

# LIBRARIES AND ARCHIVES IN HISTORIC BUILDINGS

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## *ABSTRACT*

The likely effects of major environmental parameters: temperature, relative humidity, light, dust and pollutant gases, have been studied in a range of historic libraries and archaeological archives. Paper lifetimes based on

time weighted preservation indices or cellulose isoperms exceeded those calculated from the maximum temperature and RH allowable under the standard BS5454. Light doses were found to be significantly below those expected from the blind management regime in place. Significant additional damage from light was not measured on the spines of leather bound books, which would be expected to receive the most light. Dust deposition was found to correlate strongly with human traffic, height and gap size between the book tops and the bottom of the shelf above.

## *INTRODUCTION*

English Heritage is charged with caring for the nation's heritage. It manages twelve large historic houses with integral collections. Six of these have significant libraries, some with their original contents. English Heritage also holds over half a million archaeological objects from its approximately four hundred sites and their associated excavation archives. To maximise resources, the long term strategy is to move the archaeological stores out of commercial storage into historic buildings within English Heritage's estate. Close environmental control presents a number of difficulties in an historic building and it is even more difficult in a building open to the public. There is also a growing awareness that the large energy consumption of whole building close-control environment systems is unsustainable. This paper evaluates the preventive conservation of library and archive material in such situations. The major environmental parameters have been assessed in a representative set five historic libraries and three archives. Experimental methods are described in Appendix 1.

Temperature and relative humidity measurements were made both in the rooms and also in several microclimates within the rooms. The temperature and humidity data was used to calculate time weighted preservation indices for the less stable

more modern papers and media. For older books with purer cellulosic papers, the relative lifetimes were based on the isotherms for pure cellulose developed by Zou [1] and the worst conditions allowable under BS5454 [2] (21°C and 65% RH).

Light exposures were measured with radiotelemetry and stand-alone loggers and with blue wool standards. All of the historic house libraries have UV film on their windows and use light plans to set manually adjusted blinds to control the visible light exposure (see appendix 2). Natural light is the major light source, with some lamps used to illuminate dark areas or because they were originally present. The effects of other environmental parameters on the fading of blue wool standards were investigated by exposing them alongside the continuous monitors to compare the real and apparent dose. Extensive research into the light dosimeters developed by the LiDo project has highlighted environmental effects other than light on these sensors and there is some laboratory evidence that this is also the case for blue wool standards [3].

Within a book shelf, the spines of the books generally have by far the greatest light exposure. Whilst manually adjusted blinds can reliably achieve 200lux, suitable for cotton bindings, it is extremely difficult to achieve the 50lux specified for leather bindings [4]. The long term effects of higher light exposures were investigated through analysis of the state of deterioration of the leather.

Since books in the libraries of English Heritage Houses are rarely studied, the main handling of the books is during conservation cleaning. Optimising the period between cleaning is vital, as this activity is a major cause of damage. Another consequence of display rather than use, is that most dust deposition is onto the top edges of the books, followed by percolation down into the pages. The distribution of dust deposition throughout the libraries was measured with particular attention to deposition on these top edges and behind the books.

The ingress of chemical pollutants into libraries and archives has been studied with diffusion tube measurements for sulfur dioxide, nitrogen dioxide and ozone, and modelling of the indoor/outdoor ratios with the IMPACT applet combined with results

from the UK government's continuous monitoring network. Air exchange rates were determined for the library and archive rooms.

Different dehumidification methods were investigated in historic rooms housing archives. The use of heating systems induces temperature and RH distributions across rooms, which were investigated by placing series of sensors through a room. Their effects on the lifetime of paper were assessed from temperature and RH data.

Embrittlement of permatrace film was observed to be a major problem in the archaeological archives and was investigated further. Samples of permatrace were removed from edges containing no information. The type of film was identified with FTIR spectroscopy.

A selection of historic house libraries and archives was studied. They exhibited very different environments (with examples of urban, rural and maritime locations) and different management methods, including automatically and manually controlled conservation heating, comfort heating, dehumidification and high thermal mass. Light was controlled with UV films, neutral density films, manually adjusted blinds and black out blinds with artificial (mainly fluorescent) lighting.

#### *THE HISTORIC LIBRARIES STUDIED*

Audley End House is in a rural environment in Cambridgeshire. It has three adjacent libraries holding over twelve thousand volumes, the earliest dating from 1549. The house is open to the public eight months of the year. Light exposure is controlled by manually adjusting blinds on the UV filtered windows to give 200 lux. Because of the short daily opening hours and closure over winter, this is equivalent to an annual dose of 156430 lux hours. The environment is controlled through conservation heating (RH controlled) via oil filled electric radiators controlled by individual hygostats.

Brodsworth Hall, again in a rural environment, has a much smaller library housed in a single room. The house is open to the public for eight months and closed over the winter. The library has important views of the gardens through the window closest to the books. The light levels in the library are controlled by the application of MT40 neutral density and UV film and lowering the blind only when 200 lux is exceeded. The RH in the library is regulated through a Building Management System

(BMS) controlled water radiator system applying conservation heating.

