The climate control of the Arnamagnæan Archive

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Abstract

The small archive of the Arnamagnæan Institute is almost passively air conditioned by being placed between a corridor in a permanently warm Copenhagen university building and the outer wall of the building. It is well insulated towards the warmed building and thinly insulated towards the outside, so that its temperature is approximately one third of the way between the building interior temperature and the running average outside temperature. The annual average temperature in the archive is above the annual average outside so that the annual average relative humidity (RH) is automatically lower than that outside: it is about 50%. The day to day RH remains steady over the entire year because of humidity buffering by the walls and by the hygroscopic content of the archive. Fine control of the RH is provided by pumping in outside air when it is, by chance, of the right water vapour content to push the archive RH towards its target 50% RH. The energy consumption by the pump is negligible but there is heat from the usually warmer building interior passing through the archive to the outside, so it does use energy. The RH has remained within the envelope of 48% to 58% over a period of 7 years. The temperature has varied within the range 14°C to 24°C with a smooth annual cycle.

Introduction

The recent relaxation in environmental advice to archives, led by the document (PD5454:2012) from the British Standards Institution, allows large saving in the complexity of air conditioning and a consequent saving in fuel and maintenance.

The recommendation allows a considerable variation in both temperature and relative humidity. Paradoxically, allowing a seasonal variation in temperature through the year offers the side effect of a stable relative humidity without active control, well within the recommended limits.

The Arnamagnæan archive anticipated by several years the current relaxed official advice and thus offers a long period of evidence for the reliability of a semi-passive air conditioning system.

A description of the archive

The archive interior is shown in figure 1. Its setting in the building is shown in figure 2.

The structure of the archive is made of reinforced concrete. Outside this is thermal insulation of varying thickness. Attached to the inside surface of the walls is a 50 mm layer of aluminosilicate fibre blocks. This is the best humidity buffer among orthodox construction materials. It is coated with a single layer of silicate paint, which prevents dusting while allowing air to diffuse into the blocks. The floor is hardened with fluosilicate. The ceiling is 4 layers of 13 mm gypsum board with insulation under the concrete slab. The shelving is hard enamelled steel. The massive concrete walls were specified for physical rather than climatic security but add useful heat capacity. The door opens to the office area, so air infiltration is mainly from the building rather than from the outside.

The air conditioning principle

The archive is exposed on four sides to a typical office temperature, kept stable by the comfort demanded by its human occupants. Two other sides are exposed to the unstable but seasonally predictable outside temperature. By careful calculation of the thermal insulation in each wall, combined with the significant heat storage capacity, the temperature in the archive at any time of year is automatically held at about one third of the difference between inside and outside temperatures, without active monitoring and control. While the annual cycle of the outside temperature is from 20°C to -5°C the archive varies only from 23°C to 15°C. This cyclic temperature is shown over seven years in figure 4.

An automatic consequence of this temperature cycle, combined with humidity buffering by the archive content, is a stable relative humidity (RH) around 50%. This happens because the RH outside is often close to 100% in winter. When this air infiltrates to the relatively warm interior, its RH decreases. Its ratio of water molecules to air molecules (the mixing ratio) remains the same inside as out, but the RH decreases. This is because the RH is defined as the ratio of the actual water vapour concentration to the maximum possible, which increases as rising temperature increases the tendency of water to vapourise. It seems strange to use such an indirect definition of water vapour potency in a museum context but experiments over many decades as well as theoretical thermodynamics show that the amount, and the influence of sorbed water in hygroscopic materials such as paper is proportional to the RH of the environment over a wide range, rather than depending on the water vapour concentration. Constancy of RH is therefore a prime concern for con-

Figure 1: A view of the interior of the archive. It measures 10 × 4 × 3 m high. The lobby is visible beyond the armoured and insulated door. The duct for pumped outside air is just visible above and to the left of the door.

Figure 2: The building in Copenhagen University which houses the Arnamagnæan Institute. The archive is behind the windowless portion of the long facade.

