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## Applying Preventive Conservation Recommendations for Silk in Historic Houses

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### **Abstract**

*Accelerated ageing experiments have been used to identify the critical deterioration factors for silk. These have shown the role of humidity to be more important than previously thought. Monitoring of environmental conditions behind tapestries has identified the formation of high humidity microclimates. High humidity levels may be the reason for the poor condition of sampled unfaded silks. The accelerated ageing results have been used to make preventive conservation recommendations and plot preliminary isoperms for silk deterioration. The use of these tools to improve display environments within mixed collections in historic houses is discussed.*

### **Keywords**

*Silk, preventive conservation, light, RH, isoperms, open display*

### **Introduction**

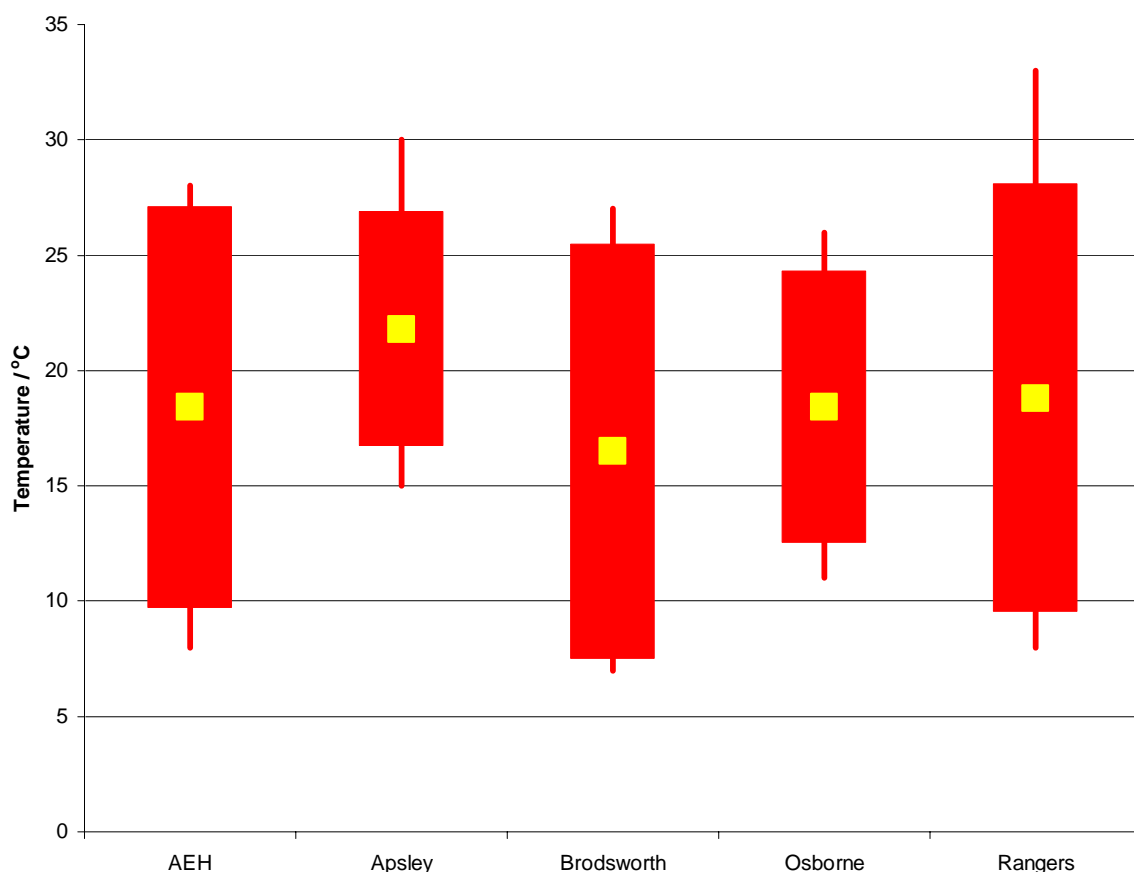
Textiles in historic houses are commonly on open display, increasing the risk of fluctuating humidity, dust, airborne pollutants and light to the objects. Silk deterioration cannot be prevented. The treatment of split and powdery silk objects has had limited success, and an alternative approach is desirable. Reducing the rate of silk deterioration by optimising the preventive conservation would increase the display lifetime of these fragile artefacts. This would also extend the period between interventive conservation treatments. However the critical factors for silk deterioration have not been determined, and so the methods of increasing the lifetime, not yet identified.

