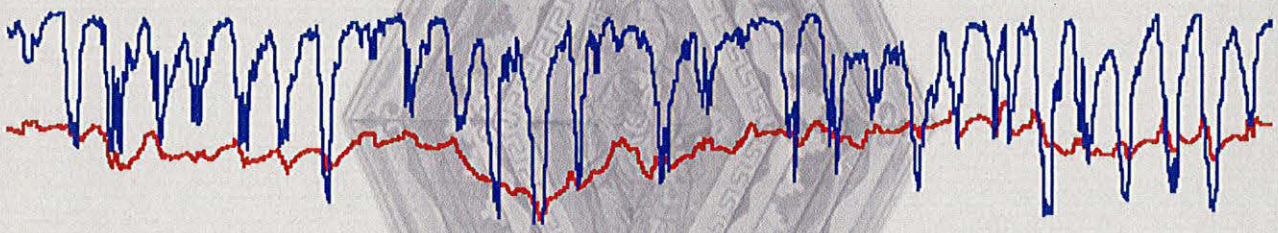
TOBIT CURTEIS ASSOCIATES

PETERBOROUGH CATHEDRAL



ENVIRONMENTAL MONITORING OF THE NAVE CEILING

JUNE 2002 – OCTOBER 2003

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CONTENTS

Report No: PTB01.2

Date: 28th November 2003

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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. I am 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

The environmental monitoring programme has been carried out as part of the conservation of the 13th century painted ceiling. The present report marks the conclusion of the full monitoring programme.

As had been shown in previous years, the conditions above and below the ceiling varied significantly (due to dramatically different heating and ventilation levels), placing significant stress on the thin wooden boards. The most extreme conditions occurred when direct sunlight from the glass panels in the roof fell directly onto the back of the boards. This effect has now been successfully eliminated by the installation of wooden panels in front of the glass along the whole of the south side of the roof.

Despite the apparent propensity for the conditions above and below the ceiling to cause structural movement and damage to the paint layer, little or no such deterioration had been observed. Tests carried out to assess the actual movement in the boards showed that short term microclimatic fluctuations caused almost no movement. However, a change in relative humidity over a period of about five days or more, did cause low level movement (this period is shorter than had previously been recognised). The fact that such movement did not cause the paint to delaminate appears to be due to the ability of the paint layer to absorb this level of movement. It is possible that in the long term the paint layer may become more brittle and this flexibility will be reduced.

The results of the light monitoring showed that lux levels were acceptably low, even when work was taking place on the ceiling. UV radiation (from daylight and tungsten halogen sources) were somewhat higher than the recommended levels. However given the low level of photosensitivity of the paint layer, it is not anticipated that this will cause any short term damage. Nevertheless, the design of the proposed lighting system should include suitable filters in order to reduce the UV levels.

2.0 INTRODUCTION

Since the mid 1990s, the early 13th century painted ceiling at Peterborough Cathedral has been undergoing a major programme of research and conservation. The conservation work has included a detailed environmental survey in order to assess how the microclimatic conditions have caused the ceiling to deteriorate.

The initial phase of environmental monitoring demonstrated that there were major variations in the microclimate 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. [1] As a result, 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.

Despite these extreme 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. Further research suggested that variations in conditions of between 20 and 30 days would be needed for dimensional change to take place and that diurnal

Figure 1. General view of the ceiling. *Photo: English Heritage 1998*

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

fluctuations would have almost no effect. The data suggested that in particular, during the winter months, such prolonged conditions could occur, which might result in a slight concave deformation of the boards, causing in the mild compression of the paint layer.

In order to examine this phenomenon in more detail the movement tests were continued for a further year and a half, and the results are discussed below. In addition, a system was put in place to measure the light levels in order to determine whether they were likely to have an effect on the long term conservation of the ceiling. During the course of the present phase of work, the monitoring system was expanded to include the area around the organ pipes, in order to provide background data for the conservation of the organ.

The present report includes the results for a period of seventeen months from July 2002 to October 2003. It is anticipated that this will be the final phase of diagnostic monitoring, although the monitoring of light will continue, in order to provide base data from the proposed new lighting system. In order to place the current results in context, certain material from the previous reports is reproduced below.

3.0 EQUIPMENT AND PROGRAMME

3.1 MONITORING METHOD AND DATA PRESENTATION

The parameters measured within the cathedral 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).

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

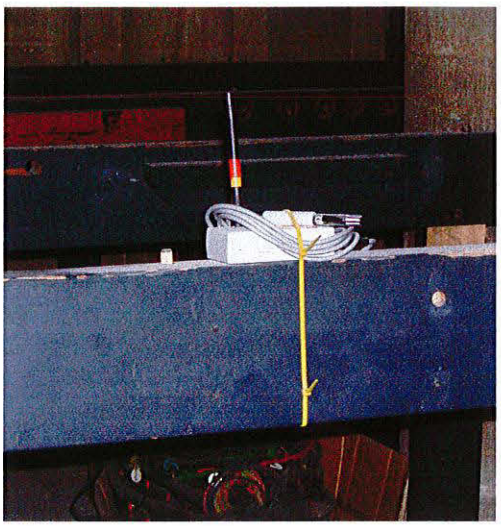

Figure 2: construction and mounting of the linear displacement transducers.

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 with Paraloid B72. The probe was then insulated using a small block of polystyrene. The external RH/AT probe was protected by a Stevenson screen.

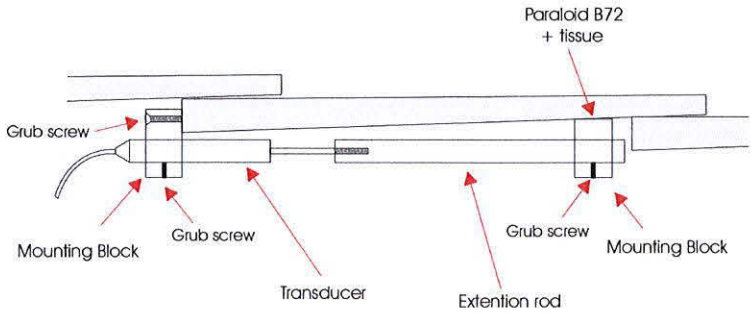

Figure 3: construction and mounting of the linear displacement transducers.

RH and AT were also measured in the vicinity of the frame for the organ pipes, in the north triforium gallery, in order to provide information for the future conservation of this structure.

The levels of movement in the boards in areas 7 IV and 8 IV, continued to be monitored throughout the period. 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

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

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

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 Plus 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] The current report includes the 17 months of data from June 2002 to the end of October 2003. It is anticipated that this will be the final phase of the full monitoring programme, although the monitoring of the light levels will continue, in order to provide baseline data for the proposed new lighting system.

4.0 ENVIRONMENTAL MONITORING

4.1 ARTIFICIAL INFLUENCES ON THE MICROCLIMATE

The main artificial influences on the microclimate in the vicinity of the ceiling are the heating system and the levels of ventilation.

4.1.1 Heating

Prior to the mid 19th century it is believed that 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 1)* 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]

The heaters are in use from approximately November until May. During the period that the heaters are active, they are run for twenty four hours per day usually at the full setting, although the half setting is occasionally used. The north east nave heater is not usually used, unless a particularly cold period occurs. Of the seven remaining units, all are usually used during the winter, although if the weather is mild, some are occasionally turned off. [7]

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[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 conversion to 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.

[7] *Pers Comm.* Nick Drewett

4.1.2 *Ventilation*

The second significant influence on the microclimate is the level of ventilation of the body of the cathedral and the roof space. The use of deliberate ventilation (opening windows and doors) in the cathedral itself is fairly restricted, and therefore the effects are limited.

However, in the roof space, the level of deliberate ventilation is far higher, as a result of the ventilation openings made when the roof was restored in the 19th century. *(Figure 3)* Insulation of the roof is limited and so the influence of the external conditions is very significant.

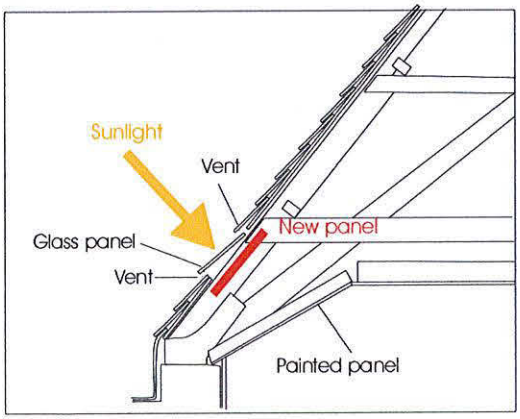
4.1.2 *Lighting panels*

At the same time, 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. *(Figures 4 & 5)* Rows 8 - 39 were covered in July 2002 and rows 1 – 7 were covered in October 2003.

4.2 *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 53.8% and 17.7°C (in the shade). The maximum and minimum RH levels were 81% and 30% while those for AT were 29°C and 13°C. Average diurnal fluctuations in the summer were approximately 9% and 3°C, while in the winter they were 5% and 1.5°C.[8]

The equivalent annual conditions in the roof space (in the shade) were 62.3% and 14.7°C. The maximum and minimum RH levels were 89% and 29% while those for AT were 32°C and 5°C. Average diurnal fluctuations in the summer were approximately 20% and 6°C, while in the winter they were 10% and 3°C.



Figures 5, 6 & 7. Panels above the windows on the south side of the nave roof *(Photo: TCA 2003)*.

As had been observed in previous years, there was a major variation between roof space conditions and those on the underside of the ceiling. In the roof space, the high level of ventilation and low level of thermal insulation meant that the microclimate fluctuated in accordance with the external conditions. In the summer, in particular, this meant that the diurnal conditions were extremely unstable. The condition on the underside of the ceiling were far more stable due to the low level of ventilation. In the summer, the primary factor destabilising the microclimate was the minor fluctuation in temperature, caused by the effect of the external conditions, and the resulting destabilisation of the RH. In the winter, the internal AT was controlled almost totally by the artificial heating, and therefore the conditions were generally extremely stable (although the RH below the ceiling was worryingly low in comparison to the conditions in the roof space).

In previous years, the conditions on both sides of the ceiling had been effected by sunlight coming through the glass panels on the south side of the roof. This had caused fluctuations in ST of up to 38°C with corresponding

[8] Diurnal fluctuations are based on visual estimates.

short term falls in the RH. However, as a result of the panels inserted in July 2002 and October 2003, this effect has been almost entirely eliminated.

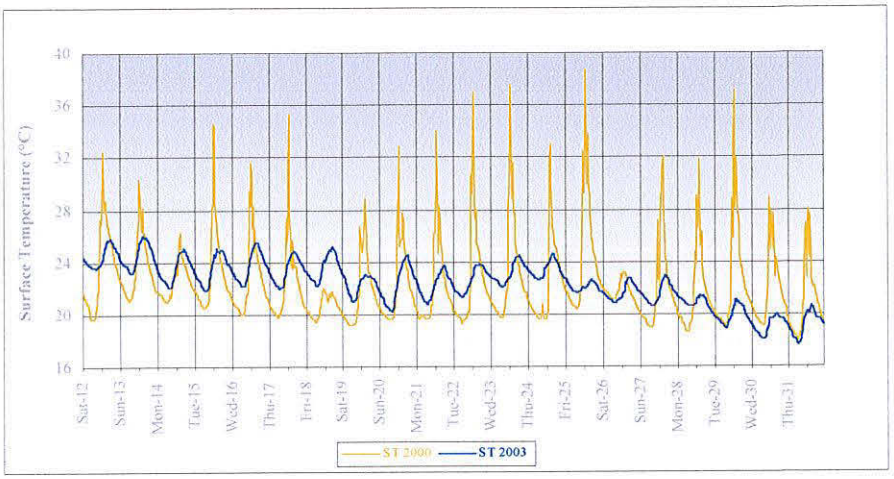


Chart 1. Surface temperature at Probe 3 in August 2000 and in August 2003, after the insertion of the window boards.

However, although the ST on the boards is no longer effected, the AT in the vicinity still shows a significant influence of solar radiation. The effect of the sunlight falling on the boards, is to heat them thus causing a warming of the surrounding air. This has an effect on the RH as would be the case with an increase in AT from any other source.

The fluctuation of the AT is not solely associated with the heating of the boards. The solar radiation on the tiled roof would also cause a significant increase in the internal AT due to the low level of thermal insulation. If one were to measure the ST of the interior face of the roof, short temperature peaks would be observed

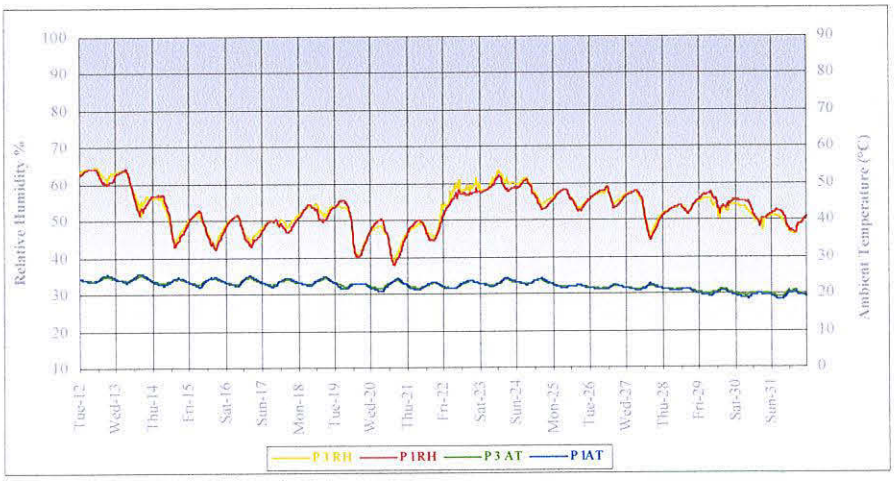


Chart 2. Following the insertion of the boards, the August relative humidity and ambient temperature at Probe 3 (previously in sunlight) are almost identical to those of Probe 1 (shade). Solar radiation on the uninsulated roof still causes significant fluctuations.

The results of the tests with the Linear Displacement Transducers in 2001/2002 demonstrated that low level movement did occur in the ceiling boards, in response to the changes in RH. However, the movement patterns were not particularly clear. Further tests carried out during the present monitoring period, demonstrated far more clearly the manner in which there was dimensional response to microclimatic fluctuations.

The boards showed little measurable movement in response to short term or diurnal fluctuations in the environmental conditions. However, longer term fluctuations in the microclimate were clearly reflected in the expansion and contraction of the wood. The precise response time was difficult to determine due to the relatively crude system of measurement. However, any significant changes in microclimate which lasted over approximately 5 days, appeared to have an effect.

As had been demonstrated in 2001/2002, the movement was proportionate and opposite to the change in RH. In other words, when the RH decreased, the boards expanded, and when it increased they contracted. This was far clearer in the current period than in the previous year. While the RH above and below the ceiling varies in level and short term patterns, the longer term patterns are similar. The upper, unpainted, sides of the boards, with their hessian and glue backing, are also far more porous and hygroscopic than the lower painted side. It is possible therefore that an increase in RH disproportionately effects the upper sides of the boards, causing a greater level of expansion as the RH increases, and thus creating a concave deformation on the lower sides. This may also be exacerbated by the methods of fixing from above.

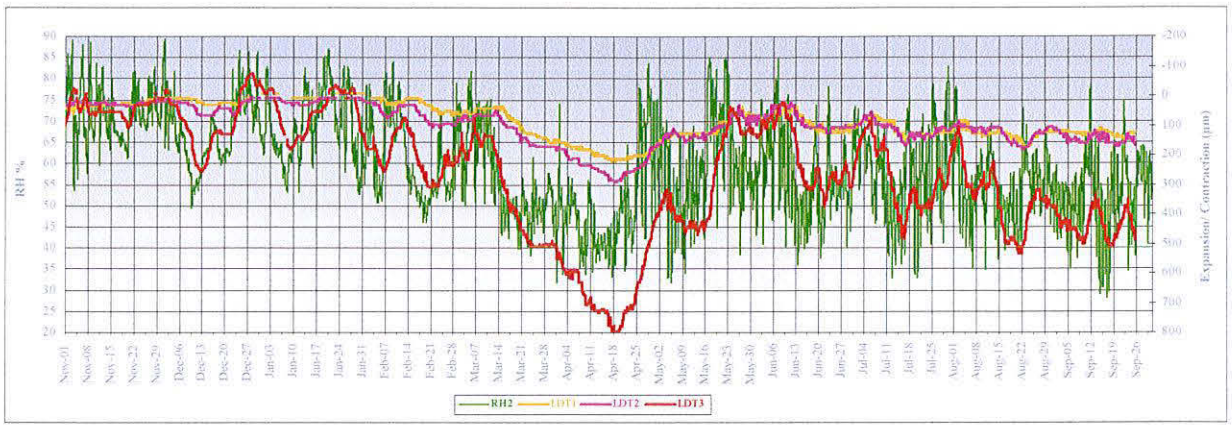


Chart 3. Movement in the boards plotted (in reverse) against the relative humidity in the roof space. A decrease in relative humidity can be seen to induce expansion in the boards.

As had been seen in the previous year, the level of movement in probes 1 and 2 (mounted on a pine and an oak board, respectively) were very similar, with a movement range of <300µm. Although the pattern of movement for probe 3 (mounted on an oak board), was similar, the range was far higher at <1000µm. No obvious difference between the two oak boards was observed and so it appears probable that the variation in movement levels is associated with the methods in which the boards are fixed.

Data collected from the area in the north triforium gallery by the organ pipes showed that the RH was significantly higher than at ceiling level. However, the AH level was similar (due to the similarly low level of internal/ external air exchange) and it was principally the fact that the AT was lower, which was responsible for the increase in the RH. The lower AT is presumably due to the passage of warm air from the stoves, which bypasses the gallery, and the cooling effects of the large north windows. The pattern of movement is extremely similar in the gallery and at the ceiling, and both areas show a relatively high degree of stability in the winter months (when the heating is in use). In the summer, there is a greater level of diurnal heating and cooling, which is reflected in a more unstable RH. However, the fluctuations in AT in the gallery are less than at ceiling level and therefore the RH is more stable at the level of the organ pipes than by the painting.

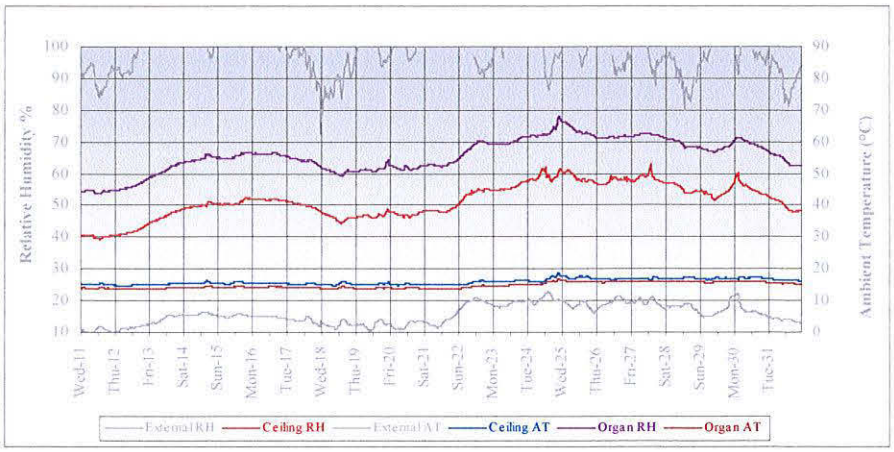


Chart 4. Conditions at the organ pipes (purple and brown) and on the ceiling (red and blue) in December 2003. Although the levels differ, the patterns are very similar

The light monitoring programme was complicated by the need to place the monitor within reach of the scaffolding, but outside the area over which the scaffolding would throw a shadow. These two requirements were to some extent incompatible as all points within reach of the scaffolding would be partially in shadow from one side (from both daylight and the ceiling lighting). The situation was further complicated in that the

scaffolding had to be moved during the period of monitoring, requiring the monitor to be moved. Furthermore, lighting used for the Phase V conservation work, inevitably had a considerable influence on the data. Therefore the collected data has a number of uncontrolled elements, and should not be regarded as a record of the general conditions, but rather an indication of the conditions during a particular phase of work. However, it does provide valuable background information for the light monitoring programme which is to continue now that the scaffolding has been removed.

Although the above complications make the correlation of specific light sources with lux and uv levels difficult, it is clear from the data that the level of light is relatively low. Even during the summer months, when work was taking place on the scaffolding, light levels rarely rose above 30 lux. Background daylight and ceiling illumination generally produced lux levels of up to 10 lux, while working lights usually resulted in lux levels of between 10 and 30. Very occasionally, peaks of approximately 80 lux occurred, when working light fell directly on the probe.

Although low lux levels were recorded from January 2003, UV radiation only became apparent in April, when the probe was repositioned in a location where it was exposed to the cathedral lights and indirect daylight from the clerestory windows. The upward facing lights at clerestory level are understood to be 1000w tungsten halogen lamps. This type of lamp is known to produce between 49-127 µw/lumen of UV radiation.[9] The suppression characteristics (if any) of the cover glass is not known. Daylight, even through standard glass, contains a far higher proportion of UV radiation, possibly up to 6 times as much radiation, as tungsten lighting.[10]

The actual proportion of UV recorded on the ceiling is generally in the region between 40 and 150µw/lm during the day, and the occasional peak over 200µw/lm. Between approximately 5.30pm and 9.30am, the UV level is generally 0. While this is above the recommended level for photosensitive materials (generally considered to be 75µw/lm), the paint analysis suggests that the painting is generally fairly robust in this regard, and these levels of radiation should have only a very limited deleterious effect.

It is interesting to note that the sharp increases in lux levels thought to be associated with the lighting for the conservation work, had little impact on the UV data, as the low power compact fluorescent lamps tend to have a lower proportion of UV than do the halogen lamps, and a far lower proportion than daylight.

5.0 DISCUSSION AND CONCLUSIONS

The data demonstrated once again, the extreme variation in conditions that regularly occurs above and below the painted ceiling boards, particularly during the winter months. This is largely due to the low ventilation, high level of internal/ external thermal buffering and high heating level in the body of the cathedral, in comparison to the level of ventilation and low level of thermal buffering in the roof space. As a result, the hygrothermal gradient across the boards is often extremely high. However, despite these conditions, there appears to have been very little associated deterioration of the paint layer.

Tests in previous years demonstrated that some minor movement was occurring, but the precise correlation between the microclimate and the dimensional response of the boards was unclear. The present data shows , very clearly, that when the relative humidity increases for a period of more that about five days, there is a consequent contraction in the painted surface boards. This is a significantly shorter period than was thought to be the case. Conversely, when the relative humidity decreases, the under side of the board expands. Although this reaction is, in many ways, counter intuitive, it appears possible that the reason is associated with the fact that the under side of the board is covered in oil paint and therefore less porous and responsive than the rear of the board which is covered in hessian and hygroscopic animal glue. Therefore, when the RH increases, the upper side of the board expands more than the lower side, causing a mild convex curve. Maximum movement is in the order of 200µm over a five day period, and an annual expansion contraction rage of up to 1mm, across the board. However, most movement is far lower than this. The only explanation as to why this does not cause the paint layer to delaminate is that the paint layer retains enough flexibility to absorb this level of movement. It is possible that over the long term, as cross linking of the medium increases, the paint layer may become more brittle and prone to crack or delaminate. In order to confirm this hypothesis, a more sensitive method of

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[9] Cassar, M. *Environmental Management, Guidelines for Museums and Galleries*, London (1995), Datasheet 4

[10] Thompson, G, *The Museum Environment*, London 1986 (2nd Ed)

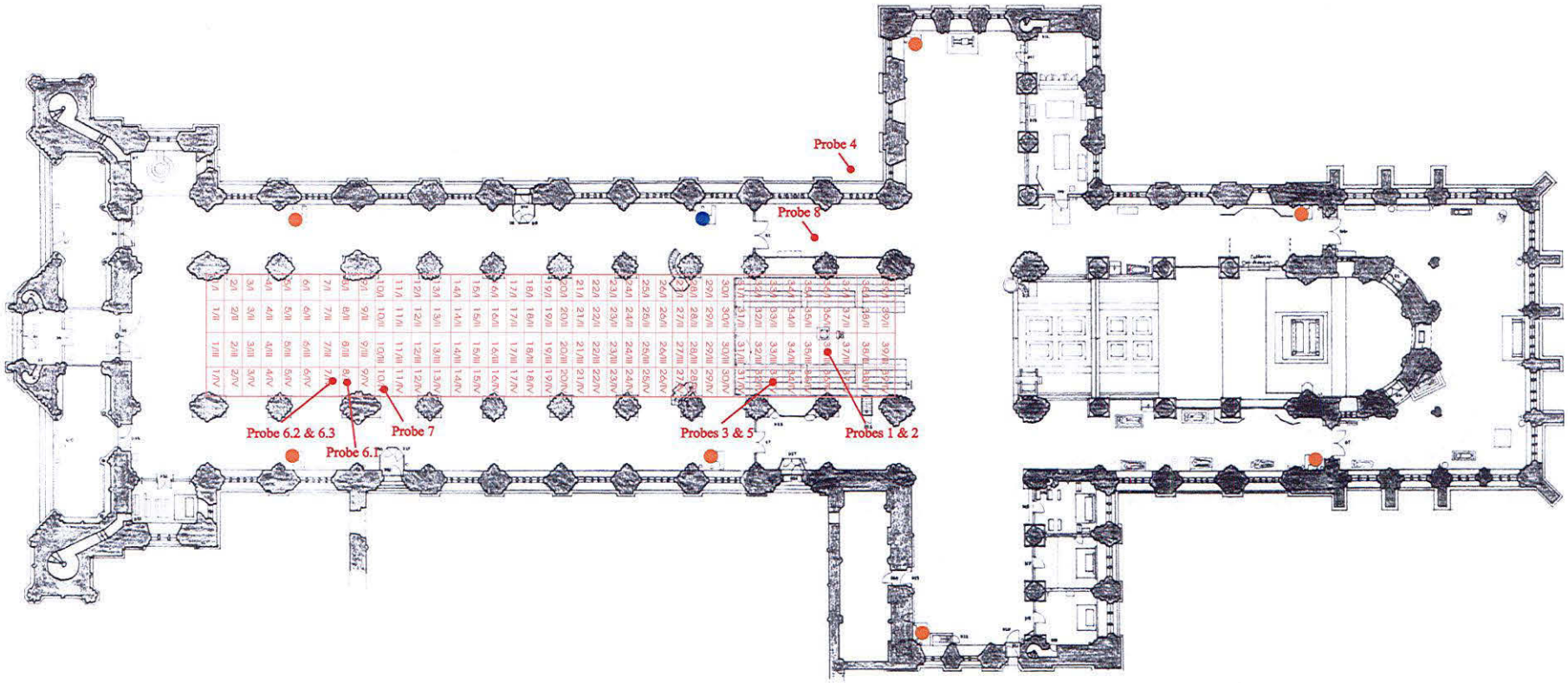
measurement would be necessary on both sides of the ceiling. However, given the present lack of recordable damage, further investigations do not appear to be justified at this stage.

In previous years, the effect of sunlight from the glass panels on the south side of the roof, has been to cause sudden fluctuations in temperature, sometimes up to 38°C, with consequent fluctuations in the relative humidity. In order to prevent this, wooden panels were inserted across the windows in 2002 and 2003. The effect has been to entirely eliminate these sharp fluctuations, creating a microclimate which is almost identical to areas of the ceiling which have always been in shade. The ventilation grills were not covered, so the hygrothermal buffering between internal and external conditions remains low, and as a consequence, the background microclimate remains unstable.

Despite the fact that much of the light monitoring was compromised by the necessity to move the scaffold, certain useful data was produced. The recorded lux levels, resulting from indirect daylight, tungsten halogen lamps and fluorescent working lamps, were fairly low and generally within the recommended levels in museums for photosensitive materials. UV levels are higher than recommended, but the analysis has demonstrated that the materials in 19th century paint layers are not particularly photosensitive. Therefore, although the conditions are far from ideal, there is no need to take immediate action. It was not clear from the data exactly how each individual light source is contributing to the current situation. However, now that the scaffolding has been removed and work has been completed, it is hoped that it will be possible to identify individual effects, more precisely. When the proposed new lighting system is installed, it is recommended that suitable filters are incorporated to ensure that the UV levels are minimised , and that the lux levels are kept relatively low.

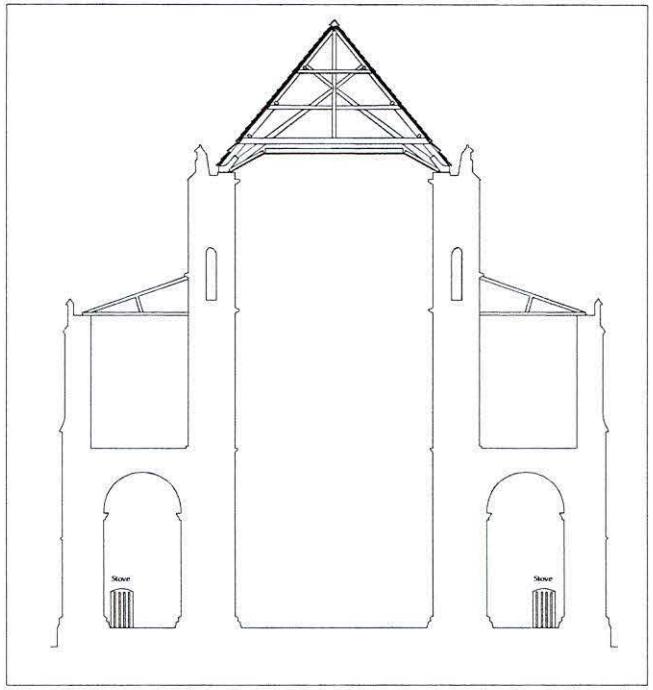
The present report marks the completion of the full monitoring programme. A final report drawing together the results and conclusions of the entire monitoring exercise is to be prepared in 2004, as part of the final report on the project as a whole. The UV and lux monitoring is to be continued for a further period so that accurate data will be available to assist with the design of the new monitoring system. Background relative humidity and ambient temperature monitoring will be continued in order that light data can be placed in a wider microclimatic context.

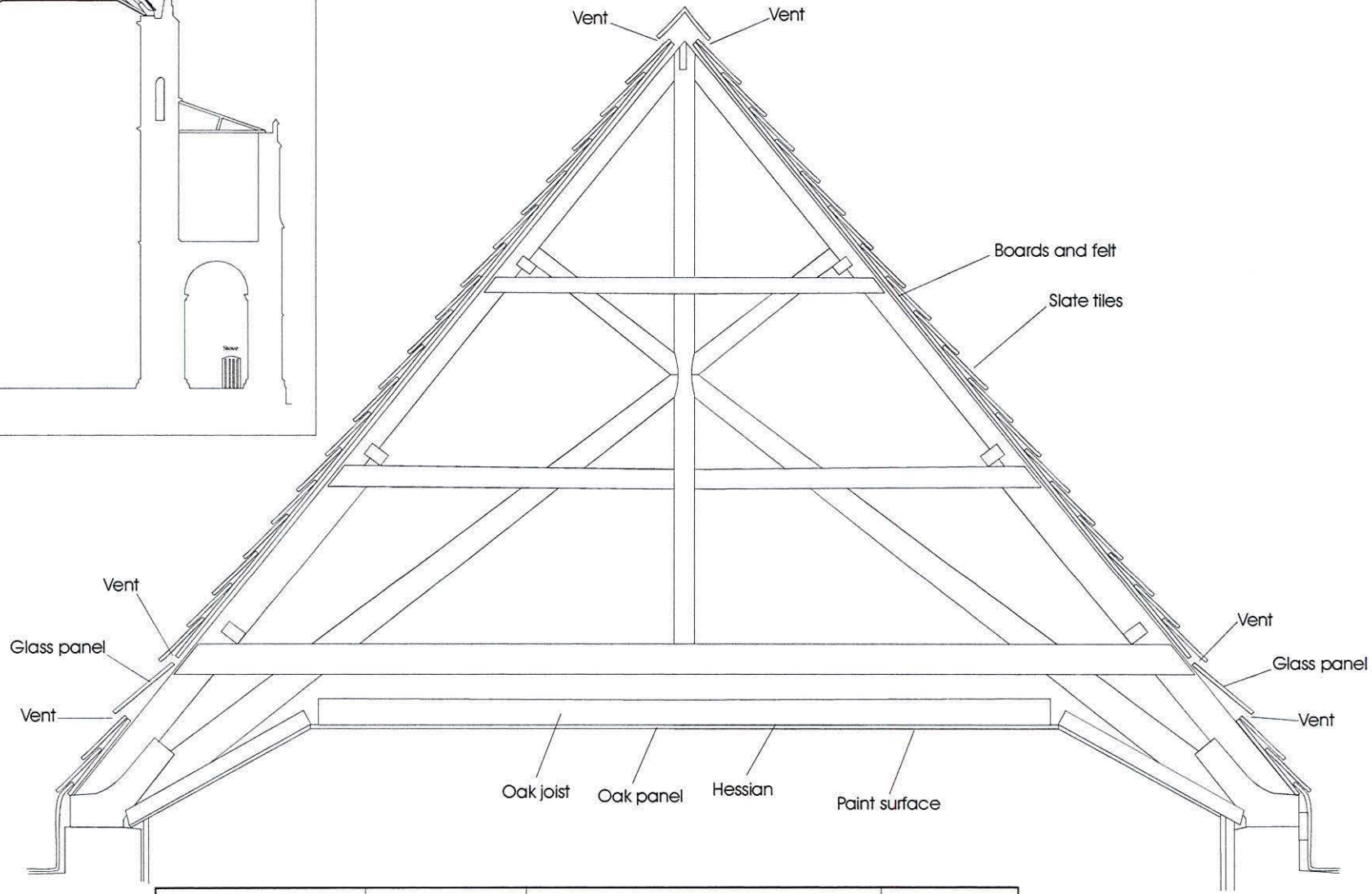
DIAGRAM 1



SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 10m 20m 30m	Full use stove
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: OCTOBER 2003	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	Occasional use stove Probe sites

DIAGRAM 2



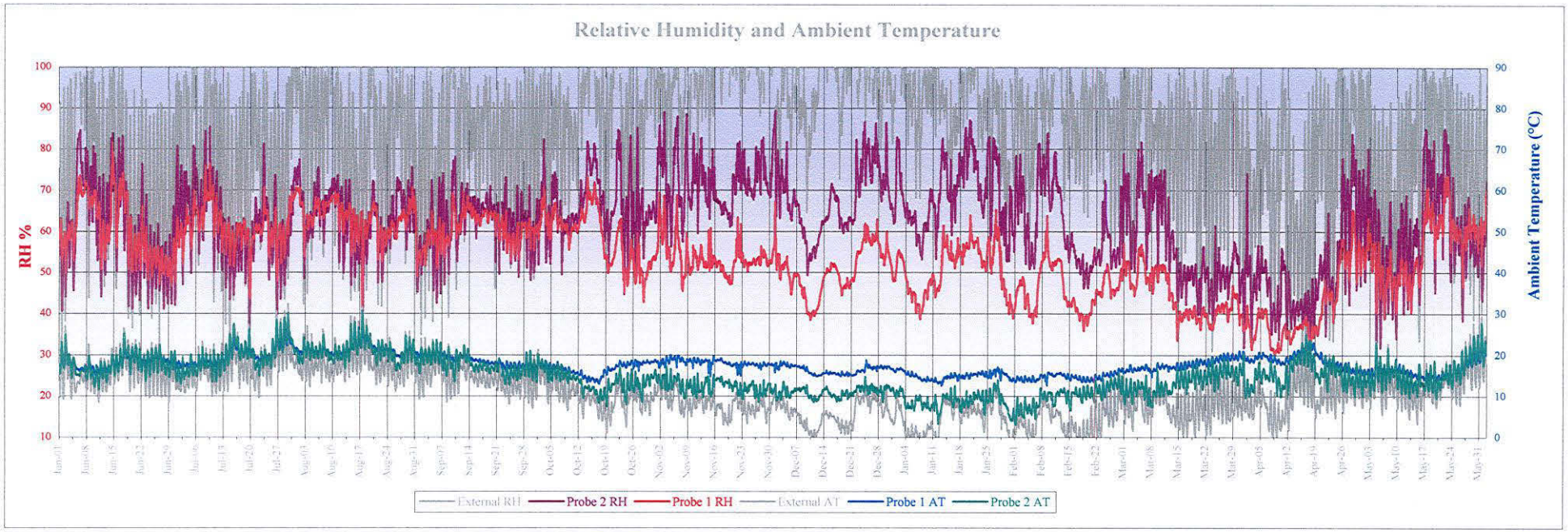


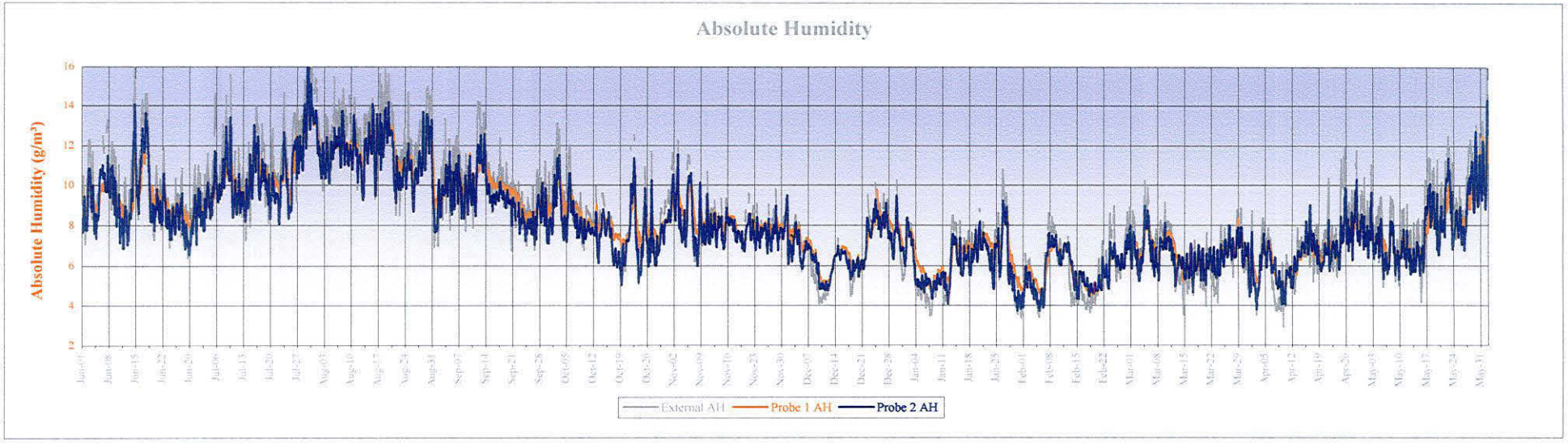
SITE: PETERBOROUGH CATHEDRAL	TYPE: PROBE AND STOVE LOCATIONS	0m 1m 2m 3m	
AREA: PLAN (BASE PLAN DRAWN BY JULIAN LIMENTANI)	DATE: OCTOBER 2003	TOBIT CURTEIS ASSOCIATES 36 Abbey Road, Cambridge, CB5 8HQ	

Peterborough Cathedral Nave Ceiling

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

June 2002 - May 2003



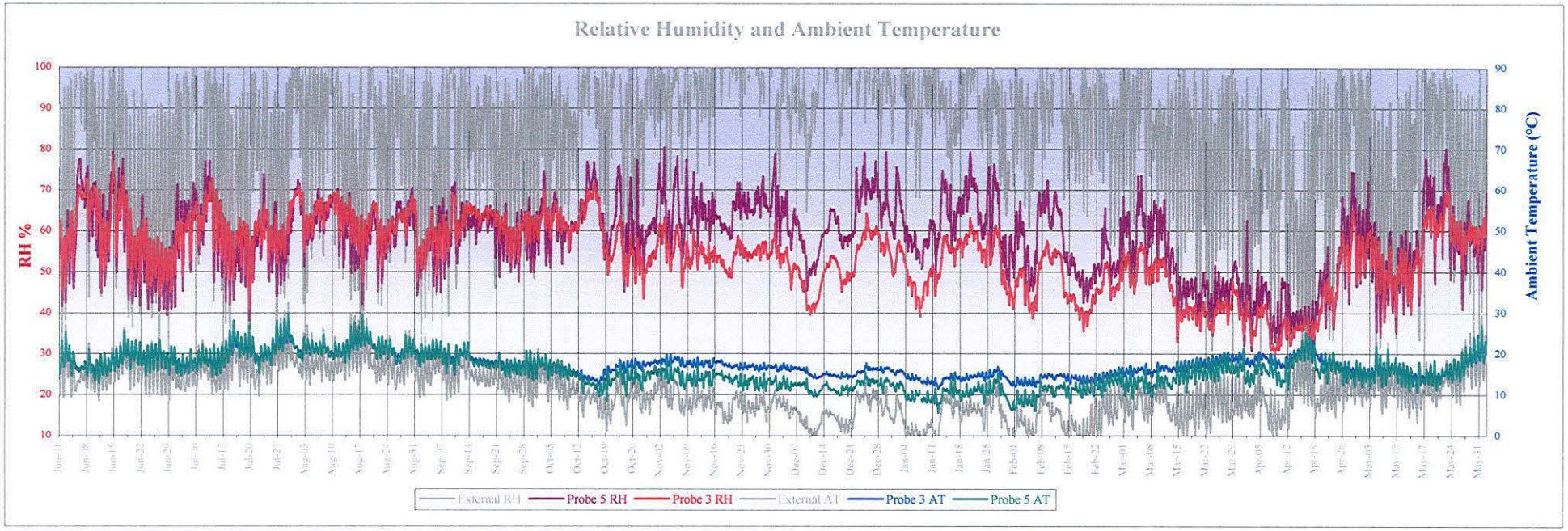


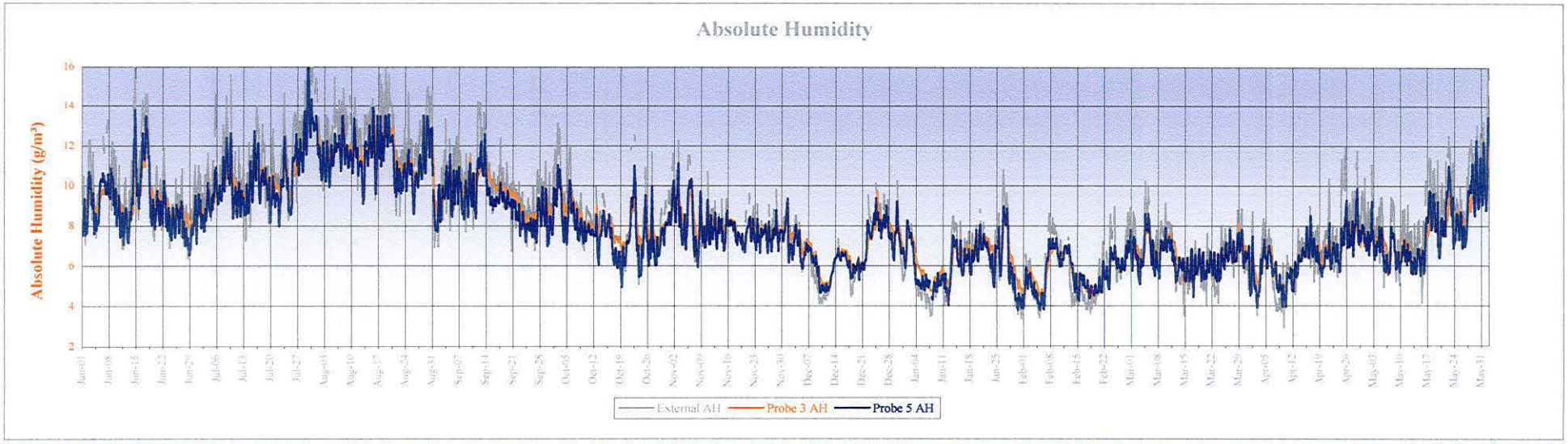
Tobit Curteis Associates

Peterborough Cathedral Nave Ceiling

June 2002 - May 2003

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

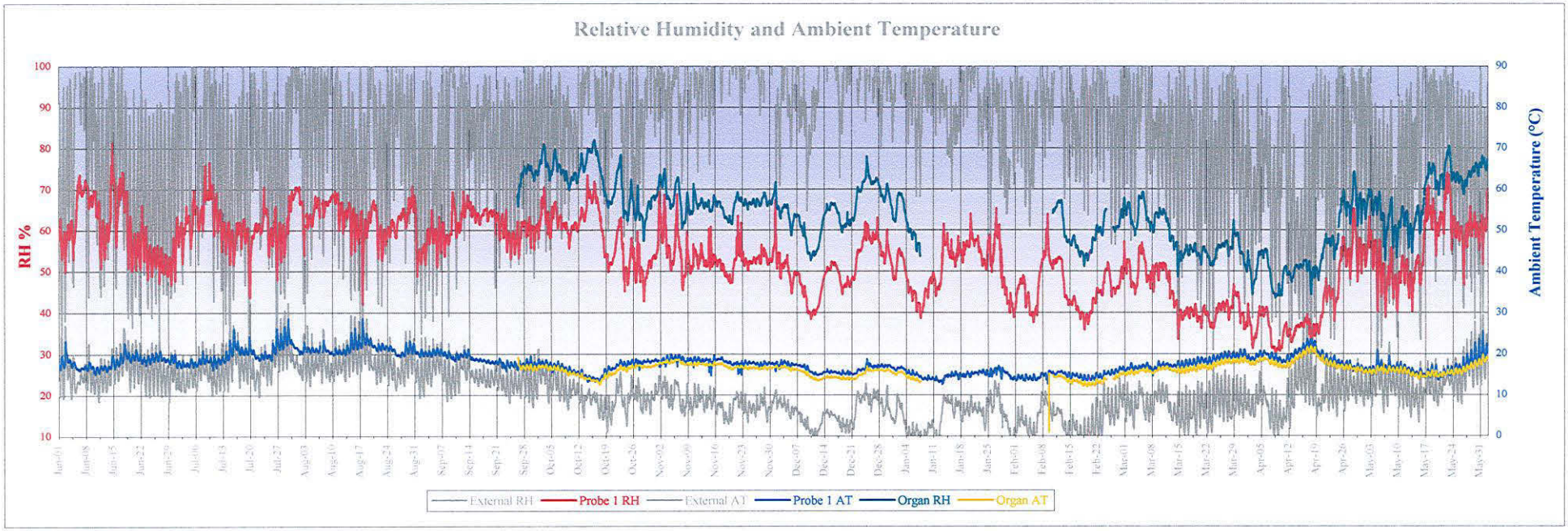


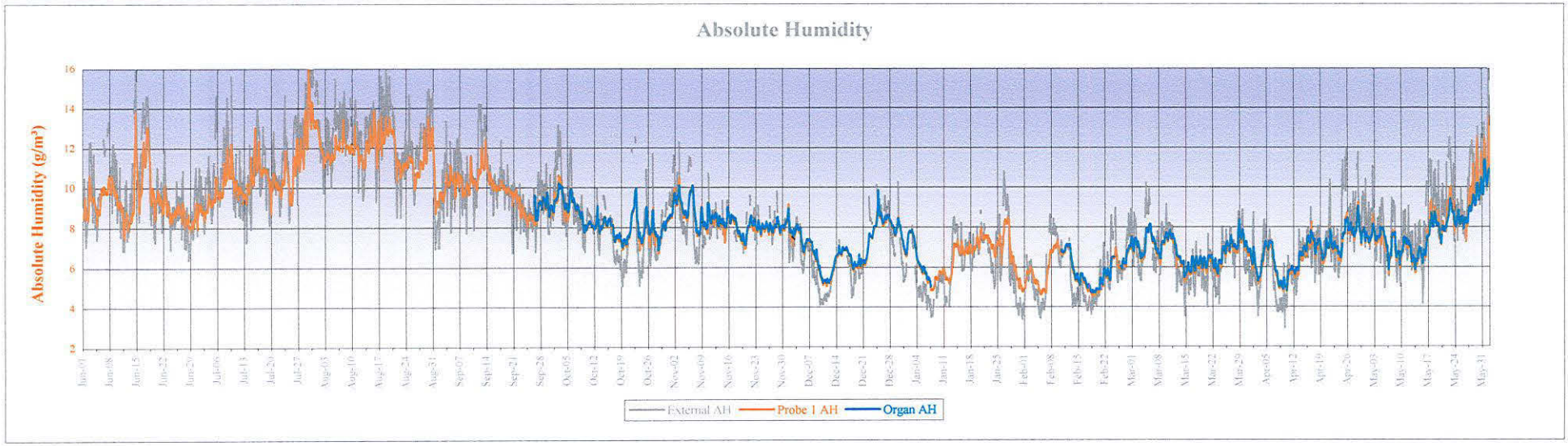


Peterborough Cathedral Nave Ceiling

Probe 8: Organ Pipes & Probe 1: Bay 36 III lower side

June 2002 - May 2003

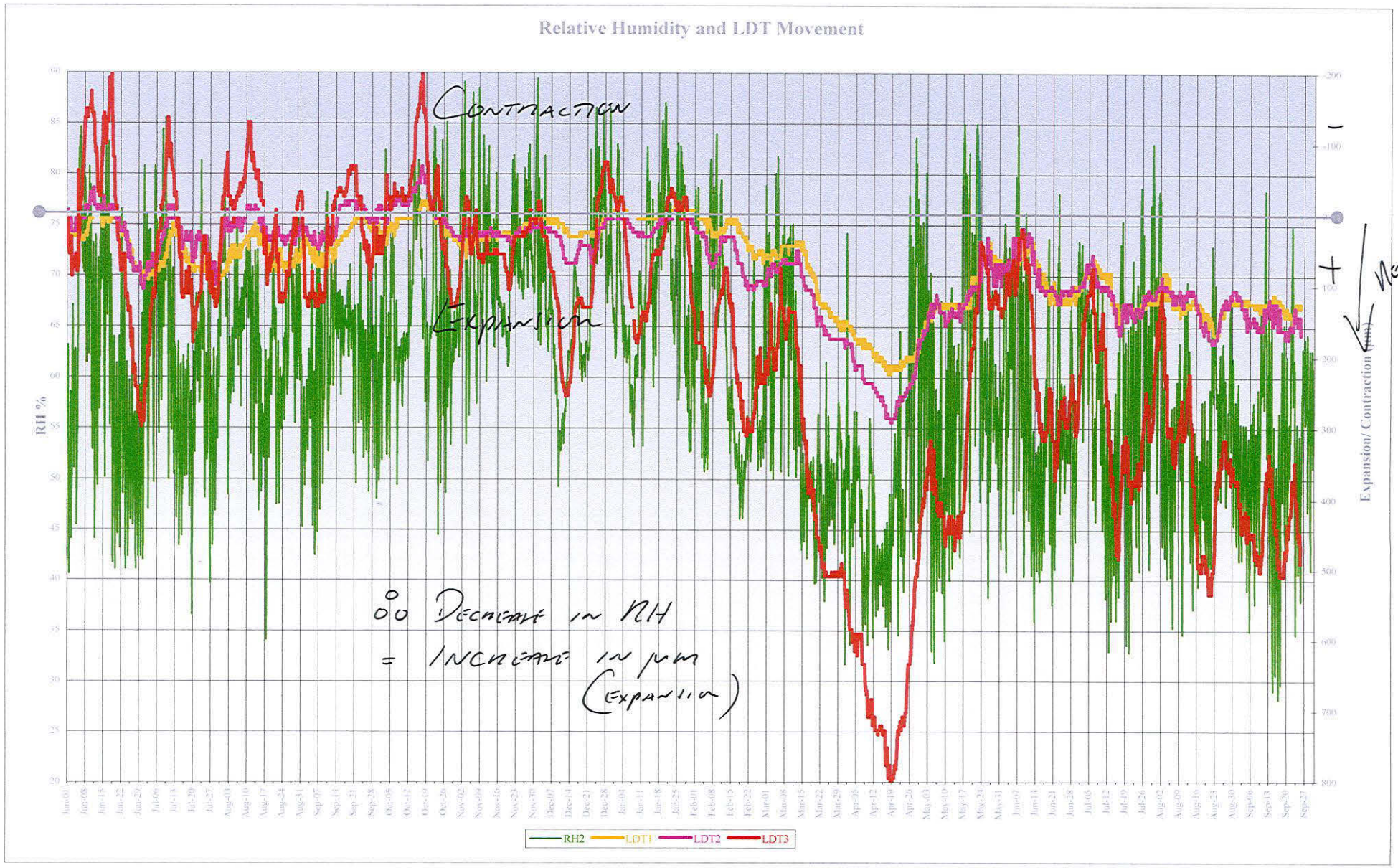




Peterborough Cathedral Nave Ceiling

Probe 2 & LDTs

June 2002 - September 2003

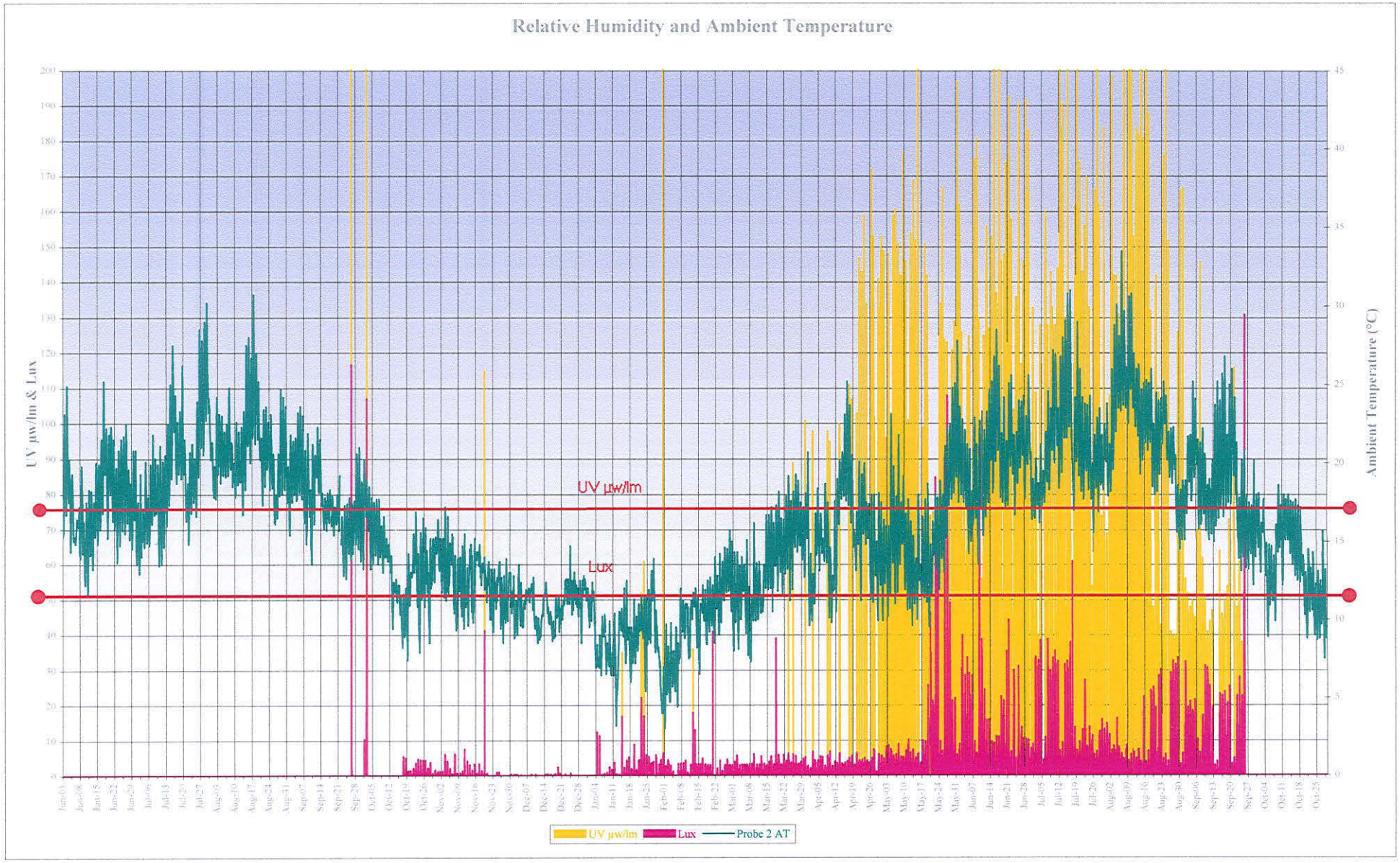


Tobit Curteis Associates

Peterborough Cathedral Nave Ceiling

Probe 7: UV & Lux

June 2002 - May 2003

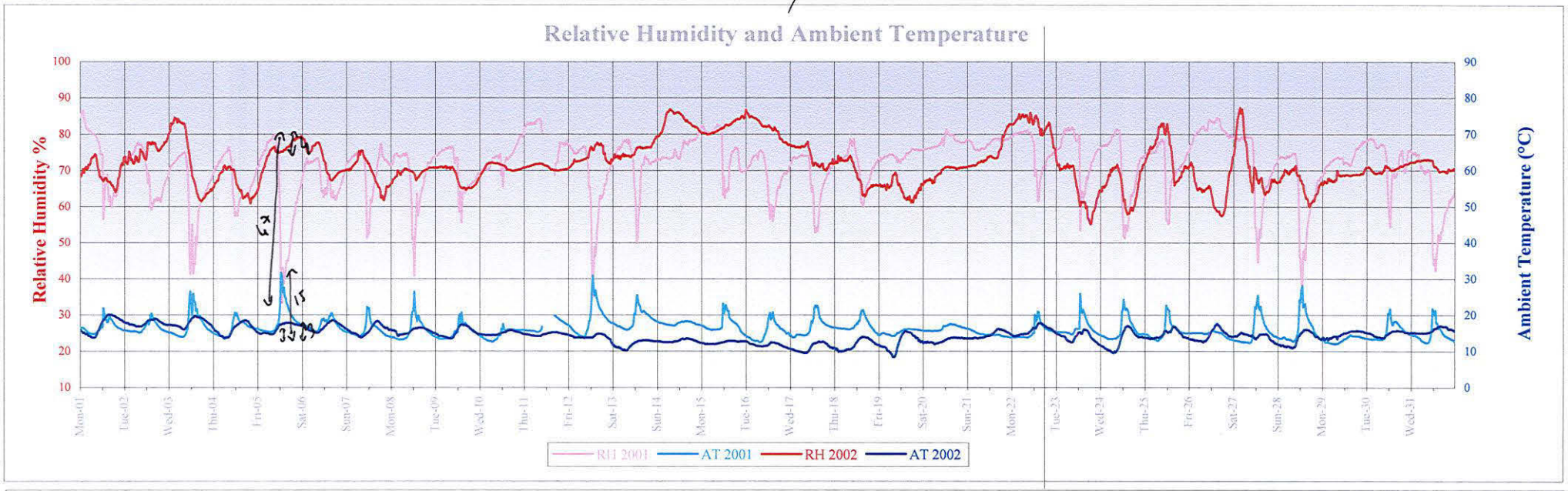


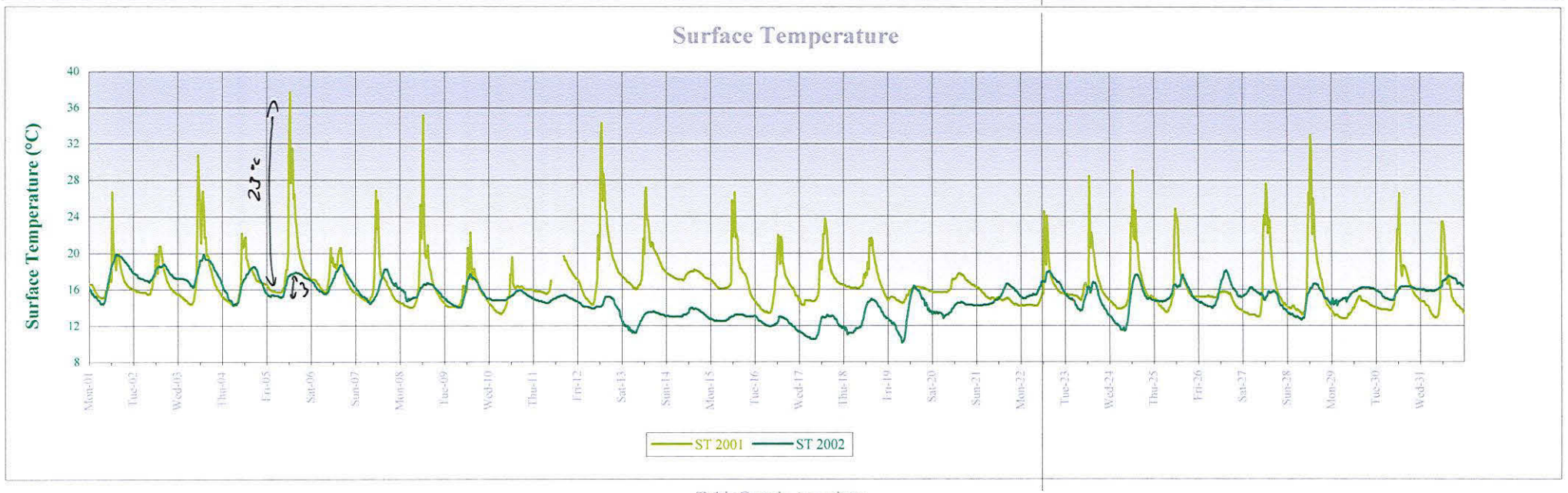
Peterborough Cathedral Nave Ceiling

Probe 5: Bay 33 III upper side (sun)

21st From July 2002

October 2001 & 2002





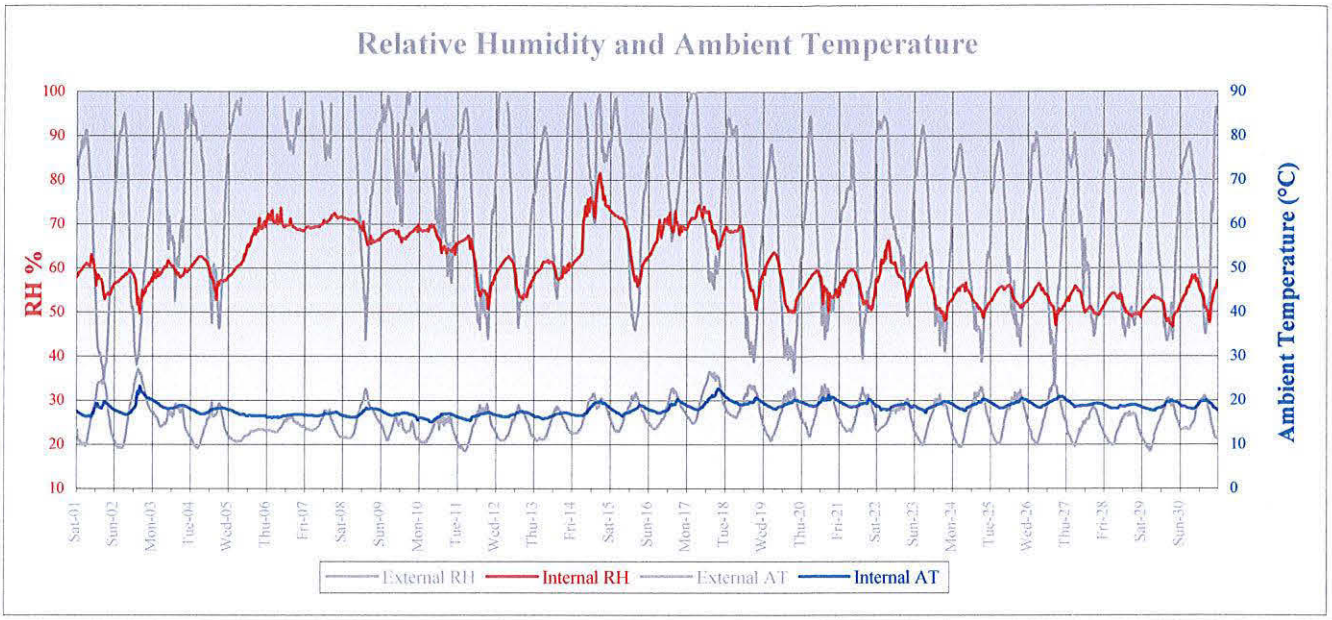
PROBE 1

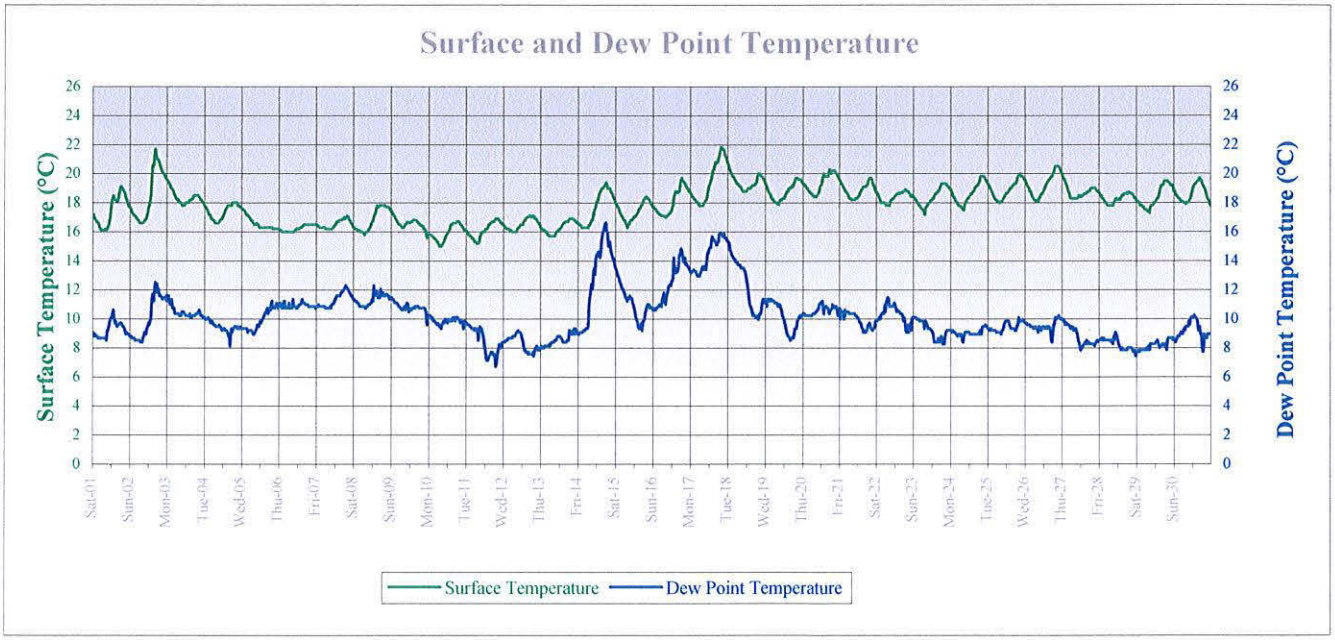
BAY 36 III LOWER SIDE (SHADE)

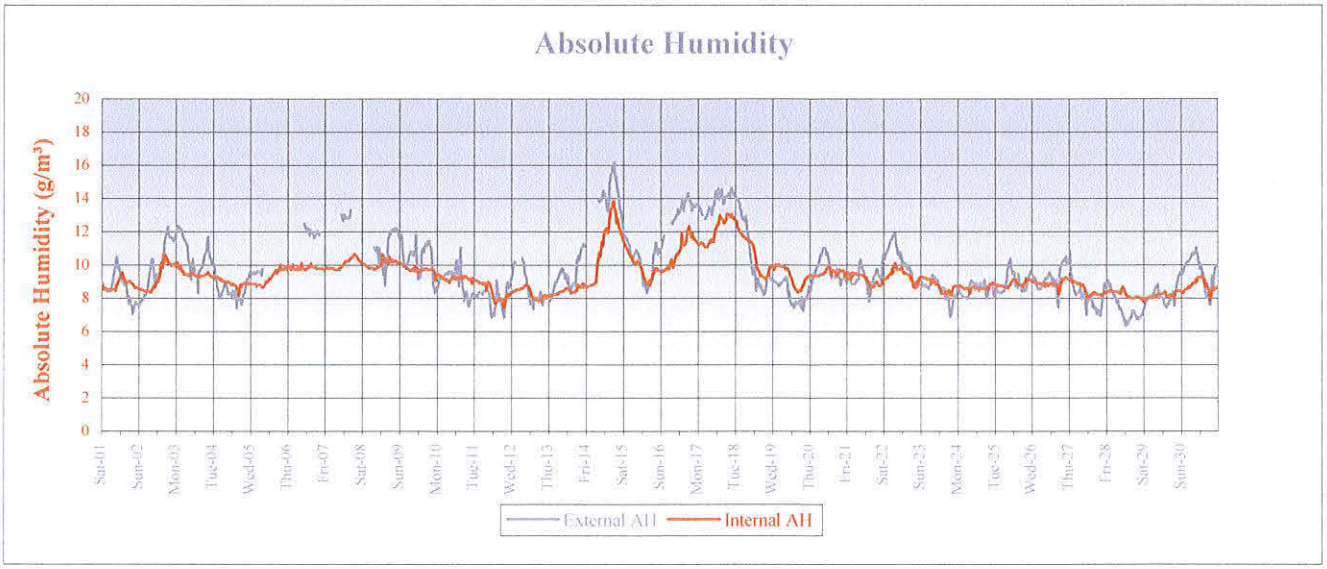
Peterborough Cathedral Nave Ceiling

June 2002

Probe 1: Bay 36 III lower side (shade)



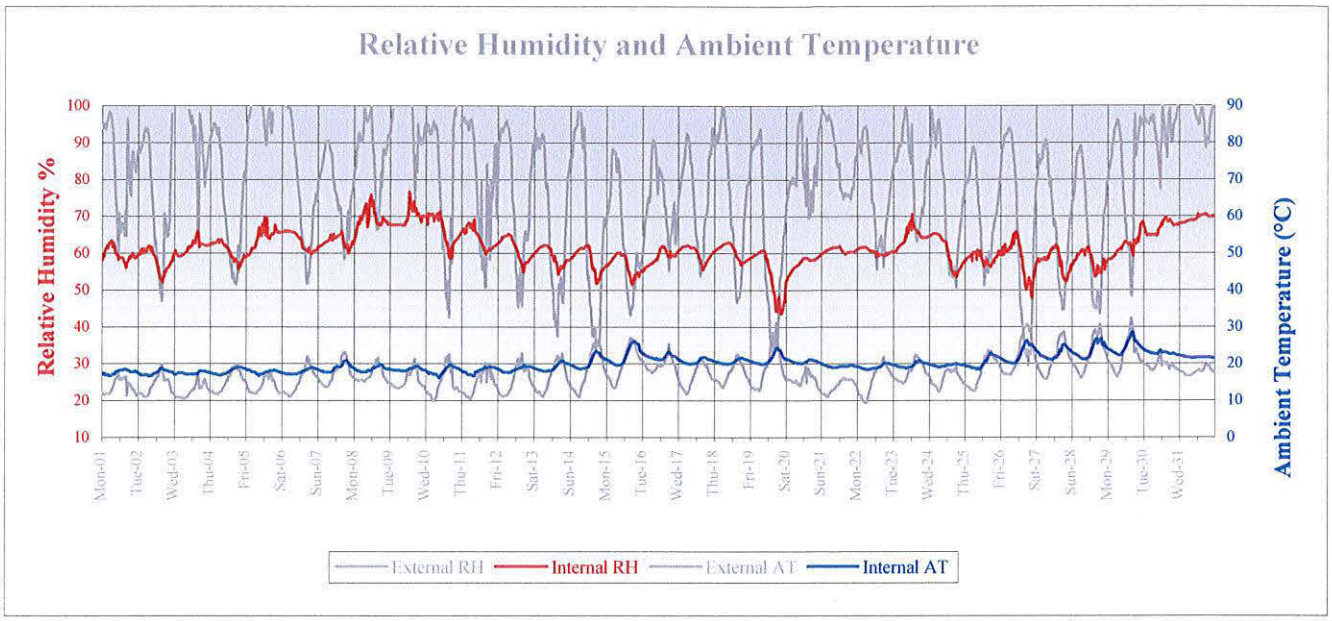


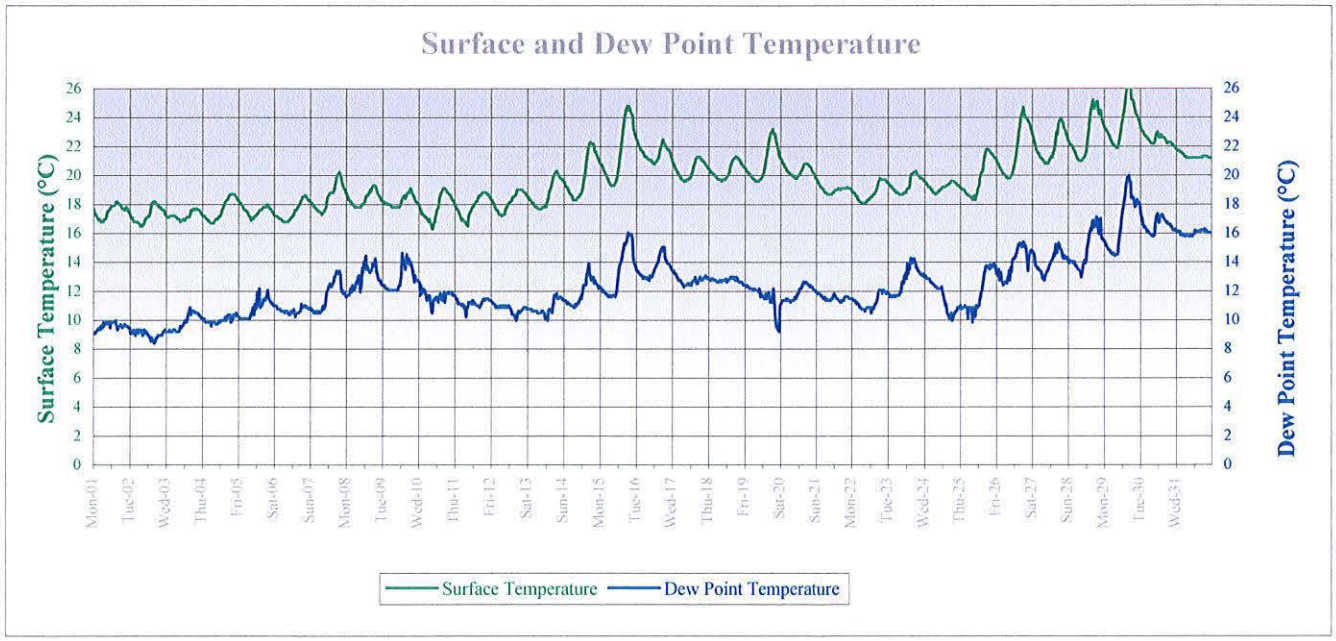


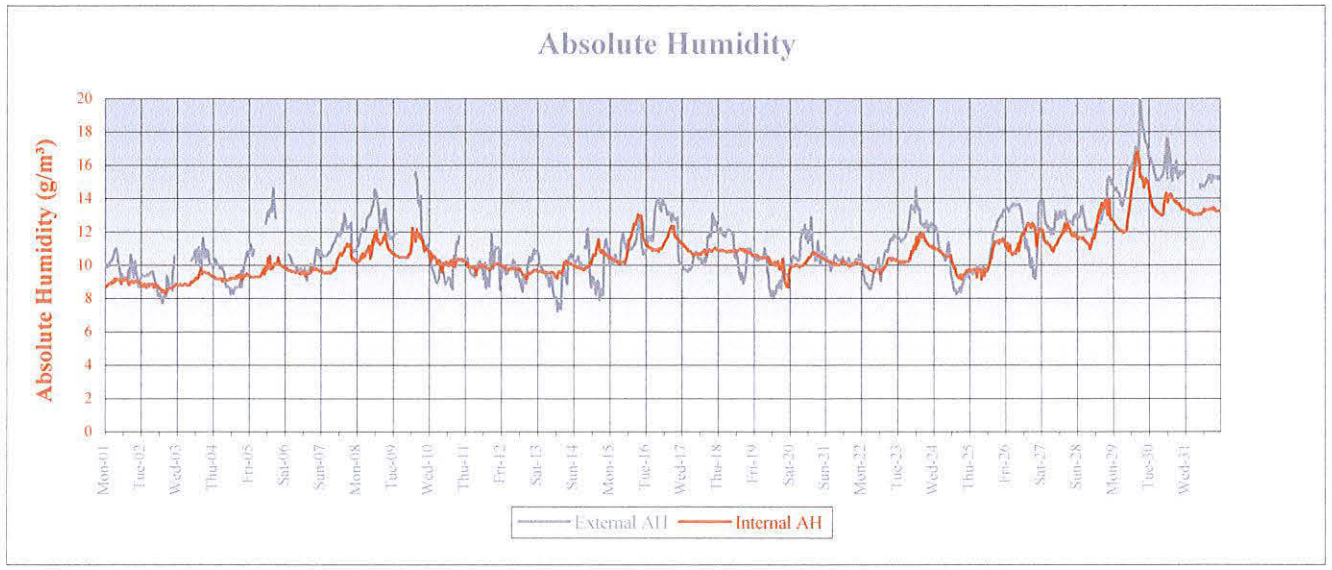
Peterborough Cathedral Nave Ceiling

July 2002

Probe 1: Bay 36 III lower side (shade)



