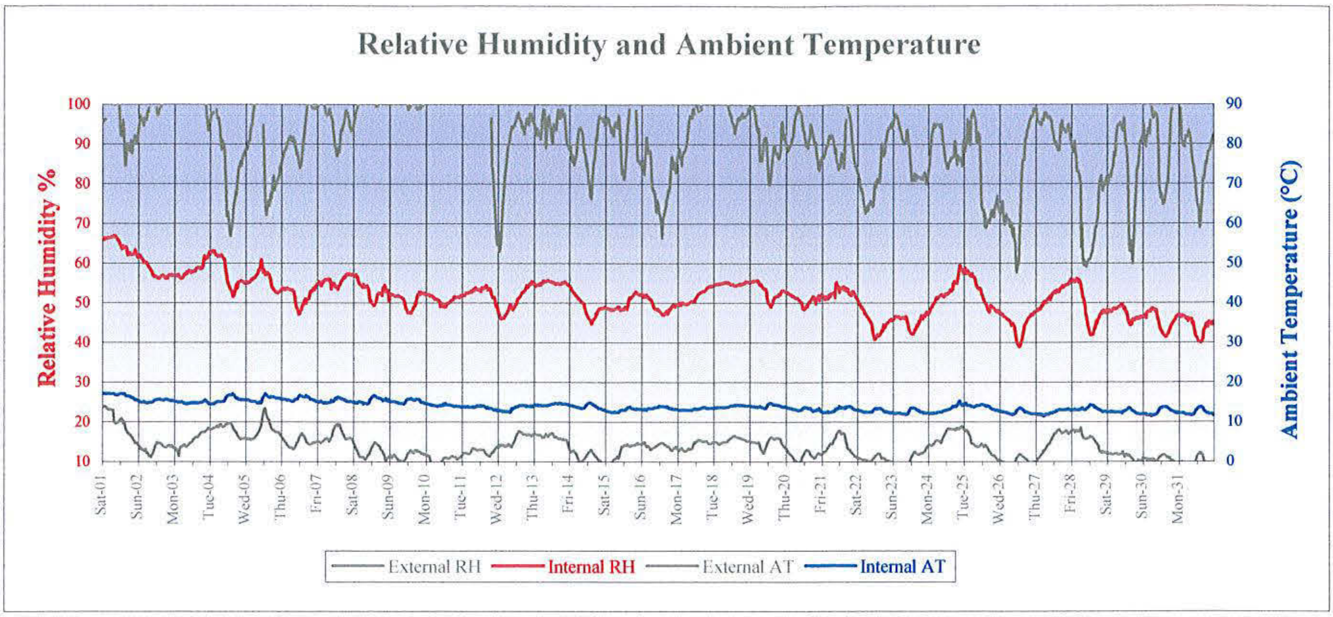


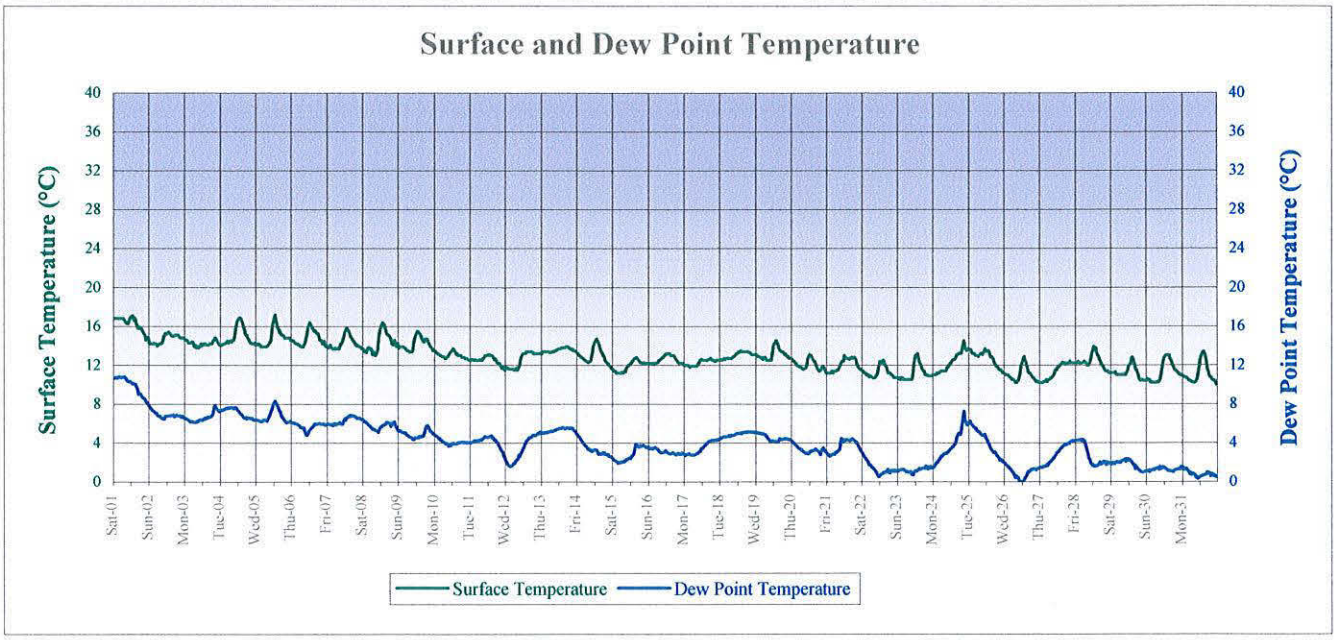


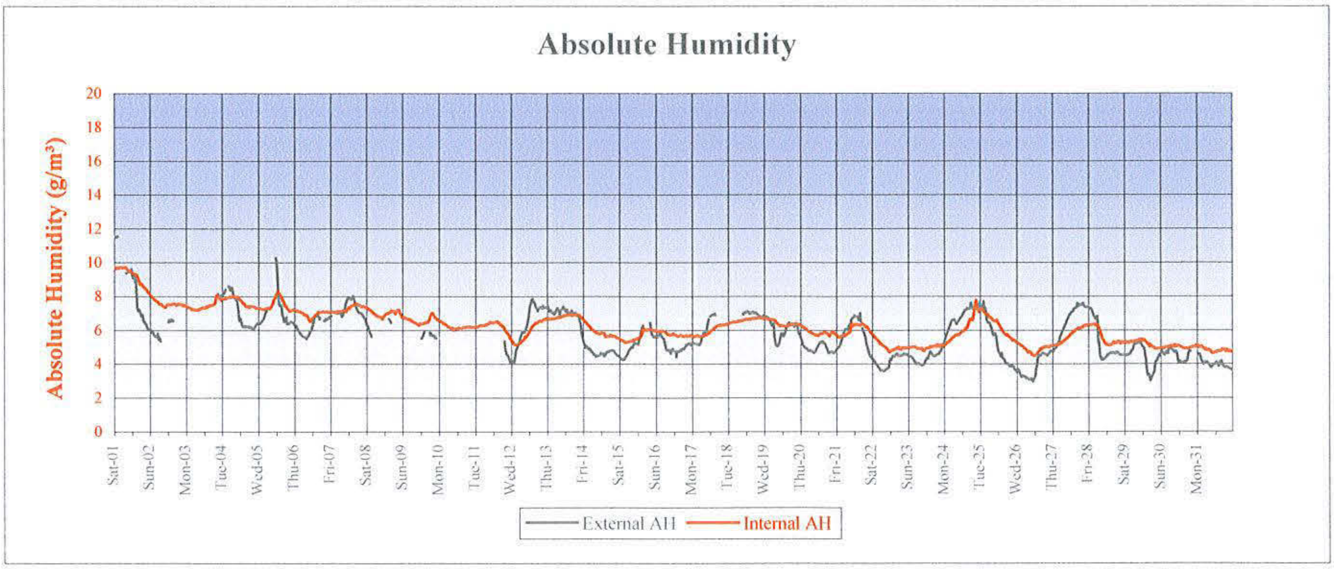
Peterborough Cathedral Nave Ceiling

December 2001

Probe 3: Bay 33 III lower side (sun)



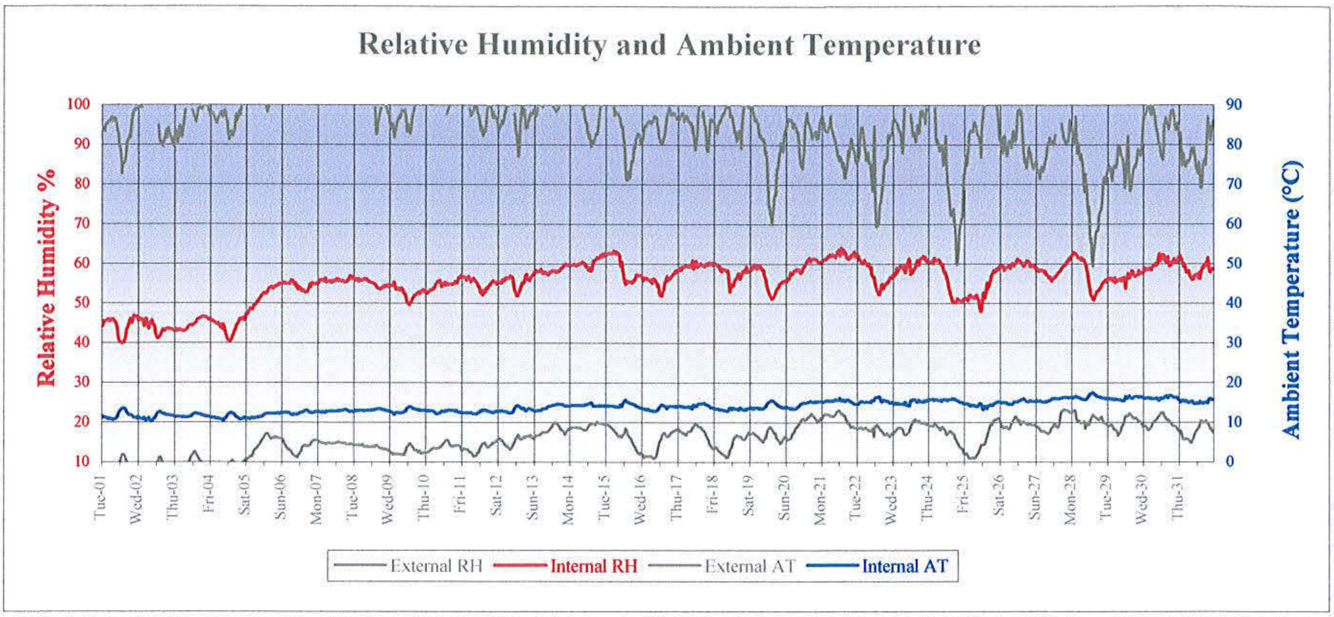


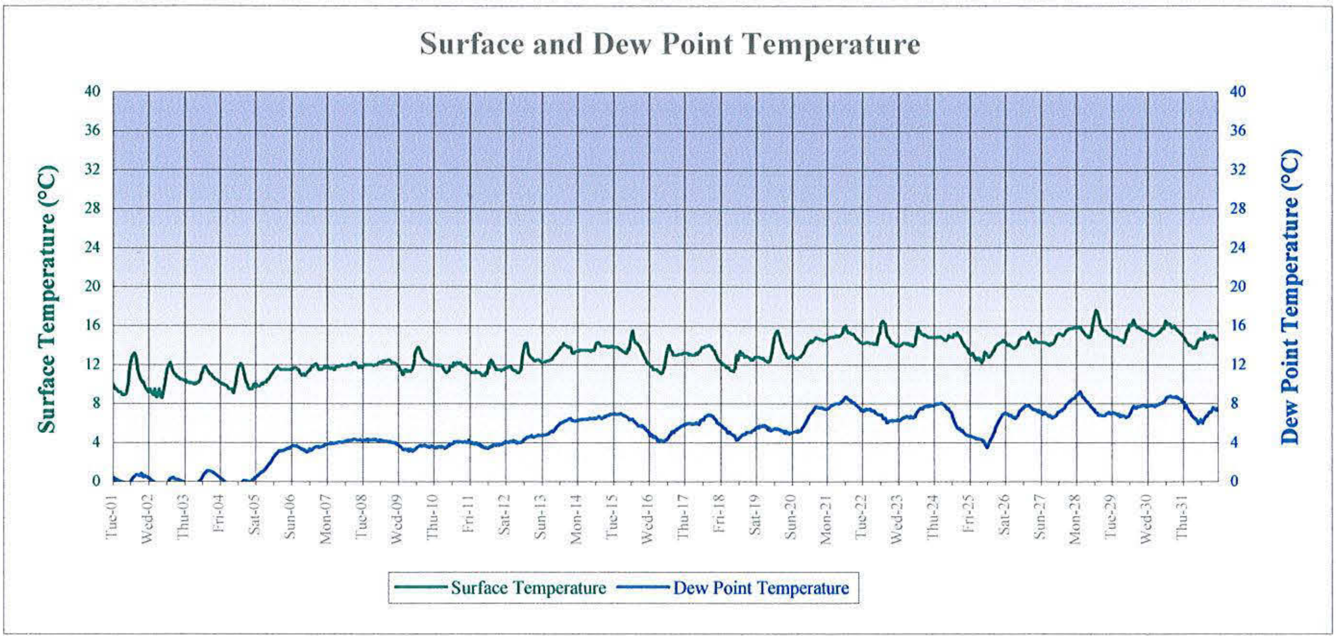


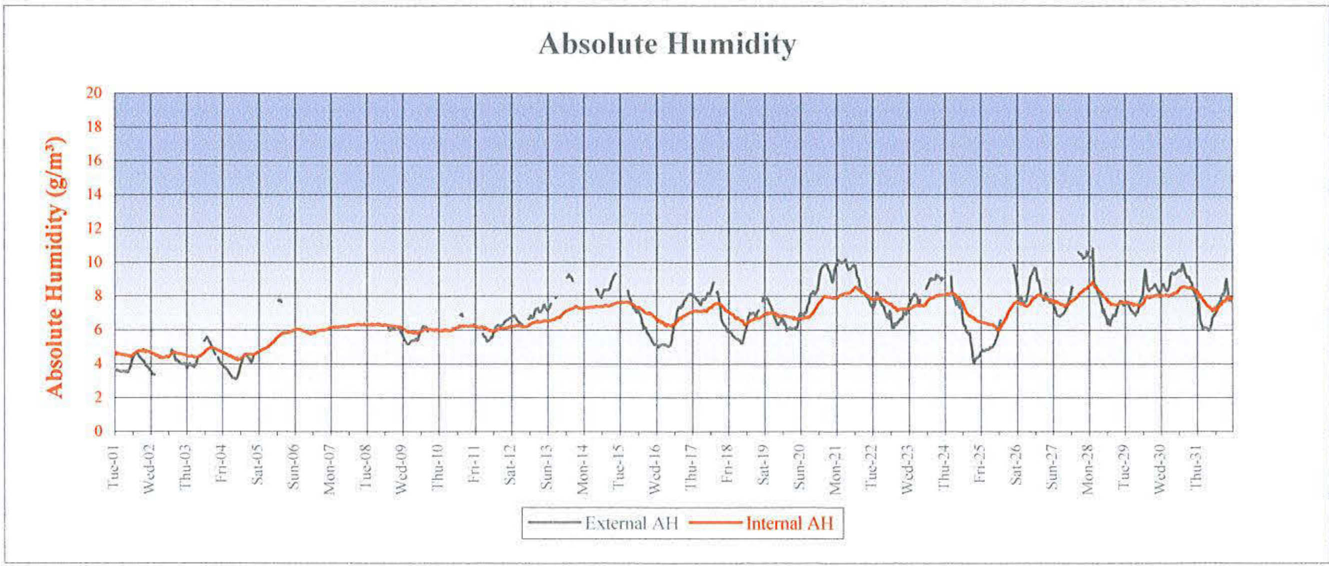
Peterborough Cathedral Nave Ceiling

January 2002

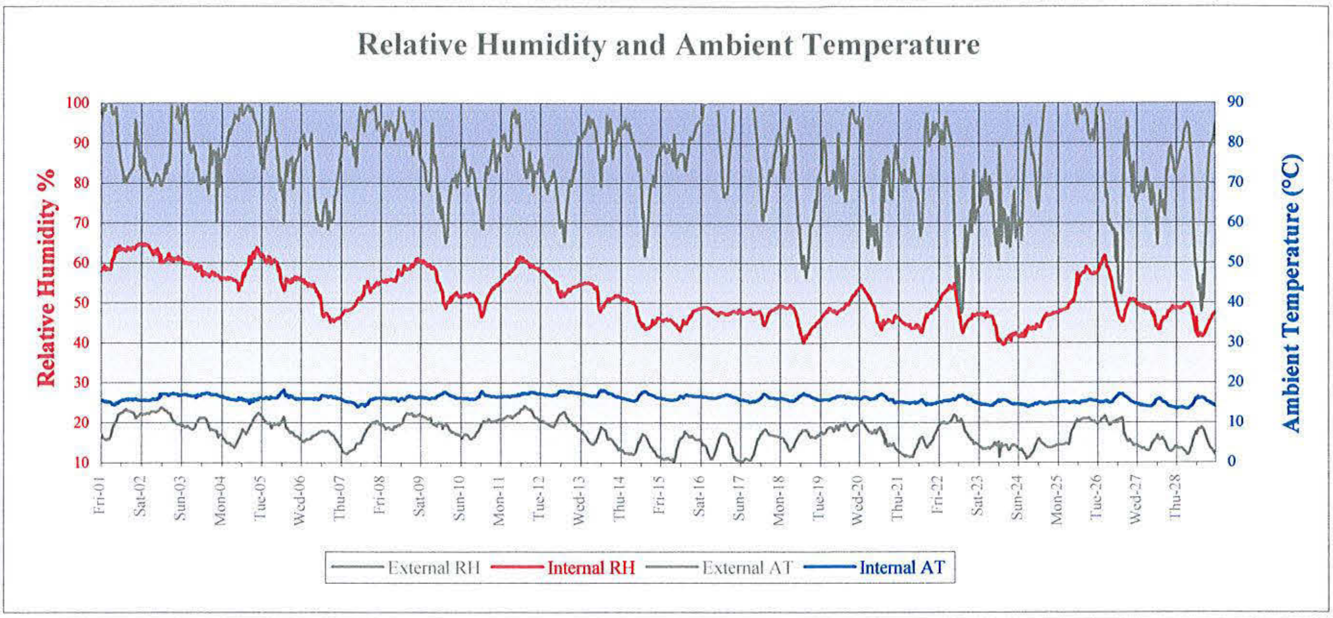
Probe 3: Bay 33 III lower side (sun)