Eltham Palace is in an urban environment in South East London and is open ten months of the year, closing January and February. The library houses twentieth century books in a single study. Light is controlled by a light plan to 200 lux. The room is heated using hot water panels in the ceiling, controlled by a central thermostat.

The Iveagh Bequest at Kenwood is in another London urban environment. It is open 364 days of the year. The Robert Adam designed library houses two thousand books. The library has large south facing windows with UV filtration. The light levels are controlled manually by blinds on a light plan to 200 lux. The heating is run for human comfort and is a water radiator system run off a thermostat compensated for the outdoor temperature.

Walmer Castle is in a maritime environment. The Duke of Wellington's room is presented as it was in 1854, when he died there. It has a single set of bookshelves covering a damp interior wall. Winter heating is through a water radiator system controlled by a compensated thermostat. Light is controlled by manually adjusted blinds.

#### *ARCHAEOLOGICAL ARCHIVES STUDIED*

Dover Castle holds the archaeological archives of ten sites. The archives are stored in a single room in a 1912 stone building. The archive room is controlled with conservation heating using a manually adjusted electric radiator. The room has black out blinds and filtered fluorescent lighting providing 150 lux at the surface where the archives are studied. Dover has high dust and pollution from the adjacent ferry port and a very high volume of freight traffic.

Atcham store is a modern commercial industrial unit holding the archaeological archives from the very extensive excavations at Wroxeter Roman City. The archive is stored in a metal container unit with a Munters dehumidifier keeping the RH below 60%. The only light sources are UV filtered fluorescent tubes.

Corbridge Roman Museum was purpose built as a museum in the 1980s. It holds the archives from the excavations at Corbridge in a basement store. The high thermal mass of the basement gives stable conditions. The store and study area are lit with filtered fluorescent lamps.

		Proportion of collection			Cellulose lifetime relative to BS5454	TWPI (years)	TWPI relative to maximum values allowed by BS5454	Air exchange Rate (day <sup>-1</sup> )
		<1840	1840-1900	>1900				
Audley end	Library	45	45	10	1.21	46	1.24	6.7
	Behind shelves (4)				1.18-1.24	44-49	1.19-1.32	
Brodsworth	Library	60	40	-	1.23	56	1.51	8.2
	Behind shelves (2)				1.20-1.15	54-57	1.46-1.54	
Eltham	Library	8	19	73	1.77	42	1.14	6.2
Kenwood	Library	29	36	35	1.12	41	1.11	12.4
	Behind shelves (5)				1.09-1.13	38-41	1.03-1.11	
Walmer	Library	95	5	-	0.98	37	1.00	22.4
	Behind shelves (1)				0.81	29	0.78	
Dover	Store	-	-	100	1.21	52	1.41	3.2
	Enclosures (5)				1.11-1.34			
Atcham	Store	-	-	100	1.02	57	1.54	2.1
	Enclosures (5)				0.96-1.23			
Corbridge	Store	-	-	100	1.57	55	1.49	ND
	Enclosures (5)				1.43-1.61			

Table 1; Collections, calculated lifetimes and measured air exchange rates.

## RESULTS

### THERMOHYGROMETRIC LIFETIMES

The time weighted preservation indices and relative cellulose deterioration rates are shown in Table 1. In all but three instances the TWPI was higher and the deterioration rates lower than those equivalent to the maximum values allowed by BS5454 [5]. This is due to the low level of heating used in these spaces.

The relative effect of conservation heating depends on the hygric response of the space. A simple calculation comparing regions of the psychrometric chart with isoperm data for TWPI would indicate that controlling the RH between 50 and 65% by conservation heating would be likely to slightly decrease the chemical lifetime of the paper at the higher RHs and temperatures and slightly increase it at the lower RHs and temperatures. Isoperm data derived from Zou would indicate a slight decrease in chemical lifetime for pure cellulose papers. However, this approach only considered the air and the paper. The internal conditions within a building vary greatly. Some are relatively dry and in that instance the major effect of conservation heating is to reduce temperatures from those expected from comfort heating, hence increasing lifetime. With damp building fabrics, conservation heating can produce positive feedback, driving more water out of the walls and actually increasing the RH (and dramatically decreasing lifetimes). Conservation heating will not work in some circumstances.

When English Heritage acquired Brodsworth hall in 1990, a three year monitoring campaign was undertaken with just low level heating for frost protection in place. This is the minimum level of heating that would ever be considered for an important historic property. The average TWPI and cellulose lifetimes over the heating period (October to May) for the library were 61 years and 1.21. Extensive modelling of the internal environment using the Energy Plus program [6] indicated that with conservation heating with limits of 50 and 65% installed into this (and adjacent) spaces, the figures would be 57 years and 0.98. The average of the monitored data over the past three years with this system in place has been 56 years and 1.47. Hence the conservation heating has decreased the TWPI, but increases the predicted lifetime of pure cellulose. These apparently contradictory results are due to the different balance between the effects of increasing temperature and RH on the two predictions. Since around 60% of the books in Brodsworth's library are likely to be printed on cotton rag paper, the majority of the collection is benefiting from conditions likely to prolong its lifetime.

