IV Sustainability and Resource Management

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Sustainable Conservation of Collections – The Push for Passive

Abstract: This paper reviews how archives and books have been stored in recent decades, identifies the weaknesses of common principles and practice applied to storage involving mechanical air conditioning systems and aims to define 'sustainable conservation storage'. It encompasses the experiences of the author and contemporary conservators, archivists and librarians and attempts to explain why heating, ventilation and air conditioning (HVAC) control happened, why it has been wasteful and unsuitable for such storage and what form of storage archival collections really need in order to be conserved. It directs the reader towards new standards and codes that are now promoting passive climate storage wherever possible and to explore reducing or ceasing to use HVAC systems for managing storage climates. Above all, it urges custodians everywhere to reduce reliance on such equipment and thereby reduce risk to collections, reduce energy use, remove or reduce the costs of installation and maintenance of mechanical systems and reduce carbon emissions.

> Conserve:
> to keep and protect something from damage, change, or waste:
> – To conserve electricity, we are cutting down on our heating.
> – In order to conserve fuel, they put in extra insulation.[1]

Since at least the time of BS 5454:1977 the first British Standard covering storage of documents, environmental control in the United Kingdom and many other nations' archives and libraries has involved using heating, ventilation and air conditioning systems (HVAC) to stabilise and manage internal climates.[2] Standards and specifications from that time were an attempt to control environments in otherwise unsuitable rooms in existing buildings, being commonly the only spaces available for growing collections. These earlier spaces were often not designed for the storage

1 Cambridge Dictionary online, <https://dictionary.cambridge.org/dictionary/english/conserve> (last accessed 23 April 2024).
2 BS 5454:1977.

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of collections which need to remain moderately cool, dry and free from the risk of mould and pests. Many spaces were damp and traversed by pipework for water and heating serving other rooms. It is perhaps notable that the popular conception of storing records in damp and unsuitable spaces is by no means a twentieth-century phenomenon. Witness for example Charles Dickens, writing in 1859 in his novel *A Tale of Two Cities*: 'Your deeds got into extemporised strong-rooms made of kitchens and sculleries, and fretted all the fat out of their parchments into the banking-house air'.[3]

We may wish to gloss over the fact that the processing of sheep skins into parchment specifically involves the removal of fats: Dickens' understanding of the effects is misdirected. Nonetheless, the insight he provides is that storing records in bulk has for many generations involved placing them in any available space, however unsuitable for their long term conservation. He used the term 'strong-room', perhaps revealing a common notion that security from theft or disassociation was foremost in the custodian's mind and that at least at that time the properties of the material stored and what they needed to survive intact were not understood. These strongrooms were described as 'extemporised', by which one must infer that the records were taking up too much space elsewhere and whatever space could be found would be used instead for storage, without recognising whether or not those new spaces were going to conserve the records.

This author is by no means alone in having spent a career working in archives and libraries where collections were, have been and in too many instances still are stored in 'extemporised' spaces instead of purpose-designed constructions. It is clear from reading BS 5454:1977, the standard's first iteration, that there was a determination that ideally stores for archives should be purpose-designed but also a recognition that this could not universally be applied, especially given the diversity of locations (buildings) already used for archive storage. The standard sought to define what a new 'archive repository' should be like and determined that these characteristics should be attempted if possible in existing stores. The Foreword of the publication asserts:

> Although these recommendations have been made as specific and comprehensible as possible, the committee responsible for drafting them is well aware that some questions require more detailed and specialized advice for their solution, that many can be fully answered only in the context of local conditions and that to others no entirely satisfactory answer has yet been found.[4]

3 Dickens 1859, 34.
4 BS 5454:1977, Foreword paragraph three.

The last words in this paragraph may be read as an acknowledgement that, for example, the costs associated with creating a suitable store may not be affordable. It could be read as an admission that the state of knowledge of the topic was not sufficient at that time to provide clearer direction as to the material needs of archival collections. The preceding paragraph states:

> These recommendations are based on the nature of the records or archives that will form the bulk of the repository's contents. These records or archives may be in the traditional media, such as parchment, paper or printed books, or photographic or electronic media.[5]

However, the standard does not directly define what this 'nature' is, only what causes damage to archives. One is left to read between the lines in the body of the standards that the media are hygroscopic, i. e. that they can absorb water when in a damp environment and will also release it again in a drier environment (their reference to electronic media was magnetic tape, the binders of which are hygroscopic even if the tape itself may not be). The primary medium for water in this context is atmospheric, in the air surrounding the archives, though clearly the drafters of the standard were also thinking of risks associated with direct contact of liquid water by leaks, penetration and flooding: 'Basement accommodation where water may accumulate is unacceptable'.[6] The primary focus on environmental protection in the standard is temperature and relative humidity (RH) and from the outset the expectation is that suitable conditions are only achieved by the use of air conditioning, though at that time 'air conditioning' was largely only air temperature control. In addition to several sub-clauses in clause 7 on fire protection relating to the installation of air conditioning systems and ductwork, see for example:

> **5.7 Air conditioning.** The design of the repository should take account of the need for full air conditioning (see clause 9).[7]

Clause 9 focuses on 'Climatic conditions', asserting that unfavourable atmospheric conditions 'have damaged documents more extensively than any other single factor'.[8] The only solution to this particular risk is defined as the installation of air conditioning systems:

5 BS 5454:1977, Foreword paragraph two.
6 BS 5454:1977, Clause 5.1.
7 BS 5454:1977, Clause 5.7.
8 BS 5454:1977, Clause 9, 9.1 Introduction.

