Preventive Conservation in Historic Houses and Palace Museums: Assessment Methodologies and Applications

SilvanaEditoriale

Preventive Conservation in Historic Houses and Palace Museums: Assessment Methodologies and Applications

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and the Research Centre
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Acoustic Emission Monitoring of Baroque Furniture as a Diagnostic Tool for the Introduction of Environmental Control to an Historic House

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Abstract

Knole, in Kent, England, houses one of the National Trust's most internationally significant collections of late 17th/early 18th century furniture in equally important early 17th century interiors. Many objects have remained on open display in the same rooms for 300 years, subject to the naturally humid climate of an unheated UK building. Conservation heating is being introduced to lower relative humidity and provide a safer environment for the collections. In order to avoid drying or desiccation during the transition to this drier environment, acoustic emission (AE) monitoring is being used to assess the environmental response of painted and gilded furniture as relative humidity is lowered. AE monitoring of pieces of Baroque furniture showed their response to be very low in the existing high RH environment with only small increases in response as environmental control was introduced.

Keywords

Baroque furniture, relative humidity, conservation heating, acoustic emission.

Knole, in Kent, England, is one of the largest and most important historic houses owned by the National Trust (fig. 1). Knole is home to an internationally significant collection of late 17th/early 18th century royal Stuart furniture, acquired by the Sackville family through their royal and diplomatic connections. A former archiepiscopal palace built by Thomas Bourchier, Archbishop of Canterbury (1454-1486), Knole was given to Henry VIII in 1538. Acquired from the Crown by Sir Thomas Sackville (1536-1608) in 1570, the interiors were remodelled in the height of Northern Renaissance taste between 1605 and 1608, shortly after his elevation to the peerage as 1st Earl of Dorset in 1604 by James I. The Royal Stuart furniture was acquired by the 6th Earl, Chares Sackville, as a "perquisite" of his role as Lord Chamberlain to William and Mary. He introduced it to Knole in 1701 to replace the 1st Earl's moveable contents which had been seized and sold by the Commonwealth in retribution for the 4th Earl's, Charles Sackville's (1591-1652), support for King Charles I.

These antiquarian charms have drawn visitors to Knole since the

Fig. 1
The west front of Knole House. (© National Trust Images/Robert Morris)

late eighteenth century. By 1874 Reginald Mortimer, 1st Lord Sackville, found that the thousands of visitors now visiting the house meant "people strayed away from their parties, broke into our rooms, tore the fringe off the chairs and couches, and did all manner of things, whereupon I felt obliged to shut up the place" [Sackville-West, 2010]. Although visiting resumed on his death in 1888 at reduced levels and the collections were repaired, often by recycling indigenous textiles, the enormous cost of maintenance and increase in taxes in the twentieth century led to the house being transferred to the National Trust for England Wales and Northern Ireland (NT) in 1946, with subsequent gifts of contents in lieu of tax.

Whilst conservation work on high priority pieces such as the King's Bed, and running repairs on other objects, was undertaken in the latter half of the 20th century, by the present century it was apparent that the house and its internationally significant collection were in rapid decline – a leaky building and roof, and no environmental control in historic showrooms had resulted in the building and contents becoming unstable and in poor condition. Physical and aesthetic damage was being caused by insect pests such as the larvae of *anobium punctatum* (woodworm), mould growth, and the cementation of dust into "mud packs" by the formation of calcite and sticky exopolymers produced by bacteria under high RH conditions [Brimblecombe *et al.,* 2009; Tarnowski *et al.,* 2004].

