

# **Reviewing past environments in a historic house library using building simulation**

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## **Abstract**

This paper reviews different heating regimes applied to the same space, using building simulation. The construction of a computer simulation model to investigate past and present environments in a historic house library is described. The model simulated four hypothetical scenarios, based on real data. The simulation outputs were reviewed in terms of the risk of physical and chemical deterioration, and their relationship with an existing national standard for archives. The possibility of simulating past environments to investigate natural ageing is also discussed.

## **Introduction**

The natural deterioration processes of organic objects have been the subject of much study, mostly experiments in artificial ageing and theoretical calculations of chemical deterioration (Porck 2000). Knowledge of long-term effects of temperature and relative humidity (RH) on organic objects offers the opportunity to review the potential impact of different environments on historic objects, by looking at their preservation qualities. For preventive conservation in particular, it is useful to be able to review the effect of

different heating regimes for the same space. It is possible to assess the potential risk of different environments to organic objects through simulation of the behaviour of internal temperature and relative humidity.

The potential impact of different heating regimes within the same space can be compared using building simulation. By keeping the location, orientation, air change rate and level of occupancy constant, the effects of different heating regimes can be estimated. Effectively, 'what if...?' scenarios can be configured for the preservation qualities of environments in historic properties. This paper looks at various scenarios relevant to historic buildings, with specific reference to historic house libraries, reviewing environments that may have existed in the past, as well as a current method of control used in historic buildings.

## **Temperature and relative humidity**

Various environmental factors contribute to the chemical instability of organic objects, including temperature, RH, light and UV radiation and external pollutants. Isolating the effects of particular agents of deterioration in real environments can be difficult

but there is the potential with bound books, which will be discussed later, since only the edges of pages and ends of books are continually exposed to all agents.

Temperature and relative humidity are two key factors governing long-term chemical deterioration. Inappropriate climates are therefore major threats to the chemical preservation of organic materials: higher temperatures speed up the reaction rate for deterioration; higher RH will generally facilitate decay reactions, particularly hydrolysis. Thus, knowledge of long-term exposure to temperature and relative humidity can lead to a better understanding of how organic objects deteriorate.

### **Building simulation**

Simulation is the representation of the behaviour of parameters in a given system or process, using software to replicate known parameters. Building simulation software is commonly used in building design to predict the internal temperature, relative humidity and energy consumption of buildings before construction or modification. For the purpose of studying unknown conditions, it enables one to go beyond recorded data and look at unmeasured conditions. Building simulation software requires inputs such as the size, shape, construction materials, orientation, together with external climate data, to predict internal temperature and relative humidity conditions. Driven by the external climate, internal sources of heat, such as radiators or fire places are inputted into the software along with the room surface area, thermal conductivity of walls,

air change rate and the volume of the space.

Various building simulation programs are available. Most are concerned with human comfort, and therefore model temperature, rather than RH. However, a historic house library has a considerable amount of hygrothermal material that will exchange moisture with the air, affecting the ambient RH. *Energyplus*® is an appropriate programme for simulating historic environments because it accounts for hygrothermal properties of the building fabric and contents - essential for attaining an accurate simulation of RH.

Research into past environments (Cassar and Taylor 2004) led us to consider the use of building simulation as a tool to study the possible environmental conditions of a library collection in a historic house. A case study building was selected, Brodsworth Hall, South Yorkshire, an Italianate mansion built in 1863. Brodsworth Hall has had a varied history of occupation that has utilised different heating methods. It is now cared for by English Heritage and is open to the public.

### **Constructing a simulation model of a historic property**

A building simulation model of the library in Brodsworth Hall in Yorkshire (see Figure 1) was constructed using *EnergyPlus*®. Before it was opened to the public by English Heritage, temperature and RH were monitored without occupants, very little heating and with the windows shuttered. This data was crucial for calibrating the simulation model from a set of baseline conditions. Calibration is an essential part of

constructing a computer model, since any inferences about the temperature and RH will only be as valid as the data entered. A working model of the library was constructed, and shown to

predict conditions accurately by validation against measured data (see Figure 2). The expertise of a building scientist is required to construct the model and interpret the data.



Figure 1. Brodsworth Hall. Copyright English heritage.