> Careful control and observation of temperature, humidity and ventilation within the repository and regular expert maintenance of the necessary plant is therefore essential.[9]

Subsequent clauses include definitions of the parameters deemed necessary for each of these three features: temperature, humidity and ventilation. Ventilation is considered a climatic feature itself and defined as requiring the air to be in 'continuous motion day and night, being recirculated to all parts of the repository six times an hour, with a 10% intake of fresh air'.[10]

No reason is given in this 1977 standard for the need for this level of circulation and fresh air ventilation. Later iterations of the standard (1989 and 2000) make reference to air conditioning that 'eliminates pockets of stagnant air' and that shelves must be adequately ventilated 'to allow the free movement of air and prevent the build-up of pockets of high relative humidity'.[11]

Although by the 2000 iteration there is express recognition that air tightness and thermal insulation or mass (in the form of 'high thermal inertia') are important and that there is 'Greater emphasis on […] provision of stable environments […] with minimal mechanical intervention', more reasons are given to justify fresh air ventilation.[12] Clause 7.4 Ventilation asserts that:

> The air within the repository should not be stagnant. There should be sufficient air movement to avoid pockets of stagnant air.[13]

For the first time a note is added making the bald assertion that, 'Air movement removes off-gassing of organic materials and prevents build-up of high relative humidity,' with no reference to any source that might back up the assumption that any off-gassing of these materials presents a risk to themselves (and equally failing to observe that the same standard recommends in extensive detail the enclosure of these materials in sleeves, folders and boxes, apparently leaving them to cook in an unspecified soup of their own juices).[14] One type of archive material alone, cellulose acetate, in the form of sheet film (negatives and transparencies), cine film and earlier reel-to-reel audio tape, can exist in archives in sufficient quantity to represent an internal pollutant risk, emitting as it does acetic acid as it decays over time. However, as a format it tends to be the target of projects to separate it from

9 BS 5454:1977, Clause 9, 9.1 Introduction.
10 BS 5454:1977, Clause 9.3.
11 BS 5454:1989, Clauses 7.2 and 9.7.
12 BS 5454:2000, Foreword.
13 BS 5454:2000, Clause 7.4.
14 BS 5454:2000, Clause, 7.4.1.

archives and provide different storage. Failure to recognise the inevitable and rapid deterioration of acetate has led to the decay and inaccessibility of negative collections; finally, BS 4971:2017, the new standard that inherited the conservation management elements of the old BS 5454, set out the requirement to separate and freeze this material as it will not last in temperatures above zero centigrade.[15] The clauses on this material in the old 5454 standards do not identify this material as an internal pollutant risk, however, so the perception of hazards associated with decay of archive materials are at best non-specific.[16]

Even if the drafters did know that only acetated plastics were the subject of their concerns about internal off-gassing (there is no evidence of this specificity), to propose running fresh air ventilation and constant cooling and dehumidification for an entire traditional archive collection solely for the purpose of attempting to manage the behaviour of one modern and minority format has since been recognised as inappropriate. Furthermore, since the temperatures recommended in those earlier standards were not going to conserve this material anyway, the approach may be seen in hindsight as wasteful and misinformed. Nonetheless, the notion of deleterious off-gassing and the need for fresh air in archives gained common currency and in this author's experience continues to be recalled by older engineers as justification for constant ventilation.

Retrospectively reviewing these standards implies that the lived experience of archivists and librarians included the use of stores that had sources of uncontrolled water or moisture and the only means conceived of overcoming this problem was by changing the qualities of the air in the store. Certainly in the UK this continues to be the situation for many archives. Reference to build-up of high RH does not identify the real sources of such water; it assumes moisture will continue to be input into a store even if there is no source. RH is a measurement, not an object: it requires input of water to stay consistently high. A waterproof structure with a high level of air tightness and with no additional internal sources of water will not change its moisture content significantly: there is no water input except tiny quantities in infiltrating air when it is at a sufficiently high moisture content. Nonetheless the fear of RH measurements has been commonplace.

An electronic humidity sensor sitting in an open place in a room where the temperature changes rapidly will automatically recalculate the RH of the air. RH in such a sensor is a mathematical calculation based on the moisture available in the air when the air is at a specific temperature. If the temperature suddenly changes it will recalculate and show a higher or lower RH but the actual weight of moisture in the

15 BS 4971:2017, Clause 5.1.4.2.

16 Ligerink and Di Pietro 2018.

room will not have changed. This simple fact is behind some of the misconceptions of what constitutes suitable storage and in its way may have led to the promotion of using HVAC equipment to control the temperature and moisture content of the air that it circulates. Witnessing a momentary increase in measured RH of air in a room has caused custodians to fear that their collection will rapidly grow mould but the reality of this process has been misunderstood and the solution was perceived to be air movement.

Air movement alone does not prevent mould from germinating. The germination of mould is reliant on a source of nutrition (such as a parchment document or a leather book cover etc.), a significant moisture content in that substrate (e. g. caused by liquid water or by the absorption of atmospheric water vapour over time) and a stable high RH in the air surrounding that substrate. Germination can be further accelerated by warmer temperatures but these are not essential: mould grows on food in fridges for example, as long as its nutrition has a high moisture content. These features of mould have been known for a very long time before these standards were published.[17]

Air movement does have the potential to dry moist materials. The surface of a moisture-containing material such as an internal wall that sits against earth outside with no moisture barrier will dry out if air is blown across it constantly. It is commonplace to dry a damp wall by preventing the build-up of vegetation against it or digging a trench alongside it and allowing the natural air movement outside to draw out moisture and keep the external surface dry and reduce moisture penetration. In the past the solution to moisture penetration inside a basement store has been to introduce rapid movement of air inside the room instead of remedying the source of the moisture. When archives have been accumulated in a damp room such as a basement a solution brought in to deal with this problem was HVAC equipment.