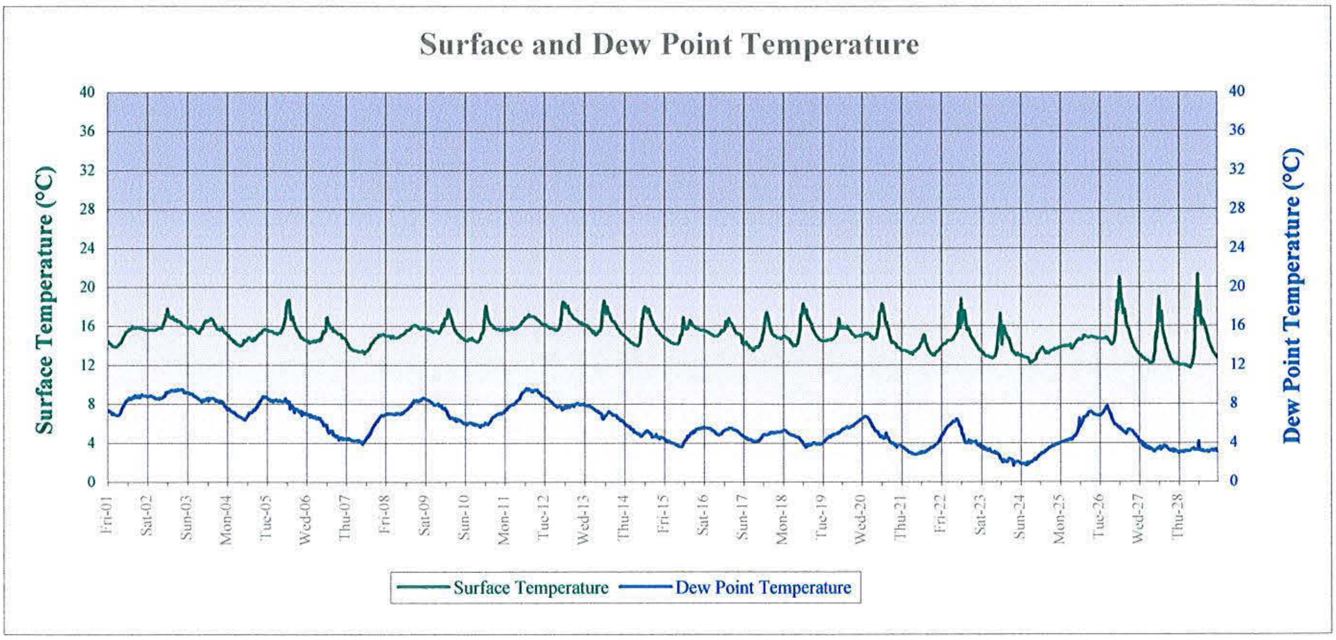


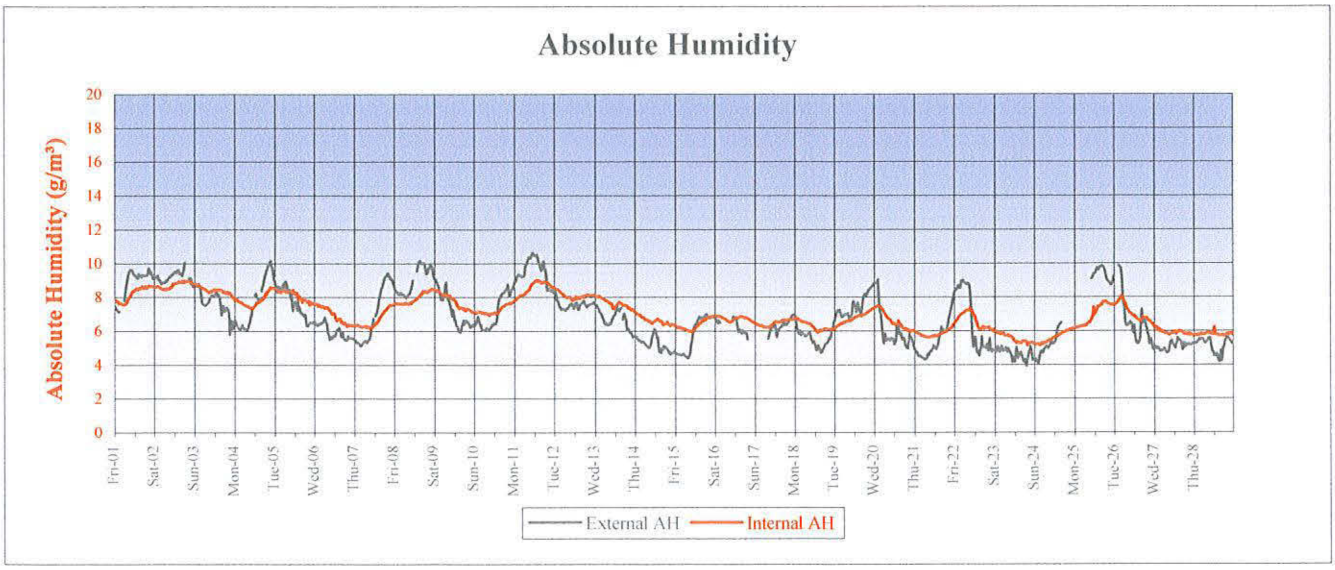




Probe 3: Bay 33 III lower side (sun)



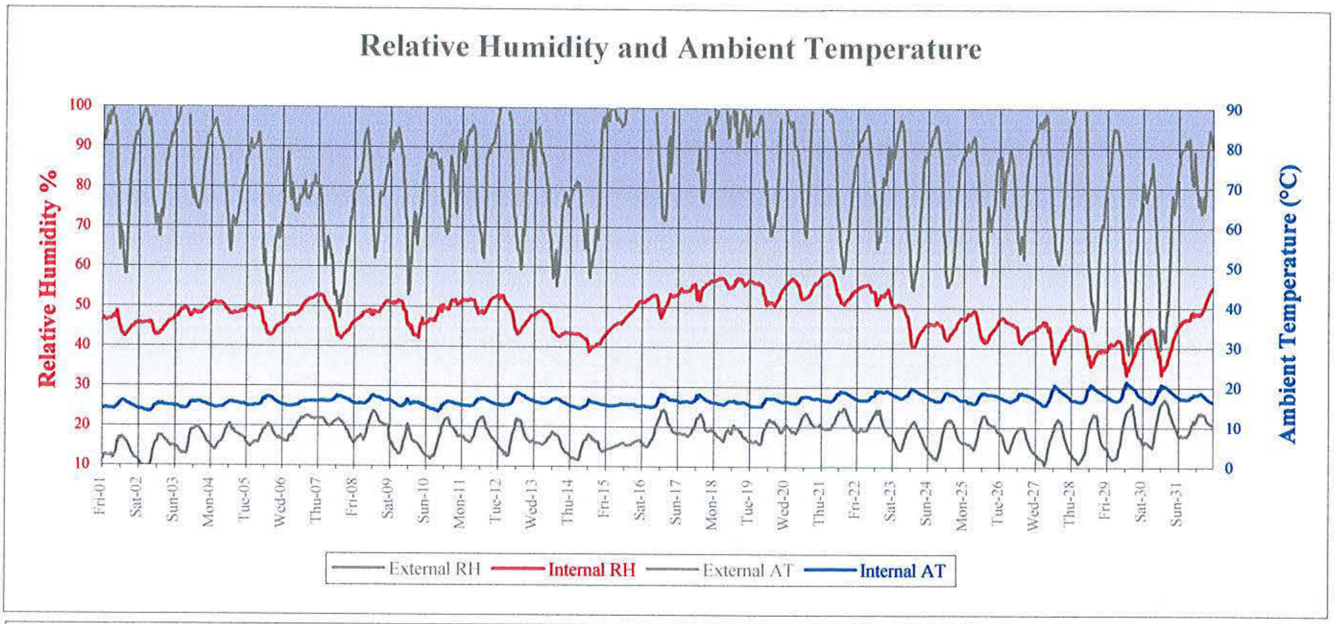


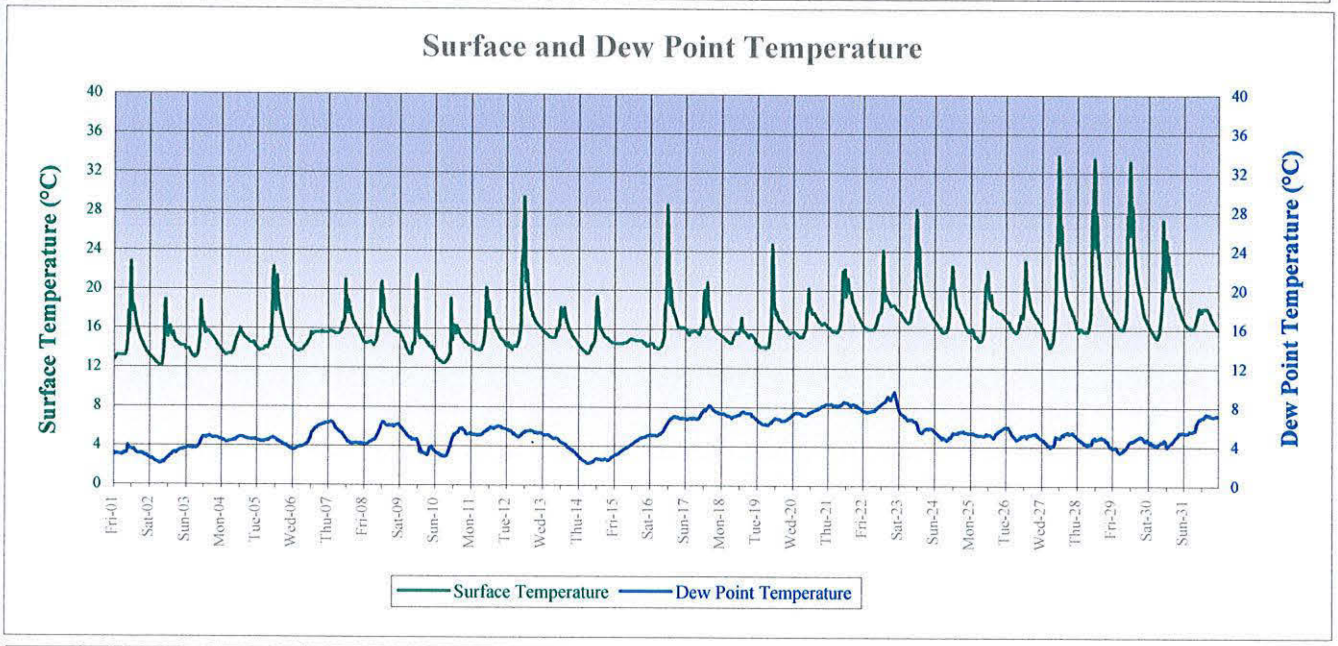


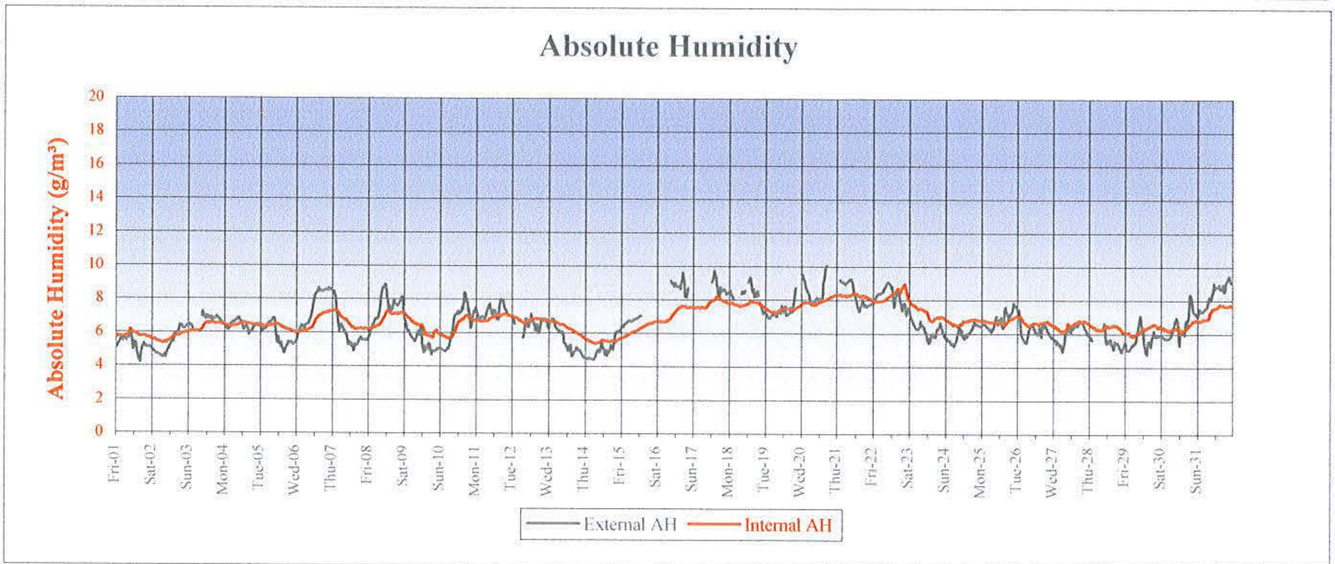
Peterborough Cathedral Nave Ceiling

March 2002

Probe 3: Bay 33 III lower side (sun)