Only one instance of a significantly different environment behind the books was observed at Walmer Castle. The archaeological archive spaces all had much longer chemical lifetimes. The enclosures used to store the archive material provided very little thermal buffering and some short term RH buffering, but this buffering had little effect on the lifetimes over a longer period. Many records of archaeological excavations are on poor quality paper, prone to rapid deterioration.

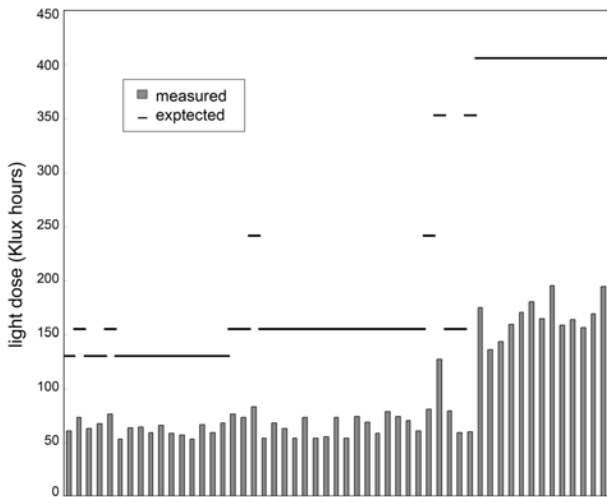


Figure 1. Measured and expected light doses in 52 locations. The expected dose is less than 60% of that expected from the light plan in all instances.

Recent guidelines on archaeological archives now recommend using archival quality material to record the excavation information [7].

#### LIGHT EXPOSURES

The light doses measured in the libraries were all significantly less than equivalent to the specified 200 lux. Individual light measurements were over 200 lux, but the accumulated dose corresponded to a much lower average intensity. This result has very important consequences for the use of light plans. Further data were examined from twenty seven other continuously monitored rooms and another twenty four rooms monitored with blue wool dosimeters. In all instances the dose experienced was under 60% of that laid out in the light plan (figure 1). This appears to verify that the use of natural side lighting controlled by manually adjusted blinds and light plans produces much lower light doses than expected from the light plans. This allows a number of options. The light plans can be retained unaltered, knowing that the doses will be lower than stated. Many historic libraries contain a wide variety of materials included silk, Audley End has silk embroidered furniture and Brodsworth has original silk fronted cabinets. These materials are often more light sensitive and would benefit from a lower dose.

Alternatively, light levels may be increased to produce the doses that have already been accepted at object surfaces. Within English Heritage, all light plans have curatorial input. Low light levels are amongst the most common cause of visitor complaints to historic properties. A five year project

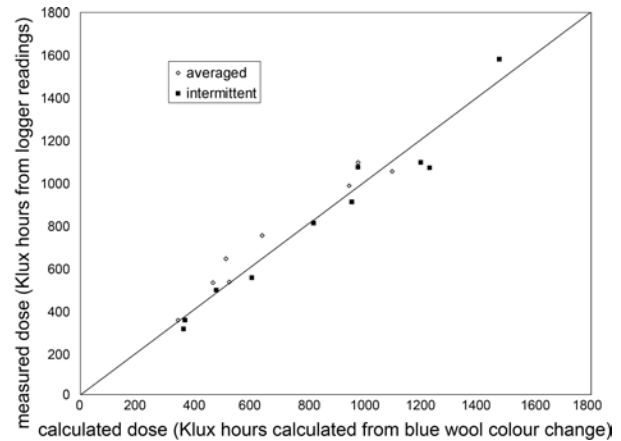


Figure 2. Accuracy of Blue Wool Dosimeter measurements in real situations. The dose calculated from blue wool colour change is plotted against dose determined by illumination measurement for both the intermittent and the more accurate averaged measurements.

is presently underway to determine real fading rates and the rates of chemical damage for silks and wooden furniture.

Comparison of the light doses determined with blue wool dosimeters and using continuous monitoring showed that the variation of the blue wool fading, due to other environmental factors, was approximately 30% (figure 2). The measurement error for the spectrophotometric

