Preservation of cultural heritage: the design of low-energy archival storage

Dr Tim Taylor[a,b*]

[a]Atkins, Woodcote Grove, Ashley Road, Epsom, Surrey KT18 5BW, United Kingdom
[b]Cardiff Metropolitan University, Llandaff Campus, Western Avenue, Cardiff, CF5 2YB, United Kingdom

Abstract. The preservation of important cultural collections in museums, galleries, libraries etc. provides a legacy for future generations to research and experience their heritage. Guidance and standards for the design of archival storage facilities have typically focused on the provision of a controlled, unfluctuating internal environment. However, the latest revision of PD5454 "Guide for the storage and exhibition of archival materials" published by the British Standards Institution encourages designers to consider passive design approaches to reduce energy consumption. This paper reviews the key elements of the PD5454 document relevant to the environmental design of archives, and temperature stability metrics are proposed for assessing alternative passive design options. Analysis of a case study building designed by Atkins is used to illustrate the application of the proposed metrics. The paper concludes by considering issues to consider for the future development of thermal performance metrics for archives.

Keywords: archive storage; conservation; cultural heritage; BIM; thermal modelling; low-energy design; energy performance

1 Introduction

The preservation of historical and cultural artefacts provides a direct, tangible connection to cultural heritage for future generations. Archival storage facilities are designed for the function of mitigating the physical deterioration of their collections, as well as providing some safeguards to fire, theft and deliberate acts of damage. These collections are mostly irreplaceable, as well as potentially having significant financial value, and their damage or destruction may represent a permanent loss to the appreciation and understanding of our human history.

Until recently the design of mechanical services for archival storage has generally followed a paradigm of "close control" of internal conditions using energy-intensive Heating, Ventilation and Air-Conditioning (HVAC) systems. However, the most recent revision of PD5454 "Guide for the storage and exhibition of archival materials"

* Corresponding author. Tel.: +44 (0)1372 75 2628
E-mail address: tim.taylor@atkinsglobal.com

Y. Bahei-El-Din and M. Hassan (eds.), *Advanced Technologies for Sustainable Systems*, Lecture Notes in Networks and Systems 4,
DOI 10.1007/978-3-319-48725-0_2

(published in 2012 by the British Standards Institution) permits gradual fluctuation of temperature and relative humidity (RH) within archives where this is considered safe for the collections. This aims to reduce energy use for the conditioning of archives to lessen the impact on the environment as well as cutting down operational costs. Whilst PD5454: 2012 refers to the importance of maintaining stable temperature and RH conditions in archives, it falls short of recommending measurable criteria for assessing design or operational performance. This paper describes a case study of an archive storage facility designed by Atkins and the metrics developed to assess thermal performance at the design stage. These metrics are readily assessed using thermal modelling software and may be used for comparing alternative design options.

2 Design standards for archives

There are a range of published standards and best practice guidance for the operation and management of archives. In a UK context, PD5454: 2012 "Guide for the storage and exhibition of archival materials" is of primary relevance to the environmental design of archival storage facilities. At a European level, conservation standards are currently under development by Technical Committee 346 of the European Committee for Standardization (CEN/TC 346). Standards published under the auspices of CEN/TC 346 that are relevant to defining internal environmental criteria for archives include EN 15757: 2010 "Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials". The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) also define a range of temperature and RH performance target specifications in the ASHRAE Handbook "HVAC Applications".

Environmental risks for the preservation of archive collections cited in PD 5454: 2012 include:

- Mould growth (in damp conditions).
- Potential damage to documents if stored in excessively dry conditions (e.g. when folded, or rolled items).
- Accelerated chemical deterioration if temperatures are excessive.
- Presence of atmospheric pollutants (ozone and sulphur and nitrogen oxides).
- Off-gassing from construction materials or items stored in the archive (e.g. plastics).

Other relevant considerations for the design of archives referenced in PD5454: 2012 include:

- Thermally massive, air-tight construction is recommended to provide stability of environmental conditions. This is also beneficial in the event of HVAC control systems being interrupted by equipment failure or maintenance activities.