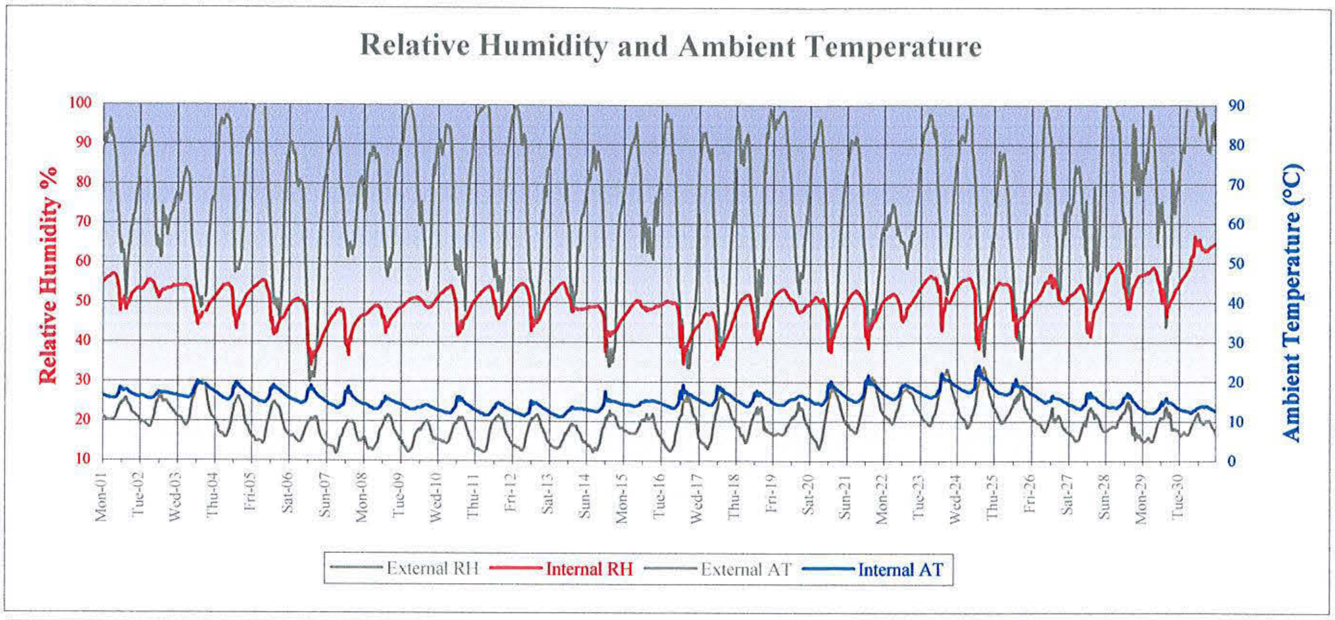


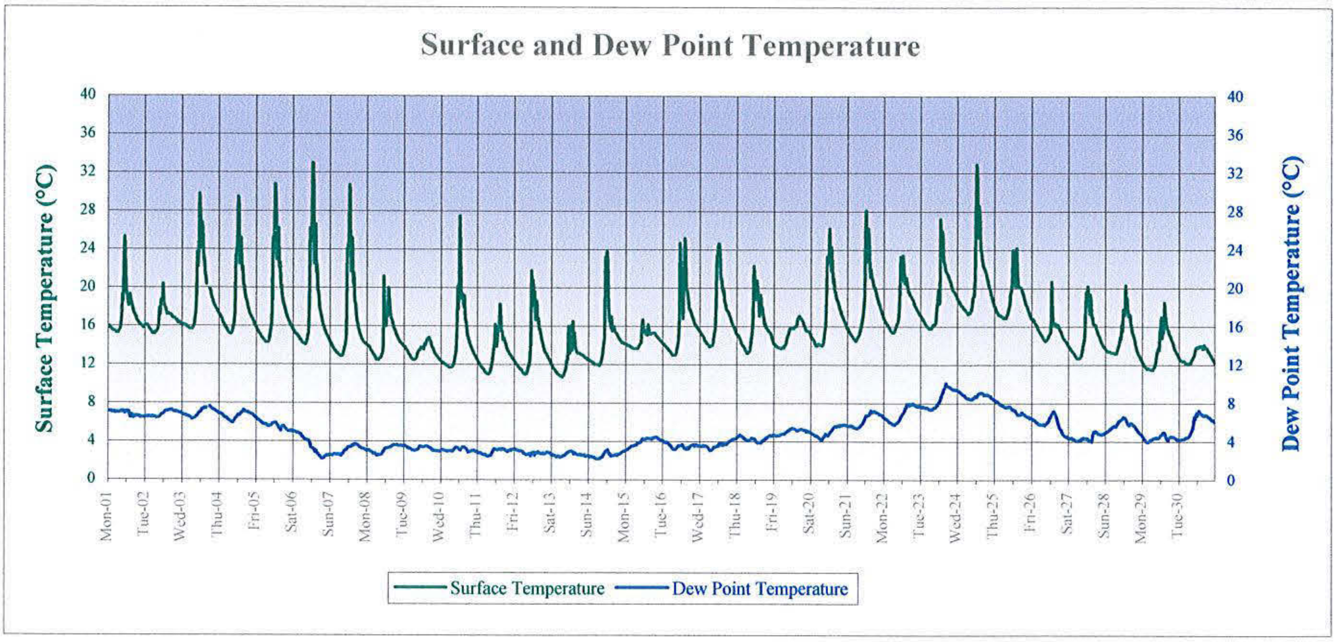


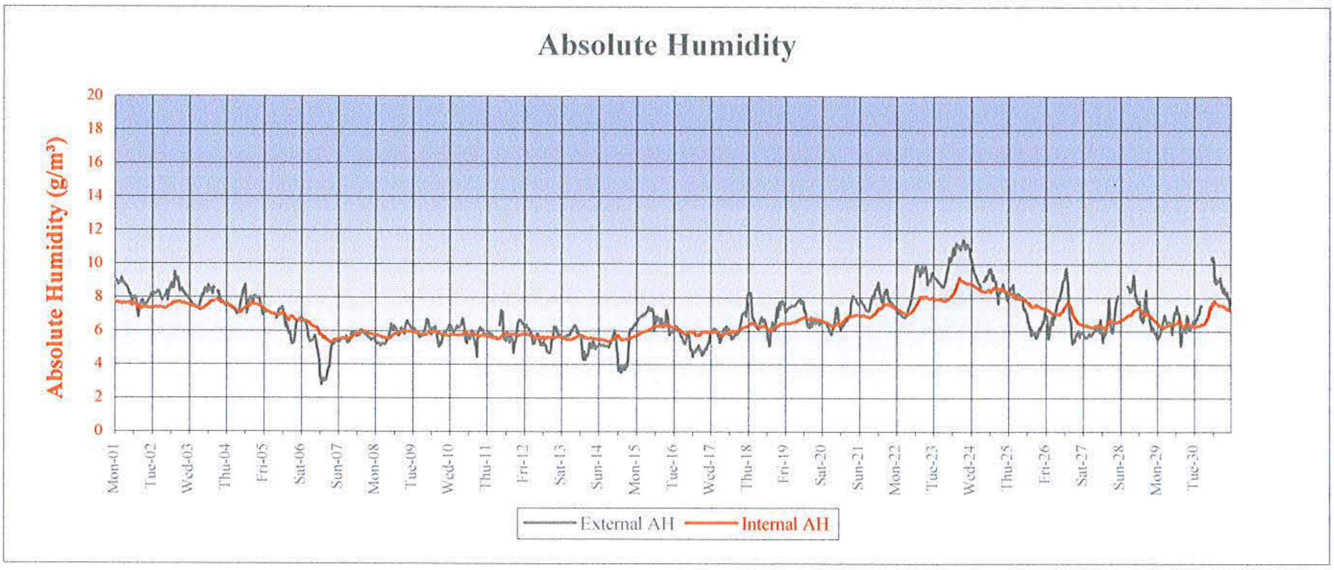


Peterborough Cathedral Nave Ceiling

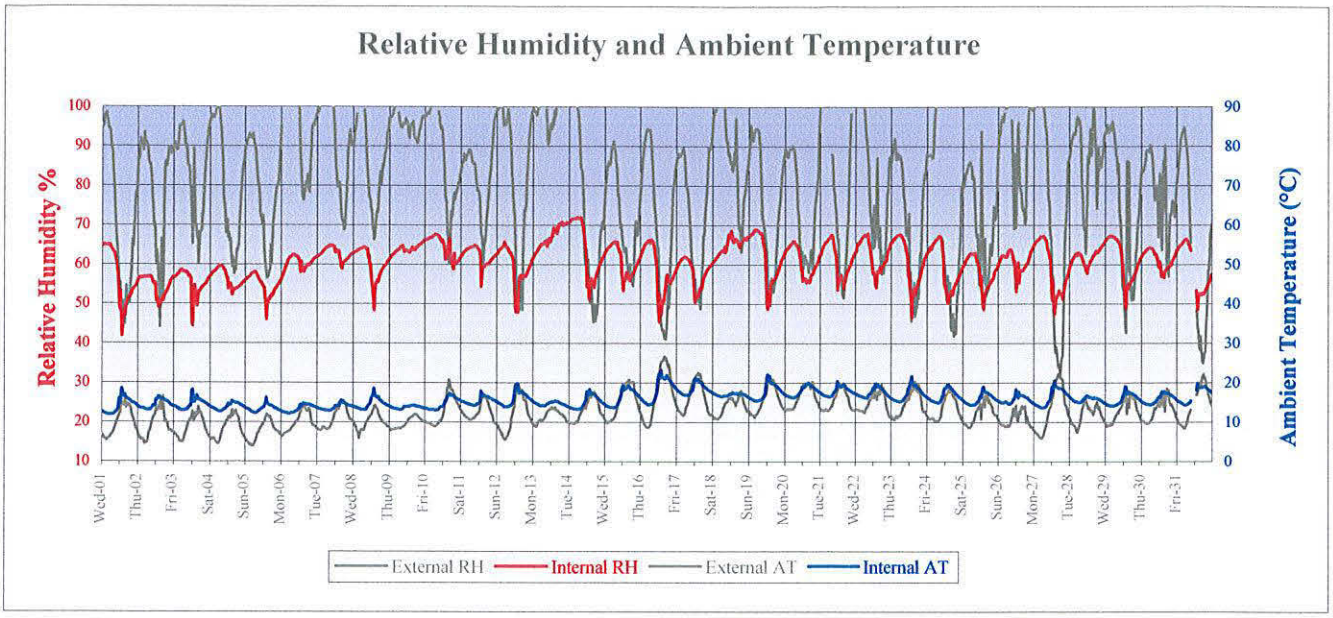
Probe 3: Bay 33 III lower side (sun)

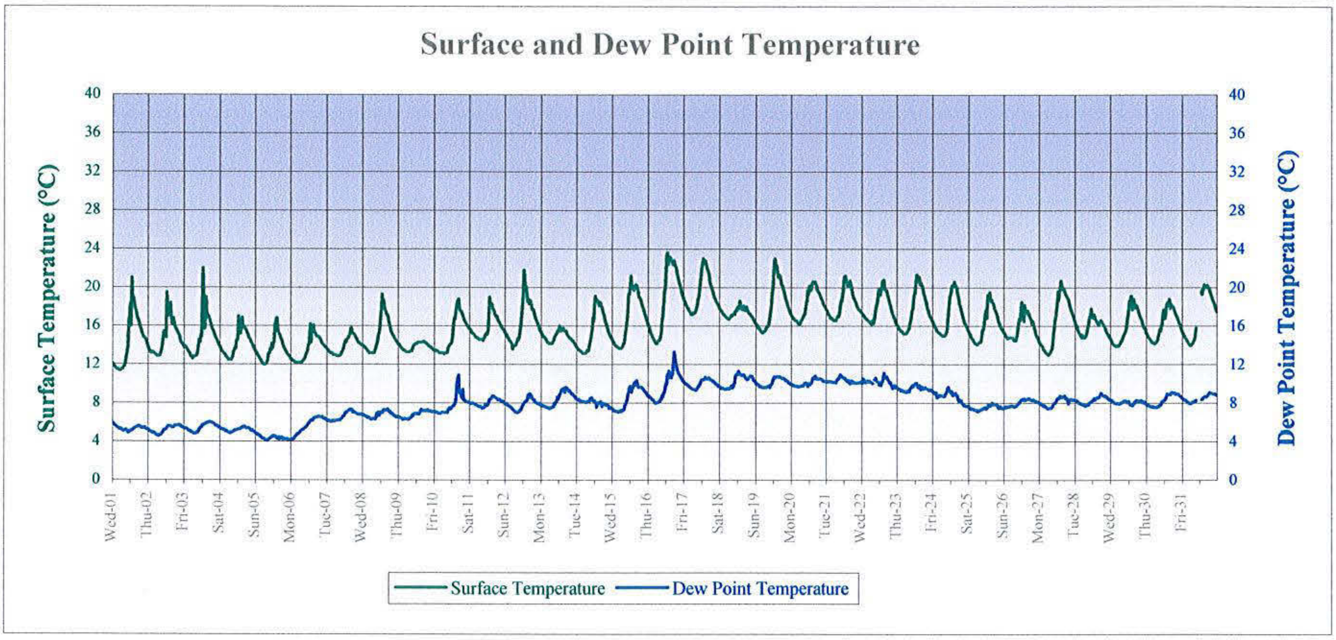


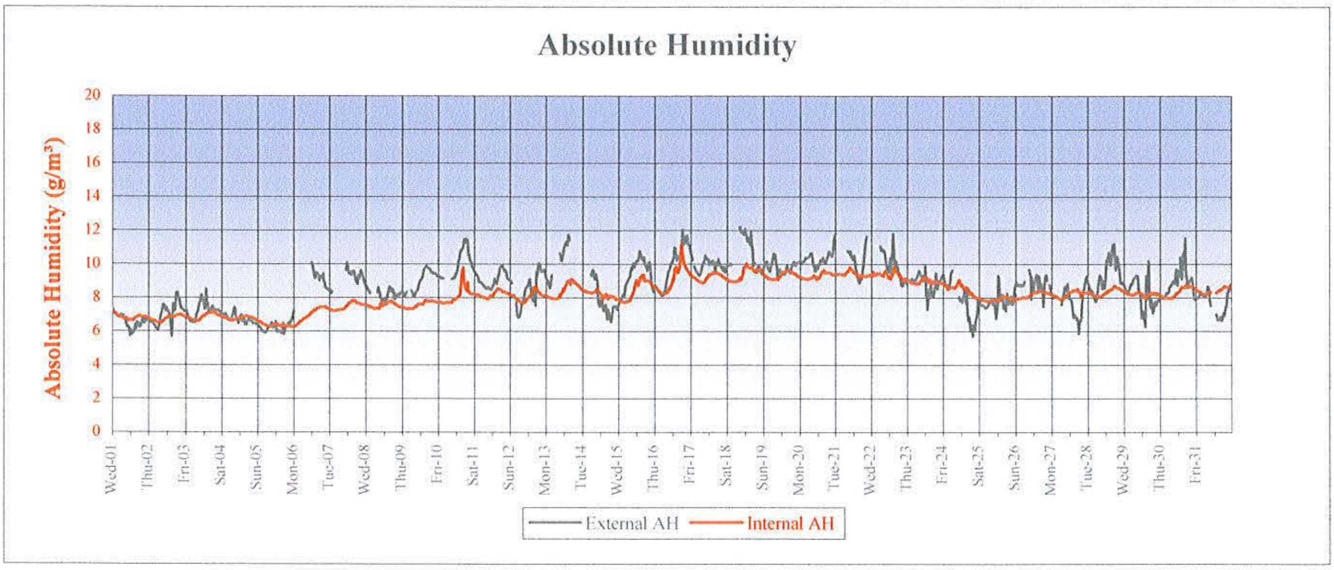




Probe 3: Bay 33 III lower side (sun)



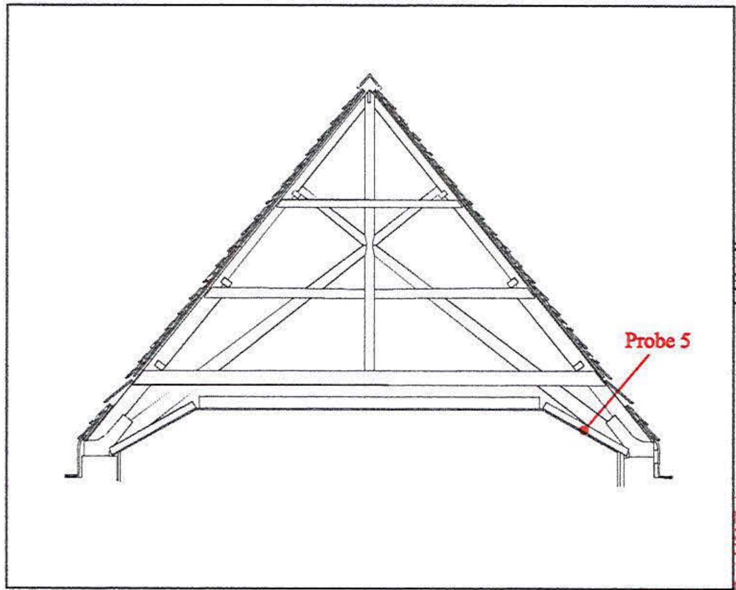


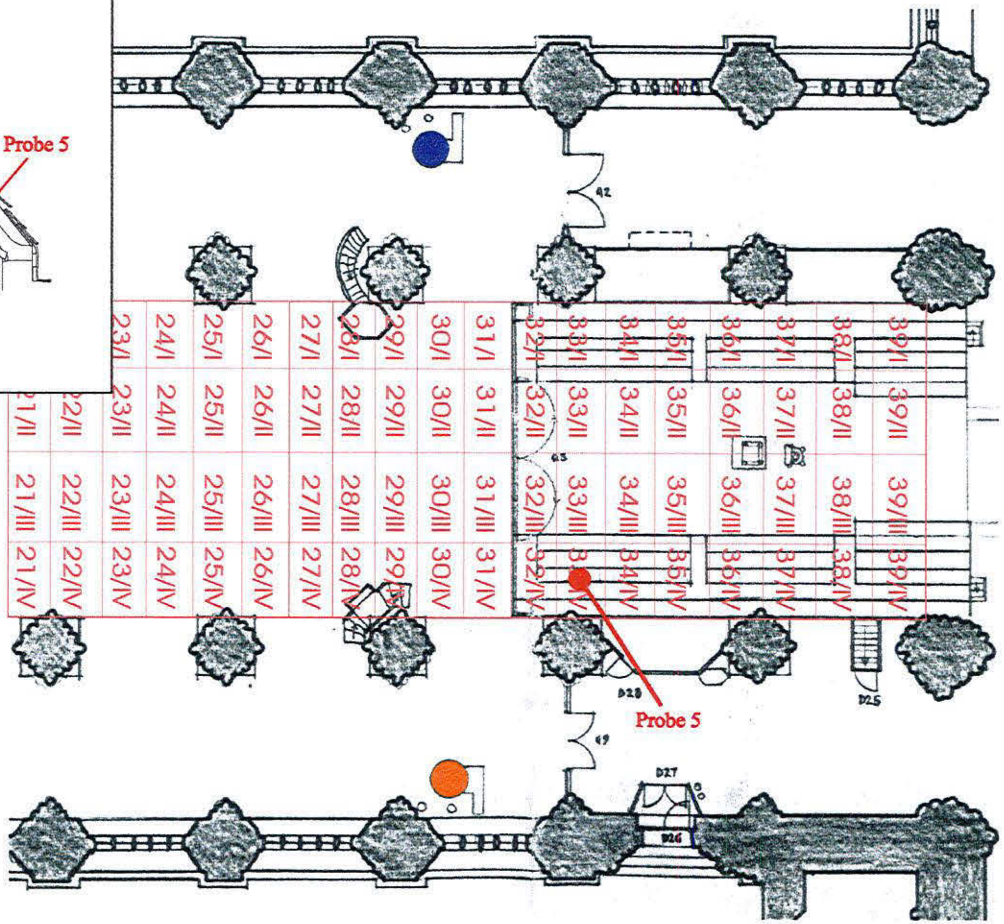


PROBE 5

BAY 33 IV UPPER SIDE (SUN)