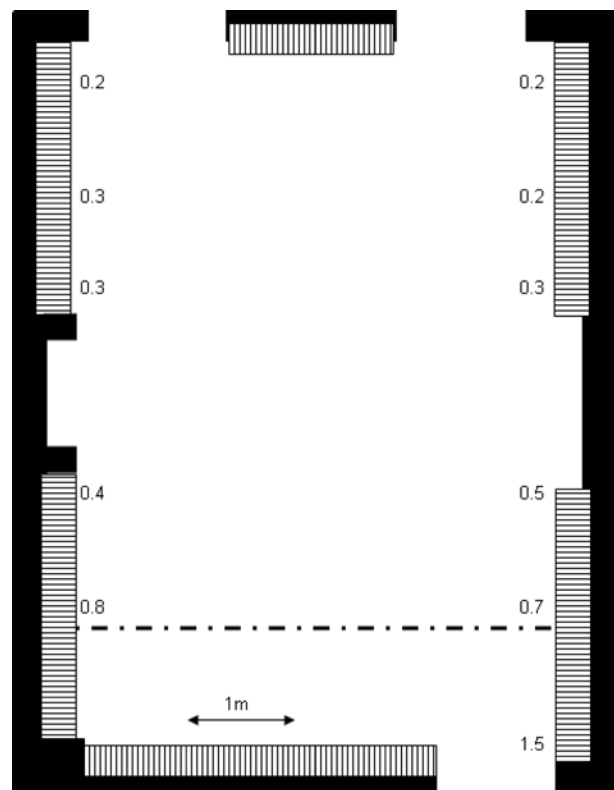


Figure 3. Dust deposition in the library at Eltham House, South West London. The numbers are dust deposition rates measured as percentage coverage of a glass slide exposed for 30 days. The values drop off as the distance from the barrier (marked by dotted line) increases. All measurements were made at 1m height.

determination of  $\Delta E_{76}$  was estimated at 3.5% from replicate measurements. Precise repositioning of the spectrophotometer head was achieved using Melinex masks built into the dosimeters and the view-through facility of the instrument, whilst the orientation of the spectrophotometer head against the blue wool fabric weave was controlled by the dosimeter design. Fitting the  $\Delta E_{76}$  values to the empirical calibration curve derived by Bullock and Saunders will introduce further errors, estimated to give a total error for the measurement and fitting of 5%. The radiotelemetry based light sensors transmit data every hour, so doses calculated from these data for rapidly varying natural light levels will be less accurate than the measurement error of 5%. The loggers used were set to record averaged light levels for the sixty minute logging intervals and the errors in the doses calculated will be predominantly

determined by the measurement error of the light intensity, which was 5%.

Analysis of identical leathers exposed and shaded from relatively high light doses showed no significant increase in deterioration in the libraries studied. Samples were taken from either the same book binding on the spine and light shaded cover; or from known identical samples one of which faced the windows, the other being shaded. Light control was not as rigorous in some properties in the past and evidence of very dramatic fading is present on other parts of the collections, known to have been exposed under those early lighting regimes. Table 2 shows the sets of FTIR, polarised FTIR and moisture regain values. Within the precision of these methods no significant increase in deterioration through light was observed.