- To prevent uncontrolled air changes and potential ingress of pollutants contained in atmospheric air, a new repository "should be built to an air infiltration rate not exceeding two air changes per day".

In relation to temperature and RH conditions, PD 5454: 2012 states that gradual change within recommended control bands may be considered acceptable where this occurs over a period of a month or more. However, it also cautions that "a continuous weekly cycle up and down the ranges will cause a gradually increased rate of deterioration of most archival materials when compared with this rate of change in a very stable environment". Whilst stability in average annual conditions is preferable with respect to preservation, PD5454: 2012 acknowledges the importance of striking a balance with energy economy.

3 Case Study

3.1 *Introduction*

The Atkins design for Plymouth History Centre includes a number of archival storage areas. The largest of these is located on the second floor of the building, cantilevering above a new exhibition space. The design internal environmental criteria for the second floor archive are based on the ranges of temperature and RH defined for "mixed archives" in PD 5454: 2012, which recommends temperatures of 13°C to 20°C and RH of 35% to 60%. A comparison of these design conditions and monthly average weather data for Plymouth is given in Figure 1. Weather data for Plymouth has been sourced from the CIBSE Test Reference Year (TRY) weather file, which is derived from historic observations and is based on the most average weather data for that period i.e. it represents typical weather conditions.

The climate of Plymouth is strongly influenced by its proximity to the sea. This results in higher winter temperatures and lower summer temperatures relative to areas further inland. Figure 1 indicates that average external temperatures fall below the lower temperature band for the winter period (October to April) and therefore heating is likely to be required to maintain the specified internal temperature criteria. However, the data also suggests a significant opportunity for passive temperature control in summer, provided that the response to daily external temperature variation can be controlled. The annual average RH is 86% and does not fluctuate significantly during the year. Dehumidification may be required to control moisture introduced to the space via ventilation, infiltration and latent gains from occupancy, particularly during the summer months.

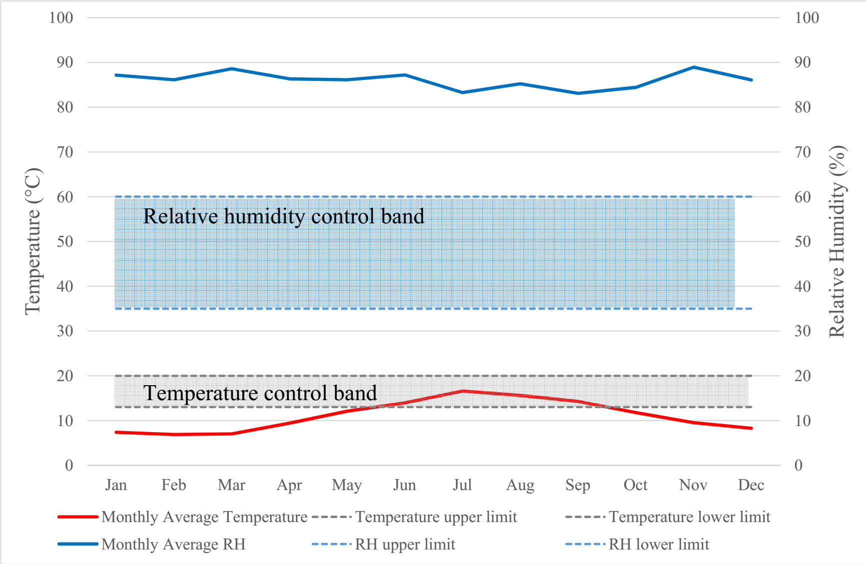

Fig. 1. Temperature and RH criteria for "mixed archives" and monthly average weather data for Plymouth

3.2 *Thermal modelling*

The proposed construction of the archive comprises an internal 300mm reinforced concrete skin. This provides the required 4 hour fire resistance recommended in PD5454: 2012 and is enclosed by a continuous layer of insulation. A rainscreen cladding is fixed back to the structure for external walls and the roof is constructed from an insulated flat roof system. Based on the results of a parametric study of thermal performance, the design of the archive has progressed based on the building fabric standards given in Table 1.