Amongst the natural fibres found in historic houses, silk is reported to be the most vulnerable to damage, especially from light [Tucker et al., 1980, Tímár-Balázsy and Eastop, 1998]. Historic houses tend to

utilise natural lighting from windows. With this approach it can be difficult to balance sufficient light to view collections whilst controlling the dose. Research on historic tapestries reported the poor condition of samples taken from the reverse side [Quye et al., 2009]. These reverse side fibres had retained bright colours indicating light may not be the only important deterioration factor for silk. There are few published studies on the effect of humidity on silk deterioration. A review by Hansen and Sobel [1994] cites a number of studies, however a large proportion of these relate to raw silk, which is known to be more hygroscopic. Nevertheless these reviewers suggest that silk should be stored below 50% RH.

## Experimental details

To determine the critical factors for silk deterioration, accelerated ageing experiments have been undertaken. The ageing conditions were selected from environmental data collected at five historic houses managed by English Heritage. The display conditions in each property were collected from January 2005 to December 2008. For both temperature and RH average values [central spots in Fig. 1]; the minimum and maximum values (narrow bars) and the region covering 95% of the data (wide blocks) were determined. Each of the five properties has a light plan which is checked with some continuous monitoring of light and UV levels. The light plan considers the property opening hours and the light sensitivity of the collection in each room, to determine an annual light budget and maximum light levels. The annual light budgets are calculated using a maximum illumination of 50 or 200 lux, giving equivalent annual doses of 146100 lux hours or 584400 lux hours respectively.



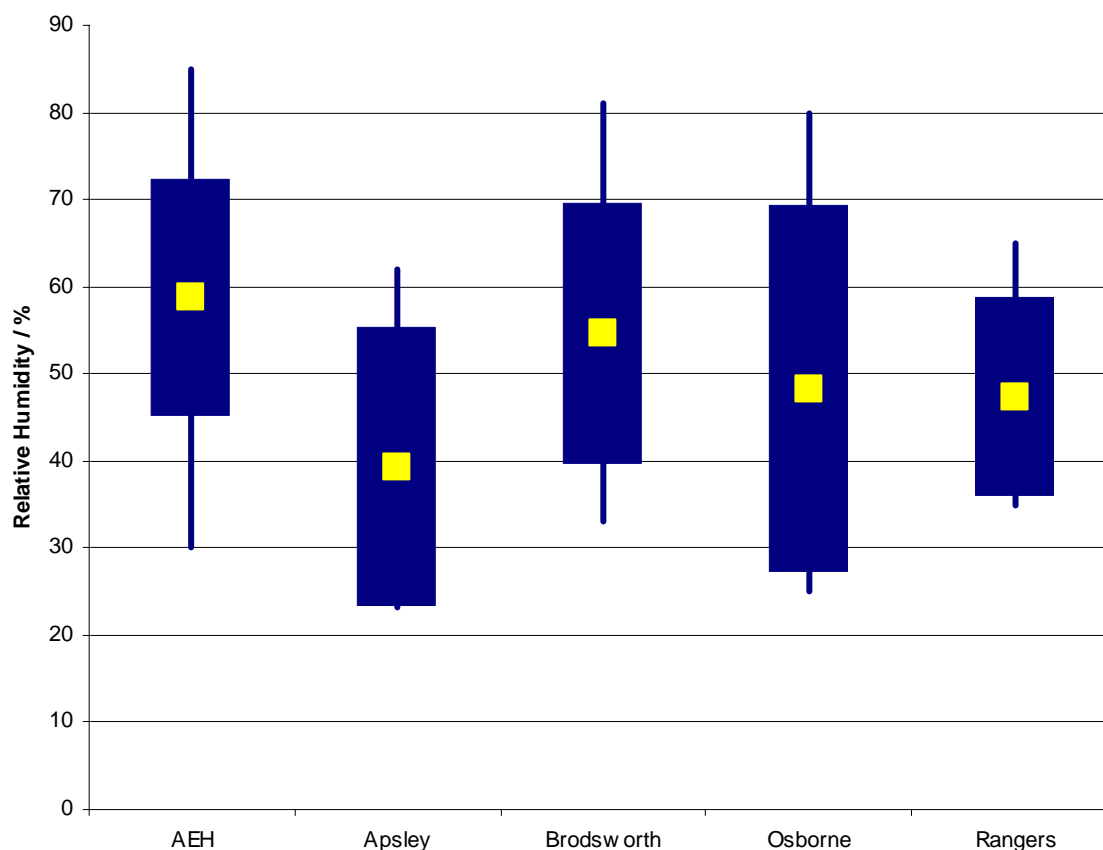


Fig. 1 (a and b): Temperature and relative humidity data for five selected English Heritage properties