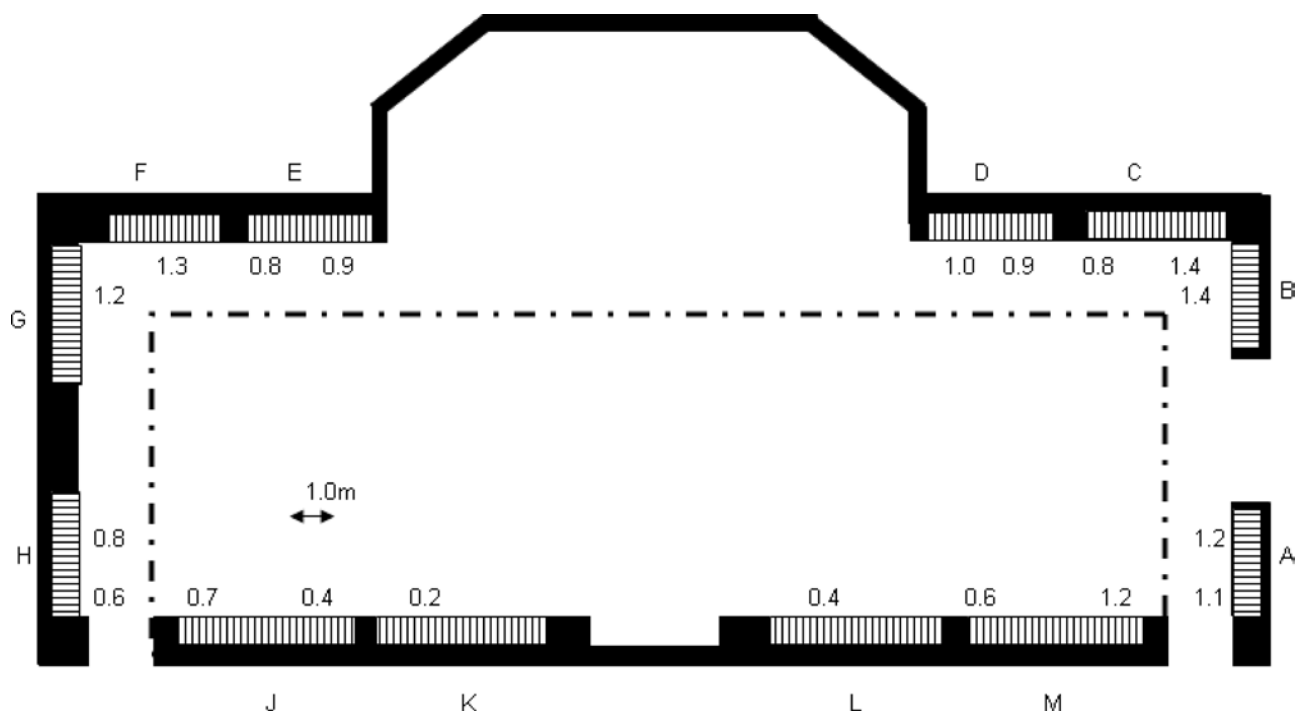


Figure 4. Dust deposition in Great Library at Audley End House, Cambridgeshire. Letters are book case identifiers. Numbers are dust deposition rate measured as percentage coverage of a glass slide exposed for 30 days. Deposition rate is higher at beginning of tour route, bookcase A and where the tour route turns book cases B and F.

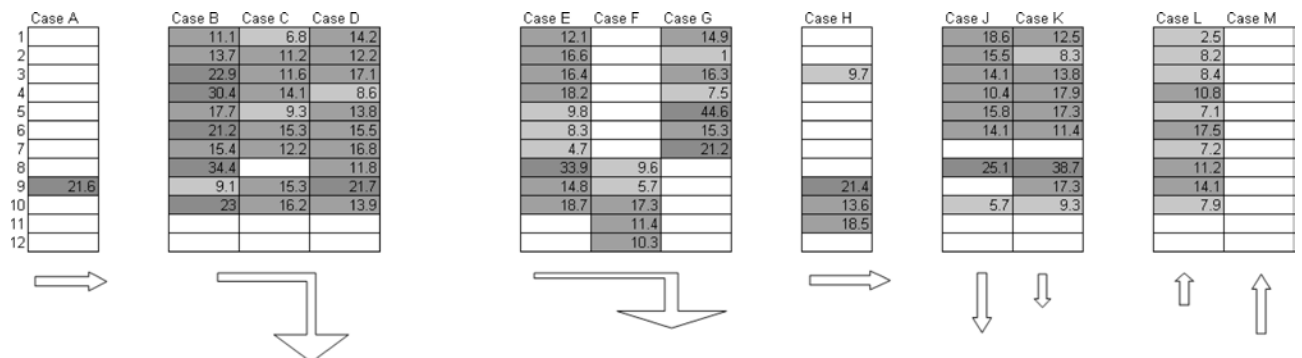


Figure 5. Long term dust deposition over shelves in Audley End House library. The numbers represent the loss of gloss on wooden shelves caused by the deposited dust. The readings are coded as a grey scale to clarify the overall pattern. Arrows represent the tour route. This long term data reinforces the conclusions from Figure 4.

Sample	Date	FTIR	Amide III dichroism ratio	moisture regain (°C)
AEH 1 exp	1821		4.5 ± 0.4	ND
AEH 1 unexp			4.8 ± 0.6	ND
AEH 2 exp	1798	Vw	3.5 ± 0.7	0.84
AEH 2 unexp		Vw	3.4 ± 0.6	0.82
AEH 3 exp	1840		3.7 ± 0.6	ND
AEH 3 unexp			3.6 ± 0.	ND
AEH 4 exp	1798	W	3.2 ± 0.6	1.15
AEH 4 unexp		W	3.1 ± 0.5	1.14
AEH 5 exp	1707		3.6 ± 0.7	ND
AEH 5 unexp			3.7 ± 0.7	ND
AEH 6 exp	1781		3.1 ± 0.5	1.23
AEH 6 unexp			3.2 ± 0.6	1.20
AEH 7 exp	1802	Vw	2.4 ± 0.7	1.44
AEH 7 unexp		Vw	2.1 ± 0.5	1.47
AEH 8 exp	1789		3.6 ± 0.4	ND
AEH 8 unexp			3.7 ± 0.5	ND
Kenwood false exp	1950-70	ND	ND	1.37
Kewood false unexp	1950-70	ND	ND	1.39

Table 2; Leather deterioration measurements with FTIR and moisture regain. See the appendix for an explanation of the measurements.

## DUST DEPOSITION

Dust deposition in the open parts of libraries followed patterns previously observed in other display rooms [8]. The dust deposition dropped exponentially with distance from the tour route (figure 3). It was highest at points where the tour route turned corners (figures 4 and 5). The vertical deposition profiles on the front edge of shelves had maxima at low level and at approximately 1m (figure 6). The ingress of dust behind the books and its deposition onto the top book edges could be defined as two different types of behaviour, determined predominantly by the gap between the top of the books and the shelf above. With a gap greater than about 20 mm, the profile along the