A thermal model for the archive was developed in IES Virtual Environment (Figure 2). To simulate the internal conditions within the archive, internal heat gains arising from the presence of people and the use of electric lighting need to be accounted for in the thermal model. Both archivists and visitor groups are anticipated to require access to the collection. Making provision for visitor groups in the design is an unusual requirement for this type of archival storage facility. Although the proposed archive tours are of short duration, the presence of people contributes sensible and latent gains to the space and has further implications for the ventilation system design. Heat gains from electrical lighting have been calculated based on an LED lighting installation with automated presence detection controls. An average infiltration rate of 0.022 ACH has been assumed. This is based on achieving a building envelope air permeability of 0.4 ACH at 50Pa (a standard previously achieved in the Hereford Archive and Repository that was designed to PassivHaus standards, as reported by Grant & Clarke). Ventilation to the archive incorporates CO_2 demand control.

Table 1. Archive building fabric performance standards

Element	U value (W/m²·K)
Roof	0.12
External Wall	0.18
Exposed Floor	0.18
Internal Floor	0.18

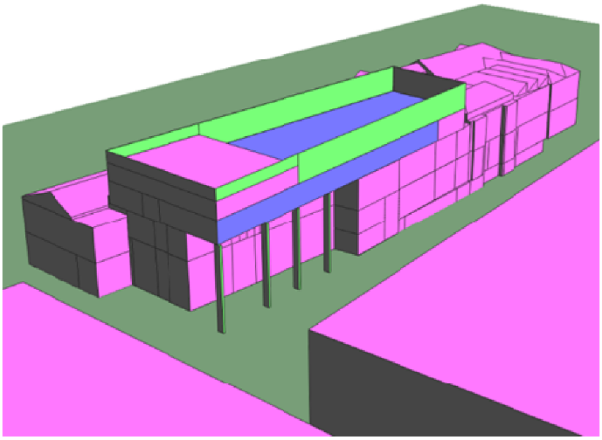

Fig. 2. Image of Plymouth Museum archive model geometry in IES Virtual Environment (second floor archive shown in blue)

The thermal performance of the archive was simulated using the Plymouth CIBSE TRY weather file.

3.3 *Results*

The air temperature profile within the archive without active heating, cooling or dehumidification (i.e. “free-running”) is shown in Figure 3 alongside the external dry-bulb (DB) temperature. Summary statistics for the variation of temperature are given in Table 2. Four metrics are reported:

$\Delta T_{max,\ day}$: the maximum daily variation in air temperature.

$\Delta T_{max,\ week}$: the maximum weekly variation in air temperature.

$\Delta T_{avg,\ month}$: the magnitude of change in average internal air temperature from the preceding month.

$T_{avg,\ annual}$: the annual average internal air temperature.

Table 2. Summary statistics for thermal performance of the Plymouth Museum archive in free-running mode

Month	ΔTmax, day (°C)	ΔTmax, week (°C)	ΔTavg, month (°C)
Jan	0.30	0.64	0.37
Feb	0.29	0.65	0.87
Mar	0.30	0.51	0.08
Apr	0.31	0.72	0.72
May	0.37	1.08	1.78
Jun	0.32	0.76	1.07
Jul	0.33	0.85	2.12
Aug	0.29	0.51	1.11
Sep	0.29	0.62	0.63
Oct	0.28	0.77	1.39
Nov	0.30	0.83	2.16
Dec	0.30	0.61	1.29
Maximum	**0.37**	**1.08**	**2.16**
Annual average internal air temperature (Tavg, annual)			**15.4°C**

4 Discussion

The thermal modelling results demonstrate that an airtight, thermally massive construction enclosed with insulation is effective at isolating the case study archive from daily and seasonal variations in external temperature. The annual internal temperature profile shown in Figure 3 is approximately sinusoidal and falls within the specified temperature control bands of 13°C and 20°C for the majority of the year. This indicates significant potential for passive operation of the archive, thereby reducing energy use.