The standards referred to here reflected those assumptions in context, anticipating that the costs or practical obstacles of remedying problems in the many archive store buildings that had been inherited by archivists and building managers over generations were too insurmountable solely to recommend such structural improvement. Gradually but steadily institutions came to rely solely on mechanical engineers and the budgets held by building managers to dictate what was possible and affordable. Quite simply, it was perceived to be easier and in the short term at least cheaper to fit a new piece of equipment than to fix the structural problem. It appears the ongoing costs of energy and maintenance were not routinely included in comparing the cost of equipment versus the cost of providing a dry environment and, of course, while the standards actually said you needed to move and refresh

17 For example, see Snow et al. 1944.

air constantly regardless of the moisture properties of the structure there was no reason to do anything else but fit the equipment. This inevitably led to design engineers being seen as the pre-eminent source of knowledge needed to define how best to store archives. Archivists were obliged by building managers and architects to defer to the engineers in defining what is best for environmental protection of their collections. In every building project this author has been involved with (dozens over three decades) it has been the mechanical and electrical engineer who has been delegated by the project team and architect to define the environment and how it should be achieved even while demonstrating an absence of understanding of the nature of archival and library materials. Similarly, when reviewing failing systems in existing archives, building managers have deferred to maintenance engineers and largely ignored archivists, librarians and conservators.

This historical analysis of reasons for increasing organisational reliance on HVAC is one perspective; another is the failure accurately to comprehend the hygroscopic behaviour of archival materials. Clues as to the possibility of a lack of knowledge are present in the standards. There is for example reference in BS 5454:2000 to environmental control being achieved by the provision 'of a building, or compartment within a building, that gives… a high level of hygroscopic buffering'.[18] It is true hygroscopic surfaces of walls, for example, can be used to absorb moisture in the air when the RH is high and release it again when it is low, thereby stabilising the air RH somewhat seasonally. But what about the archives themselves? Why would one need hygroscopic walls internally that will offer litres of moisture buffering, when your collection itself contains tonnes of embodied moisture and will give it up when the temperature rises and re-absorb it on cooling?

Another clue is the contradiction of proposing to allow good air movement between shelves to prevent the build-up of high RH but at the same time requiring the use of multiple layers of packaging to enclose records, thereby promoting microclimates inside boxes. If records from a location with a very high RH are placed, well packaged, into the store they will hold that moisture internally for long enough to promote mould growth inside, regardless of the RH of the room air at the time. Certainly, if the store is running HVAC systems continually drying and rapidly circulating air there is the potential for such a moisture-bearing box of archives steadily to dry out but nowhere do the standards suggest that the purpose of an archive repository is to act as a drying room.

These inconsistencies suggest that the relationship between moisture content and safe environments was not understood, nor was the physical and chemical nature of the archival materials. Furthermore, although monitoring environments

18 BS 5454:2000, Clause 7.2.

was recommended by those standards this did not extend to monitoring inside the boxes and packages holding documents. Perhaps if they had done there would have been earlier realisation that some assumptions were inaccurate. This may have led to a more scientific questioning of what constitutes safe storage for collections.

By the 1990s and beyond computerised control of storage climates and eventually the use of computer modelling became the norm in planning new and refurbished archive stores. The mechanisms for controlling air quality by sensors and equipment were confused with what archive collections needed, apparently without question as to why so many documents had survived centuries without tight mechanical control. BS 5454:2000 asserts that documents need to be stored and used in a strictly controlled environment deviating from a single set point by only ±1˚C and 5% RH.[19] These numbers are the typical hysteresis values in a computerised building management control system (BMS). They are not the requirements for safe conservation of archival materials which can accommodate wider seasonal variations without harm. It is true that rapid and wide changes in RH concurrent with rapid changes in temperature can cause stress on the structure of the materials but the achievement of stability does not need to involve circulating and changing the air rapidly and continuously. Packaging alone can reduce rapid RH fluctuations from above 10% down to below 3% and conversely stabilising RH by enclosure renders changes in temperature harmless if they remain under a safe maximum threshold.[20]

The impact on air RH of enclosed hygroscopic materials can be seen inside packages and on a much larger scale inside an archive store where the archives themselves and their hygroscopic properties are the dominant influence on RH readings. In such a scenario the short-term impact of a change in temperature is the opposite of that in the free air of a room. A good example of this can be seen in the graphs below (Figures 1 and 2). The data for these graphs were collected with a temperature and RH logger in the same location in the strongroom at the University of Bangor Archive before it was refurbished in 2015. In the first period the logger was placed on an open shelf; in the second recorded just over a year later it was placed inside a filled archive box on the same shelf.

The opposing patterns of change in each graph demonstrate that while a rapid upward change in temperature in free air will result in a measured fall in RH and vice versa, in the small area of tightly enclosed air inside the box with the mass of hygroscopic materials (paper and parchment) the opposite effect is recorded: the RH rises with an increase in temperature and drops as the temperature drops.