Although there was a great need for remedial conservation, the constraints of time, money and the need to develop a bespoke conservation

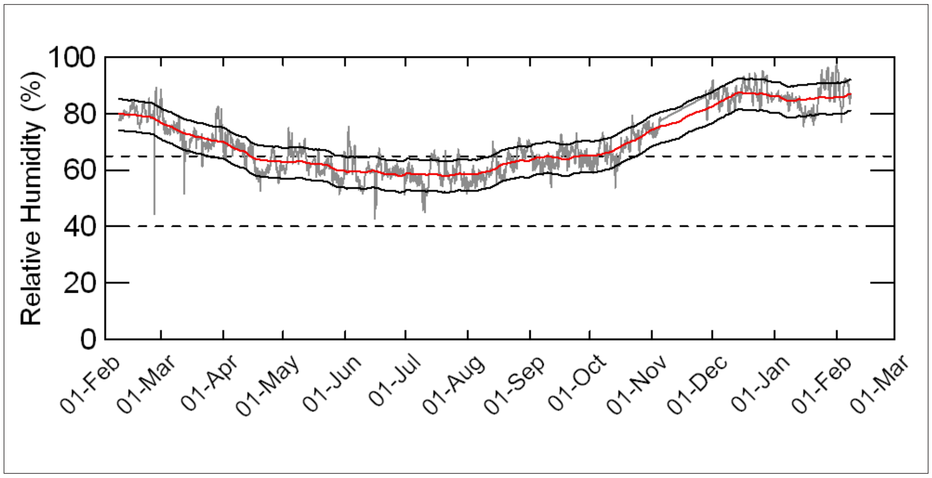

Fig. 2
RH in the Knole Spangled Bedroom, 2015-2016. The measured RH is shown in grey with the 30-day moving average in red. Solid black lines denote the 7th and 93rd percentiles, taken to represent the safe range of RH variation as defined in EN15757. The dotted lines define the National Trust RH 40-65% control band.

approach to prolong the life of such important but fragile collections constrained the speed with which such work could be carried out. The National Trust aims to present collections in "original" condition on open display as much as possible to retain an evocative spirit of place. Therefore, the approach to collection conservation prioritised preventive conservation, and minimal intervention until the funding of the major project "Inspired by Knole" which began in 2012 and was completed in March 2019 [Barratt 2012]. This is the most complex project undertaken by the National Trust, and one of its most expensive, costing just under £20 million, part funded by the Heritage Lottery Fund. Although the scope of the work is broad, from improving visitor facilities to introducing a new electricity sub-main and opening new areas to the public, conservation has always remained at the heart of the project, manifested in the construction of a Conservation Studio in the restored medieval Tythe barn, where conservators carried out light touch treatments in front of the public as part of the visitor offer, to gently lift the appearance and stabilize the condition of the collection, whilst more complex work was outsourced to freelance conservators studios with more sophisticated equipment. In the showrooms, preventive conservation is being enhanced through the provision of environmental control through conservation heating, enhanced light control and use of case covers to protect vulnerable textiles.

The Environment

Knole is distinctive amongst National Trust houses in that, since the early 18th century, most of the showrooms were set up to display the most important furniture and paintings rather than for living or domestic occupancy. These rooms have remained largely unchanged for 300 years, with the collections on open display and subject to a naturally humid climate as the showrooms have largely been unheated throughout this time and into the modern era.

Fig. 3
Left: frass from anobium punctatum emergences on a table leg in a piece of Baroque furniture from Knole. Right: mould growth on surface of a painting. (© National Trust)

As such, the collections have become accustomed to a high relative humidity (RH) environment where the annual RH typically ranges 55 to 90% with an annual average of about 70%. Research in the last two decades has greatly advanced our understanding of the climatic response of hygroscopic materials and it is no longer assumed that controlling to a museum RH standard, such as 55±5% is the correct approach for the care of such a collection. Modern preventive conservation thinking takes far greater account of the historic climate of the objects, and the concept of long-term acclimatization is at the heart of the European Standard EN15757, *Specifications for Temperature and Relative Humidity to Limit Climate-Induced Mechanical Damage in Organic Hygroscopic Materials*. Applying the EN15757 method to determine safe climate for mechanical damage to the conditions at Knole, suggests, a winter RH range of 75-90% (fig. 2). Indeed, the Knole collection appears to be stable mechanically at the current high RH conditions. However the high RH also promotes wood-boring insect attack, which is evident on much of the furniture and regular and persistent mould growth on textiles and paintings (fig. 3).