Diagram 6



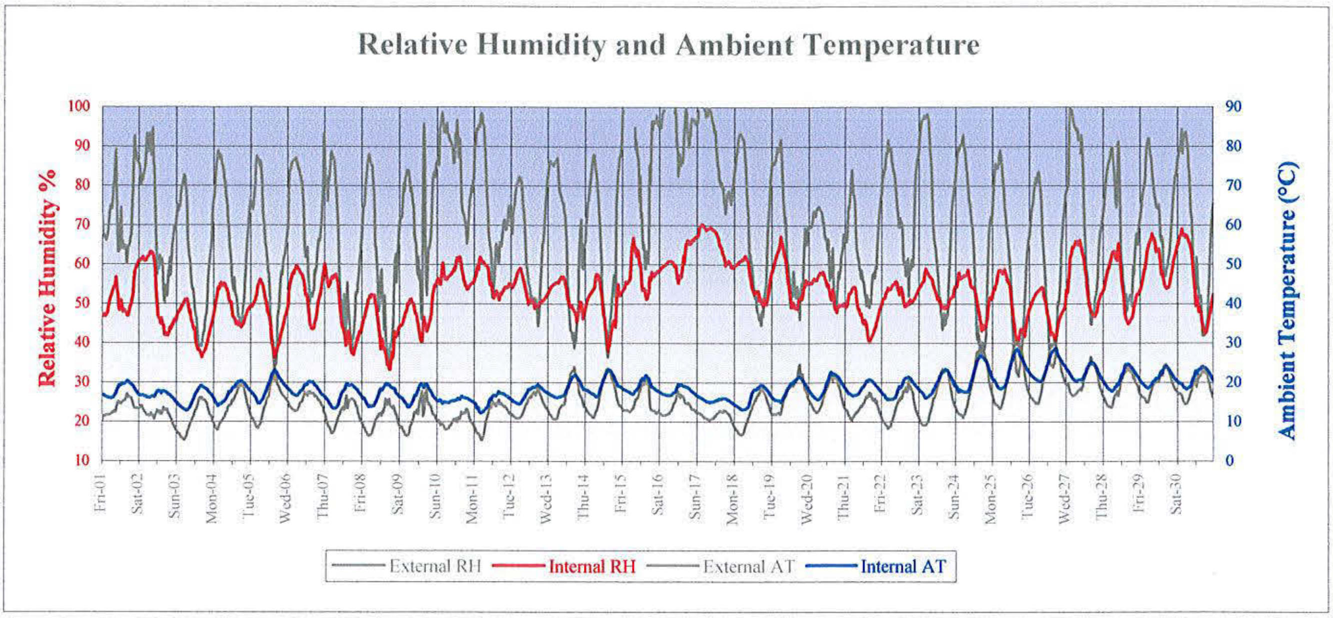


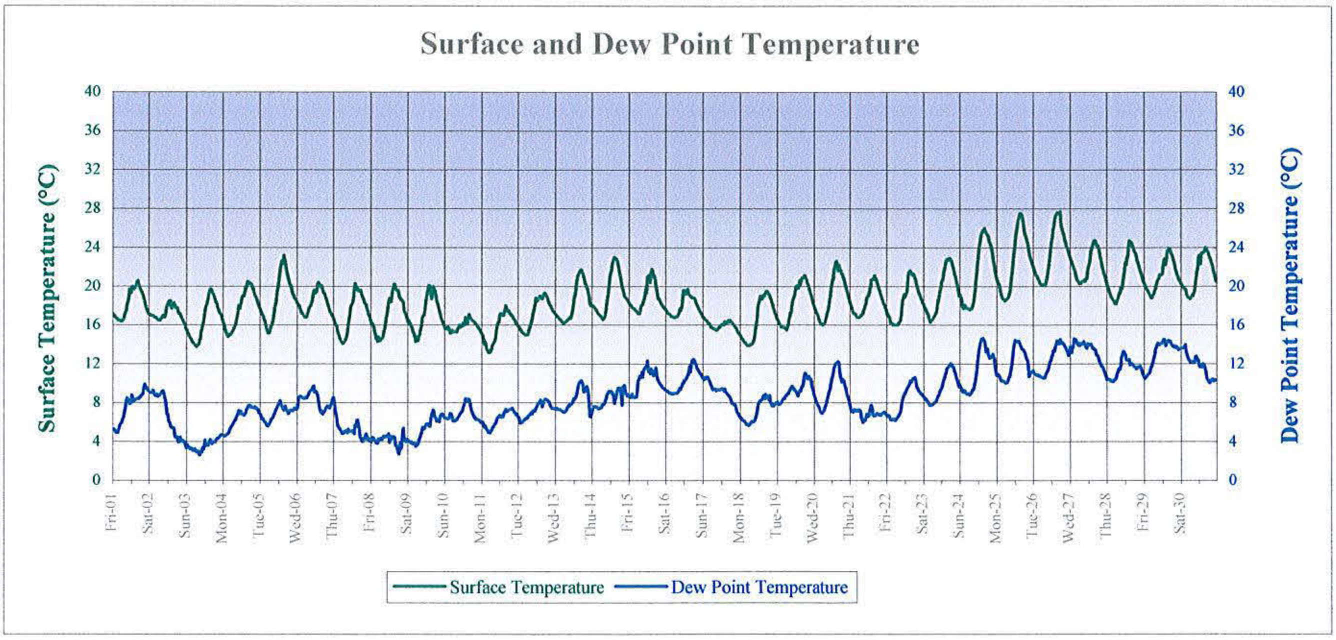
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 5m 10m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: JULY 2000	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

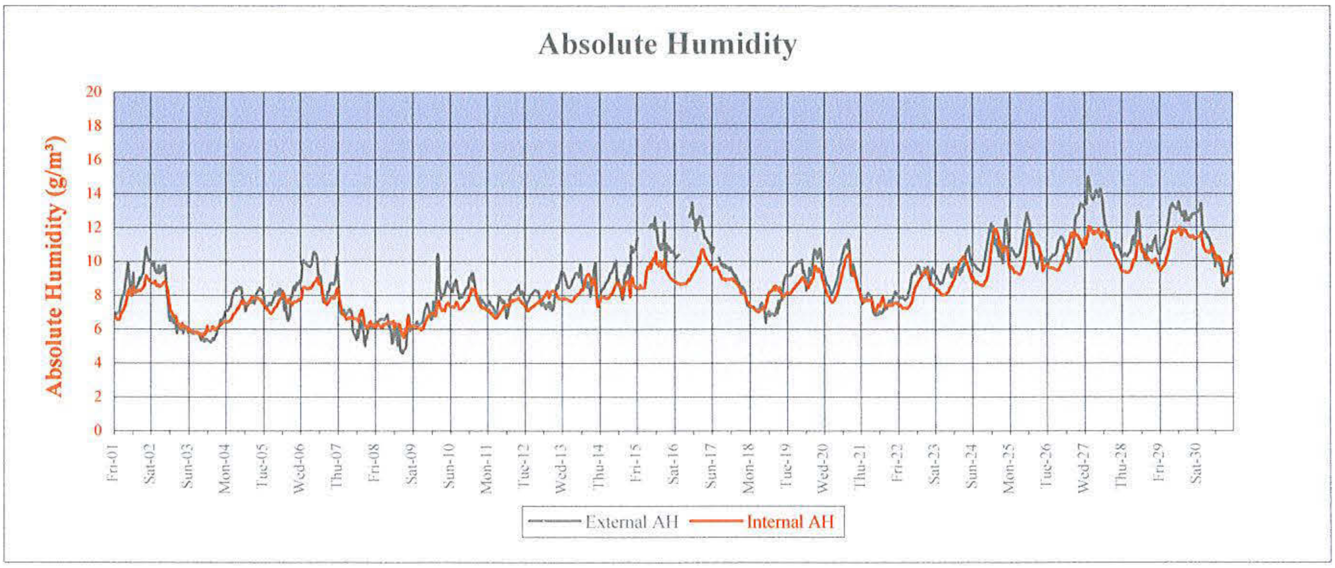
Peterborough Cathedral Nave Ceiling

June 2001

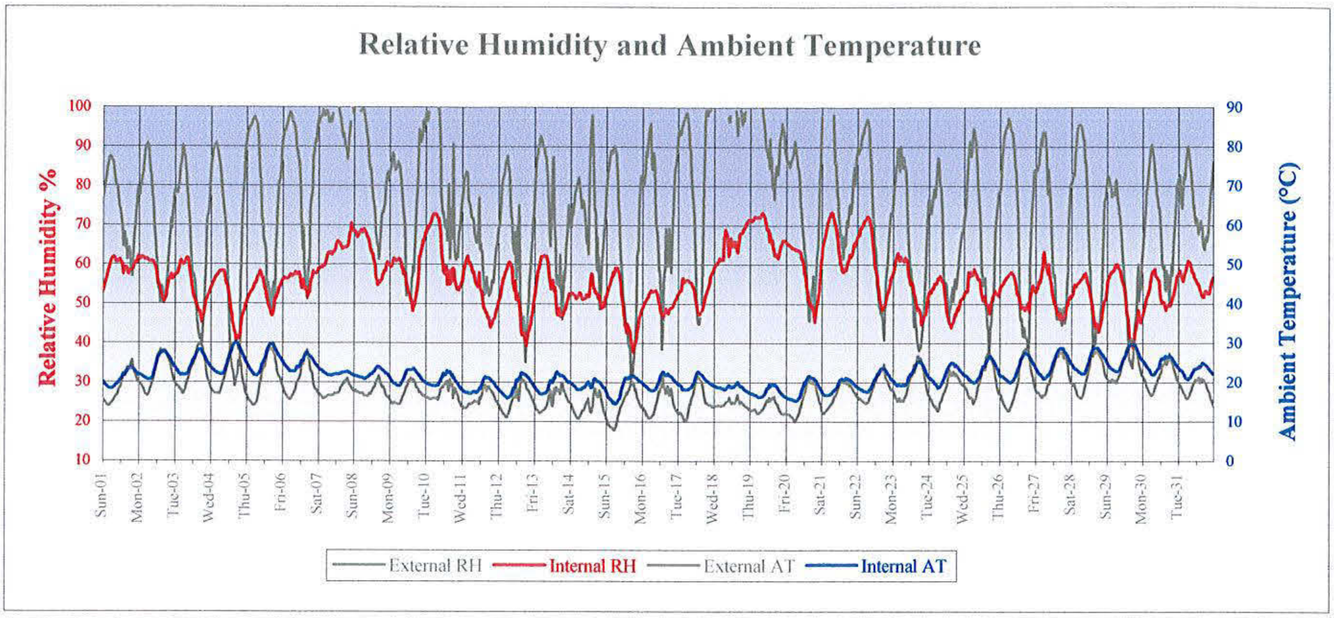
Probe 5: Bay 33 III upper side (sun)

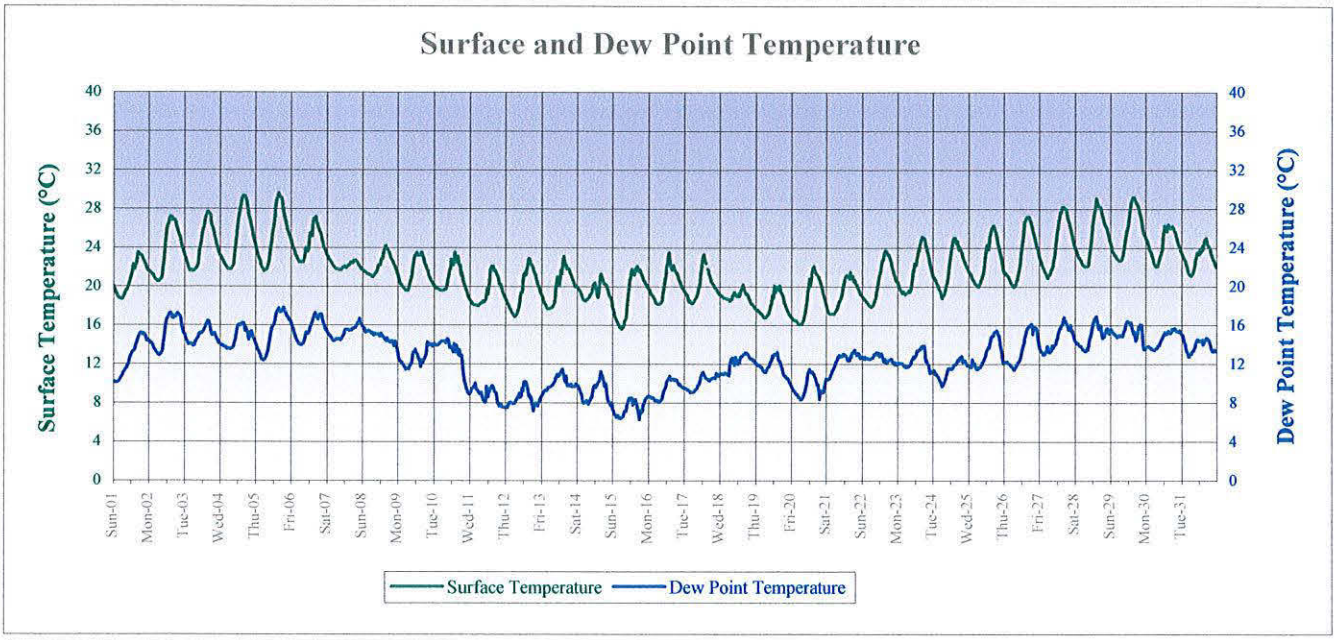


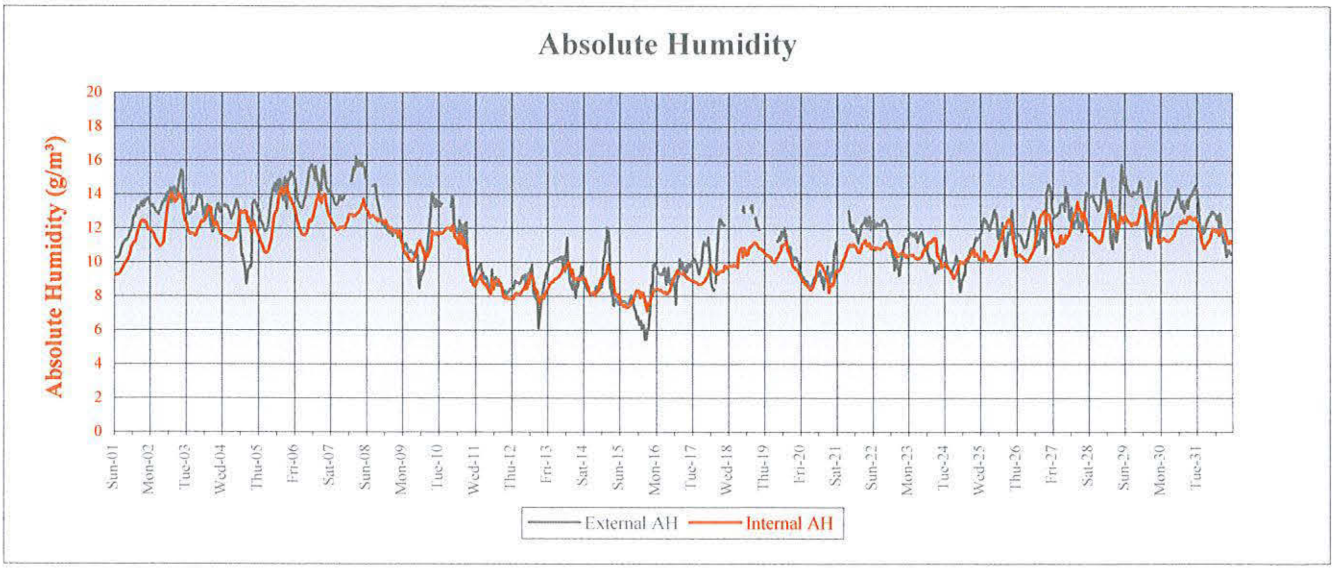




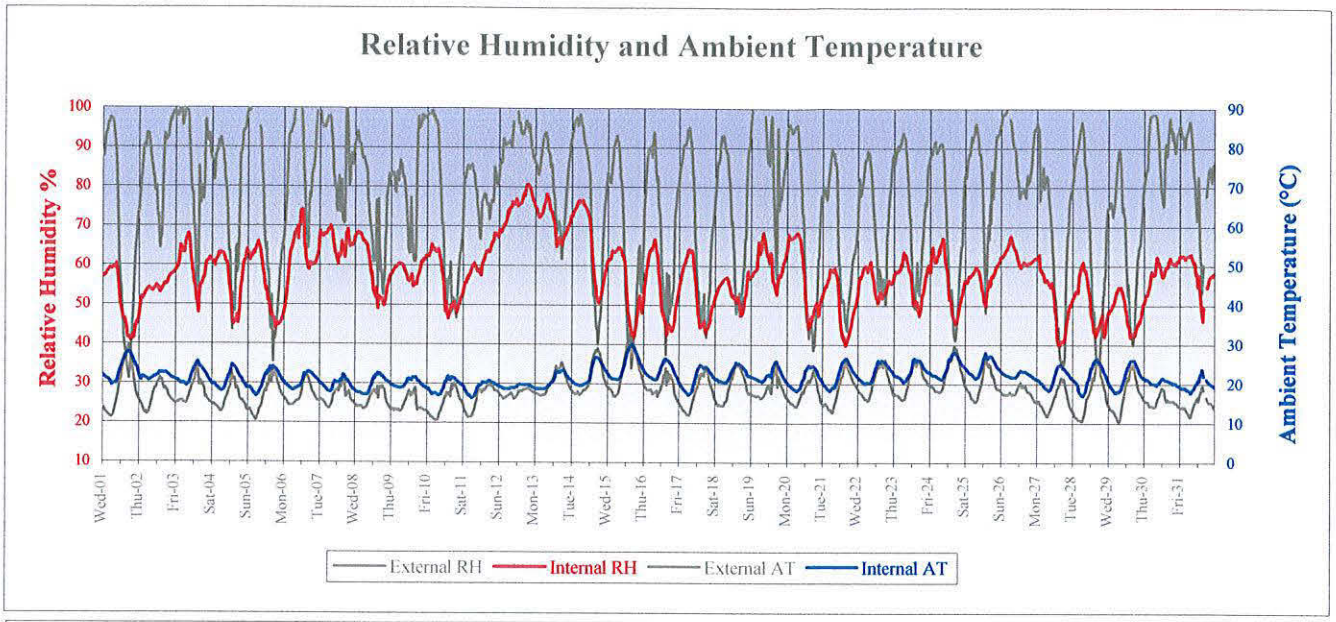
Probe 5: Bay 33 III upper side (sun)

