LOW ENERGY AIR CONDITIONING OF ARCHIVES

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INTRODUCTION

Climate control in archives can be managed very differently from other buildings, but very often standard technology, and reliance on standard specifications is applied. This article is a re-investigation of how best to control the climate in archives, based on the chemistry of decay and the physics of the atmosphere, at first discarding the pedantic strictness of the archival standards but paradoxically showing that they can indeed be attained by very simple means.

Figure 1: "I have here the result of our combined efforts to build an archive with a stable climate."

THE IMPORTANCE OF HUMIDITY BUFFERING TO EFFECTIVE CLIMATE CONTROL

The potential for synergy between relative humidity (RH) and temperature control by passive means has hardly been considered by building engineers. This is because passive RH control can hardly be realised in well ventilated and sparsely furnished buildings. Archives, however, need not be well ventilated and are certainly not sparsely furnished but full of humidity buffering materials. In such a building the relative humidity inertia can easily exceed the thermal inertia. It turns out that a nearly airtight building with moderate thermal inertia combined with large moisture inertia can hold a steady climate long enough to allow it to be refreshed with outside air during occasional advantageous moments in the unpredictable variation of atmospheric temperature and water vapour concentration.

Our assumption that an archive does not need ventilation must be defended. Ventilation is often cited as an important inhibitor of fungal growth but this is

Figure 2: Archives are best kept cool.

irrelevant in most archives where the collection is boxed or closely surrounded by other pages so that the local air exchange rate is very low. The accumulation of reactive air pollutants is another reason given for ventilating a collection but the same reasoning applies: most of the internally generated pollutants will have plenty of time to react in the unventilated enclosure immediately surrounding the archived pages, so general ventilation hardly helps. The room air can be re-circulated through a pollutant filter, if that is thought to be helpful.

In northern Europe the annual average RH is around 75%, which allows some biological activity. However, if this air is heated about 6°C, the RH goes down to about 50%. This is the principle behind *Conservation Heating*, which is heating to reduce the RH rather than to give comfort to humans. In summer, the excess temperature indoors, rising to 23°C, accelerates chemical deterioration of the archive. For this reason it is important to bring RH buffering into the design, to allow the archive to coast through the summer at a relatively low temperature, without becoming humid.

Figure 3 shows conservation heating diagramatically. The monthly average temperature and RH in Copenhagen are plotted, together with the room temperature required to lower the RH to a constant 45%.

Figure 4 shows the physical basis for relative humidity buffering. It describes the relationship between temperature, ambient relative humidity and water content of cotton, which is representative of all organic materials. The slope of the curve varies for other materials but the shape is much the same. As the RH rises, cotton absorbs water, which is released again when the RH falls. In an archive, the water stored in this way in the archived materials is vastly greater than the amount in the air of the archive, so we can regard the archived materials as buffering against change in their environment. If the air in the room changes frequently, this buffering effect will vanish, so it can only be part of a practical climate control strategy if the air change rate is less than about once every six hours.

Notice that the lines for widely different temperatures are close together on the graph. As a first approximation therefore we can ignore temperature variation. This diagram can be read either way: one can take a given RH and read across the water content of the material once it has reached equilibrium in surroundings of that RH. One can alternatively take a material with a given water content and predict the equilibrium RH in the space around it. Water content of materials and RH of the immediately adjacent space are linked

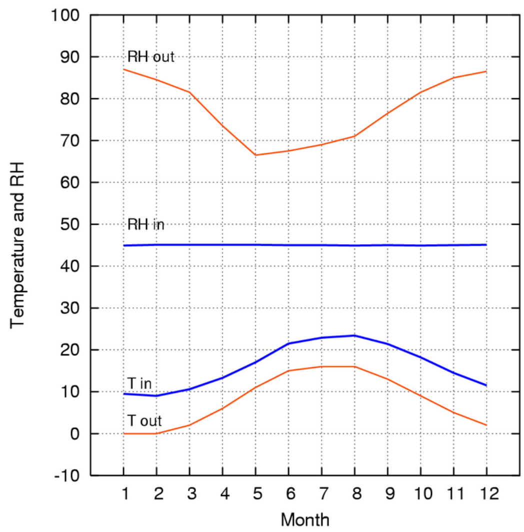

Figure 3: The monthly average climate in Copenhagen and the indoor temperature required to reduce the RH to 45%.