It was our goal therefore to lower the average RH to prevent these biological damage processes whilst at the same time avoiding the risk of increased mechanical damage as the RH is reduced. Over the last 25 year the National Trust has developed conservation heating [Staniforth *et al.*, 1994; Bullock, 2009] as its main method for controlling and reducing RH. When conservation heating has been introduced at other properties a gradual lowering of RH set points over several months and years has been adopted to allow collections to acclimatize. The fragility and significance of the furniture at Knole was felt to warrant close monitoring of the acclimatization process from a high RH environment to levels considered to lower the risk of mould and insect pests. The method chosen to monitor the environmental response of

Object type	Materials	Description
Gole Suite Side Table	Oak, possibly lime, gilding layers, tin and brass	Carved, gilded and silvered table with a top of pewter inlaid with elaborate scroll foliage of engraved brass Believed to have been made in the workshop of Pierre Gole (1620-84), Paris
Gole Suite Torchère	Oak and possibly lime, gilding layers	One of a pair of carved gilt-wood torchères, in the form of putti on tripod bases, possibly representing Summer and Autumn from a set of four seasons. Thought to have been made in the workshop of Pierre Gole (1620-84), Paris, around 1671.
Jensen Suite Side table	Japanned and ebonized pine and possibly beech	A black and gold japanned pier table with one long drawer, the top with raised gesso and gilded border, on ebonized scroll legs, parcel gilt shaped stretchers and bun feet. The set is attributed to William III's cabinetmaker Gerrit Jensen, who is recorded to have charged the 3rd Earl of Dorset £18 for 'a Table, Stands and Glass Japan' on 21st December 1691.
Jensen Suite Torchère	Ebonized and japanned wood with brass mounts	One of a pair of elaborate black, gold and japanned torchères with octagonal tops with raised gesso and gilded borders, on baluster supports with scroll tripod bases, decorated in the so-called Chinese style.

Table 1
Knole Furniture selected for AE monitoring.

the Knole furniture was acoustic emission (AE). The monitoring was carried out in collaboration with the Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, who have developed acoustic emission as a method for understanding the mechanical response of hygroscopic cultural heritage objects to changing RH [Lukomski *et al.,* 2017].

Acoustic Emission Monitoring Programme

Four objects from two suites of furniture were selected for the AE study, chosen for their high significance and fragile decorative finishes: a table and one torchère by Gerrit Jensen, and a table and one torchère by Pierre Gole. Taking analogies from demographic studies, it was hypothesized that if these "canary objects" did not respond adversely to environmental change, then the majority of the collections at Knole would also be safe. Additionally, the AE technique required objects to be monitored in pairs so it made sense to choose two items from each suite of furniture.

Acoustic emission monitoring uses small acoustic sensors or microphones, working in and above the frequency range audible to humans, to detect acoustic events caused by mechanical changes in the wood. Acoustic emission is defined as the energy released due to micro-displacements in a structure undergoing deformation. The energy passes through the material as ultrasound and sound waves, and is detected on the surface of an object using a piezoelectric transducer which converts the surface vibration to an electrical signal. The AE sensors

Fig. 4
Attachment of AE sensor to the Jensen Suite table, March 2016. Left: tissue pasted to bracing bar of Jensen table with sensor mount ready for attachment. Right: completed sensor mount with cylindrical steel sensor in the acrylic moulding (© National Trust).

need to be physically attached to the objects in order to detect sounds correctly. A reversible method of attachment was devised in consultation with, and applied in March 2016 by, the Trust's specialist furniture conservation adviser John Hartley. Japanese tissue was first glued to the object surface using starch paste and then the acrylic AE sensor mount was adhered to the tissue using Paraloid B72 adhesive (fig. 4). In the case of the Gole table the AE sensor, located between table leg and support, was wedged in place using plastazote.