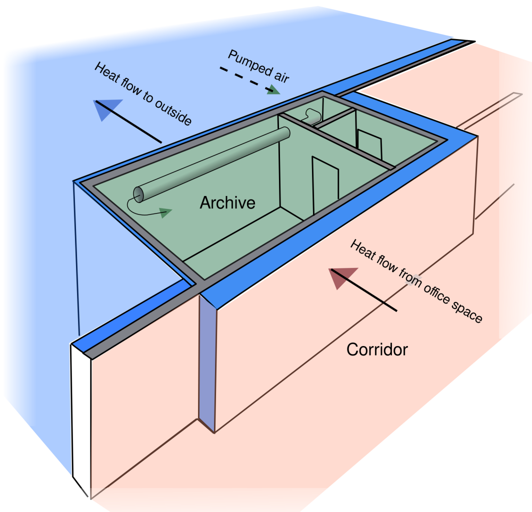

Figure 3: A perspective sketch showing how the archive temperature is set by the competing heat flows through the interior walls and the exterior walls. The RH is fine-tuned by pumping in air when by chance the outside air has suitable water vapour content.

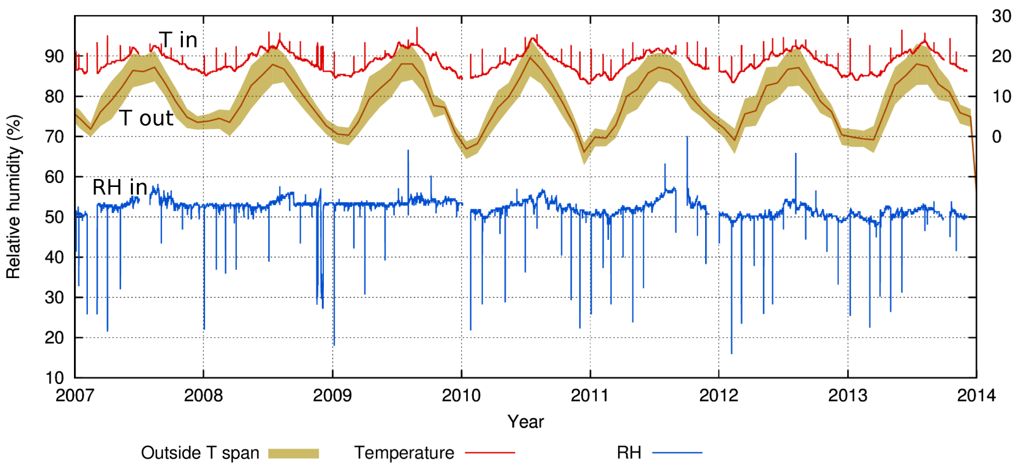

Figure 4: A record of the archive climate over seven years, compared with the monthly average outside temperature and temperature span. The spikes show the climate in the conservator's office when the logger was retrieved to extract its data.

servators. Constancy of temperature is less important; indeed the low winter temperature in the archive is an aid to preservation.

Humidity buffering

This ideal explanation glosses over the day to day variation in outside temperature and RH. This will disturb the inside climate because the archive exchanges air with its surrounding whenever it is opened. Buffering against this disturbance is achieved mostly by the archived hygroscopic materials, which absorb and desorb water as the environmental RH changes. One might object that valuable archives should not be pressed into servicing the climate in this way, but these materials exchange an infinitesimal amount of water when they stabilise the archive. Paper reacts to the ambient RH regardless of how that RH is controlled, so the idea that archived materials should not be burdened with controlling their own climate is scientifically meaningless. In a well filled archive the self-stabilising effect gives a more constant RH than is usually achieved with full air conditioning, and therefore stresses the materials less.