RH/%	0	30	40	50	60	75	100
Dark	X	X	X	X	X	X	X
Light		X		X		X	
UV				X			
RH control	none	MgCl <sub>2</sub>	RH oven	NaBr	KI	NaCl	liquid water

Table 1. Accelerated ageing conditions at 80°C and method of RH creation

The selected ageing parameters are presented in Table 1. These represent no humidity (0% RH), low winter RH levels (30% RH), a low annual average RH (40% RH), a mid annual average RH (50% RH), a high annual average RH (60% RH), high summer RH levels (75% RH) and saturated conditions (100% RH). The RH levels were created with saturated salt solutions. The salt solutions were selected from literature [Greenspan 1977]. No saturated salt solution has been found for 40%RH at 80°C and a humidity oven was used to generate these conditions. The accelerated ageing experiments were carried out as shown in Fig. 2. The prepared tubes, incubated at 80 °C, contained six replicate pieces of medium weight habotai silk suspended above the saturated salt solution.

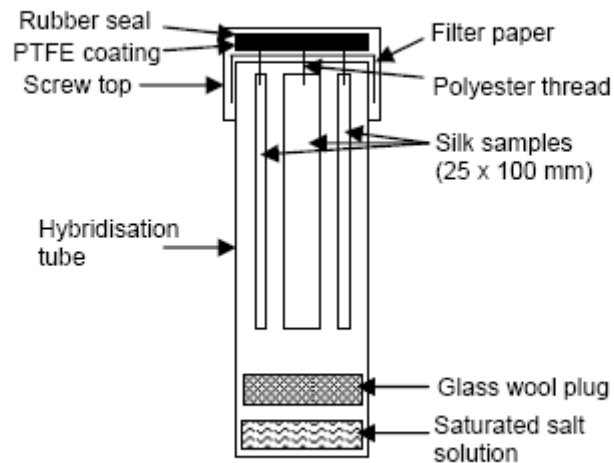


Fig. 2. Thermal accelerated ageing set up

A range of light and humidity levels were also studied to gauge any synergistic effects, including the addition of UV radiation at one RH level for comparison. Light ageing was carried out in a custom made light box from Complete Lighting Systems [Fig. 3]. This contains twelve GE F20W/AD artificial daylight, fluorescent bulbs and a polycarbonate UV filter. For one light ageing experiment at 50% RH the samples were placed above the UV filter. Light levels above the UV filter measured 12000 lux and 350  $\mu\text{W}/\text{lumen}$ . In comparison below the UV filter light levels were 7000 lux and 2  $\mu\text{W}/\text{lumen}$ .

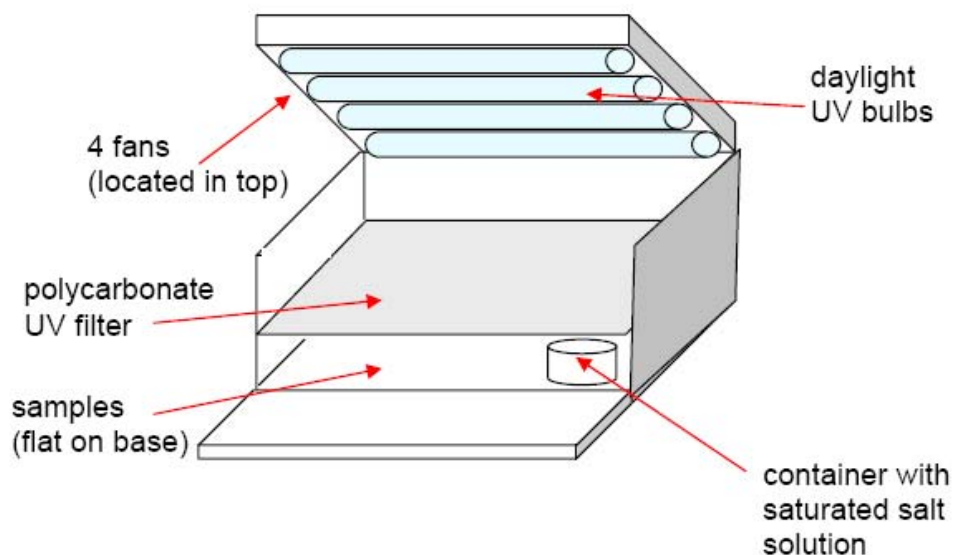


Fig. 3: Light accelerated ageing equipment

The tensile properties of the silks were determined after ageing. Tensile testing was carried out at  $22 \pm 2$  °C and  $52 \pm 5\%$  RH on an Instron 5544 instrument. An adaptation of the standard method for fabric strips (BS EN ISO 13934-1:1999) was used, with gauge lengths of 50 mm and a crosshead speed of 10 mm/min. Results for strips which broke close to the jaws were discarded and average values calculated.