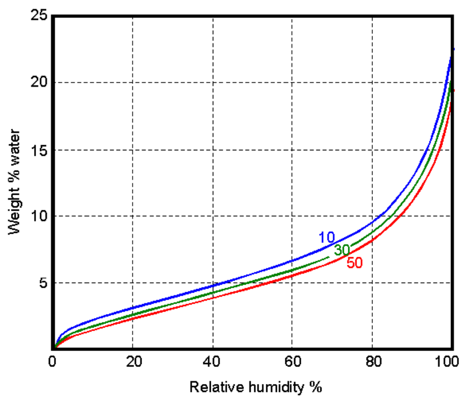

Figure 4: Sorption isotherms of water in cotton for three different temperatures. After Urquhart and Williams [1].

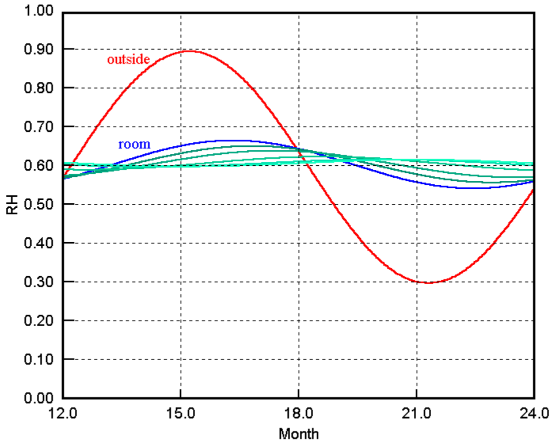

Figure 5: The course of the relative humidity (RH) in an archive (blue line) as the outside RH (red curve) varies in a yearly cycle. The archive has one air change per day and is empty but stabilised by 40 cm of light clay plaster on the walls. The green lines show the RH at various depths within the absorbent plaster walls. The temperature is constant [2].

through this diagram. The water content affects the dimensions of materials and also their flexibility; water increases both. But the water content does not directly influence the chemical decay rate or the growth of micro-organisms - that is controlled by the relative humidity. The RH can mathematically be shown to be identical to the activity of water in a chemical reaction, that is its potential for causing chemical change, one aspect of which is biological growth. There is abundant evidence linking biological growth rate and rate of hydrolytic breakdown of polymers to high ambient relative humidity.

We normally regard RH as a property of air which controls the water content of materials. However, in an unventilated archive box the ambient RH is dependent on the exchangeable water content of the archived materials, because this water content, of paper particularly, is huge compared with the water content of the immediately surrounding air. In the crowded archive space, with low air exchange rate, it is the cellulose water content that defines the RH and ensures that it changes slowly with the inevitable small air exchange with the outside. This is the process that is defined as *relative humidity buffering*.

An appreciation of the puny influence of airborne moisture on archives is very important to understanding how to control the climate. If the air exchange in the archive is about one air change every 10 hours, the archive can look after itself for a year, maintaining a safe RH. Adding in the temperature information from figure 4, we can say that even considerable variation of temperature during this year will not disturb this stability of RH. This is fortunate, because it is much more difficult, or more costly, to stabilise temperature than RH.