19 BS 5454:2000, Clause 7.3.

20 For example, see Batterham and Wignell 2008; Toishi and Gotoh 1994, 39.

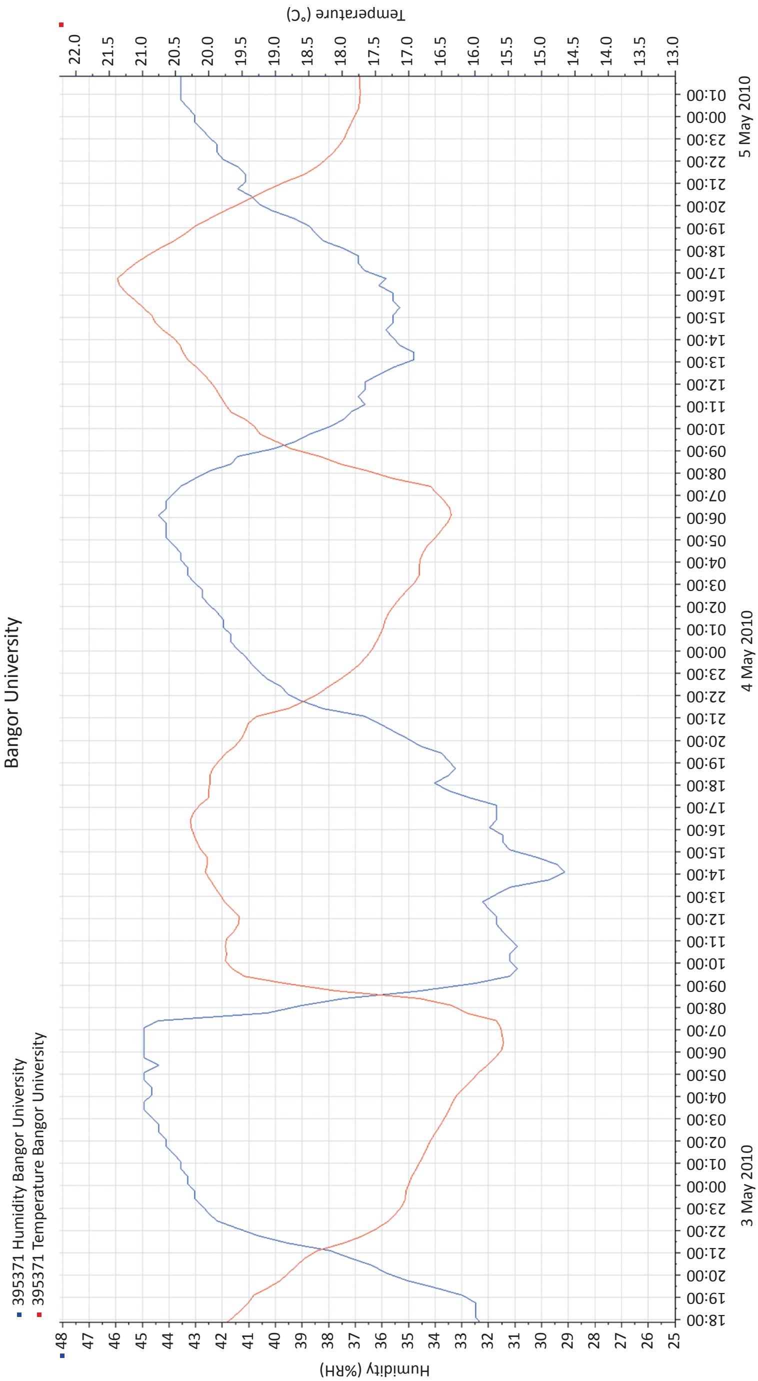

Fig. 1: RH and temperature trends outside an archive box. Image: National Conservation Service

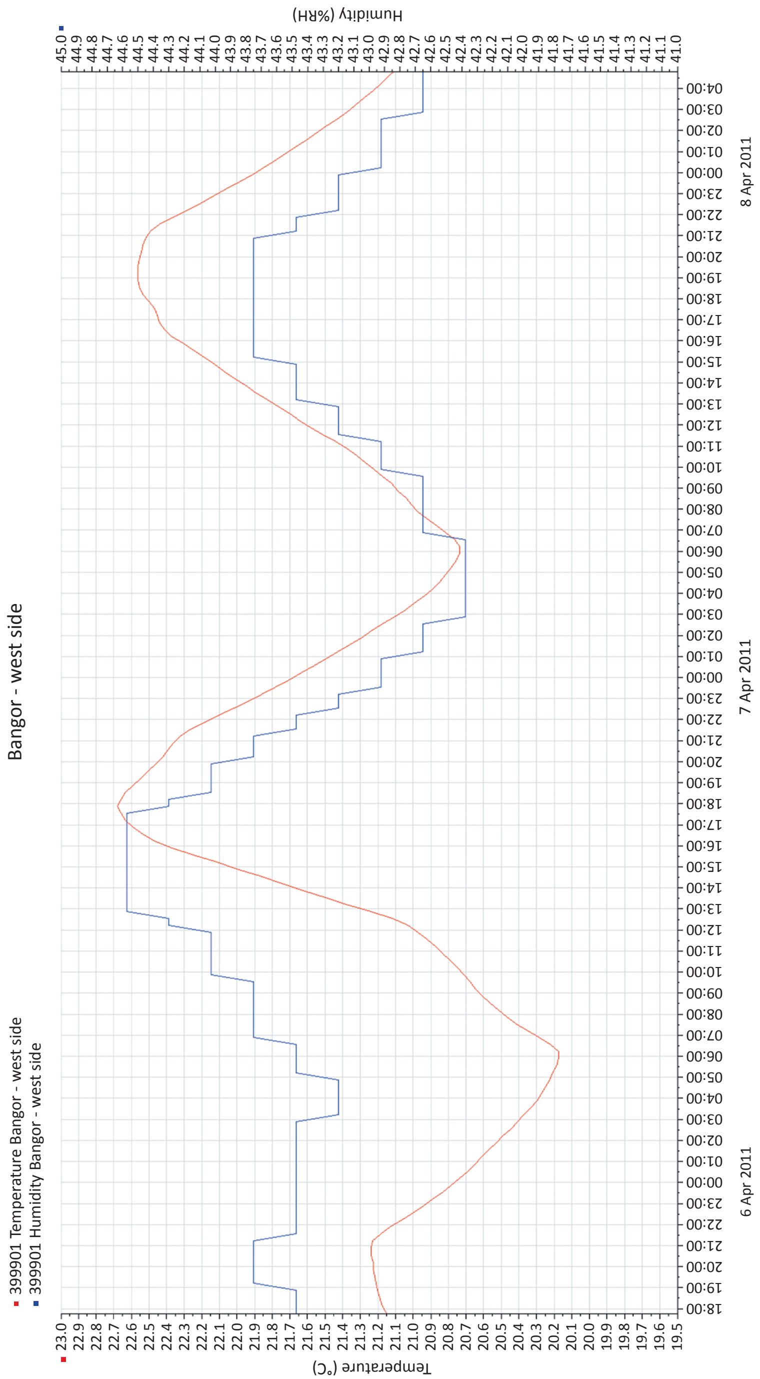

Fig. 2: RH and temperature trends inside an archive box. Image: National Conservation Service

It will also be noted from the above example that the amount of RH change inside a box is much less per degree change than outside a box: 0.6% RH for every 1˚C inside compared with 3.7% RH for every 1˚C outside.