In the Arnamagnæan archive many items are enclosed in boxes with generous air space, so the buffer capacity is smaller than one would estimate from a visual inspection. For this reason there is a secondary mechanical climate control which guards against high RH in summer, when the archive is at almost the same temperature as outside. Occasionally, by chance of the weather, the water vapour concentration outside is such that when pumped in, it will nudge the interior towards its target 50%. This mechanical system, which gives about half an air change per hour, does require computer control and mechanical components but its power consumption is very low. Its effectiveness is shown in figure 5. Although the energy used by the air pump is negligible, the heat energy moving through the exterior walls of the archive during the heating season amounts to about 14 kWh/m^3 per year

Humidity buffering is essential to the success of this climate control method. It only works if the air infiltration rate is low. In this archive it is about 0.1 air changes per hour. The exchange rate can be regularly measured by following the rate of diminution of the pulse of carbon dioxide which is emitted by people visiting the archive. This is conveniently measured over the weekend.

Humidity buffering is particularly important in winter, when the archive temperature is higher than that calculated to give 50% RH in the archive, and thus tends to depress the RH. The error in the prediction of the archive temperature at the design stage was happily compensated by forgetting to include in the calculation an estimate of the water vapour generated by human activity within the archive and in the adjacent office spaces. This serendipitous combination of errors causes the winter RH to be close to the target, without any active control. This is fortunate because the opportunity for pumping humid ambient air to raise the RH in winter is very rare. The effectiveness of

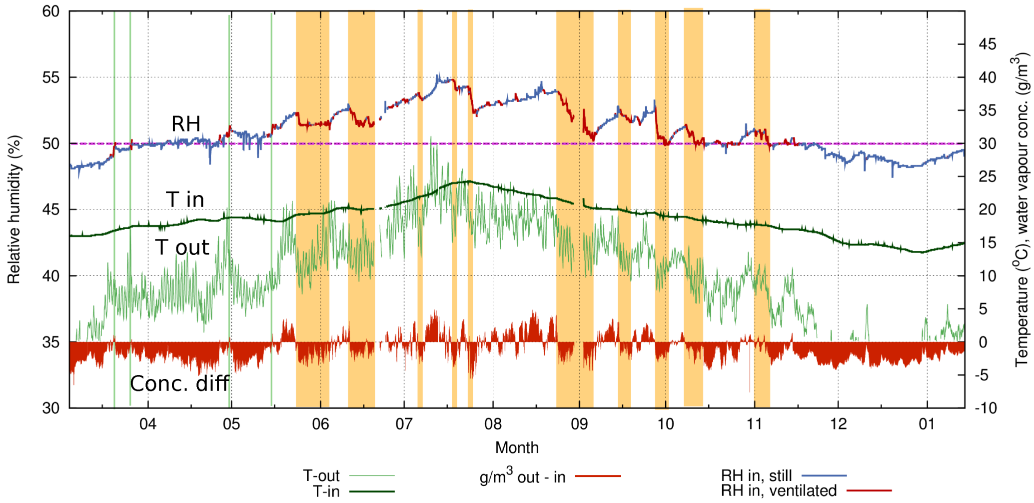

Figure 5: The year 2010 in the archive. The shaded vertical strips indicate periods when outside air was pumped in to raise the air exchange rate from 0.1 per hour to 0.5 per hour. The shaded strips correlate with the difference in water vapour content between the outside and the archive air. The dashed horizontal line marks the target RH.