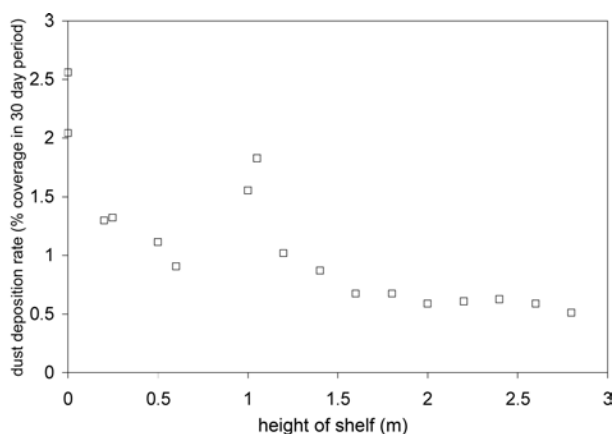


Figure 6. Dust deposition in the library at Brodsworth House, Yorkshire plotted against shelf height from floor. Glass slides were placed on the front of the shelves and the percentage coverage of deposited dust measured after 30 days. There is a maximum near floor level, with a second maximum at approximately 1m height and then a diminution. Heights were limited by available shelves.

top edge dropped approximately linearly (figure 7). With smaller gaps, the profile has a more exponential character. Dust did not penetrate as deeply and dust deposition levels behind the books were much lower. Dust deposition levels behind books are of critical importance when book shelves are on wet walls, as a higher RH microclimate can develop behind the books, as at Walmer Castle. These higher RHs encourage cementation of the dust, bind it more strongly to the paper and mean that more aggressive cleaning methods are required for its removal. Comparative values are given in Table 3.

Dust deposition in the archaeological archive rooms follows very different patterns, as it is not dominated by

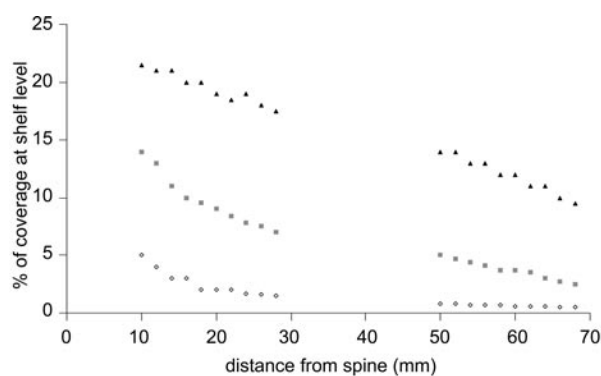


Figure 7. Dust deposition onto the top edges of books with different gap sizes between the top of book and the shelf above. Glass slides were placed along top edges of books and analysed after 30 days exposure. Dust deposition is expressed as a percentage of that occurring on the shelf at the front of the book to account for different positions of books within a library. Two different behaviours are observed, with larger gap sizes showing almost linear decay, whilst smaller gap sizes show more exponential decay.

Location	Dust Deposition Rate Range Overall (%/30days)	Dust Deposition Rate Range Adjacent to tour route at 1m height (%/30days)
Audley End House Library	0.20 - 1.83	0.62 - 1.76
Brodsworth Hall Library	0.48 - 1.45	1.04 - 1.45
Eltham Library	0.20 - 1.51	0.98 - 1.51
Kenwood House Library	0.67 - 2.05	1.34 - 2.05
Walmer Library	0.75 - 4.56	0.95 - 4.56
Dover Archive	0.04 - 0.33	0.04 - 0.33
Atcham Archive	0.03 - 0.25	0.03 - 0.25
Corbridge Archive	0.04 - 0.12	0.04 - 0.12

Table 3; Dust Deposition Rates Measured in Historic Libraries and Archives. Right hand column is subset of results attempting to standardise measurements and take into account effects of distances from visitors and height.

Location	Pollution Concentration Range (ppb)		
	Sulfur dioxide	Nitrogen dioxide	ozone
Brodsworth external	0.75-0.98	4.50-6.56	25.3-33.8
Brodsworth library	0.26-0.61	3.70-4.25	0.98-1.39
Kenwood external	1.21-1.81	34.2-44.7	16.4-33.4
Kenwood library	0.26-0.62	5.08-6.54	0.68-1.25
Kenwood behind books	0.23-0.64	4.70-5.98	0.53-0.98
Dover external	2.43-3.23	6.54-8.65	12.80-14.67
Dover archive room	0.20-0.41	0.20-0.41	0.99-1.53

Table 4; Pollution Measurements in Libraries and Archives

coarse dust from visitors. Even the archive at Dover, which suffers particulate pollution from the nearby ferry port and associated heavy diesel traffic, has very significantly lower deposition rates than any of the historic libraries.