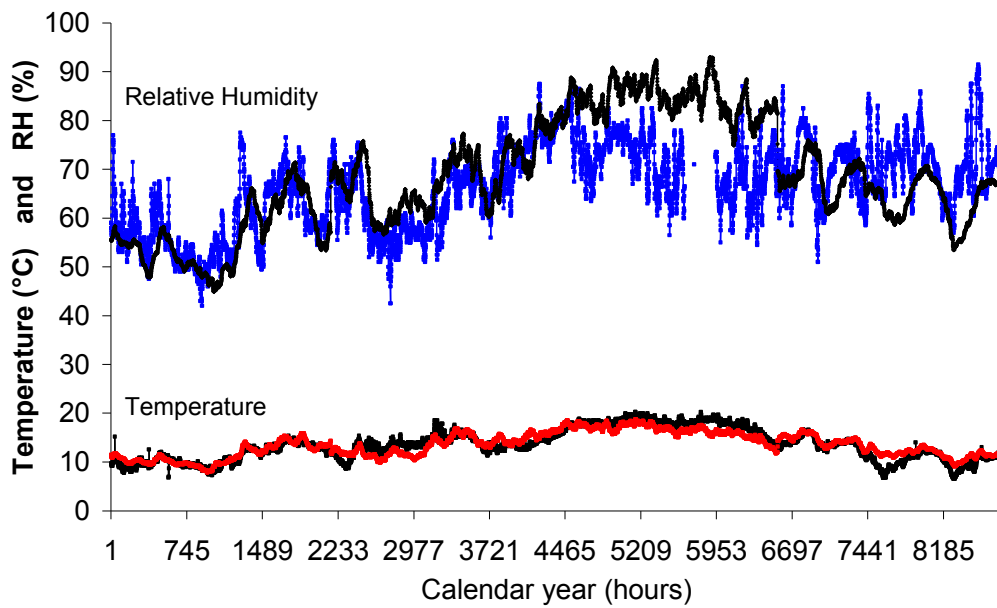


Figure 2. Comparison of measured temperature and RH (coloured lines) with predicted values (black lines) from the calibrated model.

A difficulty with building simulation is the number of assumptions that need to be made, such as heating and moisture inputs, heating patterns and use of the space, which are unlikely to be constant. As a result, predictions have an inherent uncertainty and a building scientist is required to determine the most appropriate assumptions to be made. In cases where the management and occupancy of historic buildings are not known precisely, RH fluctuations and critical value exceedences would be impossible to predict. Averages over long periods, however, can be predicted with reasonable confidence.

Archival information on the dimensions, original

construction methods and materials of Brodsworth Hall were used to construct the model. These were available from the house archives and included the original building specifications. Accounts and bills gave information about past coal consumption and occupancy that were also used in the model. This work has been described in Cassar & Taylor (2004). Since the library has both internal and external walls (see Figure 3), it responds to both external and internal environments. To model this, an internal zone was created for three of the walls, using existing measured temperature and RH data; the measured air exchange between internal and external environments was used to model the effect and influence of the external wall.



**Figure 3.** Floor plan of Brodsworth Hall. Copyright English Heritage.

### Scenarios

Four scenarios of Brodsworth Hall's library have been developed to review the impact of different heating regimes. They illustrate the differing levels of preservation that can exist within the same library under different environmental management scenarios. The scenarios are hypothetical but based on archival research and evidence of actual heating regimes during different periods of the Hall's history. The accumulated hygrothermal deterioration of historic objects in the library could be expressed by linking these scenarios together, assuming objects were in the library all this time. As well as scenarios derived from archival documents, there is one scenario of humidistatically controlled heating. The model included heat from sunlight (solar gain) from a test reference year (TRY), which is based on typical sunlight hours and movement of the Sun in that region (Cawood, Lat. 53.3, Long. 1.08). This is based on an average from measurements at that location between 1950 and 2000 as a reference input typically used by modellers. Occupancy was assumed to be constant in all the scenarios to reduce the variables, so the impact of different heating regimes can be compared. It was based on documentary records of the family and servants (5 adults and 12 children as family in residence, and 15 indoor servants).