At this particular archive the sources of rapid and wide temperature changes were resolved by insulation, winter excess heat was greatly reduced by re-routing and removing hot water pipework and excessive moisture input was stopped by removing a fresh air ventilation unit (and winter extreme dryness remedied through the same means). The store has since provided a much more stable and seasonally safe environment through passive means alone.

This examination of inside and outside boxes may seem like a microscopic observation but it is significant because the same effect happens in a room (and indeed in the atmosphere surrounding much of the Earth). A seasonal pattern inside a closed room that has much of its volume filled with archives and books (even one that is not designed to be very airtight, above the level now promulgated in BS EN 16893:2018 of <0.5 $m^{3/}m^{3/}$hr@50Pa) will present the same effect and the more airtight it is the more uncomplicated the pattern. Figure 3 below is a graph of long-term data recorded in a store at Brasenose College, Oxford, across nearly four years from 2015 to 2019.[21]

The upper line shows the periodic data for RH and the lower line for temperature (the vertical peaks are data when the logger was removed for downloading and returned). It can be seen from the graph trends that the RH rises as the summer warms the space and falls as the winter cools it.

There is a considerable imbalance between the weight of water carried by free air and that stored and available in archive and library collections. A single cubic metre of air at 50% RH and 15˚C contains c. 0.004 kg of water, or 4 millilitres (a small teaspoonful).[22] A single cubic metre of mixed archives (paper, parchment, leather etc.) equilibrated in air at 50% RH contains between 20 and 26 kg (20–26 litres) of water depending on the mix of materials, their age and production. An archive store measuring 10 m x 20 m x 3 m with approximately 50% of its room volume taken up by racks of archives, has c. 8,600 boxes on c. 1,400 linear metres of collections, weighing c. 56,000 kg (assuming c. 40 kg per linear metre of boxed documents). At the above RH this means 8–10% by weight is embodied water, so c. 5,600 litres of water (5.6 tonnes). The other 50% of the room is free air and contains about 1.2 litres of water. If the moisture content of the air rises to read 70% RH this equates to an input of c. 0.5 litres of additional water. If the archives absorb this 0.5 litres of water

21 BS EN 16893:2018.

22 For example, see <https://i.pinimg.com/originals/1c/2b/5d/1c2b5d5b0eaf6db9ae0833a0da20aacc.png> (last accessed 23 April 2024).