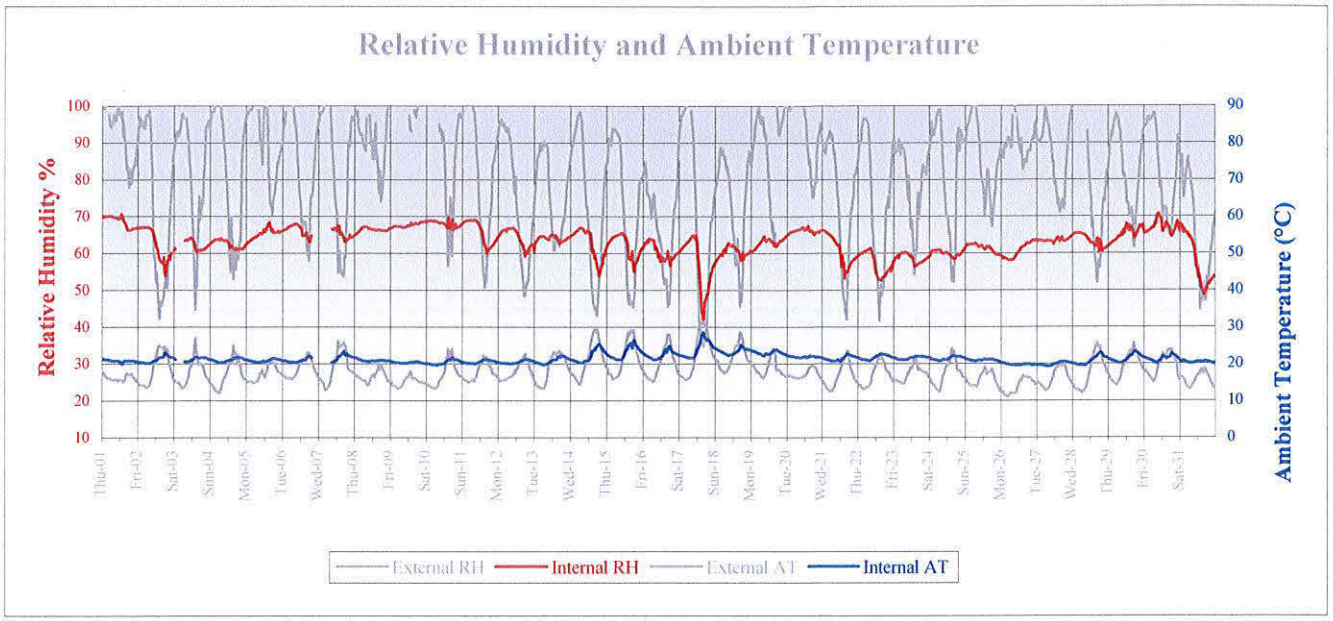


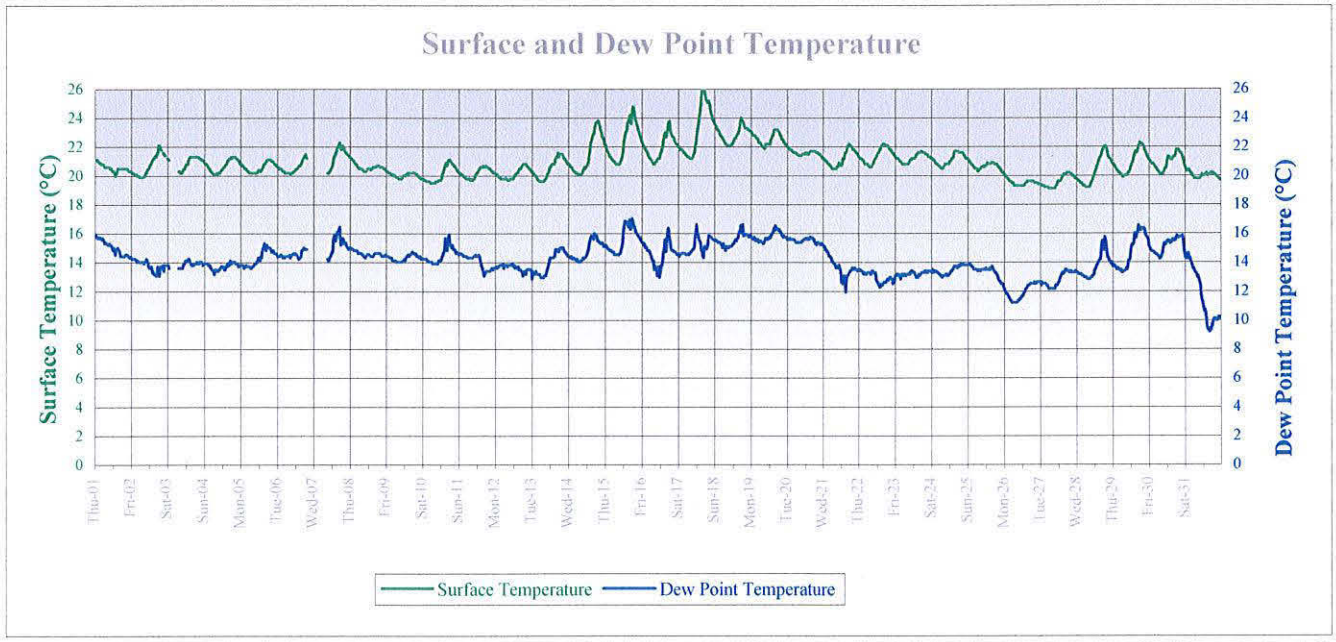


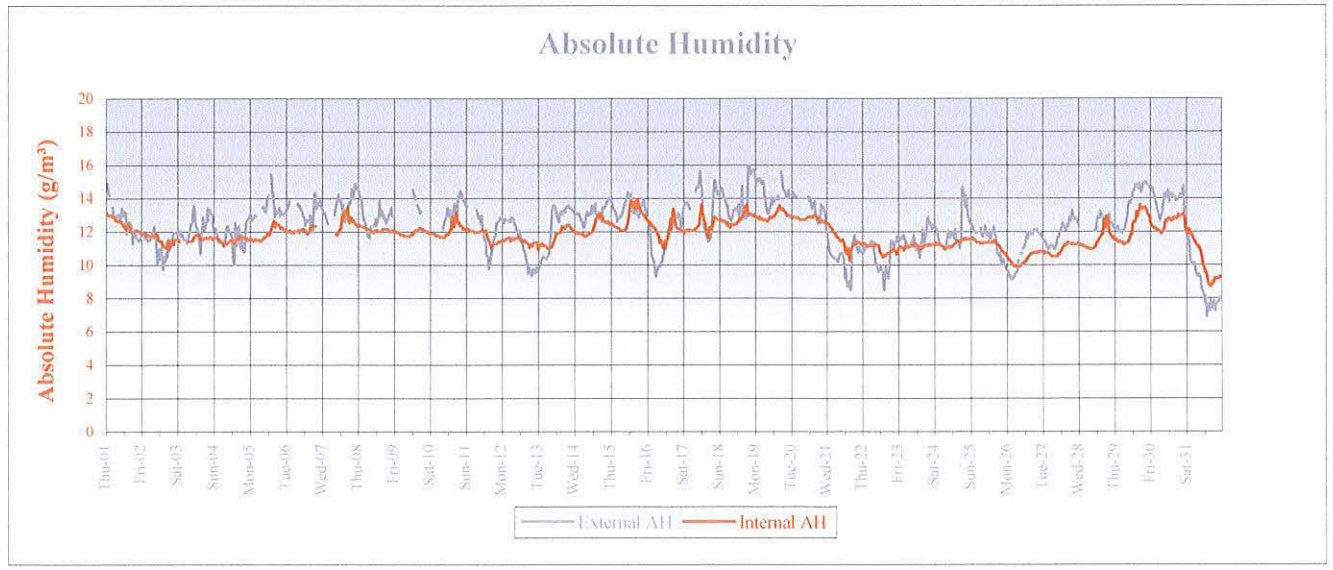
Peterborough Cathedral Nave Ceiling

August 2002

Probe 1: Bay 36 III lower side (shade)



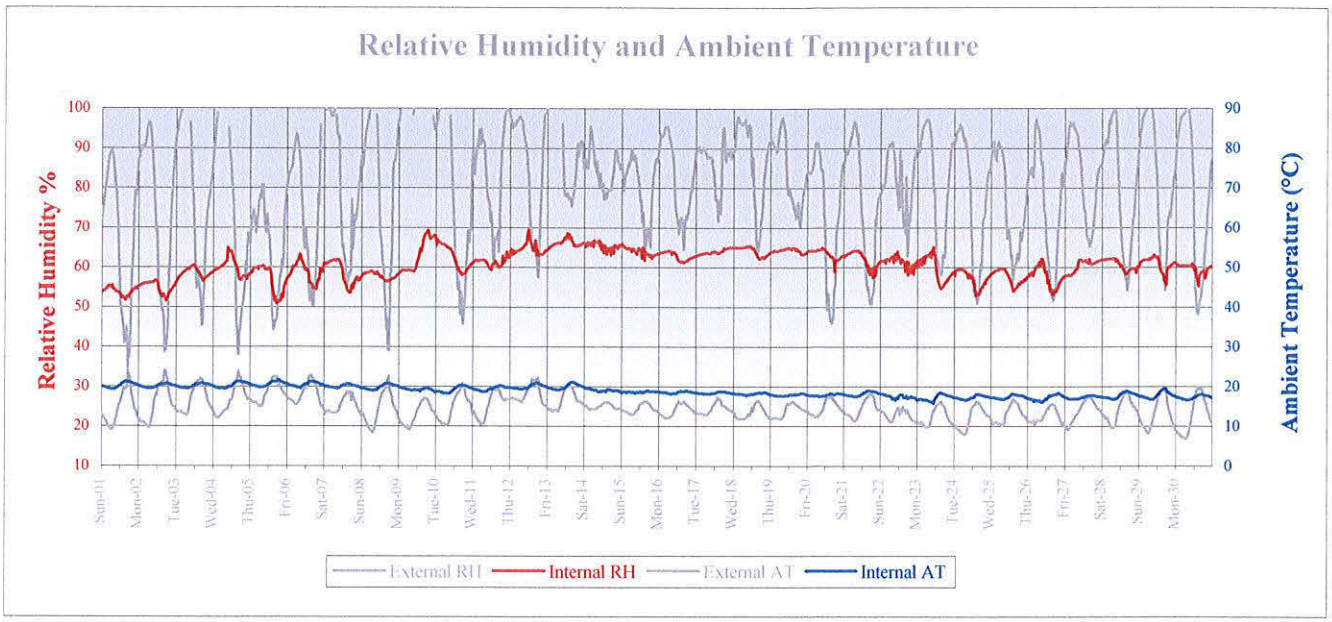


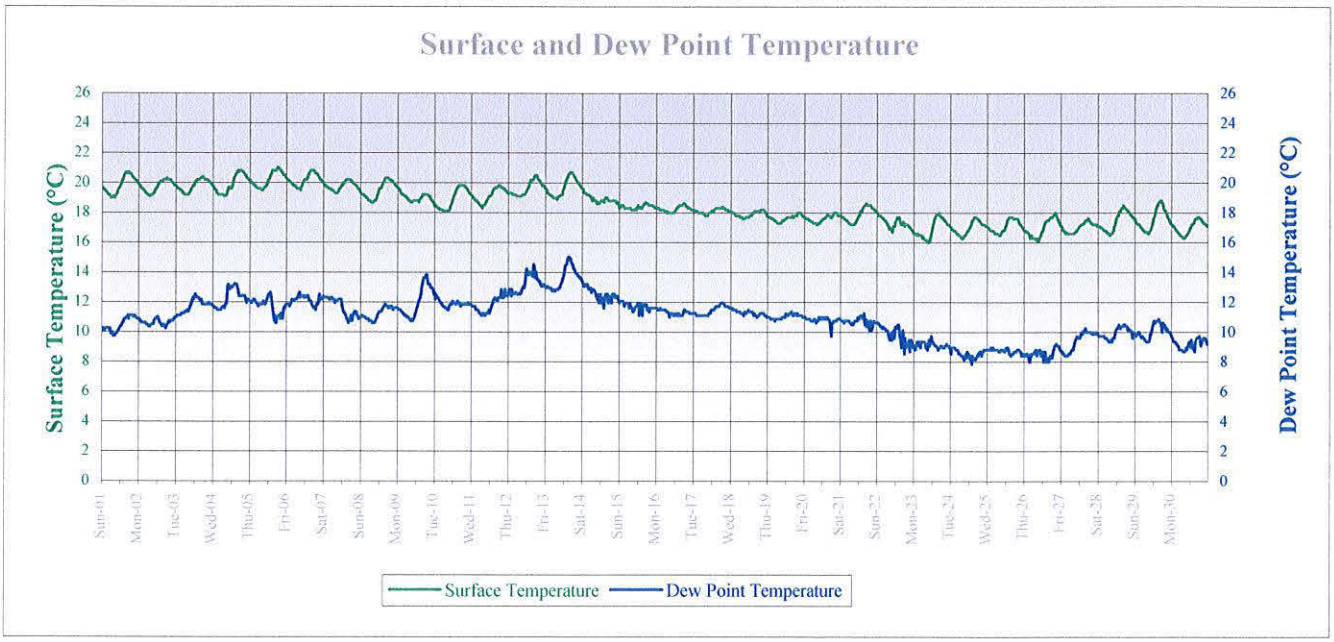


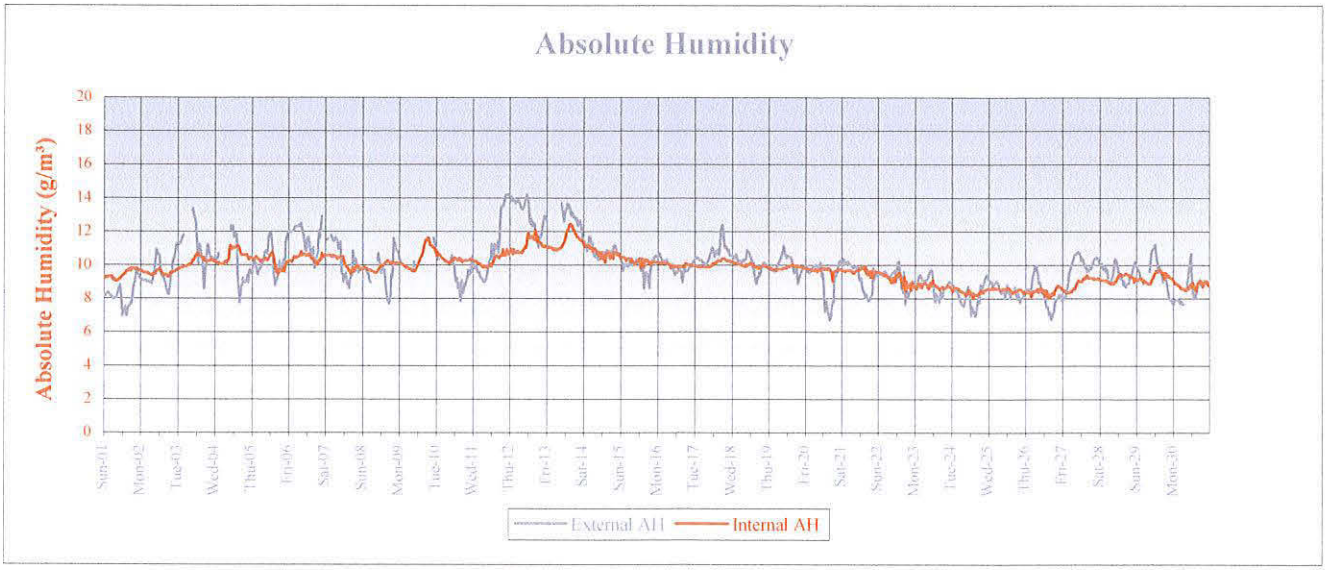
Peterborough Cathedral Nave Ceiling

September 2002

Probe 1: Bay 36 III lower side (shade)





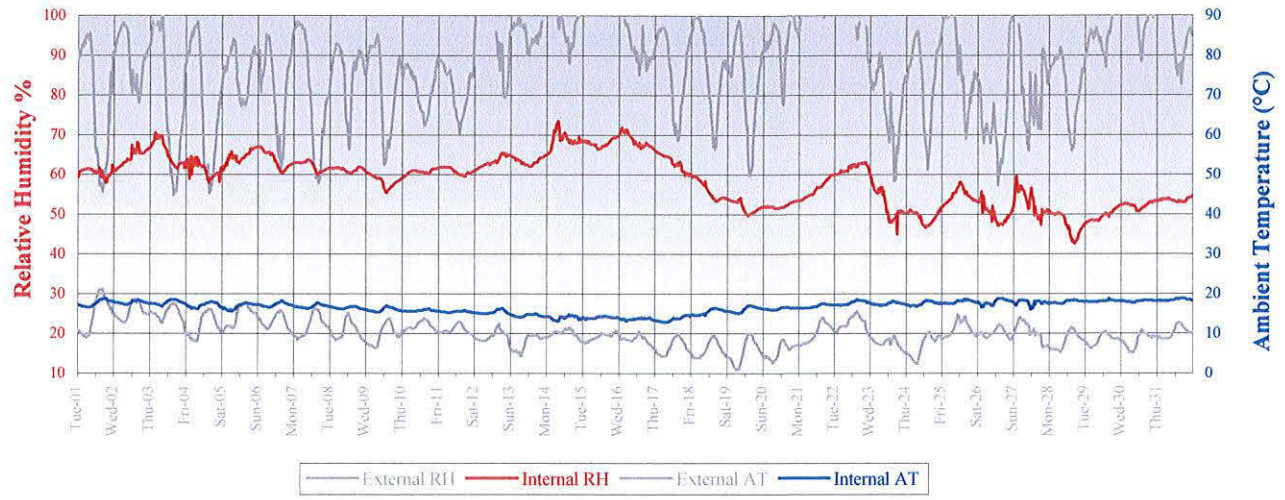


Peterborough Cathedral Nave Ceiling

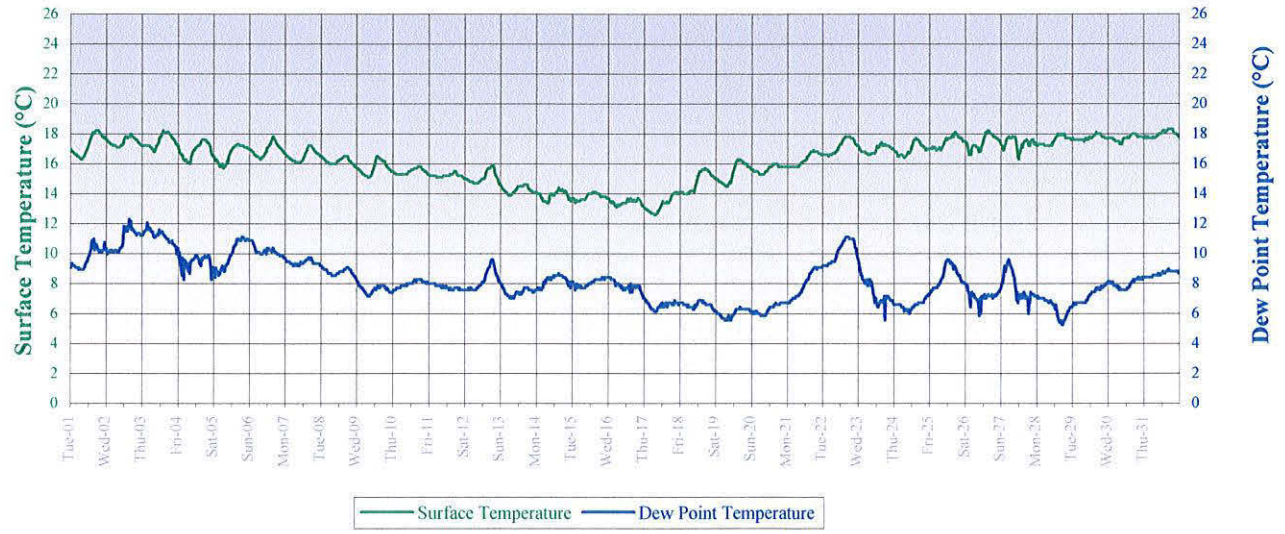
October 2002

Probe 1: Bay 36 III lower side (shade)

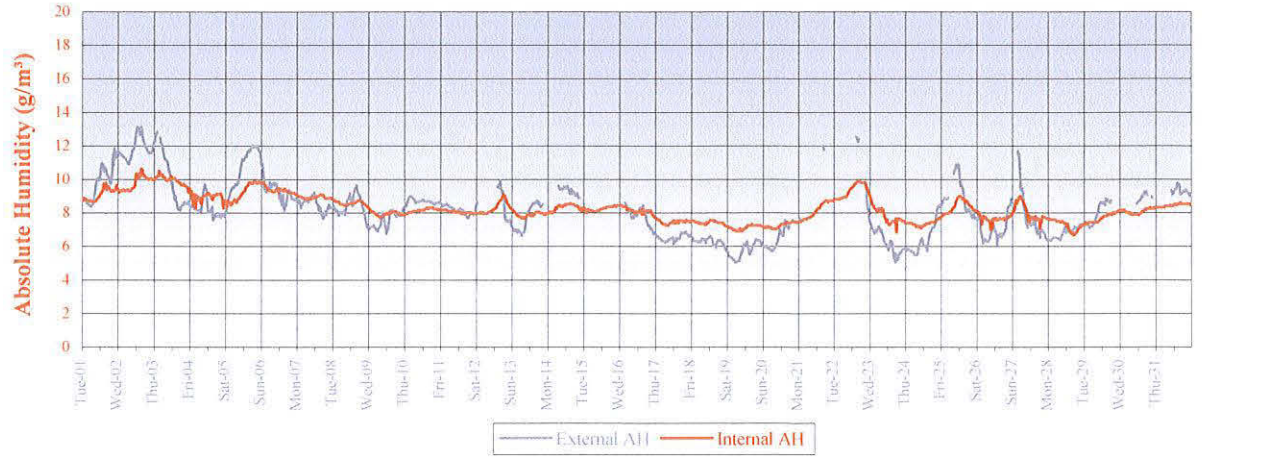
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

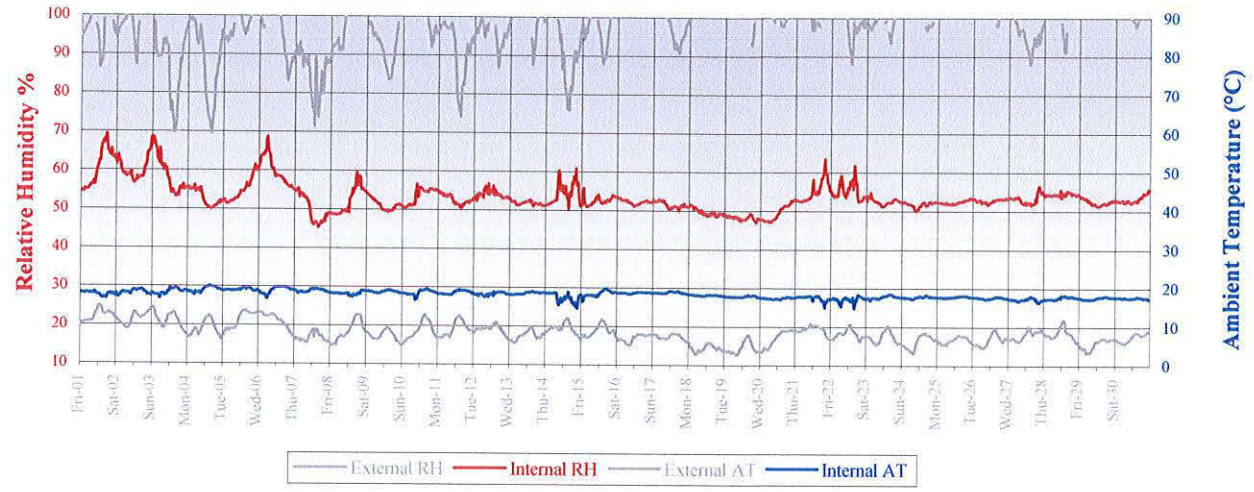


Peterborough Cathedral Nave Ceiling

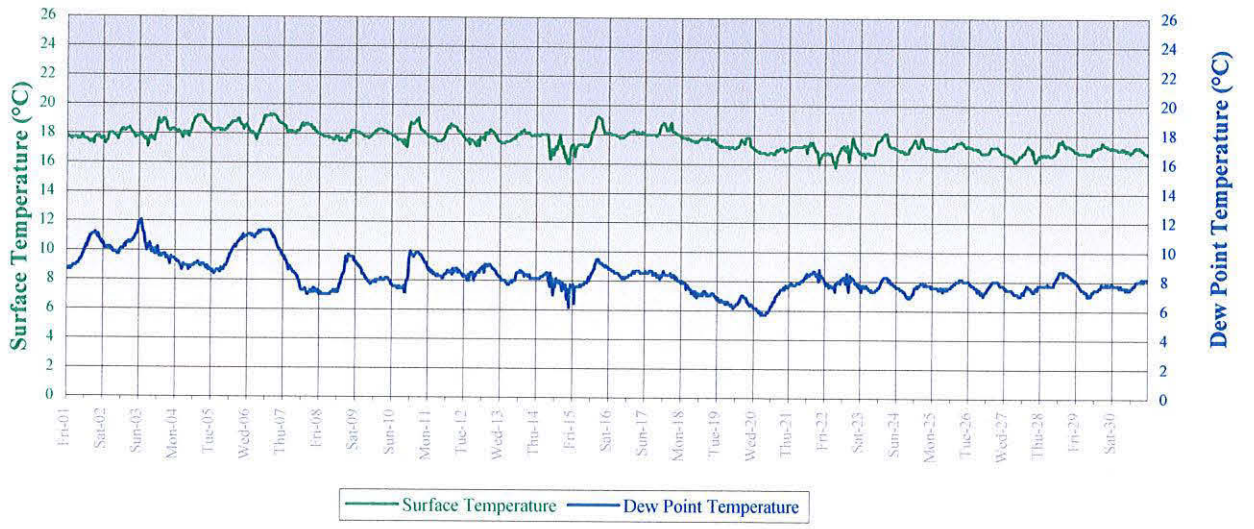
November 2002

Probe 1: Bay 36 III lower side (shade)

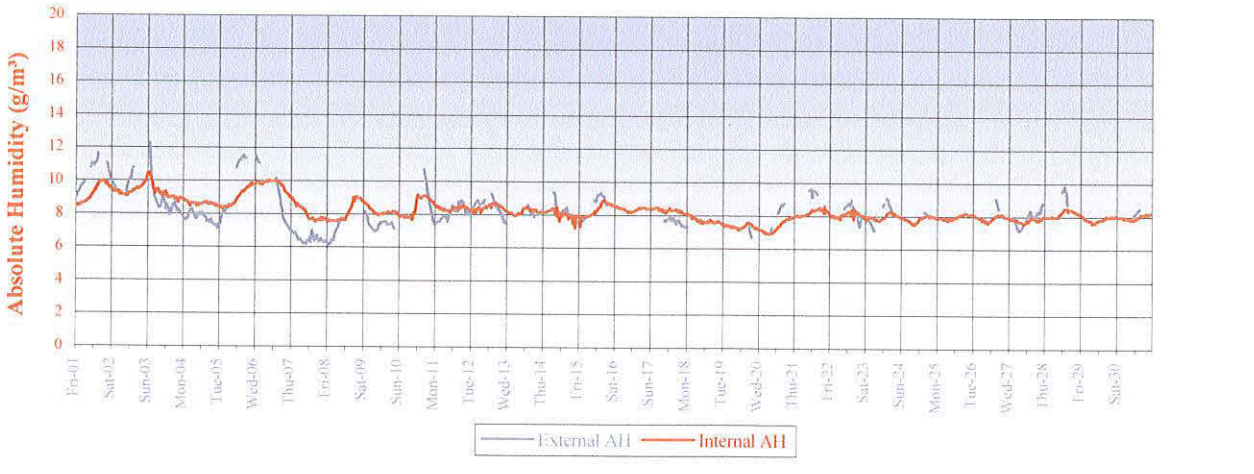
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



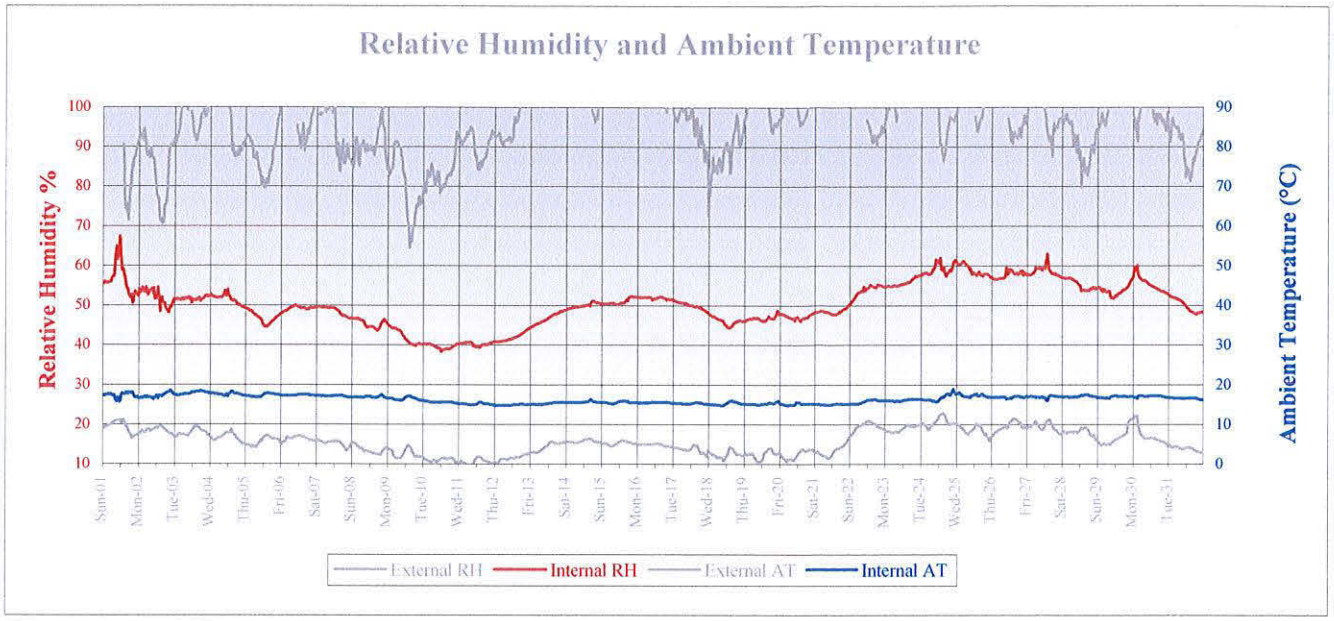
Absolute Humidity

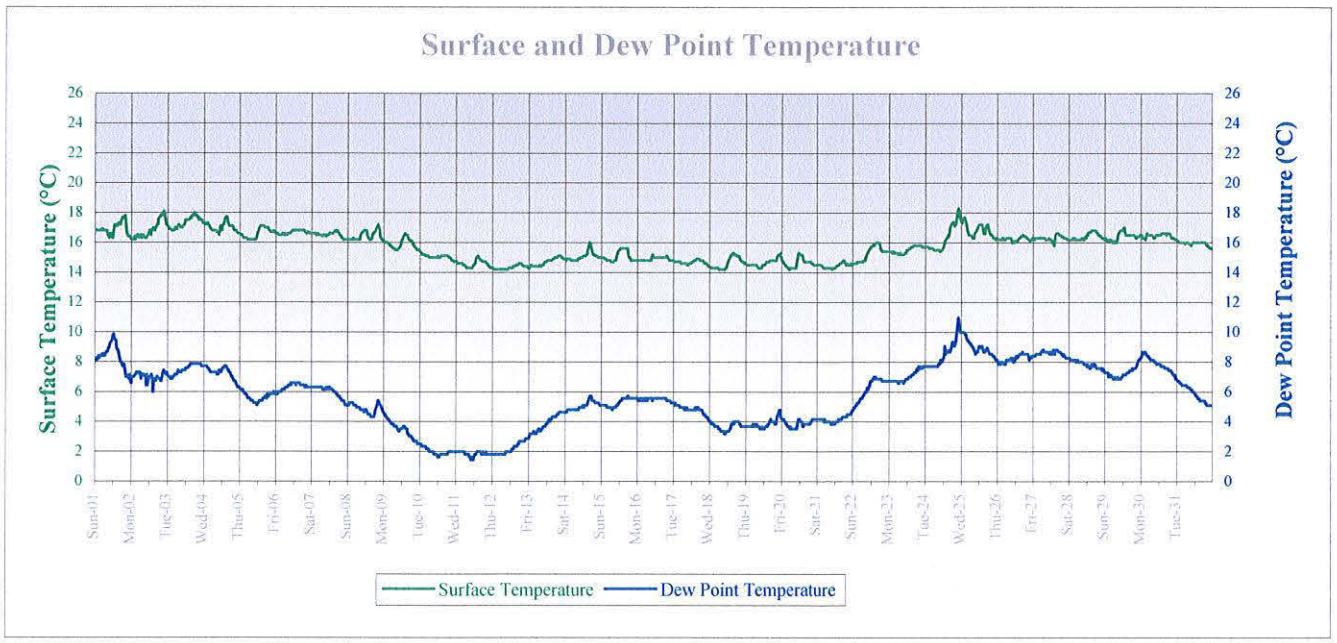


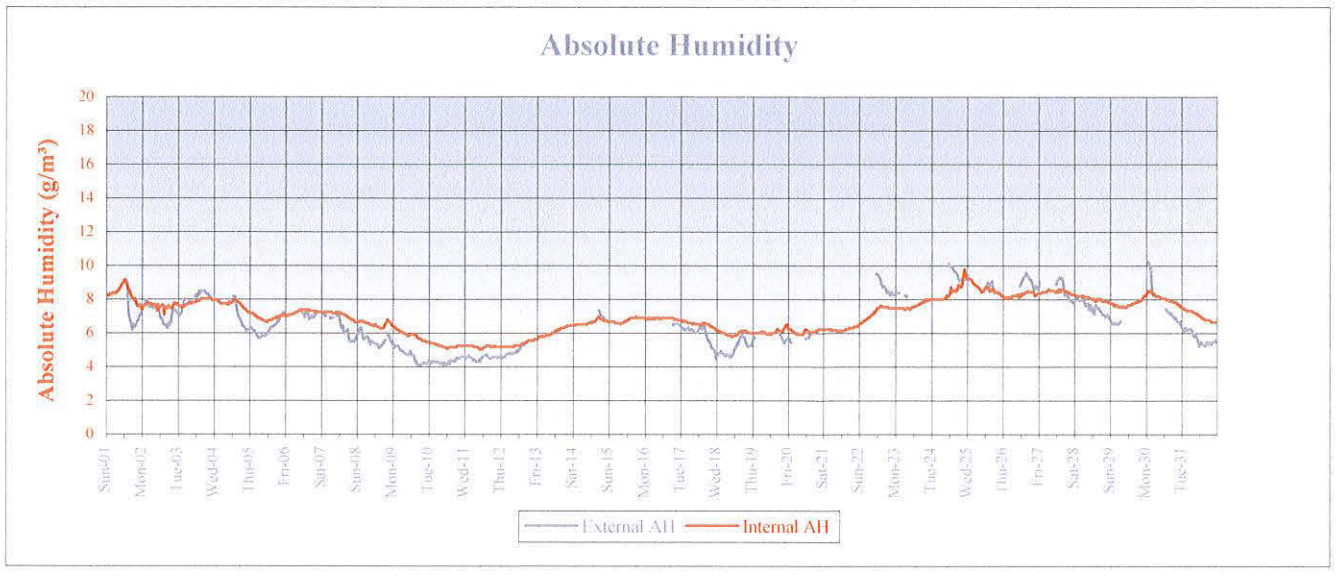
Peterborough Cathedral Nave Ceiling

December 2002

Probe 1: Bay 36 III lower side (shade)





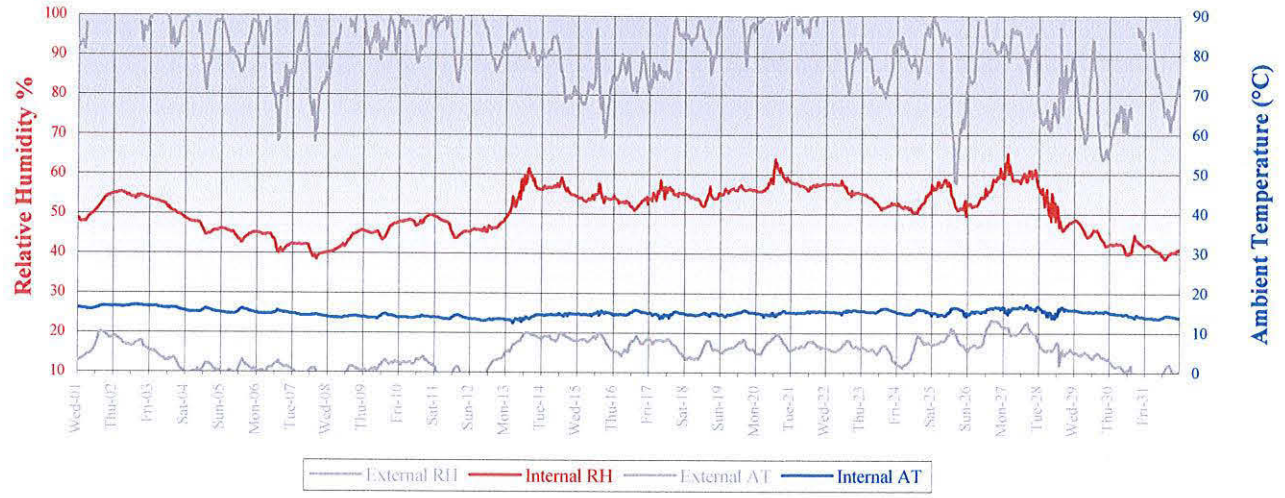


Peterborough Cathedral Nave Ceiling

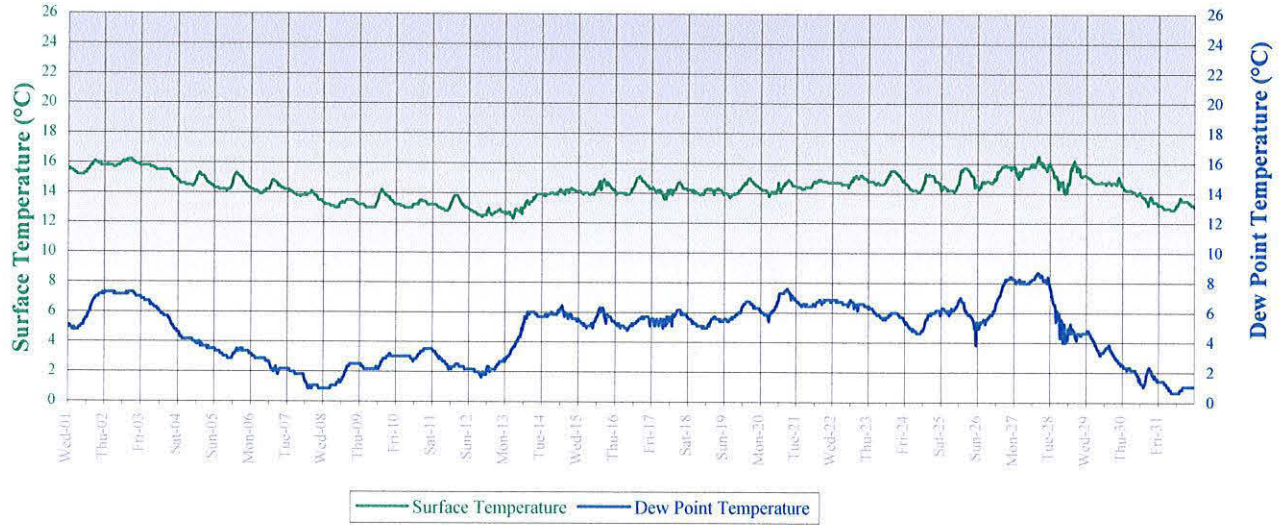
January 2003

Probe 1: Bay 36 III lower side (shade)

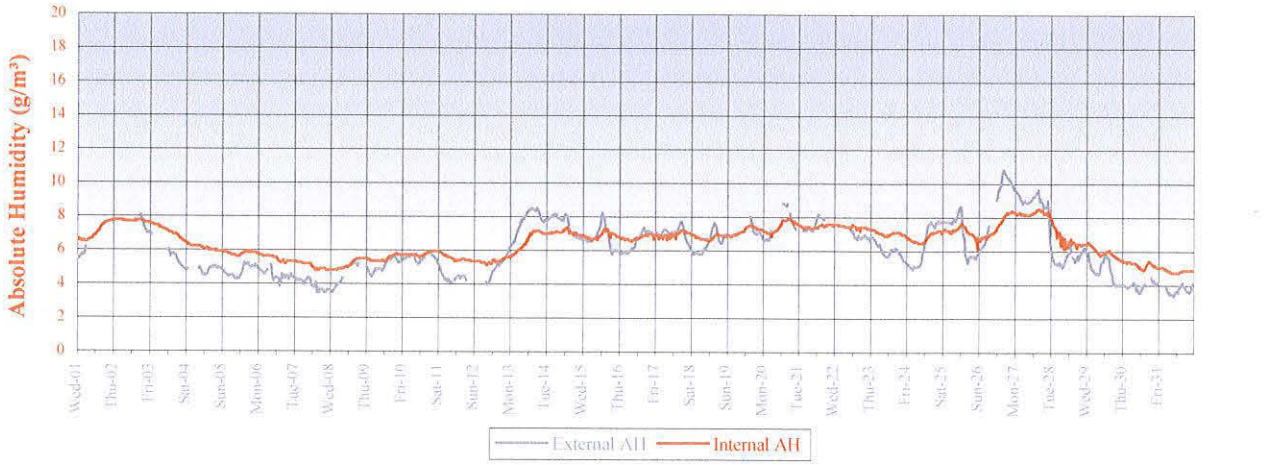
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

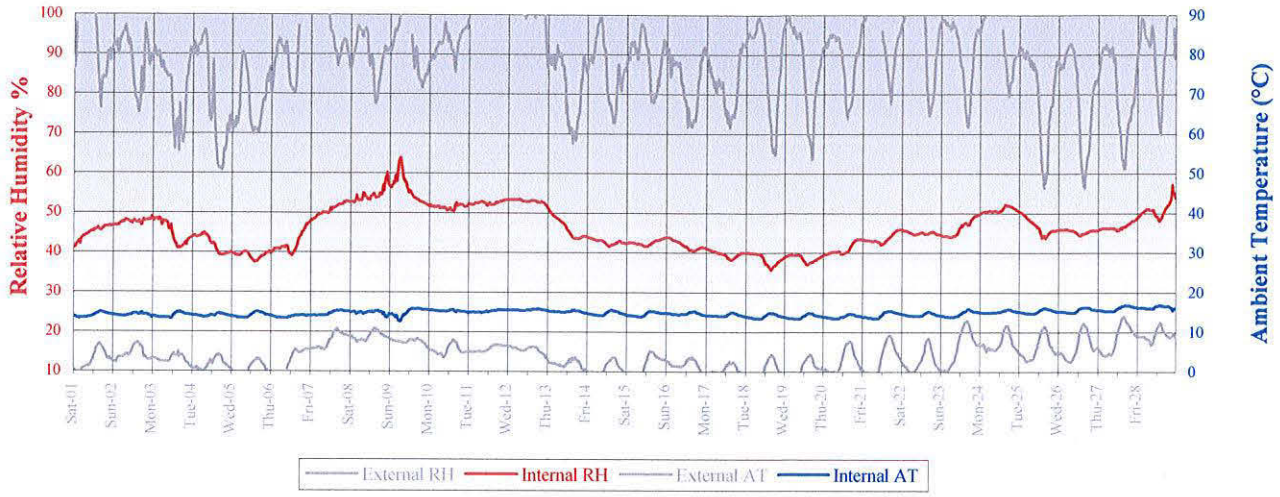


Peterborough Cathedral Nave Ceiling

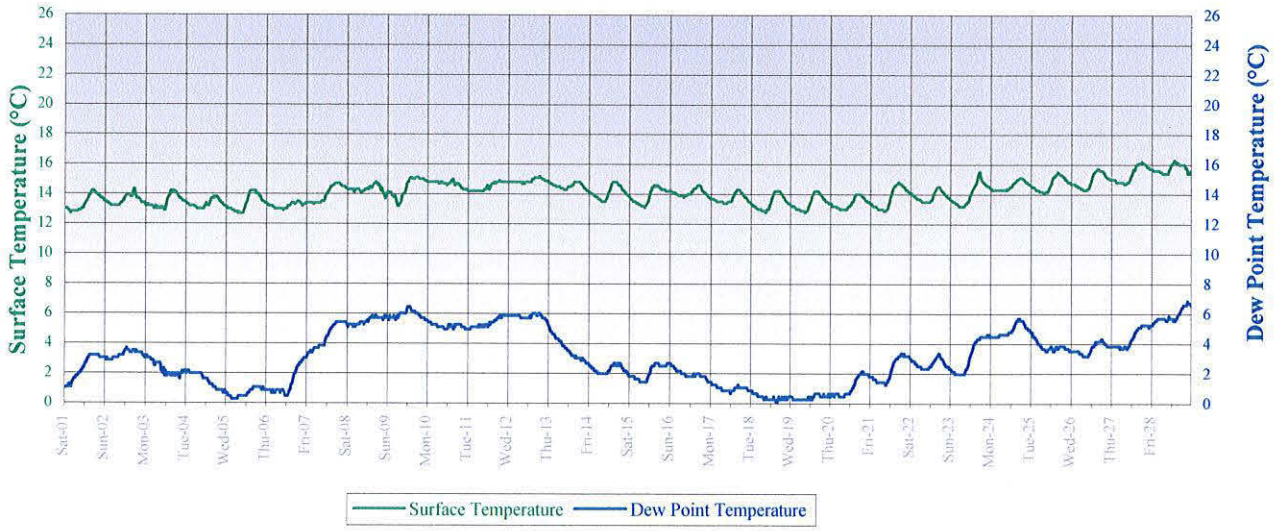
February 2003

Probe 1: Bay 36 III lower side (shade)

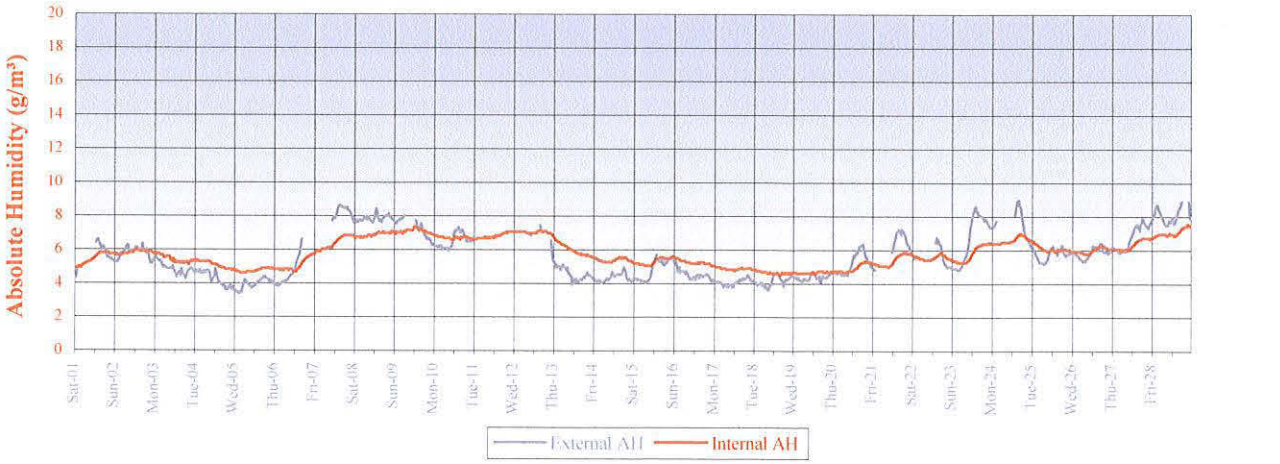
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

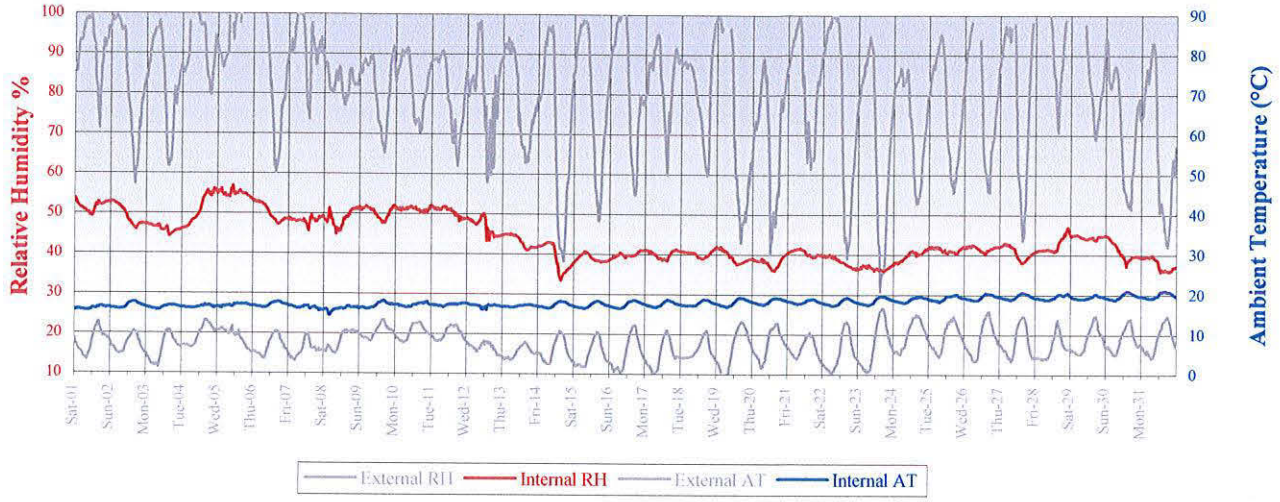


Peterborough Cathedral Nave Ceiling

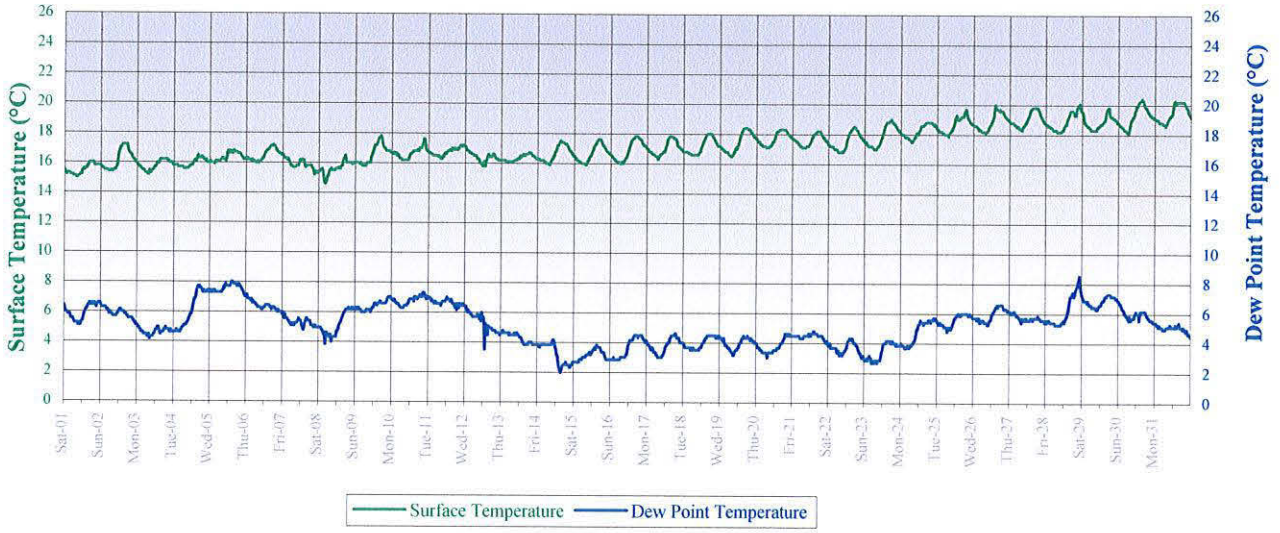
March 2003

Probe 1: Bay 36 III lower side (shade)

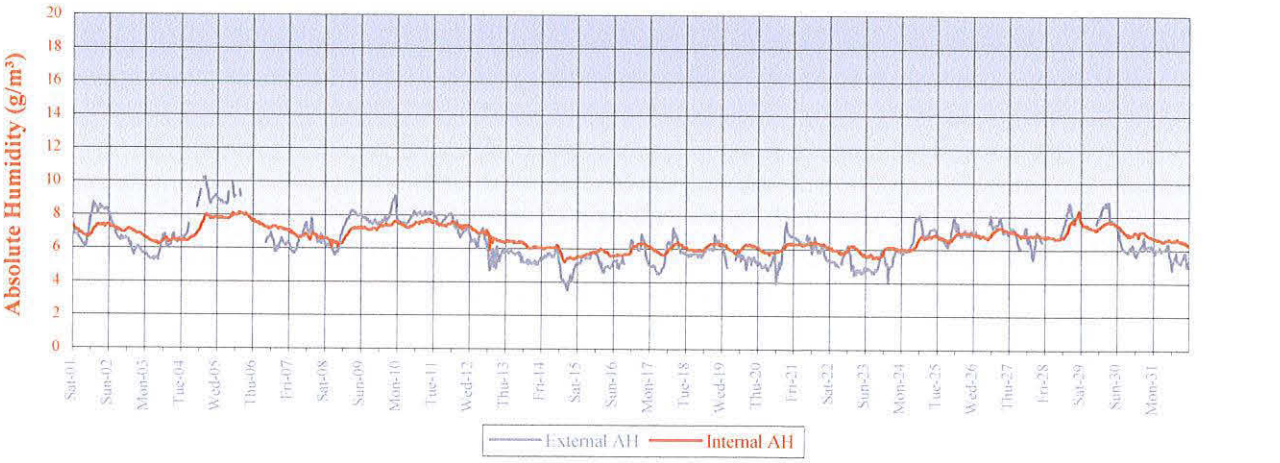
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

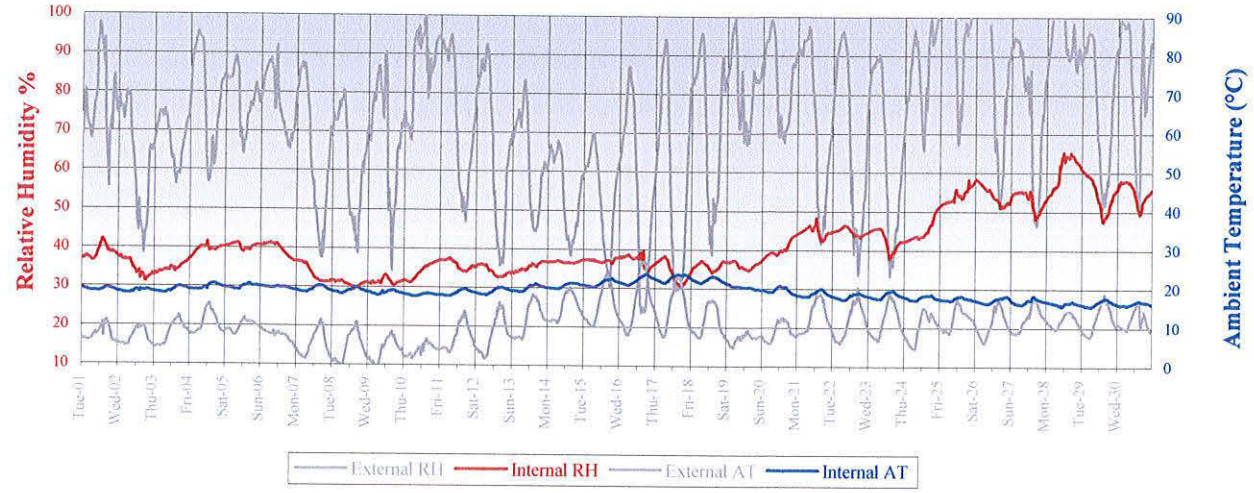


Peterborough Cathedral Nave Ceiling

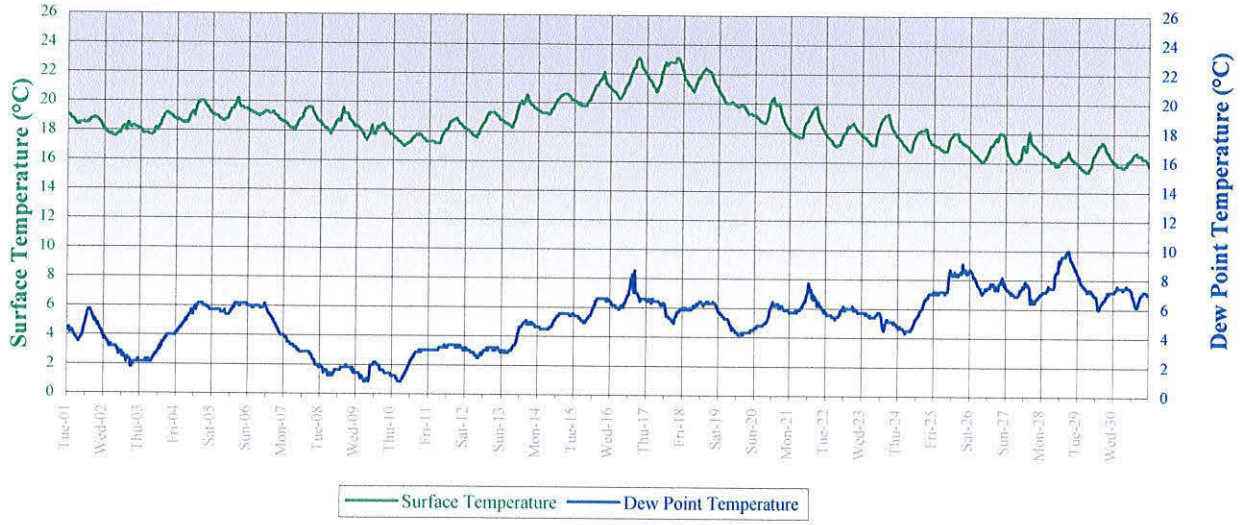
Probe 1: Bay 36 III lower side (shade)

April 2003

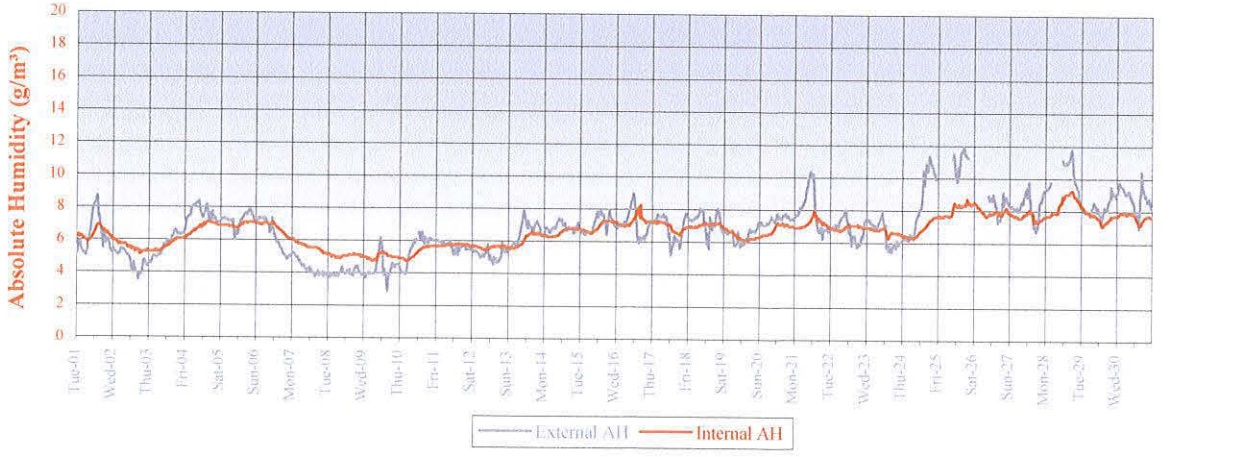
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

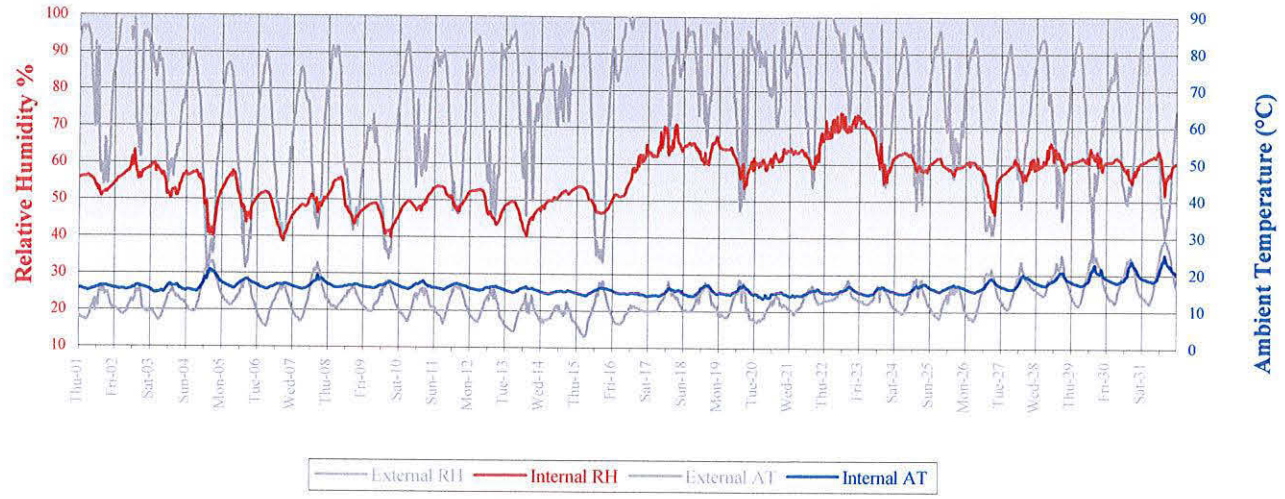


Peterborough Cathedral Nave Ceiling

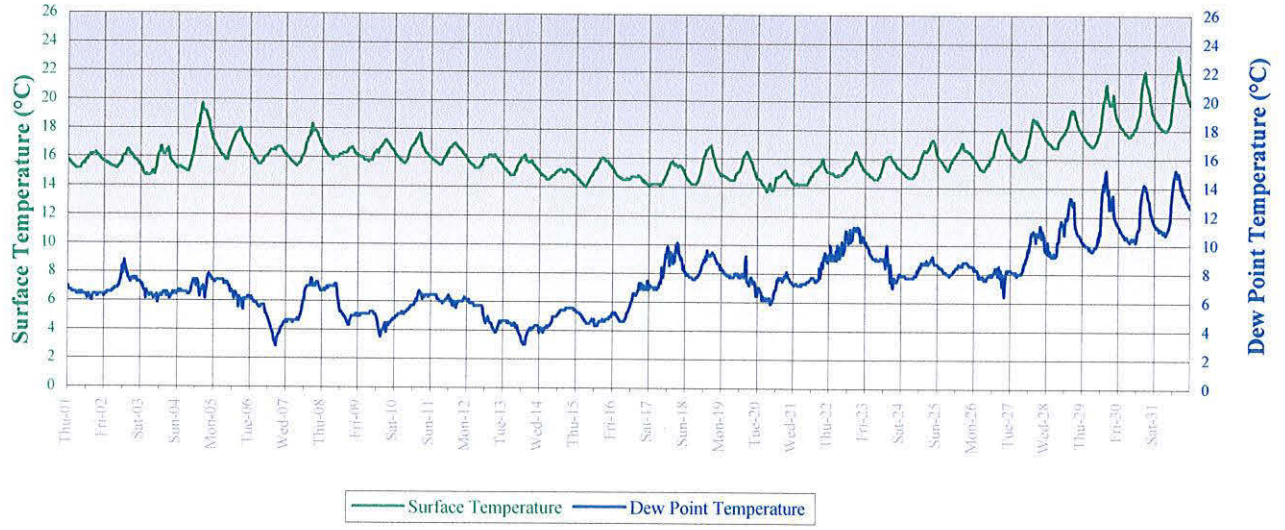
May 2003

Probe 1: Bay 36 III lower side (shade)

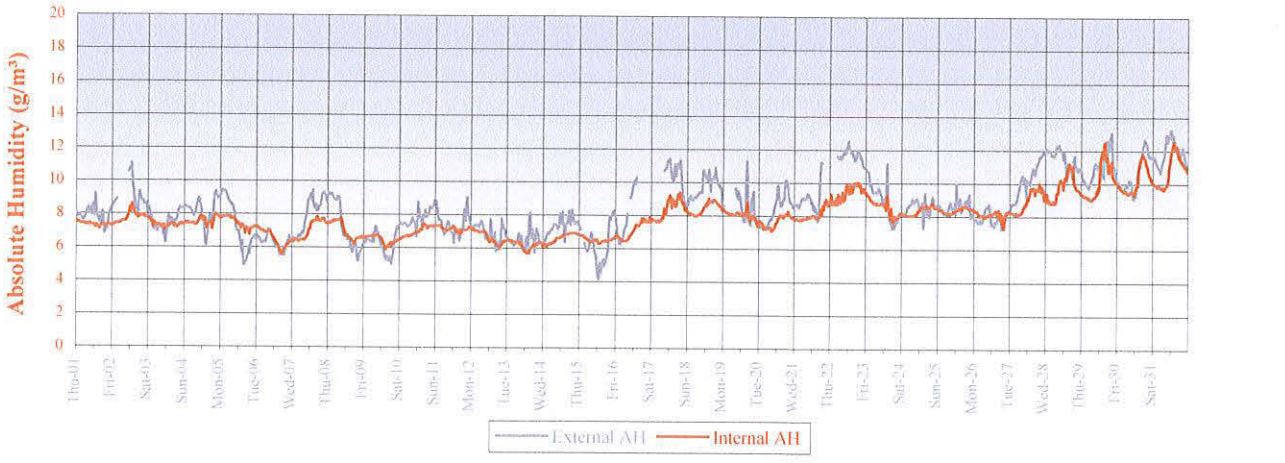
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

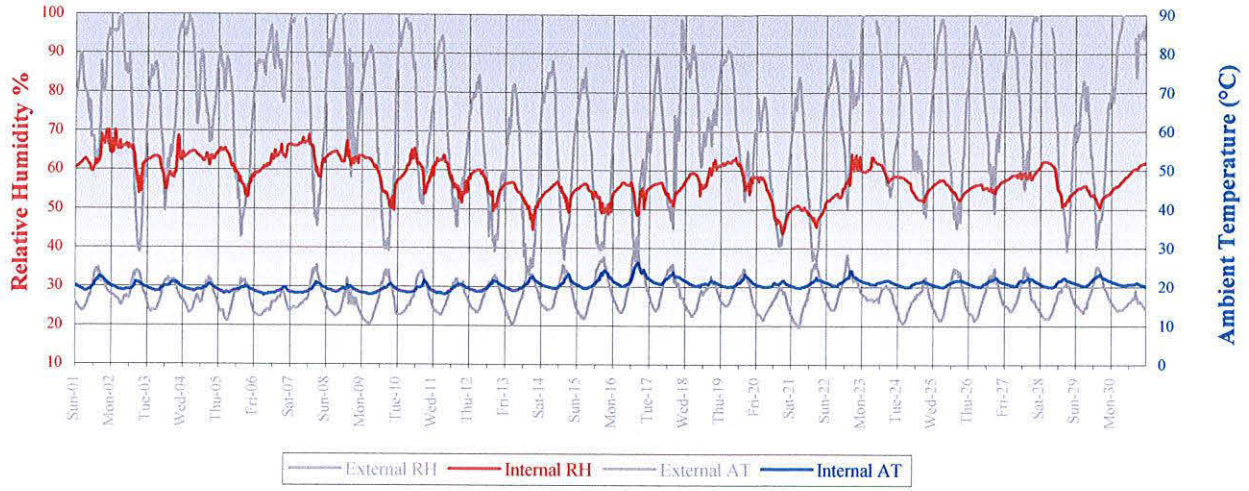


Peterborough Cathedral Nave Ceiling

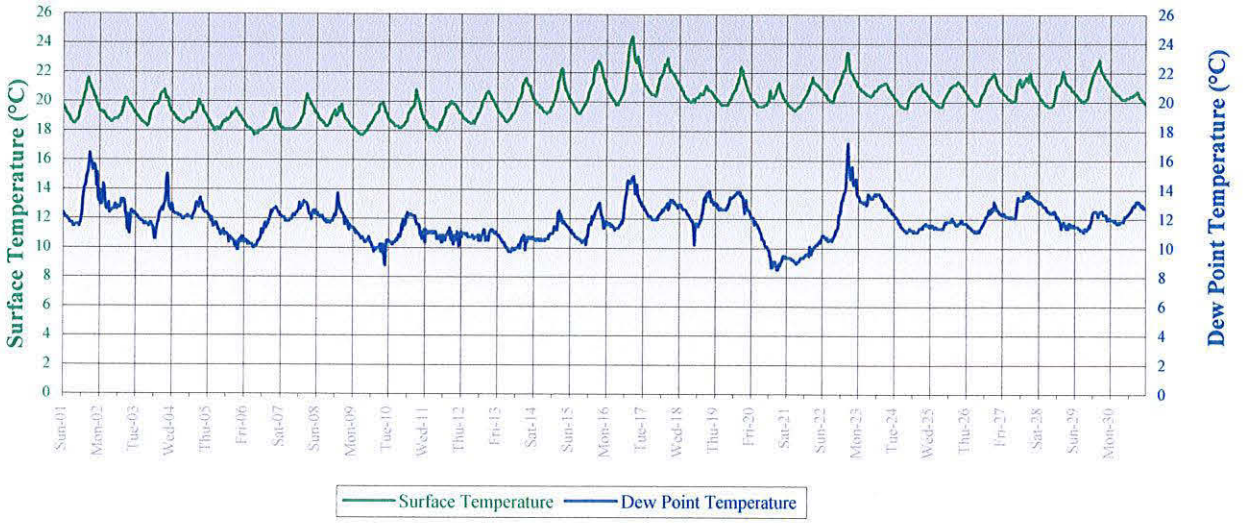
June 2003

Probe 1: Bay 36 III lower side (shade)

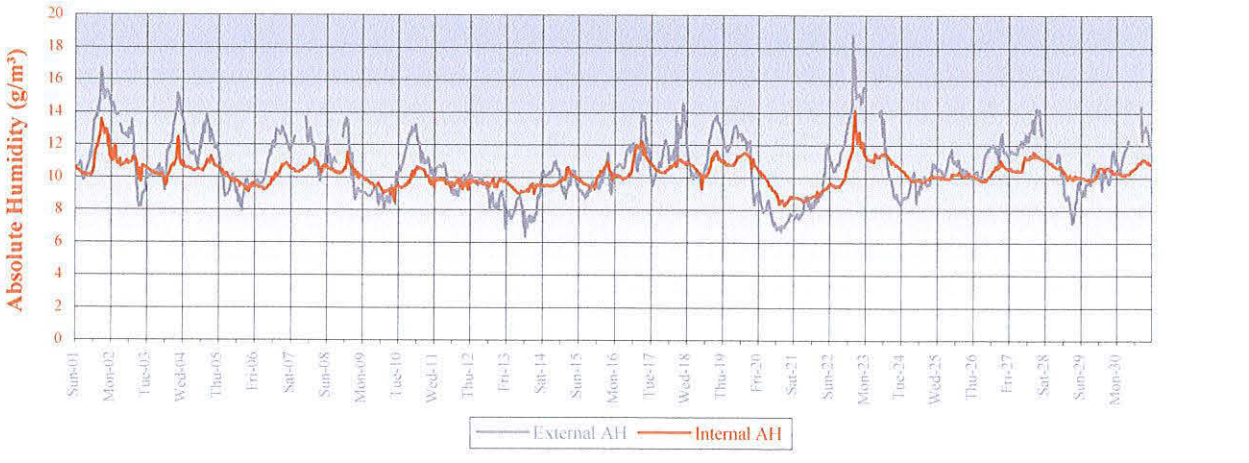
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

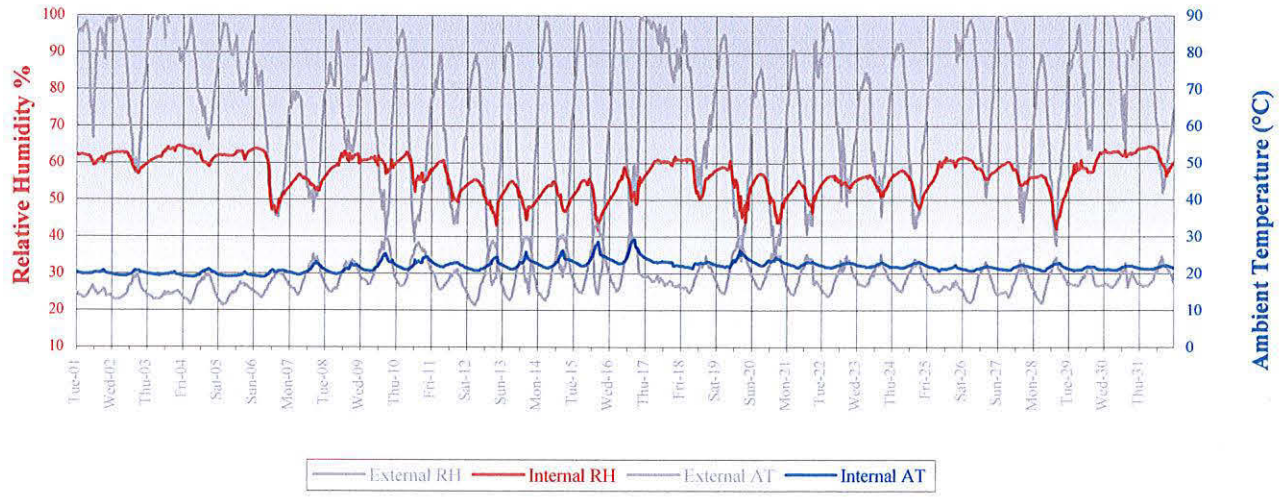


Peterborough Cathedral Nave Ceiling

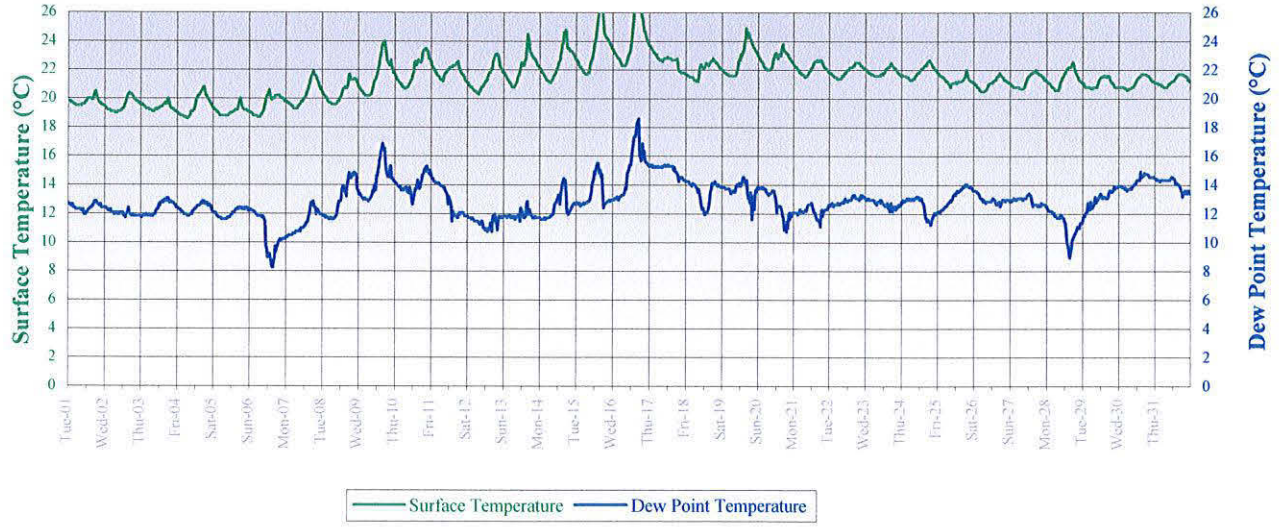
July 2003

Probe 1: Bay 36 III lower side (shade)

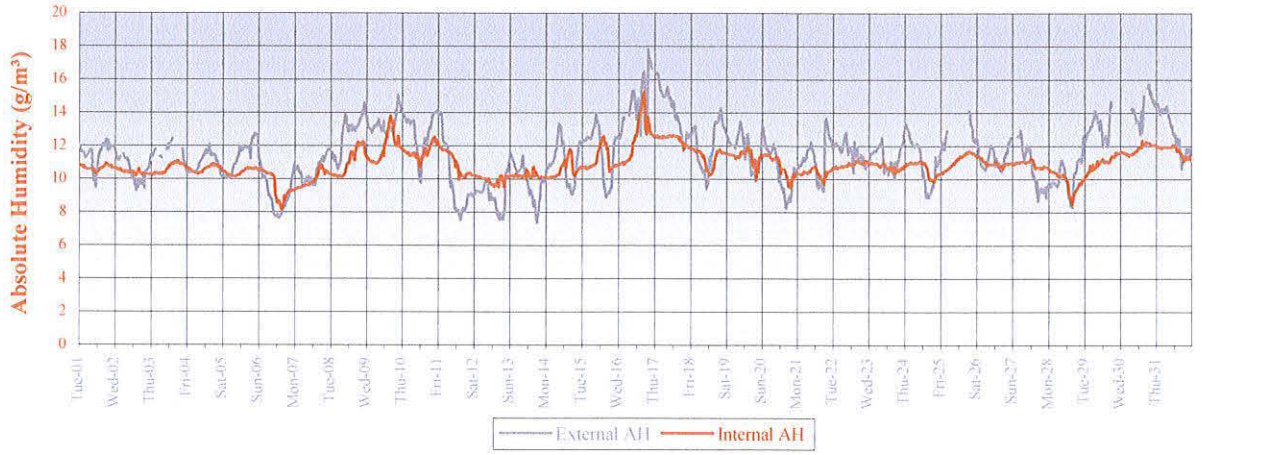
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