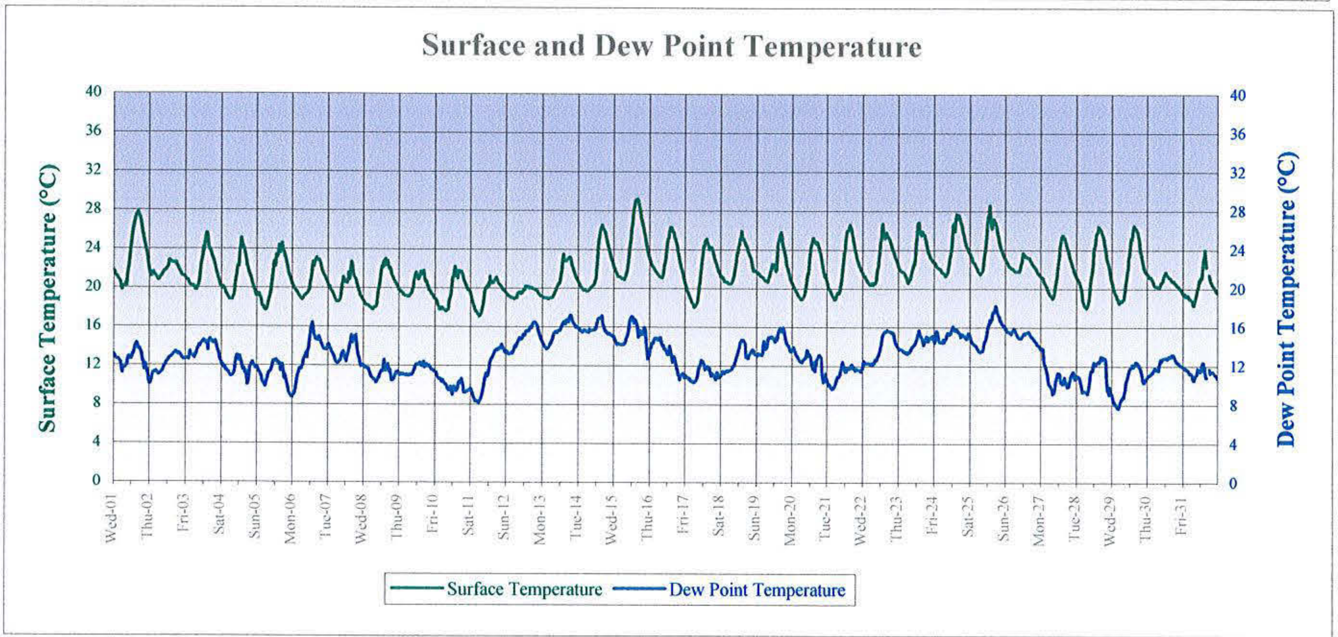


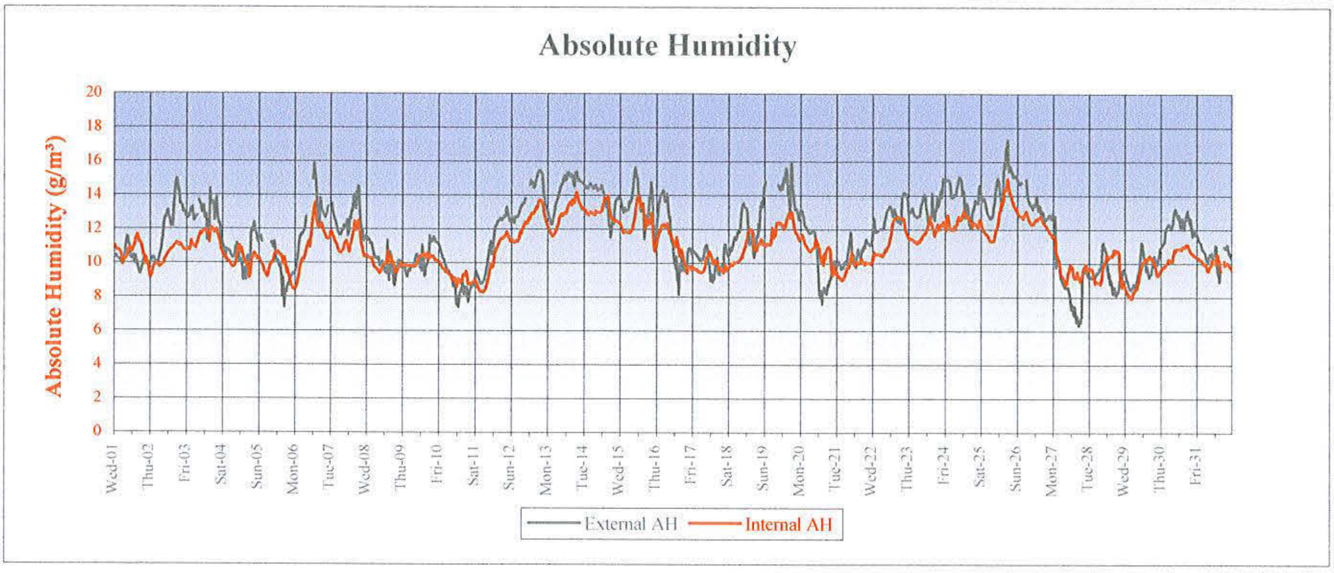




Probe 5: Bay 33 III upper side (sun)



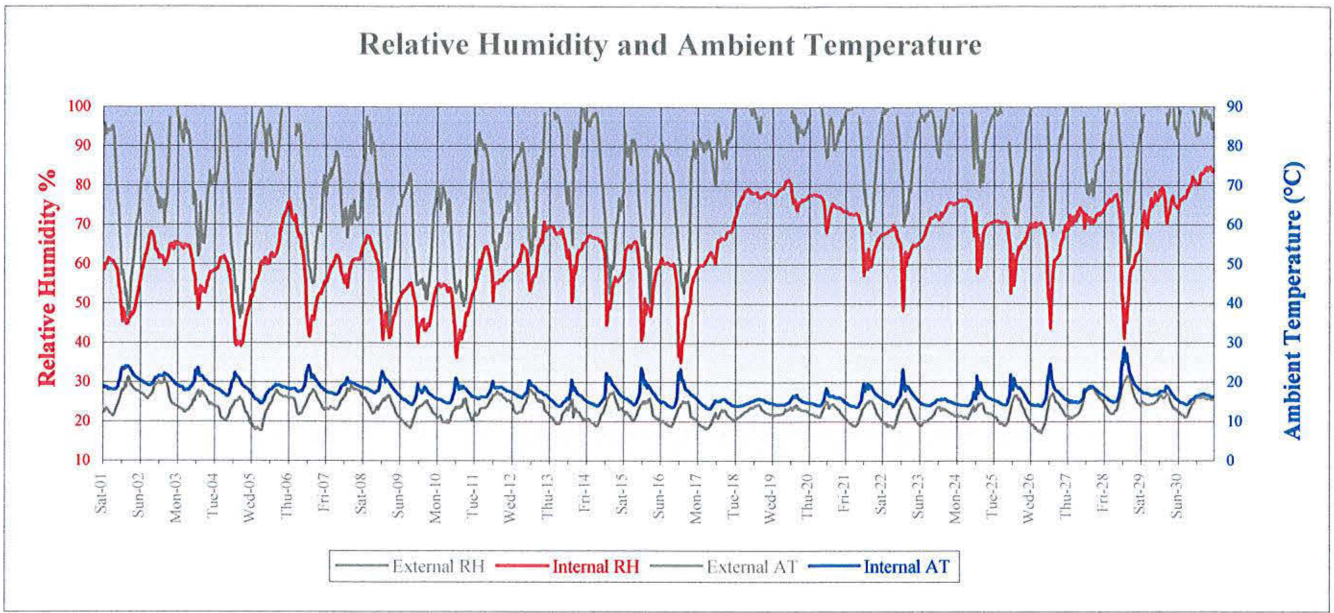


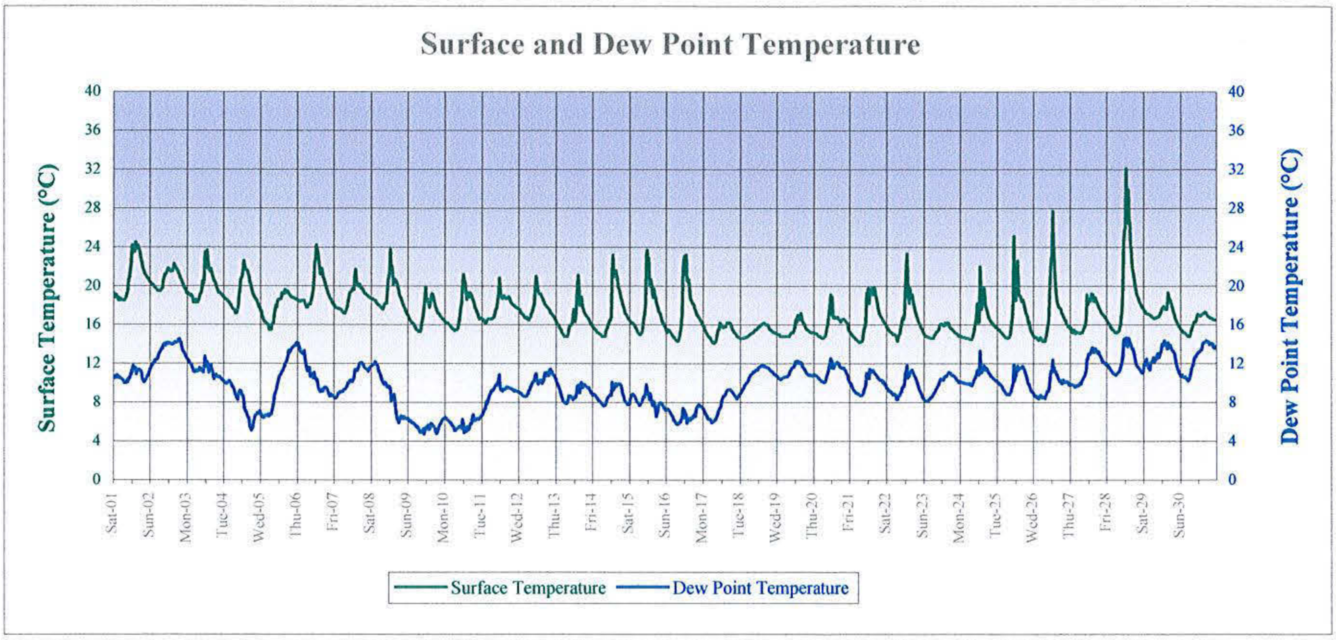


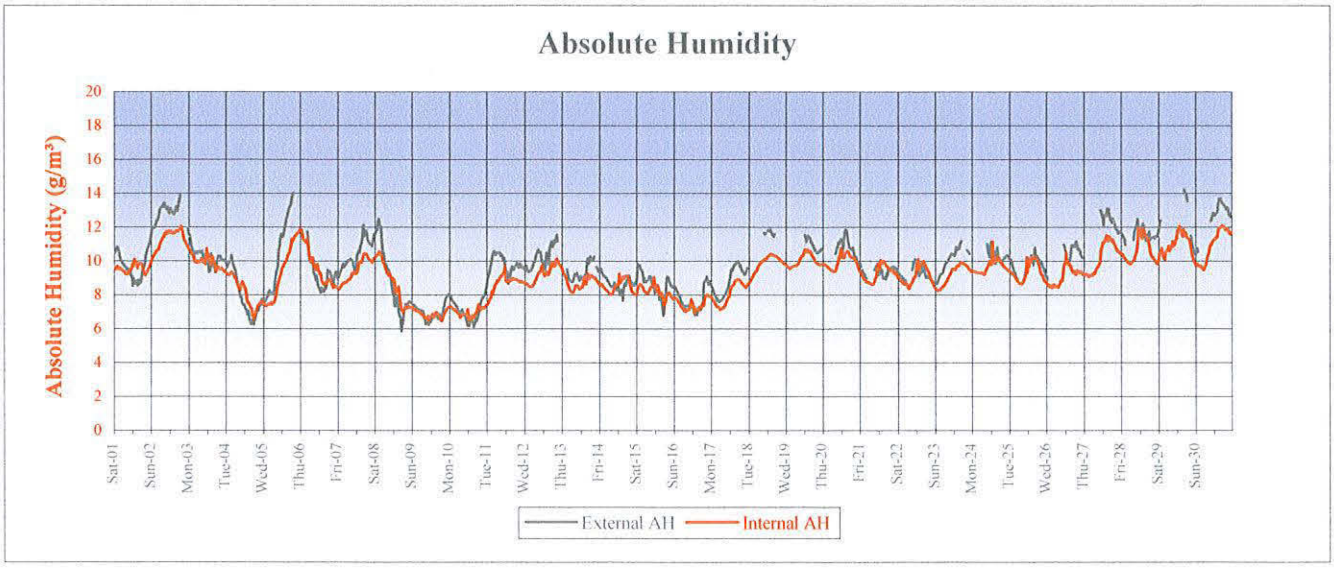
Peterborough Cathedral Nave Ceiling

September 2001

Probe 5: Bay 33 III upper side (sun)





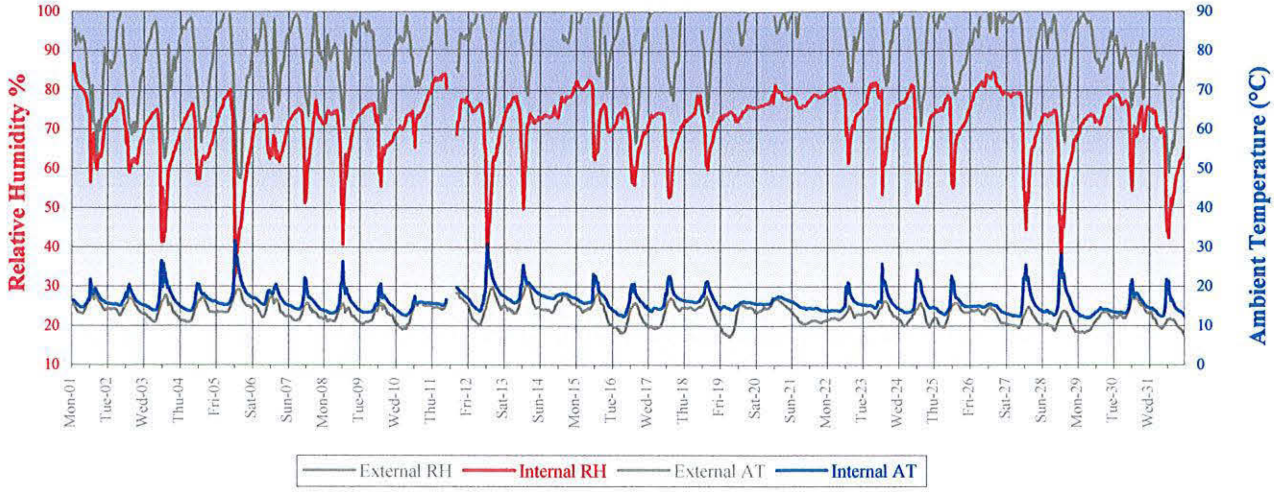


Peterborough Cathedral Nave Ceiling

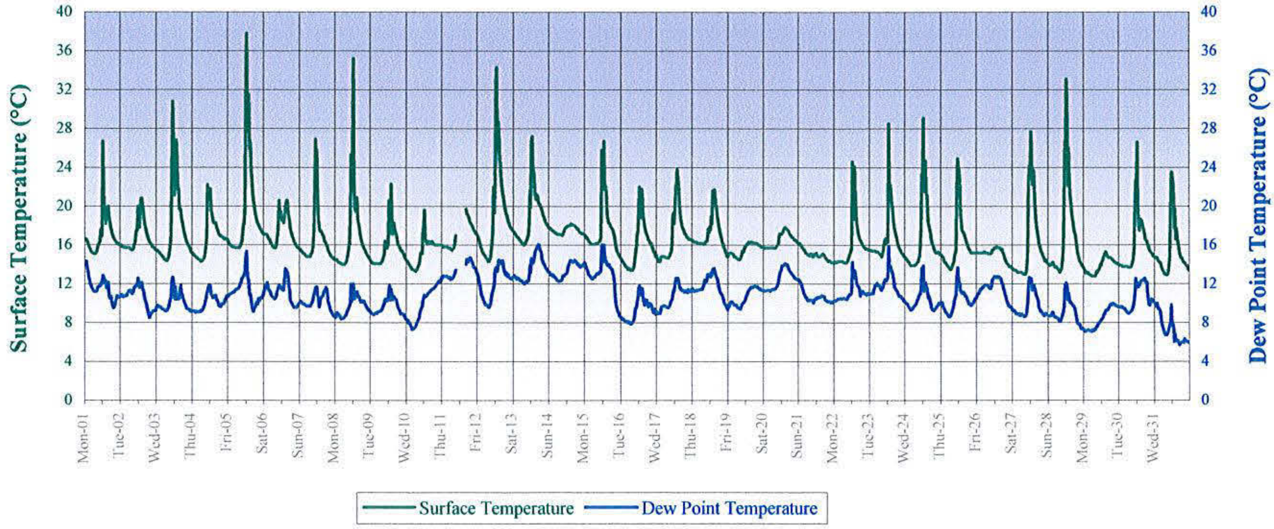
October 2001

Probe 5: Bay 33 III upper side (sun)