The AE experimental setup consisted of: a multi-resonant wideband differential AE sensor (Phys. Acoust. Corp.), an acoustic amplifier (EA System), a simultaneous-sampling analogue input card PCI-9812 (Adlink Technology Inc.) and a laptop computer. AE signal data sets were recorded within 100 ms time-windows with a 1 MHz sampling rate, whilst the duration of a typical AE event was of the order of hundreds of μs. Sets of row data recorded during each monitoring phase were post-processed with the help of a computer program searching for individual AE events, extracting them and calculating the most important AE features i.e. amplitude, energy, duration and frequency distribution. The laptop computers were fitted with 3G mobile data connection, enabling the researchers to interrogate the AE equipment and download data remotely. In parallel with the AE monitoring, T and RH data for each of the monitoring locations was collected using Knole's Hanwell radiotelemetric monitoring system.

A detailed description of the absolute energy calibration and data processing has been presented elsewhere [Strojecki *et al.,* 2014; Lukomski *et al.,* 2017]. AE data were analysed in search for possible correlations with RH, indicating deterioration of objects induced by variation of environmental conditions.

Fig. 5
Gole Suite table and torchère in Cartoon Gallery with AE monitoring equipment. AE sensors connect to the amplifier (right), which is linked by the PCI interface (left) to the laptop (rear centre). Hanwell T and RH sensor temporarily located in the foreground. (© National Trust)

The first phase of monitoring investigated the AE response in the existing room environments at Knole compared to changes, if any, in when the furniture was moved to different storage environments during the course of the project, before returning to the showroom locations. Table 2 summarizes the movements of the furniture and the different environmental conditions experienced at each location. The monitoring had to fit around the phasing of the project and the various moves between showrooms and stores as the project progressed. Nonetheless, data were collected for each item in the unheated, uncontrolled Knole environment enabling comparison with the conservation heated controlled environment.

Results

The processed and filtered acoustic emission data are shown for the Jensen Suite (fig. 6) and Gole Suite (fig. 7). Each graph shows the acoustic energy of AE events from each object after interference has been filtered out, as green or black spikes, plotted in parallel with the temperature and RH at the monitoring location. In figure 6 the AE spikes appear fairly randomly distributed and there is little evidence of correlation with RH, or difference between the two monitoring locations.

Using the same format, figure 7 shows the AE response of the Gole Suite Table. The AE response in the Great Store was small and no activity at all was detected during the Brown Gallery storage phase; however there is a considerable change when the table moved back into the Cartoon Gallery, with more frequent and pronounced AE spikes. It is believed that the high activity levels are due to wood-boring insect

Objets	Date	Location	Environment
Gole Suite Table and Torchère	Mar 2016 – Dec 2016	Great Hall temporary store	Conservation heated to 65-70% RH
	Dec 2016 – Mar 2017	Brown Gallery temporary store	Uncontrolled, unheated
	Mar 2017 – July 2018	Cartoon Gallery	Initially uncontrolled, then conservation heated to 65%
Jensen Suite Table and Torchère	Mar 2016 – Nov 2016	Spangled Bedroom	Uncontrolled, unheated
	Dec 2016 – Oct 2017 (monitoring then discontinued for object conservation)	Conservation Studio Store	Conservation heated to 65% RH

Table 2
Object locations and environmental conditions during Knole acoustic emission monitoring programme.

larvae in the Gole Suite table – AE has been used in the construction industry to detect wood-boring larvae activity in timber [Nasswettrová *et al.,* 2016]. The Gole Suite torchère showed similarly large AE activity, far in excess of what would be expected from a mechanical response to RH change. House staff and the property's conservator had previously found evidence of insect activity in the Gole objects and the AE measurements appear to confirm this. Whilst an interesting observation in itself, this finding does confound the use of the torchère data for illustrating mechanical object response, because the AE activity due to woodworm masks the smaller mechanical RH response.

To understand better the AE response from each object in the different environments, tables 3 and 4 summarize the data from each monitoring phase and express the AE response as crack length propagation in a reference wood sample, so the degree of object response and damage can clearly be visualized.

The Jensen Suite table and torchère responses from the unheated Spangled Bedroom and Studio Store controlled to 65% RH are both negligible. Interestingly, the wardrobe AE response from the much drier National Museum in Kraków, considered to be a small value by the researchers on the basis of the total length of existing cracks [Strojecki *et al.,* 2014], is 40 times greater the highest response from the Jensen Suite.