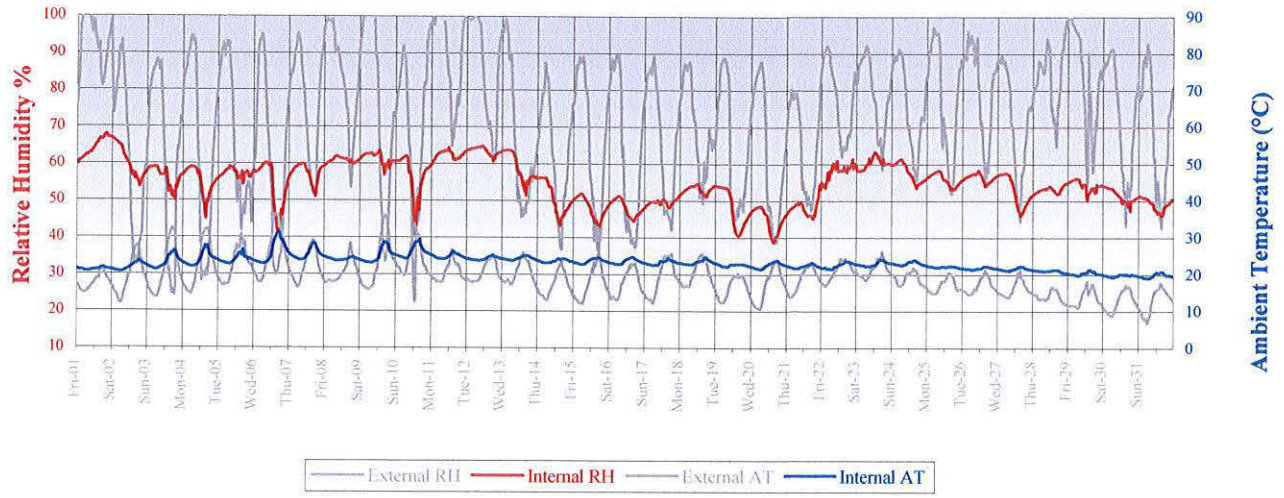


Peterborough Cathedral Nave Ceiling

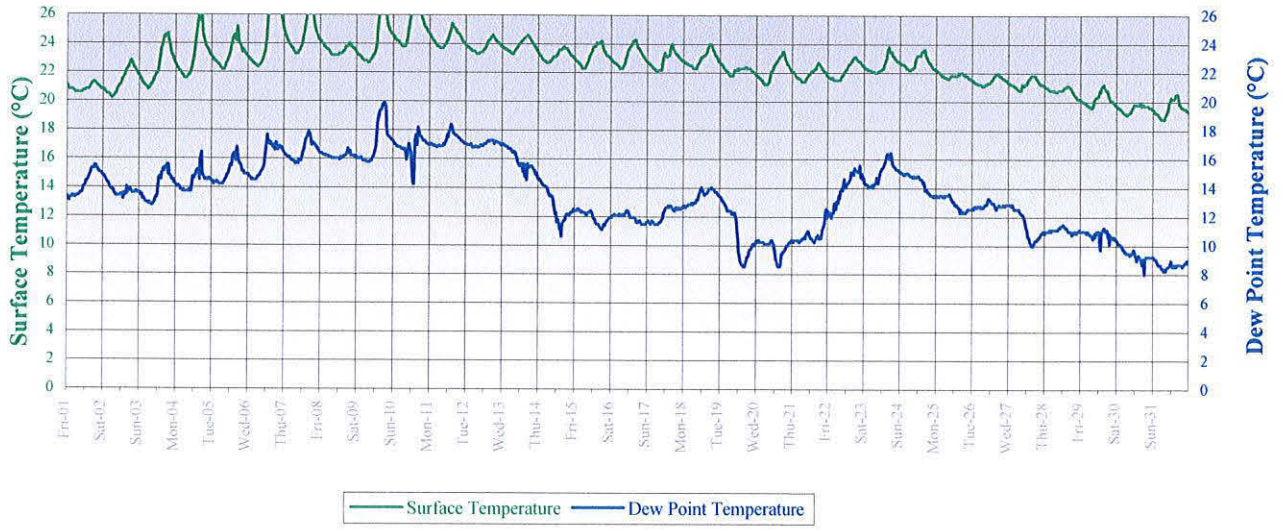
August 2003

Probe 1: Bay 36 III lower side (shade)

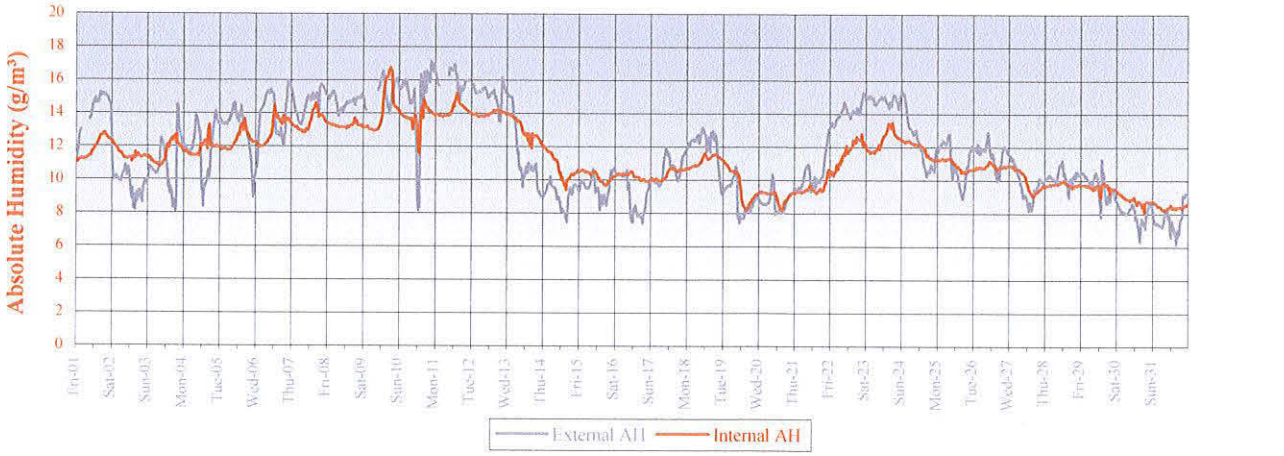
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

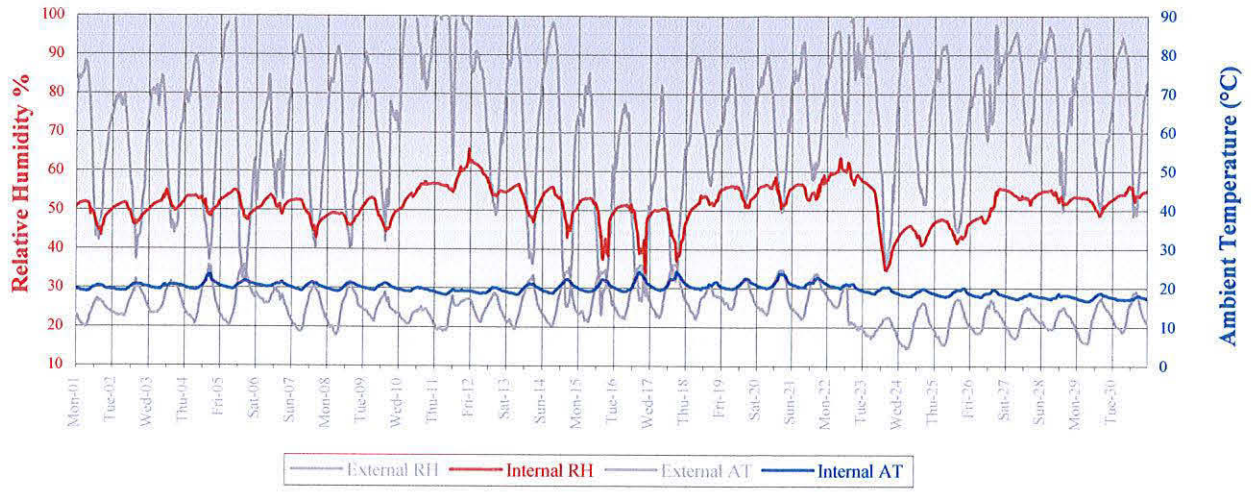


Peterborough Cathedral Nave Ceiling

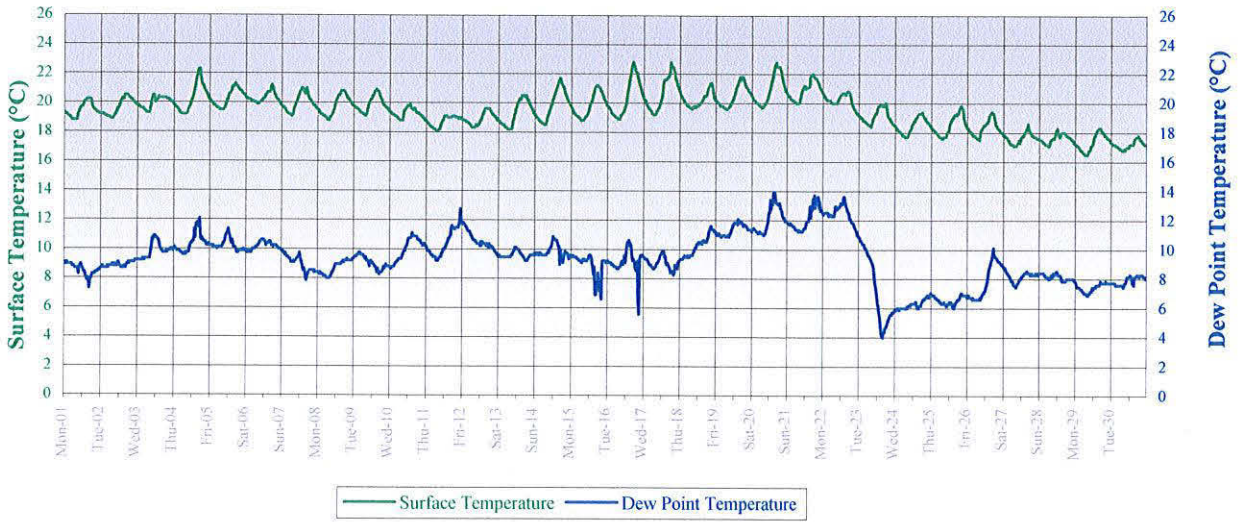
September 2003

Probe 1: Bay 36 III lower side (shade)

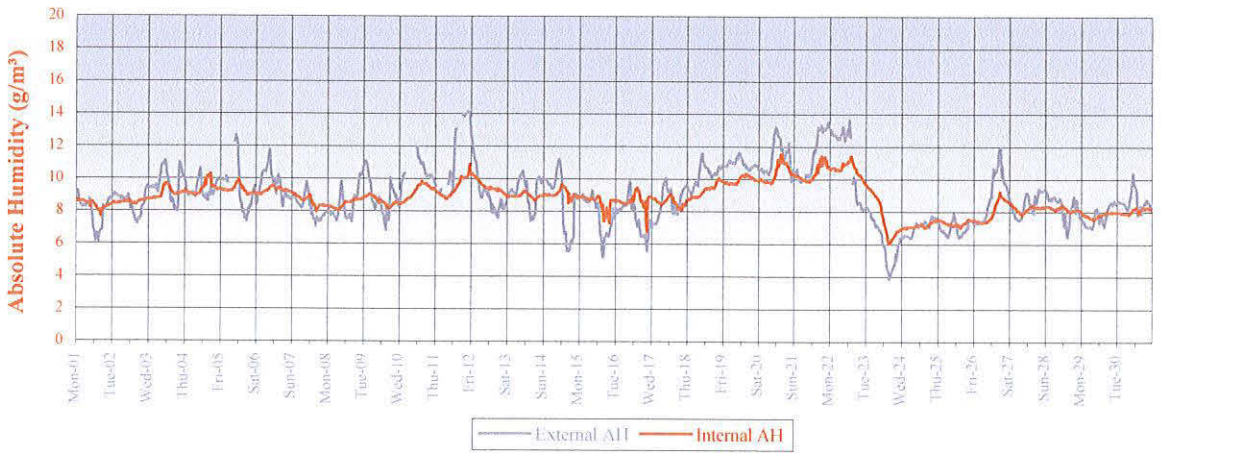
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

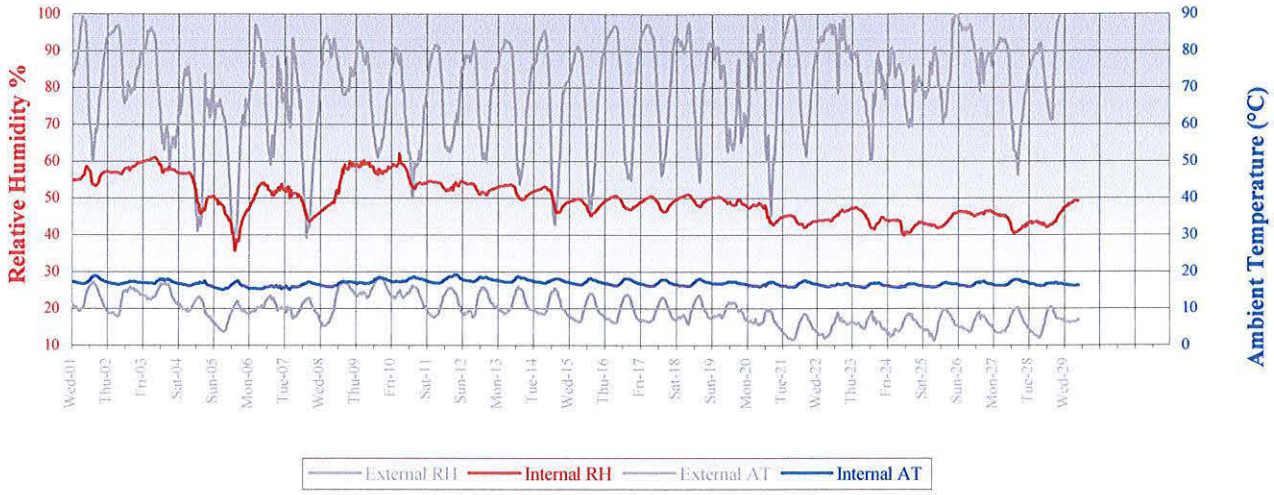


Peterborough Cathedral Nave Ceiling

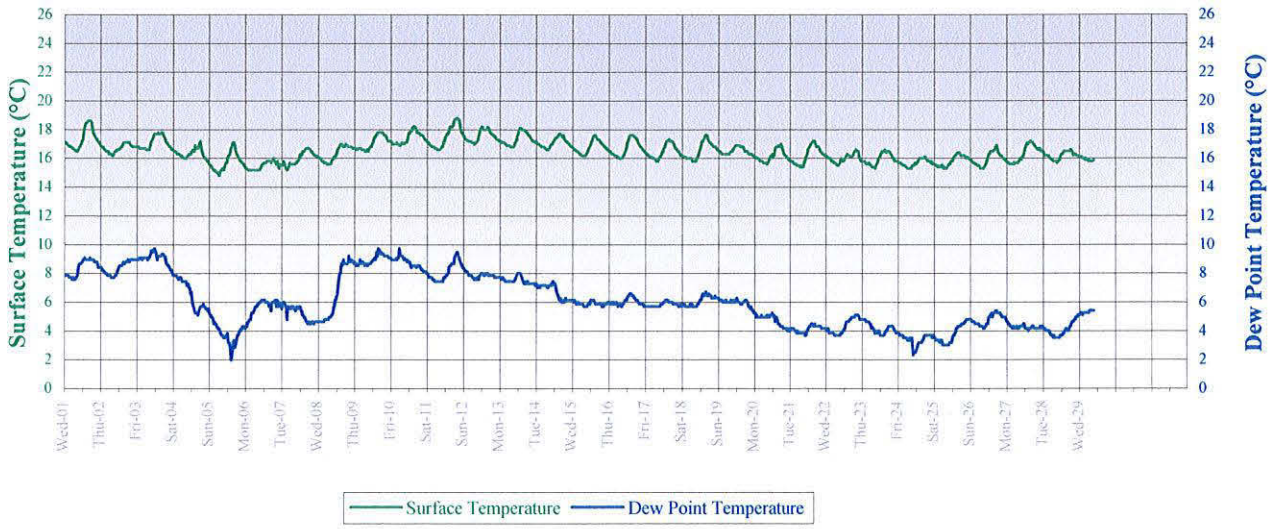
October 2003

Probe 1: Bay 36 III lower side (shade)

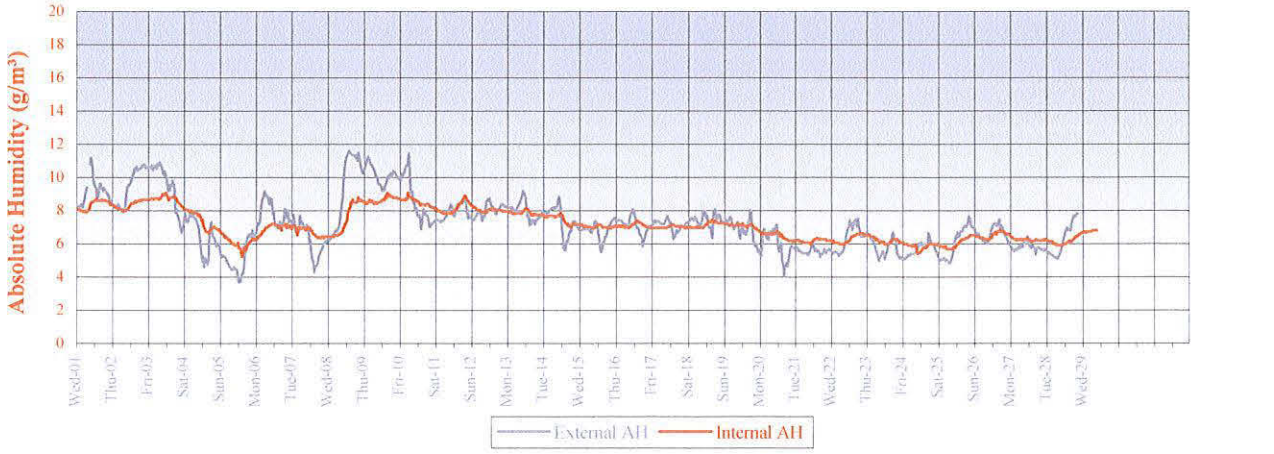
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature

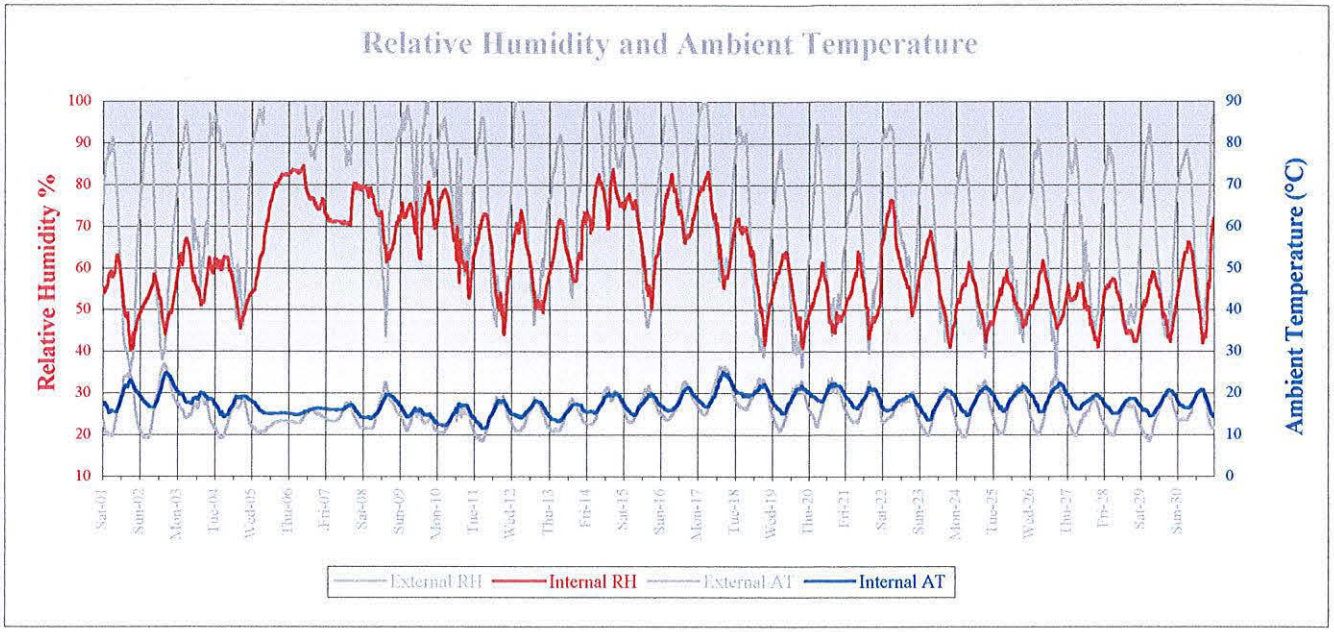


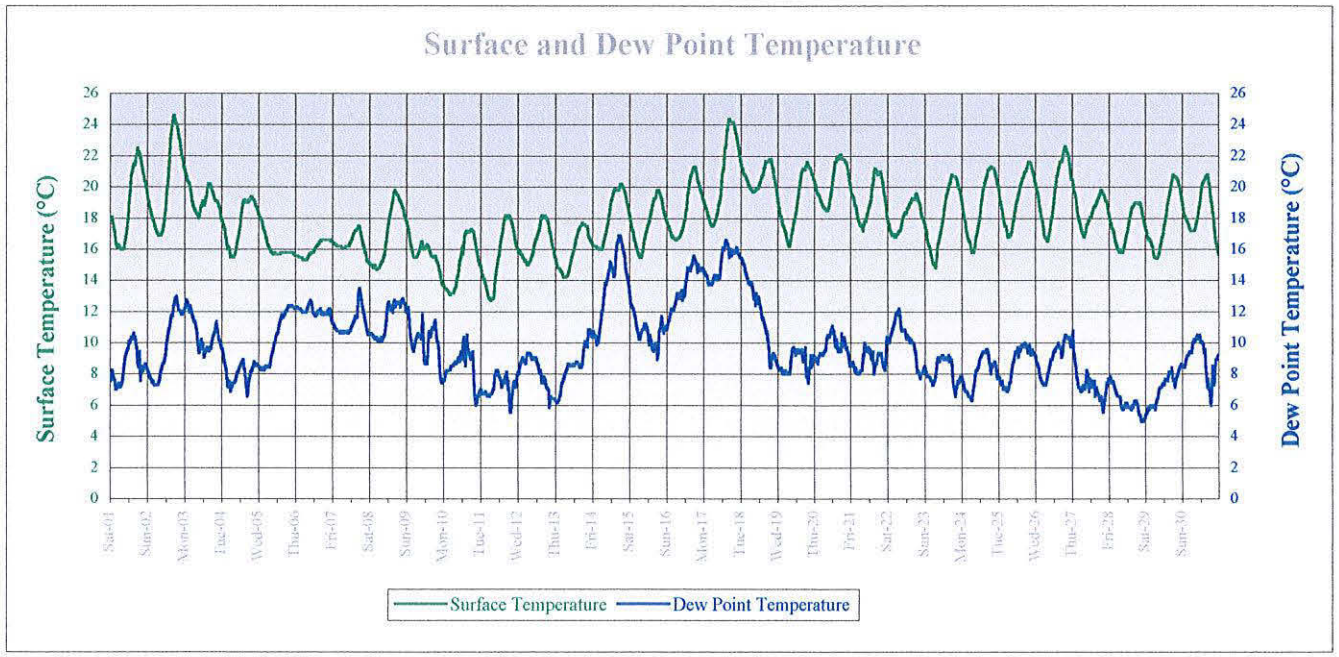
Absolute Humidity

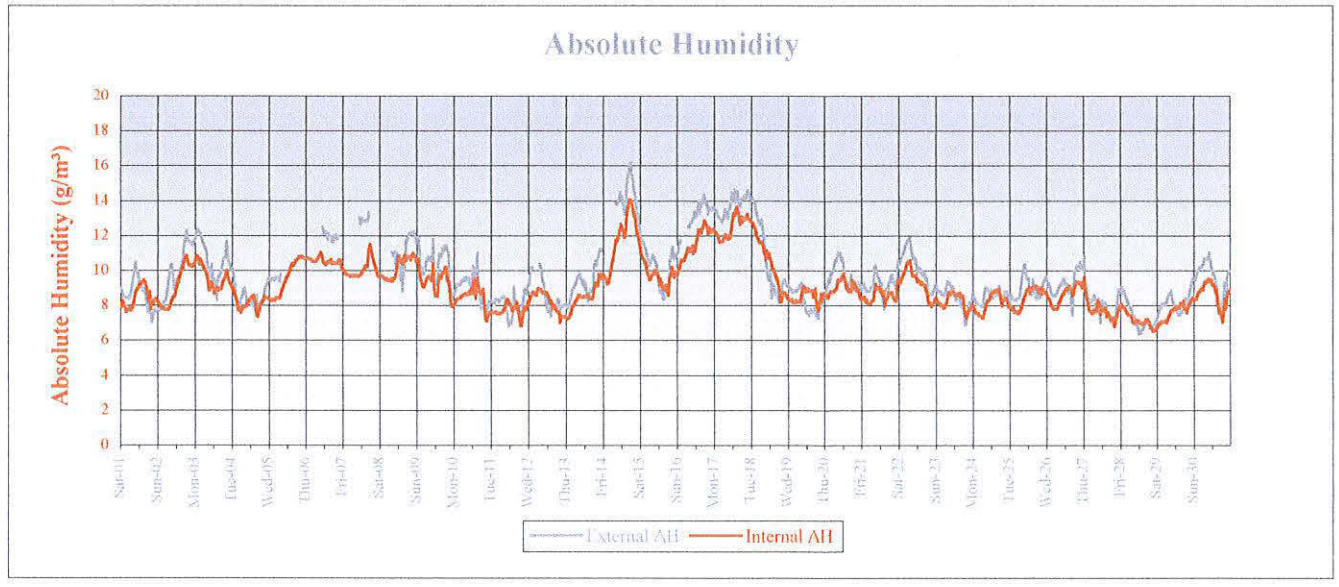


PROBE 2

BAY 36 III UPPER SIDE (SHADE)


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

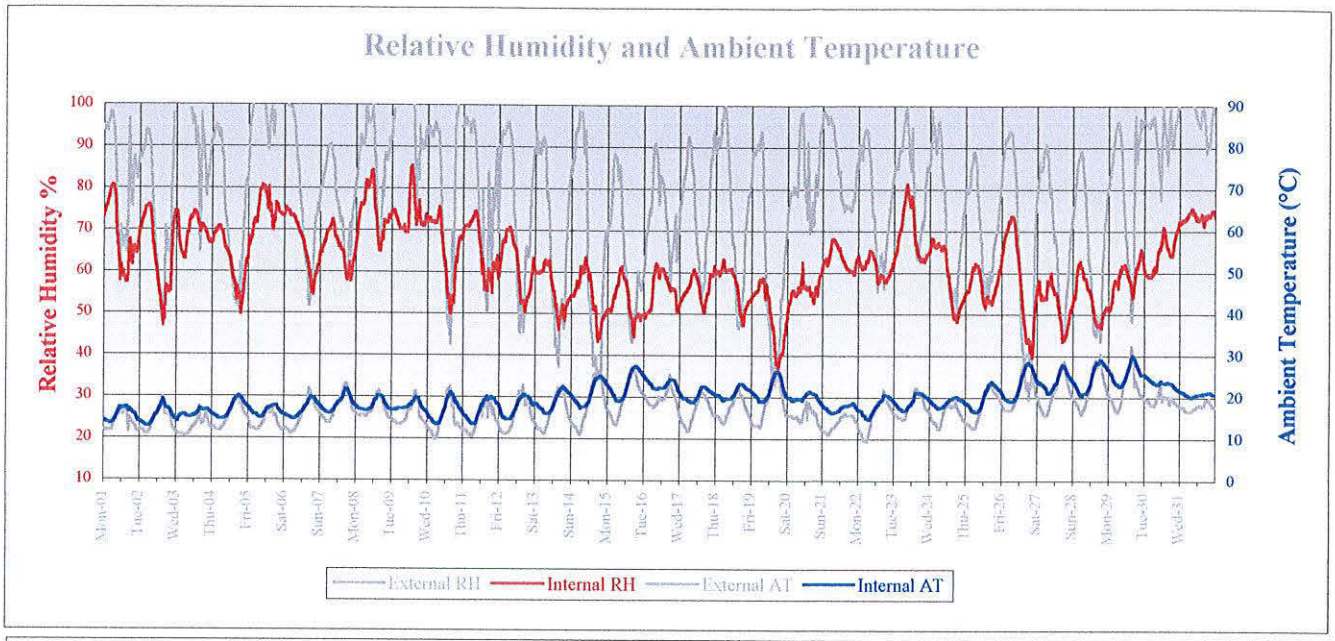

Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature

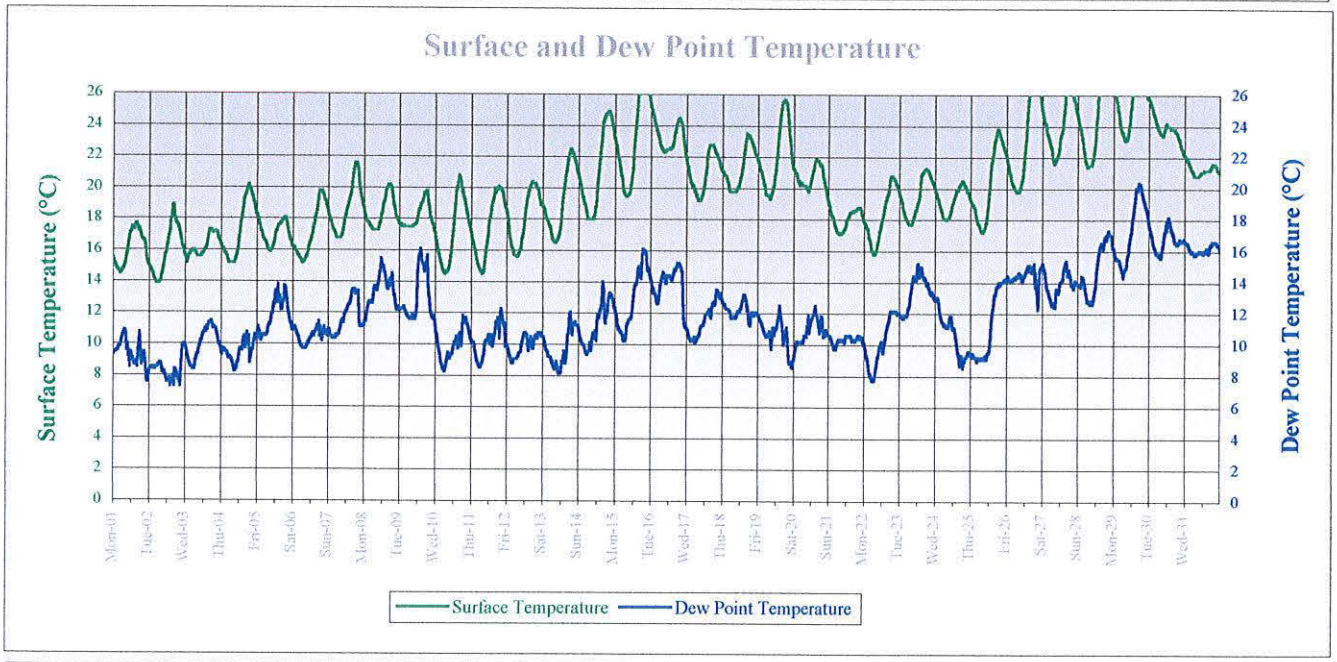

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

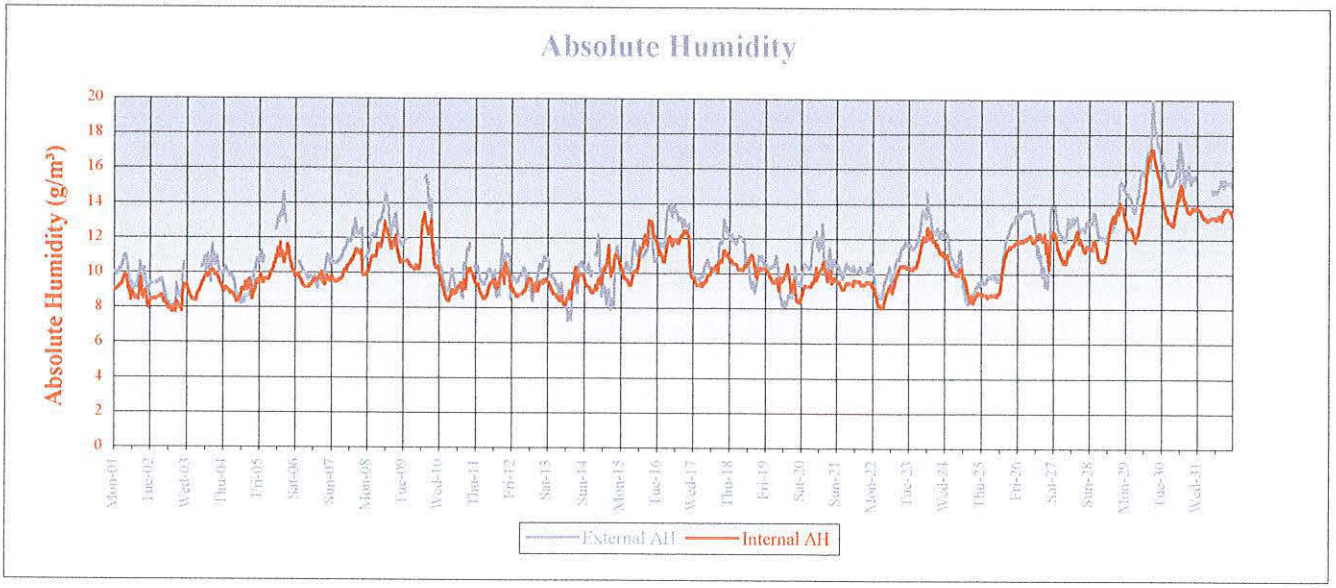
Peterborough Cathedral Nave Ceiling

July 2002

Probe 2: Bay 36 III upper side (shade)



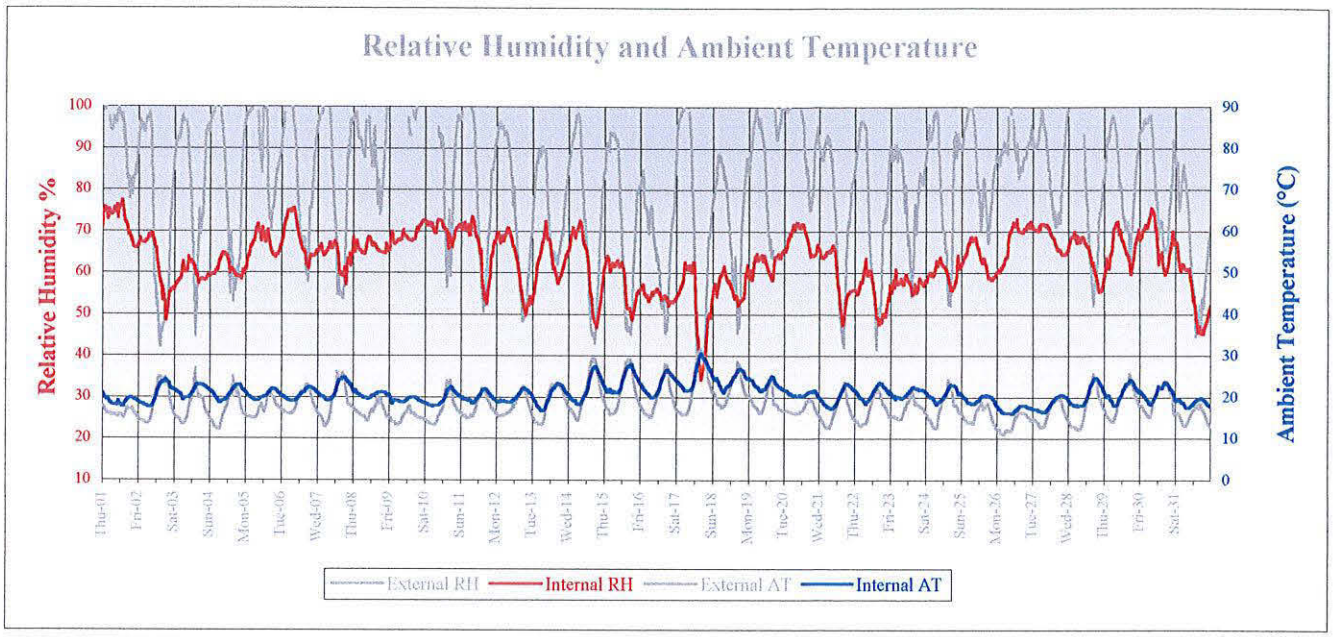


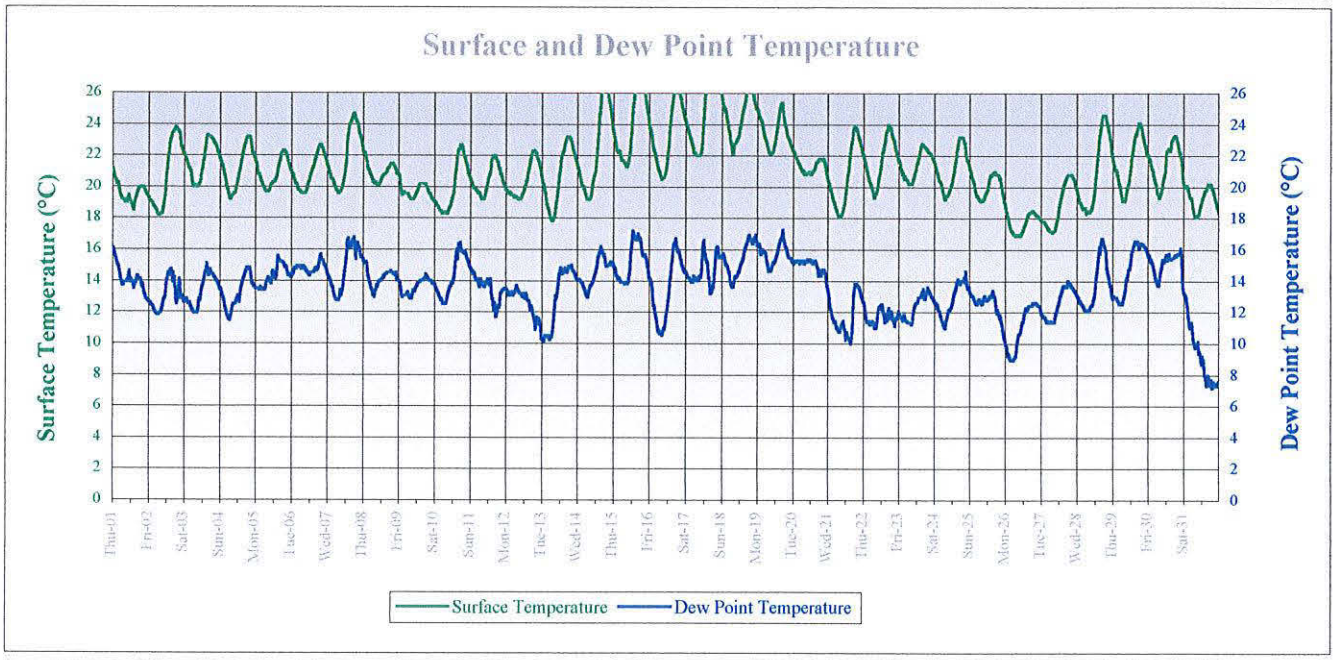


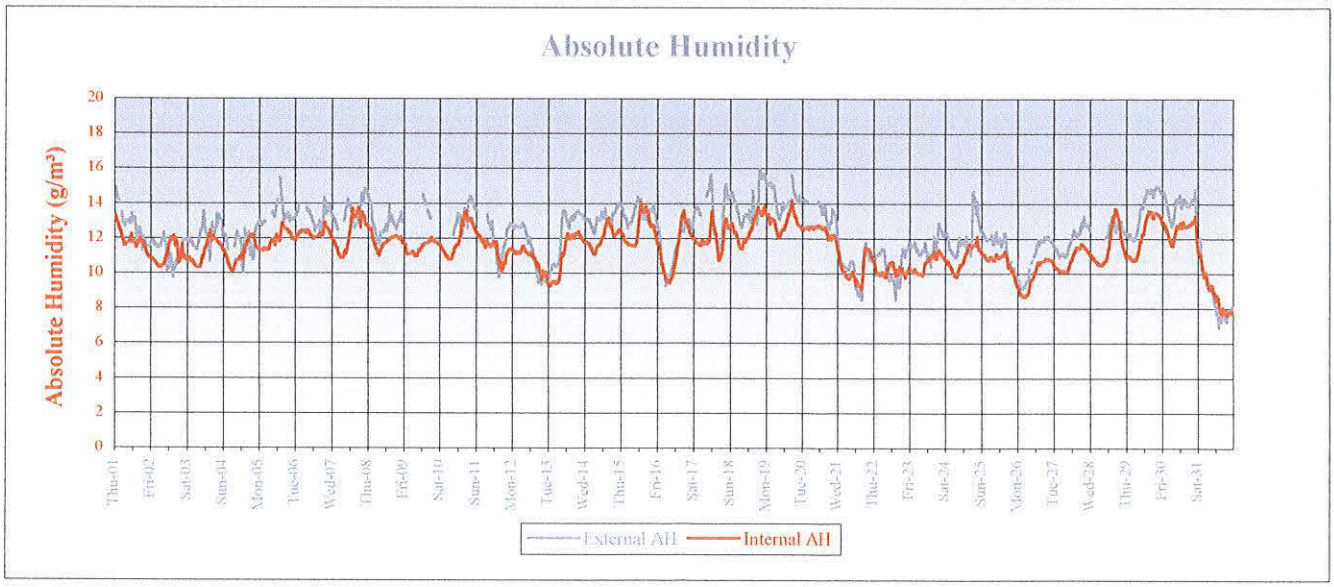
Peterborough Cathedral Nave Ceiling

August 2002

Probe 2: Bay 36 III upper side (shade)



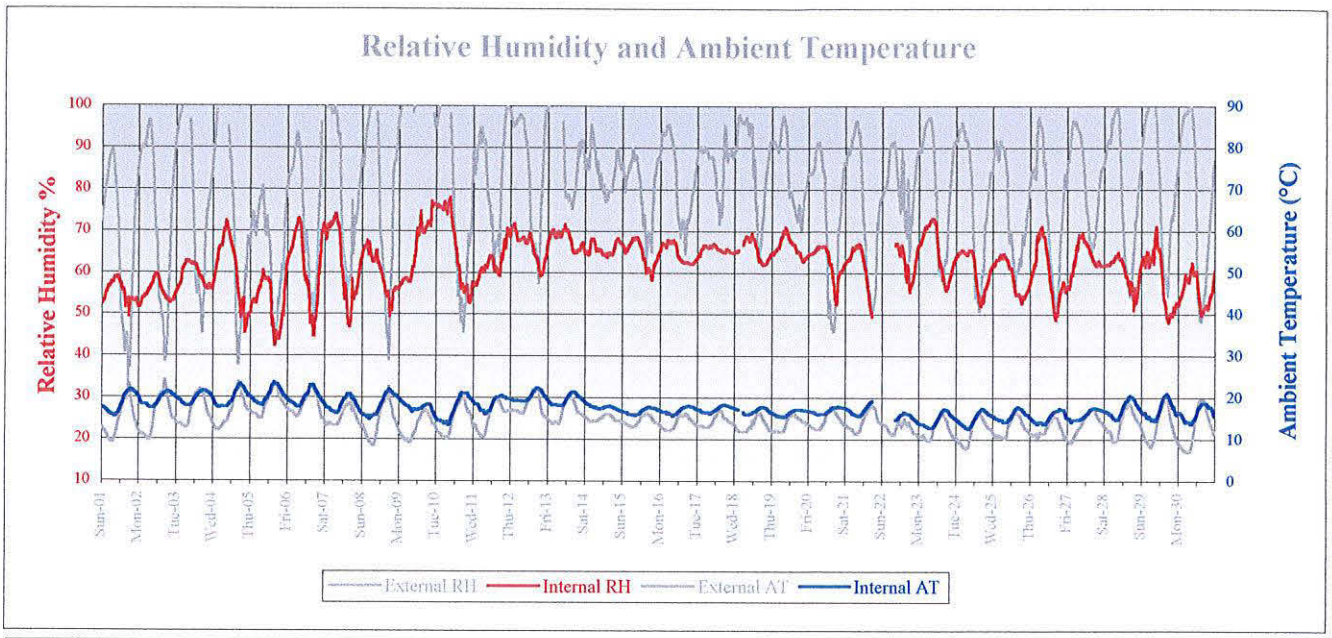


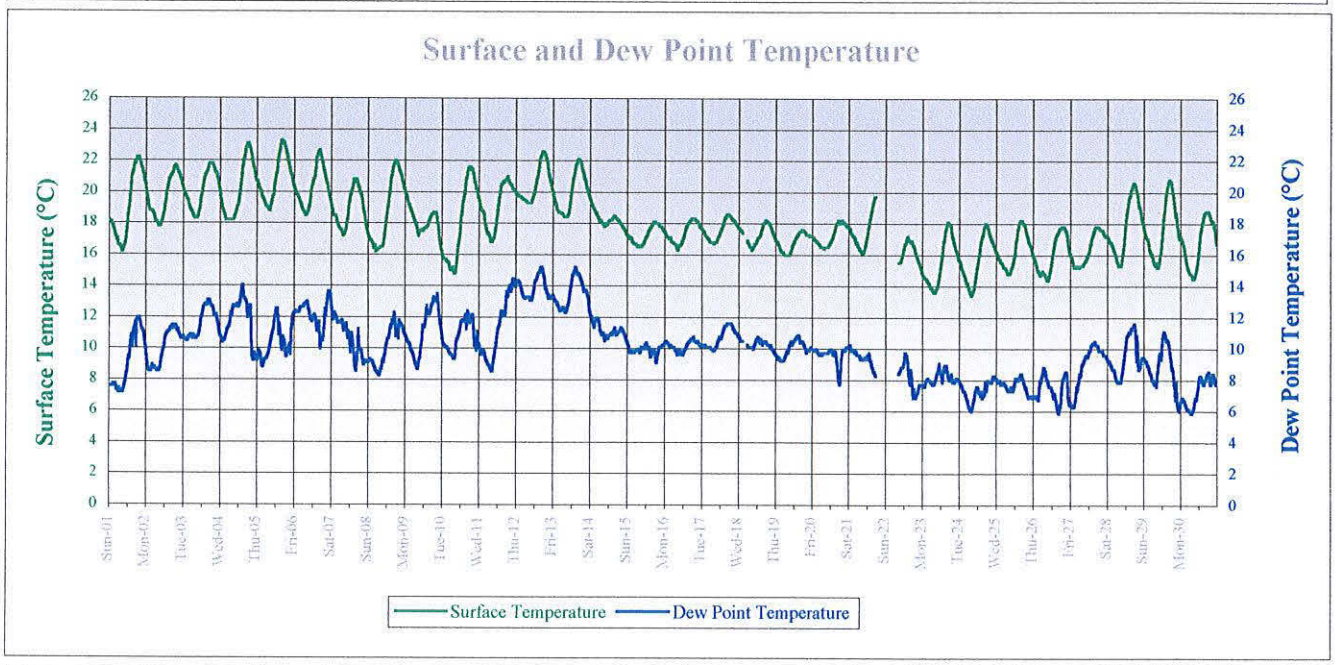


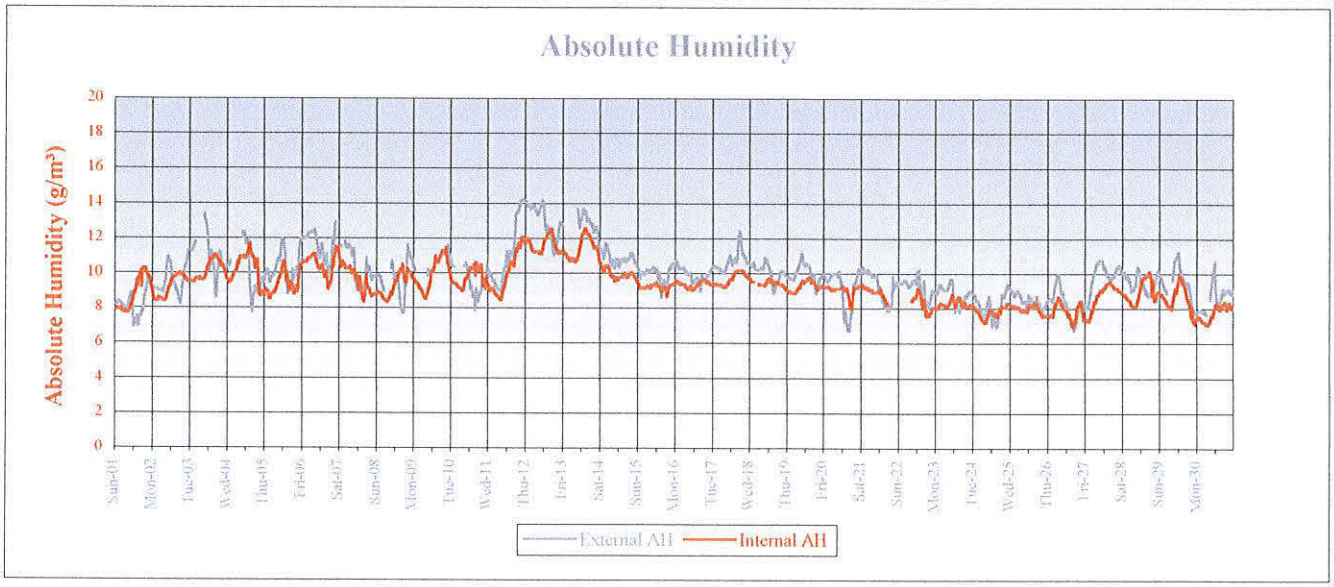
Peterborough Cathedral Nave Ceiling

September 2002

Probe 2: Bay 36 III upper side (shade)

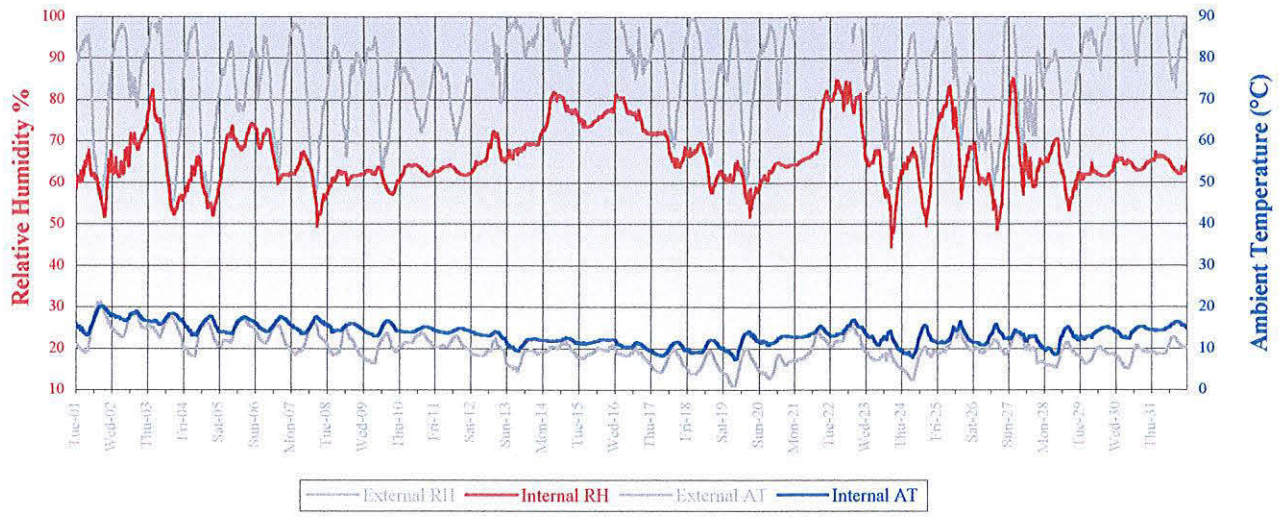




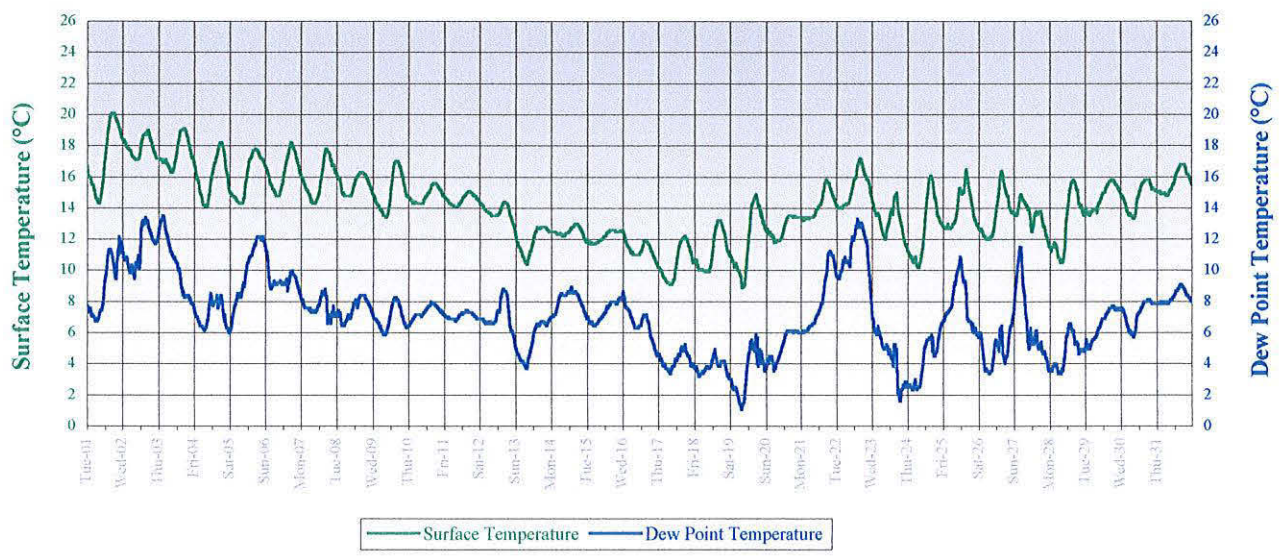


Probe 2: Bay 36 III upper side (shade)

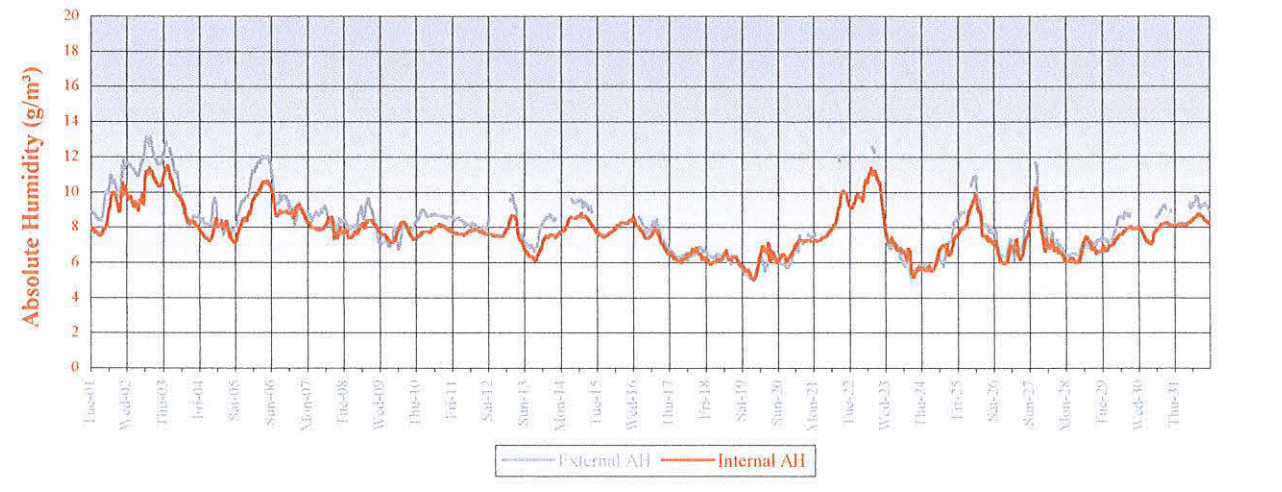
Relative Humidity and Ambient Temperature

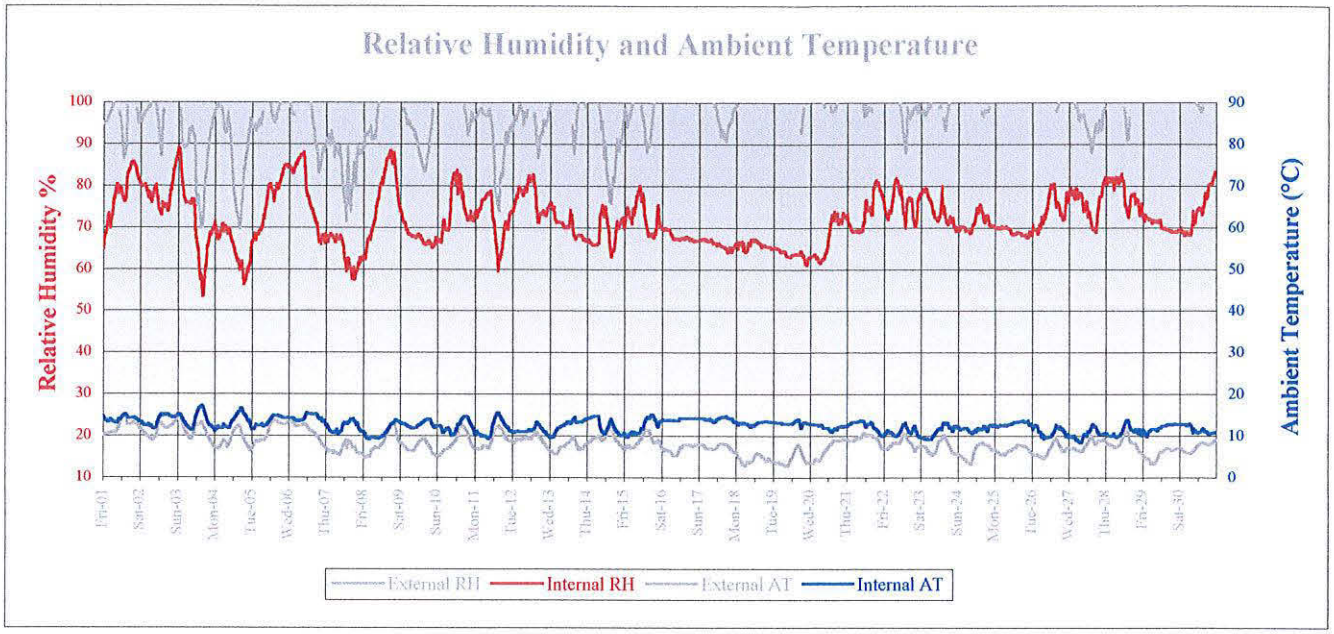


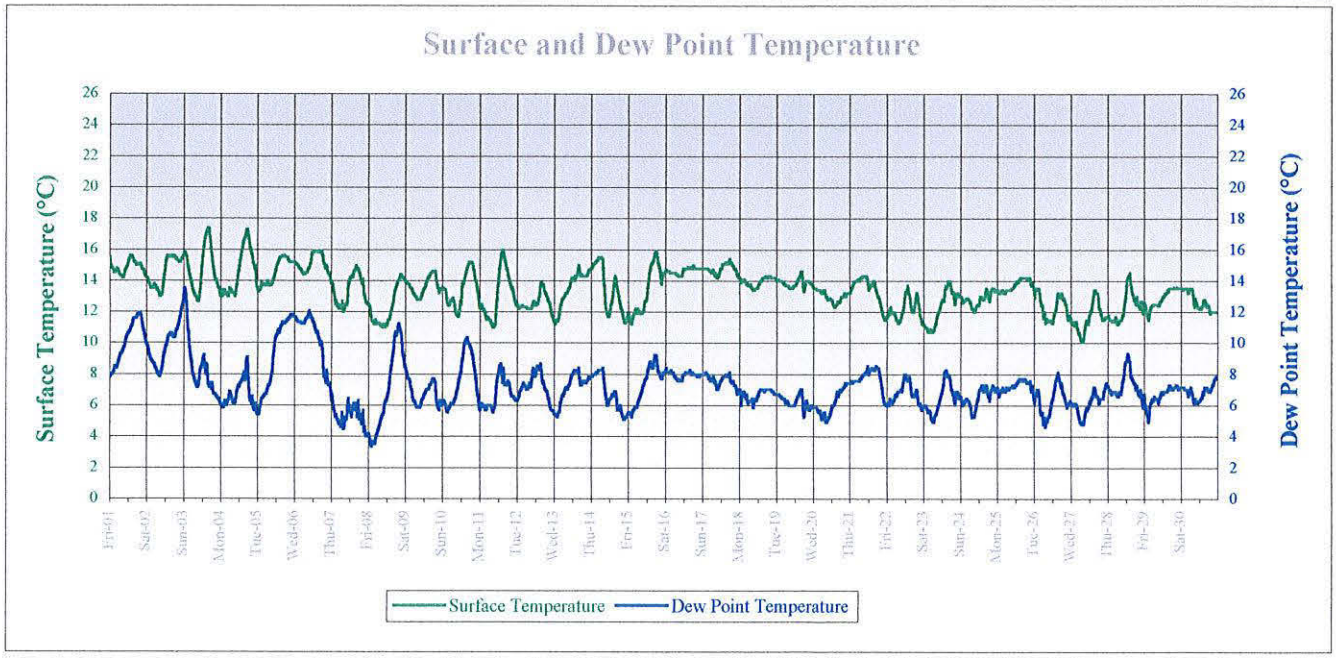
Surface and Dew Point Temperature

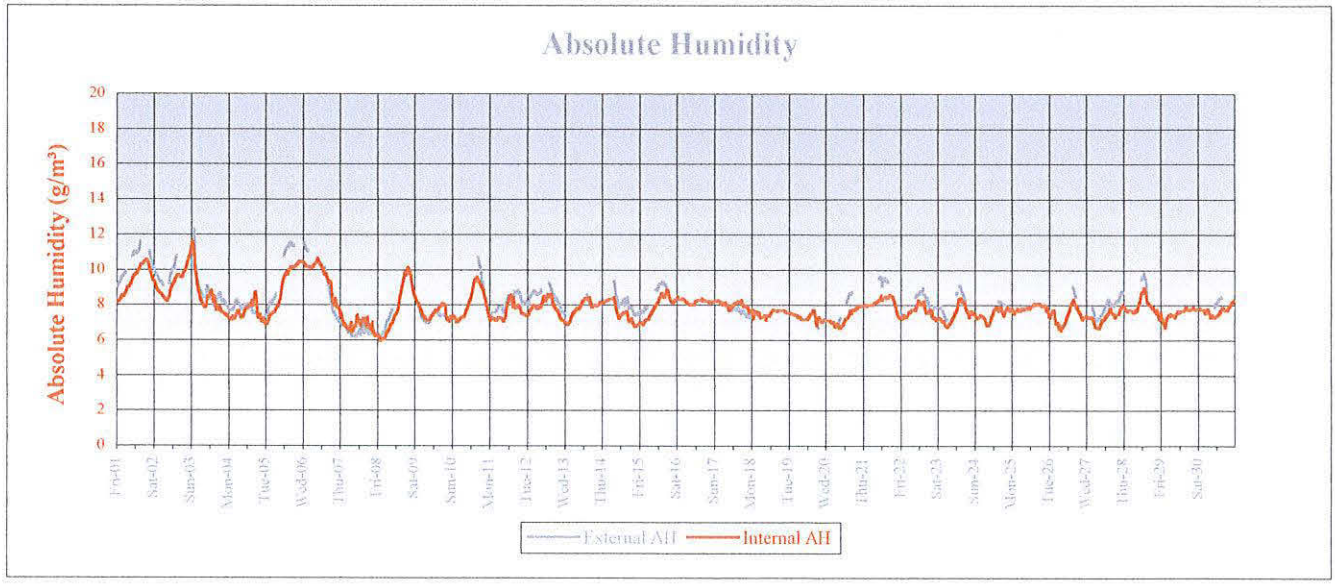


Absolute Humidity




Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

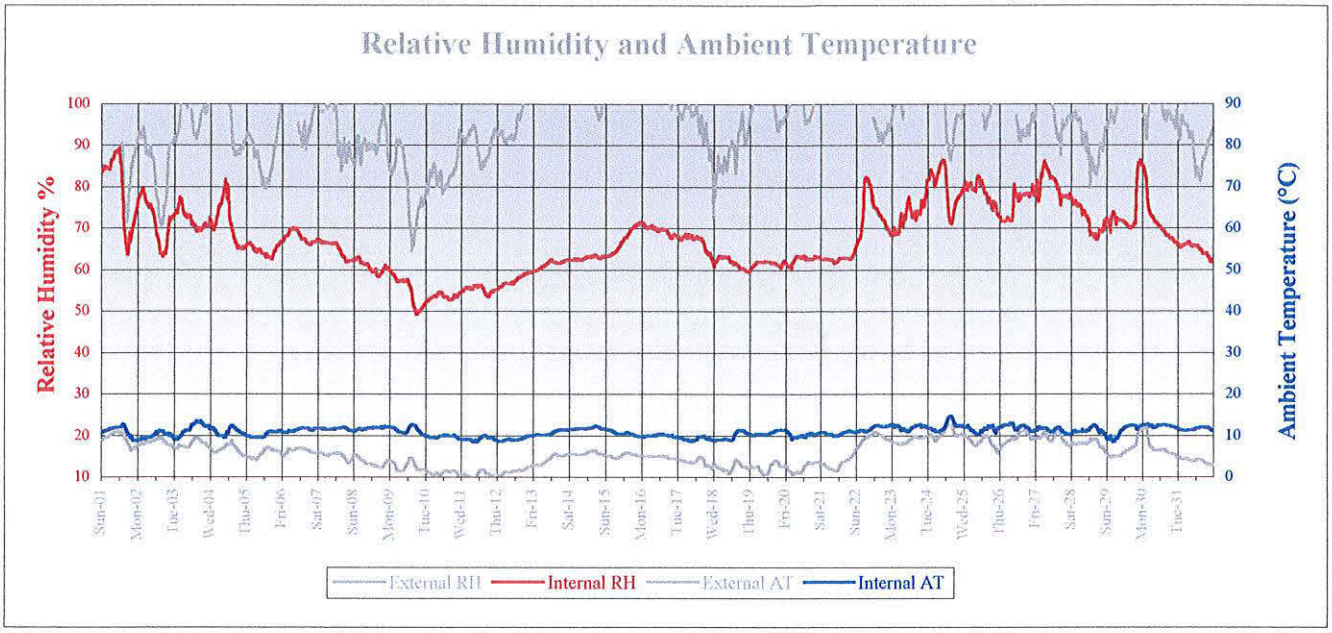

Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature

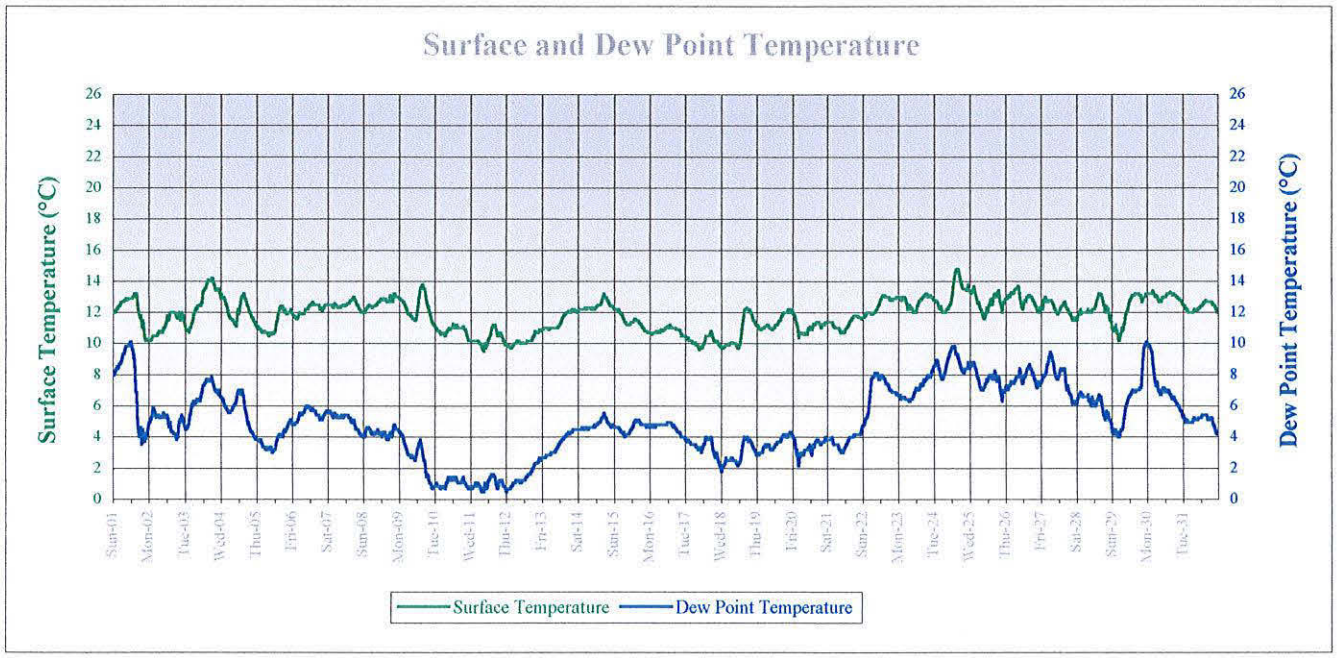

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

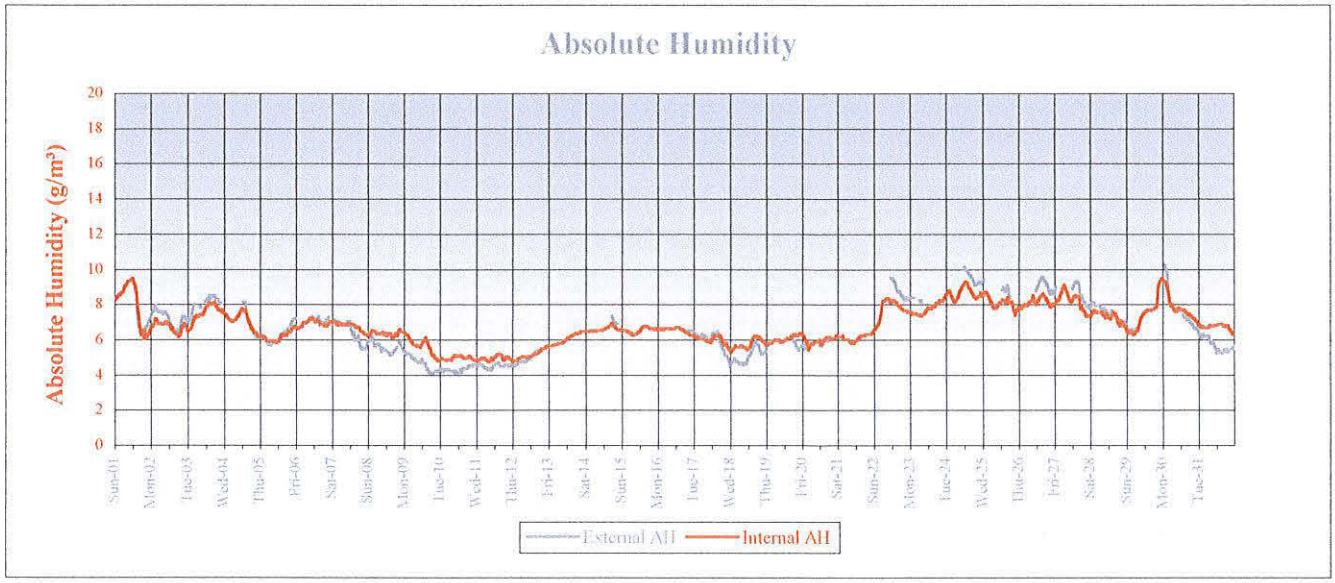
Peterborough Cathedral Nave Ceiling

December 2002

Probe 2: Bay 36 III upper side (shade)



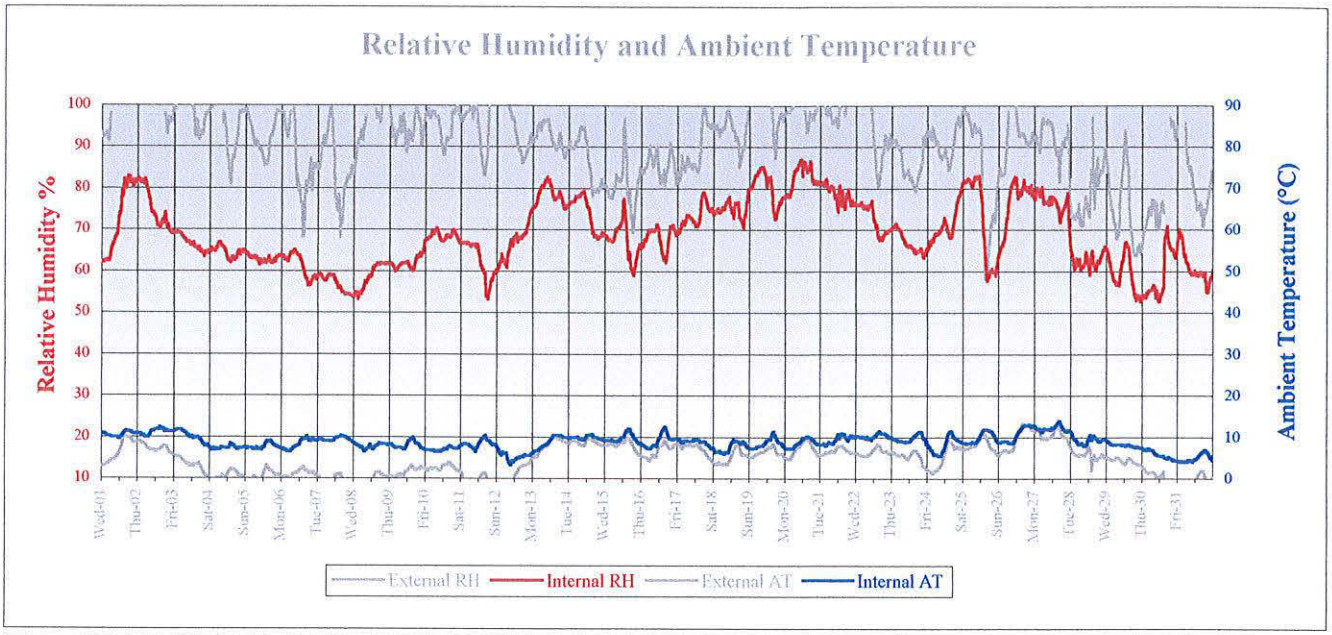


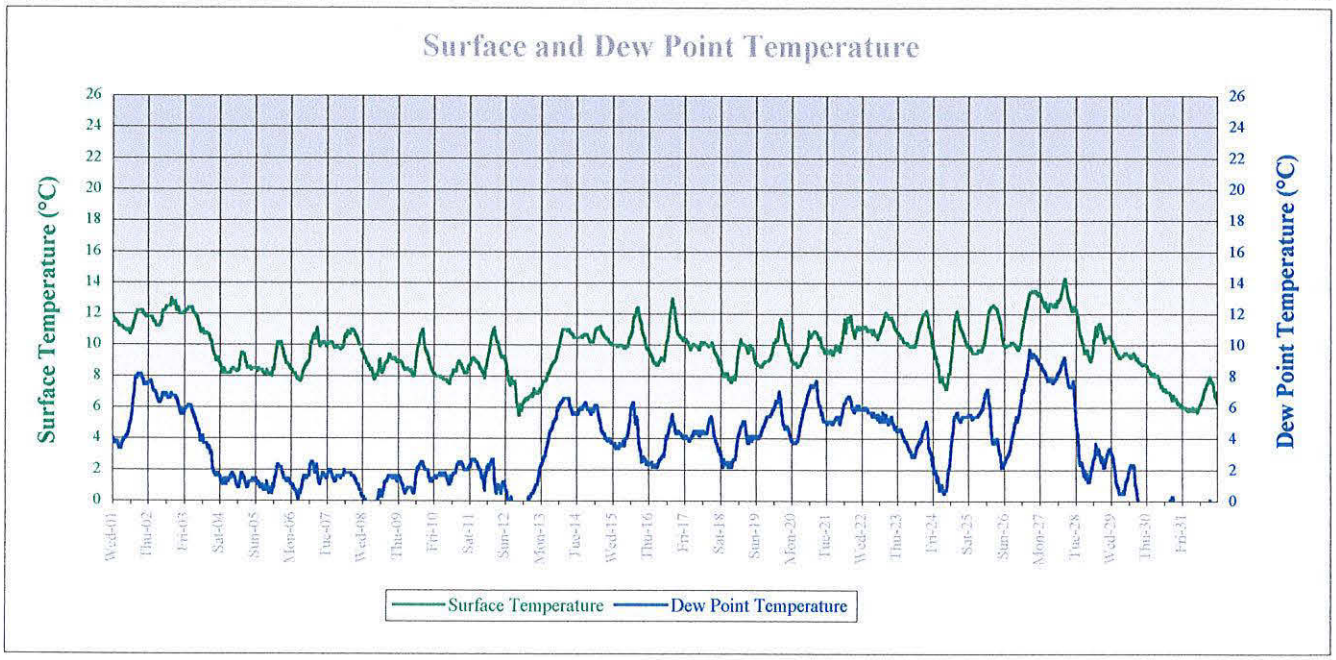


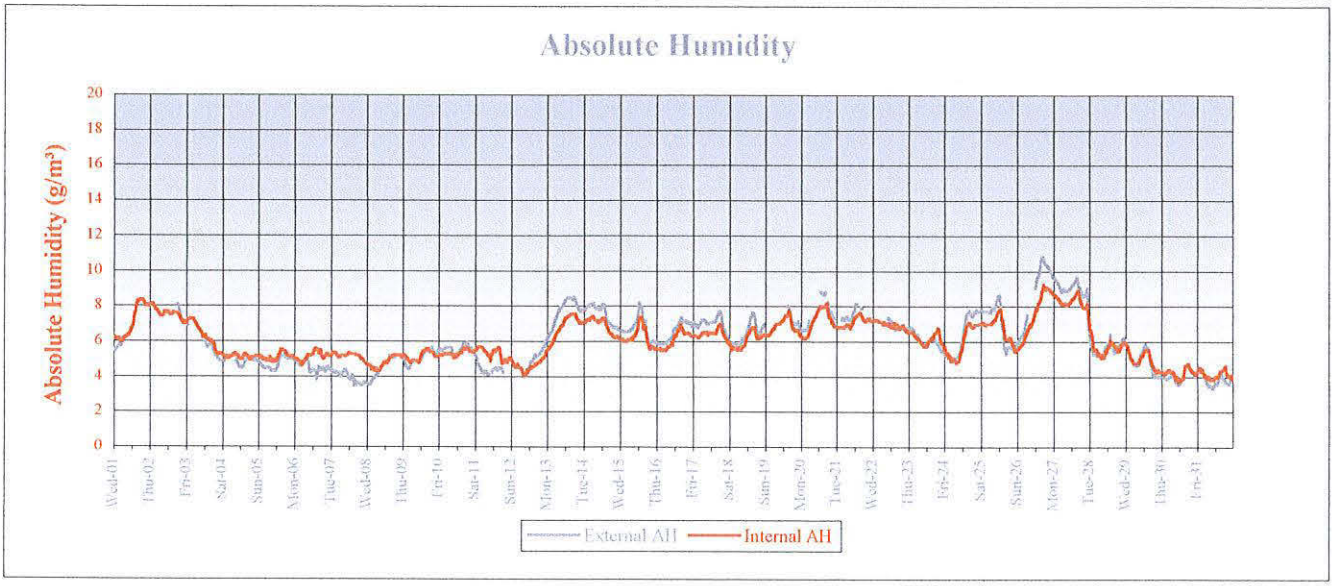
Peterborough Cathedral Nave Ceiling

January 2003

Probe 2: Bay 36 III upper side (shade)