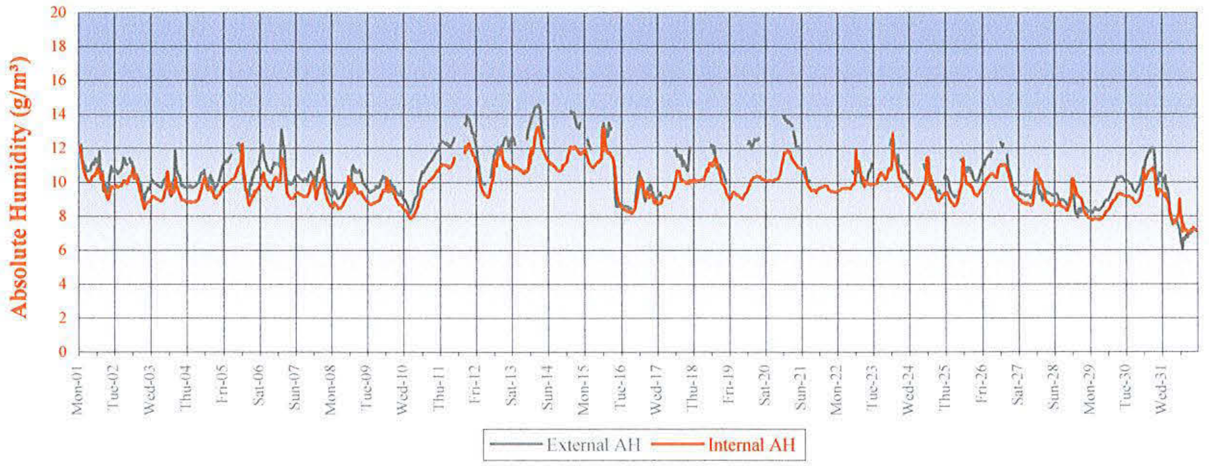
Relative Humidity and Ambient Temperature



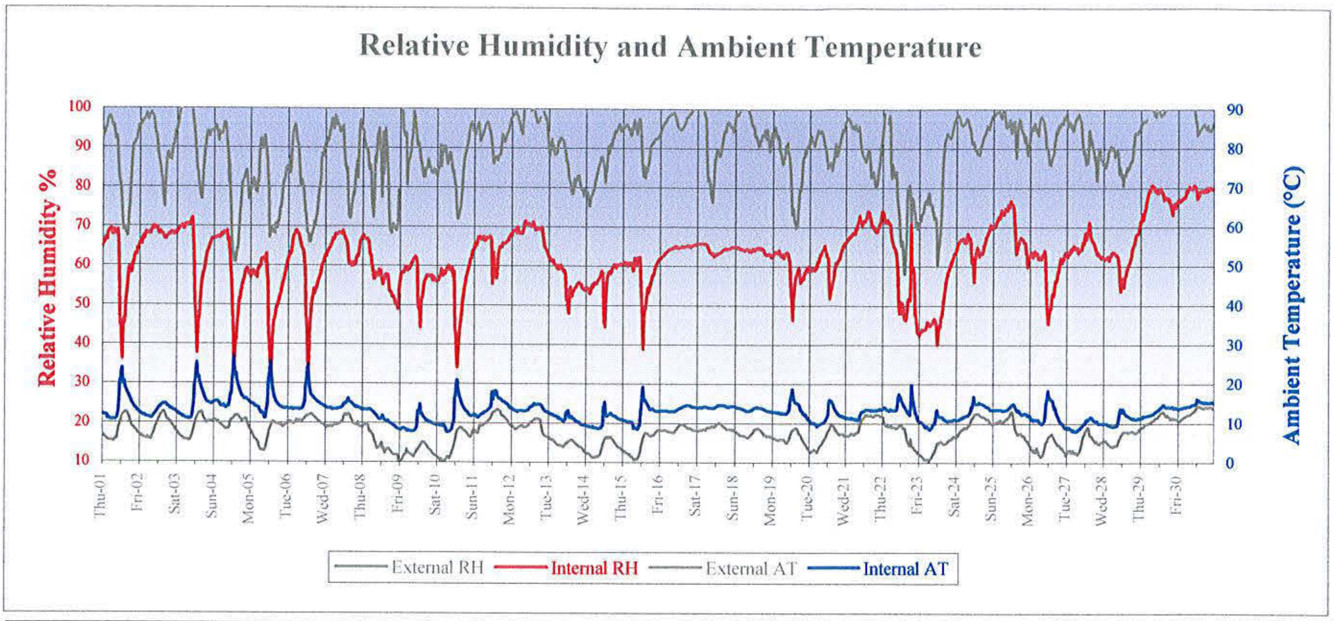
Surface and Dew Point Temperature

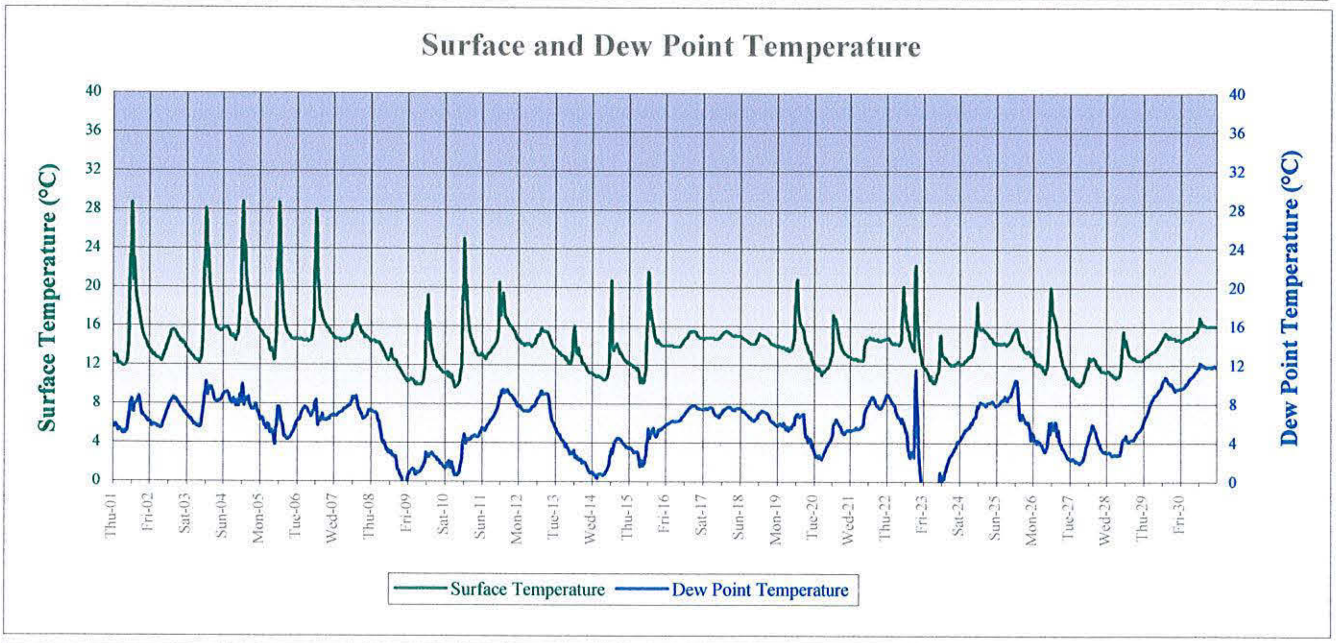


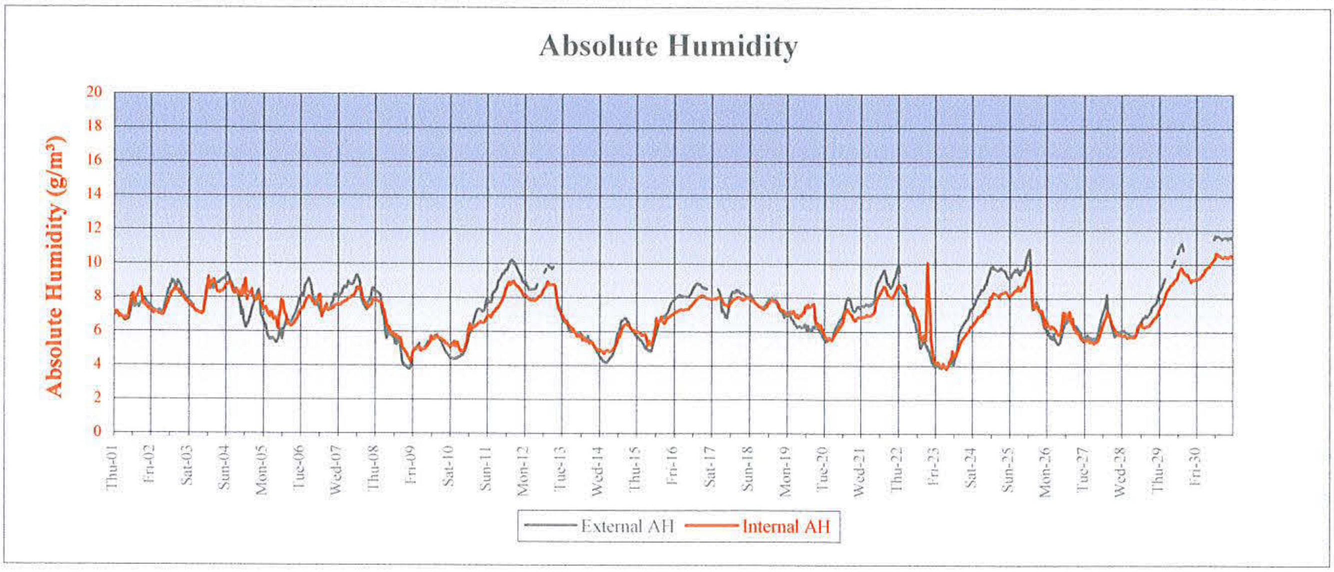
Absolute Humidity



Probe 5: Bay 33 III upper side (sun)

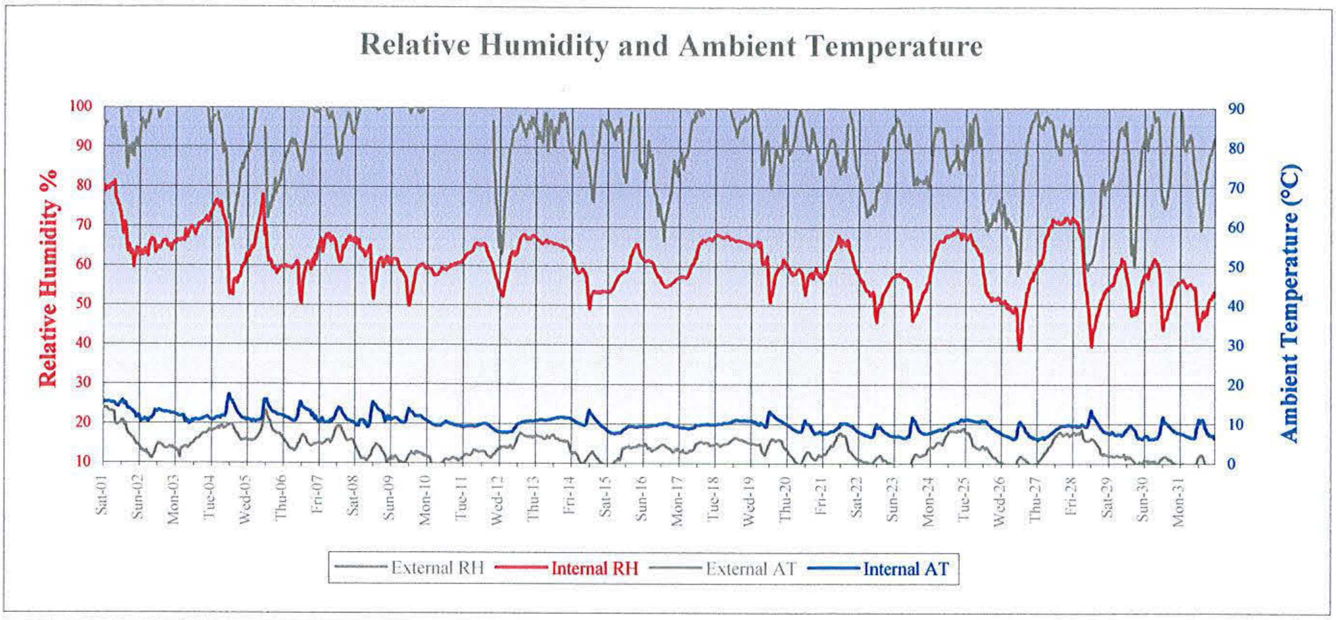


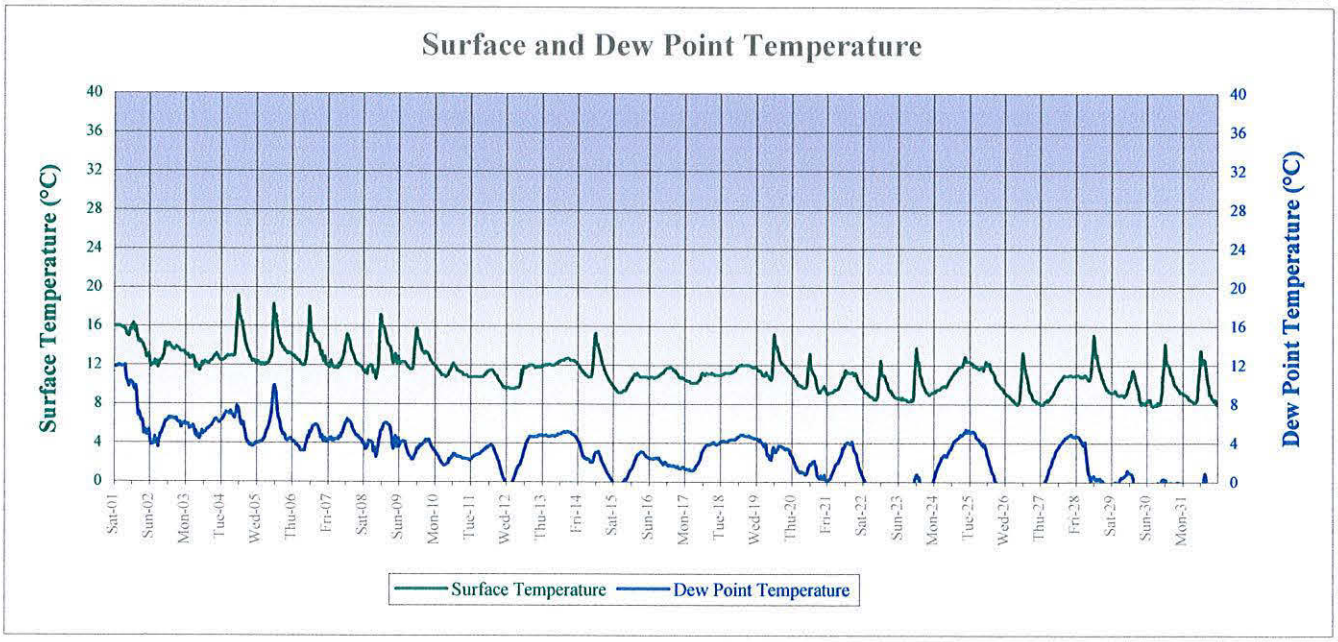


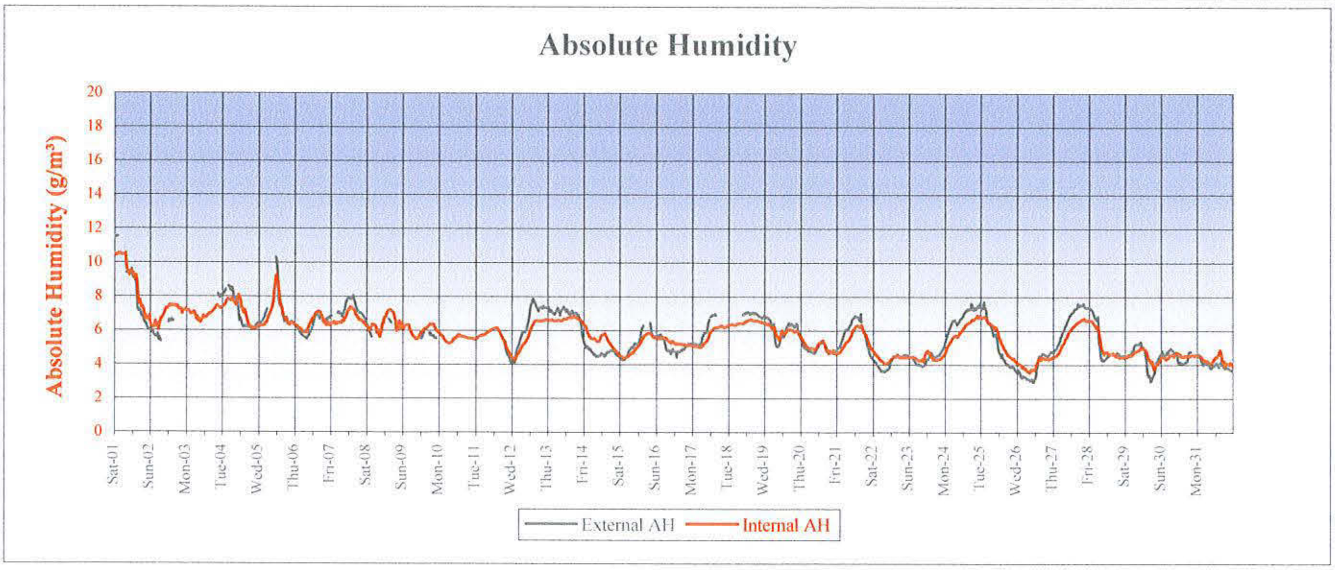


Peterborough Cathedral Nave Ceiling

Probe 5: Bay 33 III upper side (sun)