Accelerated ageing experiments have been used to try and mimic silk deterioration occurring on open display. To put the results into context, the length of accelerated ageing was related to an equivalent length of time on display. For example, is 100 years light exposure at 200 lux causing more damage than 100 years exposure to high humidity? For light ageing the reciprocal principle [Thomson, 1980] has been used. For the thermal ageing, the activation energy has been used to estimate the increase in the rate of deterioration caused by the higher temperatures. A preliminary study indicated the activation energy for silk deterioration was approximately 50 kJmol<sup>-1</sup>. This would give an increase in the deterioration rate of almost thirty-three times, for example, ageing for one year at 80 °C would be equivalent to 33 years on open display at 20 °C.

## Experimental results

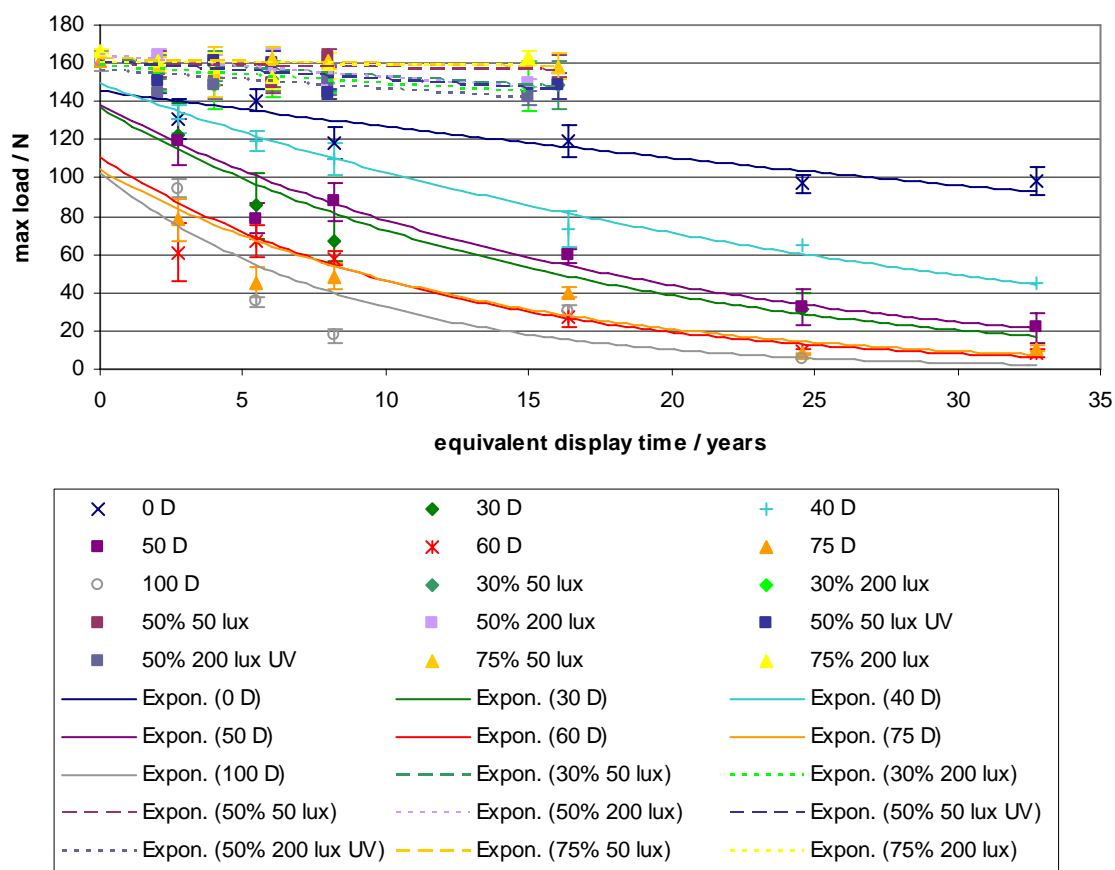


Fig. 4: Tensile testing results (exponential best-fit trend-lines are shown)

Figure 4 shows the results of tensile testing. The equivalent display time (in years) is used as the x-axis. Light ageing causes relatively small changes in the tensile strength of silk, even when UV radiation is included. In comparison, thermal ageing, even at 0% RH, causes significantly more deterioration. The ageing indicates that the tensile strength will decrease by one third after approximately 33 years on display. Increasing RH leads to greater changes, with a drop of three quarters in the tensile strength after

2 months ageing at 100% RH (equivalent to approximately 5 years on display). During the ageing experiments salt contamination of some silk strips was observed and this seems to rapidly accelerate the decrease in tensile strength. Samples aged at 30% RH were more deteriorated than those aged at either 40 or 50% RH. This is most likely to be a result of the salt ( $MgCl_2$ ) contamination. Similarly, samples aged at 60% RH were as deteriorated as those aged at 75% RH, and again contamination is the most likely cause.