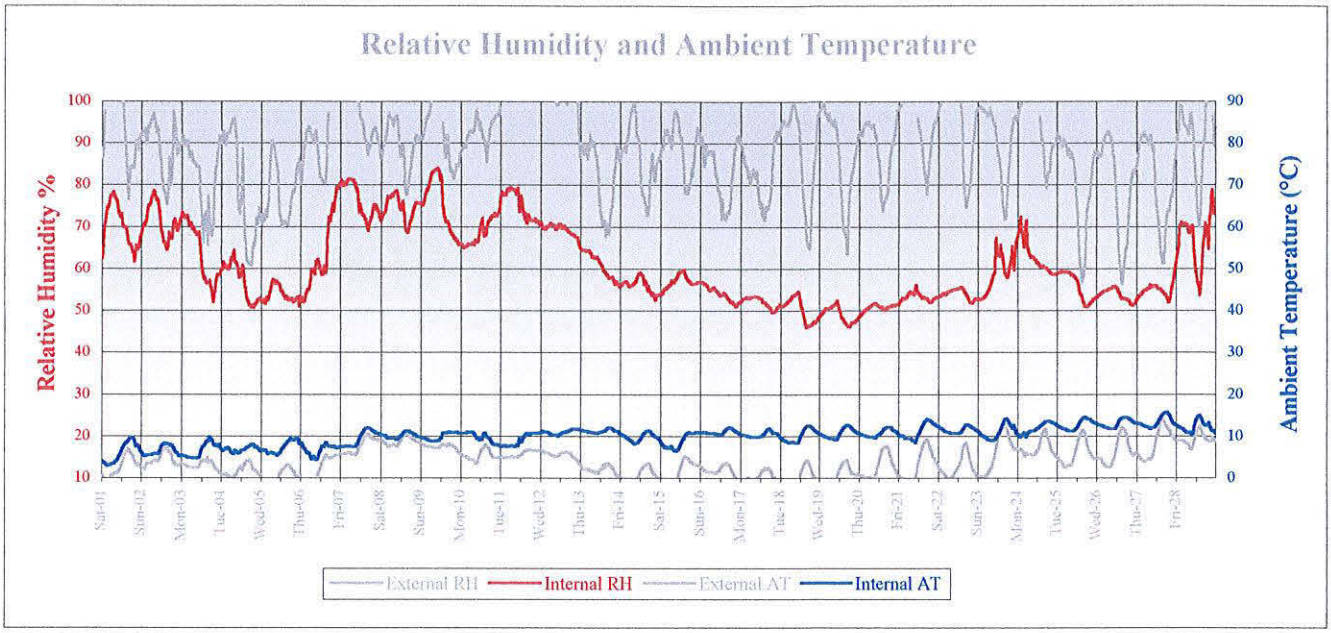


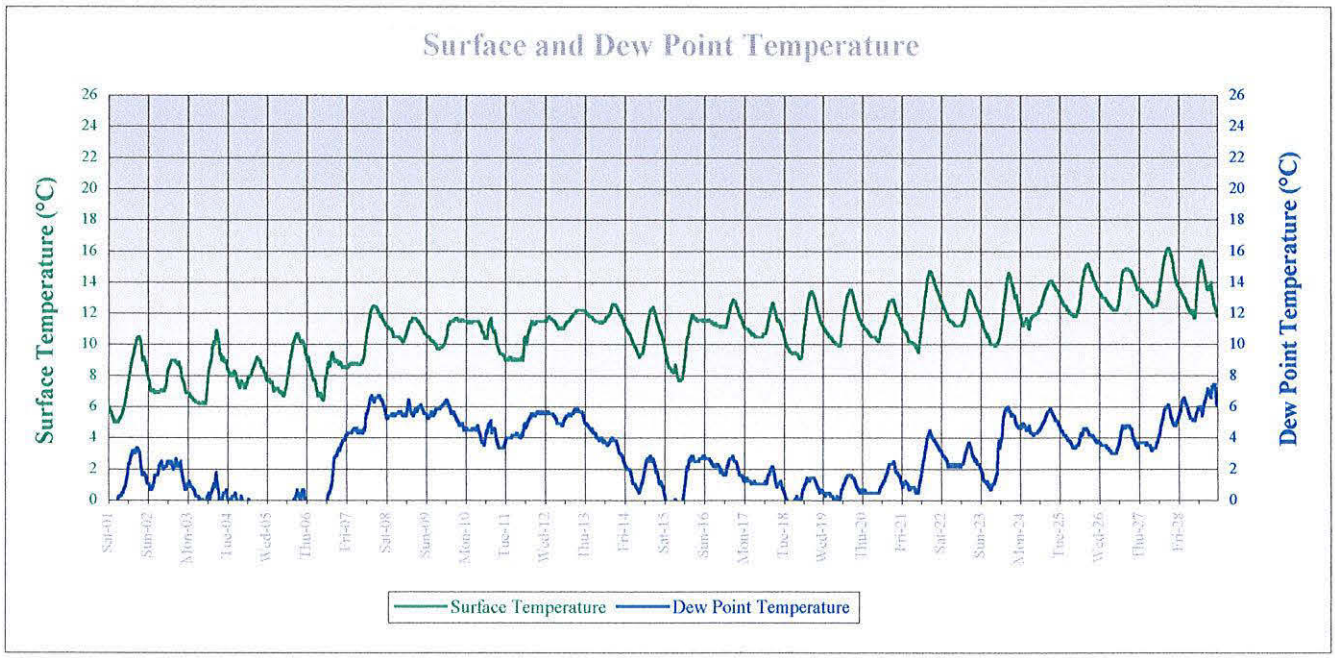


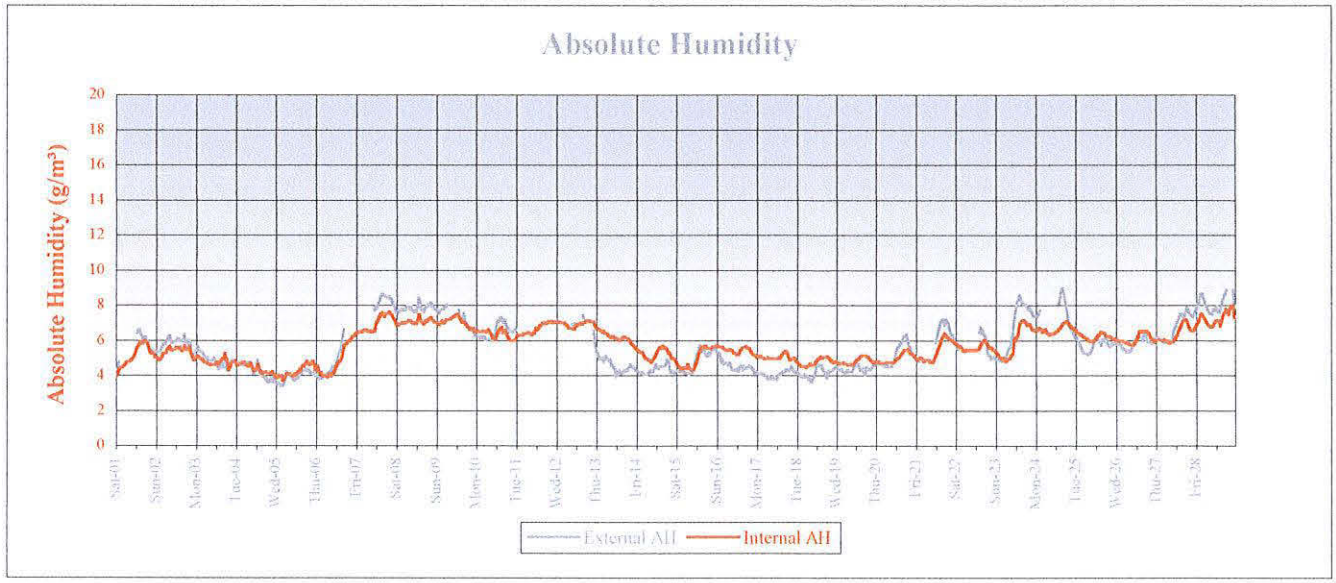
Peterborough Cathedral Nave Ceiling

February 2003

Probe 2: Bay 36 III upper side (shade)



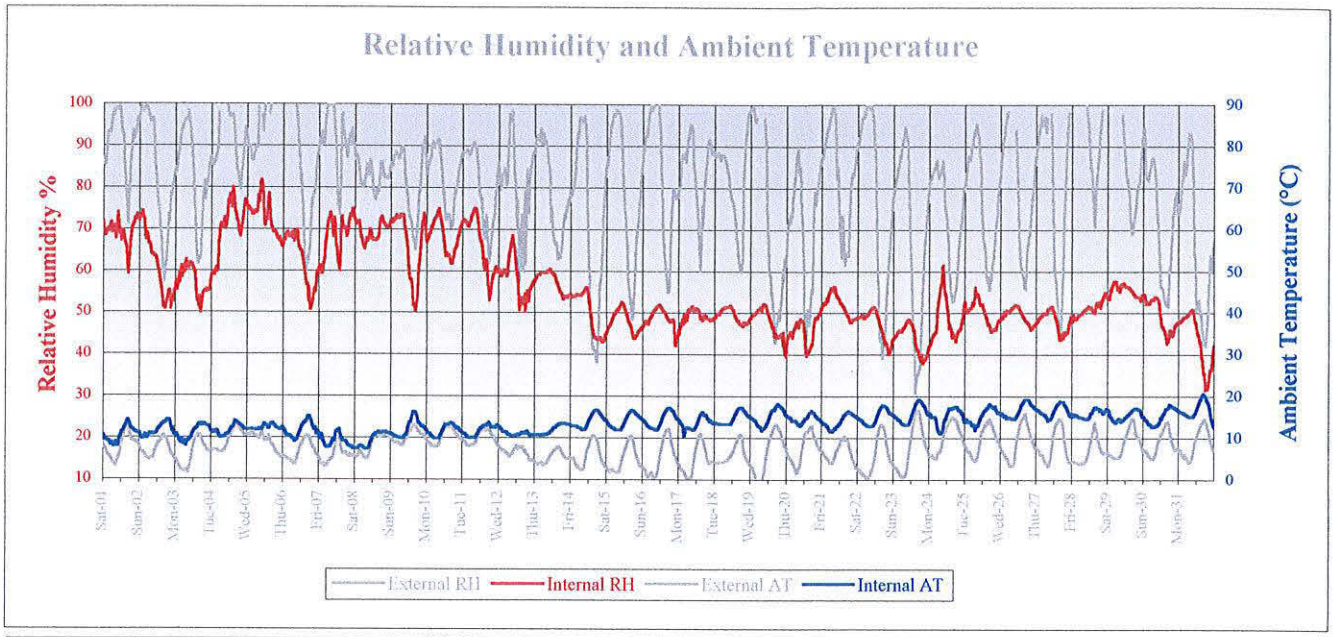


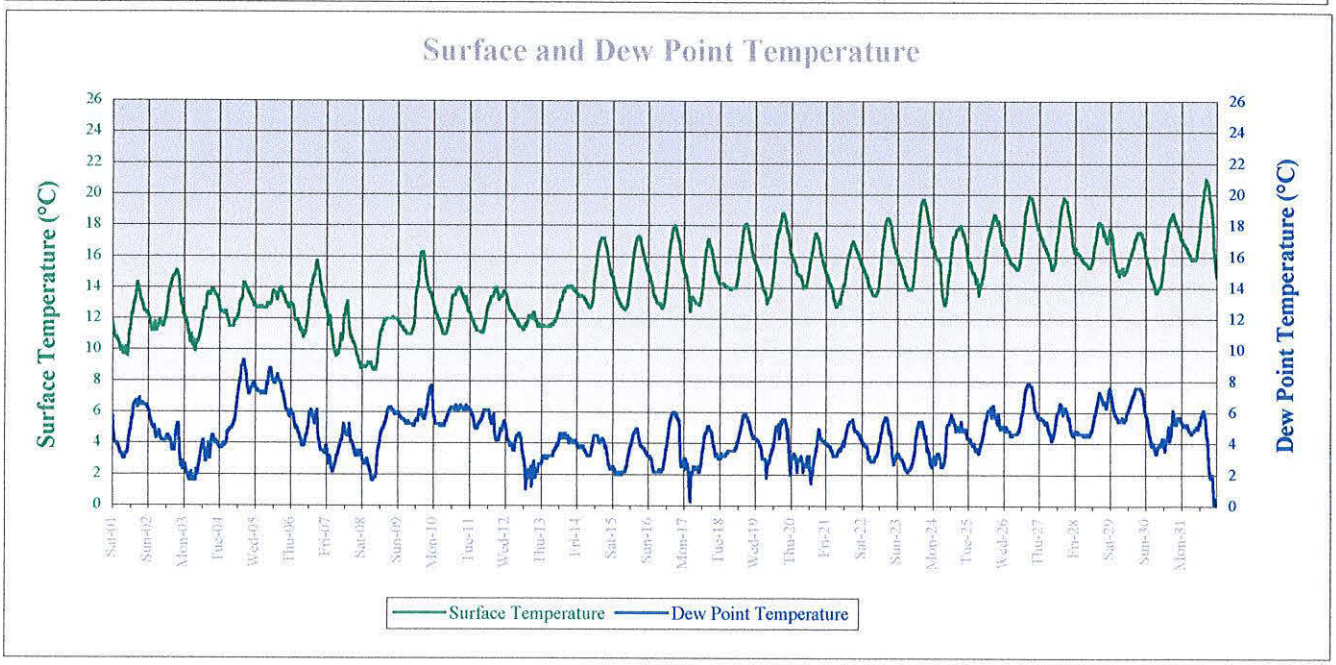


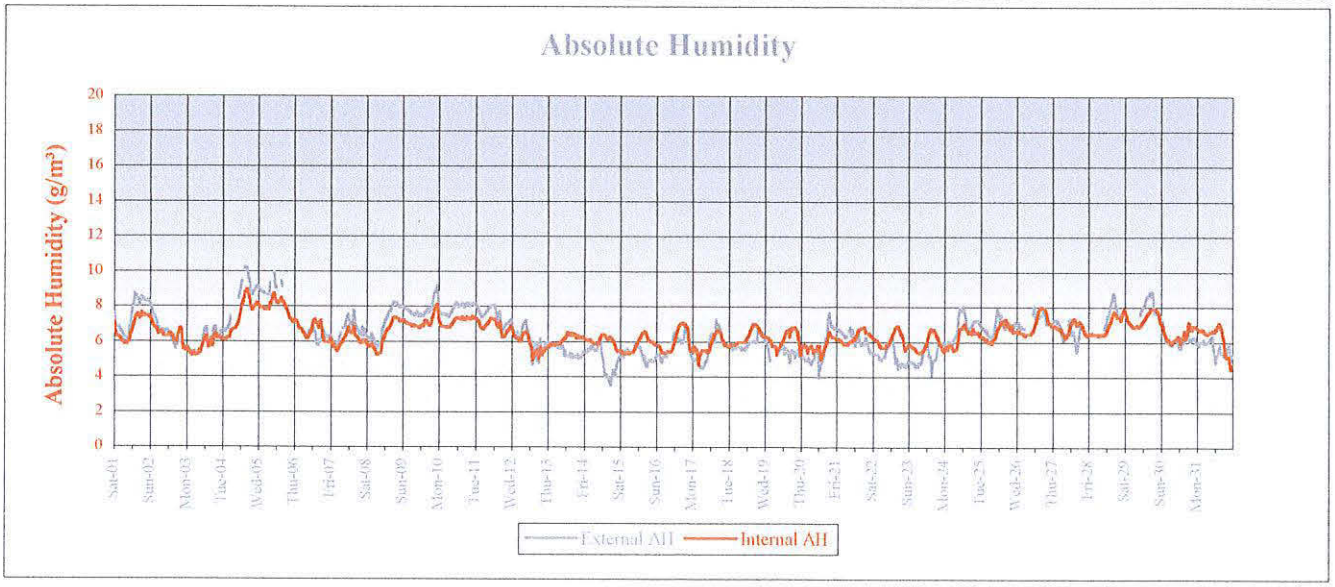
Peterborough Cathedral Nave Ceiling

March 2003

Probe 2: Bay 36 III upper side (shade)





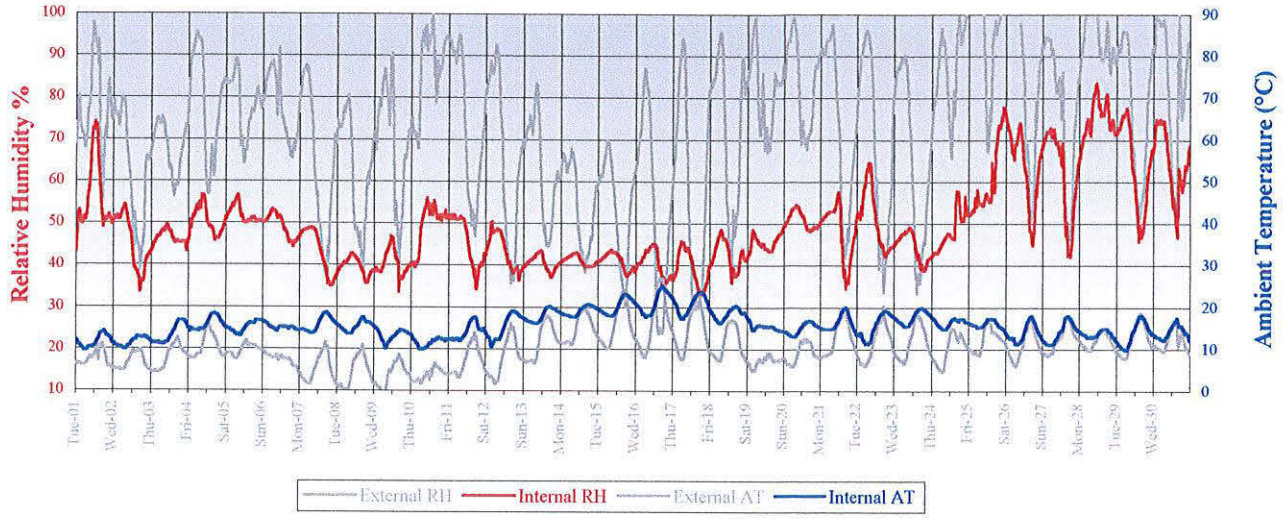


Peterborough Cathedral Nave Ceiling

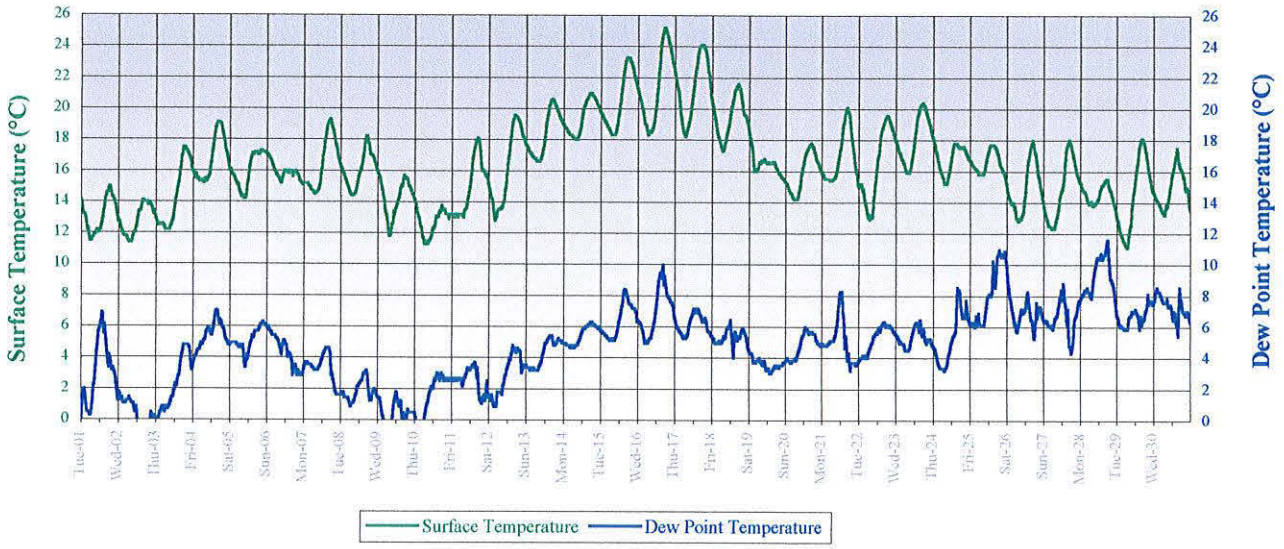
April 2003

Probe 2: Bay 36 III upper side (shade)

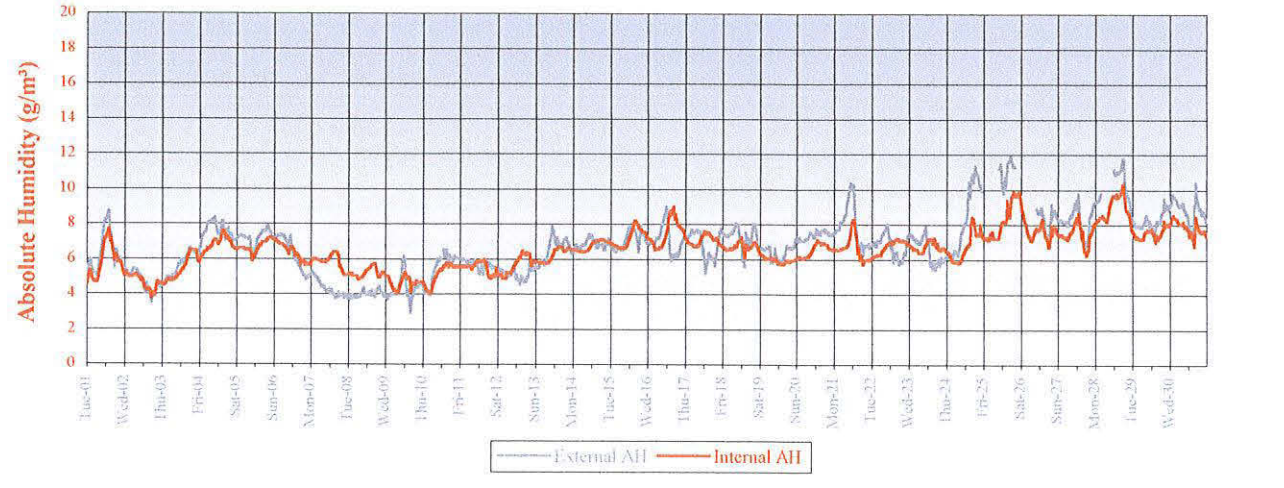
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

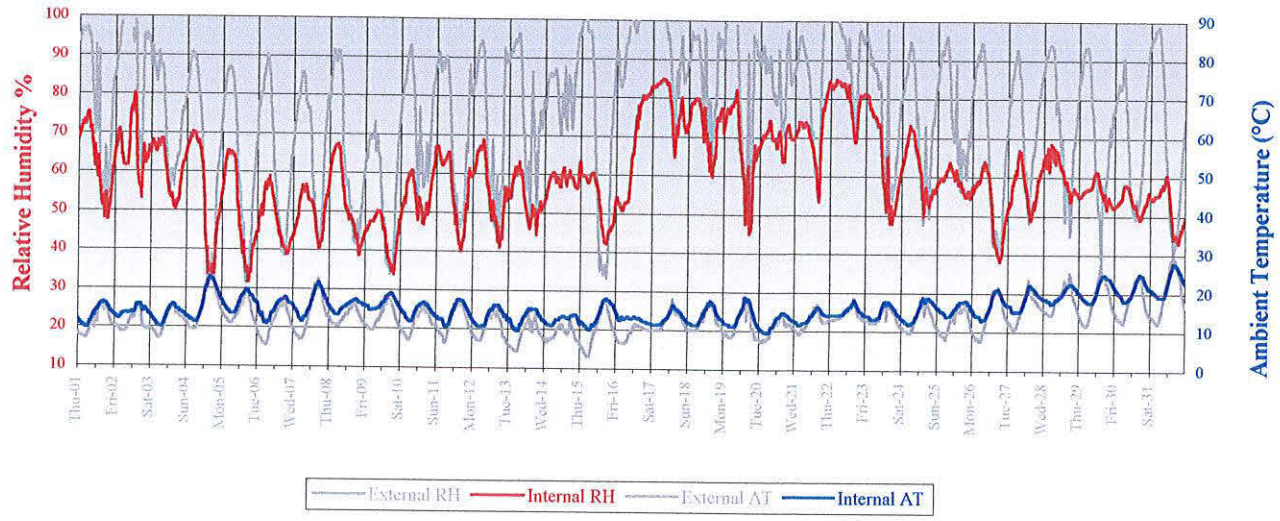


Peterborough Cathedral Nave Ceiling

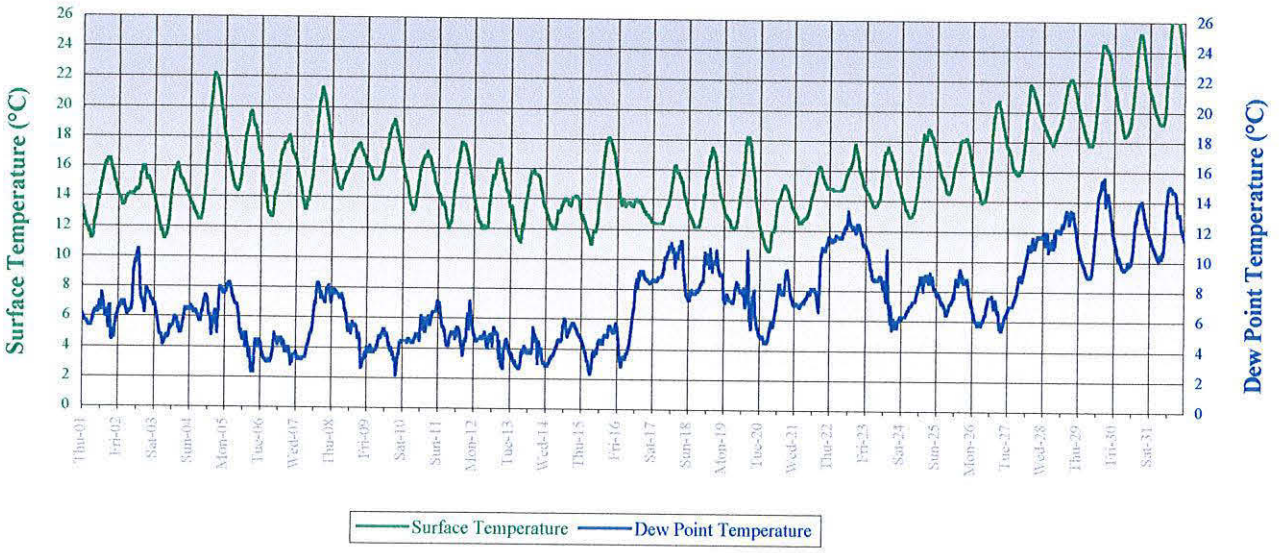
Probe 2: Bay 36 III upper side (shade)

May 2003

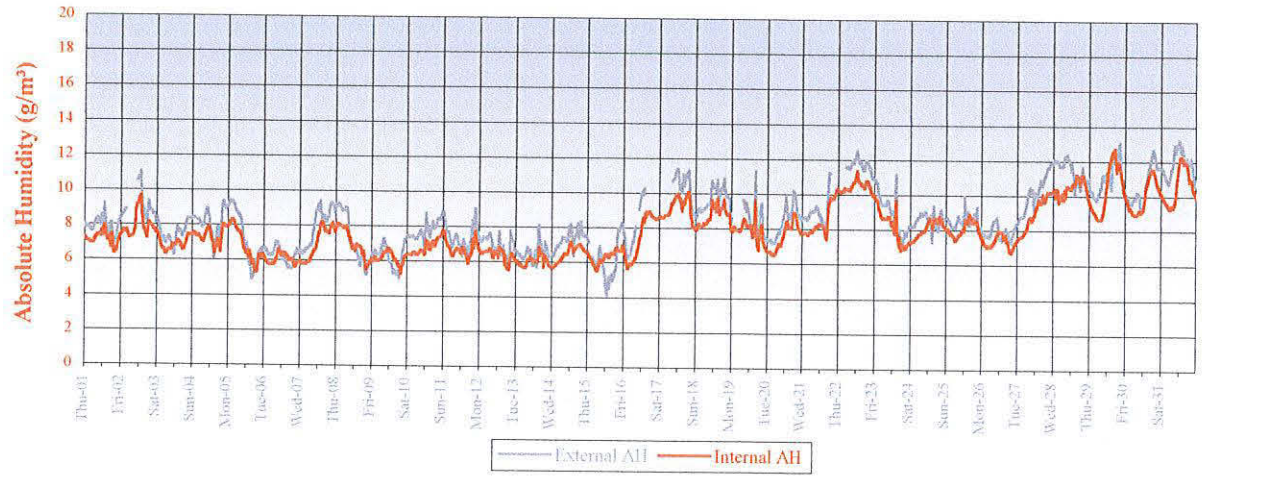
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



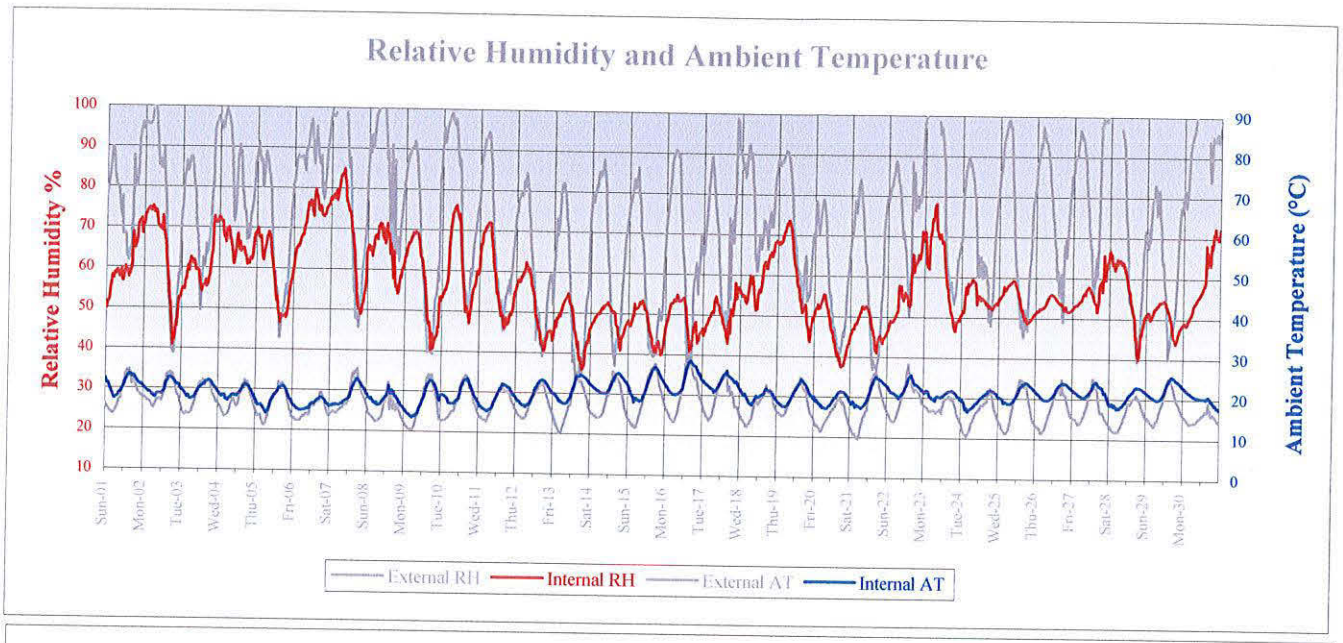
Absolute Humidity

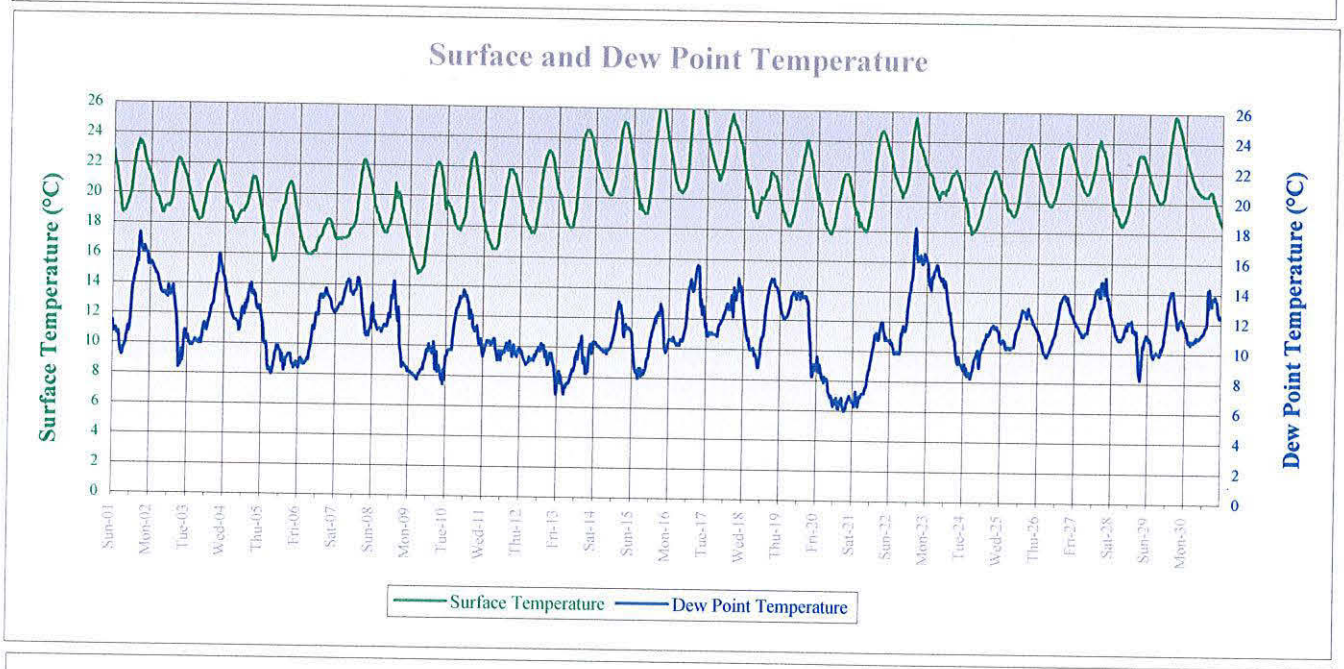


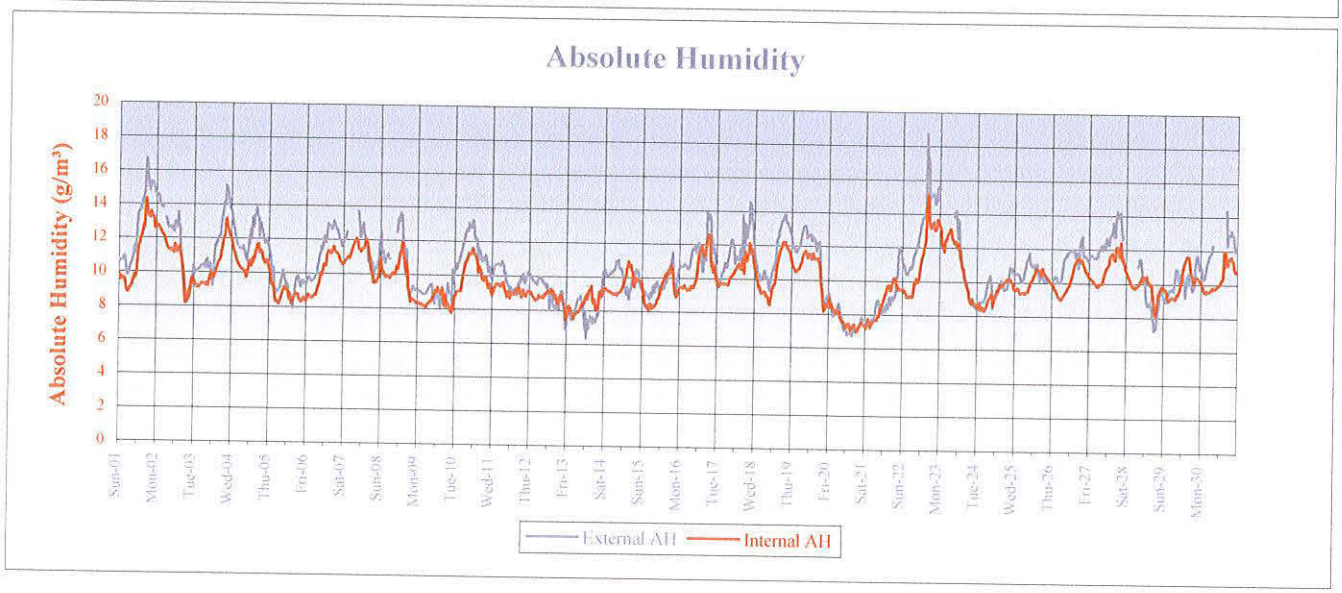
Peterborough Cathedral Nave Ceiling

Probe 2: Bay 36 III upper side (shade)

June 2003





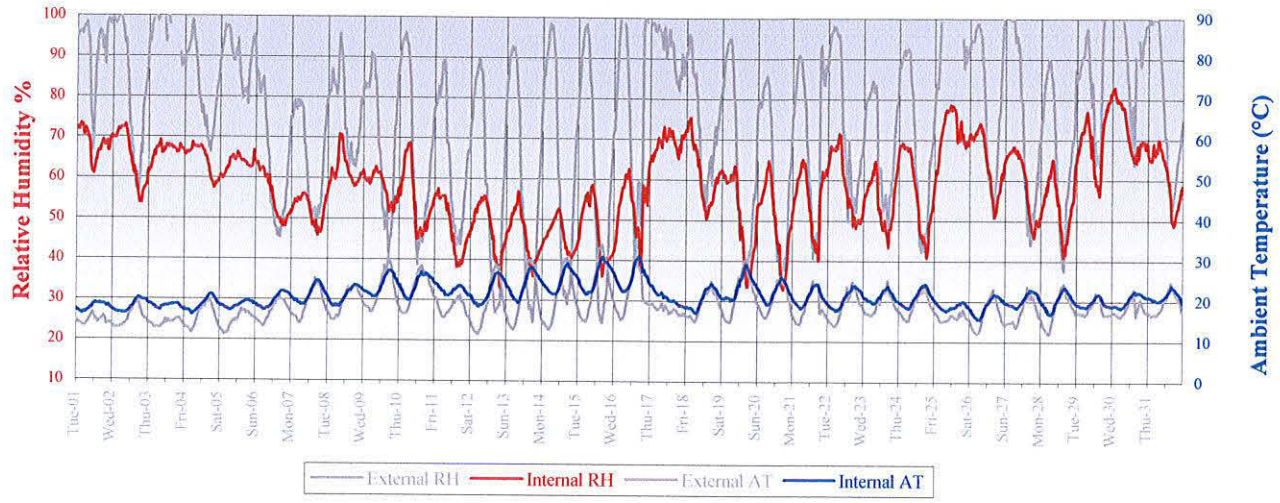


Peterborough Cathedral Nave Ceiling

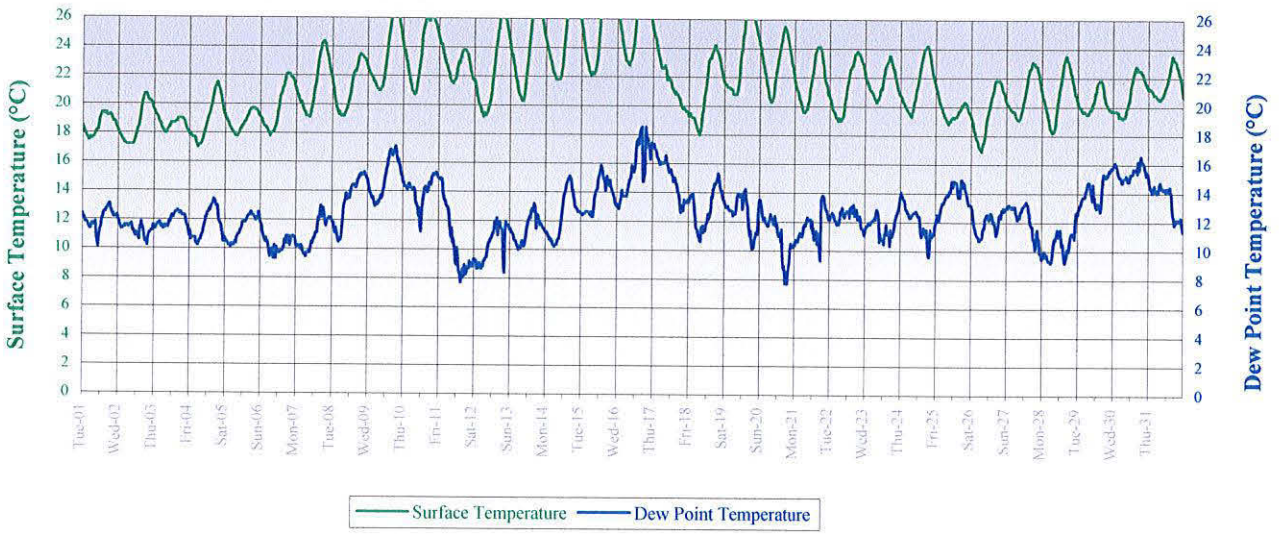
July 2003

Probe 2: Bay 36 III upper side (shade)

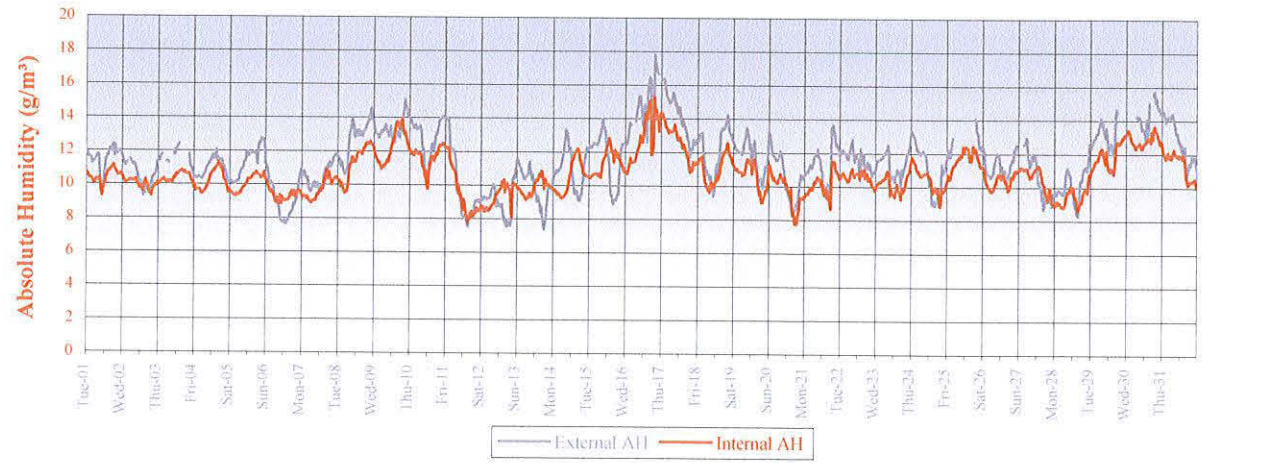
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

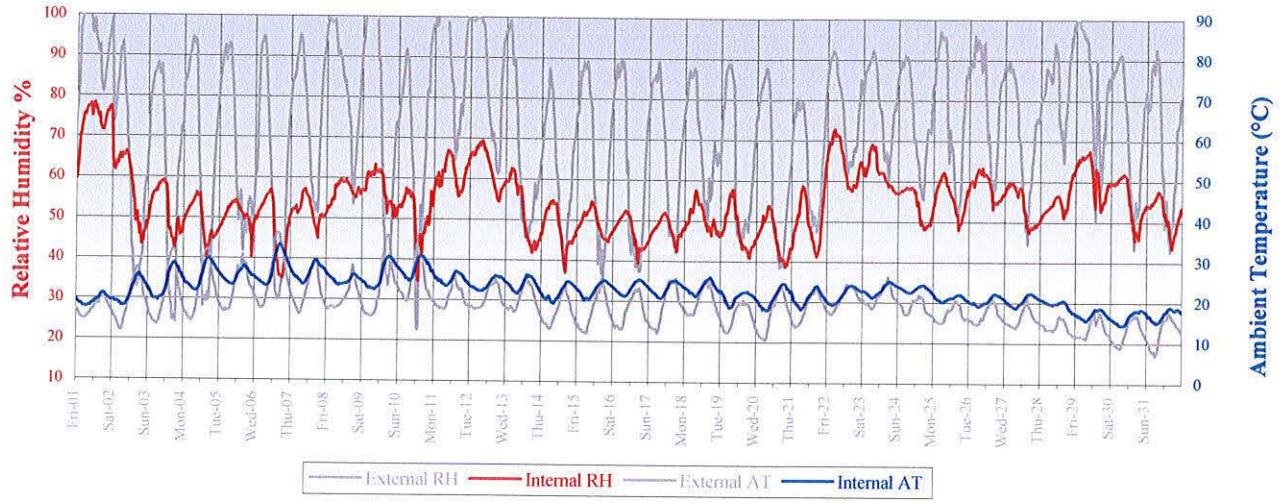


Peterborough Cathedral Nave Ceiling

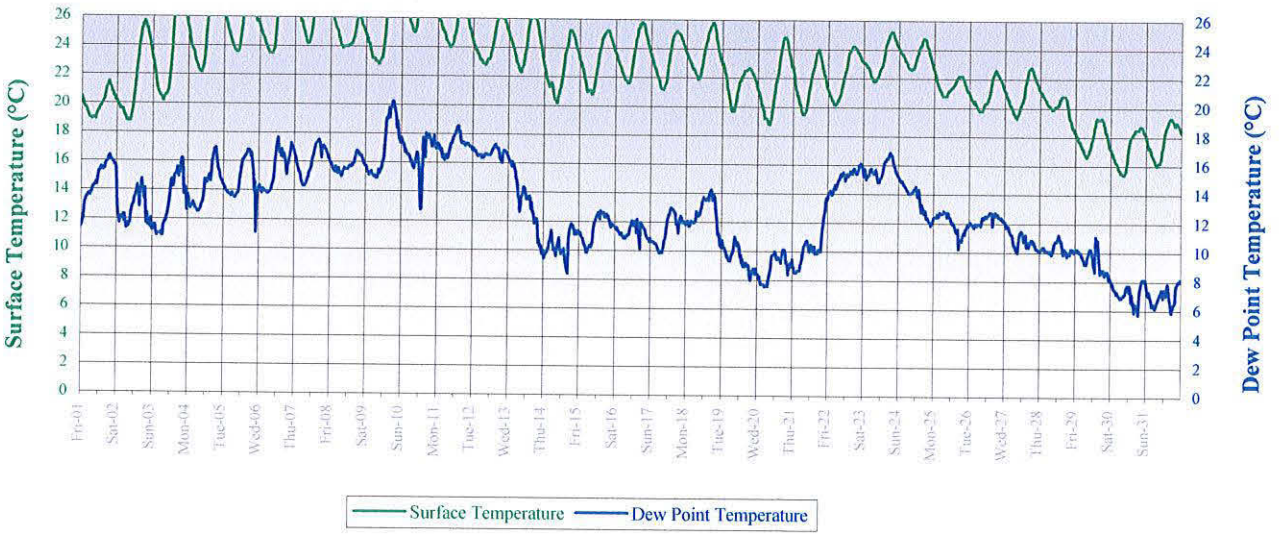
August 2003

Probe 2: Bay 36 III upper side (shade)

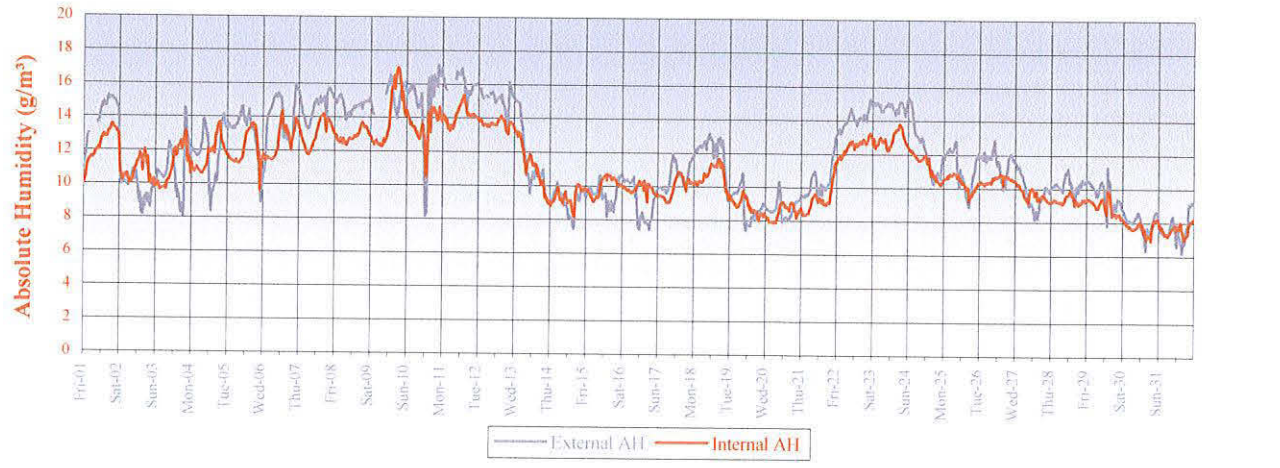
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

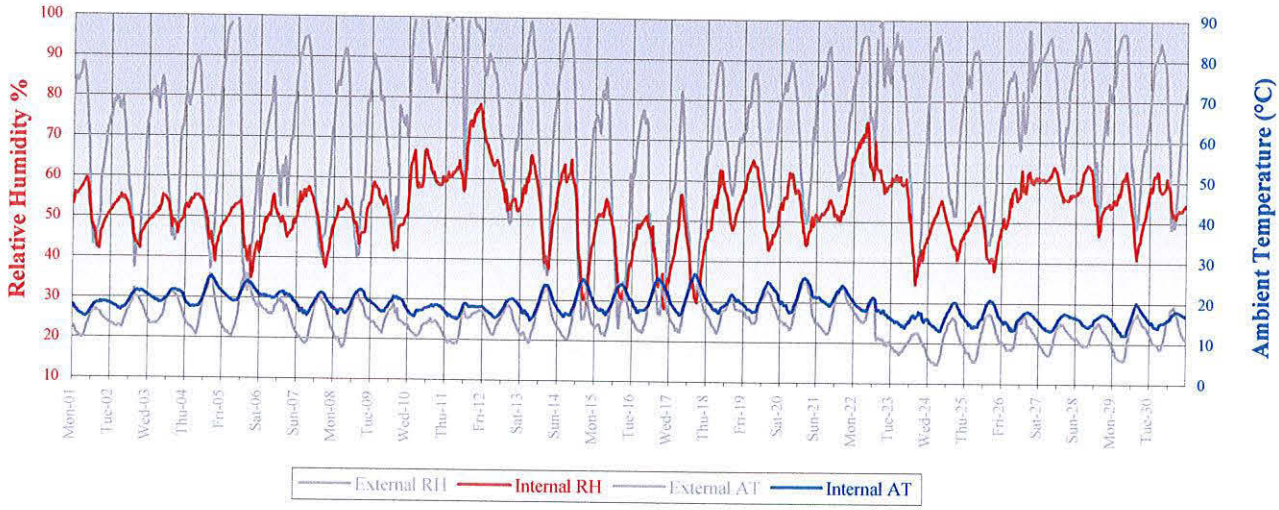


Peterborough Cathedral Nave Ceiling

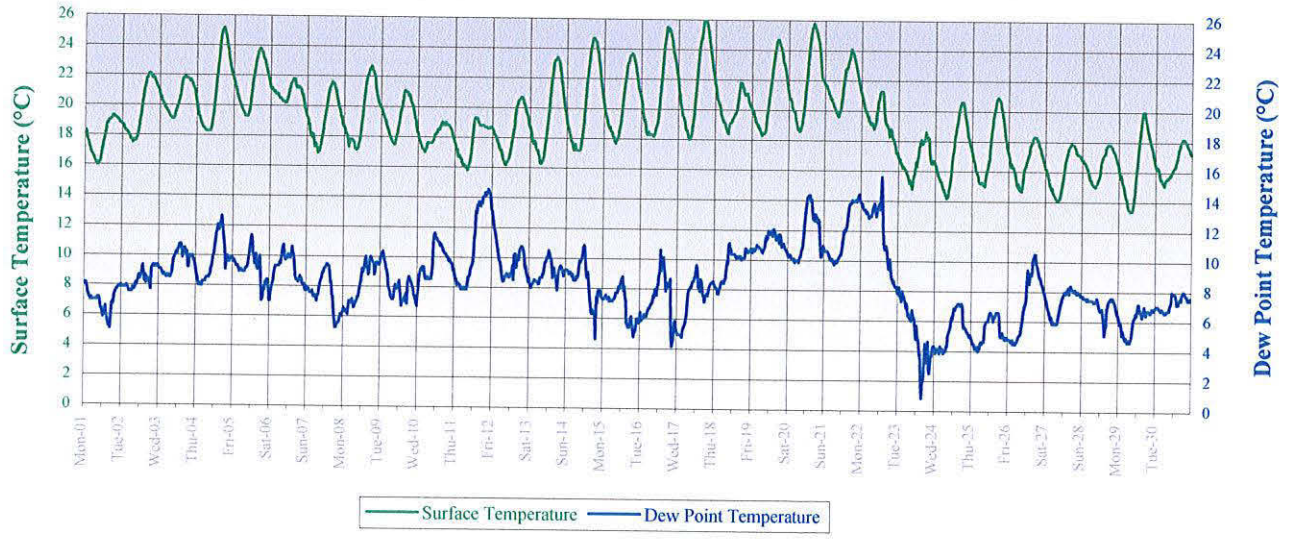
Probe 2: Bay 36 III upper side (shade)

September 2003

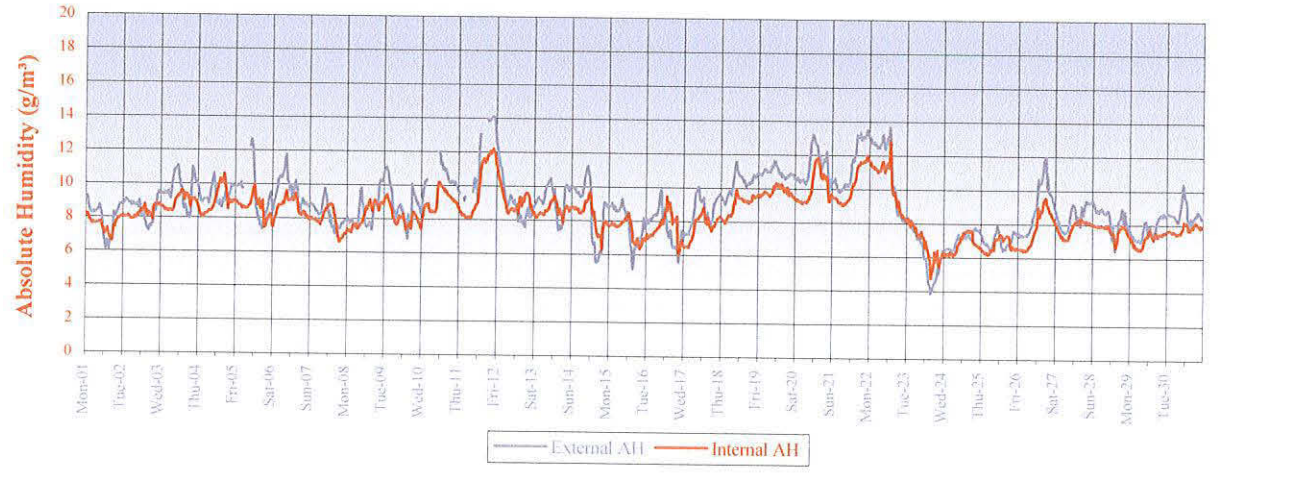
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

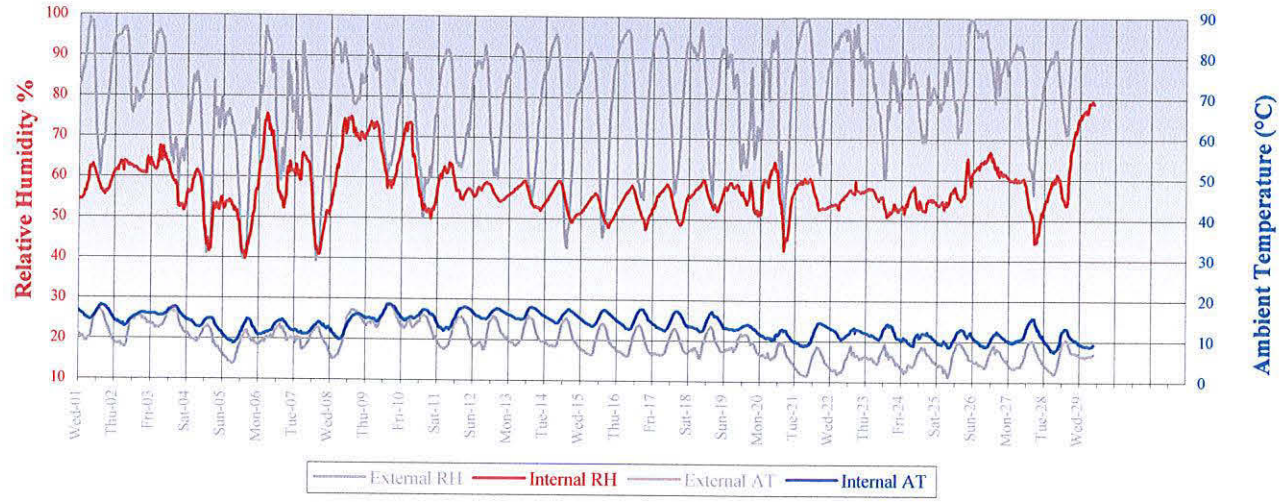


Peterborough Cathedral Nave Ceiling

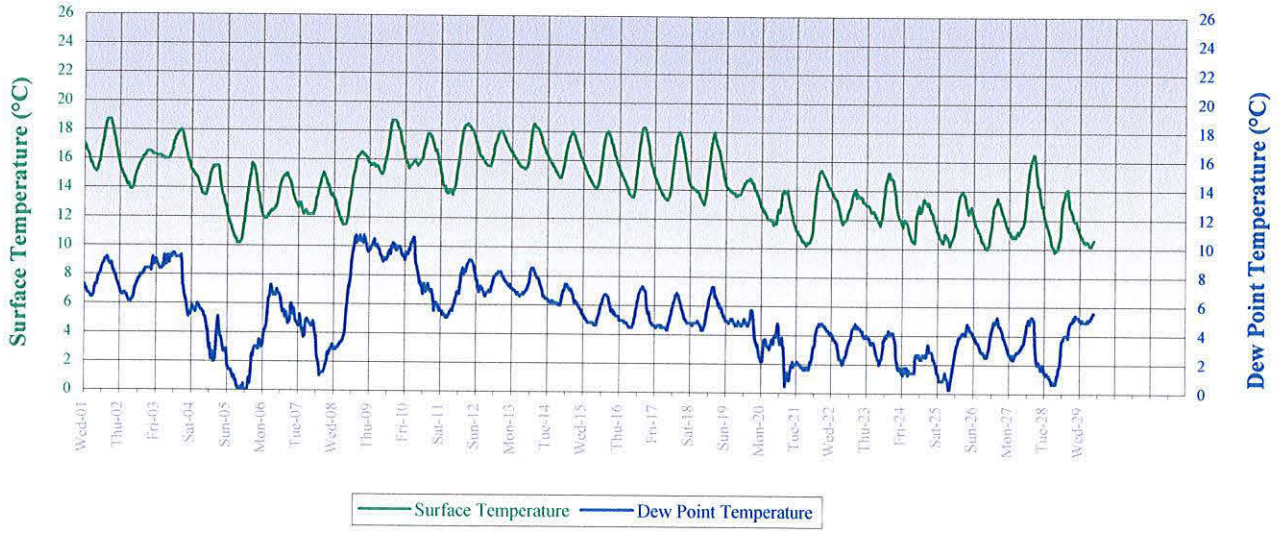
October 2003

Probe 2: Bay 36 III upper side (shade)

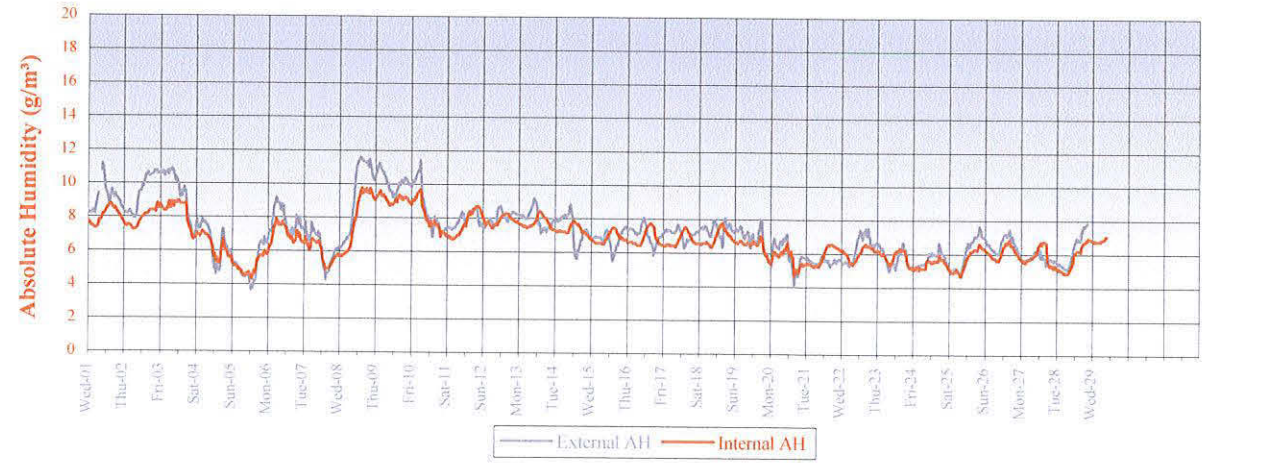
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity



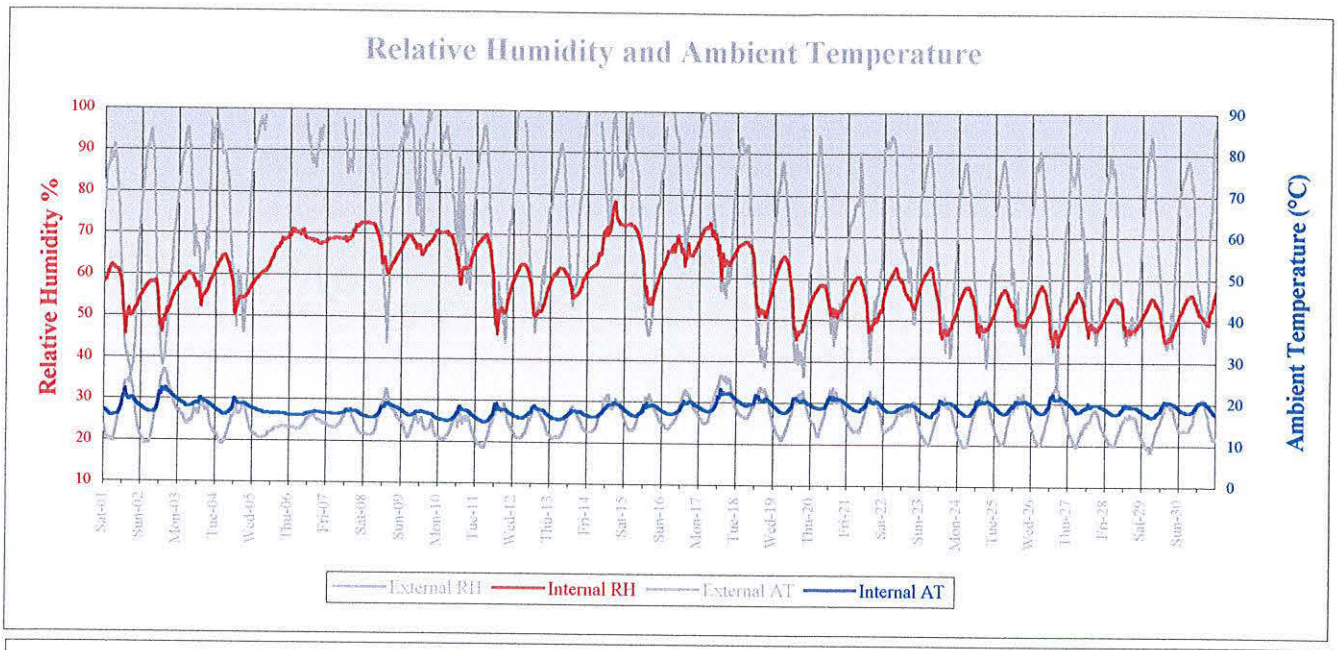
PROBE 3

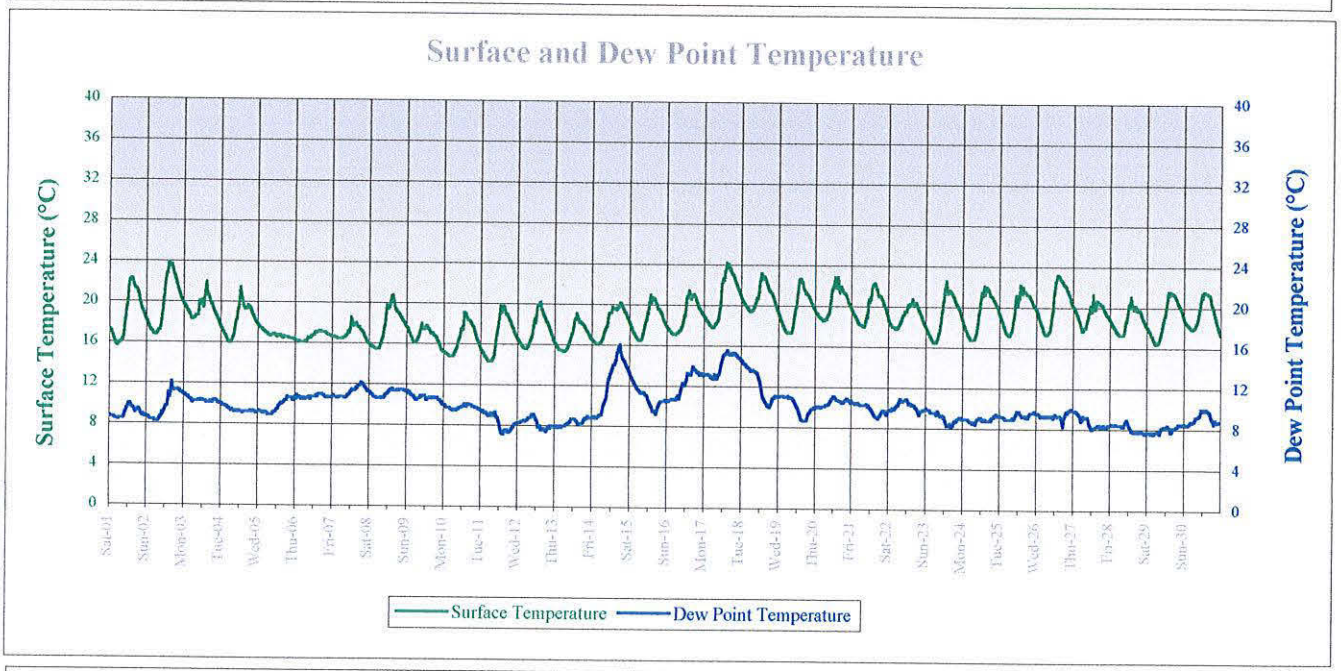
BAY 33 IV LOWER SIDE (SUN)

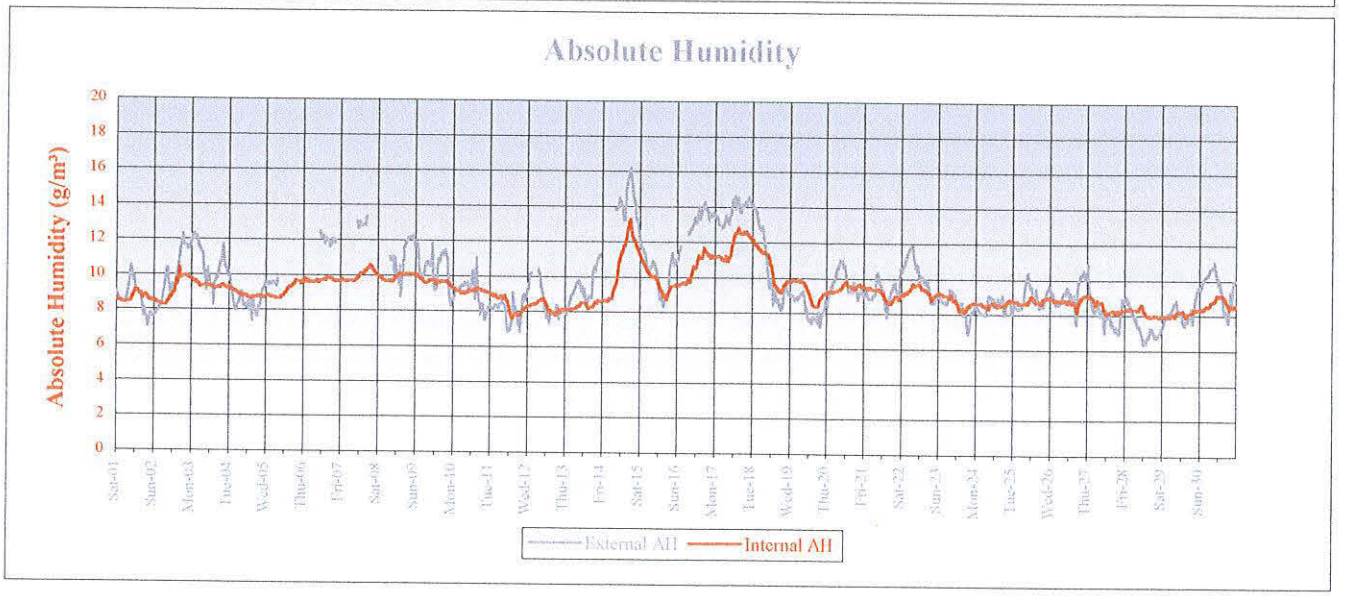
Peterborough Cathedral Nave Ceiling

June 2002

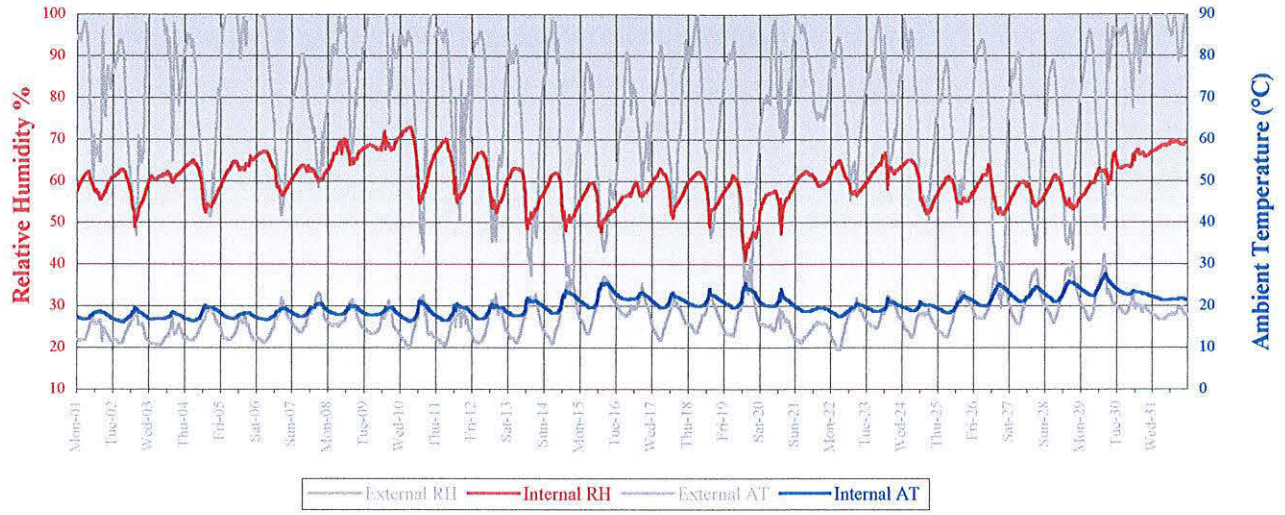
Probe 3: Bay 33 III lower side (sun)