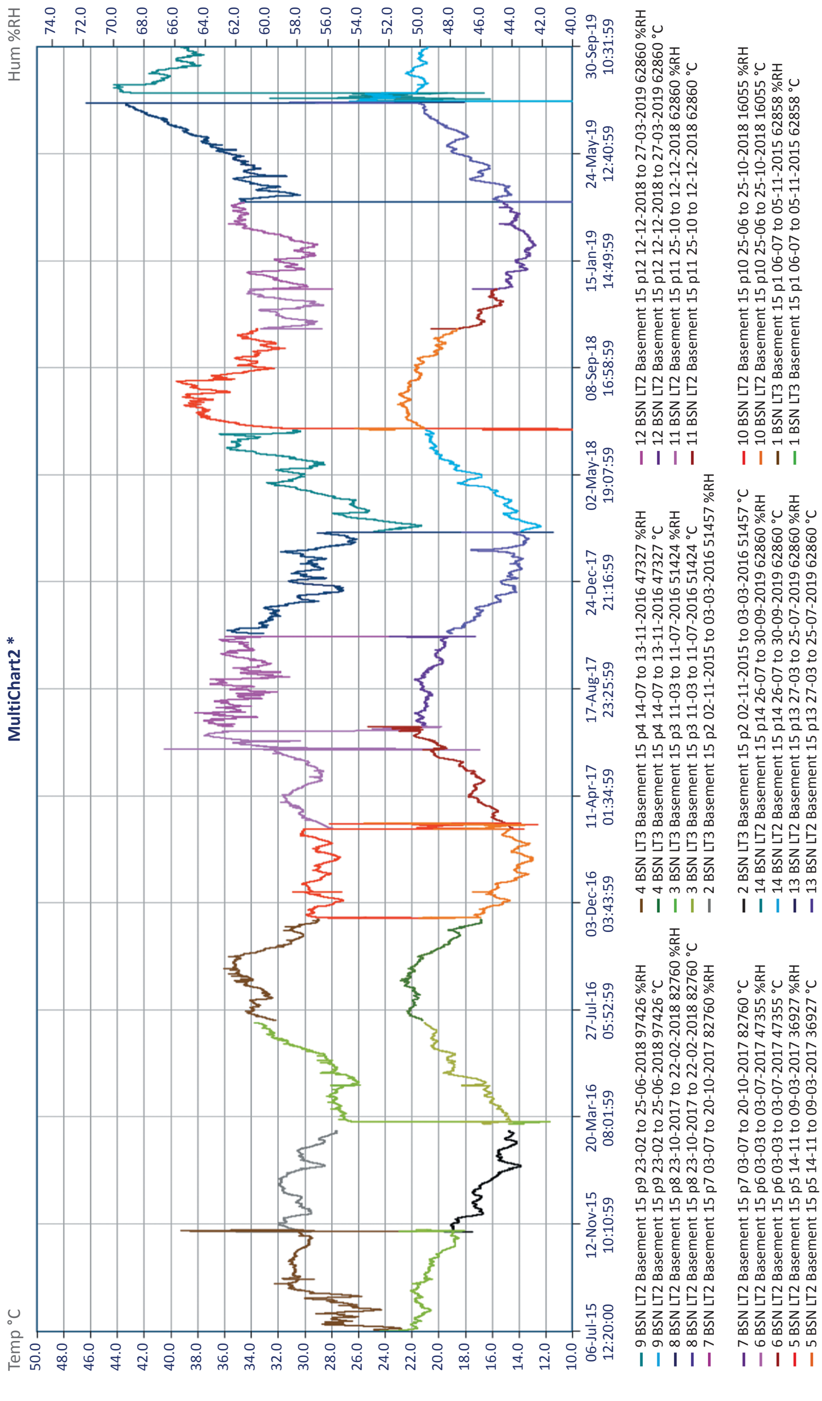

Fig. 3: Seasonal cycles of temperature and RH in an archive store (not purpose-built). Image: National Conservation Service

the RH of the air will drop back to 50% (the equivalent measurement of change for this tiny amount of absorbed water would be so small that no RH sensor would be able to display the difference in RH).

The implications of these observations are that the concepts of engineers and computer modelling used to justify the need for HVAC to control RH have been in error (current thermal modelling software is incapable of modelling the impact on RH of a roomful of archives, only modelling external atmospheric conditions). This has certainly been further complicated by the sector's own assertions that the nature of archives is such that they need tight control to prevent damage. While this might have been understandable in the late 1970s it was inexplicable in the 2000s since much of the scientific research demonstrating that hygroscopic materials present in archives can be safely stored and used across a wider range of conditions than prescribed by the standards was carried out in the 1990s and some of the key work was published in the UK archives sector.[23]

Our sectoral weakness in understanding the nature of archives and books and what it takes to ensure that they remain safely stored led to many years of wasted resources and increased risk through the use of HVAC systems intended to 'protect' them. A feature that should be noted is that mechanical equipment wears as soon as it starts to operate and the elements needed to keep temperature and RH within a very narrow range fail very quickly and need to be repaired. When they fail, engineering design has been such that the air supply, with its fresh air make-up following BS 5454, continues to be supplied and circulated through the room at the same rate (e. g. six whole room air changes per hour, every hour, day and night) until someone switches the fans off.[24] Furthermore, design engineers have been known consistently to calculate the room air change rate based on the empty room when in practice a store contains 50% or more of its volume in the form of archives, not of free air. So in effect the rate of actual air circulation by volume (in cubic metres) was more like 12 room air changes per hour. In the 2000 iteration of the standard the circulation requirement was to be 'determined from the cooling load to maintain the recommended temperature and humidity in the repository', thereby further removing the decision for what archives needed from archivists and handing it to design engineers.[25]

By the early 2000s more sophisticated means of controlling mechanical systems were being used, with BMS controllers operated by more and more advanced computers. It was notable in the UK that facilities managers and engineers were review-

23 McCormick-Goodhart 1996, 7–21.
24 BS 5454:1977, Clause 9.3 and 1989, Clause 7.4.3.
25 BS 5454:2000, Clause 7.5.3.

ing HVAC systems for archives after ten to twenty years of operation and replacing chiller mechanisms, moving from gas refrigerants to chilled water units. These were commonly centralised units that served other parts of the building, extending them to control temperature and RH in an archive air handling unit, a move away from using dedicated chillers for archive control. The objective, anecdotally, was that the new water units were more efficient and needed less maintenance than the old gas systems. Unfortunately, though, no-one in the engineering community involved appeared to have noticed that they would not work for dehumidification, particularly during the summer with high moisture content fresh air and even during the winter if the store air was cooler. The cooling coil temperature was frequently not low enough to reach the dew point and condense sufficient water out of the air to achieve the required conditions (a maximum of 60% RH).[26] The result was widespread failure of RH control and very high RH air being blown through rooms at the usual high velocity. This story is common to archives across the UK. More mould outbreaks and more widespread outbreaks (spread across a whole archive by the circulating air) were caused during this time as a consequence of failures of this kind than are likely to have been caused in stores with no such ‘control’.

A most common concern expressed to this author over the past quarter century has been that archives and librarians (and where present conservators) had no control over HVAC systems. They knew when there was a problem but had no authority to ensure that it was resolved and no access to BMS or manual control mechanisms. They were not even allowed to switch off HVAC units even if they knew how to. This shift of authority over collections conservation away from custodial professionals and towards building managers and engineers represents a generational change in management culture, not just a change in knowledge about the nature of books and archives and what they need in order to be conserved sustainably.

The wasted energy, carbon emissions and money caused both by misdirected standards and by the gradual takeover of control of archive store climates by non-experts cannot be overestimated. Finally, in the 2020s society more widely has begun to realise that energy is too expensive to waste and the carbon emissions caused by constant HVAC operation are contributing to climate change. Locally, archives and libraries have been learning that HVAC control of storage environments has not provided the protection that they needed for their collections. The concept of passive climate storage has been discussed and explored with vigour.[27] Passive storage is not new: arguably it is as old as the oldest documents and manu-

26 BS 5454:2000, Clause 7.3.3.

27 See for example Ashley-Smith et al. 2012.

scripts since mechanical control is a very recent possibility but also something that was being explored in the 1990s but which did not get taken seriously in the UK until this century.[28]

One recent impetus for exploring passive storage is the emergence of new standards that reviewed and replaced BS 5454. The key standard covering buildings that are intended to house all forms of heritage collections including library and archive materials is EN 16893:2018.[29] It was developed as a European replacement for the subsequently withdrawn BS 5454 and BS PAS 198:2012 *Specification for managing environmental conditions for cultural collections* and its drafting was led by the UK conservation and archives community as a direct response to the changing awareness of the weaknesses of the use of HVAC, particularly for hygroscopic collections including archives. It took the approach outlined in BS PAS 198:2012 of using risk assessment to make decisions about conditions for storage of different materials rather than defining fixed constants and added to it reviewed clauses concerning construction and improvement of buildings with an especial emphasis on requiring the design of storage and display spaces whose internal conditions do not rely on HVAC control.

