WHY KEEP CLIMATE RECORDS - AND HOW TO KEEP THEM

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ABSTRACT

For all our concern about the damage caused to art by the environment, there are no data which allow us to connect measured environmental variables with the rate of deterioration of the art in exhibition or storage. Recent proposals for rating the suitability of spaces and the vulnerability of individual objects require a durability of electronic data which is very unlikely to be achieved. This is a review of the state of the art of recording the environment around art.

Figure 1. The human readability of analog records produced by thermohygrographs gives many advantages. For quality control, rather than research, the thermohygrograph still has a role to play in museums.

INTRODUCTION

Climate records are evidence of care. The thermohygrograph ticking quietly in the corner of an exhibition announces the professional standard of the institution even if its ink line wanders shakily up and down on the graph. The ritual aura of the thermohygrograph, with its public display of the room climate and its evidence of a human visit once a week, has now been lost as this long lived instrument has nearly universally been replaced by digital sensors. The loss is more serious than the disappearance of a comfortingly familiar gallery exhibit. The digital records are vulnerable to erasure. They are doomed to loss by format obsolescence unless converted into a durable standard format. The digital storage media are of uncertain physical durability. One cannot assume that digital recorders are more accurate than the thermohygrograph.

THE NEED FOR DURABLE RECORDS

There are several recent initiatives in preventive conservation which require environmental records for individual objects or exhibition rooms stretching back, ideally to the birth of the object.

The first of these data hungry proposals is the call to limit exposure of light sensitive objects to a lifetime dose. This is based on the good evidence that photochemical damage accumulates according to the total photon dose rather than the light intensity in photons per second. A dim light will eventually cause the same damage as a bright light will cause quickly. Light intensity in an exhibition varies much from place to place, and from time to time if there is daylight. One would have permanently to fix a photon counter to every object, maybe on several surfaces. This can be done, in the same way security tags are fixed to items in shops. However, what is the chance that the communication and storage format for these devices will not change in the thousand years that is the conservator's perspective in matters

Figure 2. The Image Permanence Institute has developed a data logging and reporting system which measures temperature and relative humidity, from which it derives a preservation index in expected years of life for an object in that environment. The indicated lifetime is rather pessimistic.

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of durability? The blue wool standards remain the most durable device to measure accumulating light exposure.

The second example of the need for durable records is the Image Permanence Institute's (IPI) Preservation Environment Monitor and Climate Notebook [1,2]. The hardware provides a readout of the Time Weighted Preservation Index (TWPI), which is an arcane measure of the rate of damage predicted from the temperature and relative humidity recorded since the logger was switched on. This number, though expressed as years of useful life for the object, is not based on the nature of the object but on its environment, so only one logger is needed per room. The calculation is presented every few seconds but only gives a true indication of the quality of the environment on the anniversaries of its first measurement. This is because the annual climate cycle has a strong influence on the number, unless the room is air conditioned, in which case the TWPI will be constant and needs only a single reading. The TWPI for a comfortably warm room predicts a lifetime for its contents around 50 years, but for an open sided barn in northern Europe it is 150 years. So there should not be much old stuff left indoors. The fact that most things do actually survive much longer seems not to have dented trust in the TWPI. There is, however, a fundamental insecurity in relying on

Figure 3. A carved ivory tusk from Africa, almost invisible in the glare of the sunlight warming its showcase. The room temperature and RH were acceptable but a datalogger within the case registered an extreme local climate (figure 4)

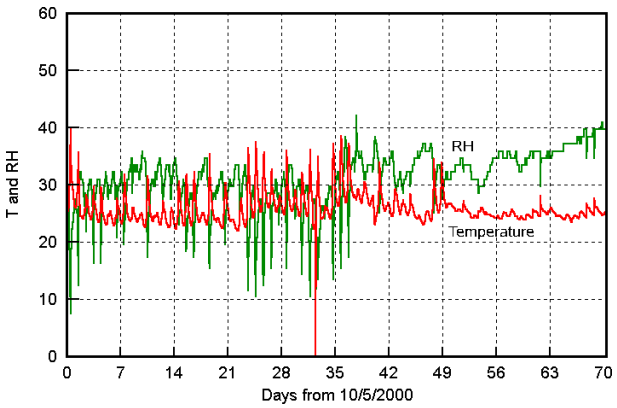

Figure 4. The climate measured inside the case shown in figure 3. The datalogger, set in the relative cool of the base of the case, was ivory coloured to ensure that it experienced the same radiant heating as the object. At day 38 the case was moved into the shade.

idiosyncratic derived values rather than fundamental and durable physical measures such as temperature and relative humidity.