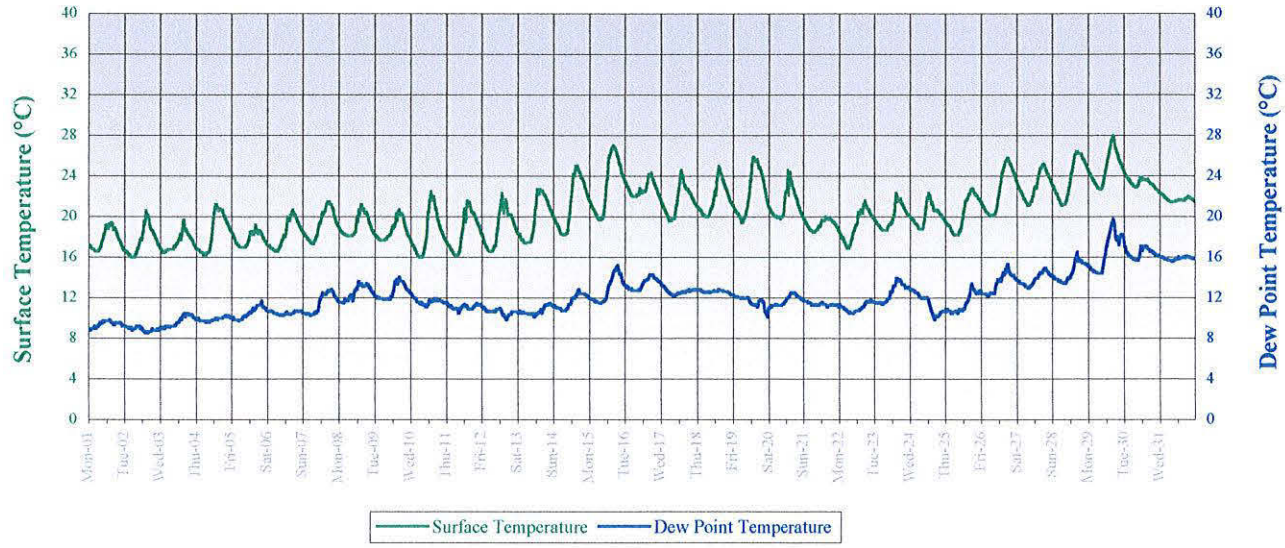




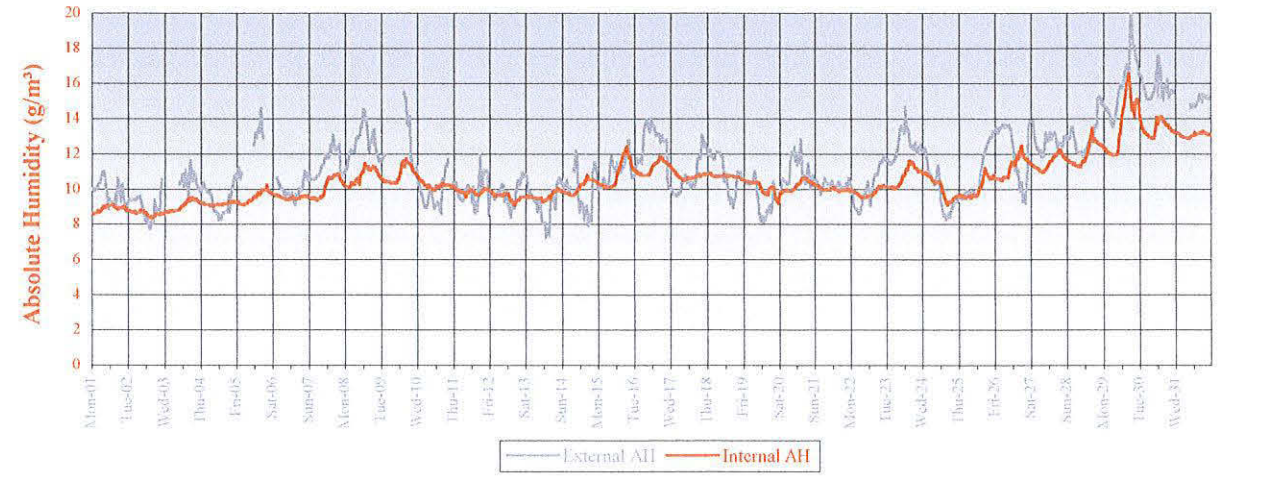
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



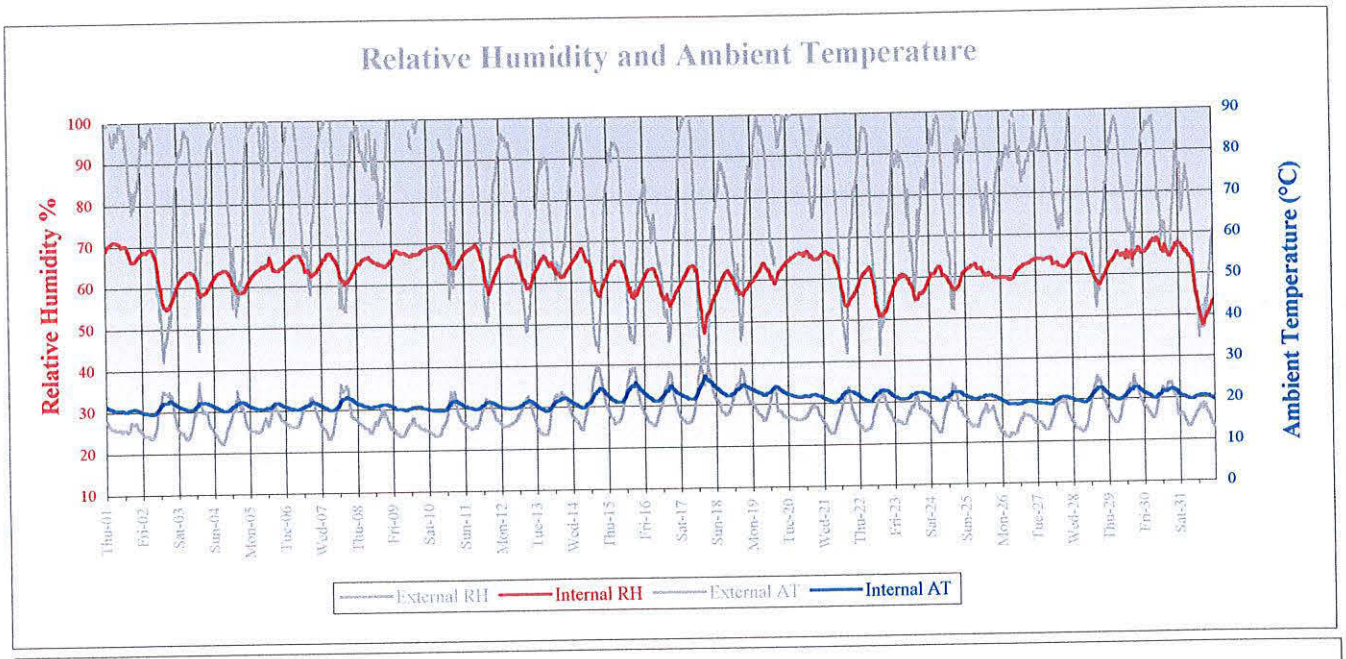
Absolute Humidity

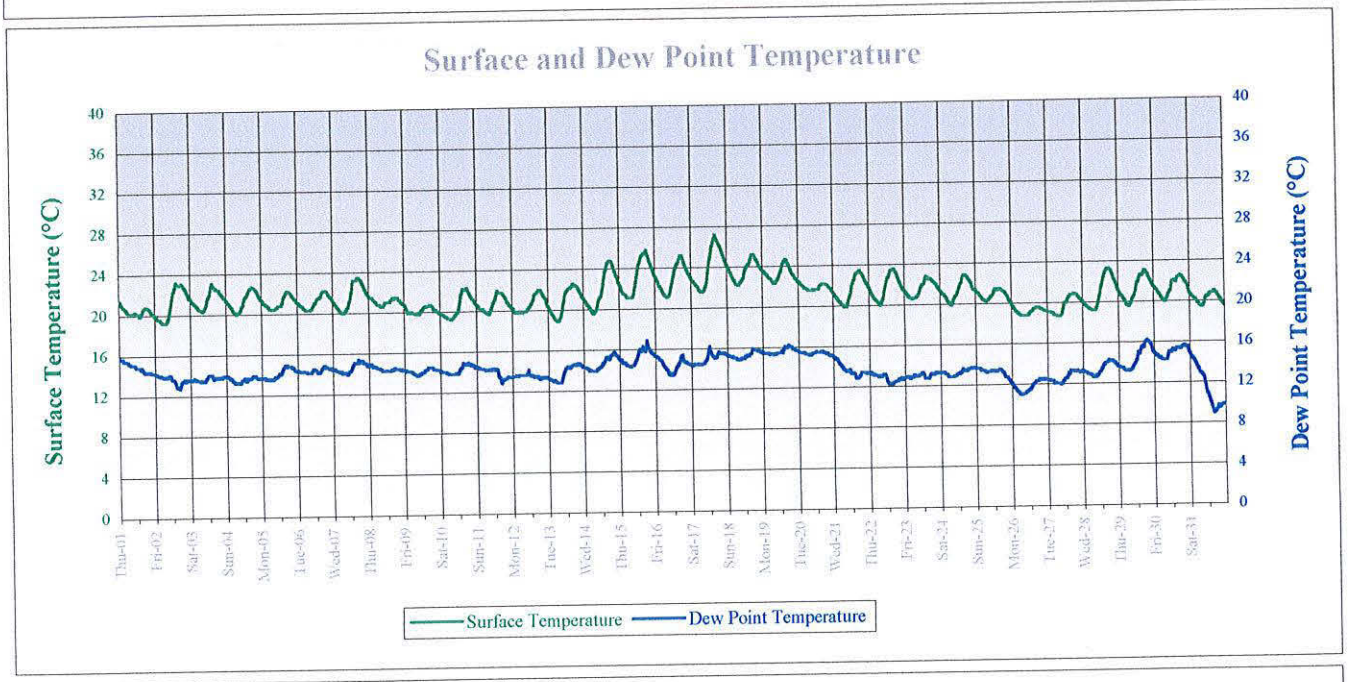


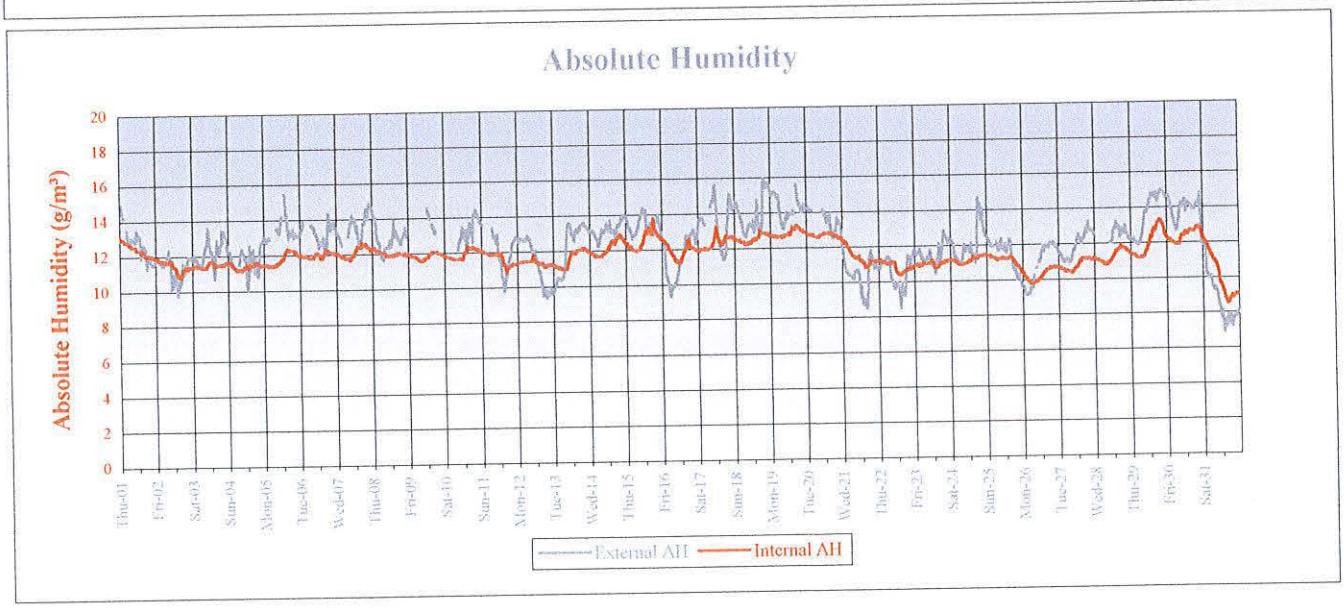
Peterborough Cathedral Nave Ceiling

August 2002

Probe 3: Bay 33 III lower side (sun)



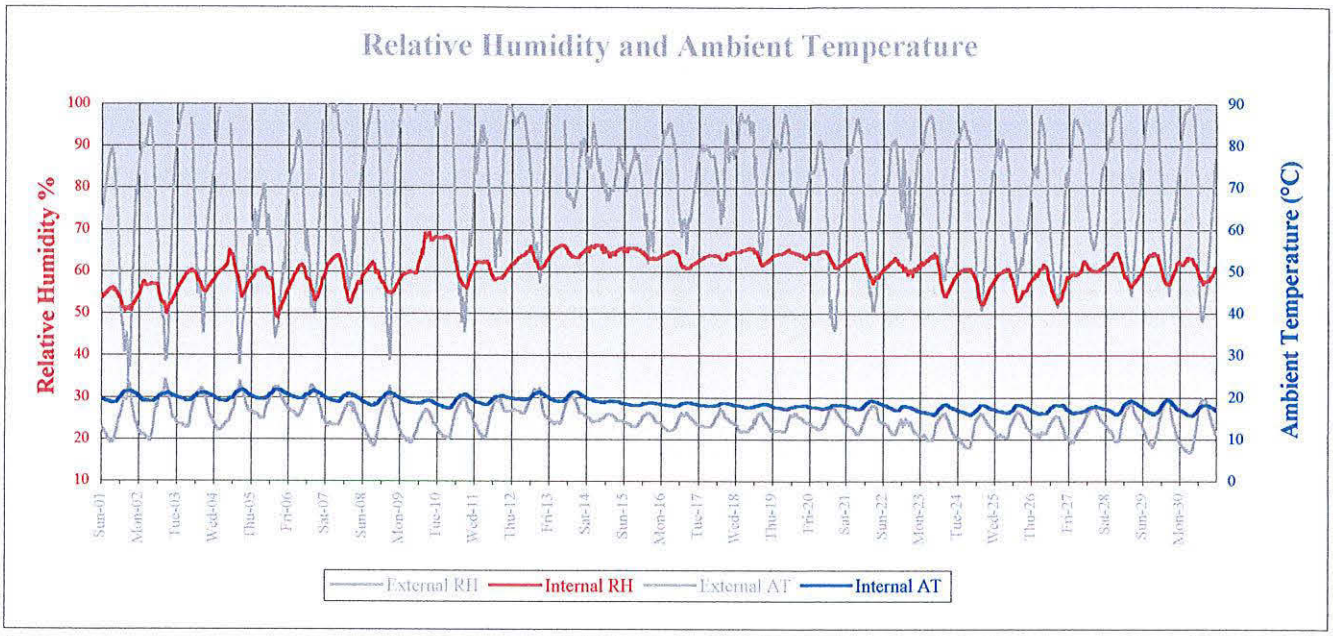


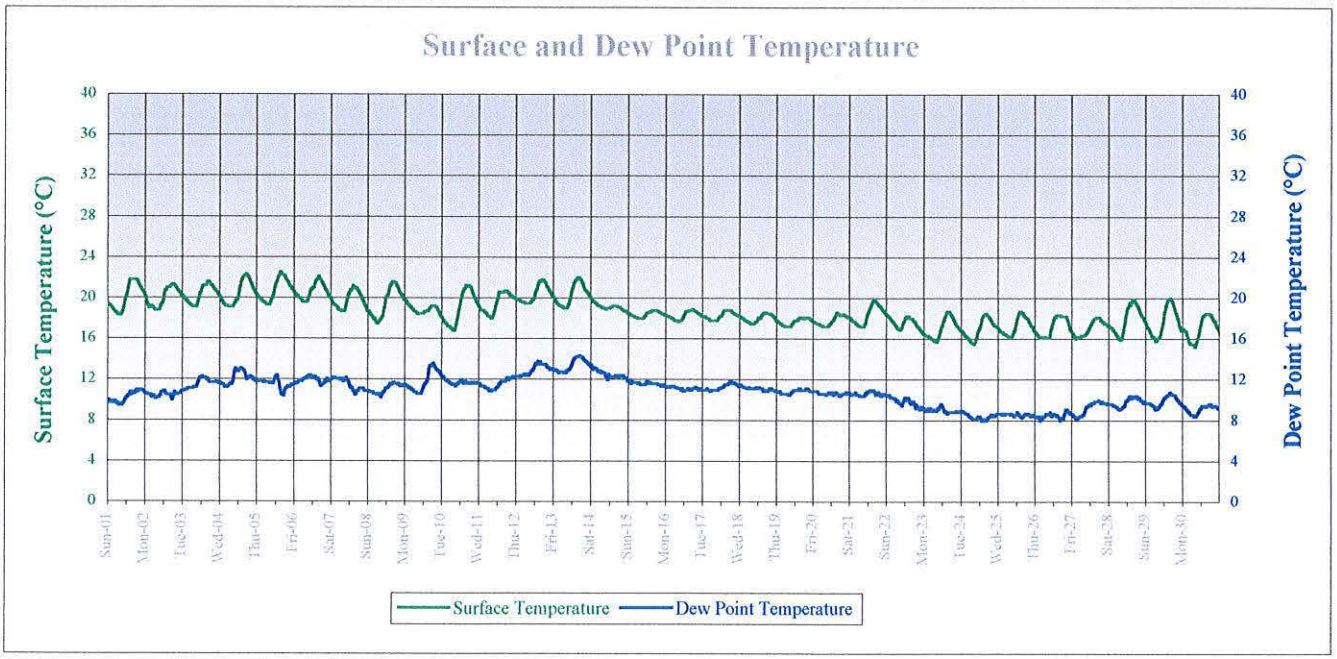


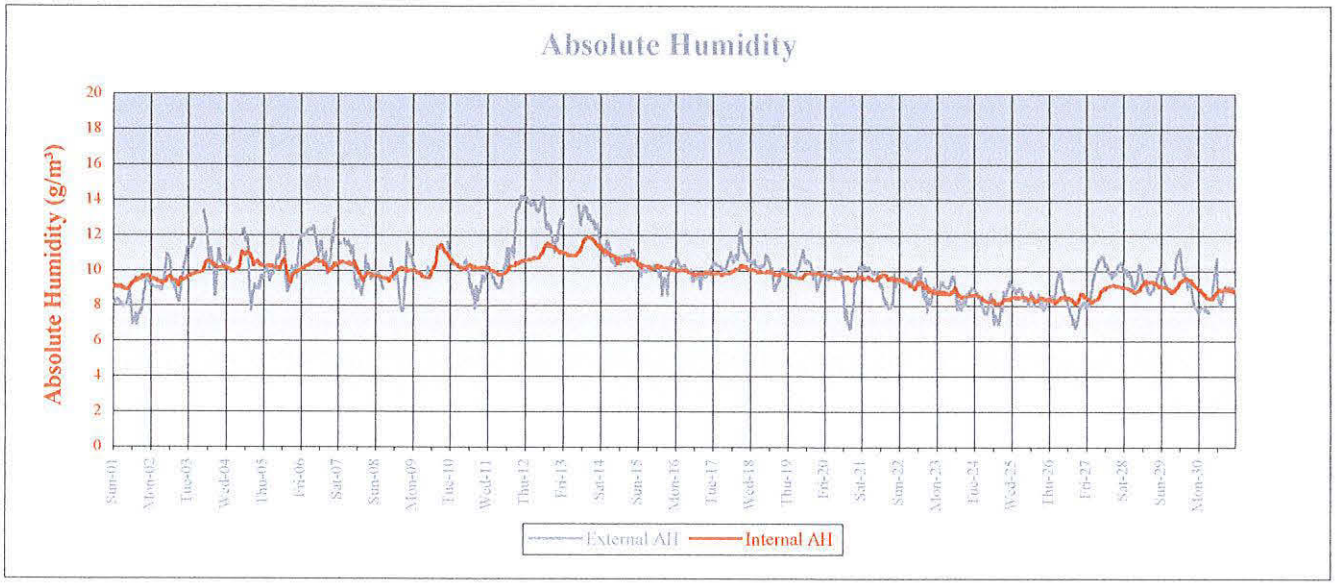
Peterborough Cathedral Nave Ceiling

September 2002

Probe 3: Bay 33 III lower side (sun)





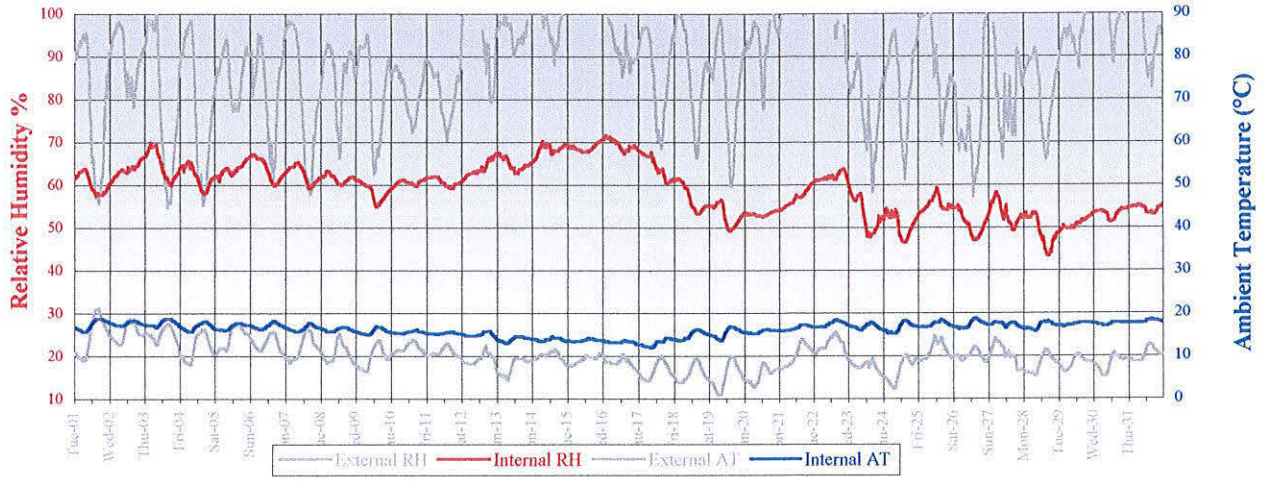


Peterborough Cathedral Nave Ceiling

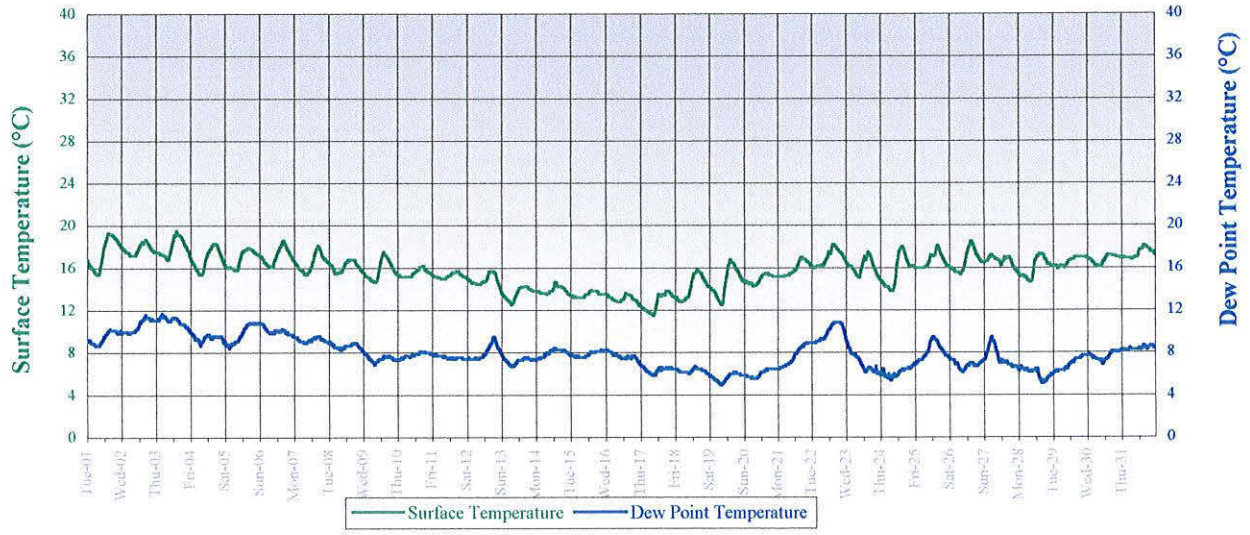
October 2002

Probe 3: Bay 33 III lower side (sun)

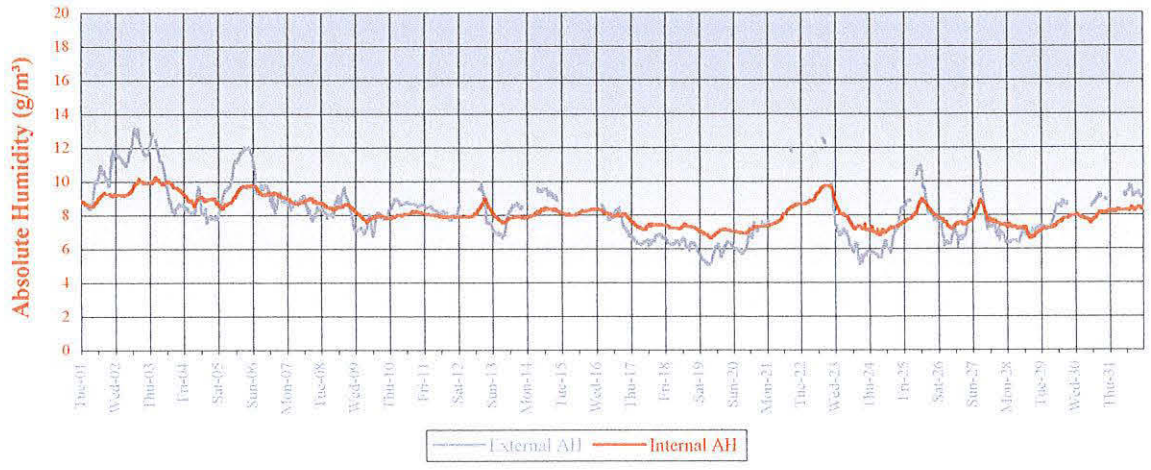
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



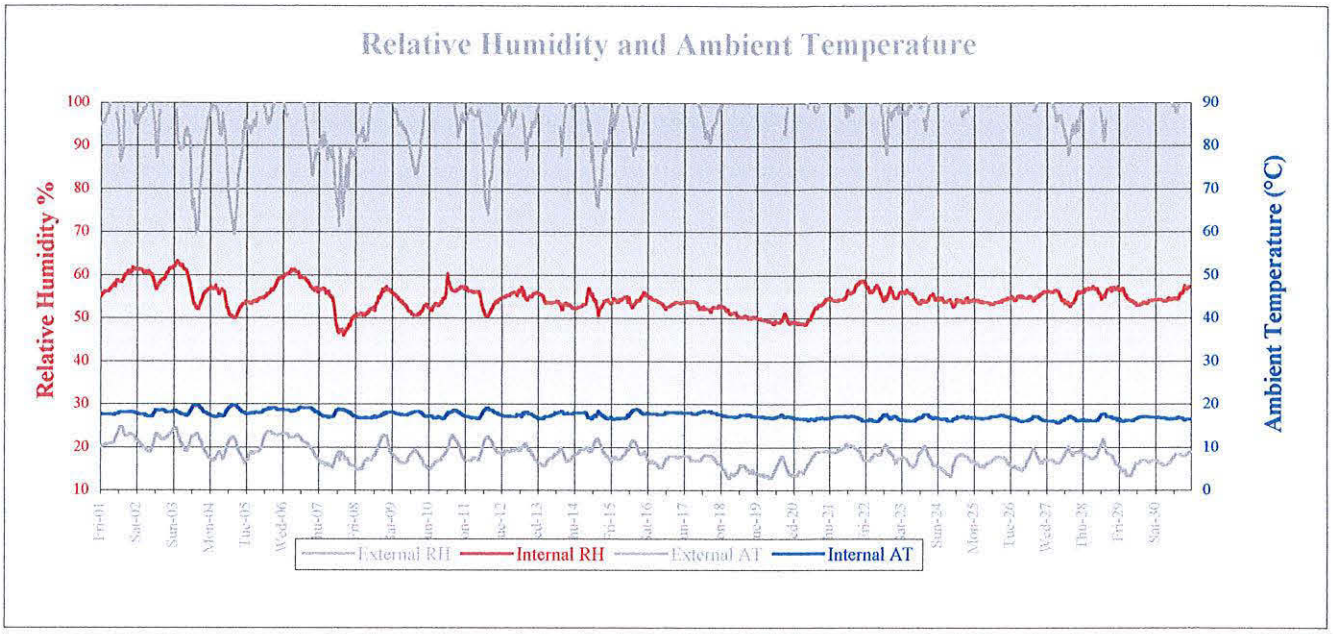
Absolute Humidity

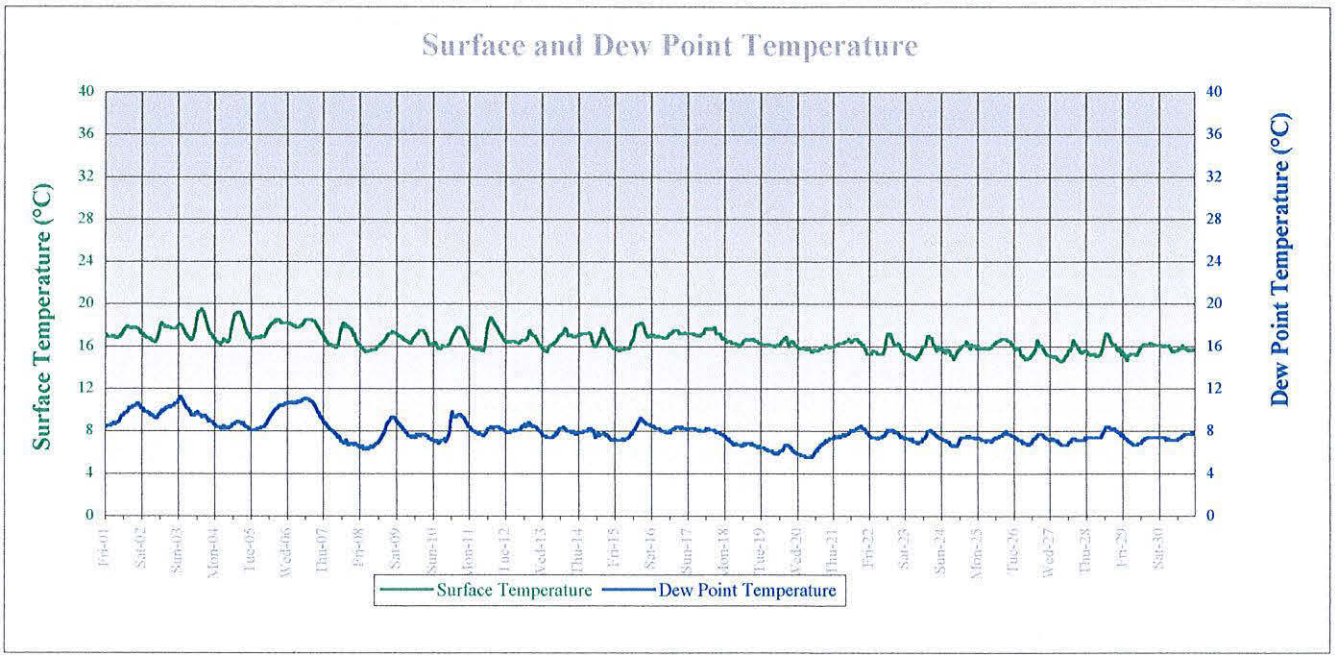


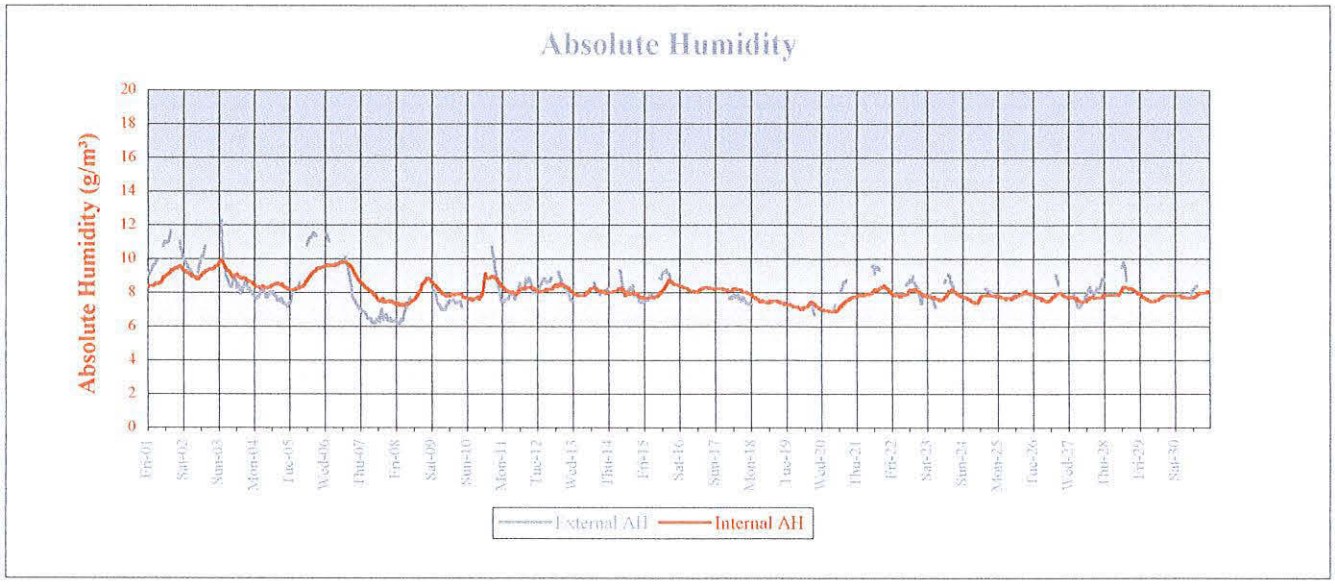
Peterborough Cathedral Nave Ceiling

November 2002

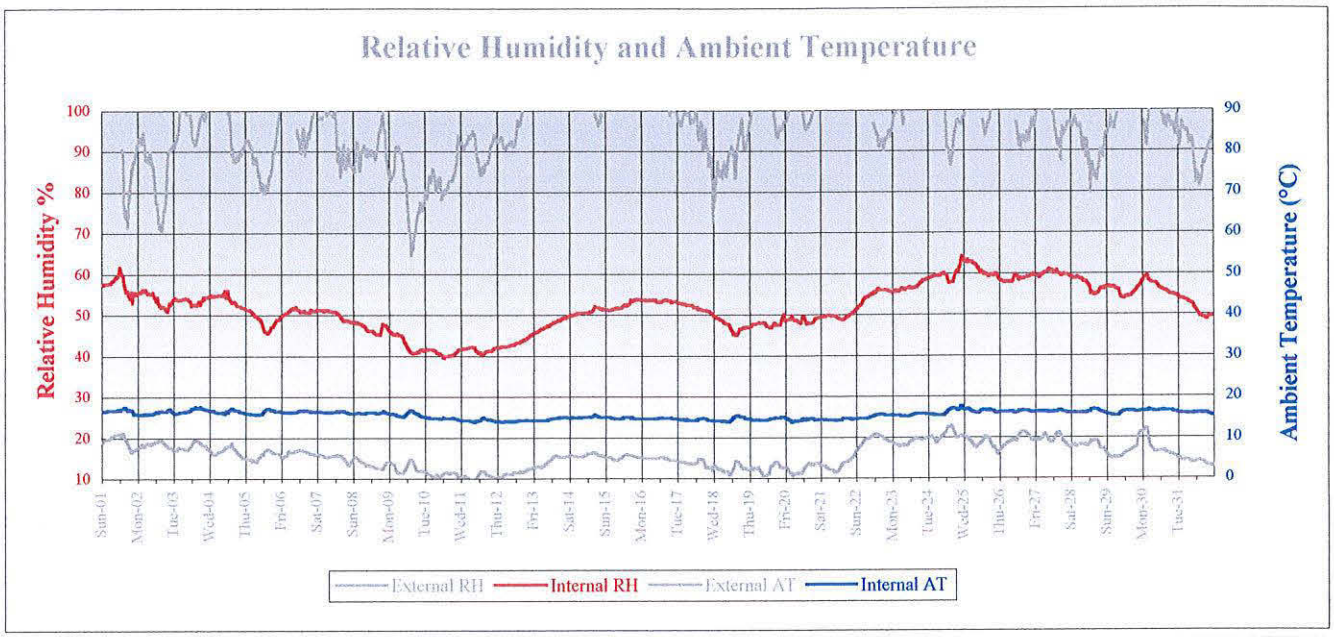
Probe 3: Bay 33 III lower side (sun)

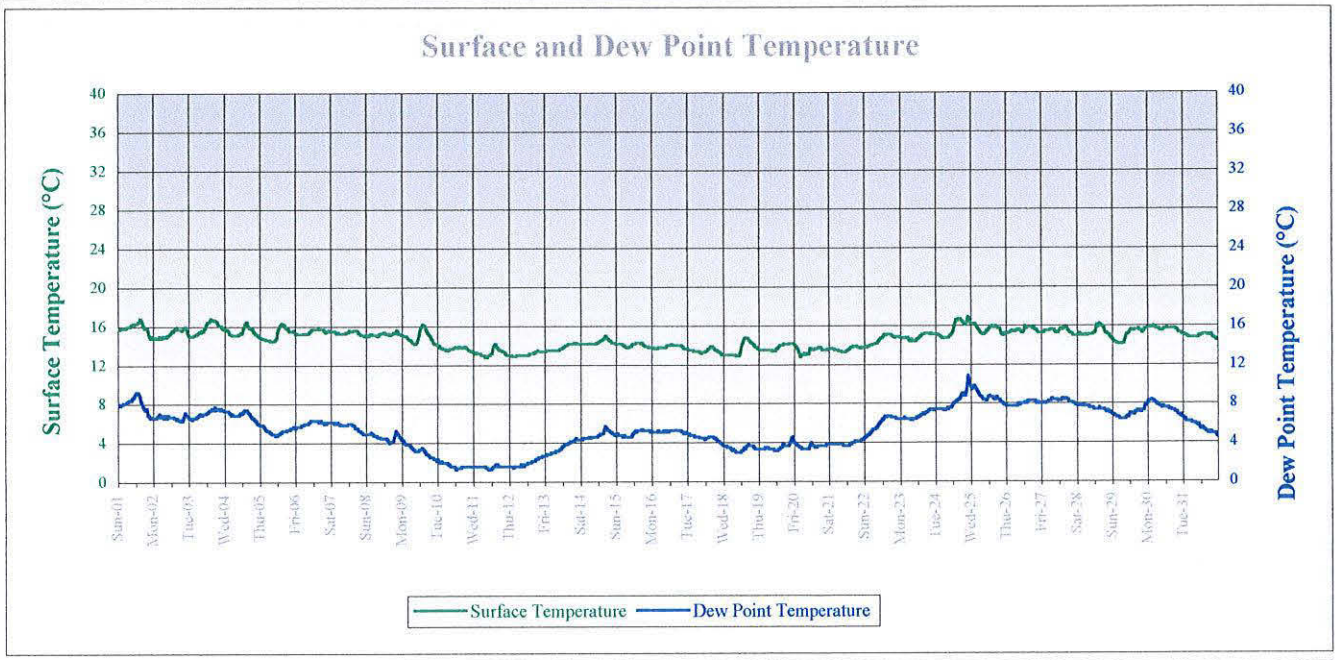


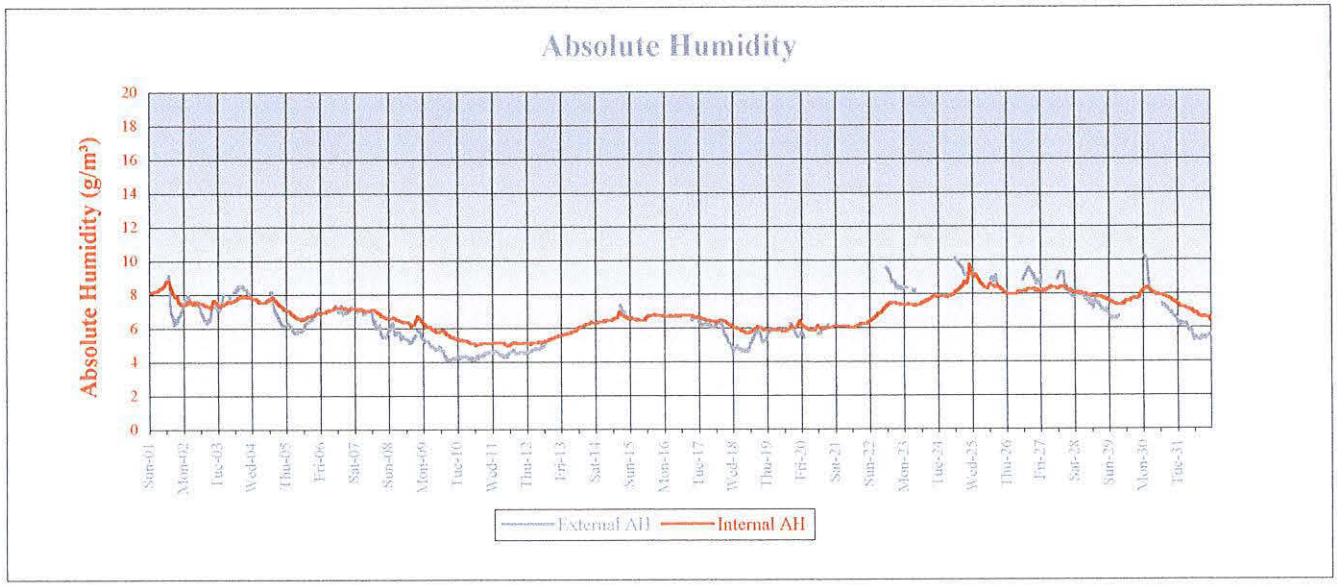




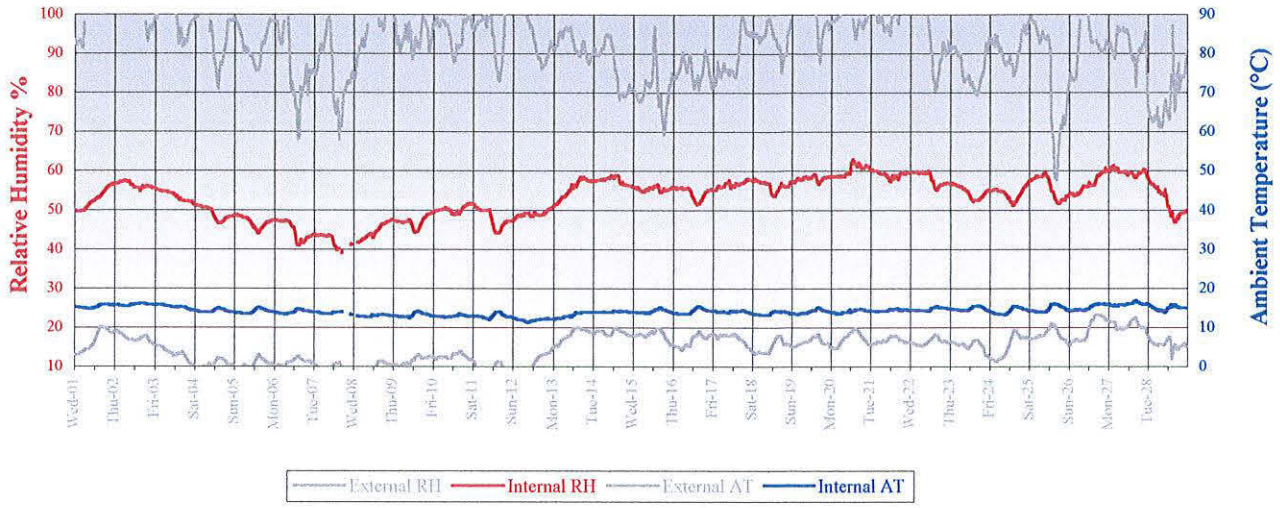
Probe 3: Bay 33 III lower side (sun)



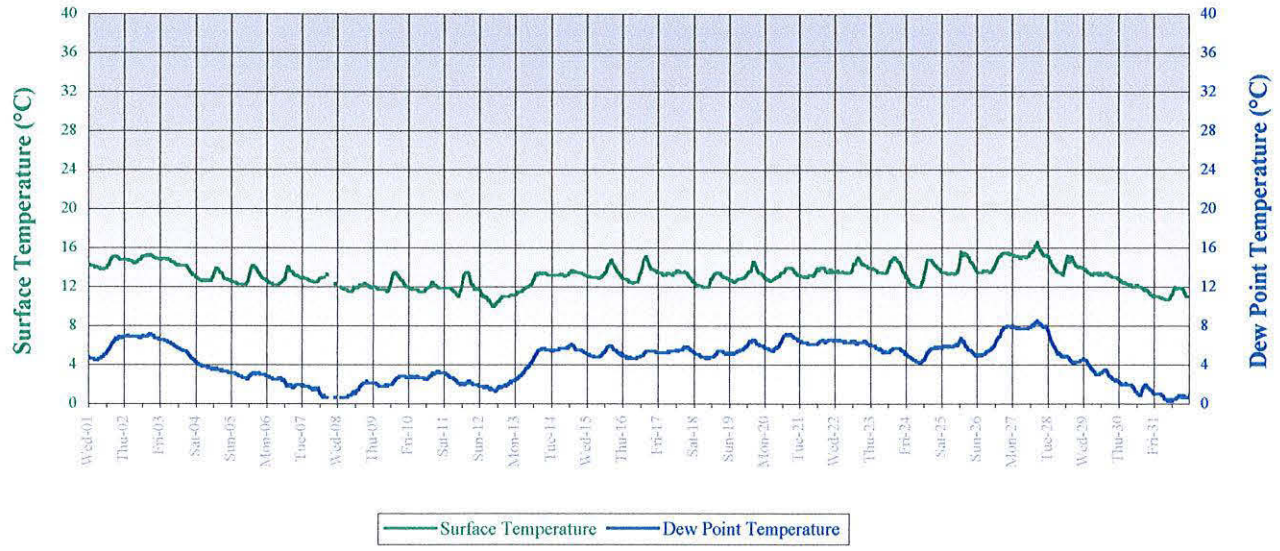




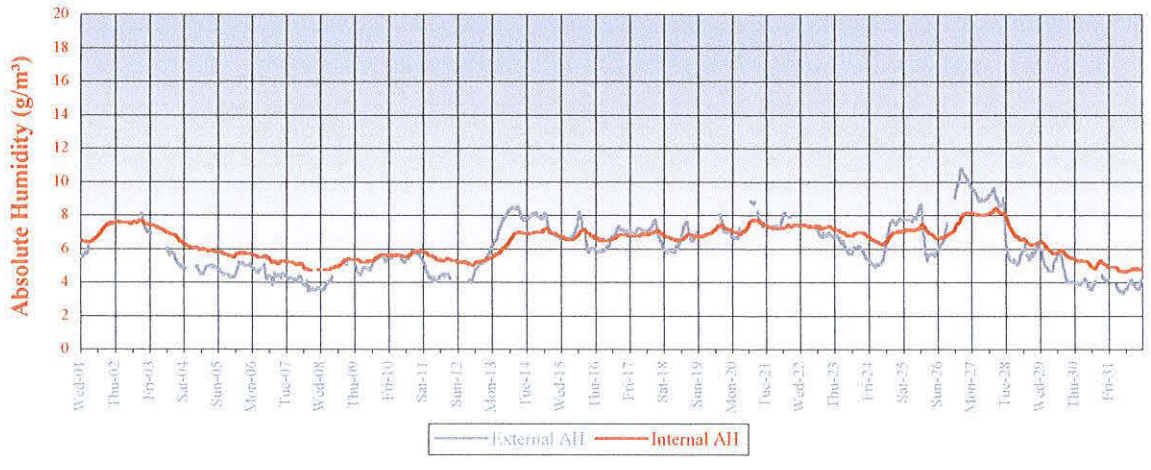
Relative Humidity and Ambient Temperature

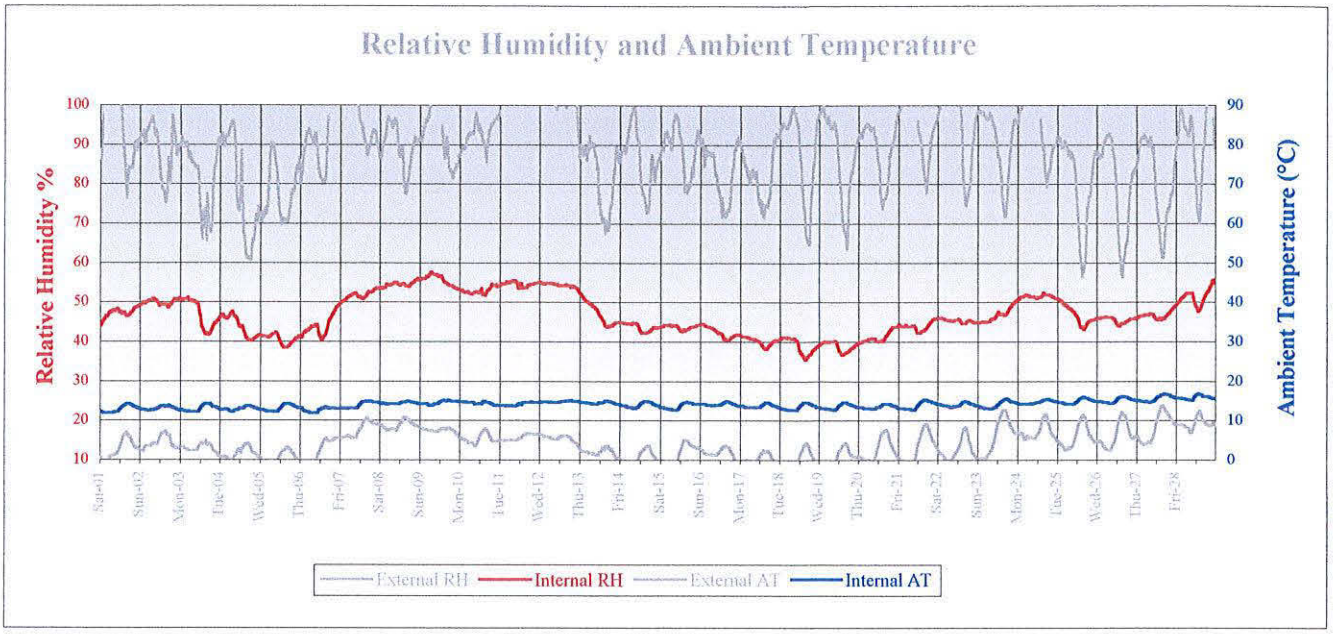


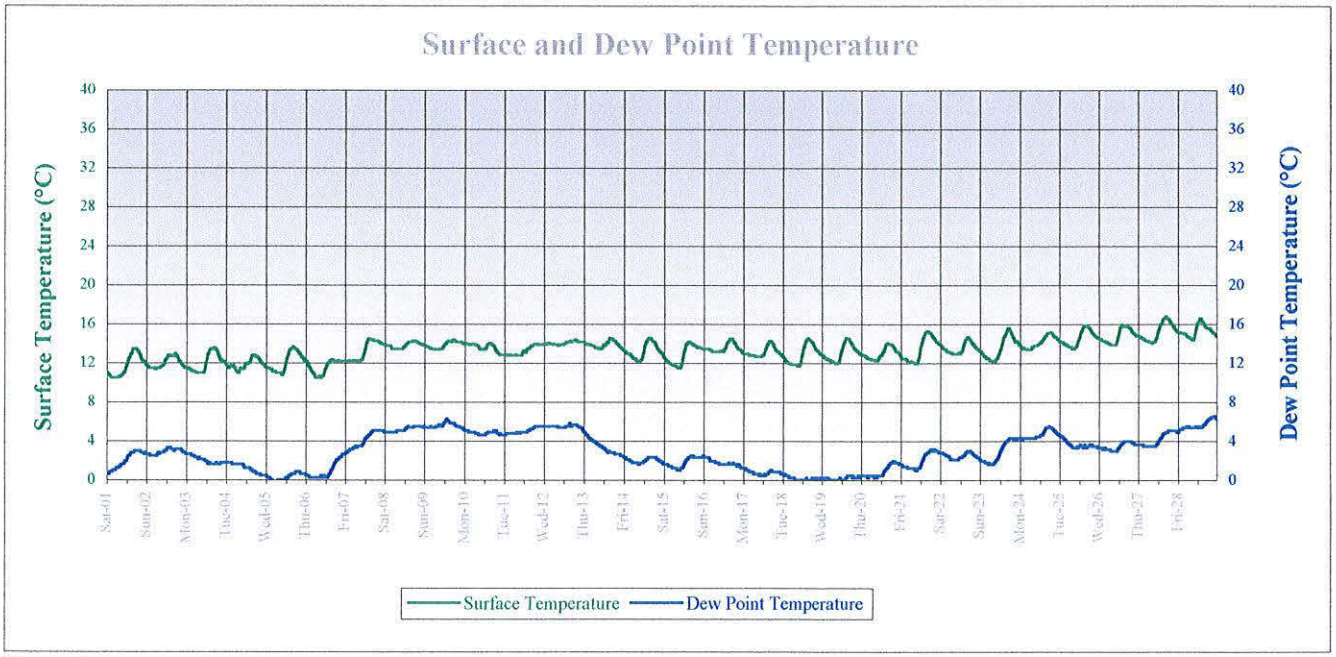
Surface and Dew Point Temperature

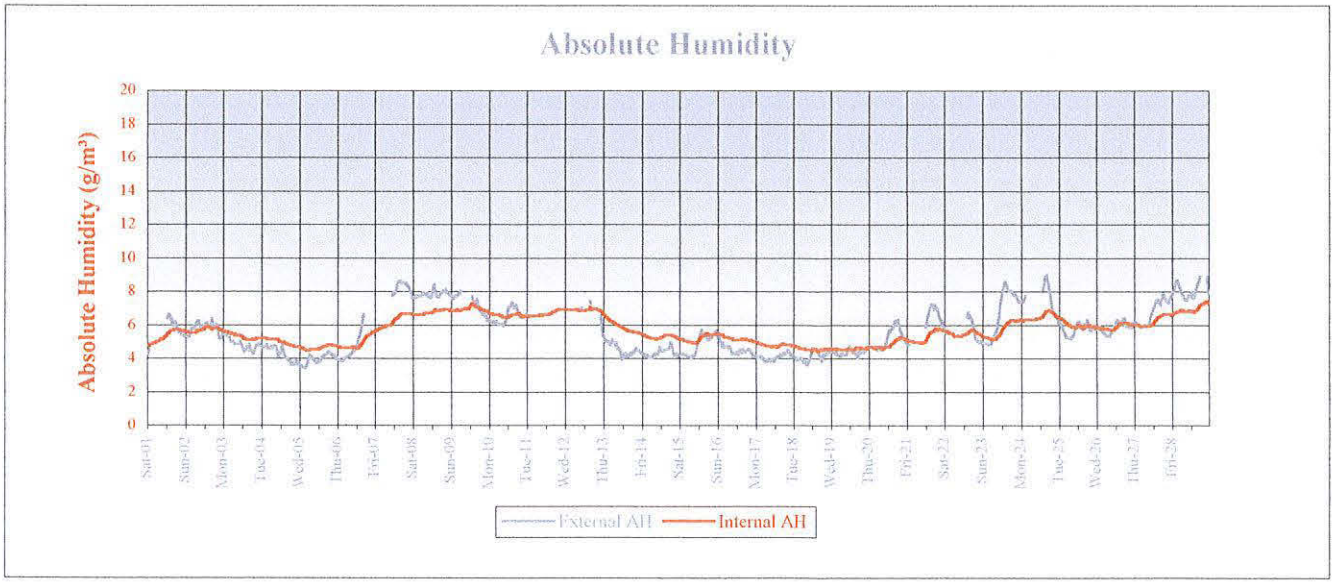


Absolute Humidity




Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

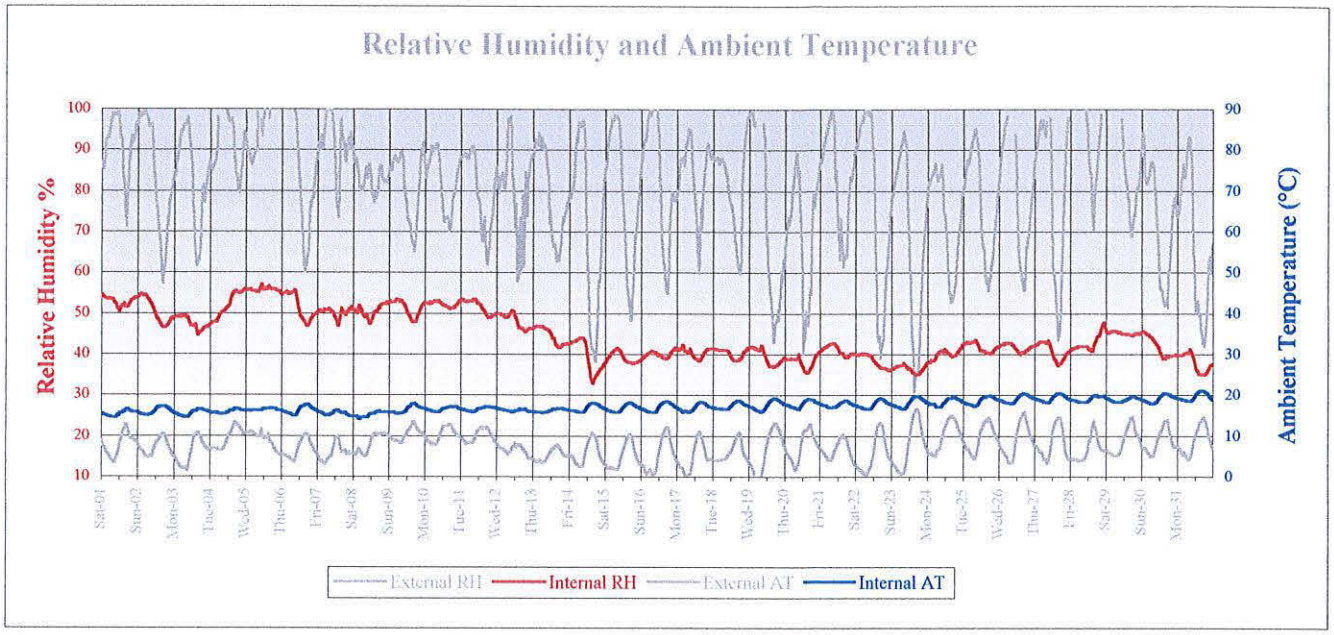

Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature

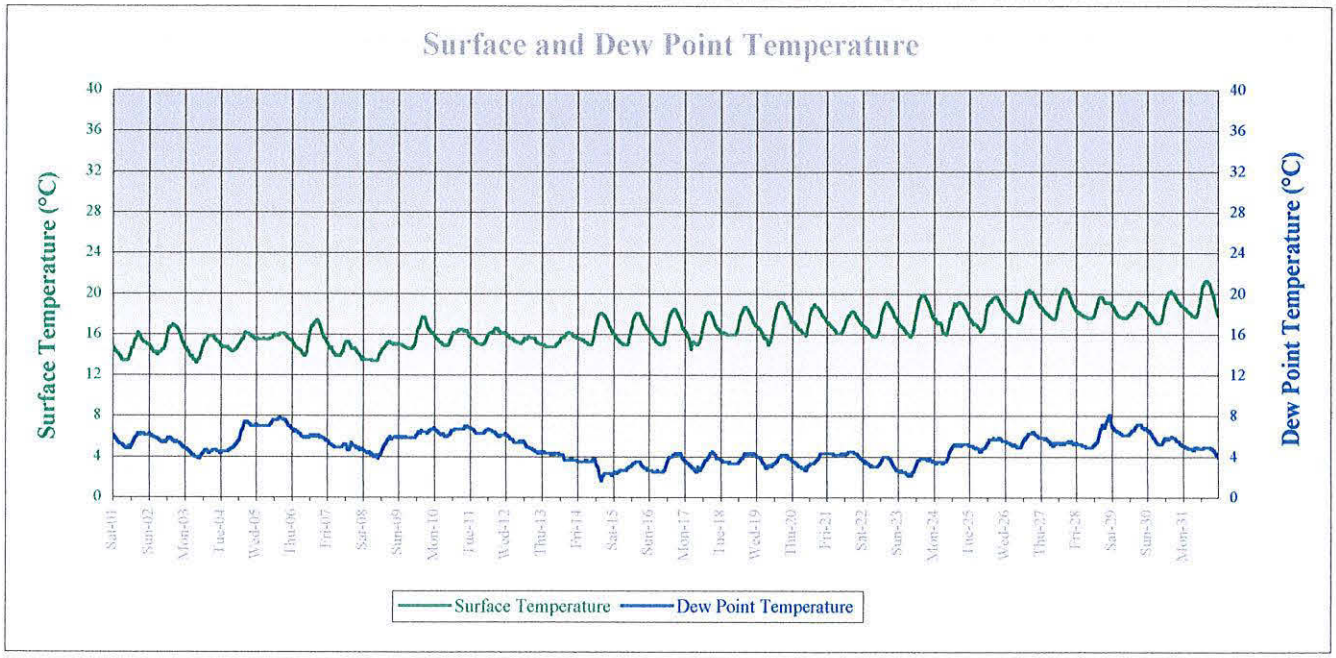

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

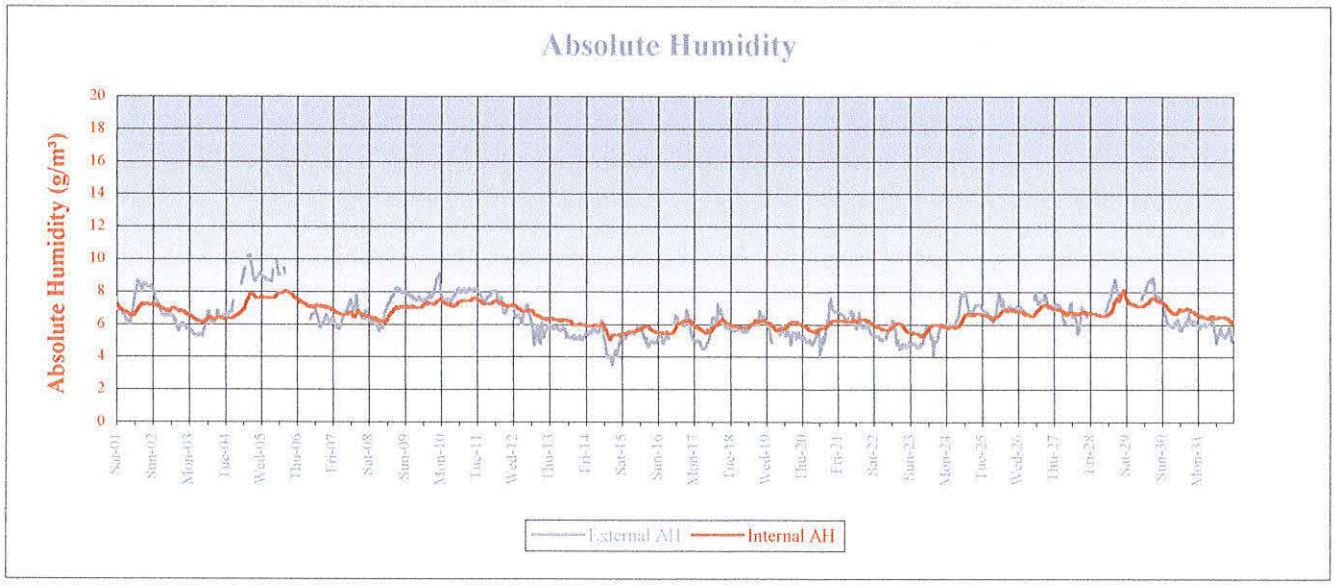
Peterborough Cathedral Nave Ceiling

March 2003

Probe 3: Bay 33 III lower side (sun)



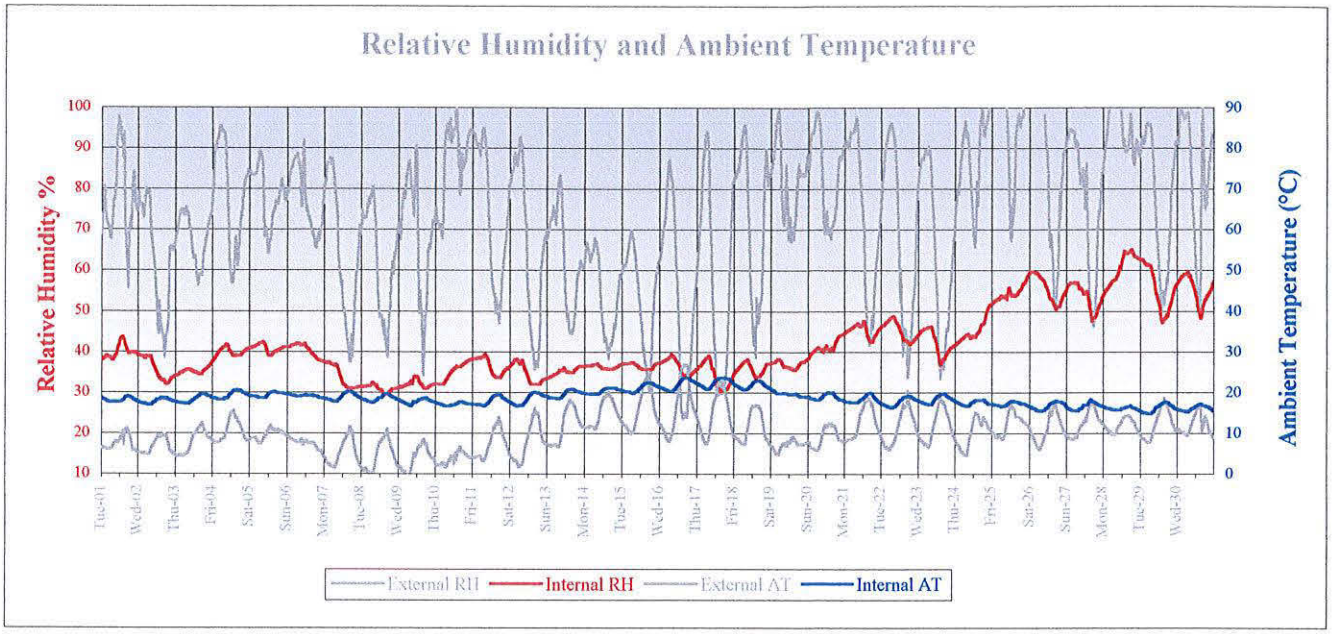


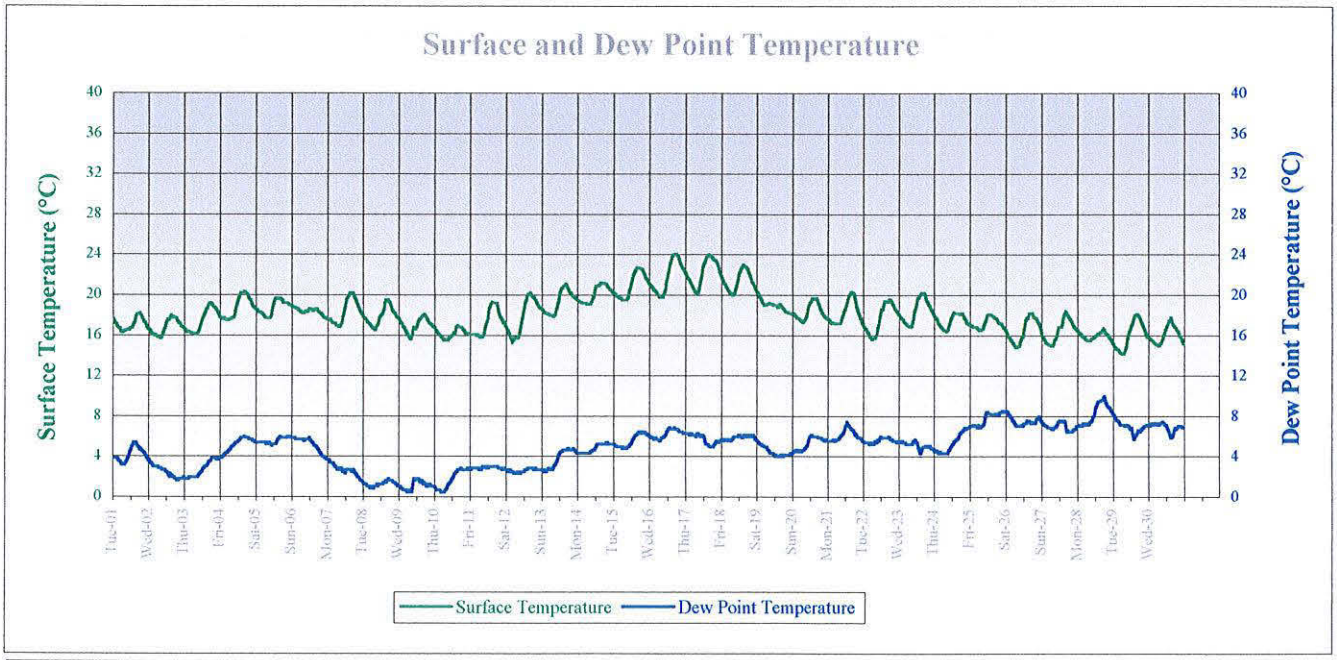


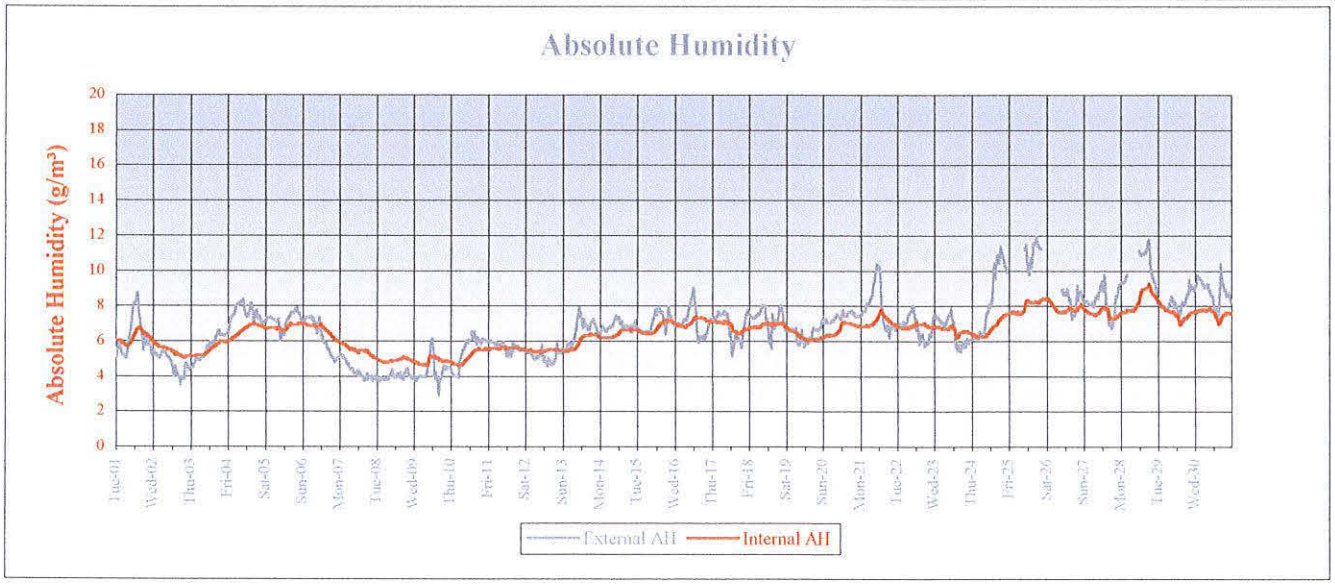
Peterborough Cathedral Nave Ceiling

April 2003

Probe 3: Bay 33 III lower side (sun)





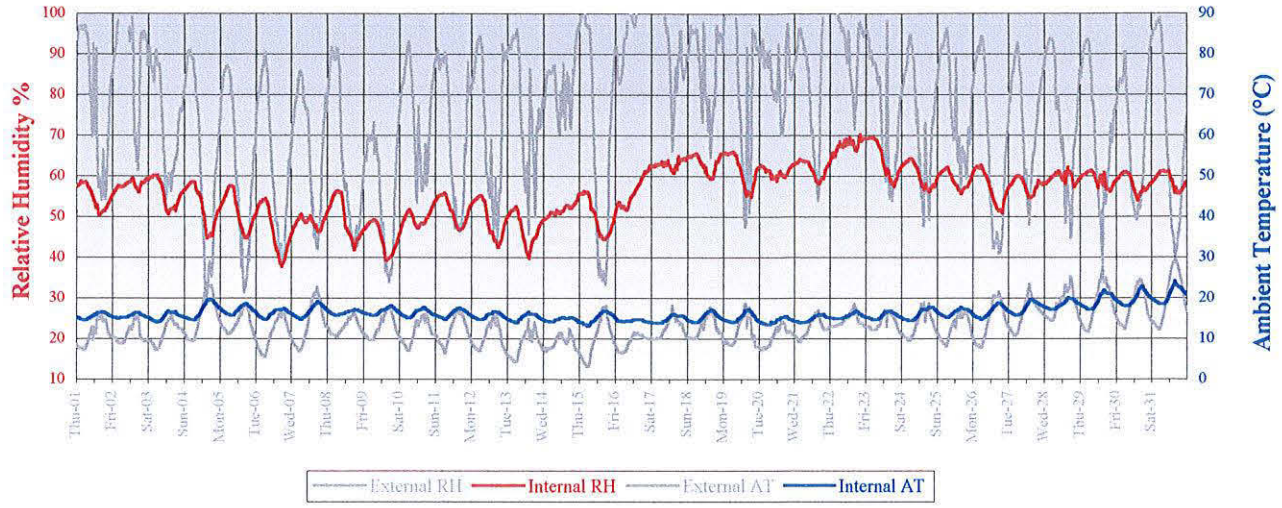


Peterborough Cathedral Nave Ceiling

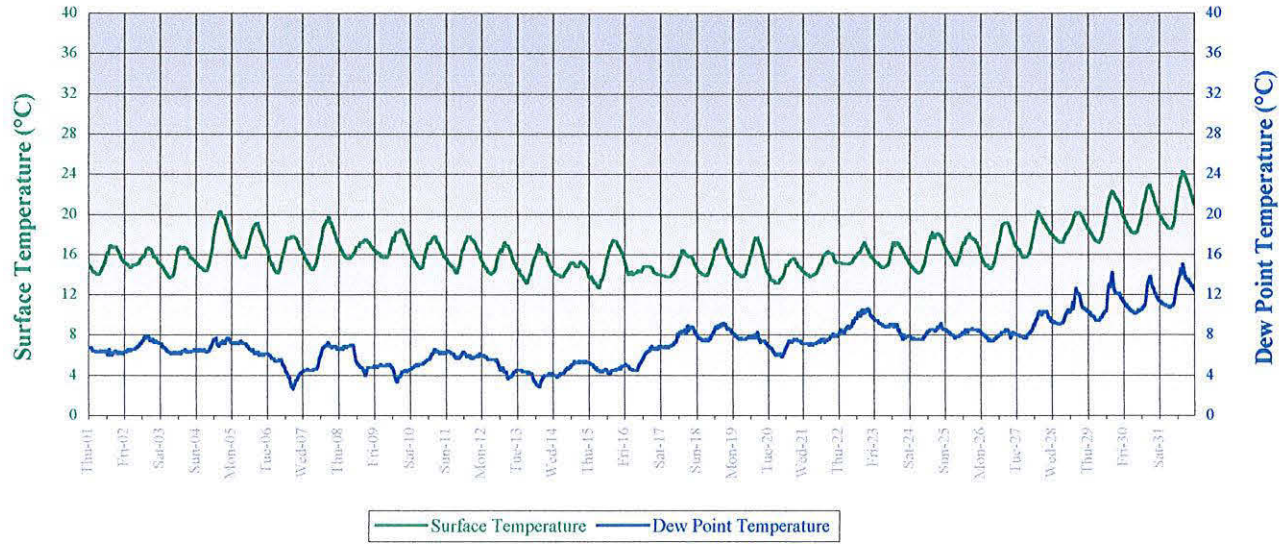
May 2003

Probe 3: Bay 33 III lower side (sun)

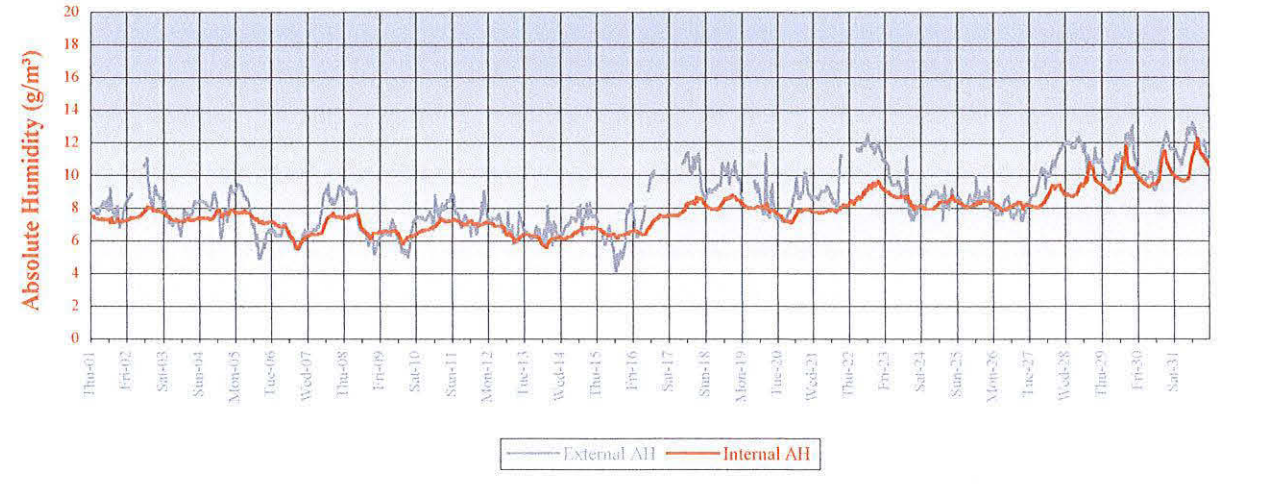
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