The apparent first order rate constants for silk deterioration are approximately proportional to RH [Fig. 5]. The anomalous data points (30 and 60% RH) sit above the line which connects the other thermal ageing RH data. A low RH environment might then be advocated for optimum preservation on display. However there could be concern about the consequent embrittlement of organic materials. This is an area which requires further work. The moisture content of silk is reported to be roughly constant between 35 and 55% RH [Zhang and Wyeth, 2007] with a rapid decrease below 30% RH. Therefore, RH levels down to 30% are unlikely to lead to serious embrittlement of silk.

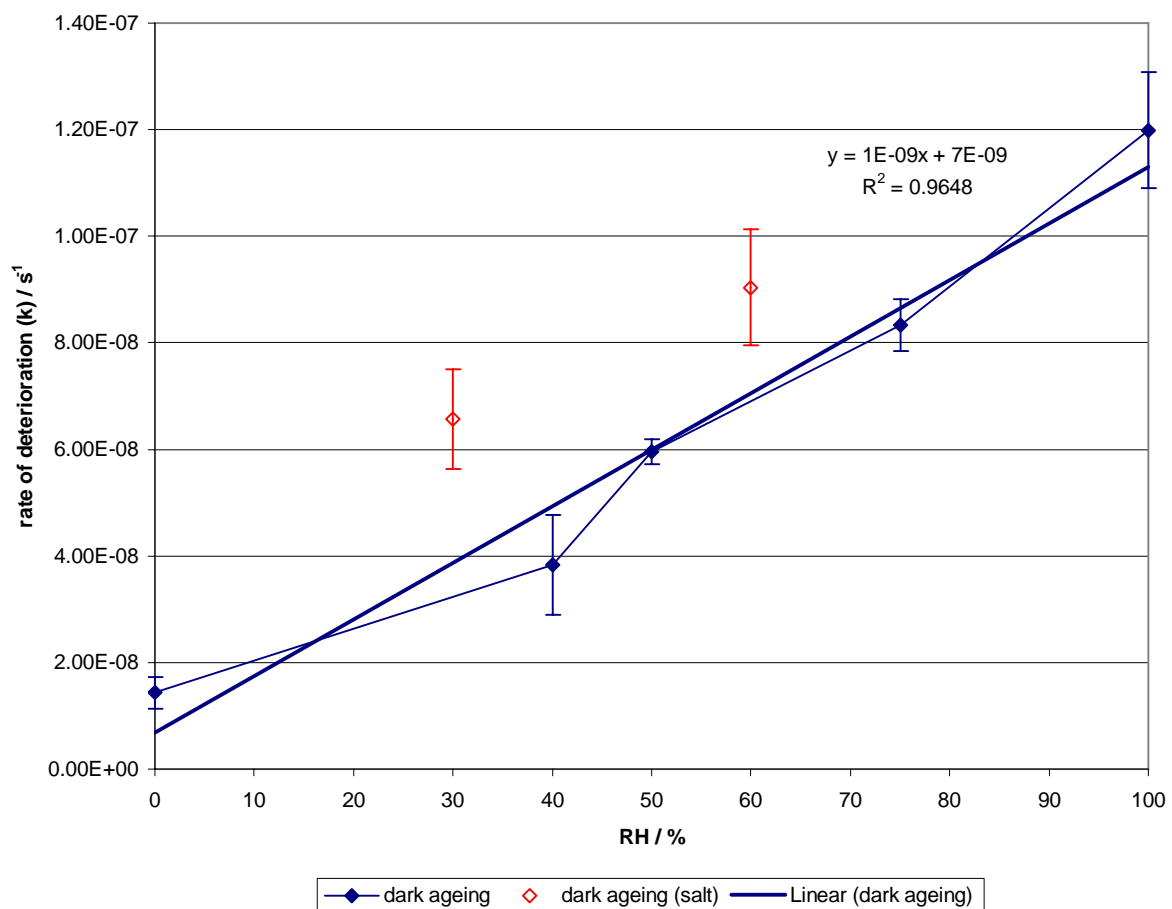


Fig. 5: Rates of silk deterioration after temperature and humidity ageing

In contrast the rate of deterioration caused by accelerated light ageing is generally much lower and there is little difference in the deterioration caused at 50 or 200 lux during accelerated light ageing [Fig. 4]. Although ageing at 50 lux with UV radiation led to increased deterioration of the light aged samples, demonstrating the particularly damaging effects of UV light. Historic Houses generally have UV filters on the windows and English Heritage has a mechanism for checking the films annually and replacing them if required.