#### POLLUTANT GASES

The pollutant gas concentrations are shown in Table 3. The archives had lower pollution concentrations due to their much lower ventilation rates. The results of the IMPACT modelling from the Dover archaeological archive are shown in Figure 8. As can

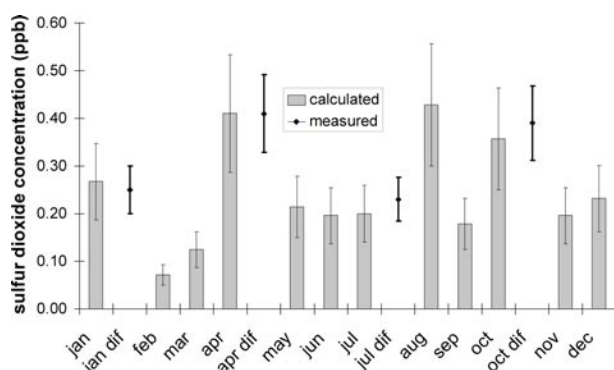


Figure 8. Pollution modelling and measurement in the Archaeological Archive Room at Dover Castle, Kent. Sulfur dioxide concentrations were calculated from the IMPACT applet, the measured air exchange rate of the room and external measurements from Dover Port authority monitoring station. Internal measurements were by diffusion tube.

be seen the model produced reasonable agreement with the measured values. Setting reasonable limits for pollution concentrations for papers is complicated by the fact that their response varies by a factor of over 100 depending on manufacture [9]. The indoor/outdoor ratios for the archive are comparable to the values quoted for filtered air conditioned buildings [9]. The libraries perform well with ozone, but much less so for nitrogen dioxide and sulfur dioxide. However, in those locations the external sulfur dioxide concentration was low, due to Brodsworth Hall's rural setting and Kenwood House being set back in its grounds.

#### CONCLUSIONS

Several authors have argued that standards for archives and libraries based on physical response are unnecessarily prescriptive and often do not address the fundamental issue of chemical decay of the paper and associated materials [2, 10]. The relatively little handling of books in libraries in historic houses, is an extreme case and standards based on physical response are largely irrelevant. The chemical lifetimes calculated from extensive monitoring are actually lower in most cases than the lifetimes predicted from the maximum allowed temperature and relative humidity under BS5454.

The light doses measured in rooms with blinds controlled manually to a light plan have been found to be significantly under the levels anticipated from the plans. This has been confirmed in a large number of cases. This allows a number of approaches, from increasing the figures on the plans to achieve the desired doses to retaining the lower doses and accepting the impairment of visitor experience.

Dust deposition is of critical importance as it drives the most damaging handling process that the books undergo: cleaning. The general principles of distribution of dust from visitors have been confirmed to operate in historic libraries. Different mechanisms of dust penetration into book shelves have been observed, controlled largely by the gap above the books.

Gaseous pollution also causes chemical damage. Sulfur dioxide concentrations were low, even in highly polluted sites. The effect of the oxidising pollutants nitrogen dioxide and ozone is less studied and it is difficult to interpret the likely effects of the concentrations measured. The ratios against the outdoor concentrations appear to be comparable with figures published for chemically filtered buildings.

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### *APPENDIX I: METHODS*

Temperature and humidity was monitored with a Meaco radio telemetry system over a number of years. The temperature and relative humidity behind the books on the shelves was monitored for a one year period with either the Meaco radio telemetry system or Hanwell Humbug data-loggers. The temperature and RH in several types of enclosure used for archives was monitored and simple models developed and tested to relate this to the room environment.

The light exposures were monitored with either Elsec light monitors connected to a Meaco radio telemetry system, Hanwell luxbug data-loggers or blue wool standards. The calibration of the electronic loggers was checked before the measurements against a commercially calibrated probe using a daylight source.

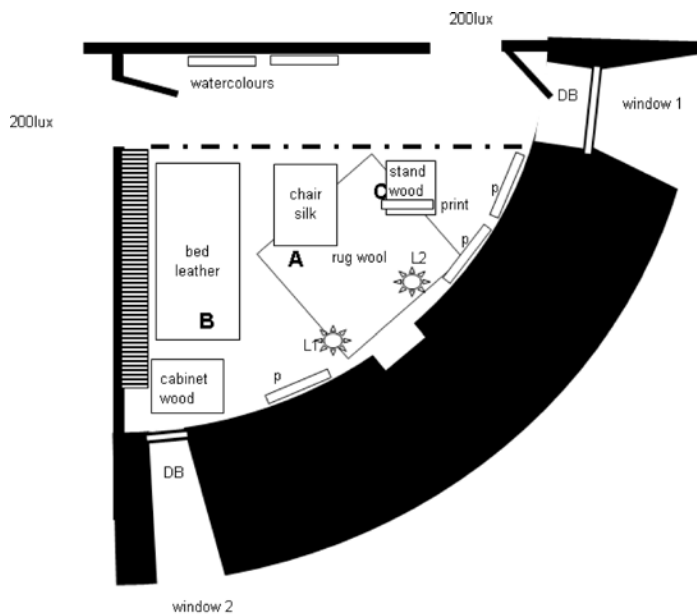
Small samples of leather were taken from damaged bindings of books that had very high light exposures in their past. Both sides of the samples were analysed with Fourier Transform infra-red spectroscopy using a diamond attenuated total reflectance accessory. The samples were taken from the lower fore-edge of the binding, such that the outer face would have had a much greater light exposure than the inside face. Large changes in the leather structure can be determined from the overall spectrum [11]. Analyses of the dichroism of the amide III bands of single fibres gives a much more sensitive probe of the state of deterioration of the leather [12]. Eight fibres residing mainly on the surface were taken from the back and front of each sample for this analysis. Moisture regain measurements were taken on eight books by measuring the surface temperature rise of the spine and one sleeve as the RH

was raised from 40% to 70% inside a showcase using preconditioned artsorb [13]. The surface temperatures were measured with PT100 sensors attached to ACR SR008 loggers. Similar measurements were taken in situ on two contemporary leather false book panels using a humidifier to control the RH under a plastic tent. Series of book spines were assessed similarly using an Infotronics thermal camera to measure the evolution of surface temperature of a large number of books simultaneously.