For the first time in such a standard the principle was set out that a combination of airtightness, thermal stability and protection from water was key to achieving safe and stable conditions for collections in storage. EN 16893 does not set out required temperature and RH parameters for any specific material; it is a construction standard for the design and/or refurbishment of buildings that hold any form of moveable cultural heritage. In the UK archive and library sector another standard, BS 4971:2017, which was produced in tandem with EN 16893 (drafting of both led by this author), covered the specifics for archival collections. Formerly, this British Standard code of practice covered the 'repair' of documents. In its new iteration it sets out preventive conservation methodologies including the environmental management of archival collections and asserts that this should be achieved without mechanical intervention.[30]

Both standards encourage review of existing buildings with the objective of achieving safe environments in compliance with their clauses. For many existing archive and library stores this means switching off HVAC systems (failing or otherwise) and following this with a period of testing and exploration. The objective is to establish whether and how the store structure and its location can provide suitably cool conditions across the year (an annual average temperature lower than 18˚C),

28 See for example Cristoffersen 1996.

29 BS EN 16893:2018.

30 BS 4971:2017, Clause 5.1.2 Environmental stability.

allowing for warming in summer as long as there is natural cooling again in winter down to a safe level and relying on air tightness and the presence of the collections to stabilise RH and moisture content. In many instances, as long as a store has an uninsulated ground-contact floor slab and/or is well insulated against external temperature influences, this is easily achievable. Even stores with poor levels of airtightness have been shown to maintain a safely low RH for a prolonged period as long as the volume of archives in the stores are sufficient to dominate the RH of the air. The greater the level of airtightness the longer the time over which a collection's moisture content will remain at a safe low level (e. g. lower than 60% at the warmest time of the year). A passive climate management methodology is emerging from these many trials and successes.

If a collection of archives and books has been stored in an environment managed by HVAC systems at a set point of c. 60% RH the moisture content of the tonnes of archives will be equilibrated to that level. Switch off the HVAC and with a reasonably airtight structure the RH measured in the space, behind shelved books and inside boxes of documents will be found to be at this 60% level. If this level is the situation at the end of winter when conditions are cool then as the summer warms the room (assuming it is above ground and the sun's warmth has an impact) the RH inside the boxes and the room will rise, placing the collection at risk of mould germination. To avoid this risk water must be removed from the collection as soon as it is safe to do so and thereby to 'recondition' the collection so that it maintains a lower annual RH cycle. This is a similar principle to the use of silica gel in an airtight display case used to 'buffer' changes in RH caused by daily temperature cycles and absorb any moisture introduced by air infiltration. The better the airtightness of a display case the longer the RH levels inside will remain at or close to the preferred levels because the silica gel is not exposed to high quantities of atmospheric moisture. Once the gel has absorbed sufficient moisture, though, it needs that moisture removed in order that it can be re-used and provide the desired case conditions.

At 50% RH, paper holds c. 6% of its weight in water depending on its constituents (wood, cotton, linen, jute etc), leather contains 15% and cotton and linen ~6%.[31] New parchment at the same levels holds c. 13% water.[32] For the sake of calculating the management of moisture content and RH it may be reasonable to assume that a mixed archive contains approximately 10% of its weight in water when equilibrated to 50%. If it holds enough water to create an RH equilibrium of >65%, the archive has absorbed c. 30% more water than it held at 50% RH. An archive holding 50,000 kg of archives at 50% RH has c. 5,000 kg water and consistently at >65% has

31 Hansen 1986.
32 Haines 1999.

c. 6,500 kg of water, now weighing 51,500 kg in total, a 3% weight increase (1,500 litres of additional water).

To bring it back down to a level where air RH in a fairly airtight room will not rise to a high RH at the warmest time of the year (bringing it down to say 40–45% RH) it will need water equivalent to c. 4% of the total archive weight to be removed (2,060 kg or litres of water). Managing a passive climate archive store that is at least as airtight as EN 16893 expects involves monitoring inside packages, observing the change in RH across the seasons from cooler to warmer temperatures and, if enough infiltrating airborne moisture has over time caused the summer peak of RH to rise to or above 60%, removing the excess water.

It can be seen from the illustrative sums used here that a great deal of water needs to be absorbed if the summer peak is up to or over 60% RH, especially if it rises from an initial base winter level in early years at c. 40% and an annual cycle of up to 10% variance. This indicates that it will take many years from that base for the moisture content to reach that high. Since it seems there is no scientific evidence that confirms there is always an annual net gain in moisture content regardless of the level of airtightness and annual exchange (for example from the opening and closing of store doors and reading room retrieval during office hours), the simple message is that a 'dry' collection in an airtight store that has no other sources of moisture penetration will remain safely dry indefinitely (though it may be safer to assume that this net gain exists, however small annually). Furthermore, the smaller the seasonal change in temperature, from say 13°C in winter, the narrower the cycle of induced RH change across the year (i. e. change only caused in the measurements by a temperature change, not by input or loss of moisture). If the summer peak is no more than 17°C, a seasonal variance of only 4°C, the RH cycle may be less than 4% RH, lifting from 40% to 44% for example, a peak that does not put the collections at risk. This is the scenario that existing archives need to work towards and new designs need to promote.