#### Scenario 1 - Open fire and solar gain (1863 - 1932)

When the house was built, it was heated by open fires. Records of

fuel bills indicate the amount and quality of coal delivered. Coal was delivered as one batch and distributed to the different fireplaces of the house. The amount allocated to the library for the purpose of the simulation was based on the number of fireplaces in the house, their likely amount of use and the energy that would be emitted from that amount of coal in an open fire. Factors such as heat loss through flues and chimneys were also considered. Deliveries were periodic, and seasonal variations could be determined from the dates and amounts of coal delivered. 8.2 tonnes of coal were delivered per year, and divided up to fuel the Hall's 47 fireplaces. The library was in heavier use during the day than many other rooms, such as bedrooms, so in the simulation 66kg of coal per month was allocated. With a fireplace energy conversion efficiency of 20%, and the energy output of coal being 7.9 kilowatts/kg and using 66 kg of coal, with seasonal variation, the inputs for the scenario were as follows:

Winter (Dec - Feb) 3.043 kWh for 6 hours a day  
Spring (Mar - May) 2.028 kWh for 4 hours a day  
Summer (Jun - Aug) no heating  
Autumn (Sept - Nov) 2.028 kWh for 4 hours a day

#### Scenario 2 -Thermostatic control and solar gain (1932 - 1945)

Records show that an oil fired boiler was installed in the basement for a central heating system in 1932. There were seven small radiators on the ground floor. The set point is not

known but has been assumed to be 21°C for human comfort.

Central heating with two 2 kWh radiators during Spring (March-May), Autumn (Sept - Nov) and Winter (Dec - Feb) aimed at a set point of 21°C, including solar gain.

Scenario 3 - Open fire, thermostatic control and solar gain (1945 - 1990)

The house was occupied by the army during the Second World War, and after 1945 was heated by a combination of radiators and open fires until the last occupant left in 1990. Oral evidence reports that the fire and radiators were used daily in the library during this period.

A mix of background heating from radiators with thermostatic control at 16°C and heating from the open fire, was used as in scenario 1, including solar gain.

Scenario 4 - Contemporary conservation heating method

This scenario is not the current environmental management at Brodsworth Hall but is based on conservation heating in general use in historic houses under public stewardship, described by Staniforth et al. (1994). Brodsworth Hall is open all year but this scenario simulates a typical closed period in winter and a period without humidistatic control in summer. *Energyplus*® cannot model humidistatic control, which had to be simulated by psychrometric manipulation of the simulated vapour pressure of the unheated room. Consequently, there is no simulated thermal lag.

Humidistatic control at 65% RH and shutters closed for winter (21<sup>st</sup> Sept - 21<sup>st</sup> March) and solar gain only for summer (21<sup>st</sup> March - 21<sup>st</sup> Sept).

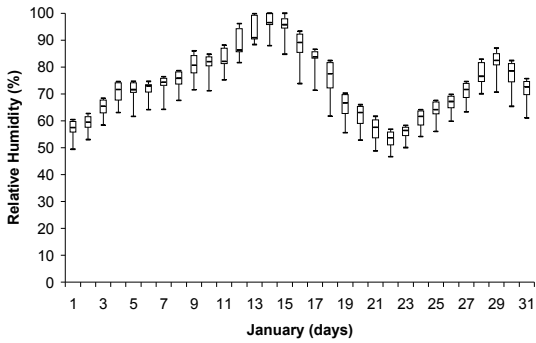
## Results

The simulated scenarios show a range of different temperature and RH conditions. The degree of chemical preservation offered by these environments can be determined using the Time Weighted Preservation Index® (TWPI) (Reilly et al. 1995), which calculates isoperm values from temperature and RH data. Isoperms are values that predict useful life expectancy of paper-based collections, based on strength loss through chemical deterioration, described by Sebera (1994). Isoperm values relate the environments to a theoretical understanding of chemical deterioration built up through accelerated ageing research. Relative, rather than absolute, values provide a rate-of-deterioration scale for possible preservation environments. This was calculated using Climate Noteboo® software, which reviews preservation qualities of different environments from a range of perspectives.

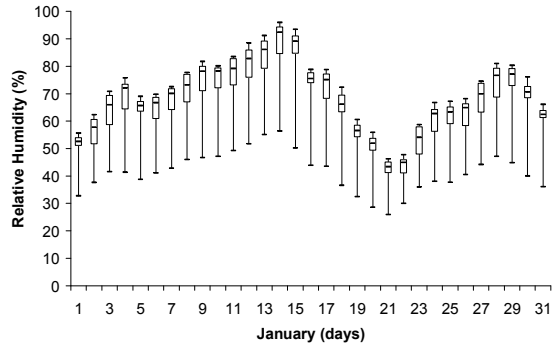
Using isoperms alone can overemphasise the role of chemical deterioration, which is less significant in historic house contexts with furniture and paintings, but is arguably the most relevant RH assessment for paper. It can be seen in figures 4-7 that the scenarios with the best preservation indices also have the greatest variation in RH over a month, reaching very low levels (see Table 1). The low level, mixed heating of radiator and fire (see Figure 6) clearly promote the least amount of chemical

deterioration but reach levels far too low for historic contents. Humidistatic control (see Figure 7) may not be the best preservation environment for the natural ageing of organic objects but provides the relatively stable and moderate levels required by many contents