The Gole Suite table gave a tiny AE response in the Great Store and negligible response during the winter in the Brown Gallery, but developed significant woodworm activity during the spring and summer of 2017. The Gole Suite torchère had significant woodworm activity

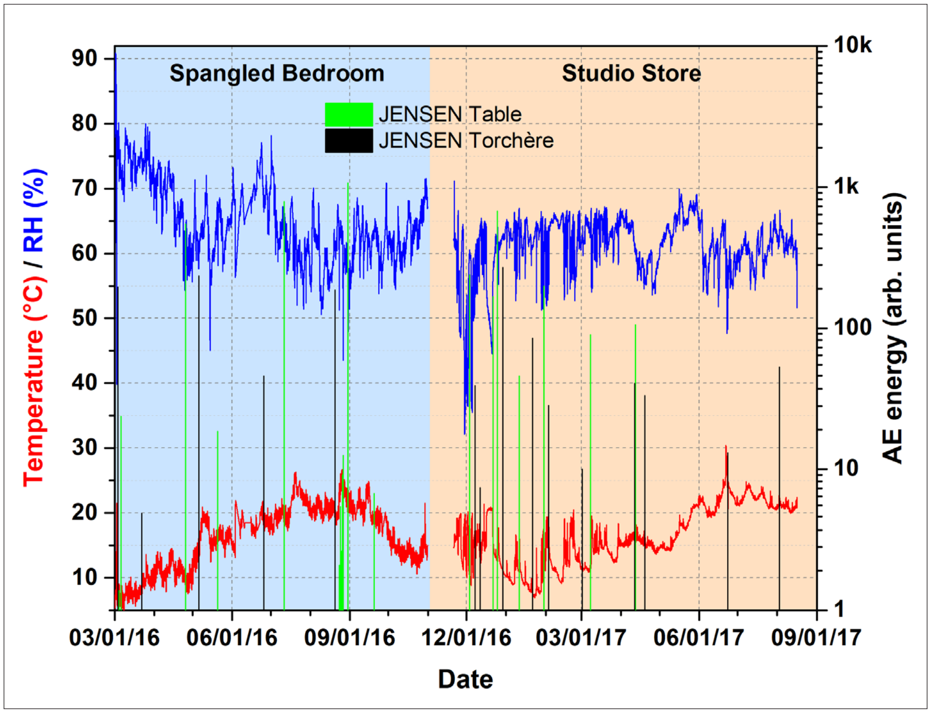

Fig. 6
Acoustic emission response of Jensen Suite table and torchère (vertical spikes, right axis) overlaid with T and RH data from each monitoring location.