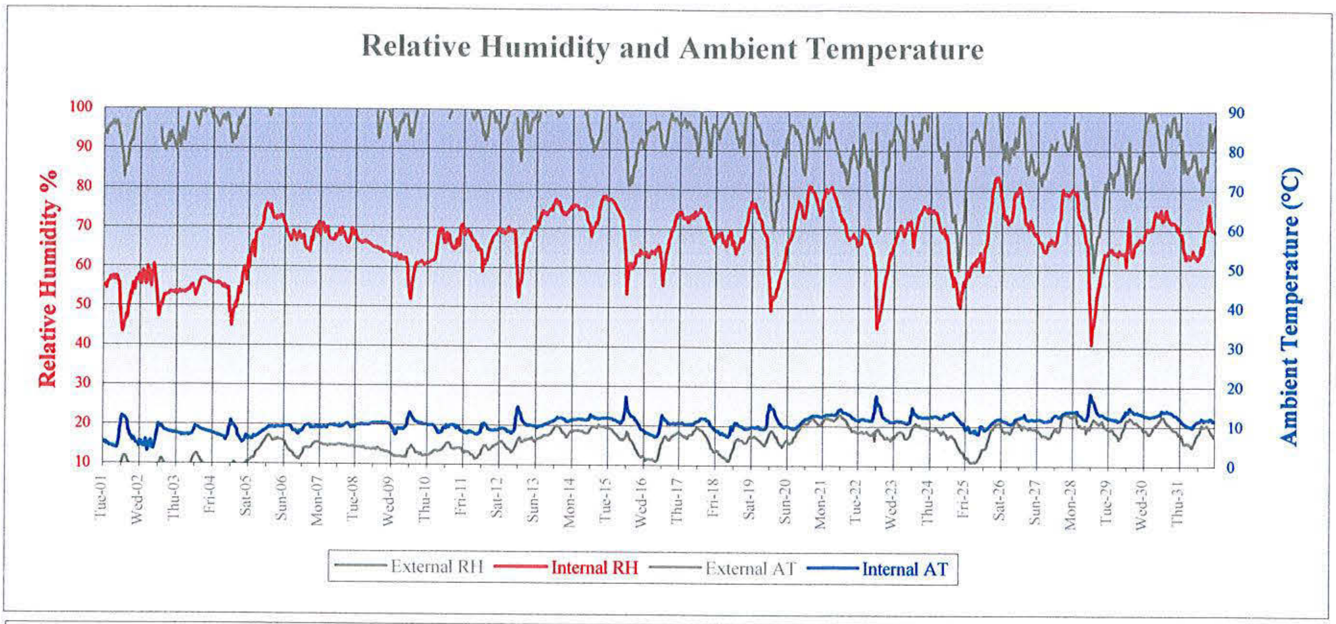


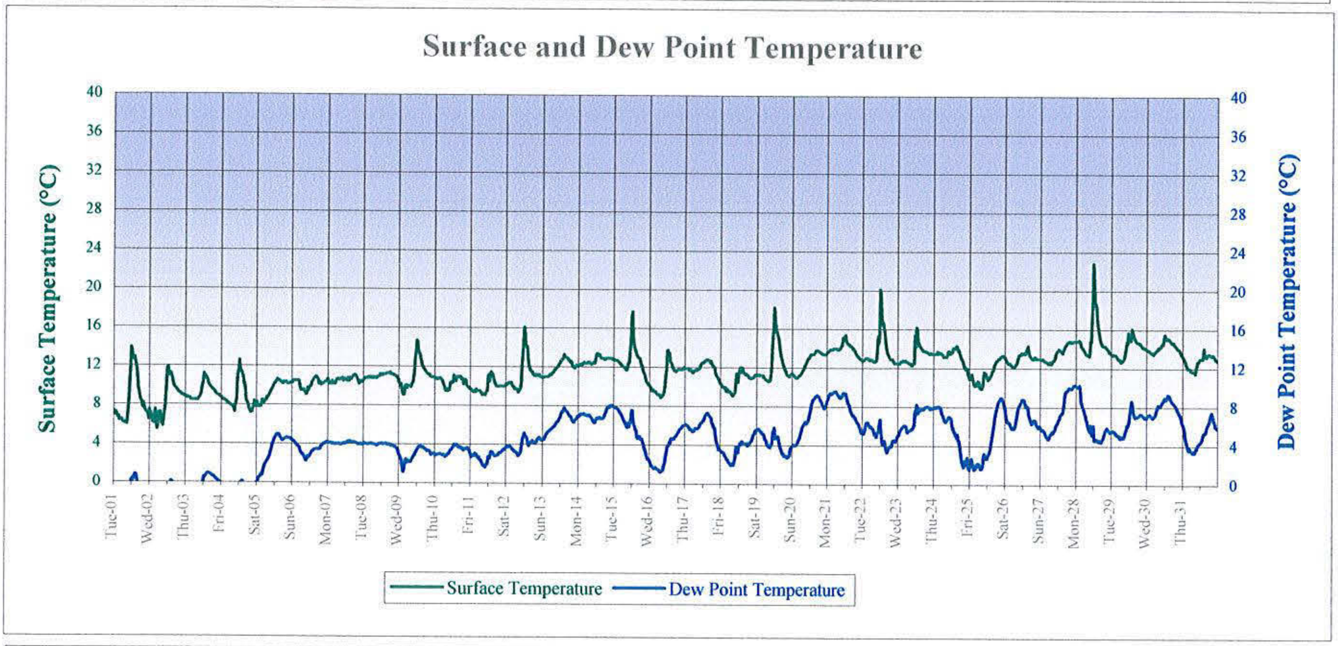


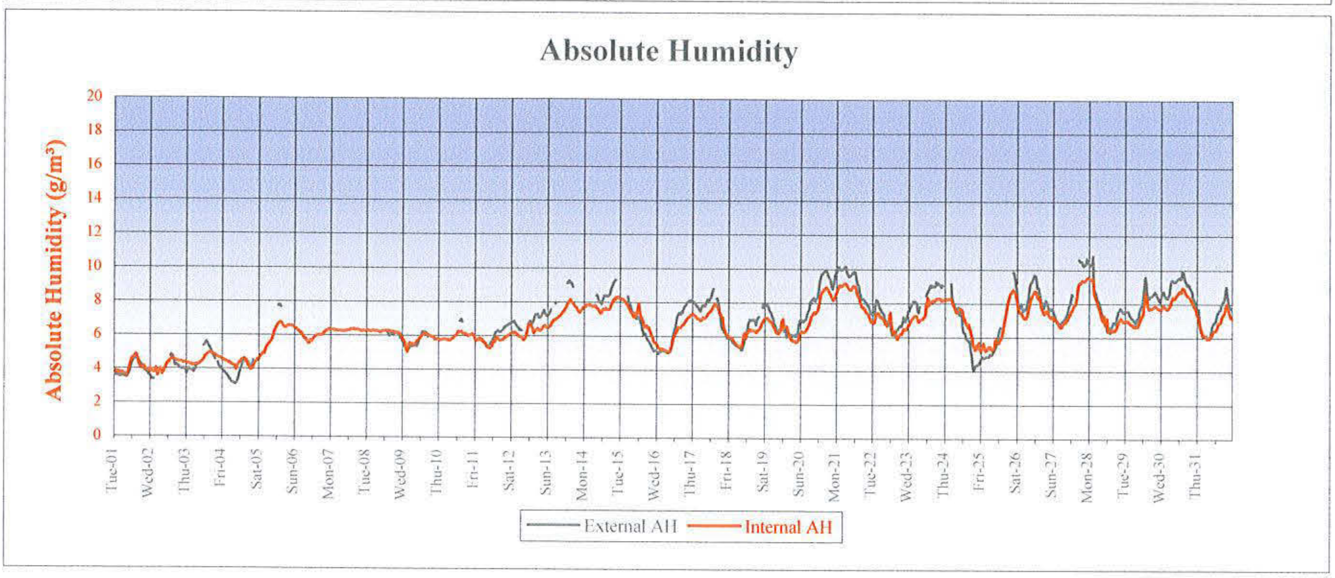
Peterborough Cathedral Nave Ceiling

January 2002

Probe 5: Bay 33 III upper side (sun)



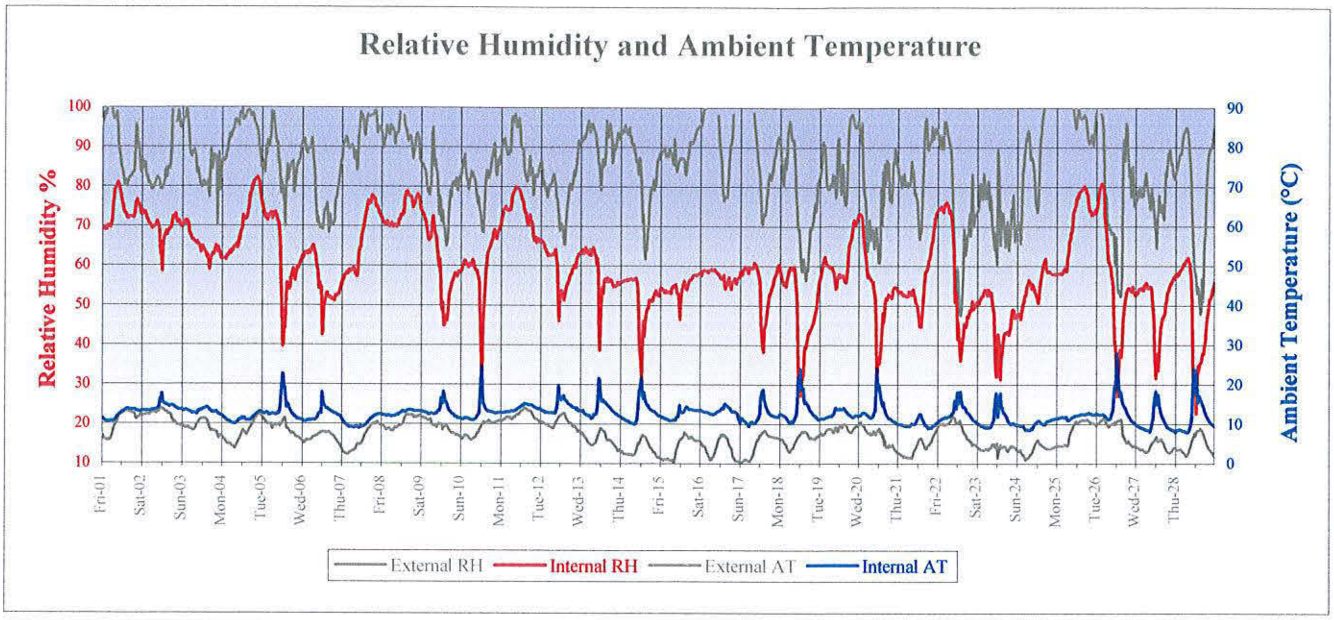


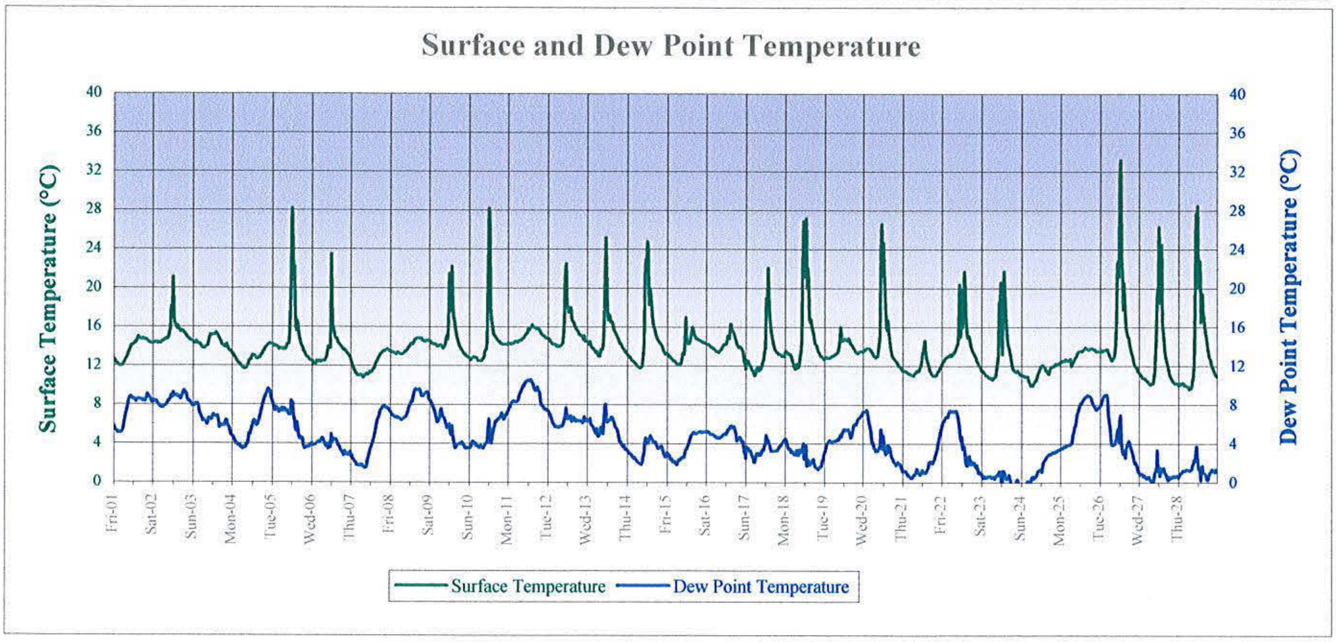


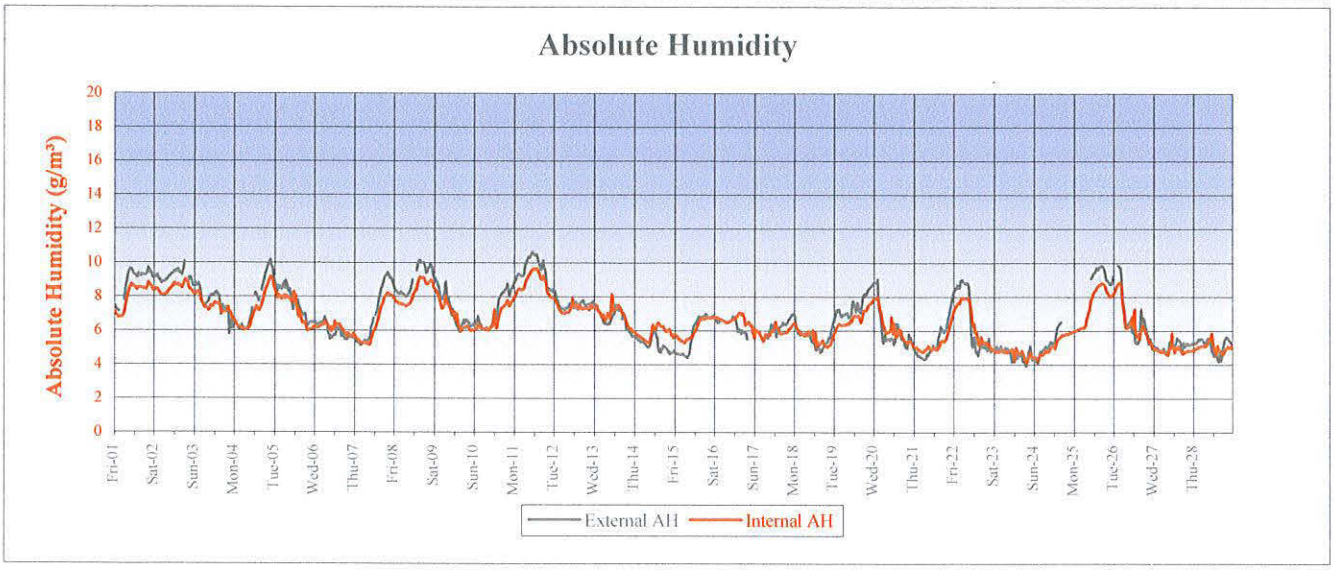
Peterborough Cathedral Nave Ceiling

February 2002

Probe 5: Bay 33 III upper side (sun)