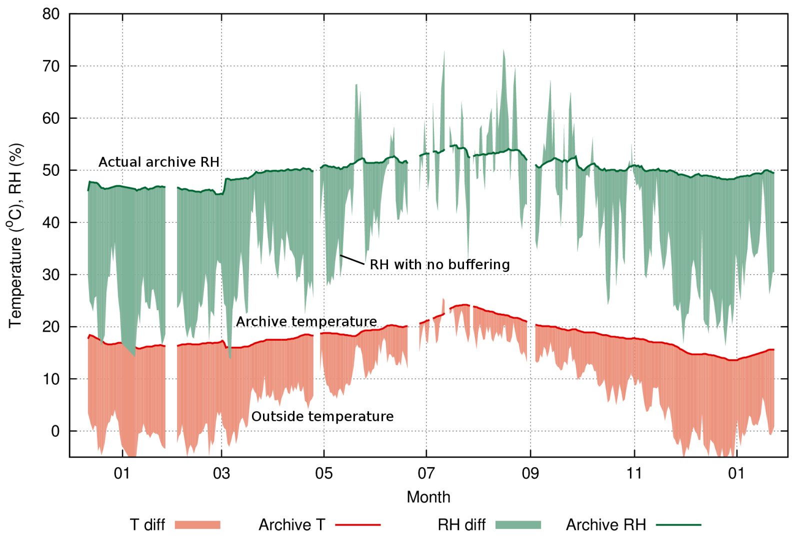

Figure 6: The climatic performance of the Arnamagnæan archive over the year 2010. The upper dark line is the measured inside RH, the limit of the suspended fringe marks the theoretical RH of outside air brought in and warmed, or occasionally cooled, to the inside temperature. The archive winter temperature is much higher than the theoretical value required for sustaining the 50% RH target. The RH is sustained by buffering by cellulosic materials and by water vapour from human activity. In summer the archive temperature is not sufficiently above ambient to prevent the RH rising above the target. Nevertheless, the archive RH remains almost constant, sustained by buffering and by intermittent injection of outside air.

the buffering of both humidity and temperature is shown in figure 6. This figure shows the stability of the RH and the gentle annual cycle of temperature. It also shows that the winter RH is much higher than would be predicted from the infiltration of air from outside, raised to the inside temperature. It is evident that infiltration is predominantly from the building interior, pre-humidified by people's breath.

Air pollution

A nearly airtight space is protected against air pollution from the outside but accumulates gases originating in the stored items and the furnishing. A particularly important pollutant is carbon dioxide from people within the space. There is a sharp spike in CO_2 when staff enter the archive. Typically there is one visit per day. This raises the concentration to 600 ppm, which is regarded as acceptable. The limit for permanently occupied spaces is generally put at 1000 ppm, depending on the local health regulations. The RH also rises briefly but is buffered by sorption into the archive materials.

Pollution from outside is intercepted by a carbon filter in the pumping system. Pollution generated internally, principally acetic acid vapour, is absorbed by recirculation through the same carbon filter.

Conformity with standards

At the time the archive was designed, the dominant, internationally influential standard for archives was British Standard BS5454:2000. The temperature specification was very strict: choose a temperature between 16°C and 19°C, then apply a variation limit of ±1°C to that temperature. The RH specification was a set point within the range 35% to 60%, with a ±5% range allowed around the chosen constant target. The archive nearly achieves the RH standard. The merits of the temperature standard have been discussed elsewhere (Padfield 2008, Ryhl-Svendsen et al 2010). After the archive was completed and put to use, the standard was relaxed considerably, but not enough to retro-regularise this archive. The successor standard, now reduced to advisory status, PD5454:2012, allows a temperature span from 13°C to 20°C for sensitive collections. The archive temperature exceeds this upper limit for nearly a quarter of the time. The maximum temperature in 2010 was 24.3°C. The effect on chemical degradation rate is approximately compensated by the lower winter temperature - the same fraction of the time is below 16.8°C. The minimum temperature was 13.5°C. The span of the annual cycle is typically eleven degrees.

The 20°C upper limit advised by PD5454 has no particular significance for chemical or physical stability of artifacts, yet it is already used as a firm specification. There is no catastrophic consequence from exceeding 20°C. There is good reason therefore to follow the normal building engineers' practice of specifying a temperature that can be achieved while the local weather is within its normal range while accepting that the outside temperature will be unusually high for short periods. For northern Europe, a reasonable design target for passive climate control of archives would be 25°C. This is achievable without mechanical aid whereas 20°C is not easily achieved. The higher limit is advocated in the joint declaration of the International Institute for Conservation (IIC 2014) and the Conservation Committee of the International Council of Museums, which endorses previously existing guidelines which set temperature limits at 16°C – 25°C (BIZOT) and 15°C – 25°C (AICCM & AIC). There are no reasons or references given for the lower limit, or for the upper limit. Whatever the reason, it is good to have retrospective endorsement of the climate in the Arnamagnæan archive.