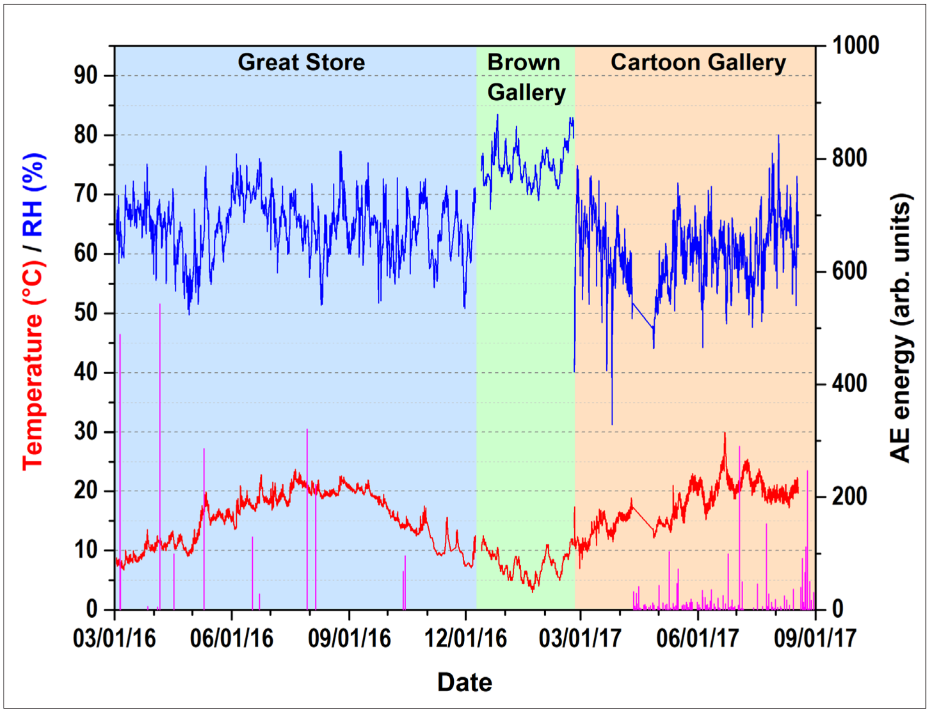

Fig. 7
Acoustic emission response of Gole Suite table (vertical spikes, right axis) overlaid with T and RH data from each monitoring location.

Location	Seasonal range (30 day moving average)	Object	Number of AE events	Total AE energy (arbitrary units)	Theoretical crack propagation
Spangled Bedroom, March – Oct 2016	57–74% RH	Table	122	3,054	0.008
		Torchère	48	5,201	0.014
Studio Store, Dec 2016 – Aug 2017	59–66% RH	Table	61	1,964	0.002
		Torchère	19	580	0.001
National Museum of Kraków	32–47% RH	Wardrobe		350,000 per year	0.6

Location	Seasonal range (30 day moving average)	Object	Number of AE events	Total AE energy (arbitrary units)	Theoretical crack propagation
Great Store Mar – Dec 2016	8.8 – 20.5 °C 59 – 71% RH	Table	48	3,713	0.009
		Torchère	18 045	424,697	Woodworm activity
Brown Gallery, Dec 2016 – Mar 2017	5.6 – 8.9 °C 75 – 77% RH	Table	negligible	negligible	negligible
		Torchère	506	67,846	Woodworm activity
Cartoon Gallery, Mar – Aug 2017	13.7 – 22.3 °C 56 – 64 % RH	Table	367	10,543	Woodworm activity
		Torchère	1 098	419,309	Woodworm activity

Table 3
Summary of Jensen Suite AE response and environmental conditions during two different monitoring phases, and in comparison with furniture monitored at the National Museum in Kraków [Strojecki *et al.*, 2014]. To compare all the monitoring results the last column presents the theoretical wood crack length propagation per year.

Table 4
Summary of Gole Suite AE response and environmental conditions during three monitoring phases, same basis as table 3.

during all monitoring periods, with the highest activity during the summer and a significant falling off in the winter.

Conclusions

The AE monitoring clearly indicated that, for the four objects tested, the mechanical changes in wooden objects induced by moving from the existing 60-85% RH environment at Knole to a moderately controlled conservation heated environment with 65% RH set point, are small, if not negligible. To date, this accords with visual assessments of the objects' condition at Knole in the first phase of the house, which was re-serviced and has been open to visitors since spring 2017.

It was interesting that woodworm activity could be detected by AE even though this confounded the use of AE to understand the mechanical response of the Gole Suite torchère. The Gole Suite table and torchères have since been treated using the Thermolignum controlled heating process to kill the woodworm infestation [Beiner and Ogilvie, 2005/6]. Monitoring is continuing on these objects and has found that the high AE response stopped after treatment, supporting the hypothesis that it was due to woodworm activity.

The AE results give confidence that the climate changes instigated at Knole are safe for the furniture and other collections at Knole, providing better conditions for their preventive conservation in the long term, by reducing the risk of mould growth and wood-boring insect infestations. In practical terms AE is very much a research technique, requiring a high level of technical expertise to set up the equipment, keep it in reliable operation and interpret the data. However as acoustic emission becomes more widely used and protocols established for monitoring it may become part of the preventive conservation arsenal of techniques for understanding direct object response rather than inferring response from measuring RH.

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