The third example of the need for durability in climate data is the concept of 'proofed climate variation', as currently championed by Stefan Michalski. Once something is broken by extreme relative humidity or temperature it will survive unscathed any number of smaller fluctuations without any more damage, unless its vulnerability is reset by conservation treatment. The problem with using this assertion is the scant information about the circumstances which caused the damage we now can see in an object. We need the climate record right back to the birth of the object, and we need to be sure that the object has not been temporarily exposed without recording its local climate. In practice, one would usually use the annual variation of climate in its present location. In other words, there is no point in improving the climatic stability of a museum which has had its collection for a year or two. This is a great relief to the management but though proofed variation is an elegantly simple concept it applies only to mechanical damage: mould, salt efflorescence and metal corrosion will continue if the climate moves into the region of vulnerability, even though a more extreme condition has arisen earlier.

The fourth example of the need for durable data is to demonstrate the effect of global warming on heritage items. There seem to be scant usable data from past measurements, so we must start now to define the 'normal' climate of a historic building, against which to judge future threats, and maintain well calibrated records for a hundred years. For this purpose we need measurements both inside and outside the museum or historic monument. For lack

Figure 5. Estimation of proofed exposure to climate requires the datalogger to be always close to the object it is monitoring. This is particularly true in transport cases, where the climate recorder must be at the same temperature as the object to report true values of the RH at the object.

of these data the English National Trust is reduced to quoting crumbling sea cliffs and flooded lawns as anecdotal evidence for its need for more money to combat the effects of global warming.

The first three examples ideally need dataloggers strapped to the individual items. The fourth requires measurement of the weather also. Apart from the environmental data, one needs an equally meticulous record of the travels of the object from room to room, noting periods out of range of its usual datalogger. I illustrate the adventures that may occur out of sight of the data collection system with an example from the routine operation of an un-named institution, from which I have recently retired. It lends out its treasures, guarded by a loan contract which specifies close limits to display temperature. When the items are returned they are promptly plunged into a cool chamber at -30°C to snuff out insects which may be hitching a ride into the store room. By some contortion of reasoning, an extreme temperature deliberately imposed in a good cause does not risk damage that is feared to arise from a much smaller temperature excursion caused by mere carelessness. Note that this treatment will earn good points from the IPI logger, which will award the cooled object an extra lifetime varying from decades to a single day, according to how long before this event the logger was switched on. The 'proofed climate variation' concept will also comfort the curator by assuring that after the first cycle through the cooler, the object can be re-cooled without further damage.

Truly, conservation is an irrational discipline. But let us set aside such cynical observations and continue on the assumption that environmental records are valuable and must be kept accurate, kept for ever, and ideally be readable for ever.

What and where to measure

For quality control of the museum environment it is conventional to measure only temperature and relative humidity. The most potent of all agents of destruction in a well managed museum is light. This is hardly ever measured, because it is so variable within a single enclosure. The photochemical potency of the radiation is never measured. The lux is a convenient and durable standard, being directly related to the SI unit, the candela, but it is only tenuously related, within two orders of magnitude, to the rate of photochemical degradation.[3] The air exchange rate is not measured because it is difficult to measure. Pollutants are getting easier to measure but there are not yet standard plug-in sensors for dataloggers. Sensors for biological activity are also rare. So we measure two variables which, though important, are far from defining all the essential characteristics of the environment. Indoor data alone are useless for diagnosing faults in the building structure, or in the air conditioning apparatus, because the outside weather must be measured and also the rate of exchange with outside air. In theory, the outside weather can be approximated by the nearest official weather station but such data nearly always cost money. There are a few internet data banks for the world's weather but the records are incomplete and intermittent from nearly all sources. It is time consuming to merge data from two sources, each with a different measuring interval and data format.