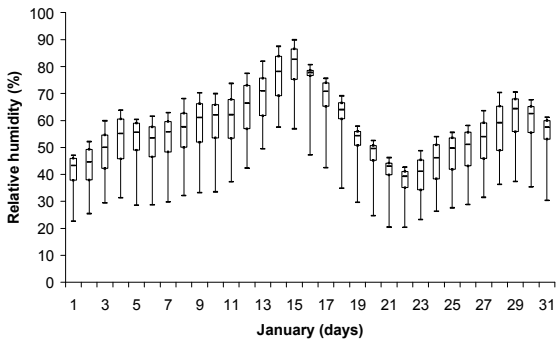
and fittings in historic buildings. Daily swings are most evident with the radiator scenario (see Figure 5), because heating to a higher set point causes larger psychrometric swings. None of the scenarios contained significant threat of biological deterioration.



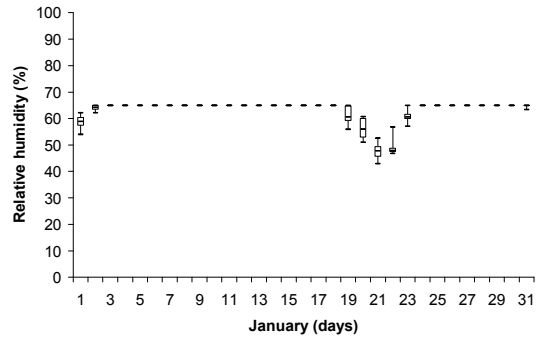
**Figure 4.** Daily RH variation in variation in January for scenario 1, coal fire. January for scenario 2, central heating.



**Figure 5.** Daily RH



**Figure 6.** Daily RH variation in variation in January for scenario 3, fire and radiator. scenario 4, humidistatic control.



**Figure 7.** Daily RH

January for

| Scenario                         | Temperature (°C) |     |     | Relative humidity (%) |     |     | TWPI<br>In years | Isoperm |
|----------------------------------|------------------|-----|-----|-----------------------|-----|-----|------------------|---------|
|                                  | Min              | Ave | Max | Min                   | Ave | Max |                  |         |
| 1 Coal fire                      | 4                | 13  | 22  | 47                    | 70  | 100 | 57               |         |
| 2 Central heating                | 4                | 14  | 22  | 26                    | 64  | 97  | 58               |         |
| 3 Fire and radiator              | 4                | 13  | 22  | 20                    | 63  | 94  | 60               |         |
| 4 Humidistatic control           | 5                | 14  | 22  | 43                    | 65  | 92  | 57               |         |
| Lowest values of<br>BS5454:2000  | 16               | 16  | 16  | 45                    | 45  | 45  | 83               |         |
| Highest values of<br>BS5454:2000 | 19               | 19  | 19  | 60                    | 60  | 60  | 38               |         |
| Real data from archive<br>store  | 15               | 20  | 25  | 31                    | 43  | 58  | 40               |         |

**Table 1.** Temperature, RH and TWPI data for scenarios, BS5454:2000 and an existing archive

| Scenario                  | Temperature (°C) |     |     | Relative humidity (%) |     |     | TWPI<br>In years |
|---------------------------|------------------|-----|-----|-----------------------|-----|-----|------------------|
|                           | Min              | Ave | Max | Min                   | Ave | Max |                  |
| 1 Coal fire               | 4                | 12  | 13  | 47                    | 70  | 100 | 112              |
| 2 Central heating         | 4                | 14  | 18  | 26                    | 64  | 96  | 113              |
| 3 Fire and<br>radiator    | 4                | 13  | 16  | 20                    | 63  | 90  | 156              |
| 4 Humidistatic<br>control | 5                | 14  | 17  | 43                    | 65  | 65  | 106              |

**Table 2.** Temperature, RH and TWPI data for the scenarios during January only

The small differences in TWPI for the four scenarios are within the uncertainty of the building simulation model, and are therefore not statistically significant. The period of no environmental control averages out differences in TWPI among the regimes. However, by examining at the month of January, when all of the heating systems are fully operational, differences are evident (see Table 2). Historic environments may not have been suitable for many objects, but unconstrained organic objects, such as books,

may actually have been quite well preserved.