Conclusions

The archive has performed well in providing a moderate climate. The RH has remained within 6% of 50% for the last seven years. The winter temperature is higher than it should be theoretically but works because the infiltrating air has been humidified by human activity within the building. The weather dependent pumping of outside air has contributed to keeping the RH down during the vulnerable summer period when the archive temperature is too close to ambient to hold the RH close to 50% while there is still a human contribution to the water vapour content of infiltrating air. In retrospect, there should be better sealing of the door against infiltration of office air.

Temperature variation in archives has hitherto been discouraged by stringent standards but the approximately ten degree annual span, without sudden changes, presents no scientifically documented danger to the collection. The 14°C minimum in winter gives a theoretical danger of transiently high RH at the object surface when it is taken out, depending on the temperature and RH of the reading room. However, a brief acclimatisation in an airtight insulated bag will entirely eliminate this risk. The summer temperature rises above the arbitrary 20°C limit advised for sensitive collection in PD5454:2012. We suggest that a fixed upper limit should be replaced by a 'design limit' which may only be exceeded for a small number of days in the year. Strict adherence to an upper limit that has no documented consequences if it is briefly exceeded will force mechanical cooling, which in turn forces dehumidification, in other words full air conditioning.

This archive is small and unusually situated at a corner of a larger building, but this principle of running the archive with a temperature cycle which rises to about the same as outside during the summer but remains warmer than ambient in winter has also been applied to large, free-standing archives. In this case it is only necessary to maintain a minimum temperature around

14°C in winter, depending on the local climate. Only thermostat control is necessary; the buffering by the archived material will automatically ensure a stable and moderate RH throughout the year (Padfield 2008).

A systematic treatment of the physics of low energy climate control in archives and museum storage is given in (Padfield et al 2013).

Acknowledgements

We thank Peter Springborg, former director of the Arnamagnæan Institute, for accepting an unusual climate control proposal. The calculation to optimise the insulation thicknesses was by Jens Eg Rahbek of Cowi consulting engineers, Lyngby, Denmark. The architect was KHRAS, Lyngby.

Notes and References

PD5454:2012. Guide for the storage and exhibition of archival materials. British Standards Institution.

Other examples of the deliberate use of a moderate annual temperature cycle in reducing the cost and complexity of climate control are presented in:
Tim Padfield, Poul Klenz Larsen, Morten Ryhl-Svendsen and Lars Aasbjerg Jensen (2013) 'Low energy museum storage' (in press). Papers delivered at the Paris conference of the Centre de Recherche sur la Conservation des Collections, October 2013.
www.conservationphysics.org/storage/low-energy-museum-storage.php

Morten Ryhl-Svendsen, Lars Aasbjerg Jensen, Poul Klenz Larsen and Tim Padfield (2010). 'Does a standard temperature need to be constant?' - Paper delivered at the Going Green conference at the British Museum, April 2009. Published in *Meddelelser om konservering* nr 1, 2010 pp13-20.
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Tim Padfield (2008). 'Simple climate control in archives is hindered by too strict standards'. Proceedings of the 8th Symposium on Building Physics in the Nordic Countries. Department of Civil Engineering, Technical University of Denmark, (2008) pp 1429-1436 ISBN 978-87-7877-265-7.
www.conservationphysics.org/ppubs/simple_ archives.pdf

IIC (2014). 'IIC announces declaration on Environmental Guidelines', *www.iiconservation.org/node/5168* (accessed at 2014-10-05).