Figure 6. A silver mirror damaged by exposure to -30°C. Physical damage is difficult to see on less optically perfect objects. The record of the appearance of an object before cooling is seldom detailed enough to convince that no change has occurred.

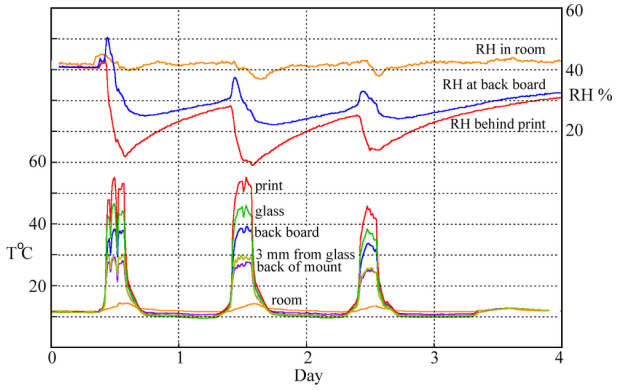

Figure 7. The temperature and RH distributions within a framed print behind glass as it was illuminated by sunlight which had already passed through a window.

A serious study of the microclimate in a building without air conditioning is therefore impossible with our present data stock. Every such campaign must be treated as a research project with its own data collection.

Placing the sensors is not a trivial matter. Even the relatively gentle light in a museum can raise the temperature of an object two degrees, depending on its colour. This will depress the surface RH by six percent. If direct sunlight, even filtered through window glass, reaches the sensor or an object, the temperature can rise by 40°C (figure 7), giving a huge change of local RH, depending on the buffer capacity of the enclosure. The ivory sculpture in the sun in a showcase (figure 3) was exposed to an extreme climate (figure 4) which was captured by a datalogger within the showcase, ivory coloured to give an accurate record of the suffering of the ivory object. This record could not be used to establish a 'proofed climate extreme' because subsequent examination revealed small clean cracks over the object together with dirt filled ancient cracks. However, the resolution of the photographic record of the object was too poor to show either type of crack.

This brings us to the one essential piece of data still missing: the evidence for change of condition of the object. This should be recorded together with the environmental record, but hardly ever is. The National Gallery, London, pioneered the real time study of colour fading. Few institutions are prepared to support such slowly unfolding projects, but many institutions are insistent on storing partial environment data that has little likelihood of providing valuable insight over the long term. There have been attempts to develop surrogate sensitive objects to set out in museum galleries, for example the tempera paint strips developed by Marianne

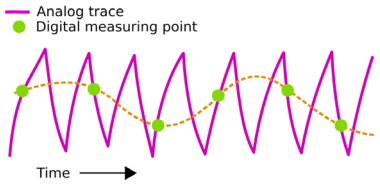

Figure 8. A datalogger which makes intermittent measurements can generate a completely different cyclic pattern of temperature and RH than that actually produced by the air conditioning.

Odlyha [4], but the rapid early changes measured in these strips seems to be a maturing process which is much faster than the rate of decay of tempera in centuries old paintings. Metal tokens are also available; their corrosion is measured by electrical resistance change or by weight change measured through vibration frequency. Such measurements are not yet commonly integrated with the collection of climate data.

Data as a series of point measurements

The thermohygrograph is an analog instrument which registers all the time, with a certain lag in response. Digital data loggers wake up at intervals to make a measurement. They can be set to measure once per hour, or once every minute, memorising the average every hour, or many other combinations of intervals. Intermittent measurement prolongs battery life but is vulnerable to a phenomenon called 'aliasing'. This is illustrated in figure 8. It is not important in naturally ventilated rooms but can cause misinterpretation of air conditioning, which usually generates a cyclically varying climate which can interact with the measuring cycle of the logger to register a spurious beat frequency cycle.

Calibration of sensors

Calibration of temperature sensors is very rarely done because even the cheapest sensors, thermistors, have become reliable. However, the sensor signal is subjected to electronic processing that may itself be temperature sensitive. Temperature compensation is quite a subtle design challenge in electronics, which cannot be assumed for data loggers operating far from room temperature. Cheap data loggers are also sensitive to battery voltage. In reality, we have no idea of the accuracy of temperature records.