Dust was monitored by exposing clean glass slides and measuring the amount of dust deposited using microscopy and image analysis [14]. Slides were exposed on the book shelves, on the top edges of the books and behind the books on the shelves. The slides on the top edges of the books were analysed to determine the pattern of dust deposition with distance from the spine. One of the libraries had not been cleaned for two years and attempts were made to determine the long term deposition rate. A Gepruft Tri-microgloss M gloss meter was used to take measurements at 60° on each book shelf in the library, that portion of the shelf was then cleaned with a microfibre cloth and the gloss re-measured at exactly the same point. The increase in gloss is a measure of the dust present initially on the shelf [15]. Several of the shelves had books too close to the edge to accommodate the gloss meter, but measurements were obtained from over 75% of the shelves.

Pollution was measured in the rooms using commercially available diffusion tubes. These measured the average concentrations of sulphur dioxide, nitrogen dioxide, ozone and hydrogen chloride gases over the four week measurement period. Where possible, tubes, were exposed externally (on the roof on a north facing wall), in the room and behind the books on a shelf. Measurements were taken every three months, over a year. Room air exchange rates were measured with tracer gas methods, either sulfur hexafluoride or carbon dioxide. Where external pollution data exist, the internal concentrations in the libraries and archives were calculated from this and the air exchange rates, internal temperatures and RHs, using the IMPACT applet [16].

The air exchange rates of the rooms were measured using carbon dioxide or sulfur hexafluoride tracer gas decay [17] with Vaisala GMP222 loggers. Air exchange through gaps between the tops of books and the shelf above was investigated using carbon dioxide tracer gas decay. Carbon dioxide loggers were placed behind the books. Carbon dioxide was introduced into the space behind the books and its



p oil painting on canvas  
 DB double blinds  
 L1 40W incandescent bulb, 24microwatts/lumen  
 L2 40W incandescent bulb, 24microwatts/lumen

Position	Blinds			Shutters	
	Up	Midway	Down	Lights	Lights
A					
B					
C					
D					

<b>Room: Duke of Wellington's</b>		<b>Date: 20/02/2002</b>		
<b>Room</b>				
<b>Contents to be considered:</b>				
Chintz armchair Silk bedcovers Bed (leather and canvas) Wallpaper (replica) Carpet (replica) Curtains (replica) Prints (watercolour and monochrome) Books Wooden tables Wooden chair Wooden book stand				
<b>Light Sources:</b>				
Two windows, two electric lights on fireplace				
<b>UV control measures:</b>				
UV film on both windows				
<b>Light control measures:</b>				
Dark coloured Holland blinds and curtains on both windows, electric				
<b>Light control:</b>				
	Open Hours	Closed Hours	Closed Season	Functions
Proposed:	Eastern blind ¾ closed Southern blind fully closed	Blinds and curtains fully closed	Blinds and curtains fully closed	N/A
<b>Desired lux level at recommended monitoring points when open to the</b>				
Maximum of 50 lux on armchair and bed.				

#### Monitoring Points

- A - Vertically at top of the armchair back
- B - Horizontally on edge of silk bedcover, on corner nearest to chair
- C - Vertically in middle of print on bookstand

Figure 9. An example of a light plan. This is for the Wellington Library at Walmer Castle, Kent. Vulnerable objects, light sources and controls and illumination measurement points are marked. Probable initial blind levels are included in the table, but blinds are set to the illumination level specified at the measurement points

decay examined. An air exchange rate for that shelf of books was calculated from the slope of the natural logarithm decay regression.

## APPENDIX 2; LIGHT PLANS

The highly variable nature of natural illumination and differential penetration into rooms makes manual adjustment of blinds to achieve set light exposures a complex task. Light plans aim to simplify this procedure. The plan sets initial blind levels in the morning and afternoon at different times of the year. The plan defines two to four measuring points for the illumination level and what lux should be recorded at those points to provide the desired illumination throughout the room. There is obviously a very significant element of compromise with illumination levels throughout the room. The light plan is developed by mapping the sensitivities of objects in the room, its orientation, the sky map from the windows, all the light sources and the illumination levels in adjacent sets of rooms. The preservation of historic views through open windows interferes with the accommodation of the eye to lower illumination levels and makes managing

illumination and visitor experience in a naturally lit historic building more challenging than within an artificially lit building. A series of measurements throughout the year define the measurement points and set illumination levels for the light plan. The plans are refined constantly. An example for a single room is shown in Figure 9.

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