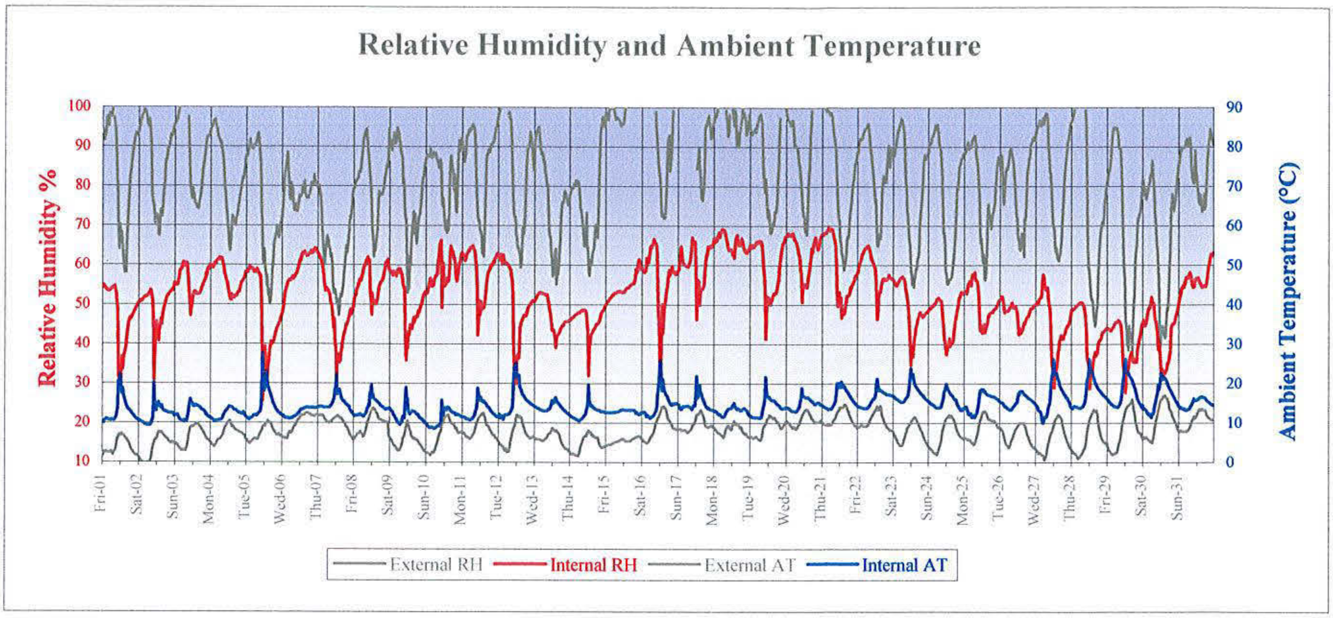


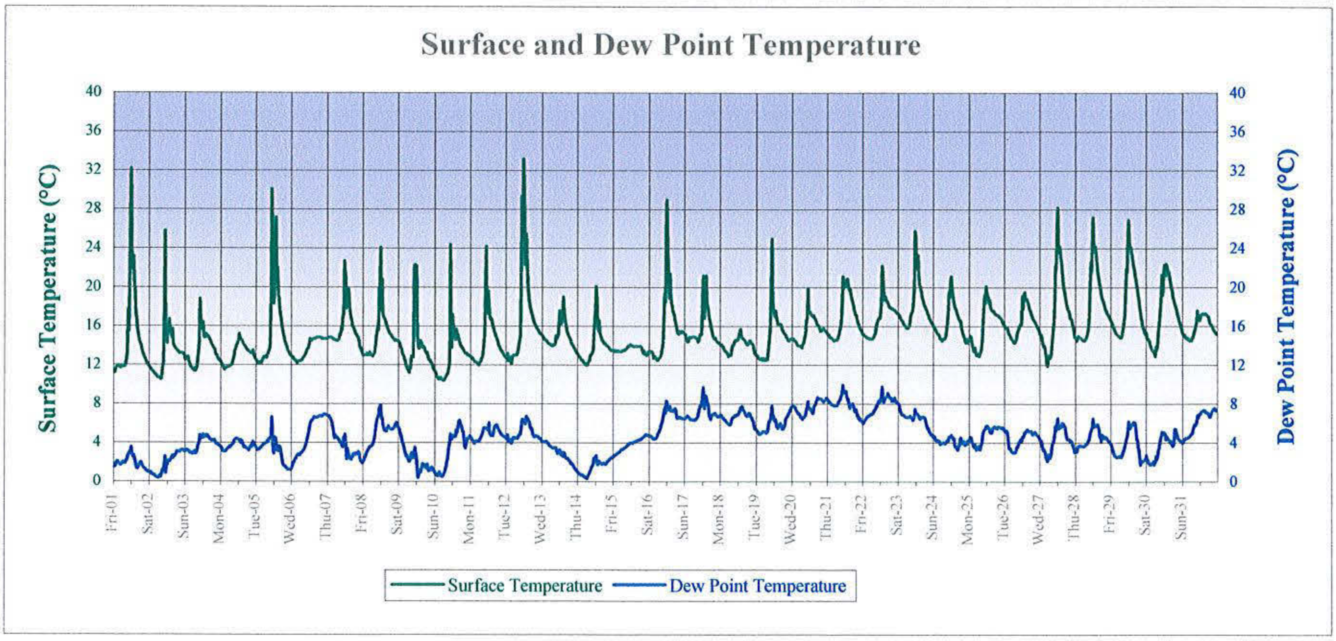


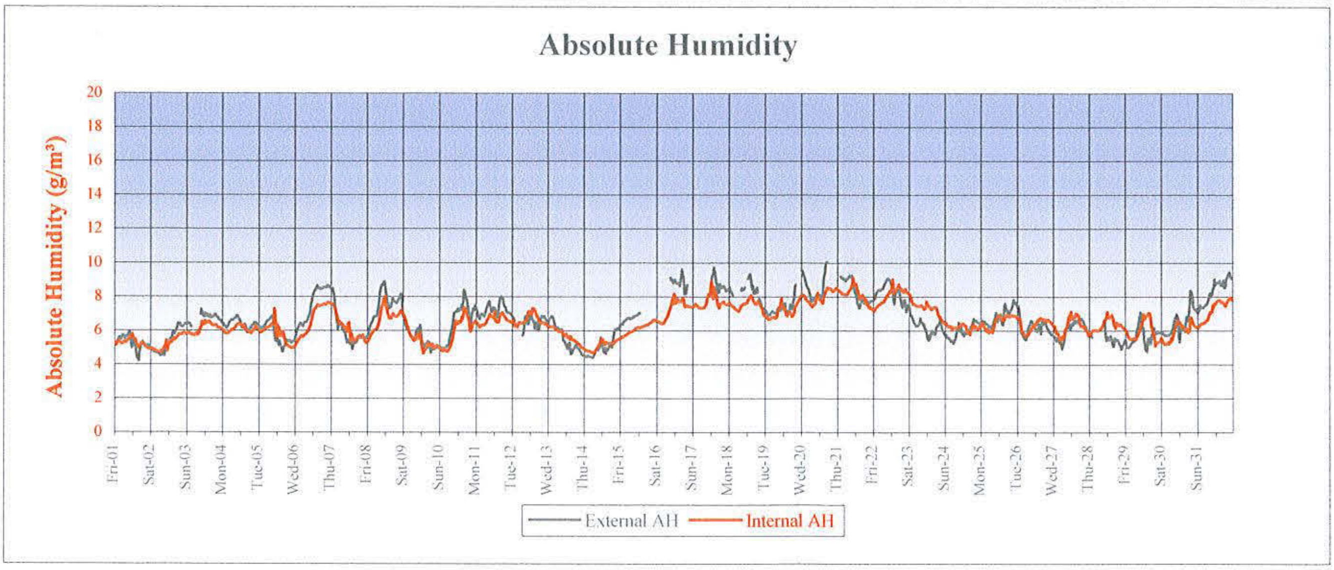


Peterborough Cathedral Nave Ceiling

Probe 5: Bay 33 III upper side (sun)



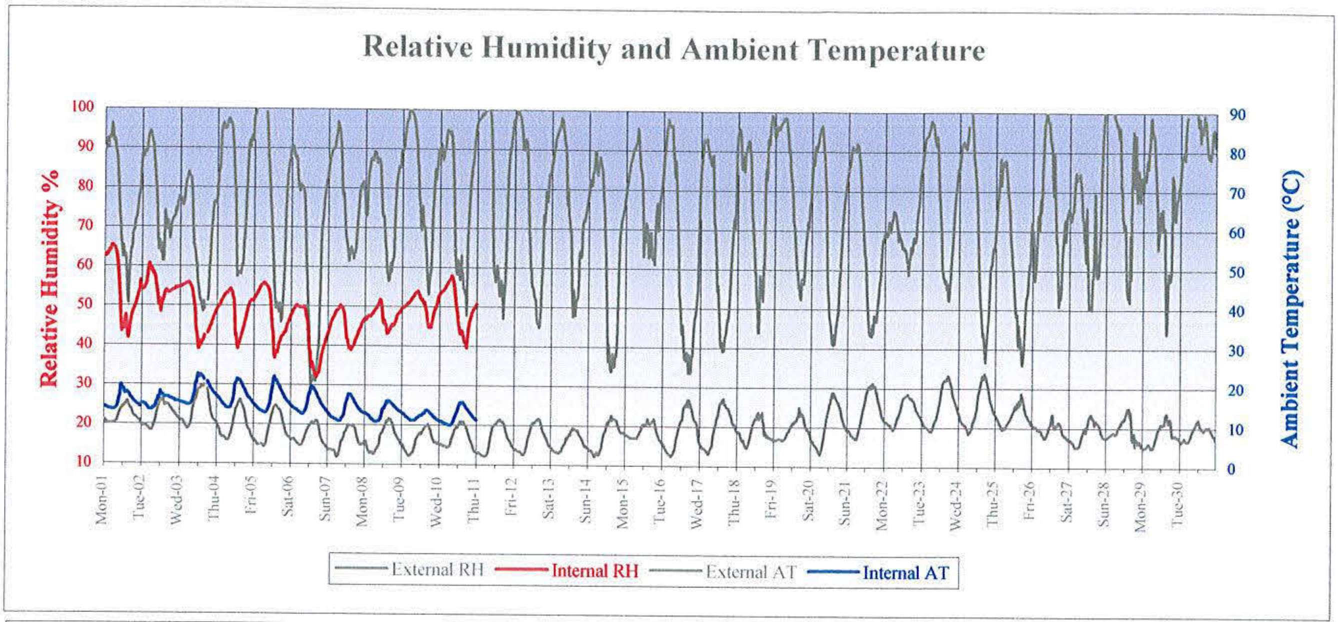


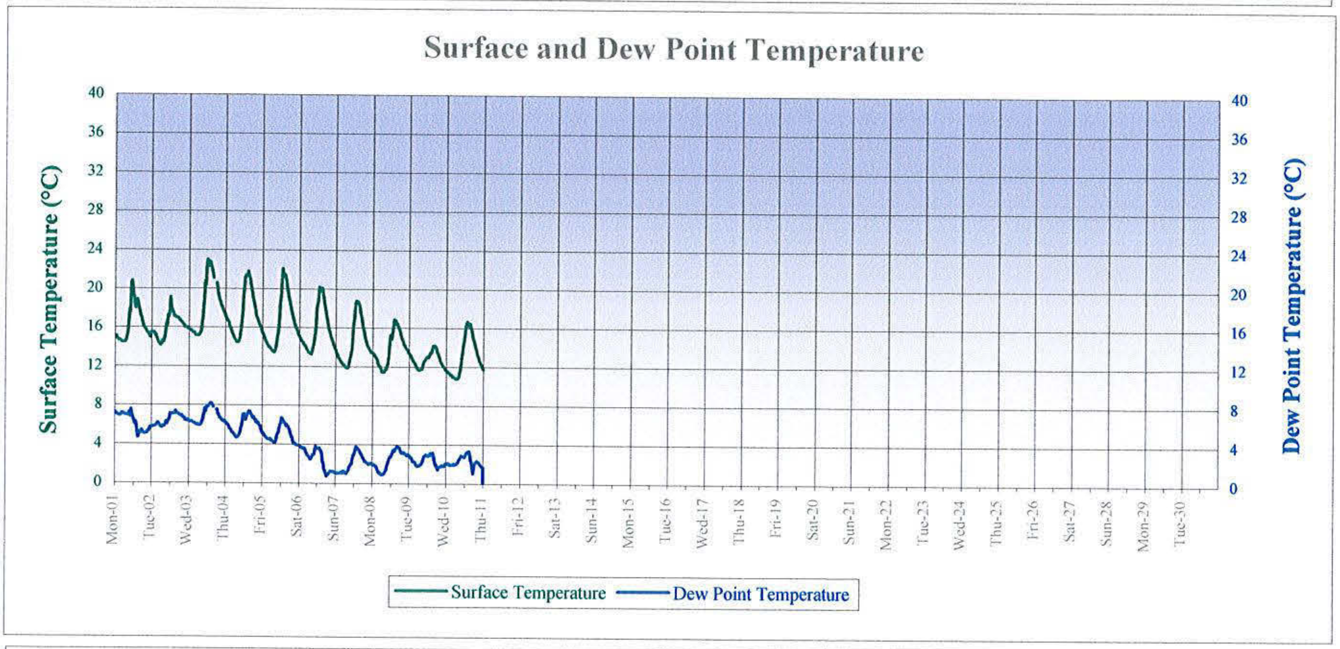


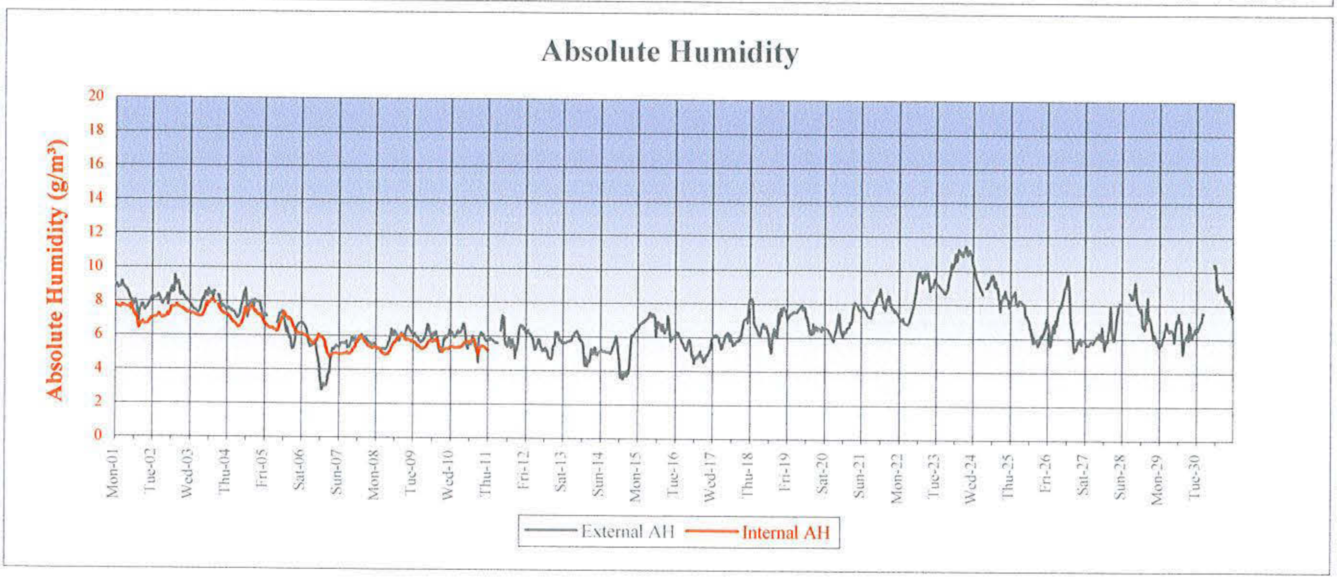
Peterborough Cathedral Nave Ceiling

April 2002

Probe 5: Bay 33 III upper side (sun)







Peterborough Cathedral Nave Ceiling

May 2002

Probe 5: Bay 33 III upper side (sun)