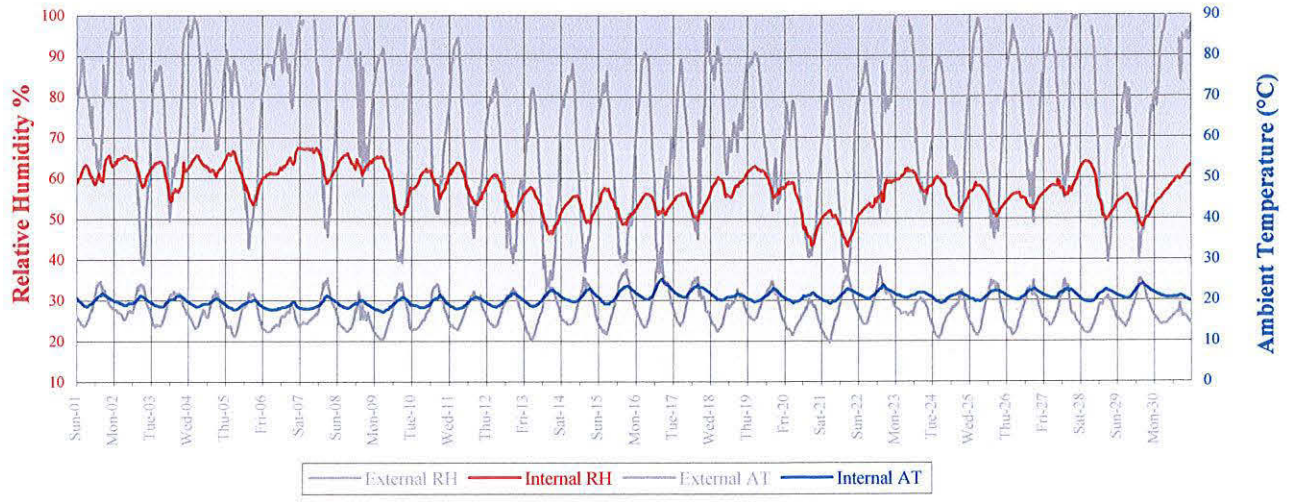


Peterborough Cathedral Nave Ceiling

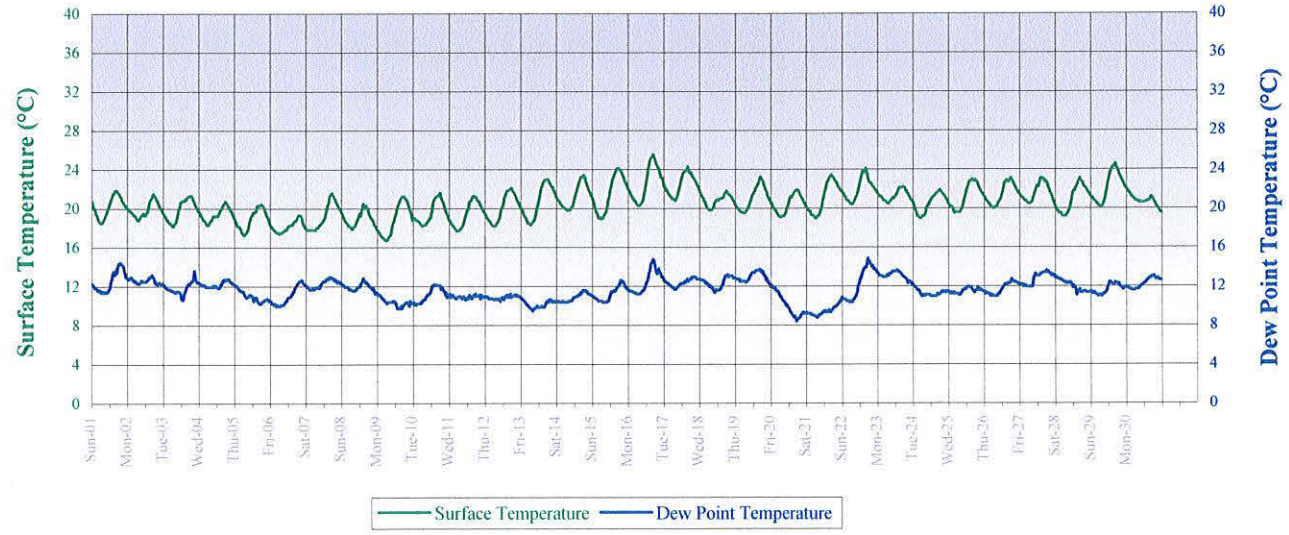
June 2003

Probe 3: Bay 33 III lower side (sun)

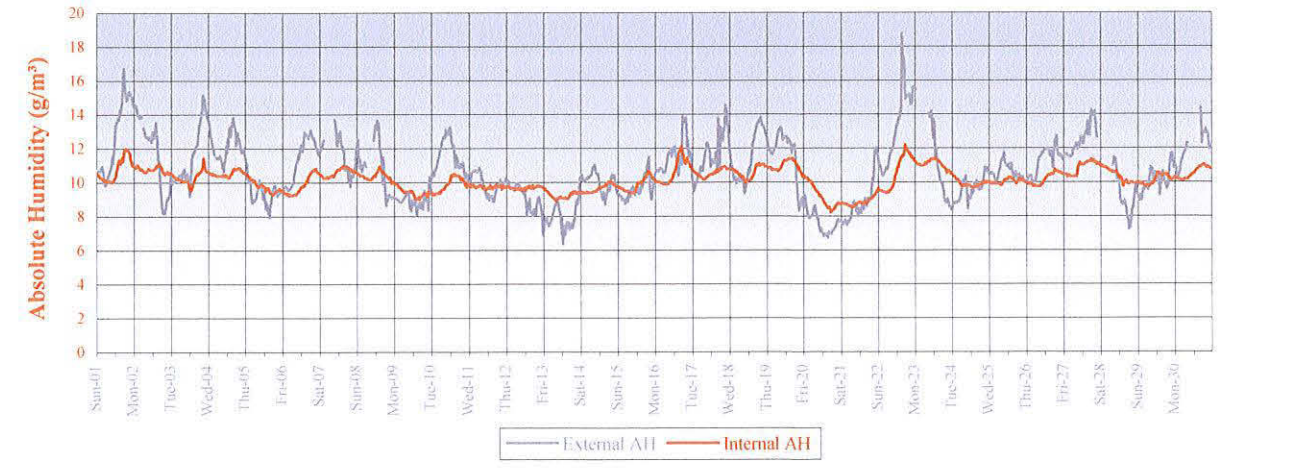
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



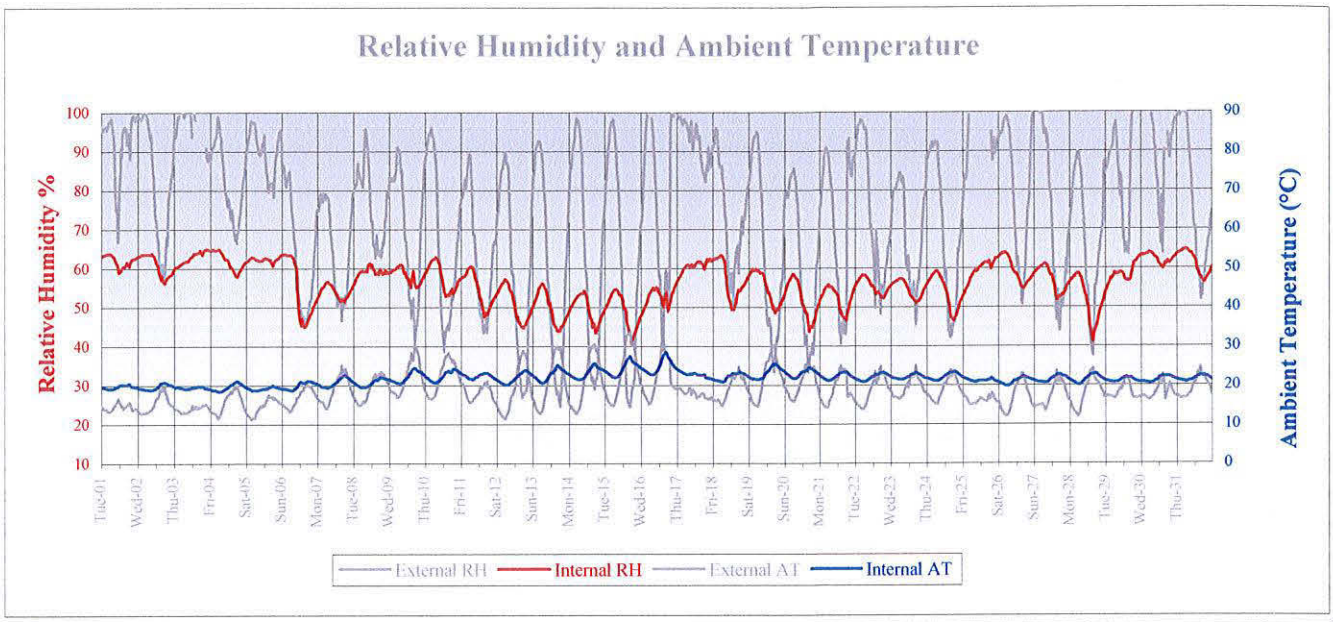
Absolute Humidity

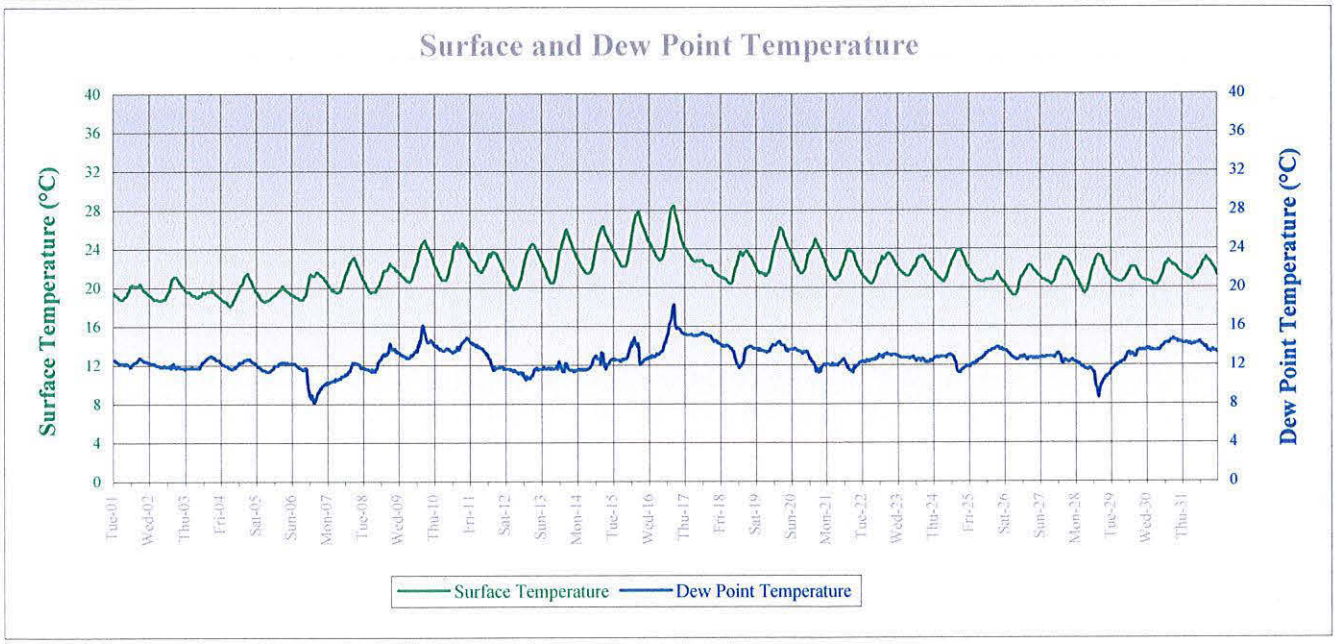


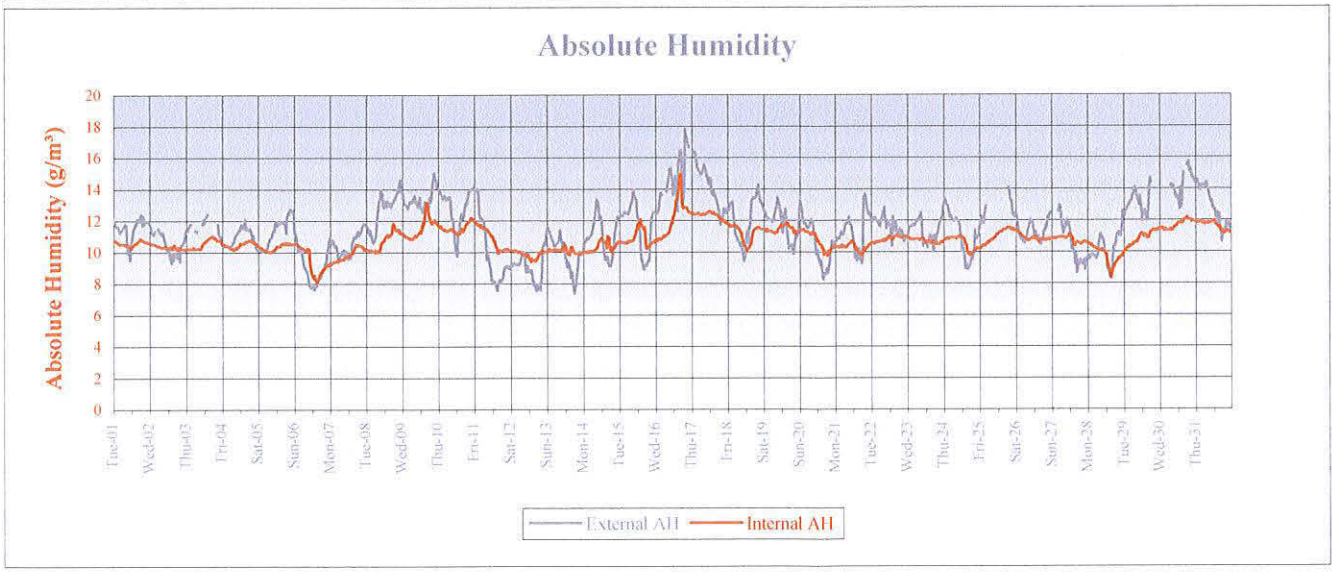
Peterborough Cathedral Nave Ceiling

July 2003

Probe 3: Bay 33 III lower side (sun)





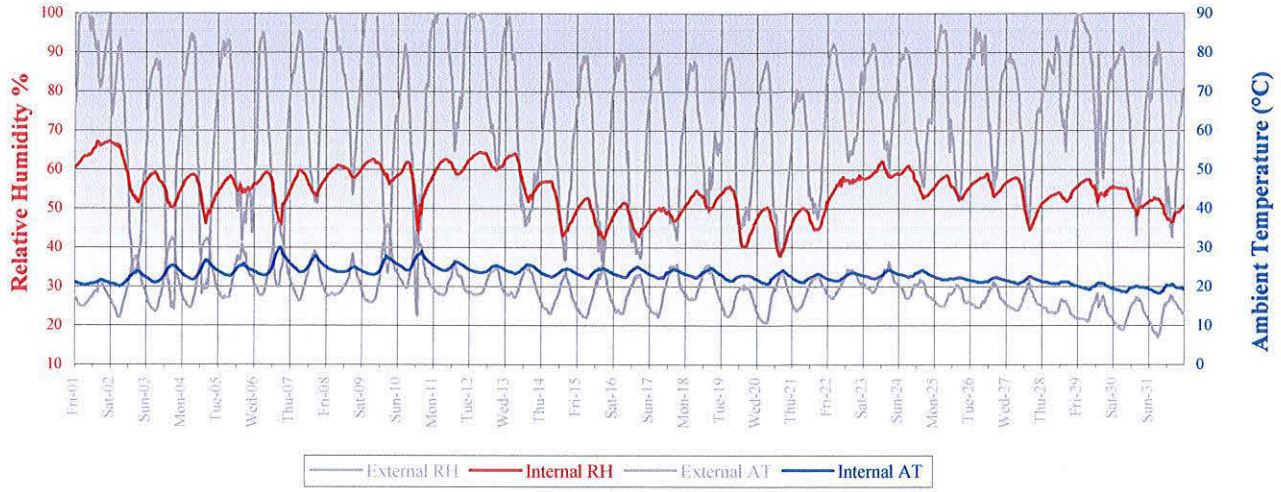


Peterborough Cathedral Nave Ceiling

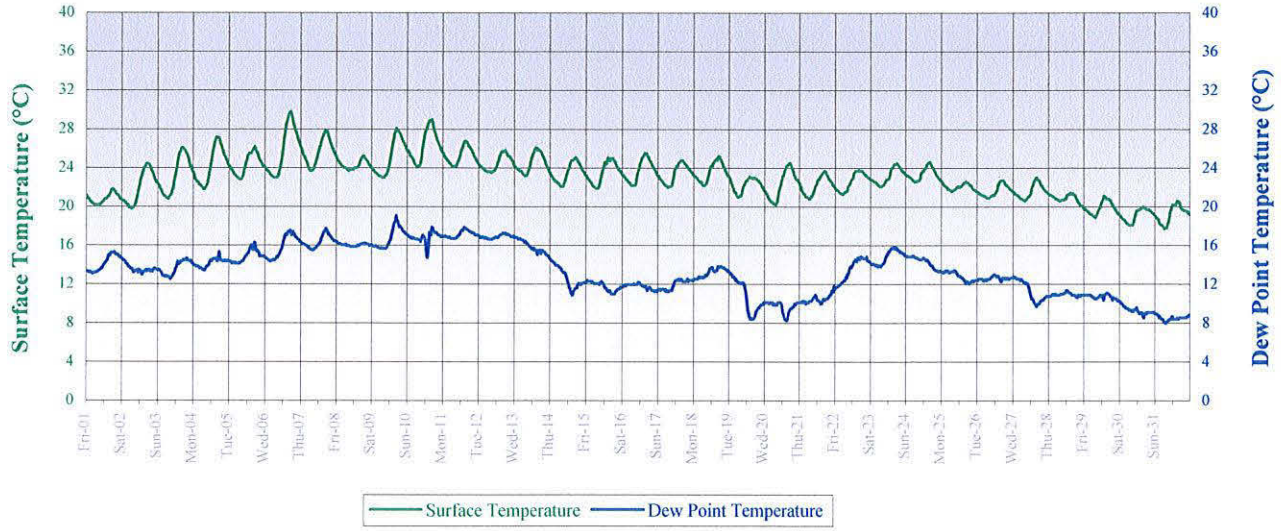
August 2003

Probe 3: Bay 33 III lower side (sun)

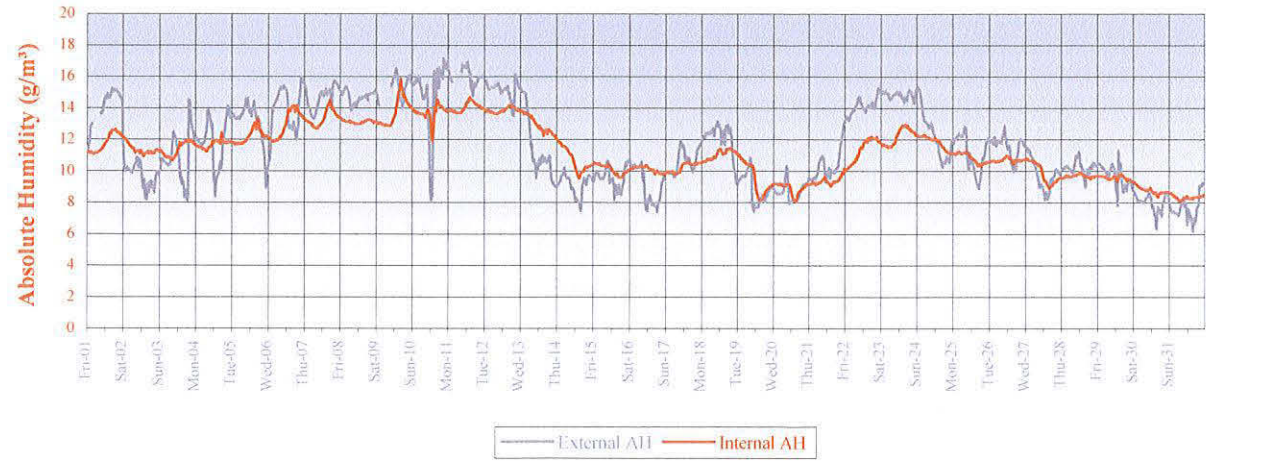
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



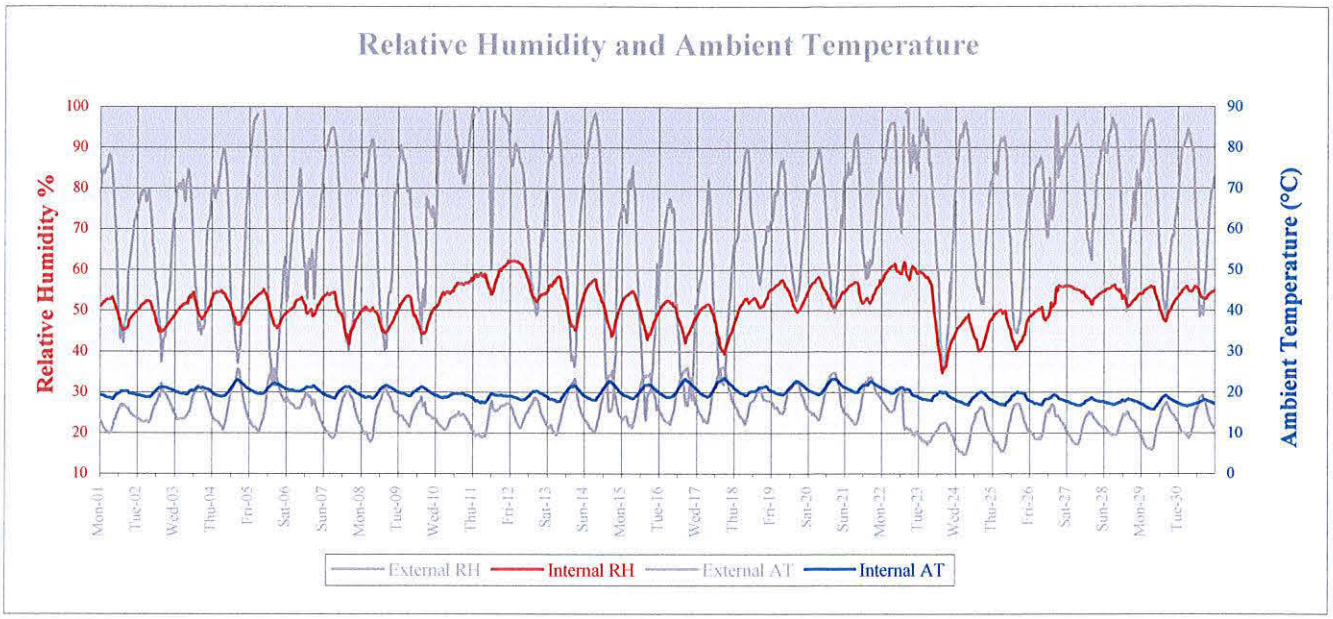
Absolute Humidity

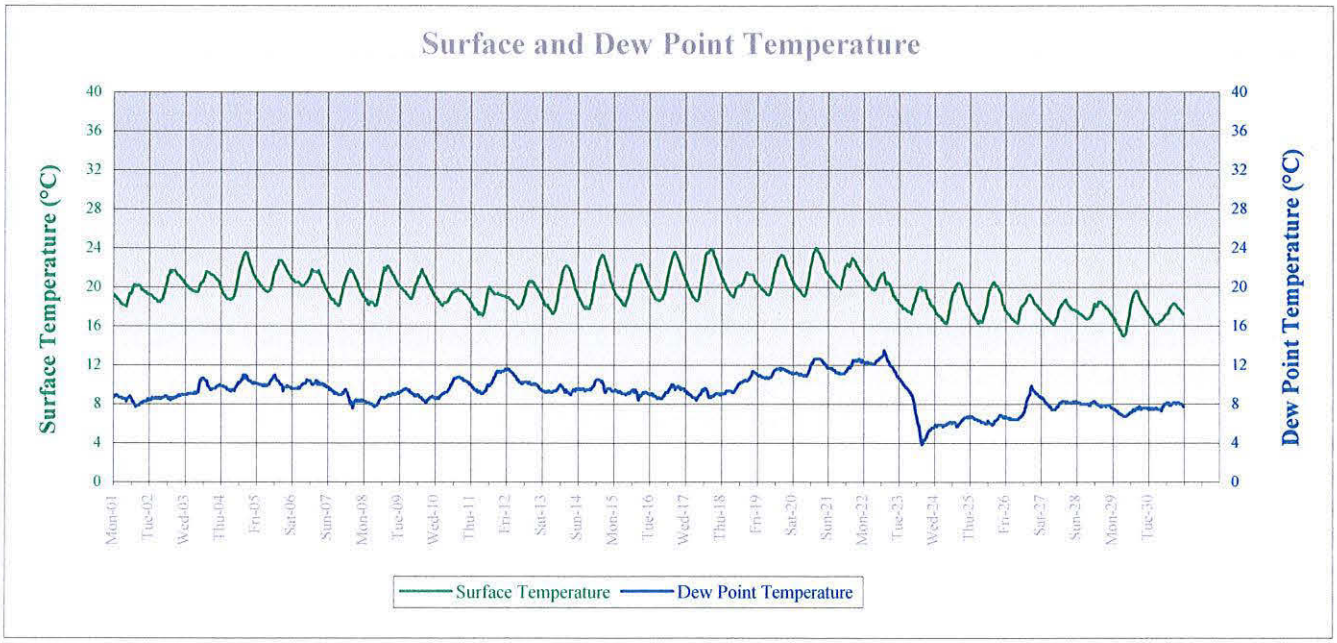


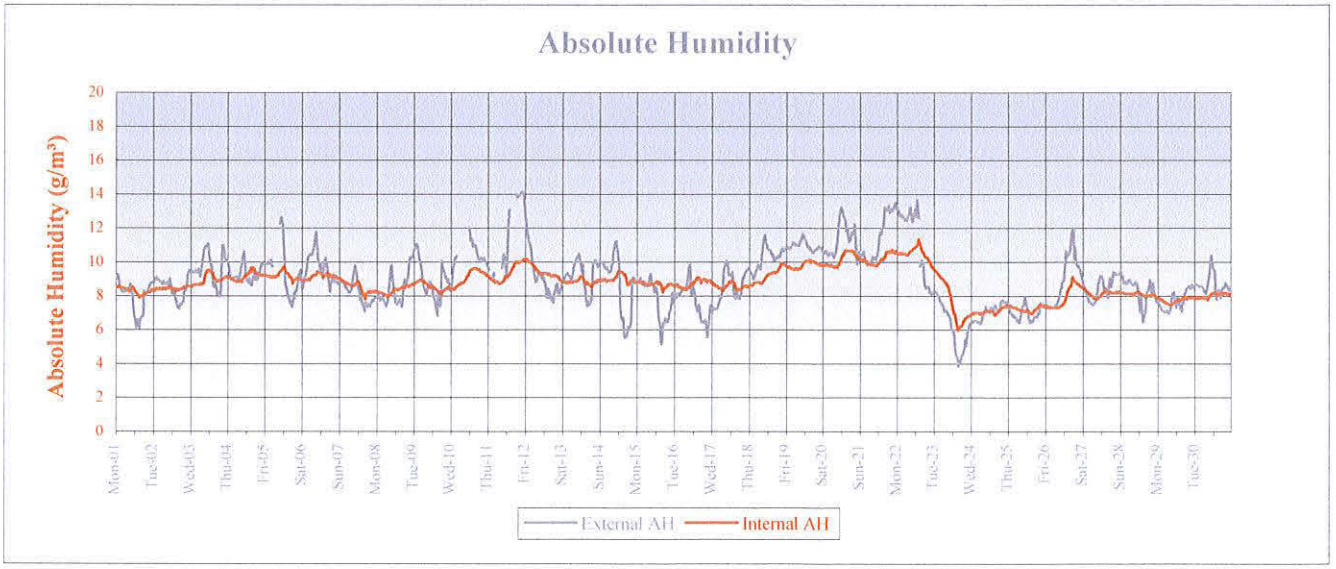
Peterborough Cathedral Nave Ceiling

September 2003

Probe 3: Bay 33 III lower side (sun)





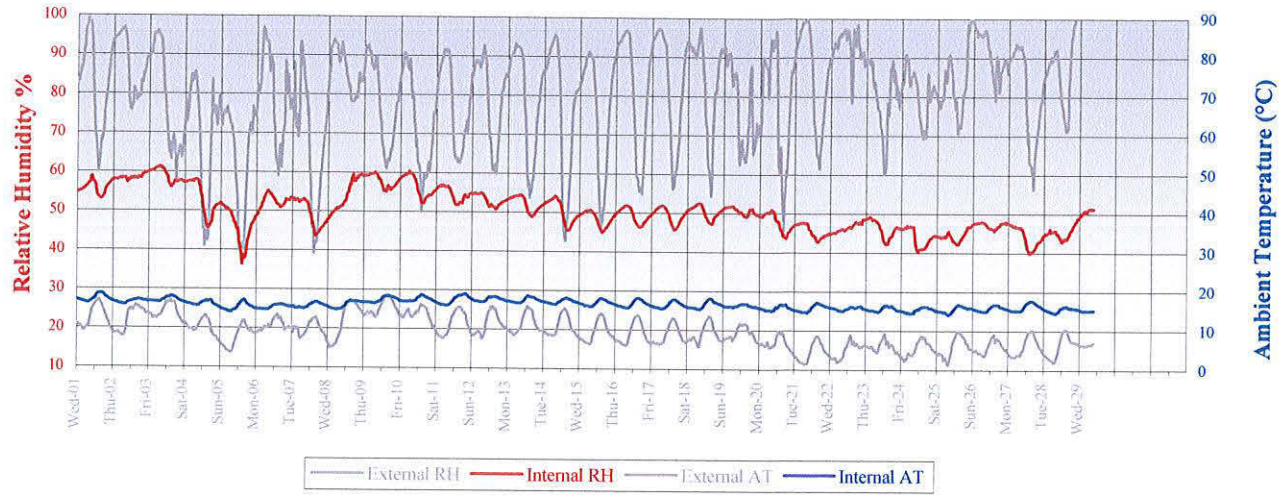


Peterborough Cathedral Nave Ceiling

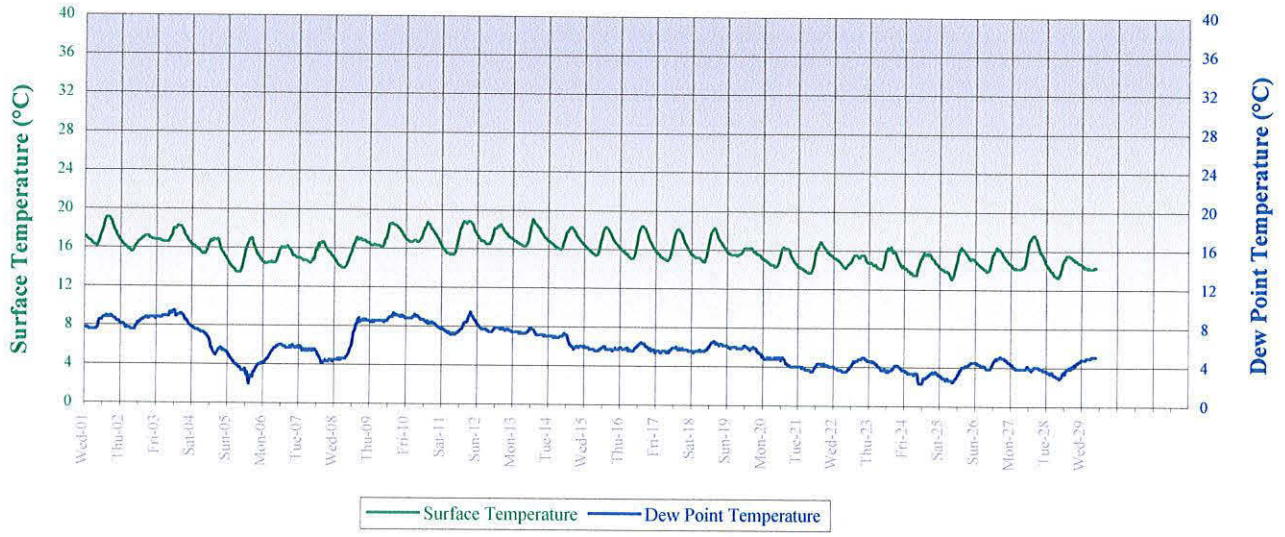
October 2003

Probe 3: Bay 33 III lower side (sun)

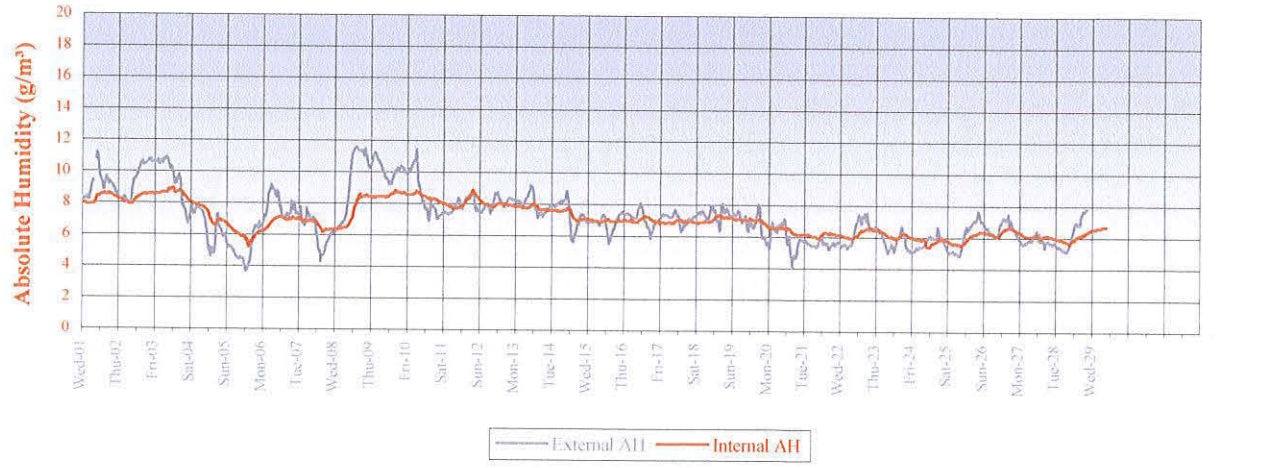
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

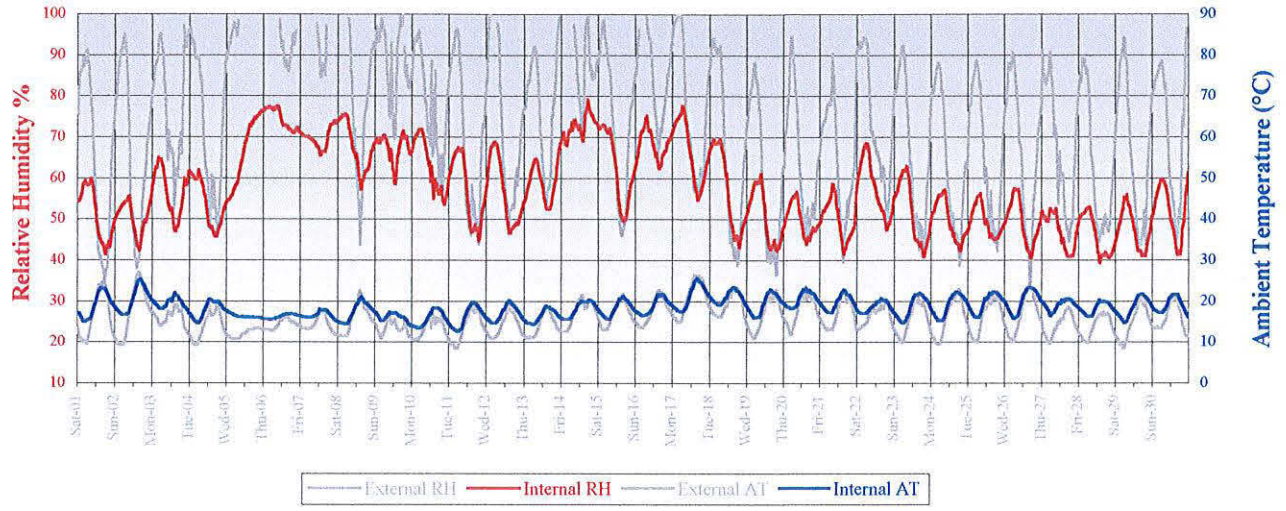


PROBE 5

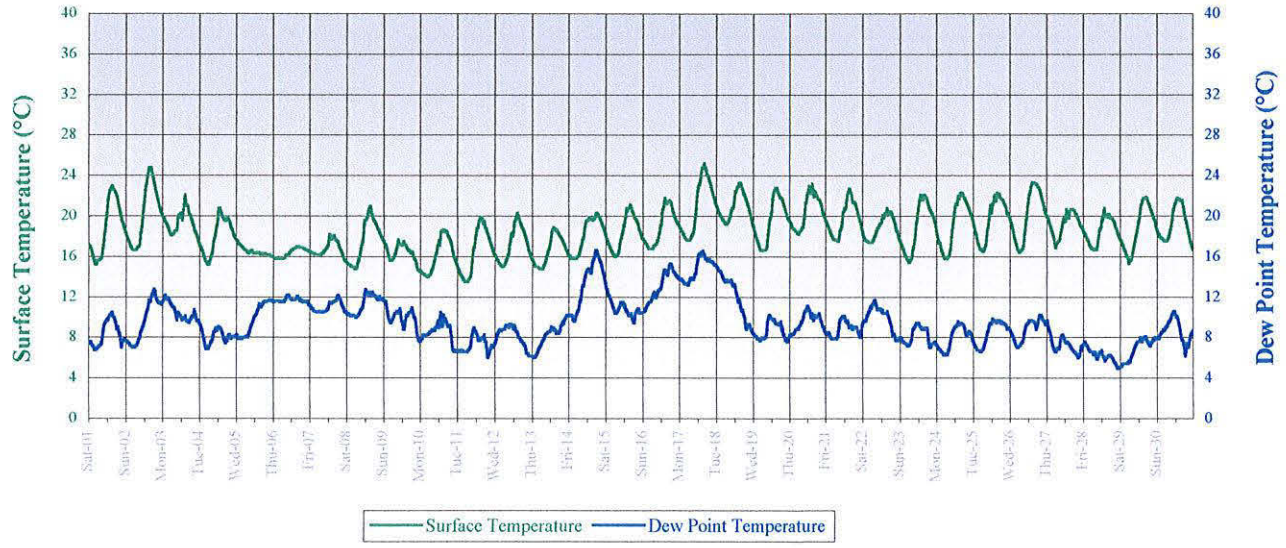
BAY 33 IV UPPER SIDE (SUN)

Probe 5: Bay 33 III upper side (sun)

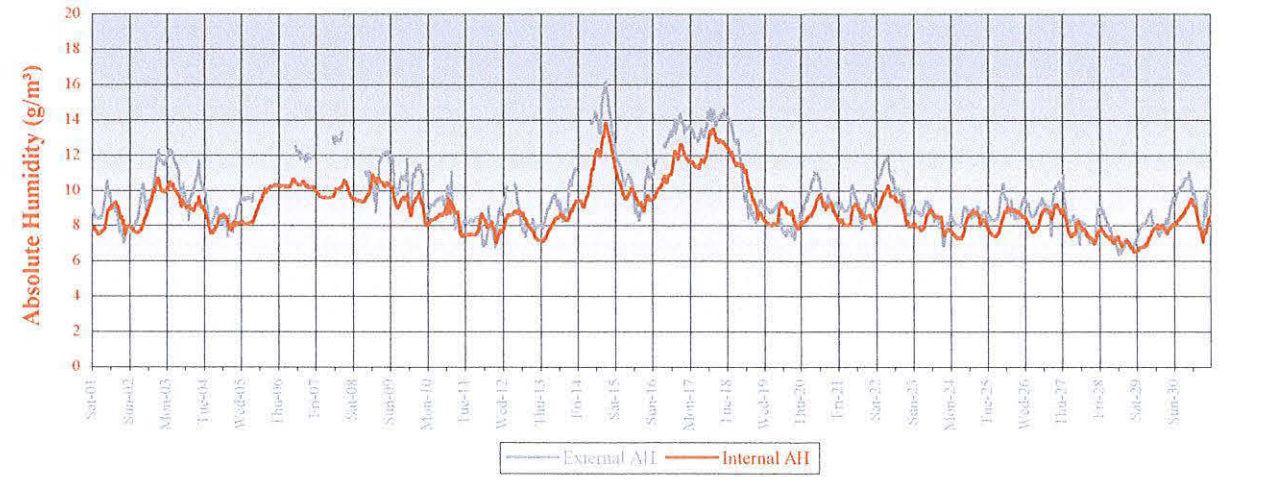
Relative Humidity and Ambient Temperature



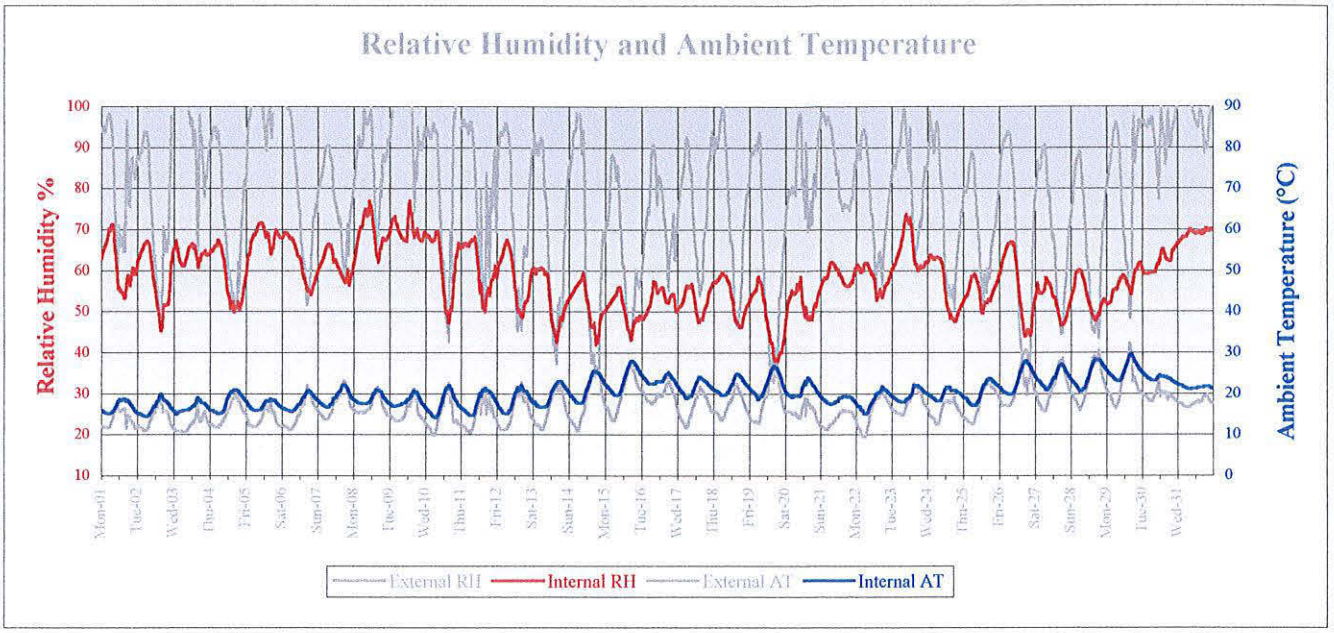
Surface and Dew Point Temperature

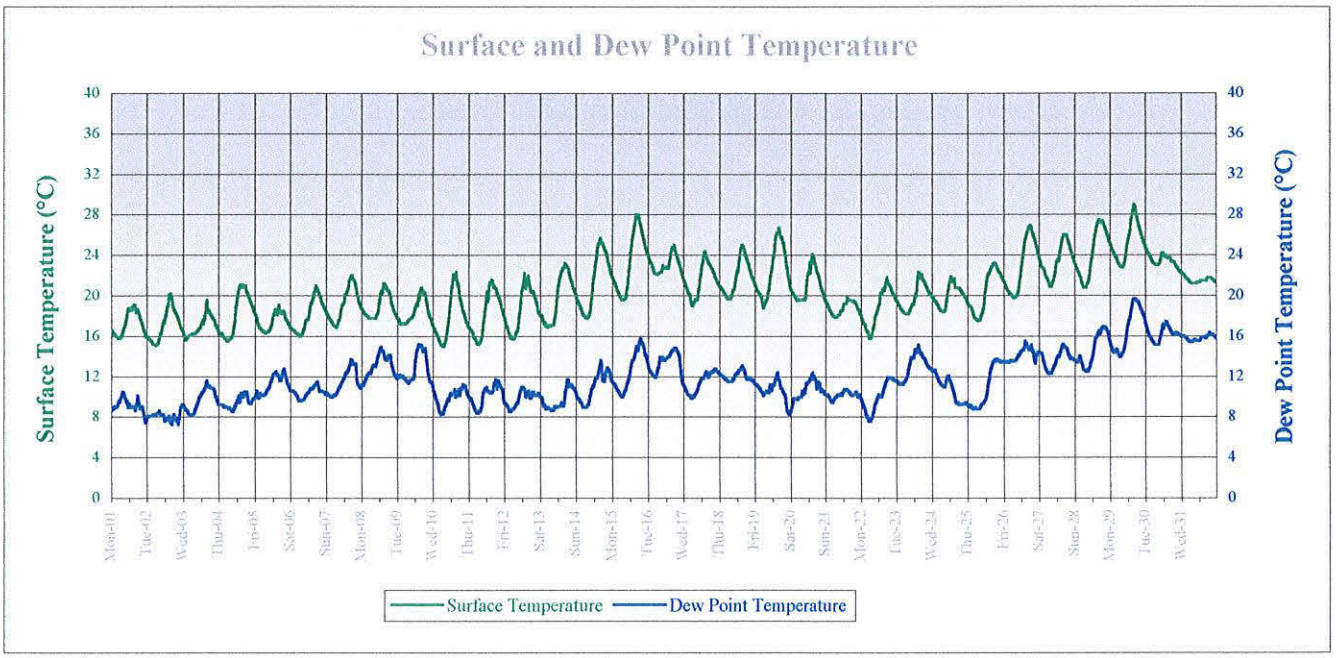


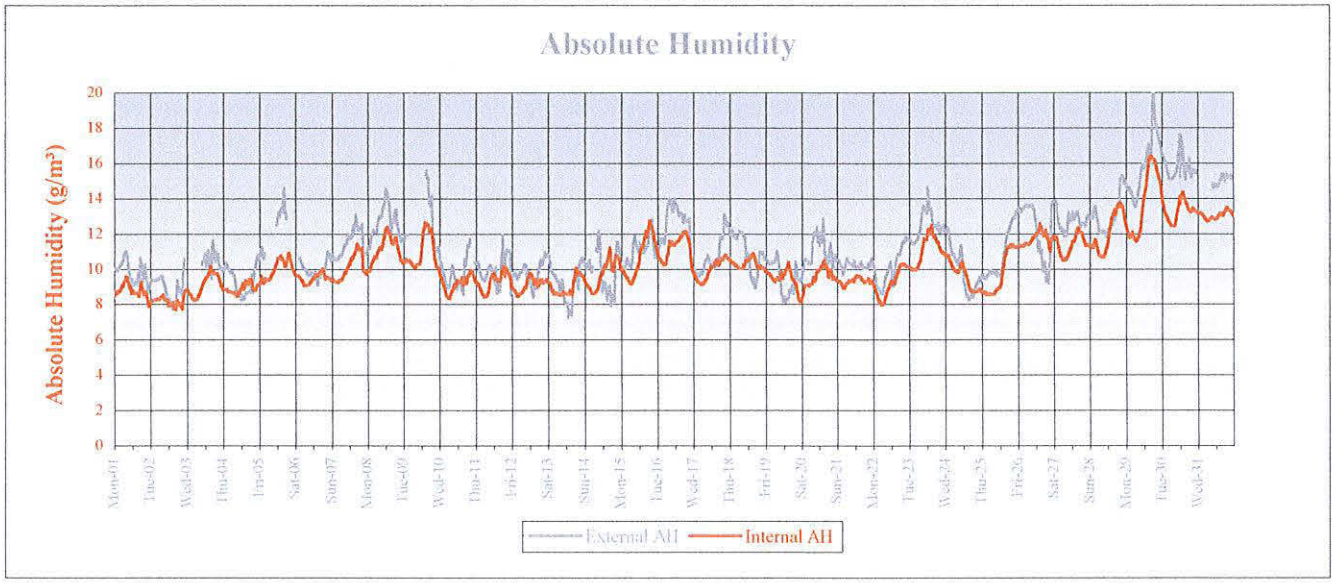
Absolute Humidity

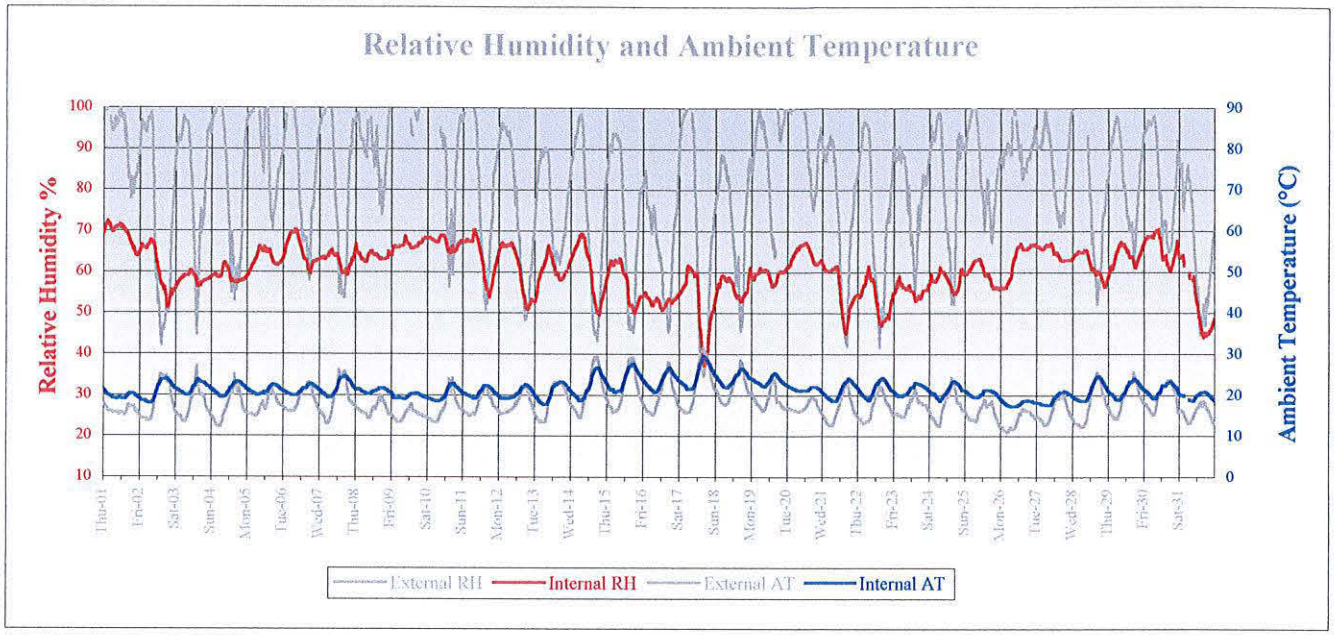


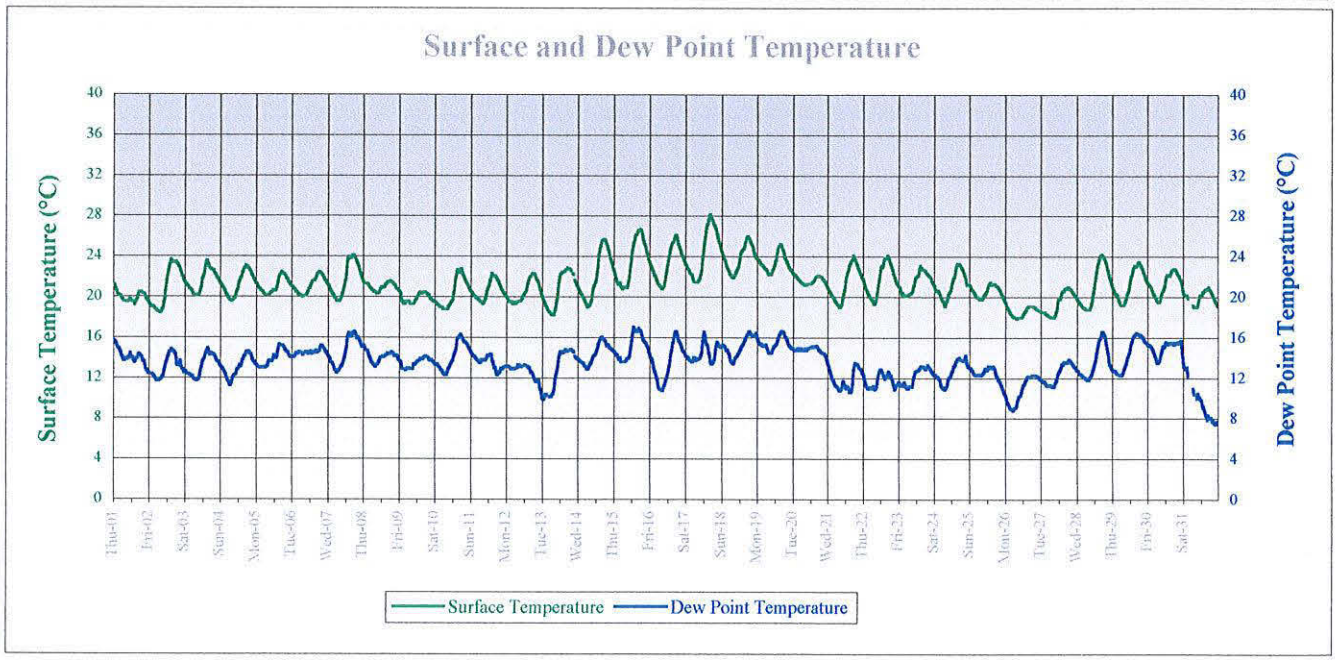
Probe 5: Bay 33 III upper side (sun)

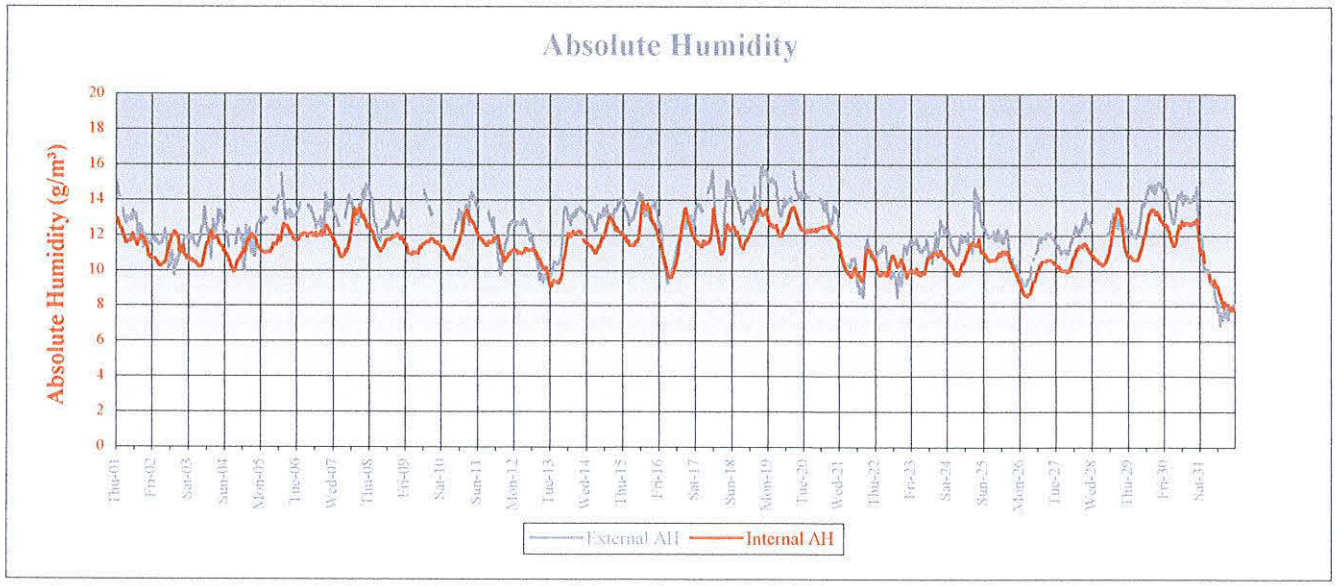







Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

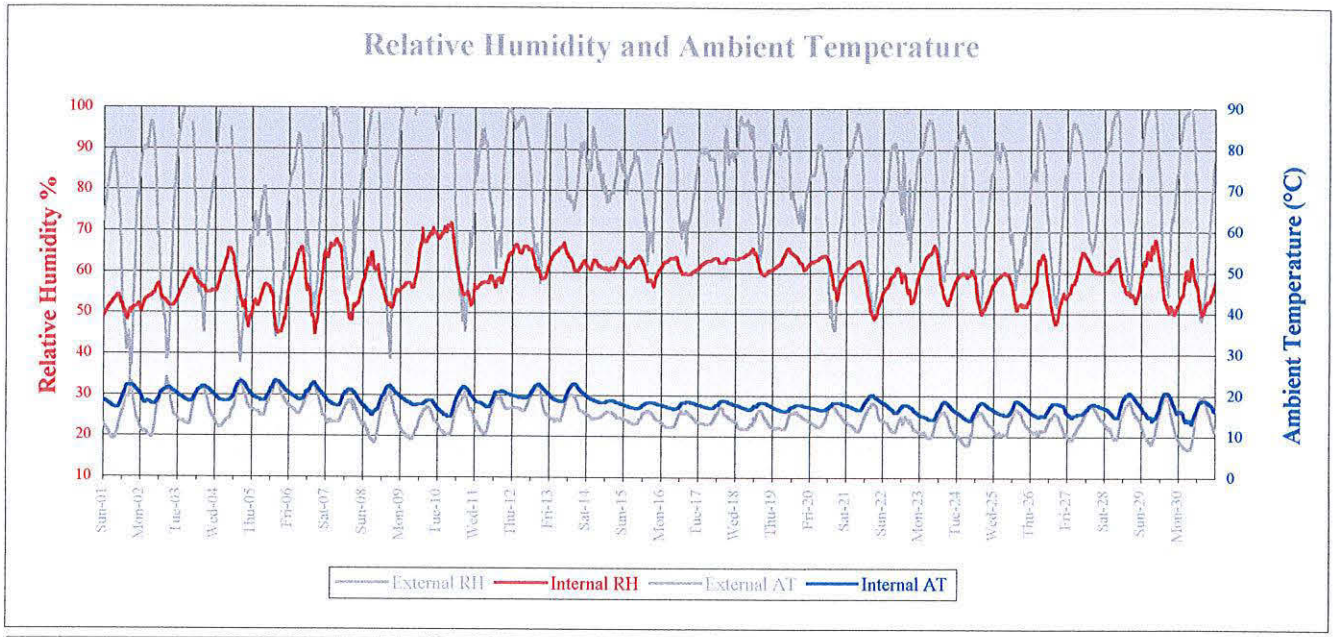

Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature

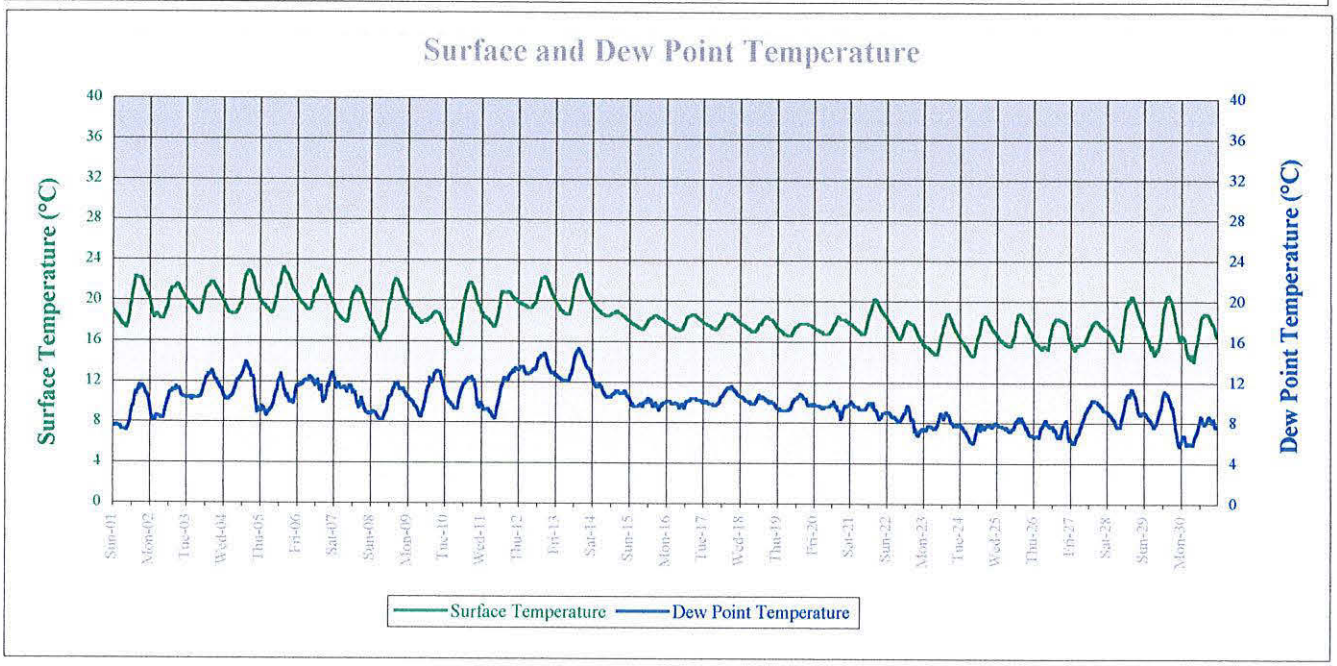

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

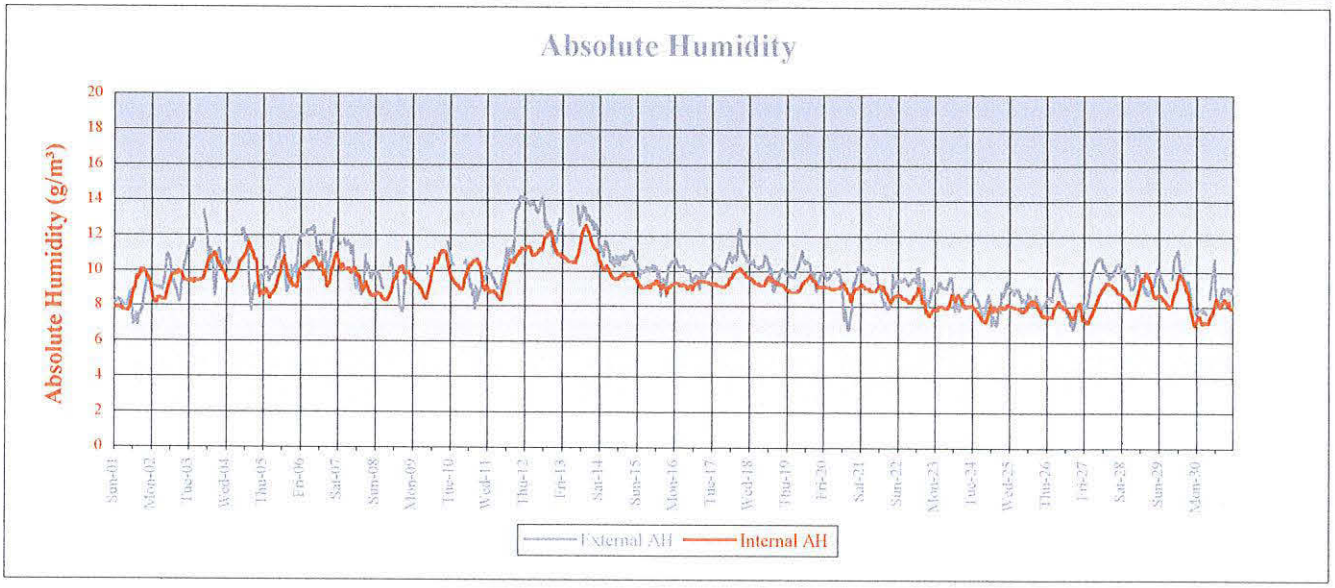
Peterborough Cathedral Nave Ceiling

September 2002

Probe 5: Bay 33 III upper side (sun)



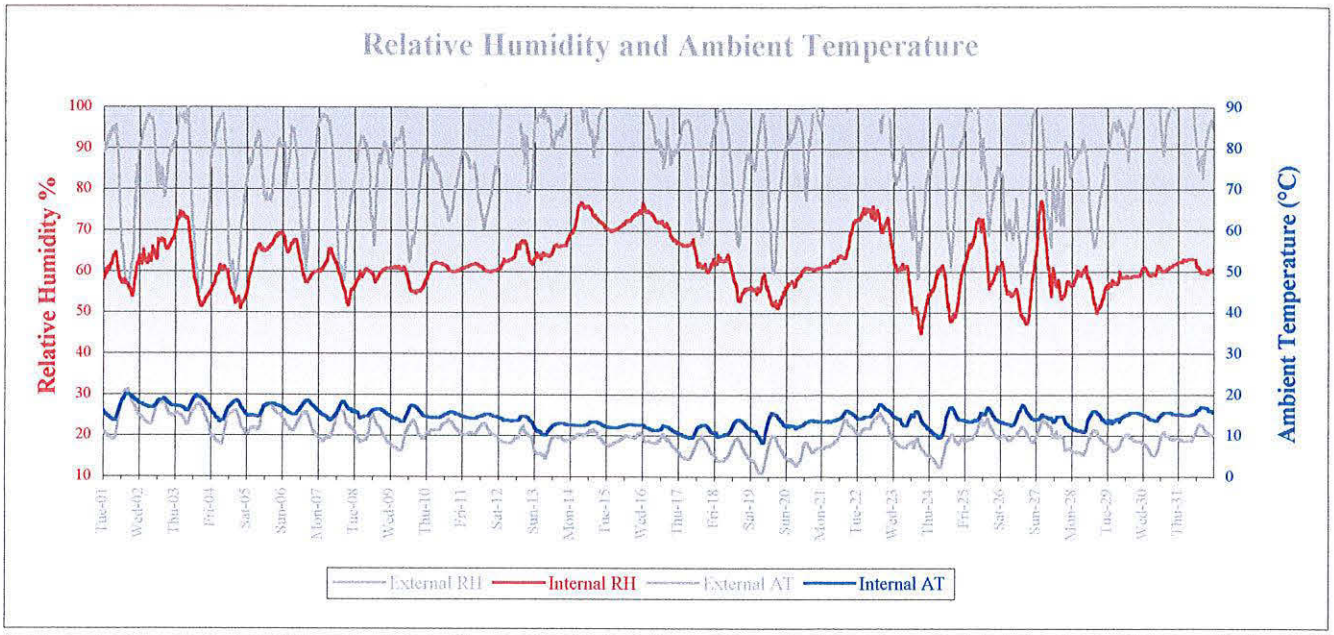


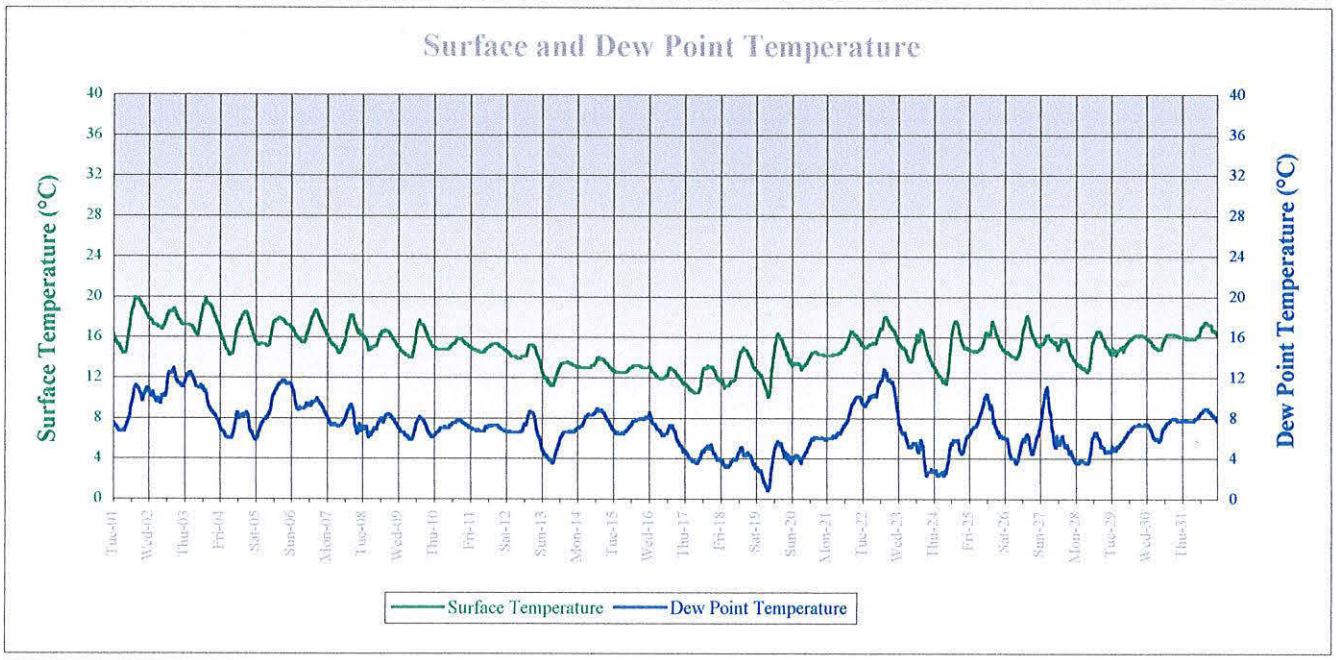


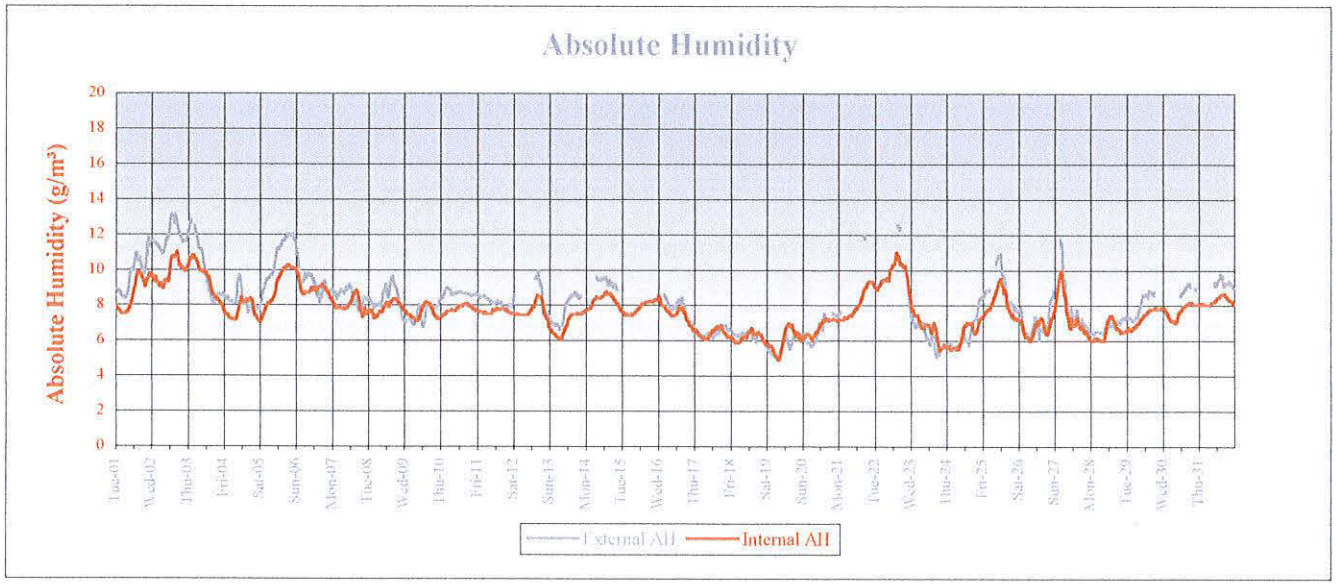
Peterborough Cathedral Nave Ceiling

October 2002

Probe 5: Bay 33 III upper side (sun)





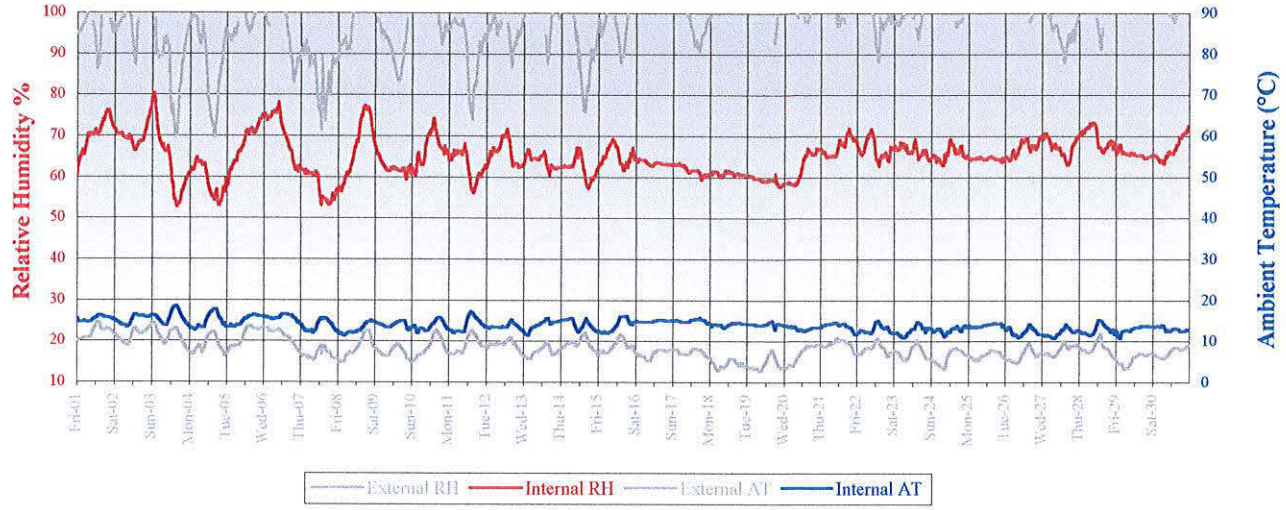


Peterborough Cathedral Nave Ceiling

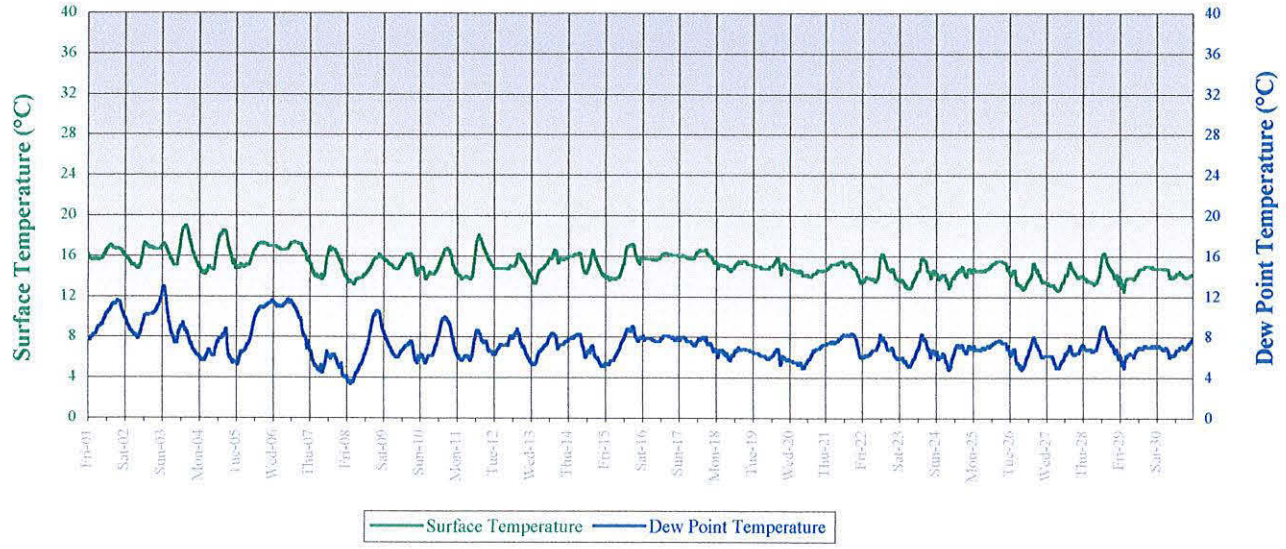
November 2002

Probe 5: Bay 33 III upper side (sun)