#### **Comparison with national standards and existing archives**

A comparison has been made between the scenarios and a national standard for temperature and RH control in archives BS5454:2000, which recommends RH control to a set-point between 45 and 60% within a tolerance of +/-5%, and temperature control to a set point between 16 and 19°C within



a tolerance of +/-1°C. The different BS5454:2000 set-points give very different preservation values. Using TWPI calculations, 16°C and 45% RH give 83 years on the preservation index, whilst 19°C and 60% RH give 38 years. The tight bands of control demonstrate a high degree of variability in terms of chemical preservation, despite the fact that buildings would need to operate a tight air conditioned regime to achieve either levels. Interestingly, all the Brodsworth scenarios and measured data fall within the preservation band of 38-83 years, even though none of them meet the temperature and RH requirements of the standard.

The fluctuations in RH in the scenarios show that physical damage is more likely to take place in all the 'historic' scenarios but chemical preservation falls comfortably within the chemical preservation band of BS 5454:2000. Real data collected from an existing archive (see Table 1) falls outside BS5454:2000 recommendations regularly but has a better PI (40 years) than the higher set-point of the standard, although the RH is low and could cause physical damage. However, in chemical terms, all scenarios fall within BS5454:2000 recommendations.

#### **Relating to object deterioration**

The possibility of retrospective assessment of climates can be facilitated by using existing data on external climate, such as the Central England Temperature Record which holds monthly temperature and relative humidity data from 1659, and daily averages from 1772.

Combined with monitored data from the location, frequently

collected by heritage institutions over the last few decades, a retrospective investigation into past climates becomes viable. This requires extensive searches of records, however, since it should simulate real, rather than the projected, events. The study of past climates is only possible because chemical deterioration relies on averages, rather than fluctuations, of temperature and relative humidity

Relating them to object deterioration involves the examination of historic objects. The mixture of different materials in a historic house or library environment complicates the problem. Therefore, a materials-based approach to assessing condition allows one to select appropriate indicator materials, enables a comparison of like with like by removing the problem of material differences, and affords some statistical refinement (Baer and Berman 1986).

The choice of material is dictated by the requirement for the material to have:

- A reasonable rate of deterioration over time
- Linear deterioration
- Deterioration over a range of ambient conditions
- Bulk, rather than surface, changes
- Simple chemistry
- Large quantities available in historic properties
- Capacity for non-destructive/ micro-destructive testing

Books of handmade paper in historic house libraries meet all these criteria, and have the added advantage that specific agents of deterioration can be isolated by looking at the centre of the book page, since light, UV radiation and

pollution are absorbed on the surface edges only. Book centres may therefore deteriorate differently from book edges. Many kinds of objects moved from location to location, being subjected to a wide range of environments and climates. It was found that library books were mostly likely to stay for long periods of time and be found in their original locations, verifiable through documentation.

Historic books have several advantages over other objects. The publication date provides a *terminus ante quem*, before which the book cannot have existed. Confounding factors, such as alum sizing and bleaching, can be eliminated by selecting books that predate such methods. Also, resources such as the English Short Title Catalogue can provide many examples of multiple copies of books, especially in copyright libraries, often the only environment in which a book will have been.

Of course, the original condition of the paper cannot be known, and even different handmade papers can deteriorate in different ways. Like TWPI®, comparative, rather than absolute, scales should be favoured. Comparisons of identical books have been carried out in the past, mostly for pollution (Smith 1972, Havermans 1997), which is the most fruitful option for retrospective assessment. This combination of retrospective environmental investigation and materials based assessment creates an opportunity to investigate natural ageing of real objects.

## **Conclusions**

Building simulation is a useful tool for determining the possible exposure of objects to temperature and humidity, providing its limitations are understood. A range of realistic scenarios that give insights into the conditions under which natural ageing has occurred enables these environments to be compared with modern conservation conditions. Integration with isoperm calculations provides the opportunity to appraise different heating regimes. The similarities in chemical deterioration in an archive that meets a national standard and a centrally heated historic house is surprising and will be investigated further. The development of simulation software to model humidistatic control would be very useful for conservation purposes.

## **Acknowledgments**

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### **Materials**

EnergyPlus Simulation Software  
US Department of Energy.  
<http://www.eere.energy.gov/buildings/energyplus/>

Climate Notebook version 3 for Windows.  
Image Permanence Institute  
Rochester Institute of Technology  
Rochester, NY 14623-5604, USA  
Tel: 585 475-5199  
<http://www.climatenotebook.org>