A year is a long time in the life of a relative humidity sensor. Most survive only until they suffer a moment of condensation. There are long lasting RH sensors but many loggers use unstable sensors. In situ calibration of both temperature and RH is

best done with a psychrometer. This instrument has the advantage of depending on two temperature sensors, which are inherently reliable and whose identical readings can be checked. Furthermore, the RH signal is in the form of a temperature difference. However, its accuracy depends on how it is used. The conventional wisdom is that distilled water must be used but that is a simplified specification of the purity required. There must be no long chain alcohols or other film forming chemicals from sweat, which reduce the evaporation rate of water. These cause a greater error than using tapwater. Another largely ignored source of error is radiative heating from the body of the operator when using the sling psychrometer in a cold place. This can easily cause a five percent error in RH. This error can be avoided by using a clockwork or electrically aspirated psychrometer which has shielded temperature sensors.

The other commonly used RH calibrator is a saturated salt solution, sometimes encapsulated so only water vapour passes through a semi-permeable membrane. The problem with these devices is that for calibrating at a RH point below the ambient RH, the salt solution will be absorbing water vapour and thus diluting the surface solution. Diffusion of ions to equalise the concentration is very slow in unstirred solutions, so too high a RH is generated. This calibration method only works for high RH points above ambient, where the calibrating solution is losing water vapour. One can stir the solution, but this heats it up, thus increasing the water vapour

Figure 9. The psychrometer is suitable for in situ calibration, if the wick is free of film forming chemicals and radiant heating of the wet sensor is prevented. There are also transportable dew point sensors, which don't need wetting.

Figure 10. Data loggers have a valuable role to play in persuading the museum authorities not to be satisfied with bad storage rooms just because they are cheap.

pressure at the surface and increasing the RH at the cooler surface of the sensor. Lack of temperature uniformity is a frequent cause of error when using saturated salt solutions for calibration. A one degree celsius difference in temperature between calibrating device and the datalogger causes about a 3% error in RH. Few conservation departments have constant temperature cabinets for equilibrating the sensor with its calibrating aqueous solution. Calibrating RH sensors is difficult even in the laboratory and is inaccurate when done in situ.

Storing the data

There are several specialised scientific groups which have established highly effective and durable databases. Notably x-ray diffraction patterns and infra red spectra are available in standard formats and are well maintained by central organisations. Every one of these spectra is useful - each describes a chemical compound or crystal. Climate data are much more diffuse, much less universal in their usefulness and only occasionally throw up diagnostically helpful events, or dramatic failures of environmental control. The signal to noise ratio is thus very small, so it is unlikely that an idealistic group of people will gather their energies to establish a data bank. One must assume that environmental records will be stored locally in the institution, for routine measurements. For investigative use of dataloggers, one must hope that developments in scientific digital publishing will allow verbose experimental data to be stored together with the compact, readable article, and thus be available to sceptical readers wishing to re-examine the evidence.

Even if data are stored in a long-lived institution, the danger to durability is the chaos of competing formats in the computing industry, whose most influential companies are mainly interested in market share tomorrow. Idealistic groups and individuals have tried to establish durable standards in their particular profession, and for general purposes, but this has only further complicated the decision on what storage format to use by widening the number of alternatives. Looking back over the mere 20 year history of widespread computing power one is struck most by our inability to direct, or even anticipate its development. The many manufacturers of small dataloggers in particular have invented their own storage formats with no thought for compatibility with other devices, or for durability.

Recently, the XML standard, which is a standard for defining a format, has become widely used. It makes it possible for anyone to define a standard by tagging the data values in plain text, with a corresponding explanation of what the value represents, in another document or in the heading of the file. XML has the advantage of being, in principle, readable by any program for ever, but it is verbose and scarcely humanly readable.