## Discussion

Monitoring of temperature and RH behind a number of tapestries, in two of the selected properties, has determined higher humidity microclimates. At Audley End House, comparison of the temperature behind the tapestry and in the room showed little variation. However, there was a 5 to 10% RH increase behind the textile. At Ranger's House monitoring behind three tapestries observed temperature differences between each tapestry and the room, varying from 0.5 to 2 °C. There are also corresponding differences in the absolute humidity behind each tapestry, and larger fluctuations are seen behind the tapestries, particularly at higher humidity levels [Fig. 6]. Higher humidity levels have been shown to lead to greater deterioration of silk. Therefore the formation of higher humidity microclimates behind large scale textiles may be the reason for the poor condition of silk taken from the reverse of tapestries during MODHT.

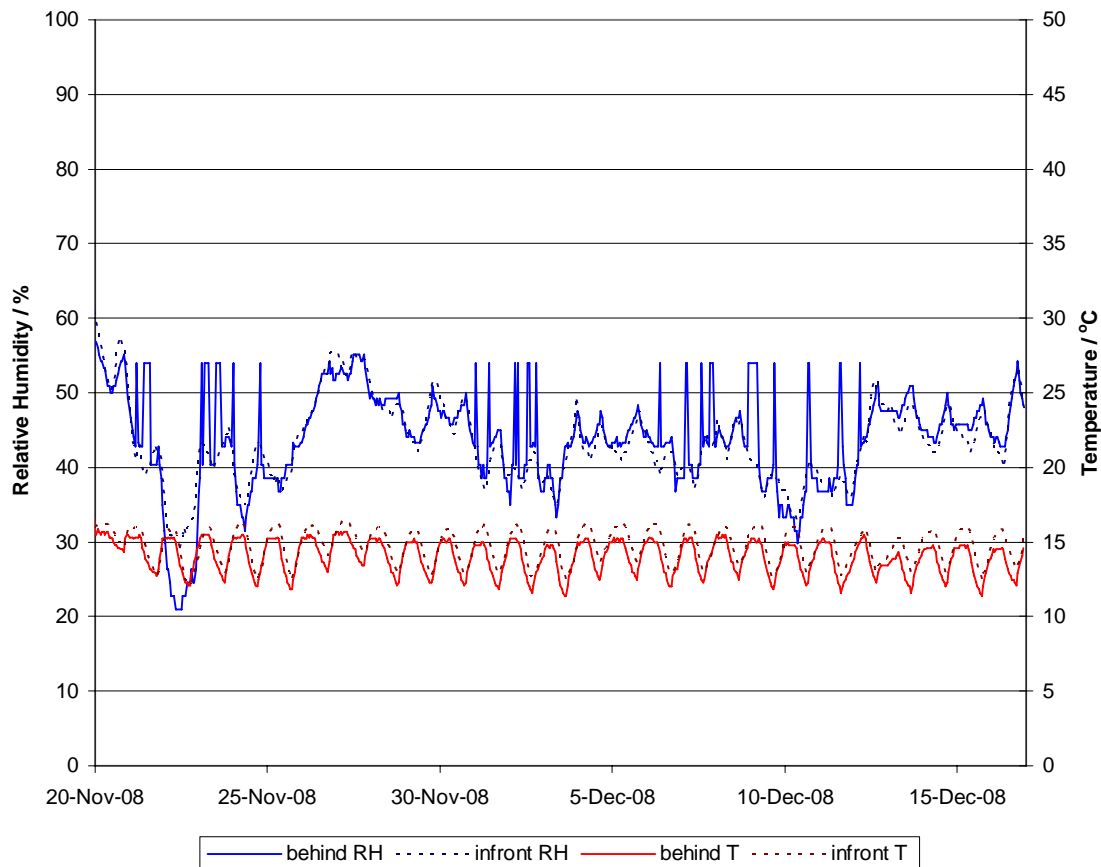


Fig. 6: Comparison of display conditions between Emperor tapestry and room at Ranger's House

Light has long been considered the key environmental factor in the deterioration of silk, and limits of 50 lux are generally recommended. However, as well as being difficult to achieve within historic houses, low light levels also make it difficult to view detail and colour differences on objects, particularly for older visitors. The above results suggest that levels of 200 lux are not critical, so that higher light levels may be appropriate where dye fading is not a concern.