When testing the properties of an existing archive by switching off systems, since it is often a failed HVAC dehumidification system that has caused high moisture content, using that system will not reduce the water content to 'reset' the collection (though in some instances, simply closing off the fresh air make-up to the supply improves the capacity of the chiller coil to remove moisture from a now recirculating-only air supply). In this scenario another form of dehumidification is needed temporarily. Drying this collection to bring it from >60% RH down to c. 40% will take a finite amount of time that is determined by the water extraction capacity of the dehumidifier used and the size and airtightness of the archive. Using the above 51,500 kg 'moist' archive example and applying a desiccant dehumidifier that extracts 35 litres per day on recirculating air only and constantly drying (with very low air infiltration from elsewhere), it will take as little as 28 days of energy input to remove the necessary amount of moisture. Once this is done the collection should be safe for many years to come if the building structure supports it.

Critically perhaps, the above means of managing the climate in the stores means manual control of dehumidification, allowing the air that is a vehicle for drying collections to continue to dry even when room air returning has reached the levels sought inside boxes. The RH in a box and within archive materials (or within the text-block of a book, evinced by monitoring in the enclosed space behind shelved books) must reach the target levels to be deemed ‘dry’ and will do so more slowly than the recirculating room air returning to the dehumidifier. Allowing a BMS sensor to monitor only the free air to control the dehumidifier will cause the dehumidifier to be switched off automatically when the dry air is recorded by the sensor, only switching back on when more moisture from the collections is emitted into the space. This intermittent drying, switching on and off automatically, will take much longer to bring the moisture content of the collection to the desired level. If BMS sensors can be installed inside filled boxes, they may overcome this, though to date this has not been seen in operation; however, in practice there is no need for this process to be controlled remotely by a computer setting. Manual control, with decisions about when preferred conditions are reached being made by custodial staff, is entirely workable and may be preferable, being less prone to ‘tinkering’ by well-meaning BMS maintenance engineers or poorly set-up software and hardware.

The reservations of the drafting committee for BS 5454:1977, set out in the Foreword, that solutions for establishing safe conditions in some existing buildings were potentially out of reach, were unduly pessimistic, even if reflecting the more limited materials available at the time. Many ground-level or below ground-level rooms, especially from that era and previously, have uninsulated floor slabs. Improving temperature stability would only involve insulating or re-routing hot water pipes and covering and insulating windows; the ground slab provides both a summer cooling mechanism and a winter minimum threshold. Improving airtightness would only involve blocking up windows, filling holes and wider cracks, putting competent seals around doors including threshold seals and painting the walls and ceilings with a membrane paint (which is invaluable on new constructions also).[33] Rising or penetrating damp can be remediated with tanking paints or tracing and removing the source. Once improved, the need for HVAC control is removed for good, if it was ever a relevant solution.

The above climate strategy implies that there is no place for fresh-air ventilation under any circumstances but that may not be advisable. If a continuous period

33 For example, see <https://www.ribaj.com/culture/imperial-war-museum-centenary-archive-duxford-airfield-architype-sustainability-concrete-corten> (last accessed 24 April 2024).

of work is needed inside a smaller store, changing it temporarily to an occupied space rather than an otherwise largely unoccupied space, CO_2 levels may rise to an unhealthy level. At that point it may be necessary to allow a period of fresh air ventilation to reduce CO_2. Or if a fire starts inside a store, smoke may need to be extracted after the fire has been put out. One store in the UK has a problem of radon gas emitting from the concrete structure of which it is composed, requiring periodic purging with fresh air. Whatever the reason, ventilating a store for a short period will only have a short-term impact on the collections. Even if it is needed for long enough potentially to increase the moisture content of the collection and there is no moisture control of the fresh air (it can be routed through a desiccant) the above routine of removing any measured increase in moisture content can be carried out safely following the ventilation, with no negative impact. Fitting a means of ventilating, capped off when not in use (which may be never), is always advisable.

The objective of both the recent BS and EN standards is to achieve more sustainable conservation of cultural heritage. The word sustainable is commonly used but not always specifically and it may be worth the archive and library sector defining what ‘sustainable conservation storage’ means and to convey this to engineers, architects and building managers in preparing them to develop news means of designing stores. The foregoing descriptions of how such collections can safely be stored indefinitely in airtight, watertight and well insulated spaces indicates that ‘sustainable conservation storage’ means stores:

- that are not reliant on constant intervention – conditions change slowly, allowing time to understand whether any changes are needed;
- that provide a suitable, stable climate achieved by building structure alone;
- in which climate management is carried out by custodial staff, not automated with BMS space sensors;
- that do not require continuous energy to maintain internal conditions;
- that can be left unattended if circumstances force this (such as pandemics or power failures) without the risk of the internal climate deteriorating.

In addition we should require that stores are constructed using long-lasting materials (ideally with low or no carbon emissions). Reliance on mechanical systems not only perpetuates the carbon emissions inherent in their manufacture and in operation but may also serve to promote the use of short-lived and poor-quality structures which, whenever the mechanical systems fail, place the collections at risk. Constructing well designed, heavily insulated, airtight and watertight buildings to house hygroscopic collections should result in long-lasting structures that do not need to be replaced regularly over the course of the intended conservation ‘lifetime’ of collections. Such planned longevity of buildings will also help greatly to reduce our sector’s carbon emissions.

In recent years numerous archives in the UK have reviewed their store buildings and wherever the stores have been found to be sufficiently sustainable they have ceased using HVAC systems, moving to passive stability and back-up dehumidification only. In doing so they have greatly reduced their current and future financial burdens, are reducing risk to their collections and are playing their part in reducing national carbon emissions. Some organisations find their stores are too poor in quality and are in locations too exposed to external conditions (for example on upper stories and surrounded by spaces that are continuously heated in winter). These organisations find they must make more substantial commitments to relocate stores and invest in good, sustainable design that allows their capital investment to be recouped over time. But when they do, as so many are now doing, they are creating much longer-term storage protection in ways that will conserve their collections for generations to come.

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