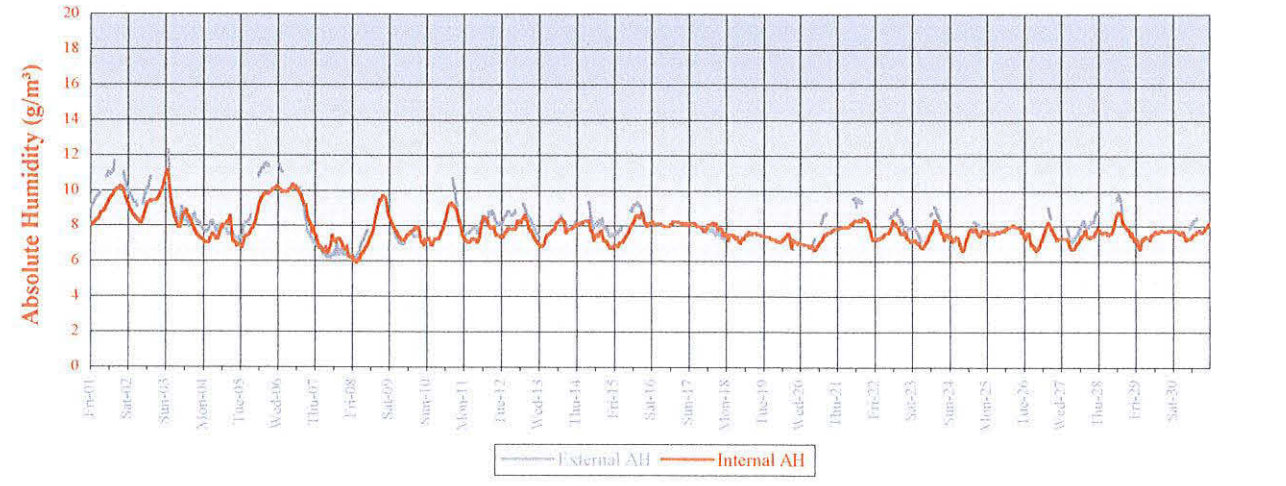
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



Absolute Humidity

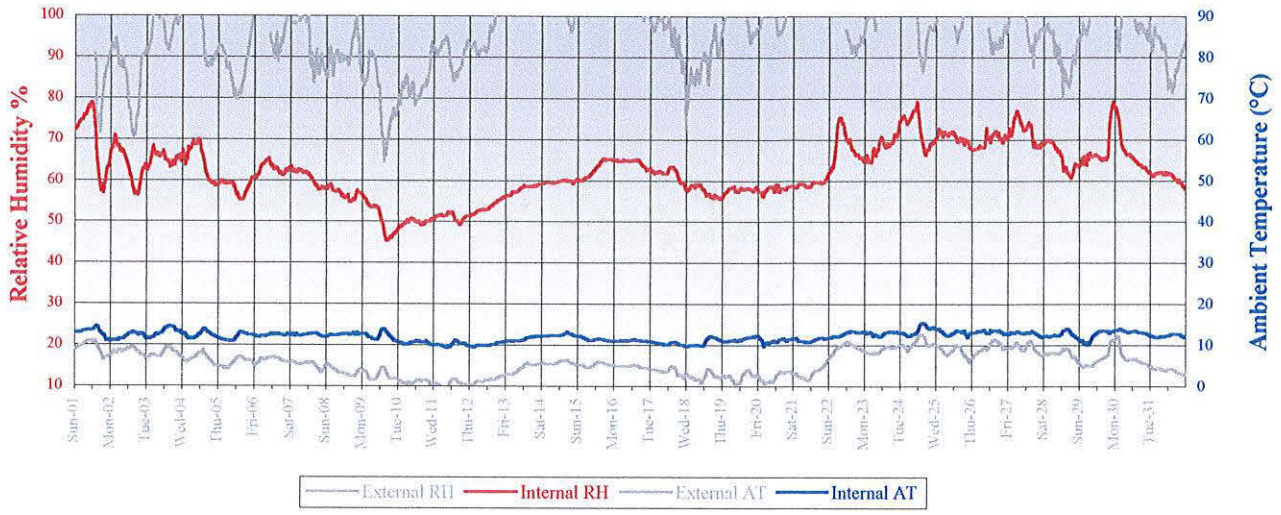


Peterborough Cathedral Nave Ceiling

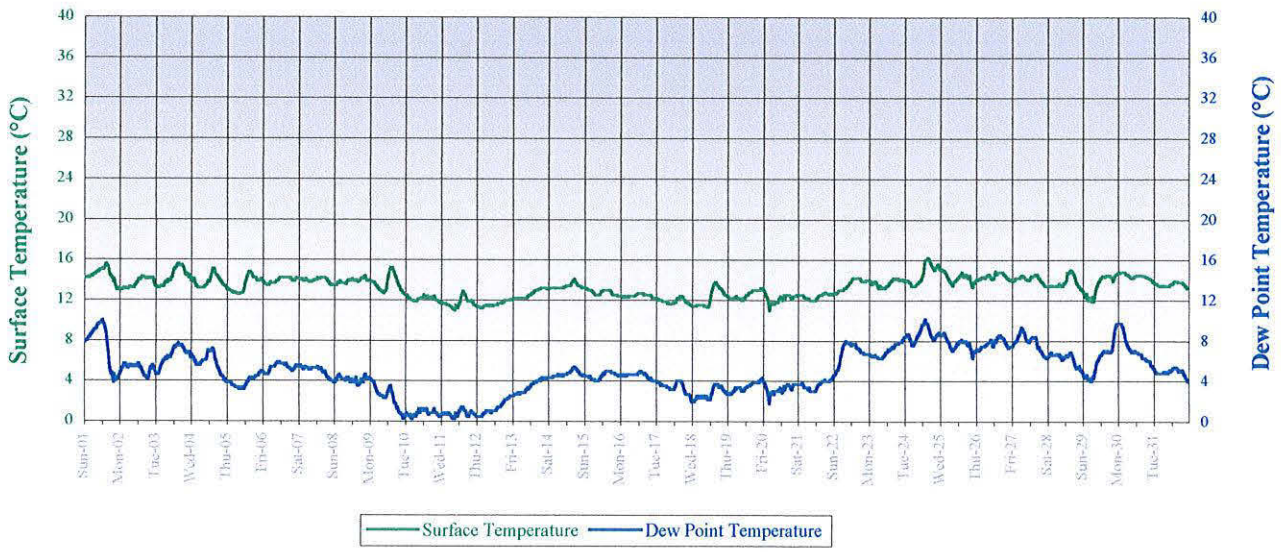
December 2002

Probe 5: Bay 33 III upper side (sun)

Relative Humidity and Ambient Temperature



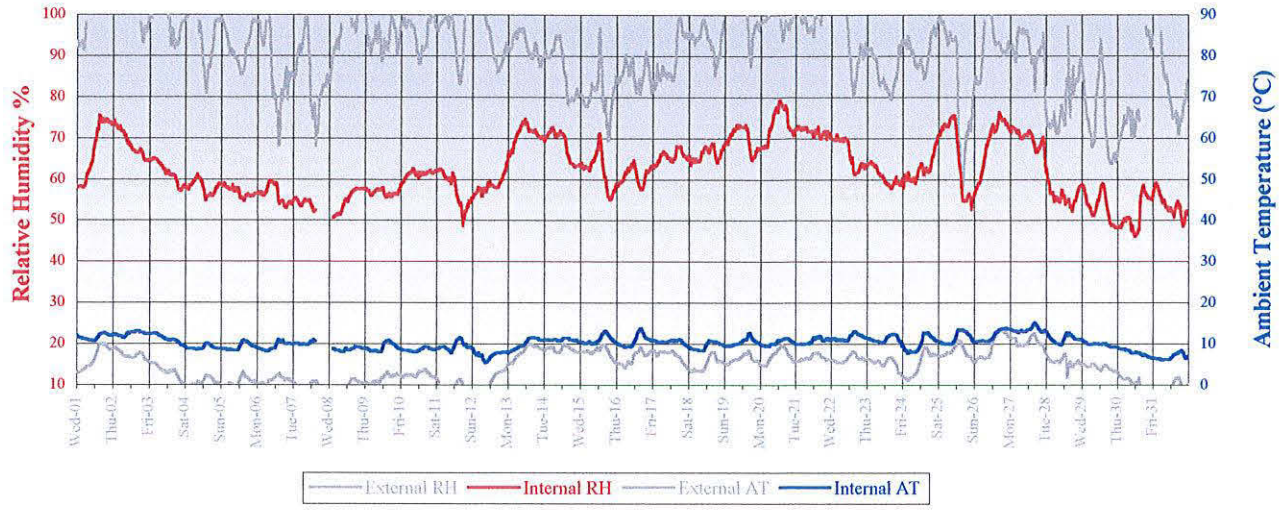
Surface and Dew Point Temperature



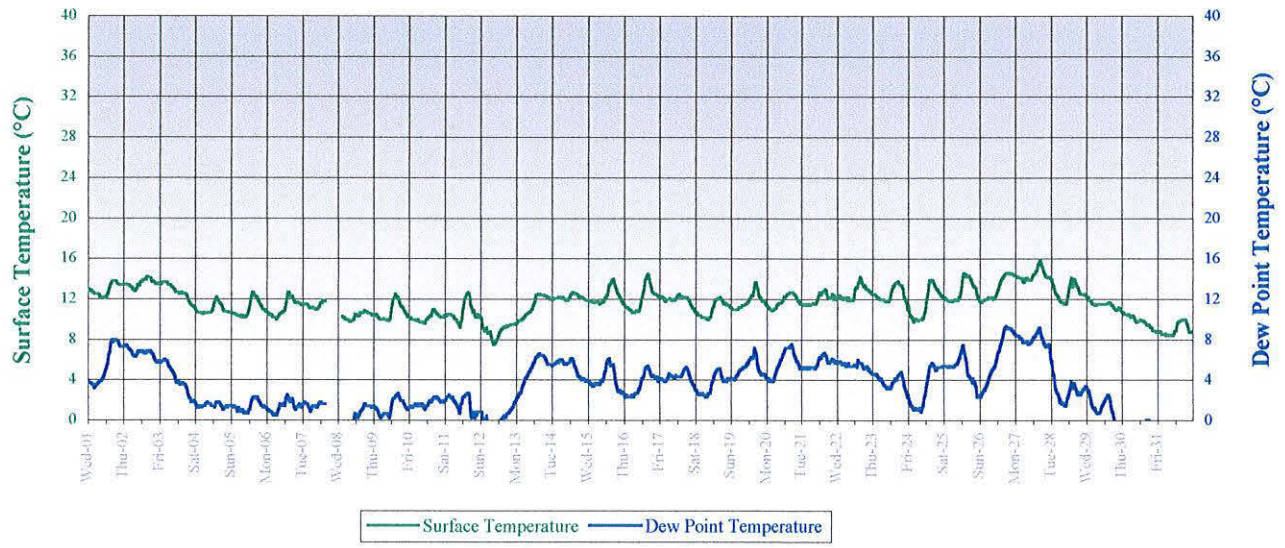
Absolute Humidity

Probe 5: Bay 33 III upper side (sun)

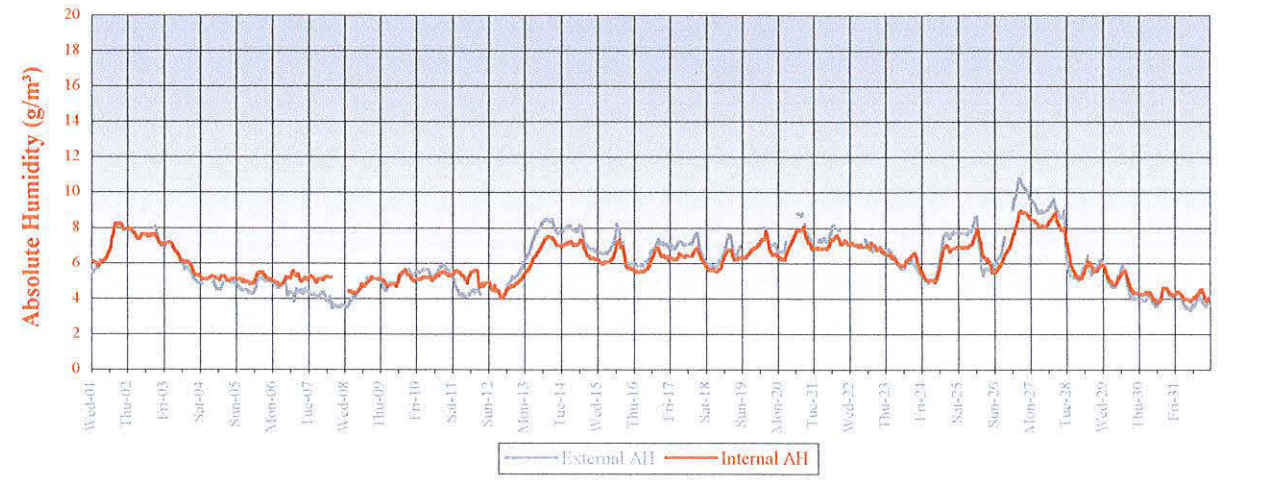
Relative Humidity and Ambient Temperature

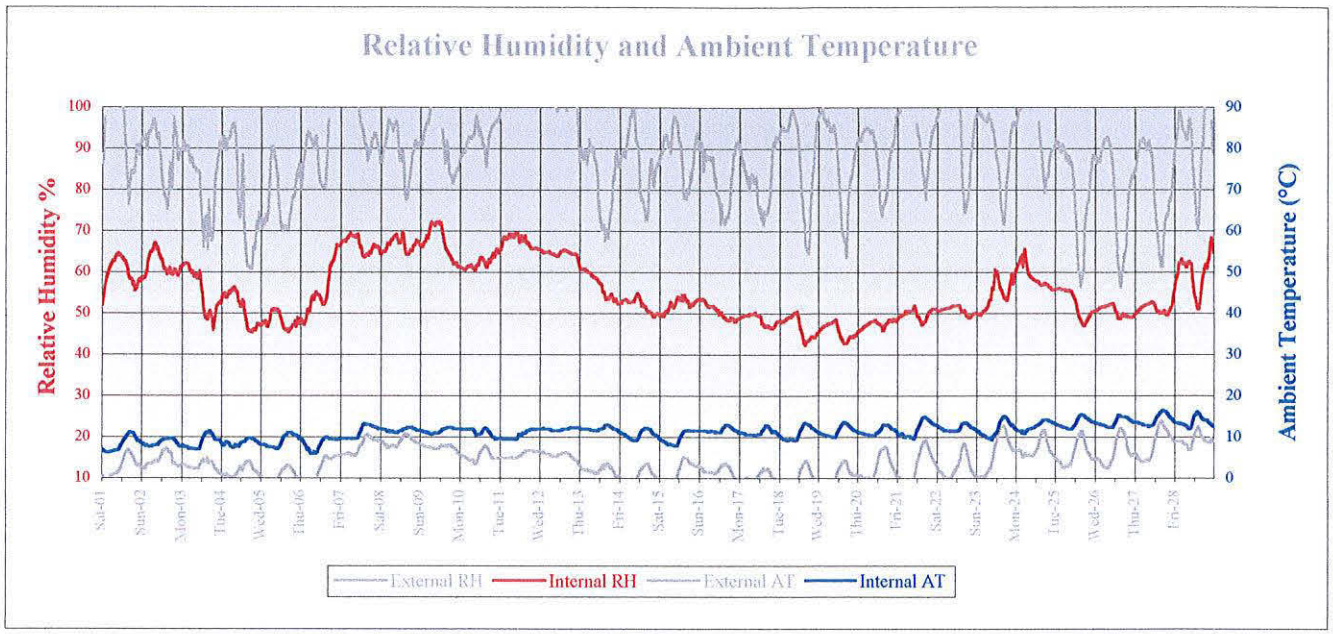


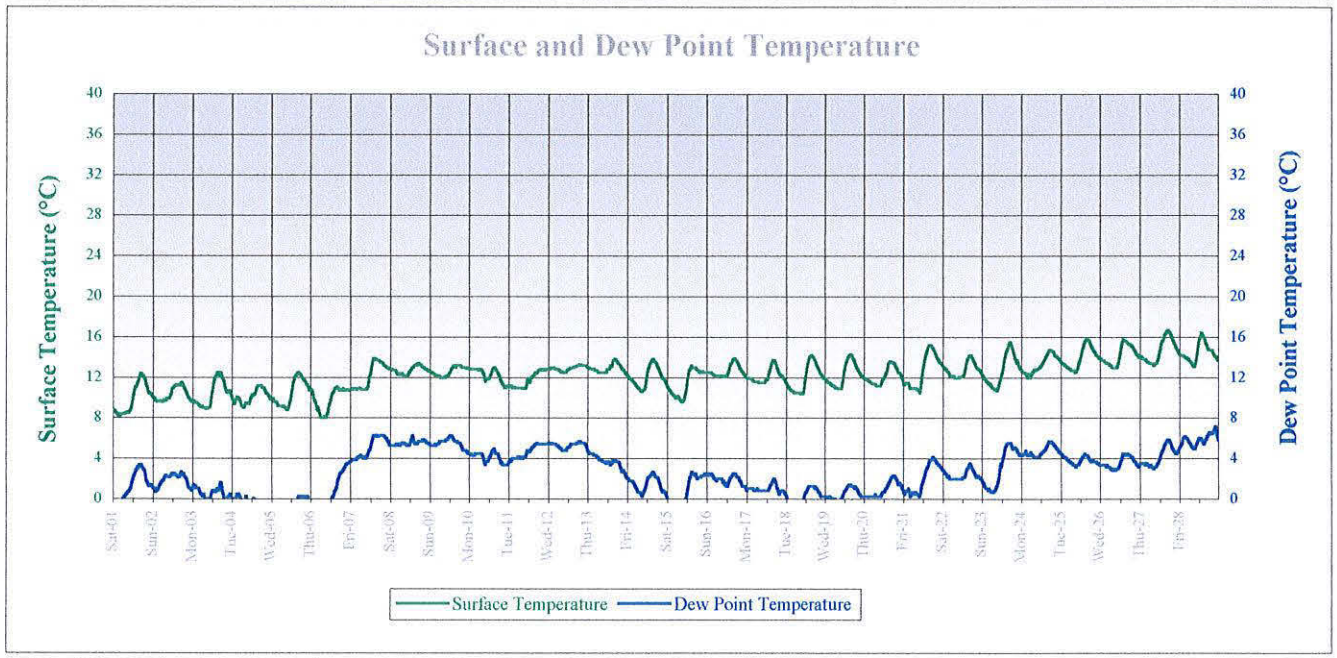
Surface and Dew Point Temperature

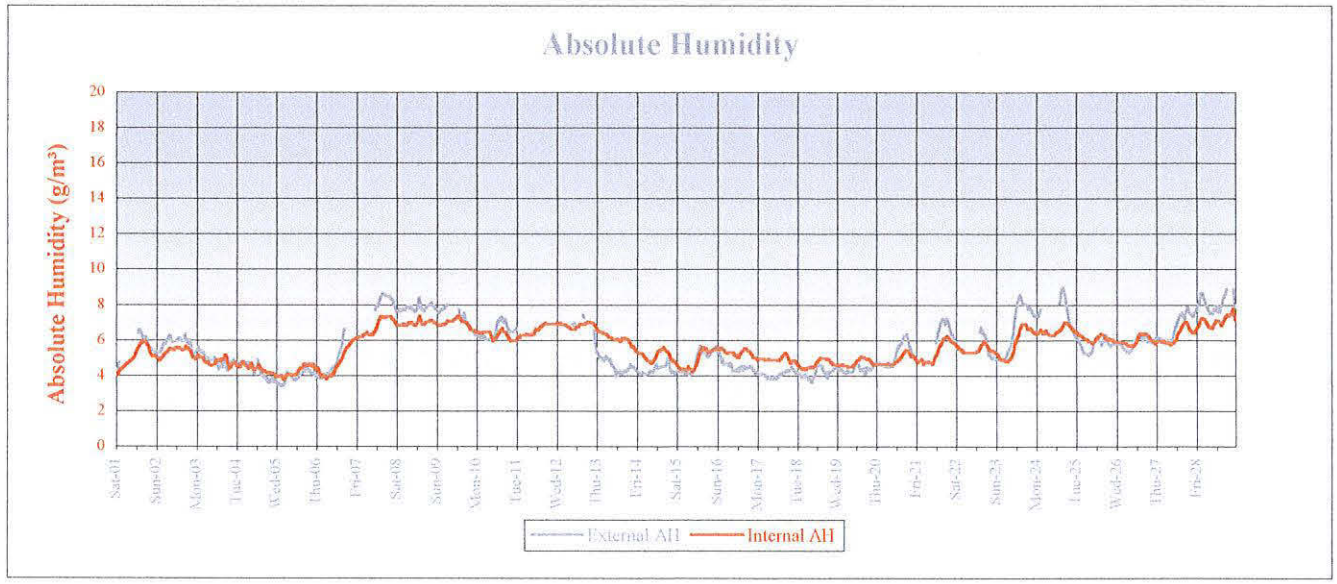


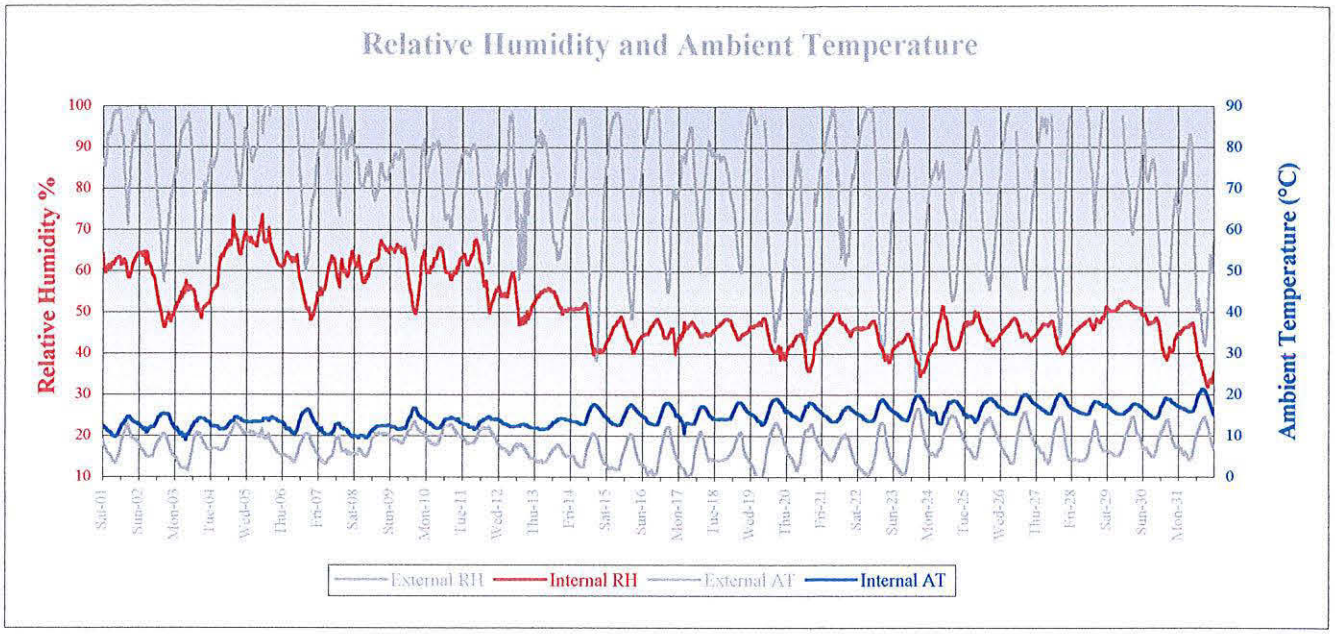
Absolute Humidity

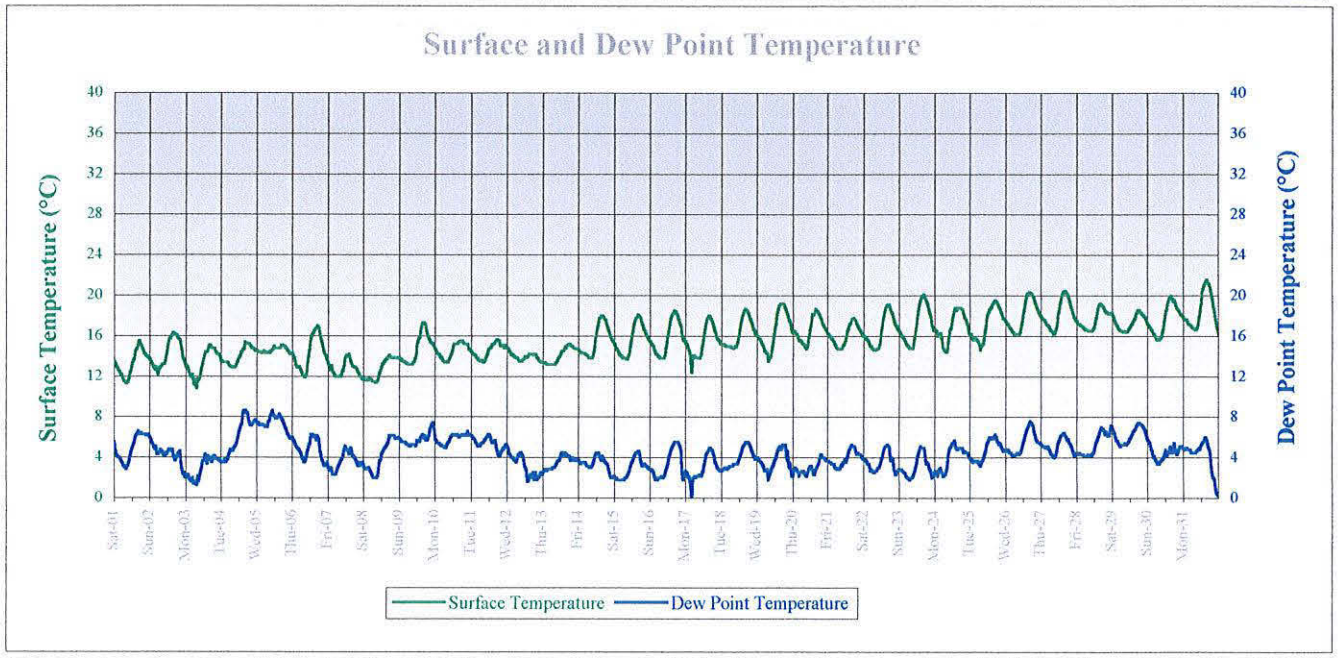


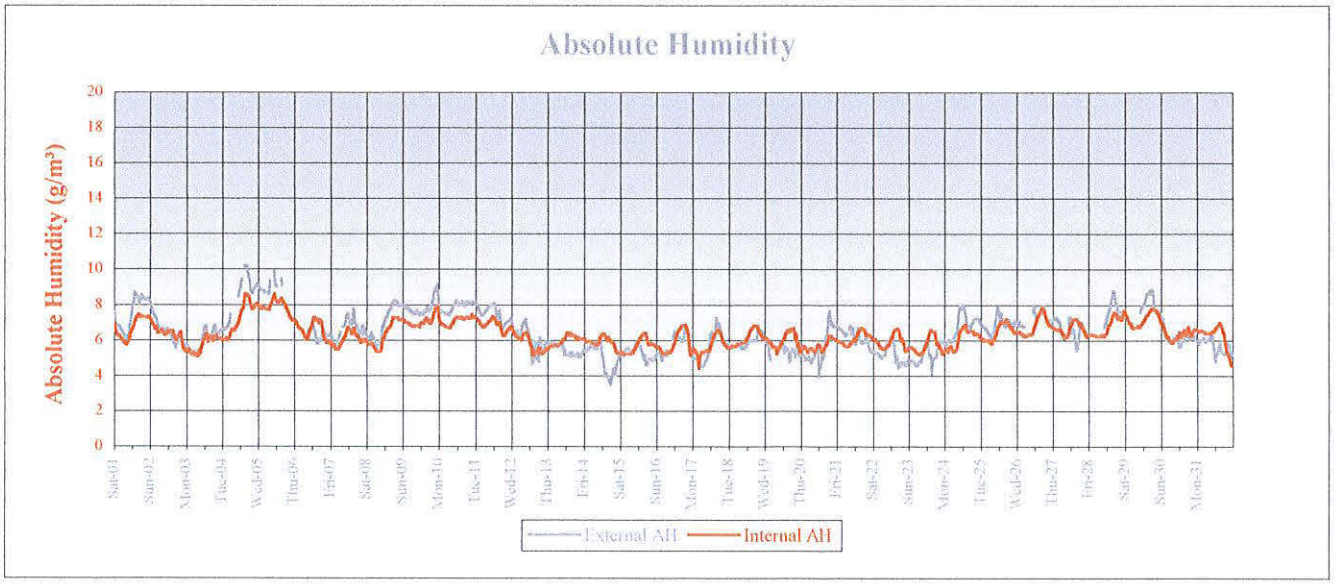

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

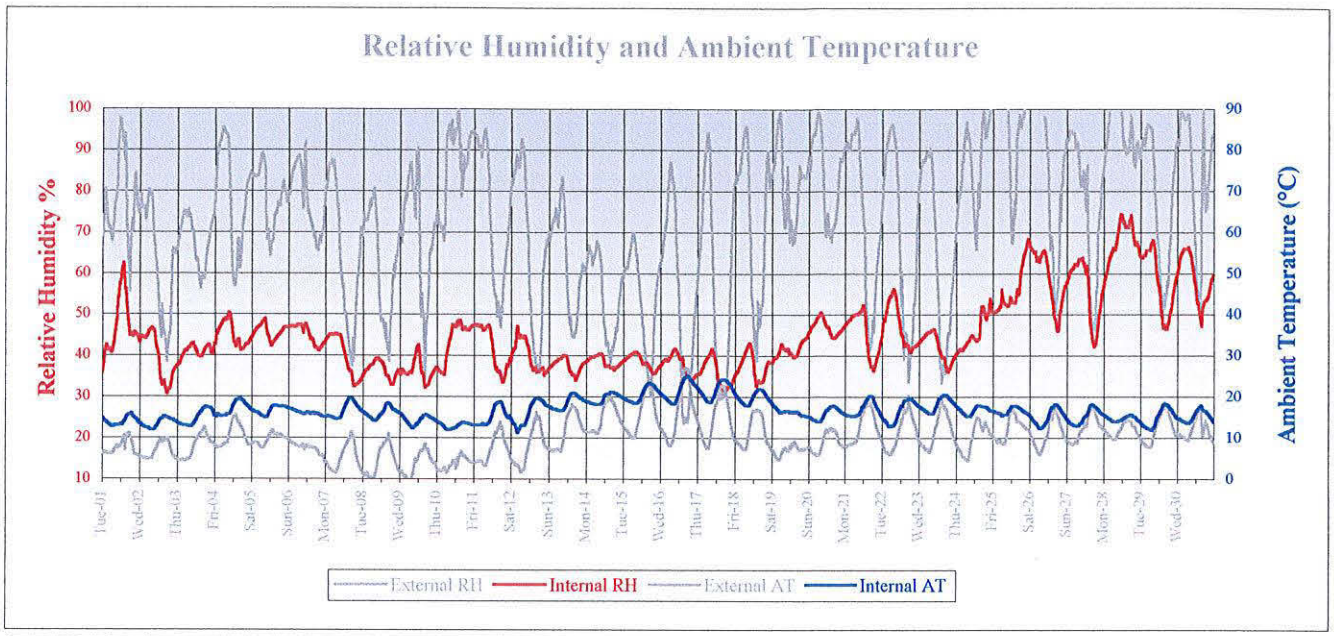

Surface and Dew Point Temperature
Surface Temperature (°C)
Dew Point Temperature (°C)
Surface Temperature
Dew Point Temperature

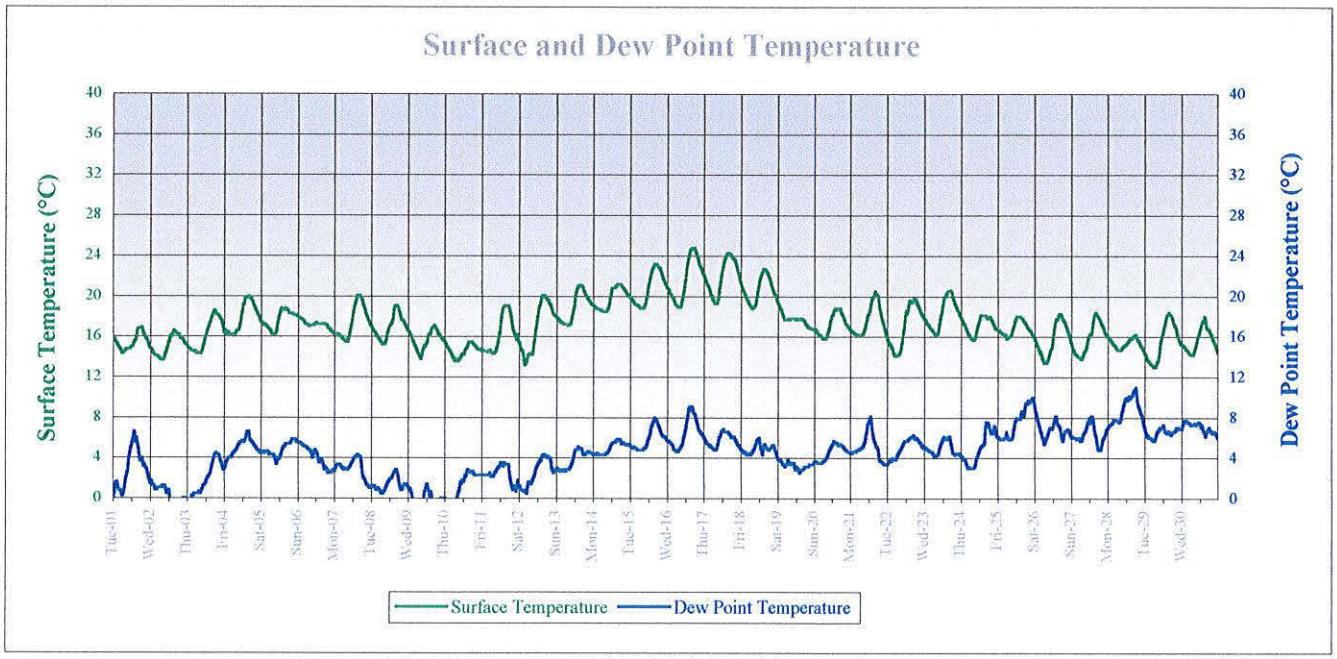

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

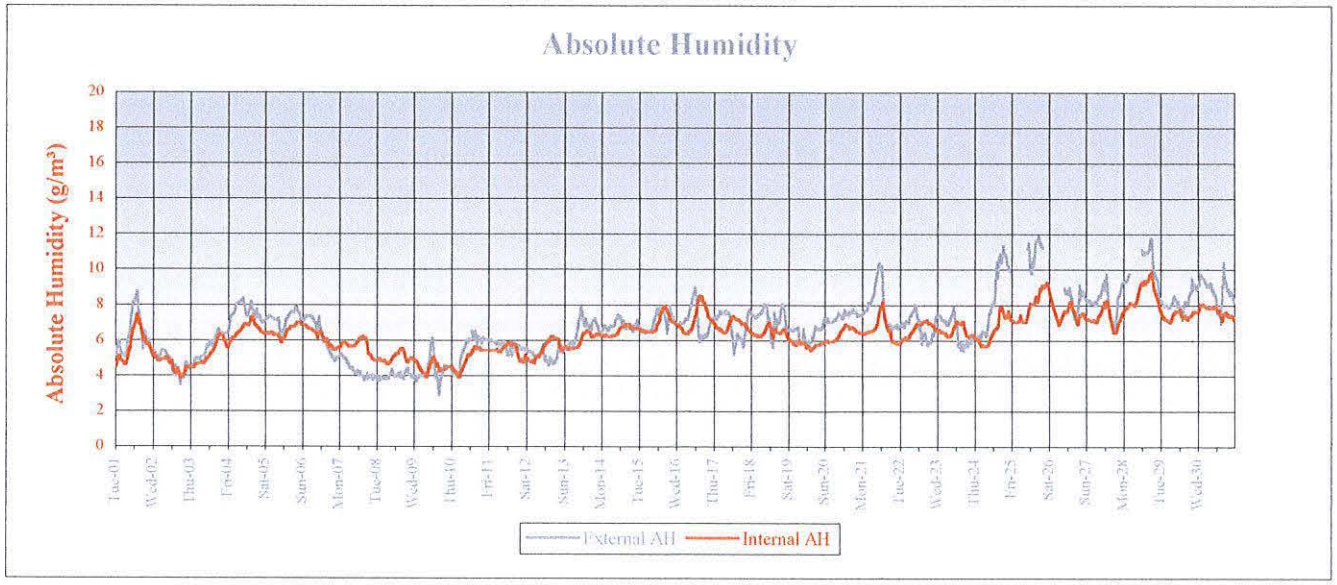
Peterborough Cathedral Nave Ceiling

April 2003

Probe 5: Bay 33 III upper side (sun)



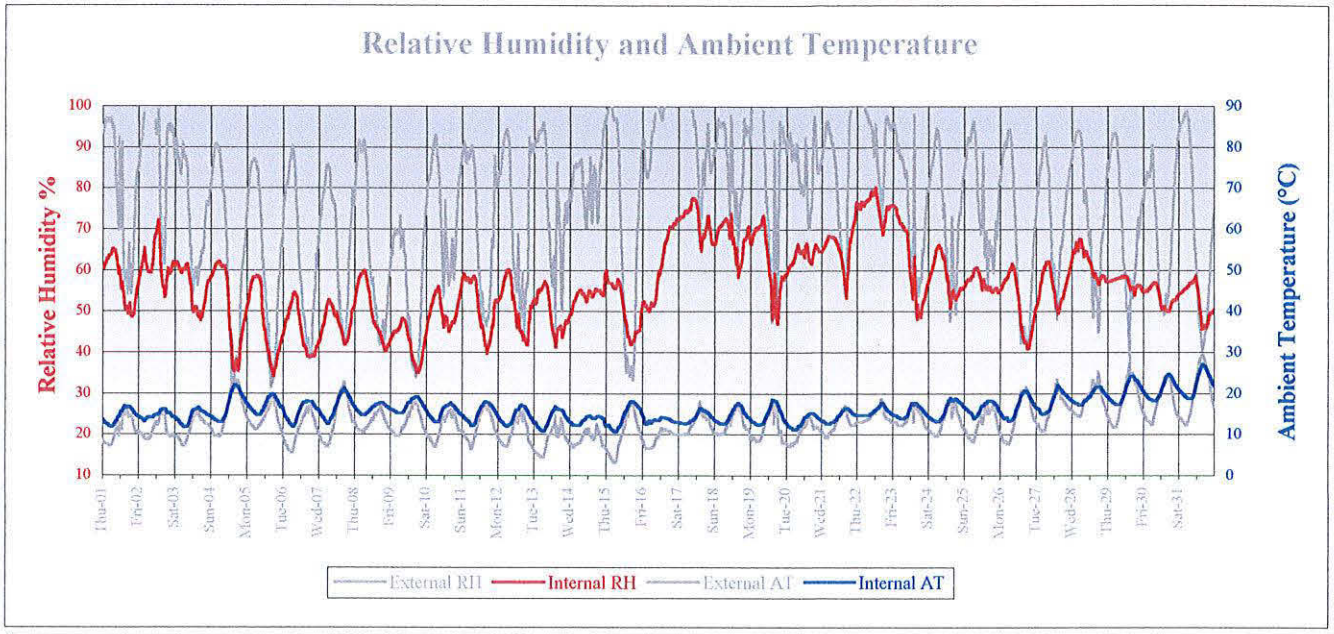


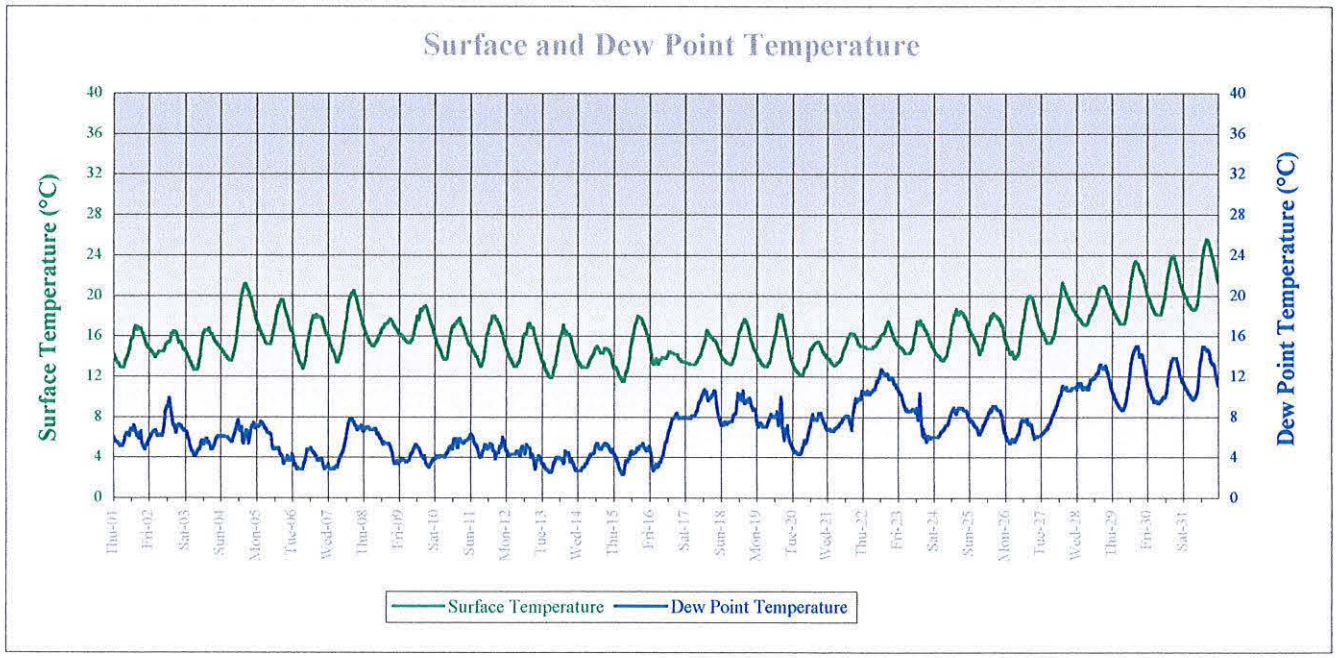


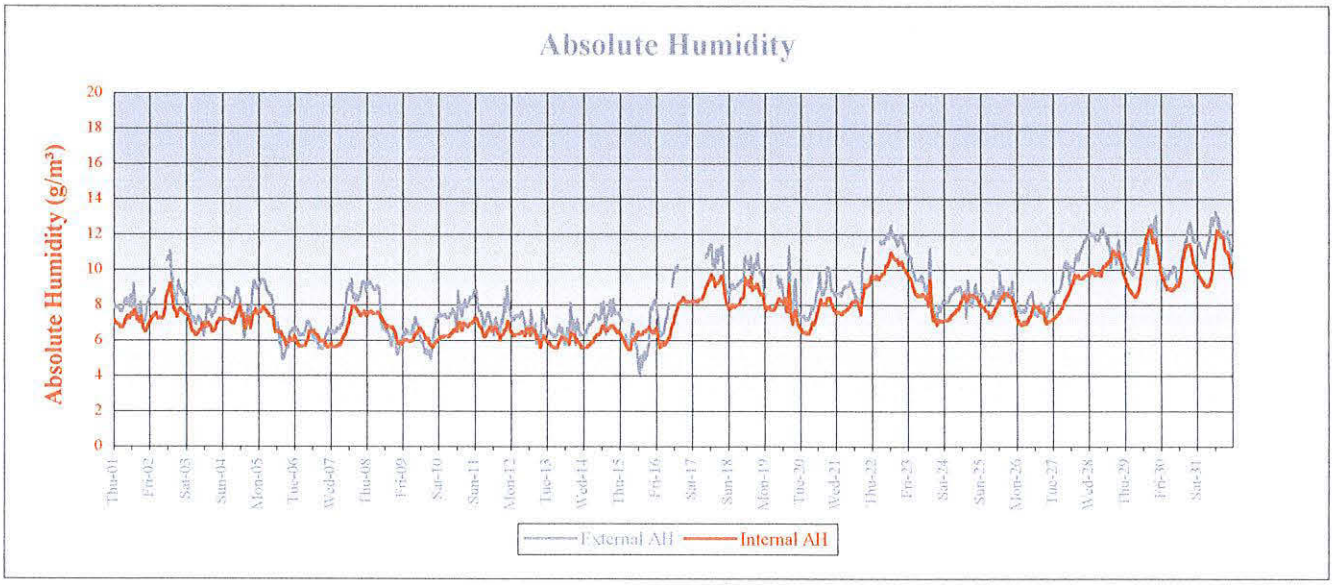
Peterborough Cathedral Nave Ceiling

May 2003

Probe 5: Bay 33 III upper side (sun)



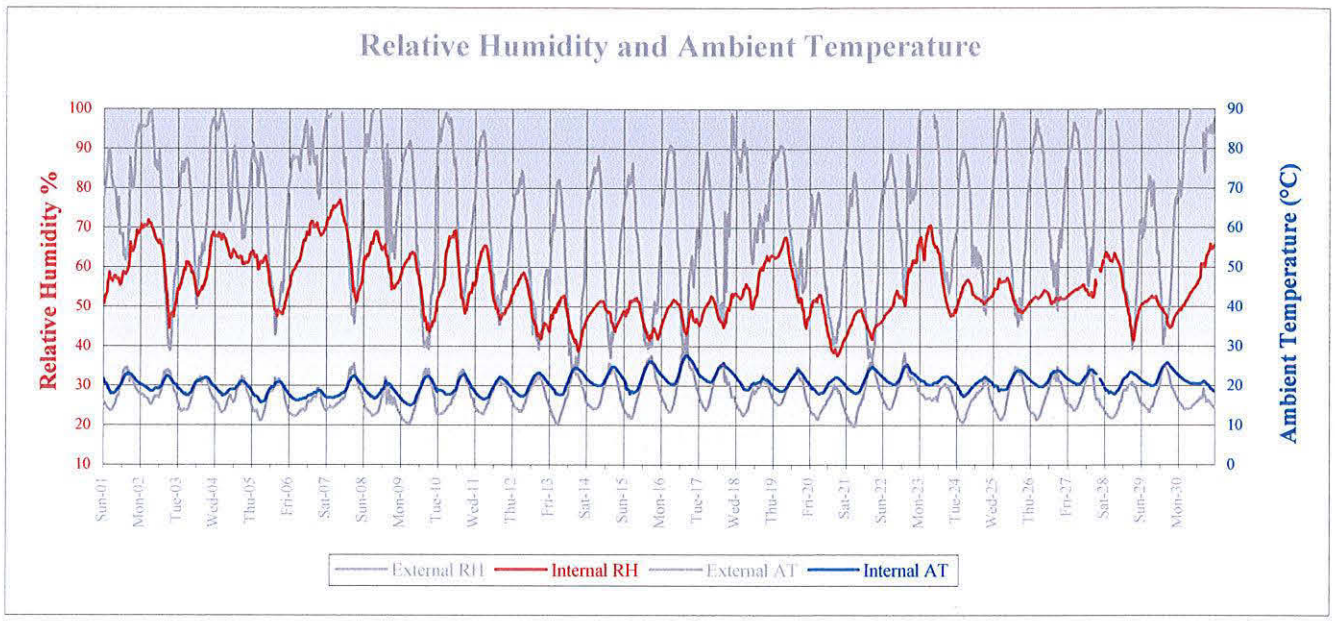


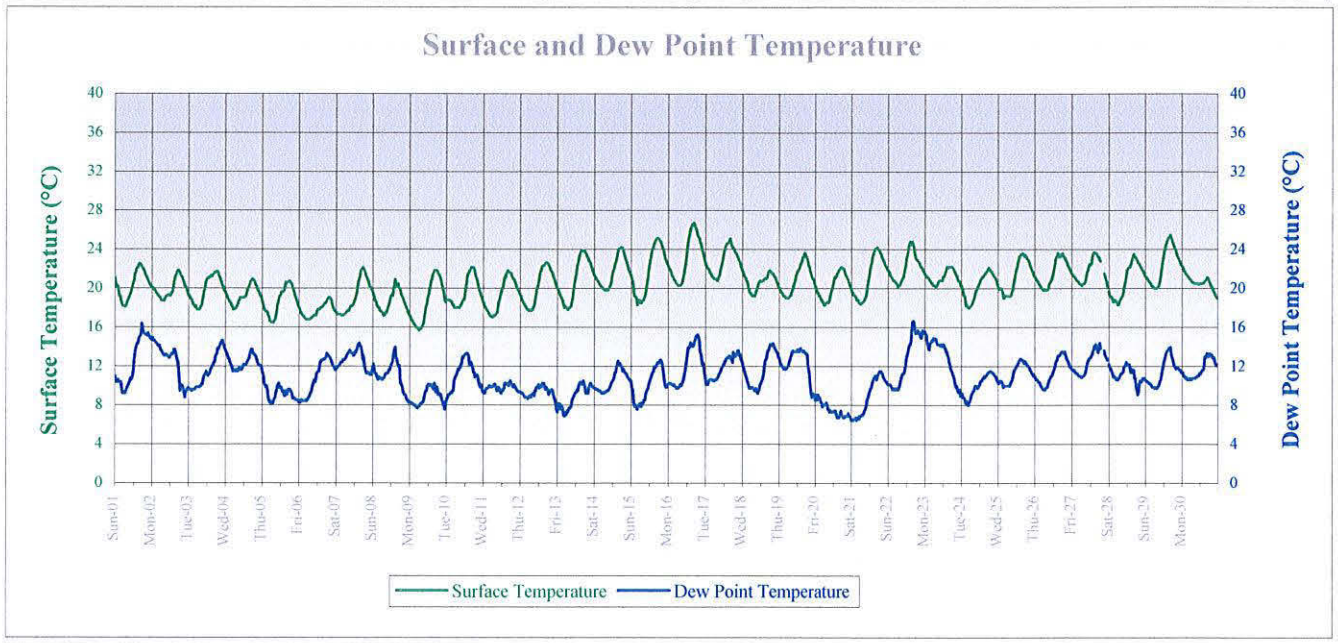


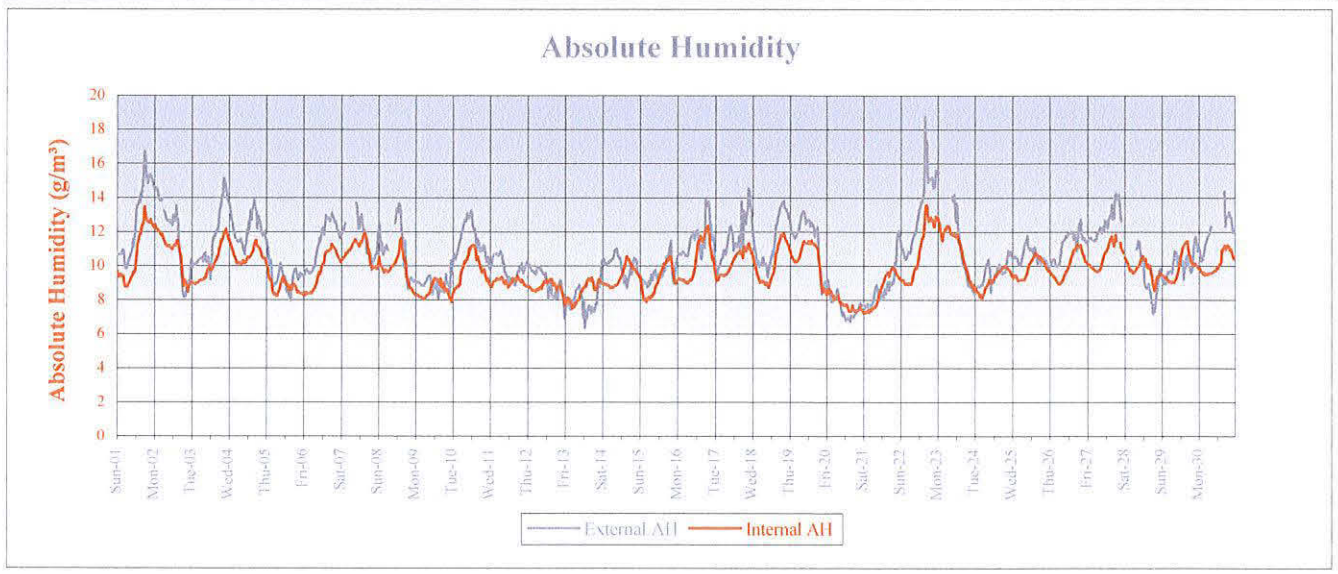
Peterborough Cathedral Nave Ceiling

June 2003

Probe 5: Bay 33 III upper side (sun)



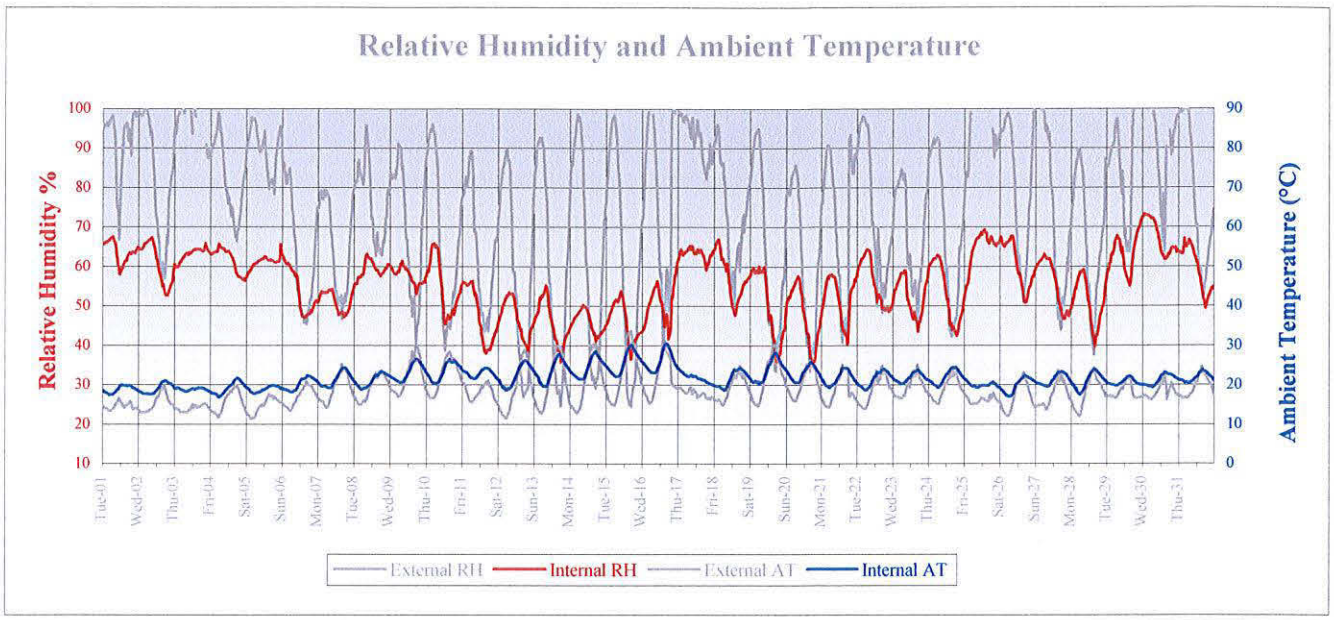


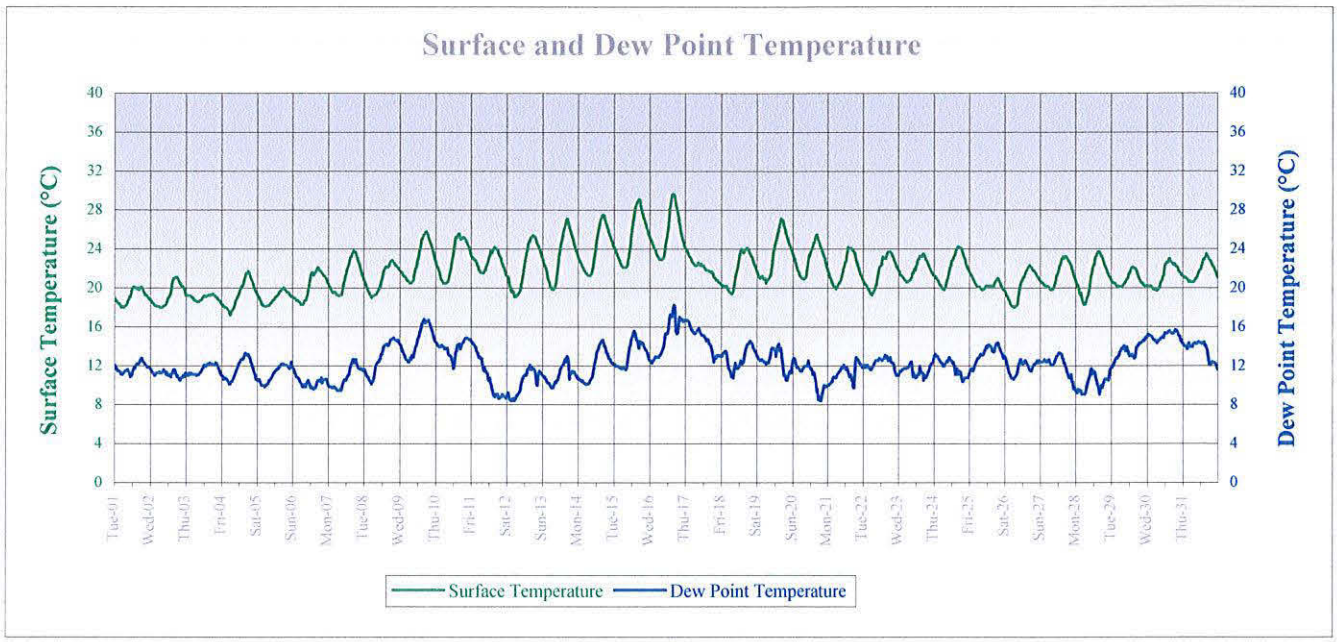


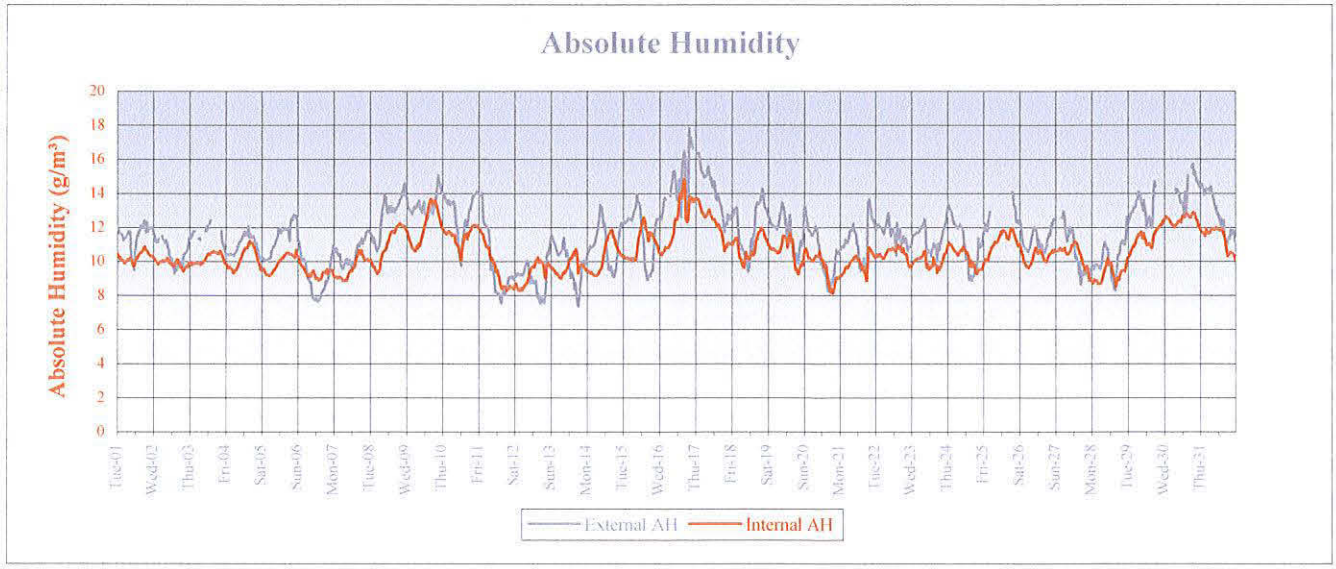
Peterborough Cathedral Nave Ceiling

July 2003

Probe 5: Bay 33 III upper side (sun)



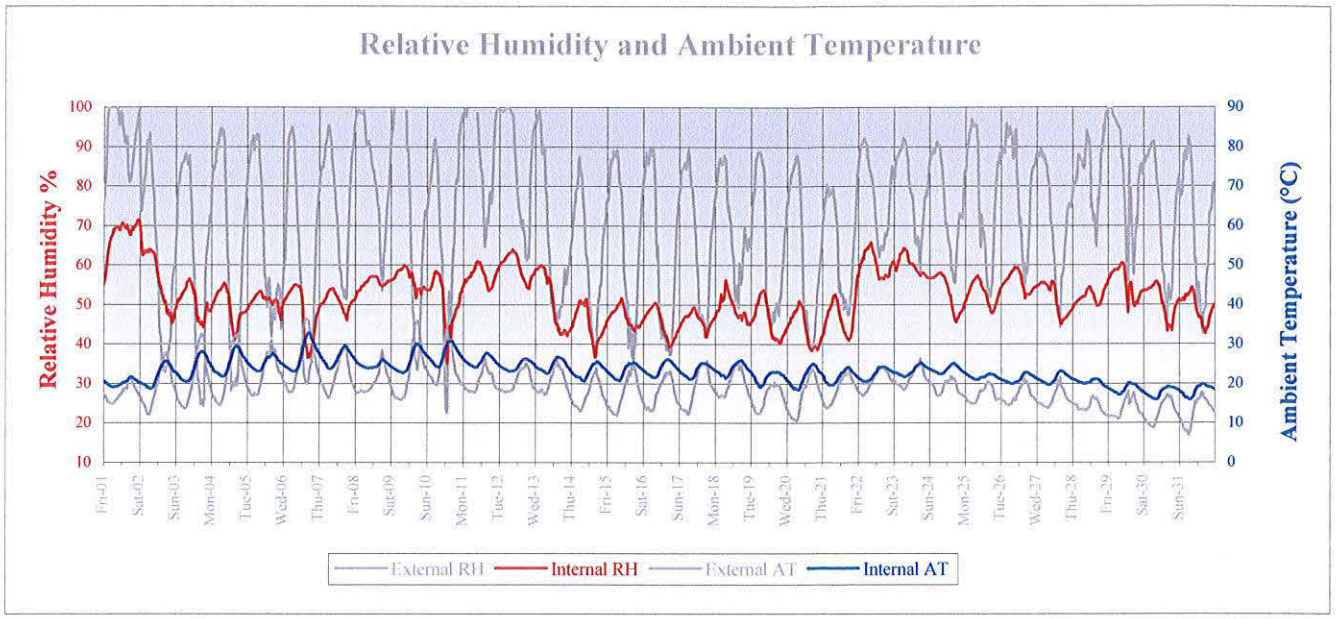


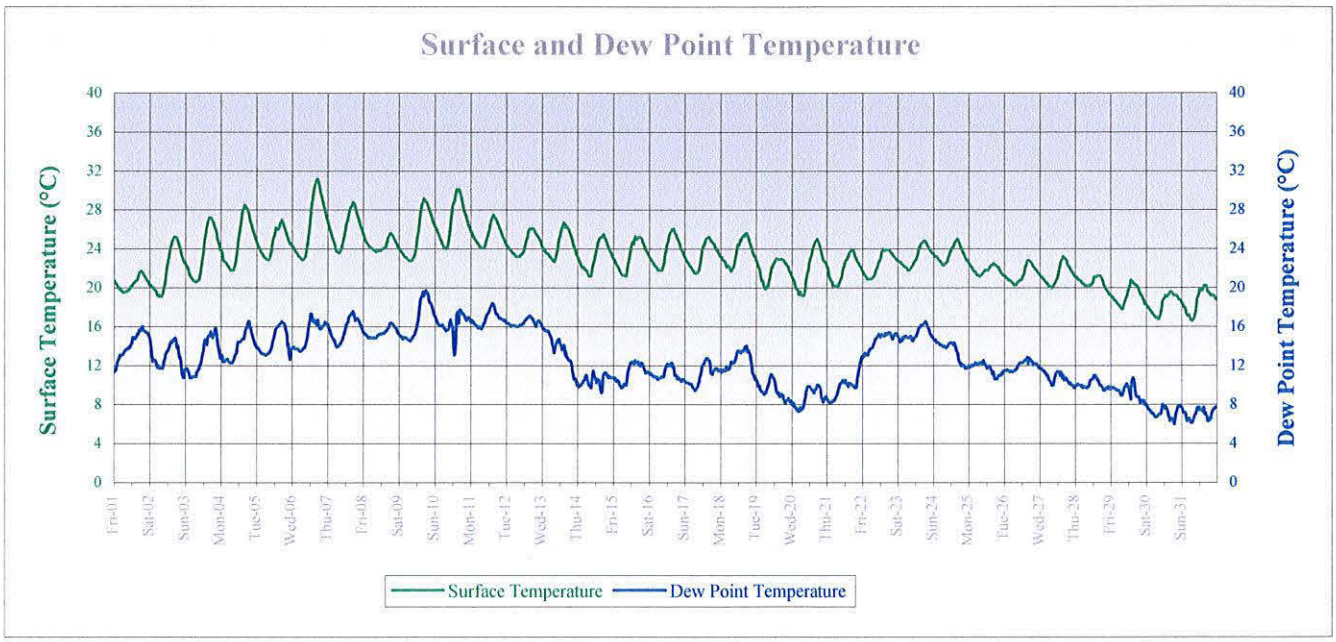


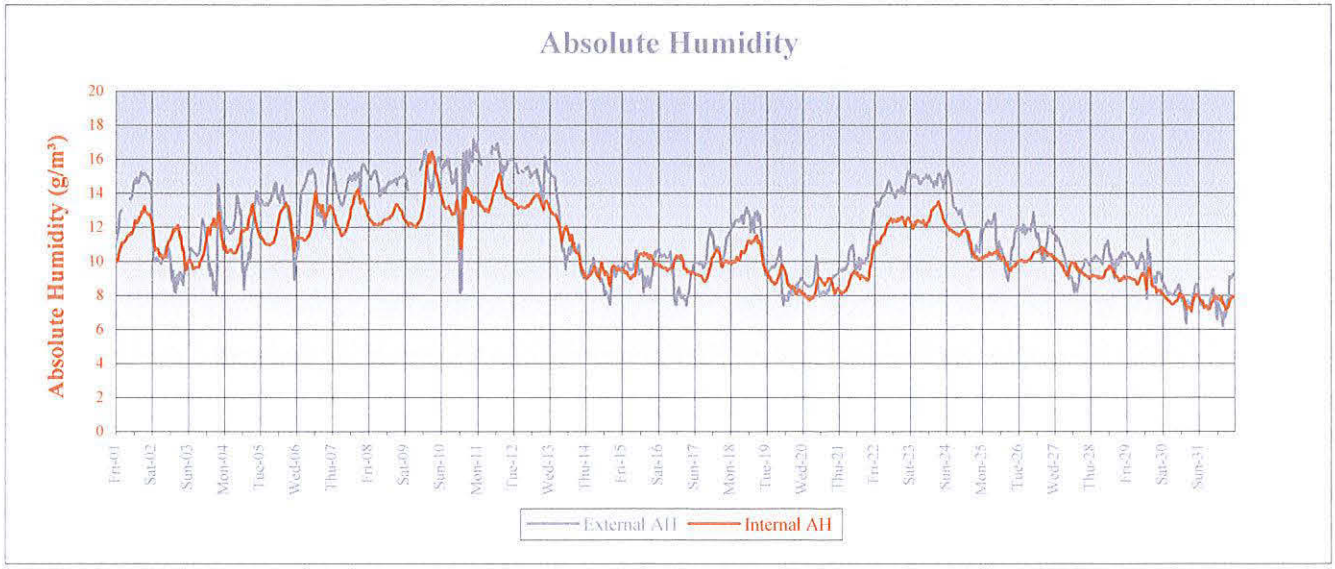
Peterborough Cathedral Nave Ceiling

August 2003

Probe 5: Bay 33 III upper side (sun)





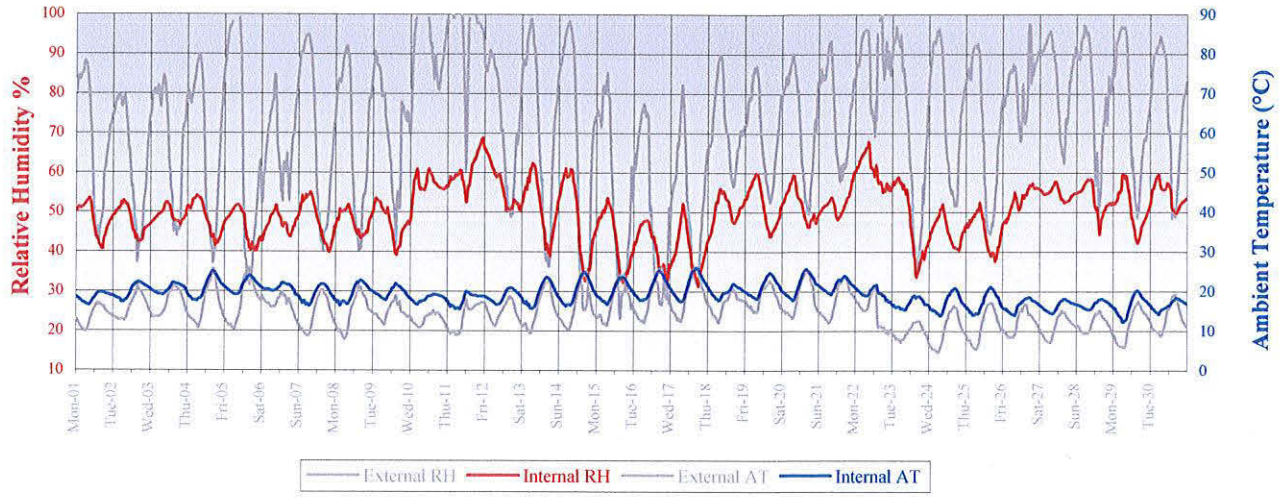


Peterborough Cathedral Nave Ceiling

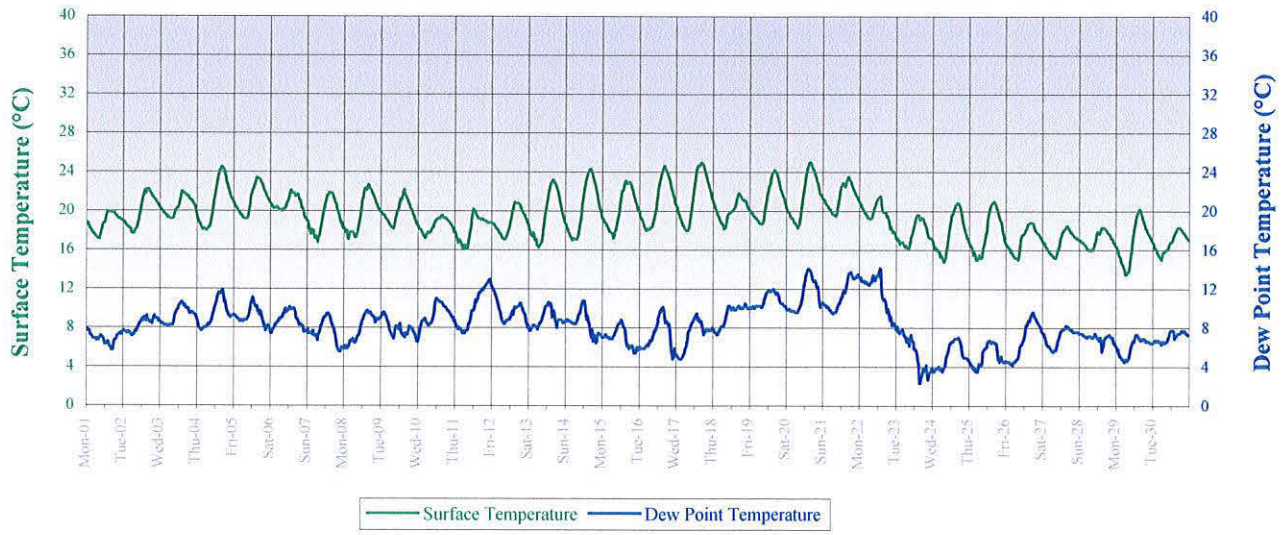
September 2003

Probe 5: Bay 33 III upper side (sun)

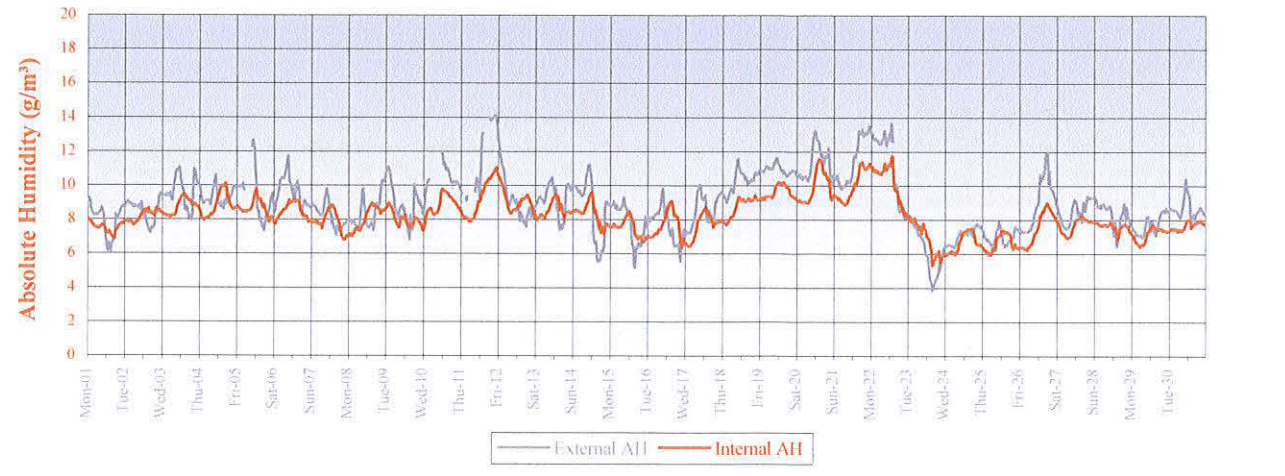
Relative Humidity and Ambient Temperature