The inevitable ageing under the long term effects of temperature and humidity appears to be more critical for silks on open display. From the present research the following preventive conservation measures for silk textiles can be recommended:

- reduce RH levels (to a minimum of 30% RH),
- reduce temperatures (10 °C decrease doubles lifetime),
- remove UV radiation from all light sources,
- display silk textiles above 50 lux (if the dyes are unlikely to fade),
- mitigate high humidity microclimates behind large scale textiles,
- prevent salt contamination of textiles (for example from efflorescence from walls).

## Application of results

Isoperms can be used to illustrate the effect of changing environmental temperature and humidity on the deterioration of a material. This approach has been widely adopted for paper [Sebera, 1994] and cellulose acetate [Reilly, 1996]. The equations used for paper isoperms have been criticised [Strang and Grattan, 2009] and isoperms do not include the effect of light ageing or pollutants on the lifetime of an object. However isoperms still provide a useful tool to compare display or storage environments. Figure 7 plots the isoperms for silk deterioration assuming an activation energy of 50 kJmol<sup>-1</sup> (from the preliminary experiments). An effective display lifetime is taken as 250 years at 20 °C and 50% RH on the basis of the condition of objects within the English Heritage collections. It has been assumed that the effect of RH is the same at all temperatures. This is due to the limited data, with RH ageing only at a single raised temperature.

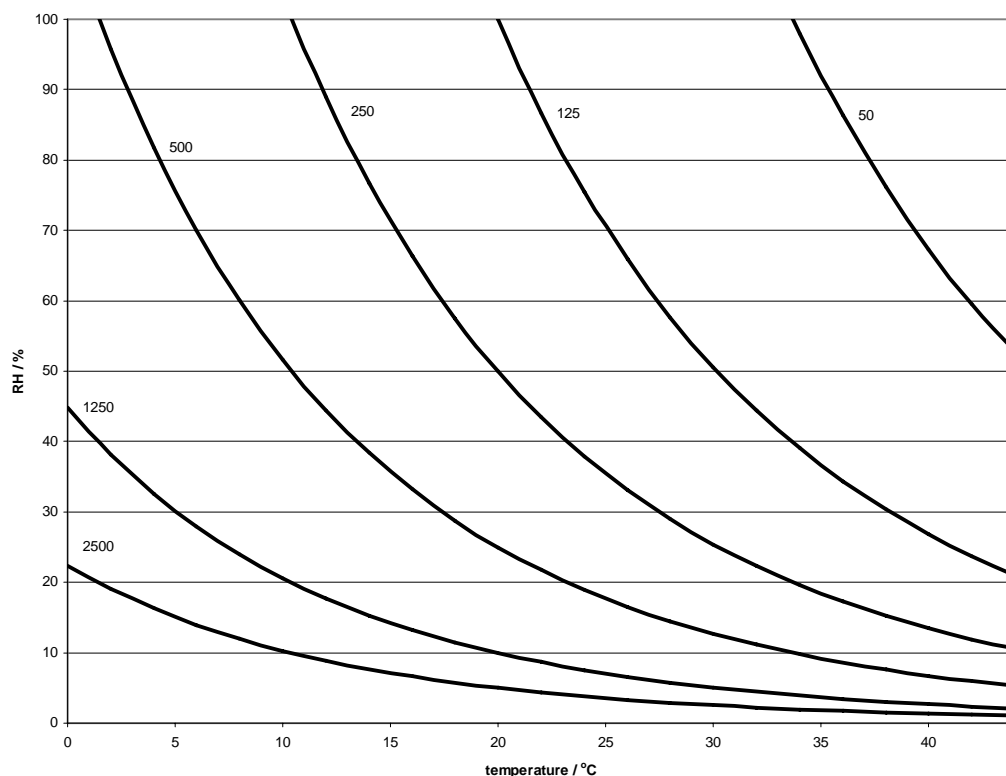


Fig. 7: Preliminary isoperms for silk deterioration



The isoperms might be used to estimate the advantage of changing the environment. As an example, at 75% RH and 24 °C, the predicted lifetime for silk is 125 years. If the environmental display conditions are reduced to 50% RH and 20 °C, the lifetime increases to 250 years. A further decrease to 35% RH, and 15 °C would double the lifetime again. It should be remembered though, that the predicted lifetimes are best suited to ranking the display environments, rather than taken as absolute values.