For example, the first three lines of the following record:

```
My kitchen
hour temperature RH
10:00 18.7       56
11:00 19.3       53
12:00 20.7       50
13:00 22.0       47
```

are represented in a spreadsheet with XML file format by this code fragment:

```
 <gmr:Cell Col="0" Row="0"
ValueType="60">My kitchen</gmr:Cell>
 <gmr:Cell Col="0" Row="1"
ValueType="60">hour</gmr:Cell>
 <gmr:Cell Col="1" Row="1" ValueType="60"
>temperature</gmr:Cell>
 <gmr:Cell Col="2" Row="1"
ValueType="60">RH</gmr:Cell>
 <gmr:Cell Col="0" Row="2" ValueType="40"
      ValueFormat="h:mm">0.4166667</gmr:
Cell>
 <gmr:Cell Col="1" Row="2"
ValueType="40">18.7</gmr:Cell>
 <gmr:Cell Col="2" Row="2"
ValueType="30">56</gmr:Cell>
```

The "ValueType" is defined at another place in the file as 60 for text, 40 for a real number and 30 for an integer. Note that the hour-minute format has been automatically changed into a fraction of the day. Each cell is painstakingly described, even though the data is a simple repeating pattern of numbers in three columns. The whole file is about 150 lines long, because irrelevant details of the spreadsheet layout, such as the font size, are also recorded.

This example comes from the 'Gnumeric' spreadsheet, but 'Excel' will also export XML in a similar but not identical format.

In earlier, simpler days, it was the convention when storing naturally repetitive, columnar data that a few lines at the top of the file would describe the data layout. In this convention the data would be stored thus:

```
#My kitchen
#hour:minute temperature RH
10:00 18.7       56
11:00 19.3       53
12:00 20.7       50
13:00 22.0       47
```

The hash sign at the beginning of the top two lines marks a comment line, by long established convention in the unix operating system and its programs.

To make this data set more specific, the date should be added. Here, the confusion becomes comic. Many dataloggers only talk to the Microsoft Excel spreadsheet. Excel supports two different start dates. The default, inherited from Lotus 123, is January 1, 1900, as day 1. However, Excel for Macintosh uses the Apple clock, which has January 1, 1904, as Day 0. The Lotus 123 date, which the tender seedling of the now dominant Excel thought it had to accept, had a wrong leap year and soon became a day wrong. The first widespread operating system, unix, settled on measuring time in seconds from January 1st 1970. ANSI dates start at 1 January 1601. There are many more date formats. Even the Julian day, used in some dataloggers, has varying definitions, but loggers never use the authoritative definition: days since noon of the first day of the year 4713 BC. You may think all this irrelevant, since the spreadsheet displays the date in calendar format, but it *stores* the date on file as a single decimal number.[5]

The solution is to ensure that the date field in the final, durable format file has the date-time expressed in the

file as a conventional calendar date in plain text, rather than a single number, as used for internal calculations in spreadsheets. However, the text calendar also has confused conventions. The first twelve days of the month are ambiguous because the US puts month before day, then year, while everyone else uses the day-month-year convention. The ISO date format solves this very neatly by using the logical sequence year-month-day-hour-minute-second. the ISO format for hour 16, minute 46 of the seventh of May 2007 is: 20070507T16:46:00. Dates formulated in this way sort well, and data sets can easily be merged, because the most significant unit comes first, as in normal numbers. However, nobody uses the ISO date format. Excel cannot export it, though it can read it. The unreflective decisions of individual programmers and the conservatism of users have often prevailed over the wise deliberations of expert committees.

Physical storage of climate data

Even if the format is durable, the storage medium is not. Optical storage media have a predicted durability of decades, compared with hundreds of years for neutral paper. And paper's durability is not a predicted value, it is based on experience.

Conclusions

We currently store only a subset of the information needed to connect environmental influences with observed degradation of materials. Only very seldom is the measuring device sufficiently close to the object for it to constitute a definitive record for that object. The data are stored in a variety of formats with no convention about what format to use for data storage and interchange. This situation is entirely adequate to ensure quality control of the environment during exhibition and transport but it is unlikely that data will be retained long enough, and the measured variables be comprehensive enough, or close enough to the object, for scientific study of the effect of environment on materials over many years. One has to conclude that routinely collected environmental data is unlikely to yield interesting information to future enquiries.

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