Daily fluctuations in internal temperature are sensitive to assumptions regarding the infiltration rate and internal gains. With respect to occupancy, this implies access to the archive should be restricted as much as reasonably possible in order to maintain a stable internal environment. It also highlights the benefits of specifying low-energy electrical lighting with appropriate occupancy controls. Infiltration has an impact on both the daily temperature and RH stability of the archive and the design should aim to reduce unwanted air leakage. In addition to reducing infiltration through appropriate detailing of the construction elements, consideration should also be given to providing entrance lobbies and sealing of services penetrations.

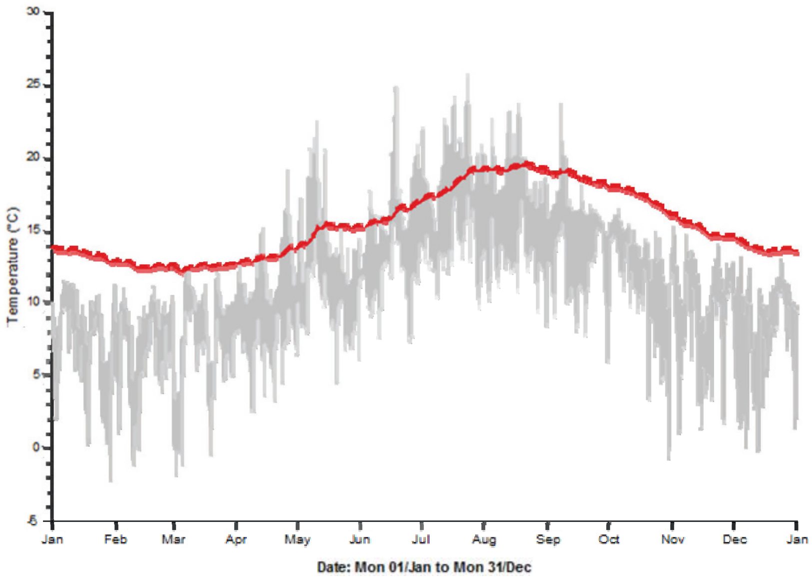

Fig. 3. Annual temperature profile of the archive in free-running mode (internal temperature shown in red, external temperature in grey)

The four metrics developed for assessing the thermal performance of archives in "free-running" mode can enable the performance of alternative design options to be compared as follows:

- The maximum daily and weekly variation in air temperature can be used to assess the thermal stability of the archive to short-term weather conditions and the possible impact of temperature fluctuations on the collection. It is the impact of changing temperatures on RH that is likely to be the concern for preservation: PD5454: 2012 notes that RH increases by approximately 3% for each 1°C decrease in temperature (and vice-versa) for small temperature differences (±5°C or less in a room at about 20°C).
- The magnitude of change in average internal air temperature from the preceding month and annual average internal temperature can be used to assess the potential for passive temperature control of the archive over longer time periods (i.e. in response to seasonal variations in external temperatures).

5 Conclusions

This paper has proposed four metrics that may be used for assessing the temperature stability of archives and demonstrated their application to a case study building. These metrics are assessed in "free-running" mode where passive operation is an integral part of the environmental design strategy. Future development of metrics for assessing the thermal performance of archives should consider:

- The selection of weather data used for assessing performance at the design stage. The impact of climate change should be included in the analysis of passive design options, given the intended longevity of archives and their collections.
- Assessment of dynamic variations in RH, including hygroscopic buffering by both construction materials and the items stored within the archive.
- The assessment of radiant temperatures within the archive and potential for air stratification. Air circulation may be required to ensure the air within the archive is well mixed.
- Monitoring and assessment of the actual operational performance of archives in terms of temperature and RH stability.

References

ASHRAE Handbook "HVAC Applications", ASHRAE, 2011.

BS EN 15757: 2010 "Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials", The British Standards Institution, 2012.

Grant, N., Clarke, A., 2016. "The first Passivhaus Archive in the UK", International Passive House Conference. Darmstadt, Germany.

PD 5454: 2012 "Guide for the storage and exhibition of archival materials", The British Standards Institution, 2012.