Traditionally the middle RH region, from 50 to 65% RH, has been suggested as most suitable for the display of organic objects, including silk. As more organic materials are studied the benefits of lower RH environments is becoming clear [Michalski, 2002]. While RH reduction seems advantageous, there are a number of complicating factors which may hinder the benefits. Historic house displays nearly always contain mixed materials within the same room, and the environment has to be a compromise amongst the varied requirements for each object. Before any changes can be made to the display conditions, it is necessary to consider the impact this would have on the rest of the collection. Wooden furniture, which can form a large part of a historic house collection, is susceptible to cracking at low RH levels, especially decorative veneers and marquetry. The consequent cracks and missing areas of decoration have a high visual impact. In contrast, low RH levels prevent corrosion of metals [Turgoose, 1982, Scott, 1990, Watkinson and Lewis, 2004, Thickett and Odlyha, 2005]. Unfortunately, for many other materials common to both museum and historic house collections, there has been little research on the optimal environmental conditions for display.

A further consideration is how the reduction in RH levels can be achieved. Within the historic houses studied, temperature is used to control humidity, but a rise in temperature will in itself speed up silk deterioration (the rate doubles for every 10 °C increase). While RH levels are generally low in winter, in summer they are usually high. For example, in July and August at Brodsworth Hall, the display rooms can be at 21 °C and 70% RH. To decrease the RH to 50% would require a temperature increase of 5.5 °C. The consequent 1.4 fold increase in the rate of deterioration would cancel the decrease caused by reducing the RH. This frustrating situation has been noted by Michalski [2002] for other organic materials with similar activation energies.

## Conclusions

A wide variety of display conditions, common to historic houses, have been used in accelerated ageing experiments to identify the critical factors for silk deterioration. The results of tensile testing suggest that, in the context of collections, heat and humidity lead to much greater deterioration than light. For silks on open display, preventive conservation recommendations include reducing the temperature and humidity (while increasing lighting where fading is not a concern). Isoperms have been generated, which allow a comparison of the effects of different environments on the display lifetime. Unfortunately, the relatively low activation energy for silk deterioration dictates that silk ageing cannot simply be slowed by raising the temperature to lower the RH, the environmental control method commonly used in historic houses.

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*All figures are courtesy of Naomi Luxford.*

## Materials:

Habotai Silk Medium  
Whaleys (Bradford) Ltd  
Harris Court  
Great Horton, Bradford  
West Yorkshire, BD7 4EQ  
England  
Tel: 01274 576718

RH salts and Wheaton Hybridisation Bottles (Tubes) 35mm x 150mm  
Fisher Scientific UK Ltd  
Bishop Meadow Road, Loughborough  
Leicestershire, LE11 5RG UK  
Tel: 01509 555500

RH oven (ESPEC SH-221)  
ESPEC North America, Inc.  
4141 Central Parkway

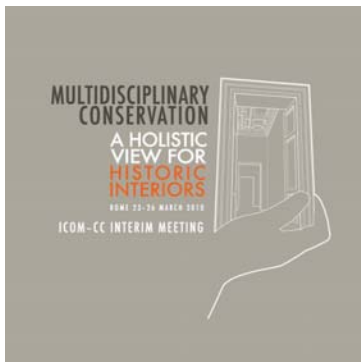
Hudsonville, MI 49426, USA  
616-896-6100

Heraeus Kendro UT6P Air Circulation Oven  
Kendro Laboratory Products Ltd  
Bishop's Stortford, Hertfordshire  
Tel: 01279 827700

Light chamber with 12 GE F20W/AD artificial daylight fluorescent bulbs, polycarbonate UV filter and 4 SUNON SF23092A fans

Complete Lighting Systems  
7 Park Industrial Estate, Frogmore,  
St. Albans, Hertfordshire,  
AL2 2DR, UK  
Tel: 01727 874000

**Naomi Luxford** recently completed PhD in Conservation Science at the University of Southampton, which has focussed on improving the preventive conservation for historic silks on open display at English Heritage. She has previously completed the RCA/V&A Conservation MA and undertaken internships at both the Metropolitan Museum of Art in New York and the Conservation Centre, part of National Museums Liverpool. She also has an MSci in Chemistry from the University of Bristol. (English Heritage, Ranger's House, Chesterfield Walk, London, SE10 8QX, [Naomi.Luxford@english-heritage.org.uk](mailto:Naomi.Luxford@english-heritage.org.uk))



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