Surface and Dew Point Temperature



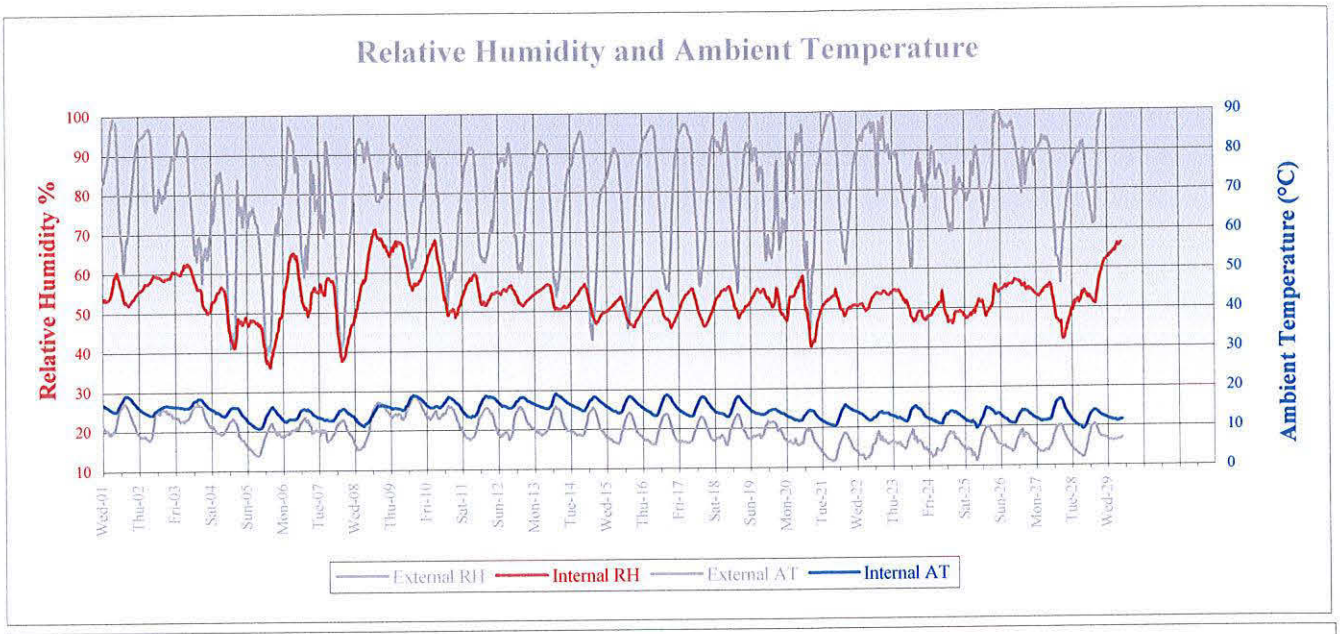
Absolute Humidity

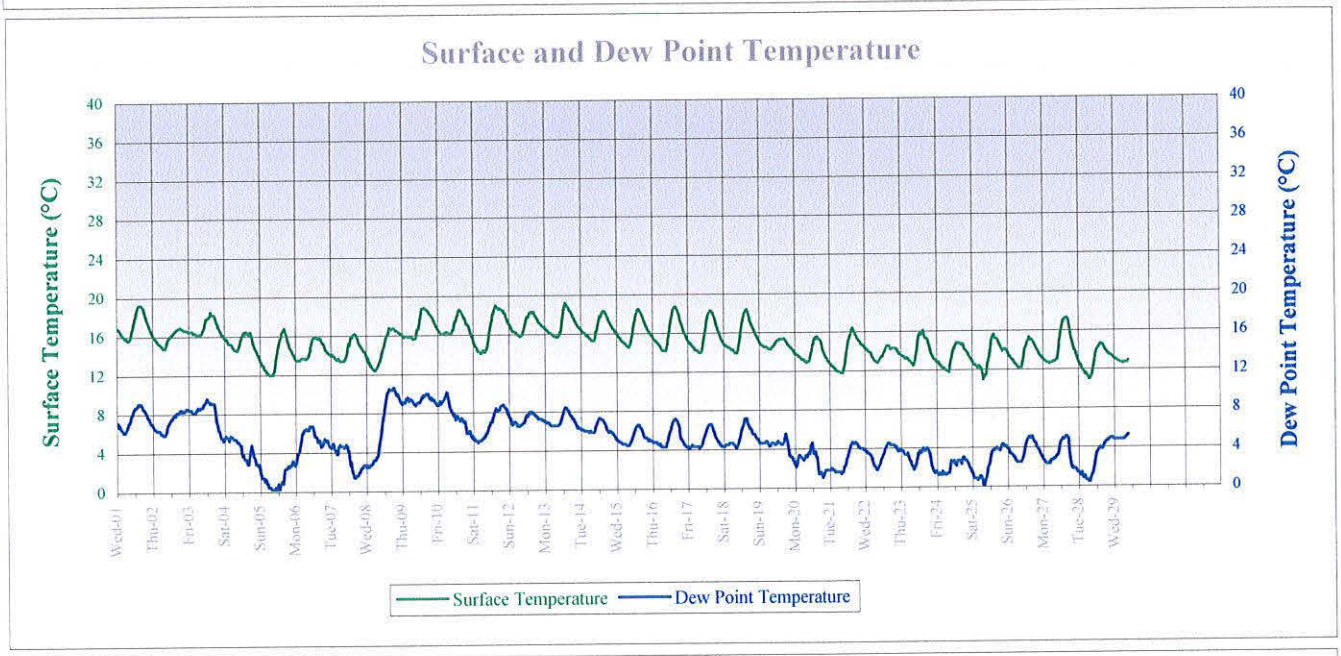


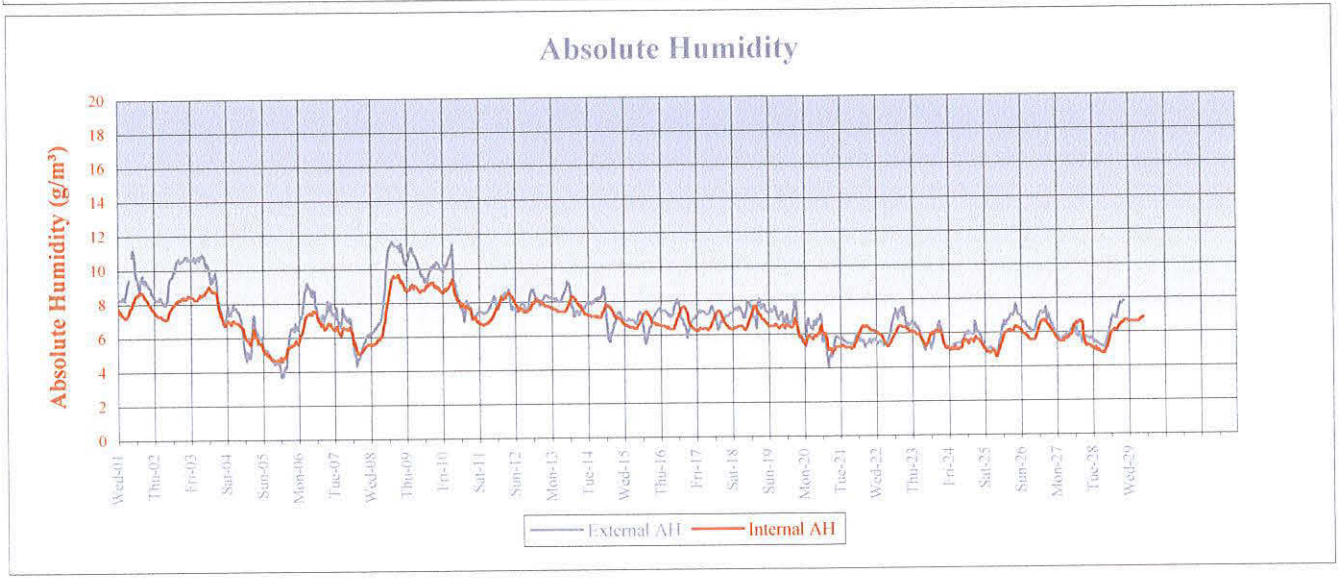
Peterborough Cathedral Nave Ceiling

October 2003

Probe 5: Bay 33 III upper side (sun)

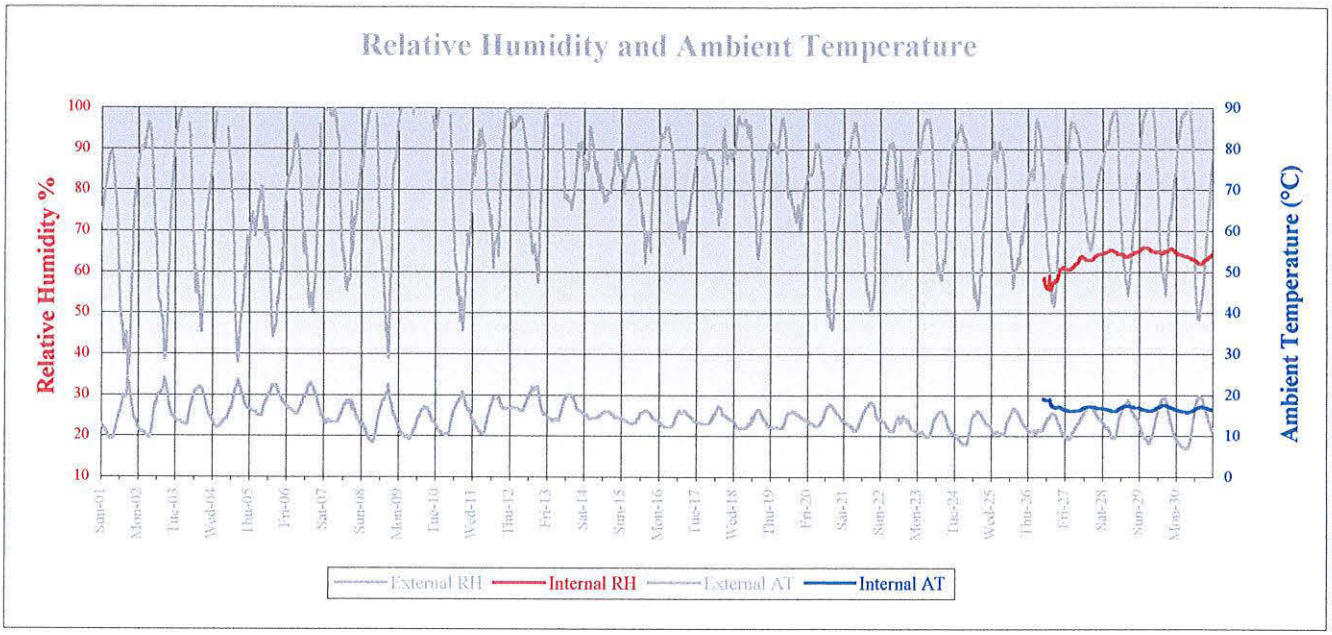


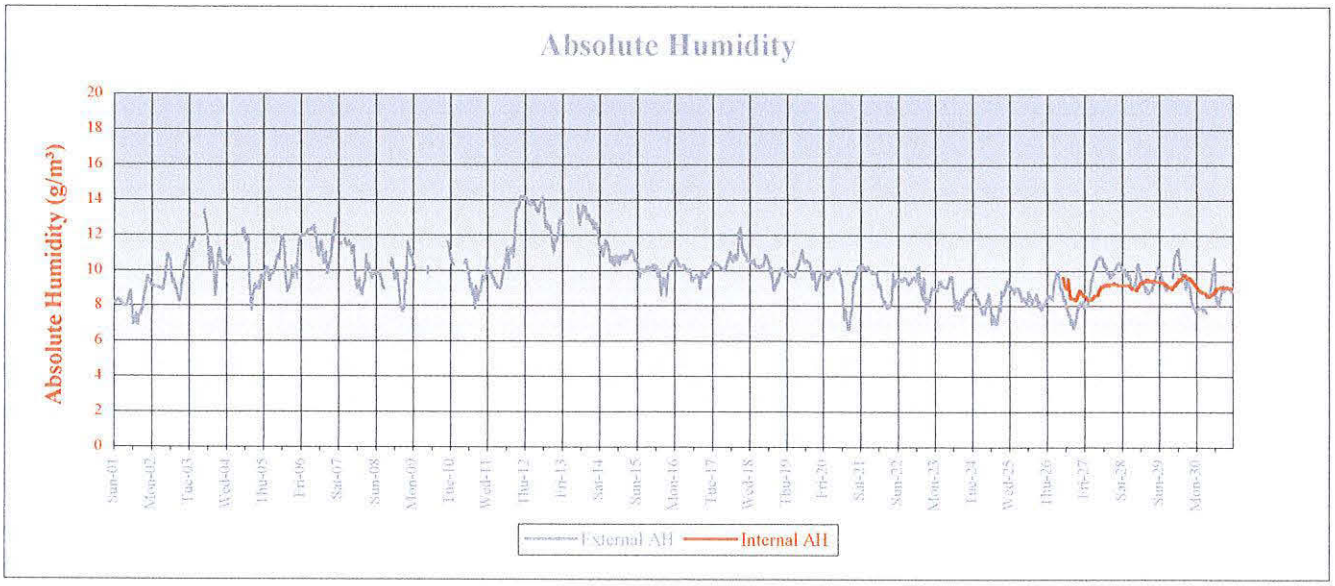


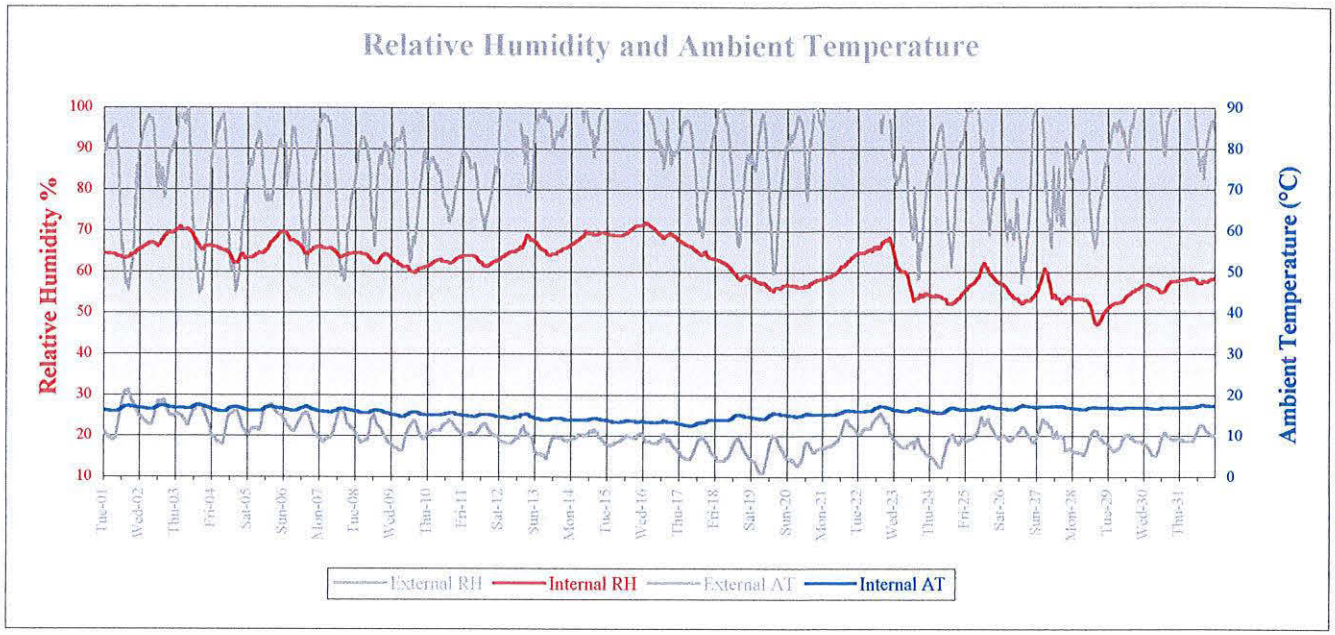


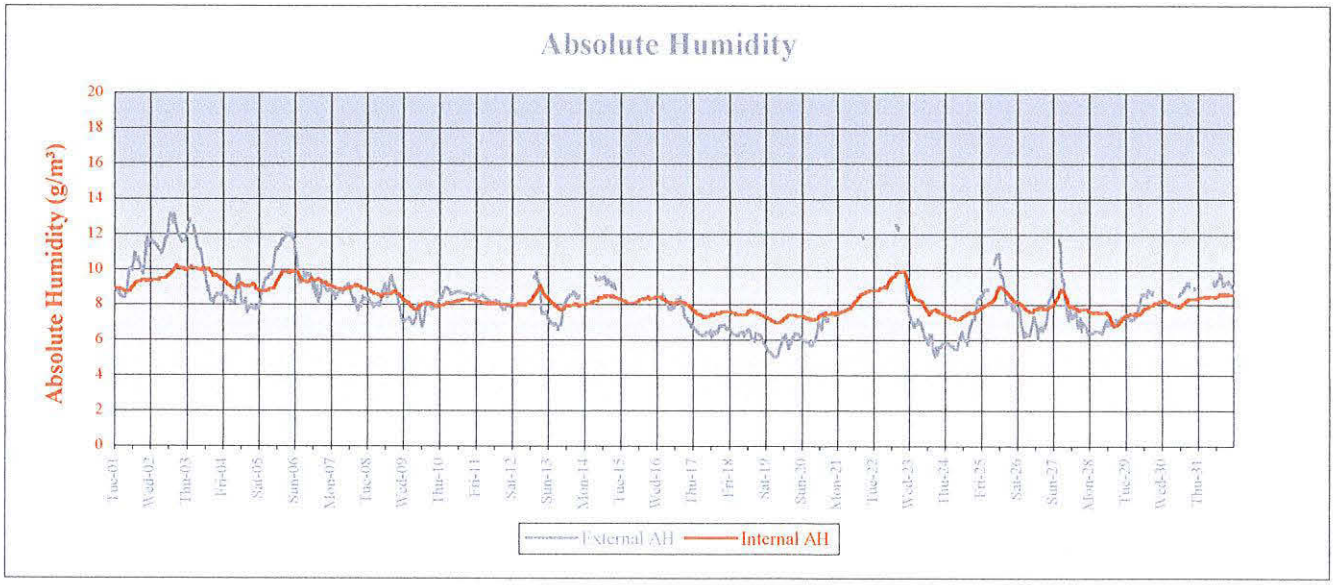
PROBE 8

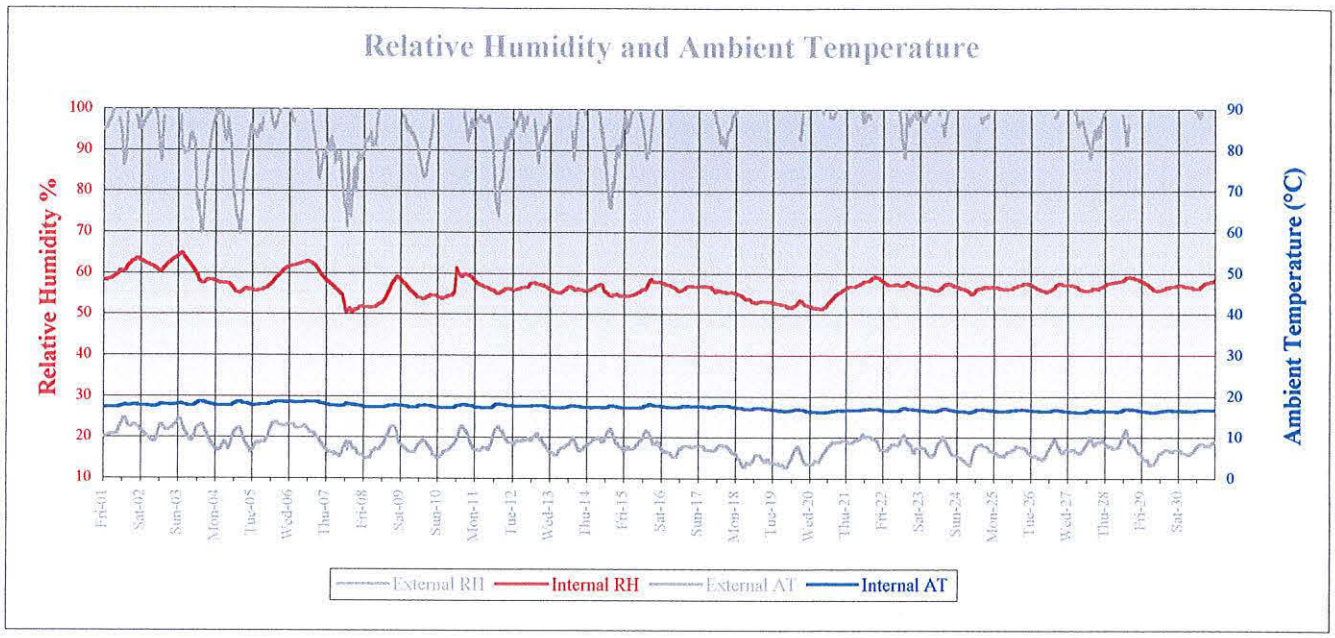
ORGAN CASING

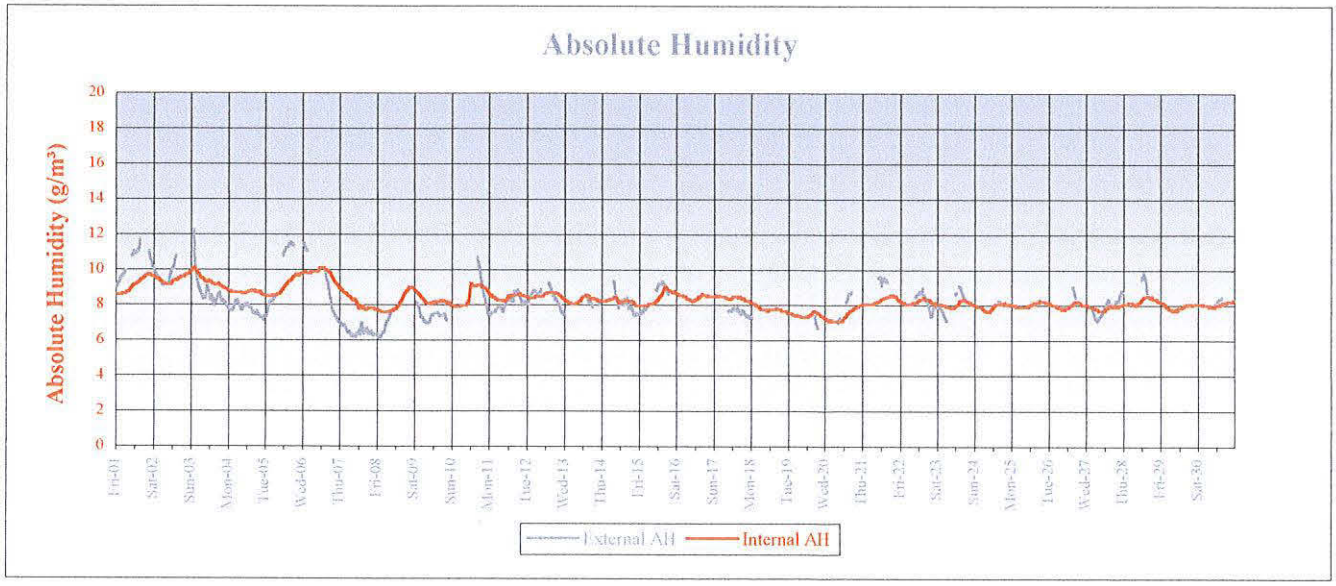

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

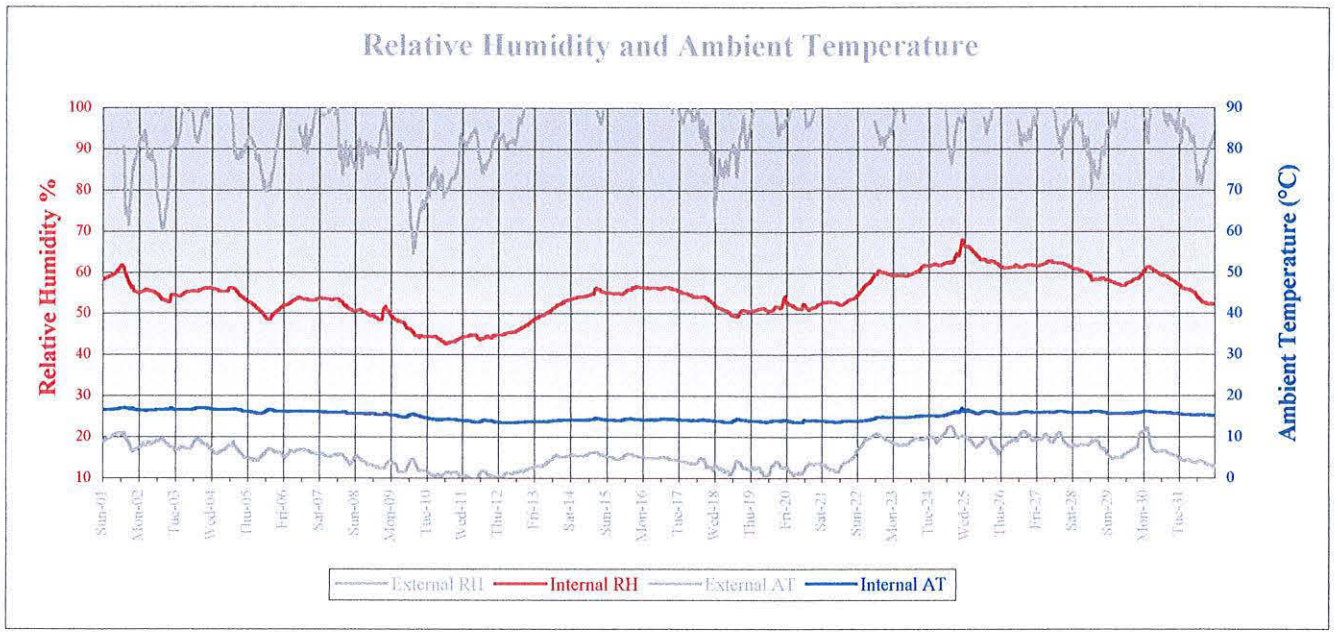

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

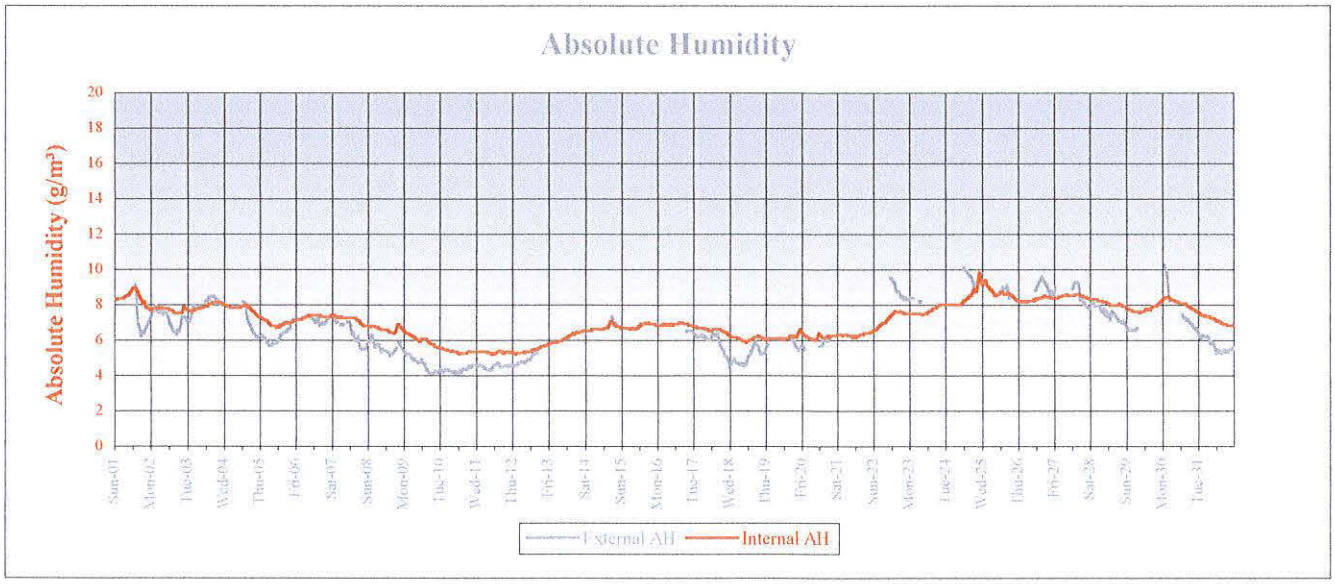

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

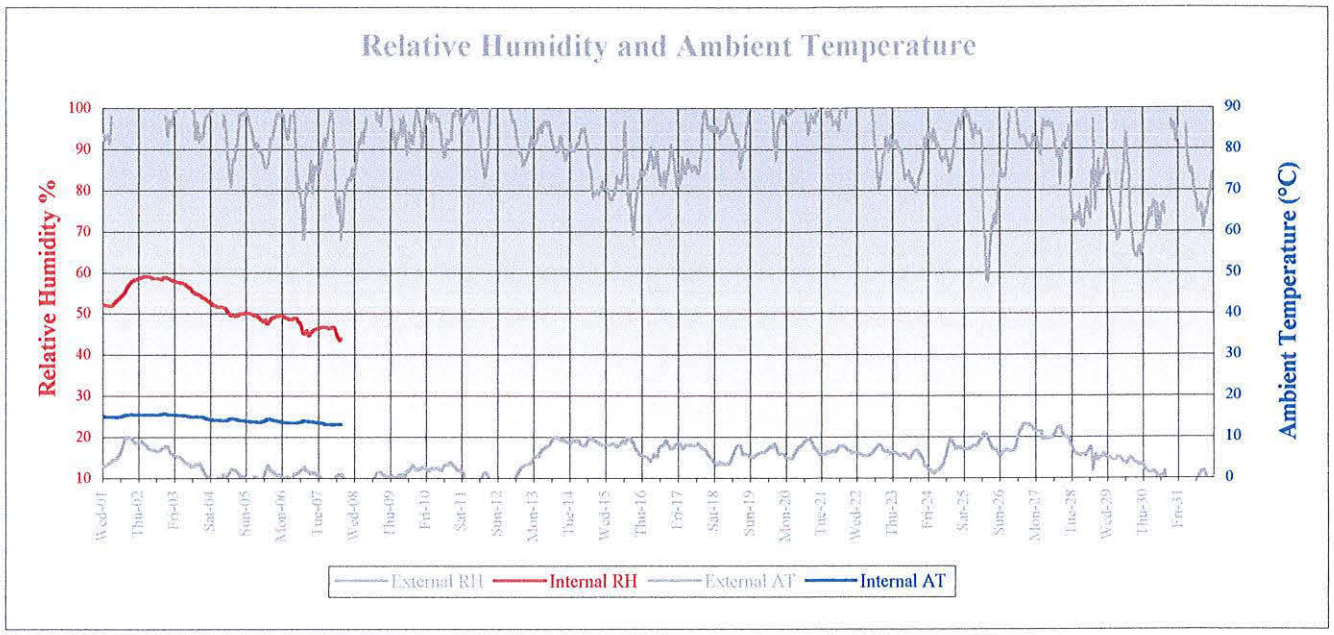

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

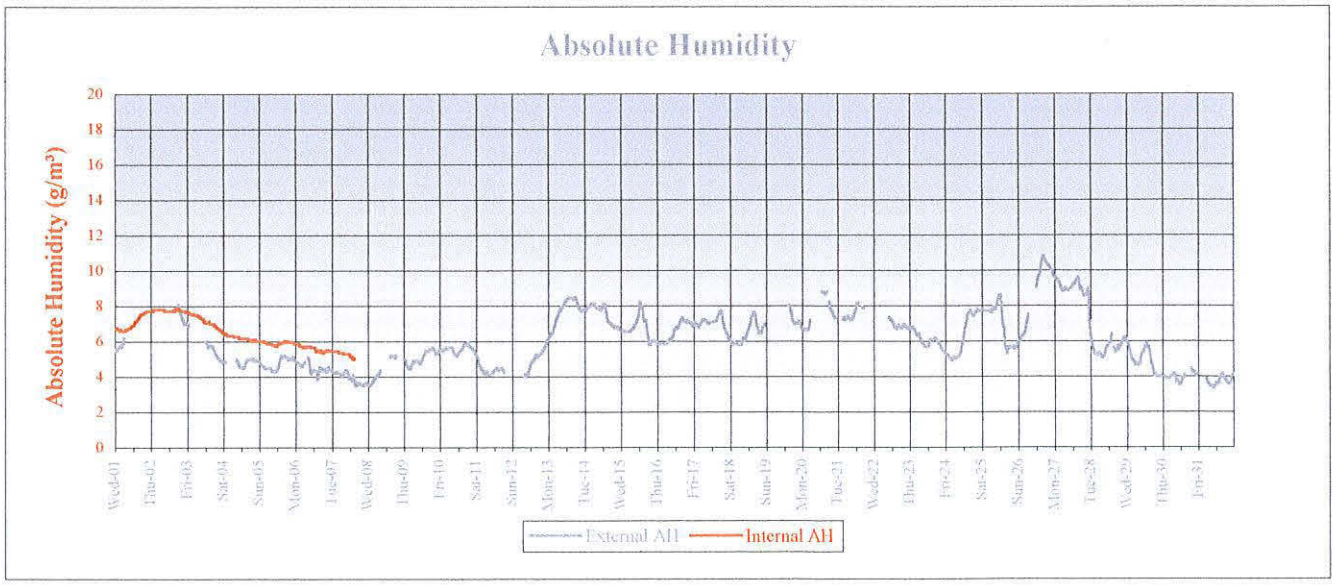

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

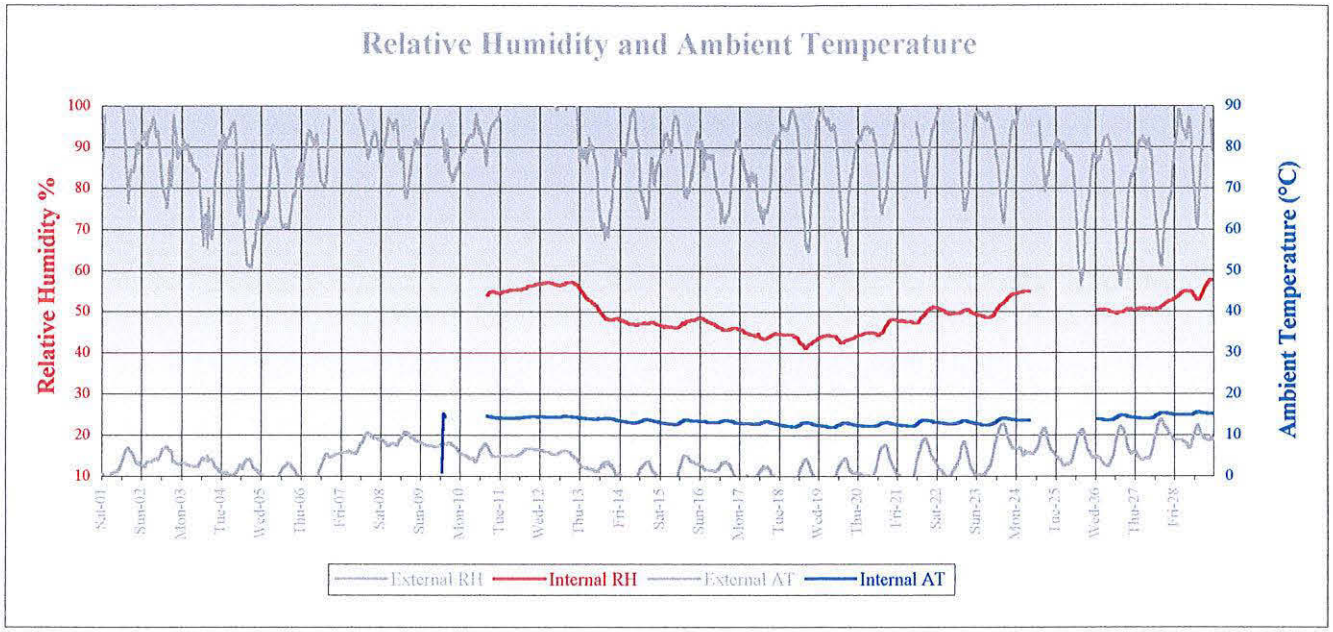

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

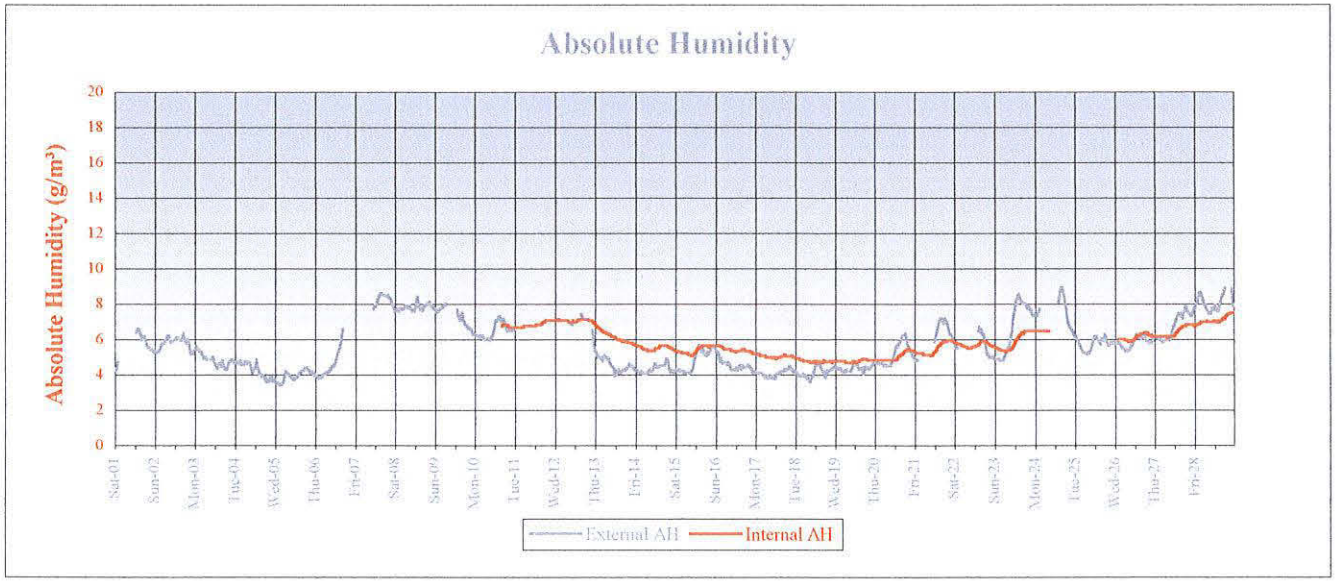

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

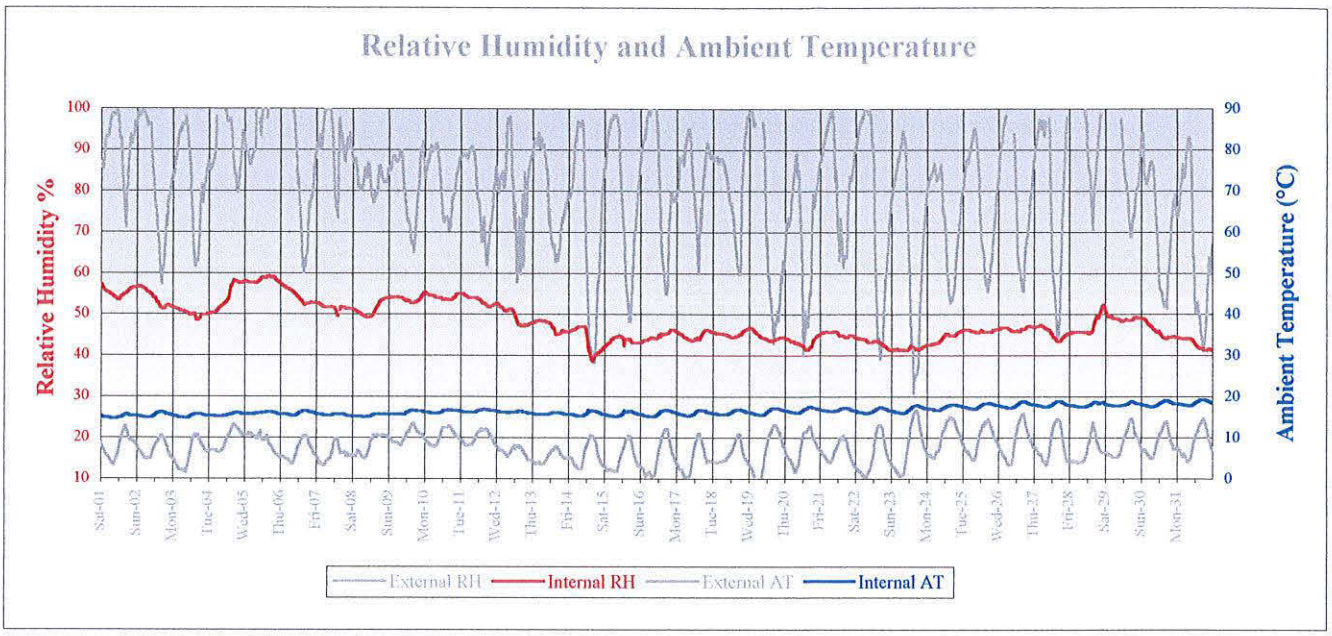

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

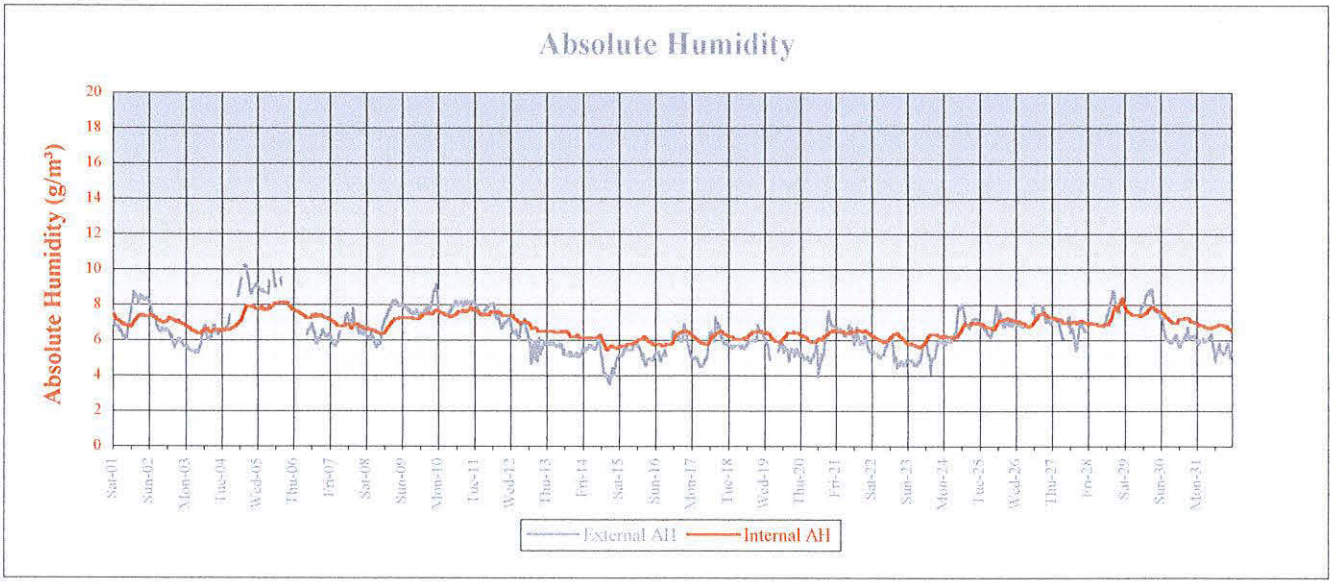

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

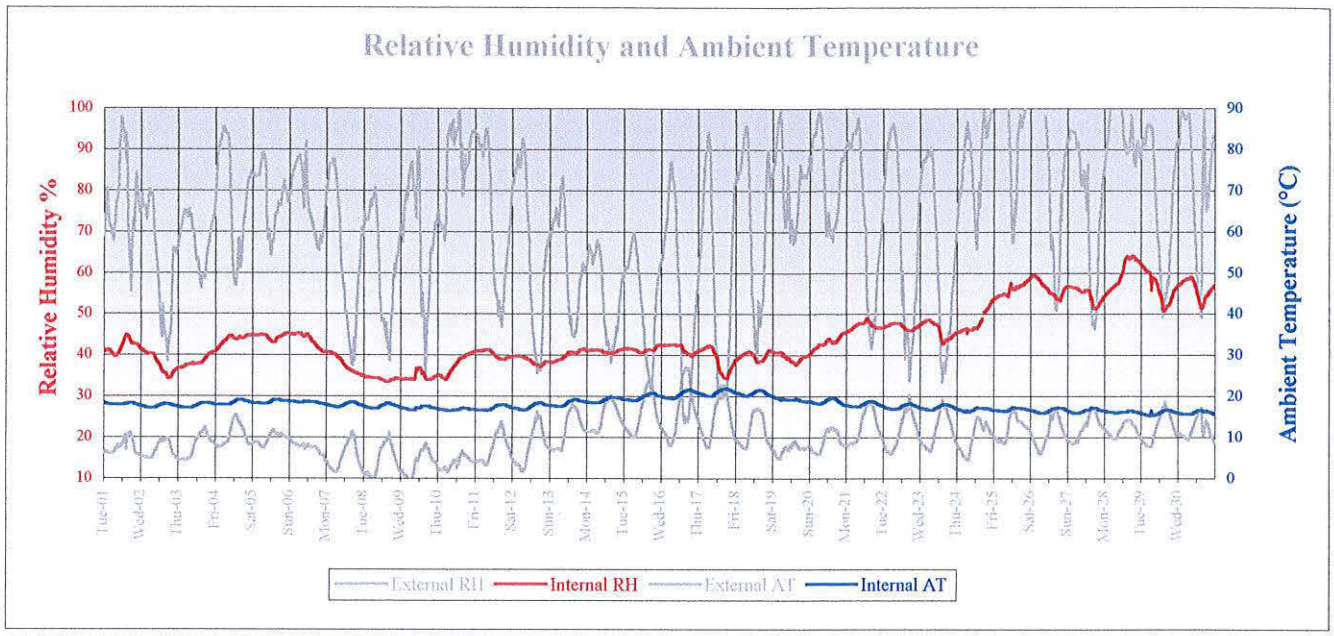

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

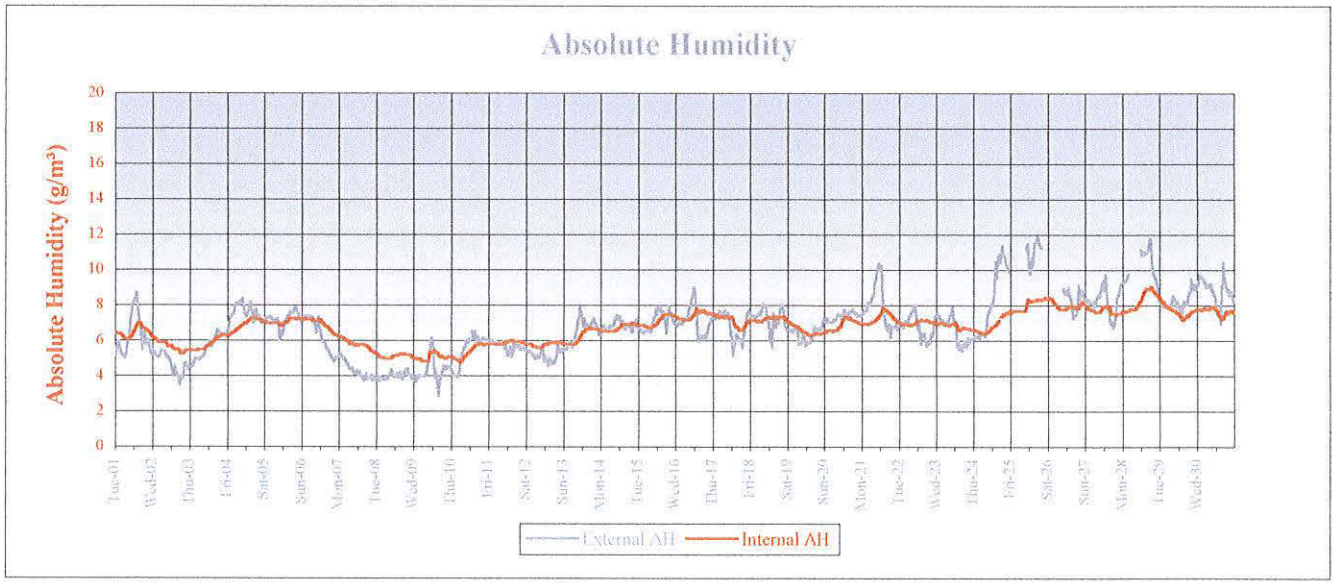

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

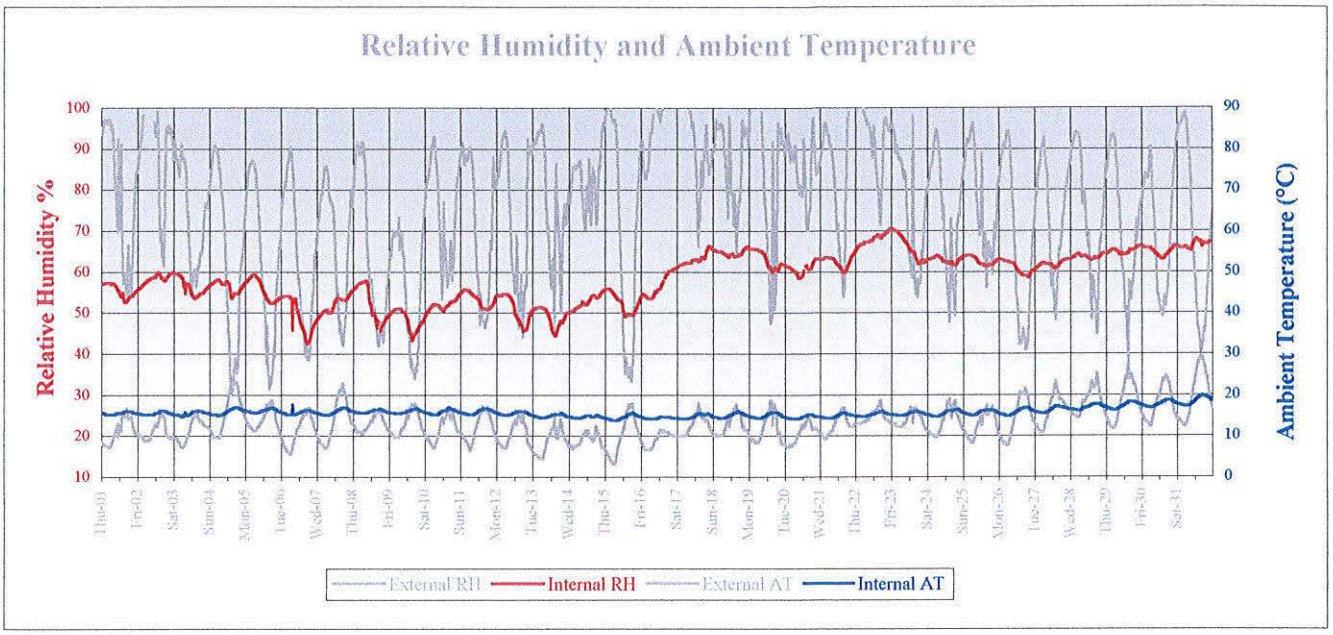

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

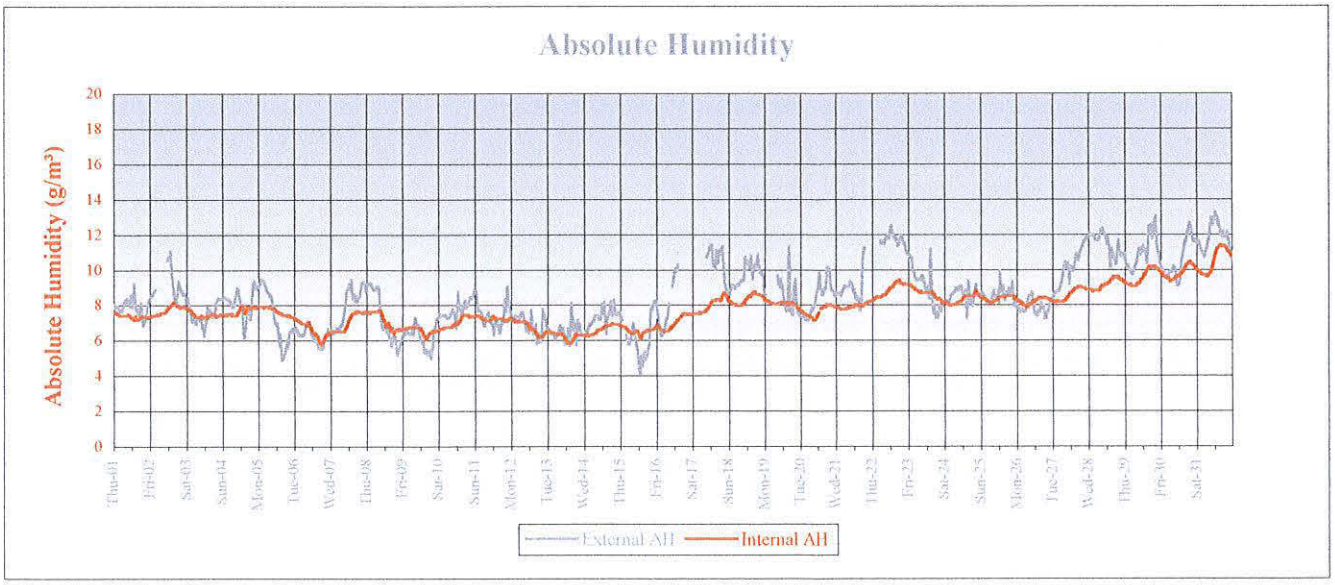

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

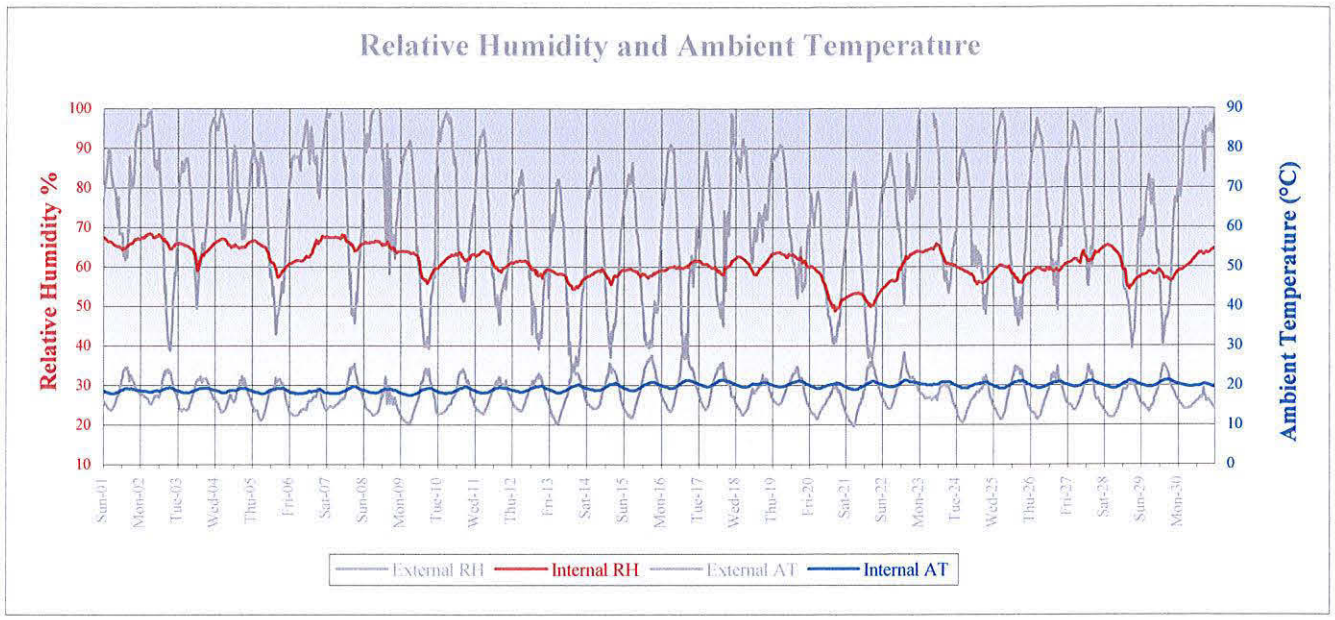

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH

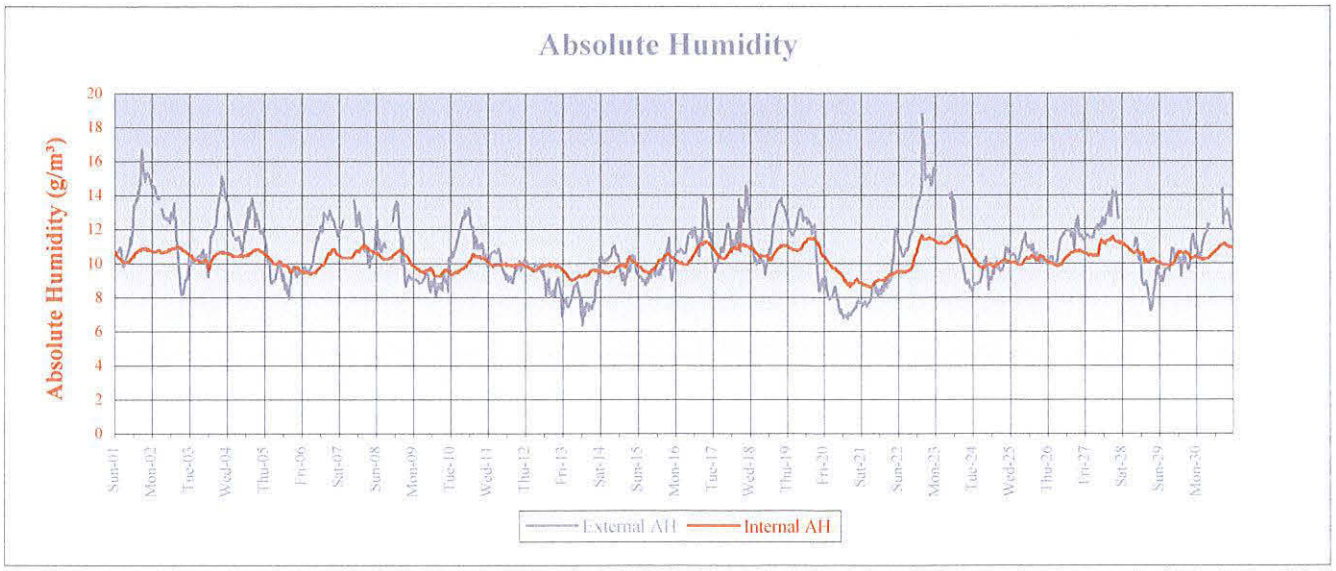

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
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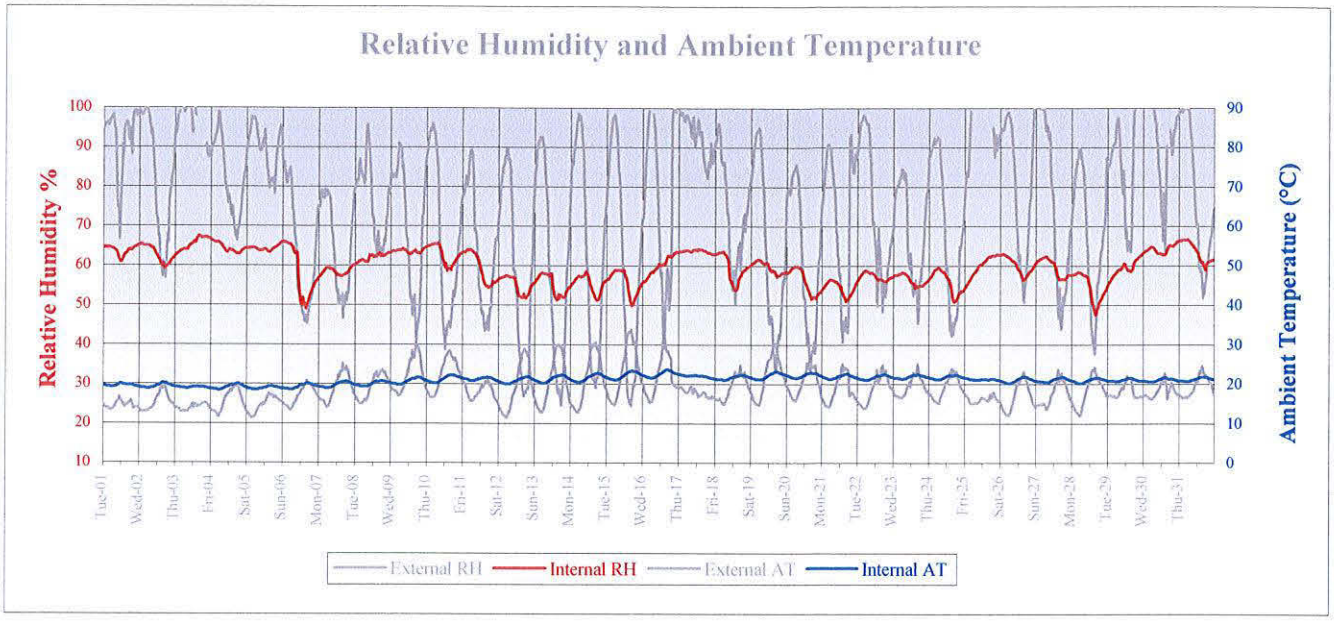
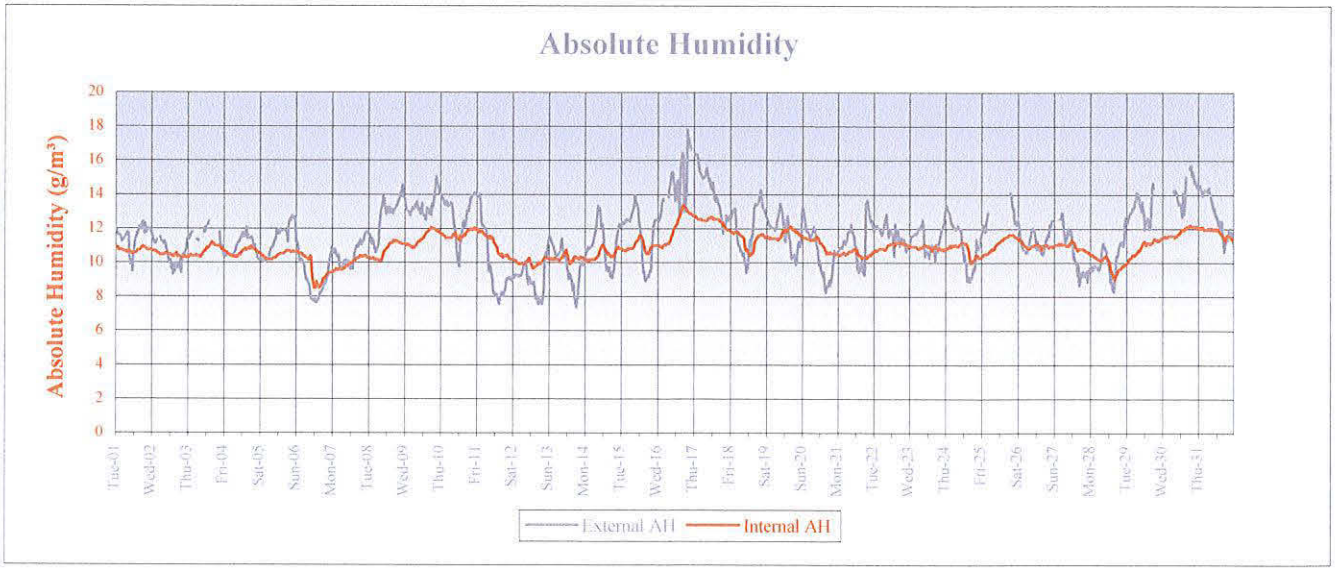
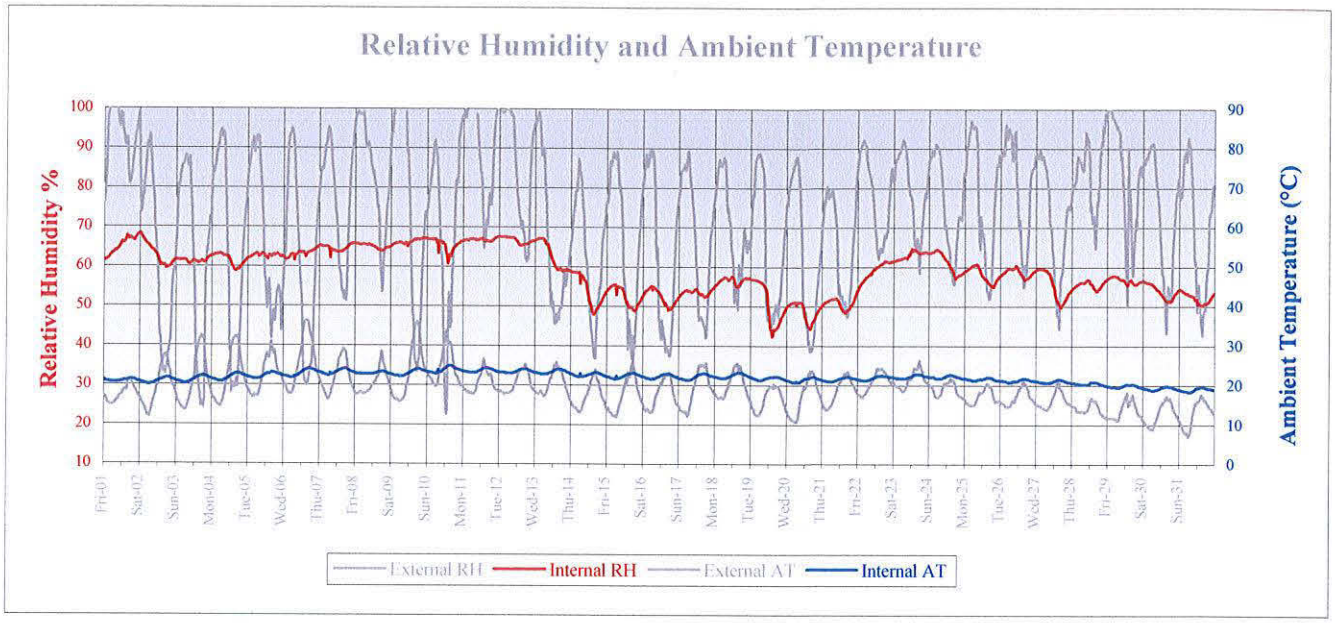
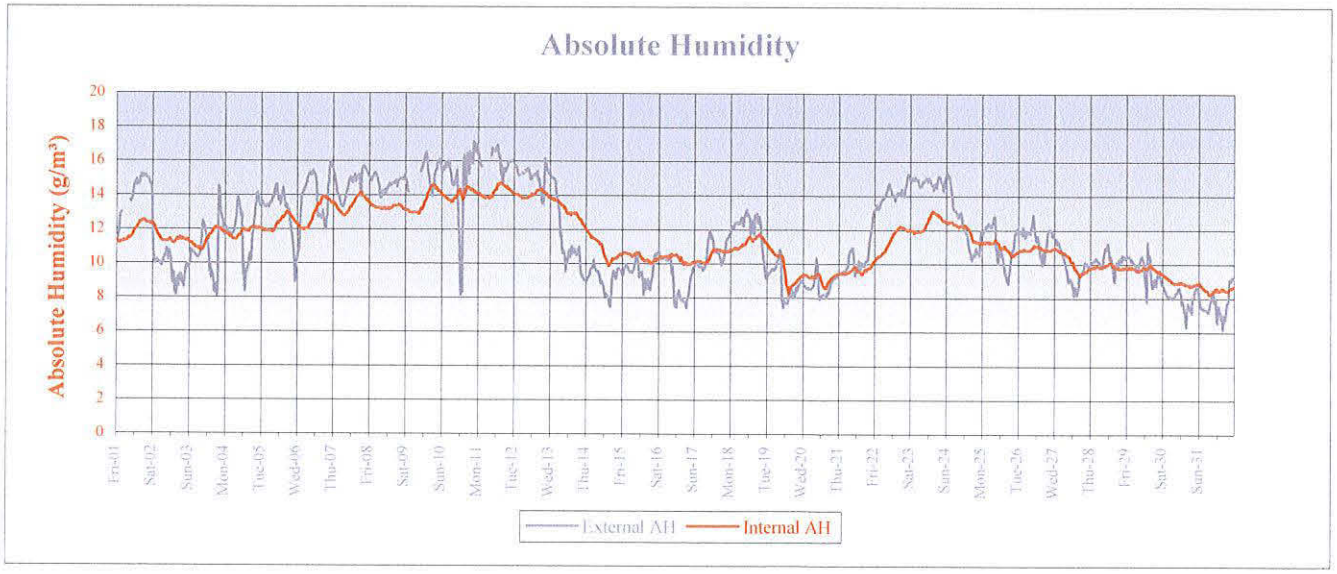
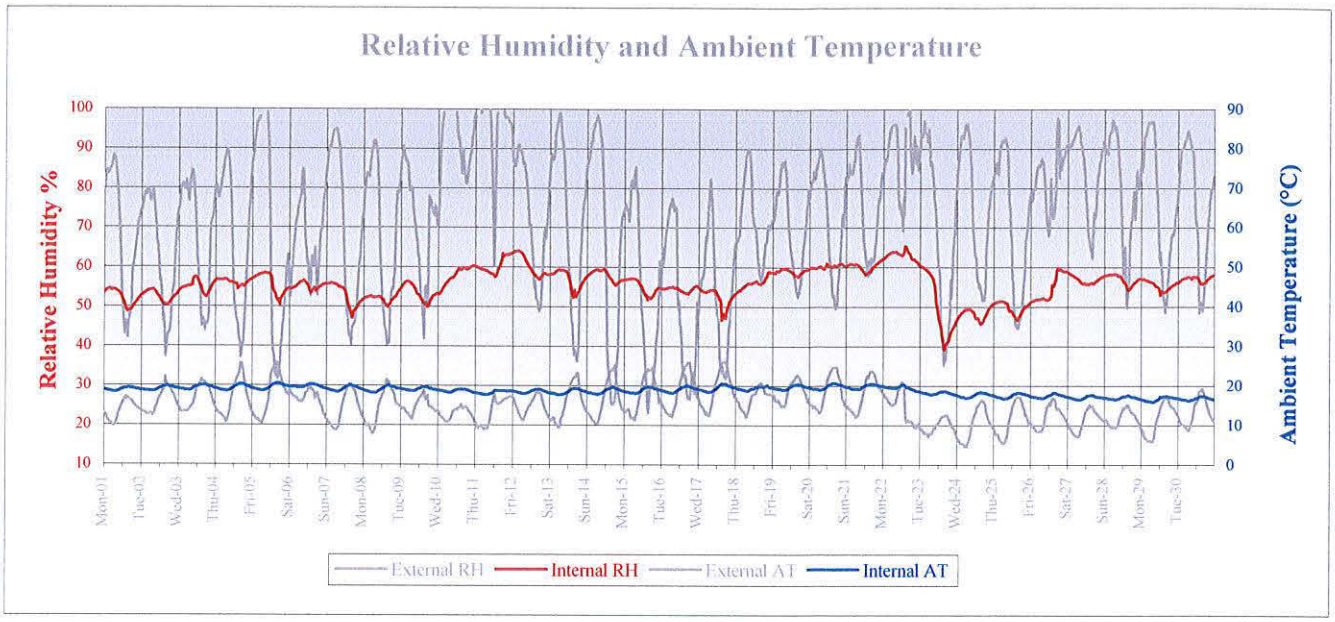
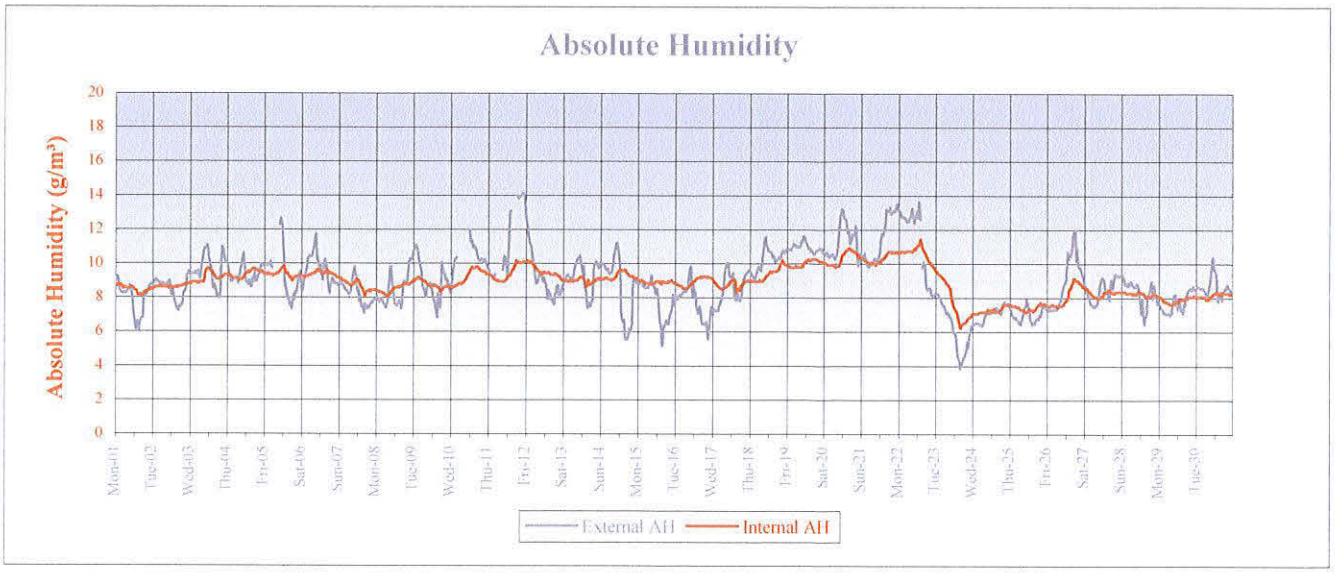

Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT

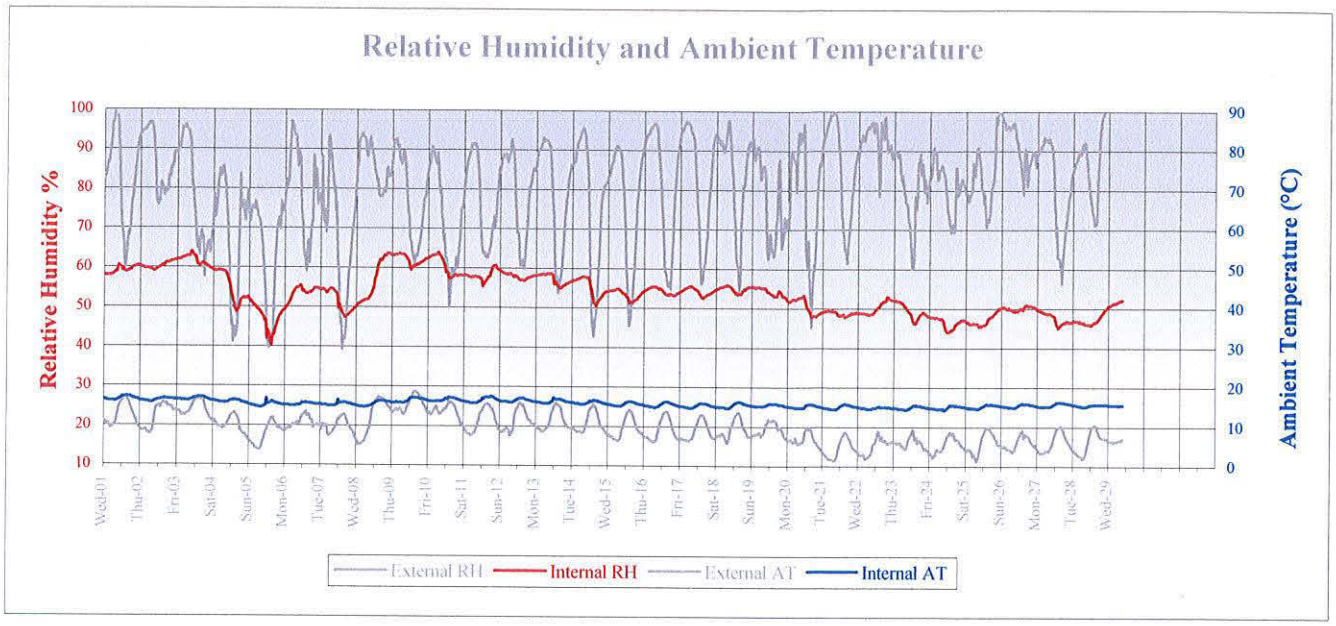

Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH


Relative Humidity and Ambient Temperature
Relative Humidity %
Ambient Temperature (°C)
External RH
Internal RH
External AT
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH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Relative Humidity %
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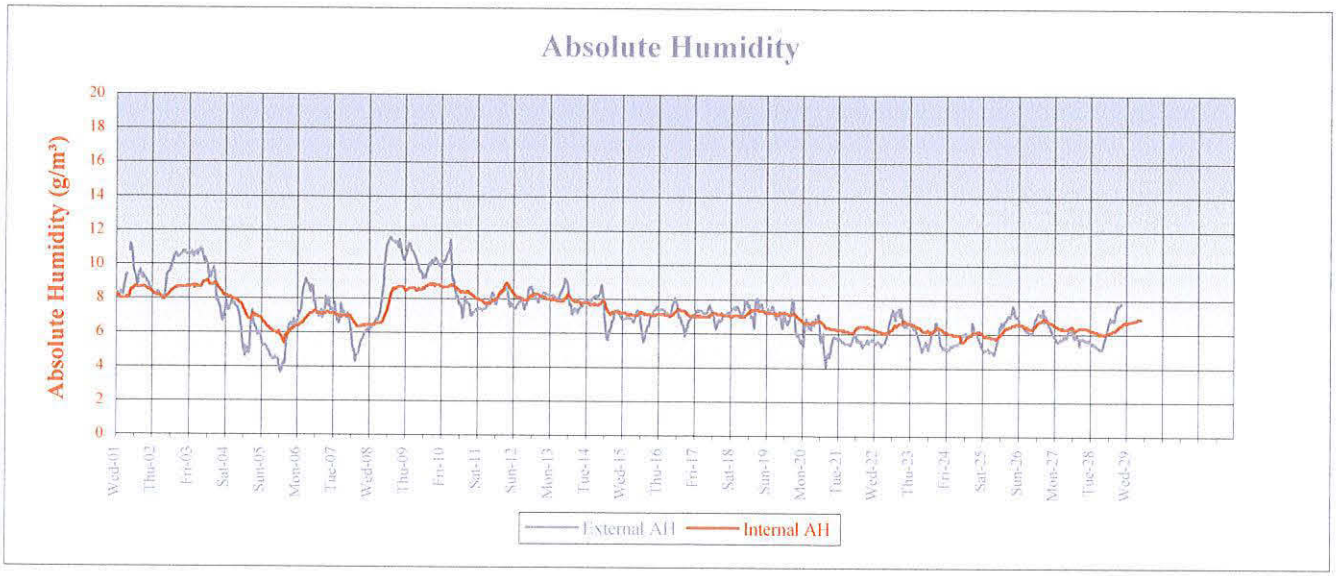
Internal AT


Absolute Humidity
Absolute Humidity (g/m³)
External AH
Internal AH