THE PRACTICALITY OF LONG PERIOD HUMIDITY BUFFERING

Figure 5 shows the humidity stability in an empty archive room which has humidity buffering walls made of clay plaster. This might seem an odd way of approaching the matter but you want the archive to work before you put your precious records in it. The message of this diagram, a prediction derived from

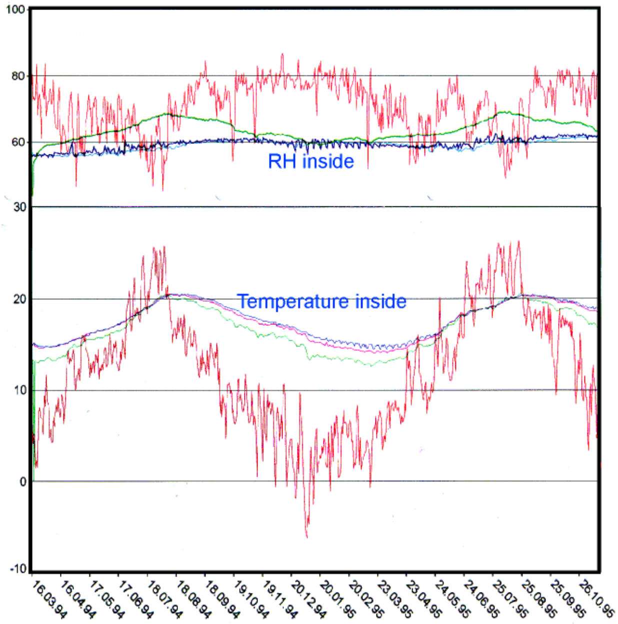

Figure 6: The course of the temperature and relative humidity inside the Schleswig archive over a year and a half (data from Lars Christoffersen [3]).

very simple and uncontroversial basic physics, is that it is easy to control the RH in a room if it is sealed to about 1 air change a day. This is feasible, but a working archive must be designed around about three times this exchange rate, because of human traffic.

One should not put too much trust in computer simulations. Figure 6 provides confirmation from reality. It is the measured climate in the archive of the German State, Schleswig-Holstein. We don't have the air exchange rate but we are lucky that Lars Christoffersen measured the climate in this archive. Indoor climate data seem nearly impossible to archive retrievably, but that is another discussion.

In this diagram the temperature also is changing only slowly with an annual cycle. But this is a massive building (figure 7) with metre thick walls, designed

Figure 7: The state archive of Schleswig-Holstein.

Figure 8: The interior of the Arnemagnaean archive in Copenhagen University. The room is 10 x 4 m.

to resist heavy artillery as well as climatic assault.

HEATING TO CONTROL THE LONG TERM RELATIVE HUMIDITY

Even without deliberate heating, most buildings maintain an average temperature above the average outdoor temperature. Look again at the Schleswig data. The indoor temperature is swinging in a reduced cycle about 5°C above the average ambient. That is because it is a massive, well insulated building. The intermittent lighting of the archive and heat from office areas provides enough energy, together with solar gain on bright days. The archive designers were surprised when the installed heating system was never needed.

Not all archives are built on such a massive scale that one can rely on this degree of thermal inertia and unintended heating. Figure 8 shows the modest repository of the Arnemagnaean Institute in Copenhagen University. It is only about 10 x 4 x 3 metres. Fortunately, the curator demanded that this also should be proof against bombardment and earthquake. It is on the second floor (figure 9), so a well built concrete shell was essential, and useful also for providing thermal inertia. For this project we used a finely porous calcium silicate block as humidity buffer. There is 5cm of this all around the room to provide buffering to the empty room.

In this archive we have provided the necessary temperature excess in winter, but have tried to minimise excess temperature in summer, relying on RH buffering to stabilise the climate until the autumn weather allows the relative humidity to be positively controlled again. This unsymmetrical temperature cycle is attained by balancing heat flow into the archive from the nearly constant temperature of the surrounding building against heat flow from the outside. There are carefully calculated thicknesses of thermal insulation towards the inside and towards the outside (figure 10), so that the archive temperature hovers about half way between the 20°C - 24°C temperature of the building and the 18°C to 0°C cycle of outside temperature, as a running average over a month. In this way we neatly avoid the excess summer temperature that would be so deleterious to the collection, relying on the RH inertia of the archive to tide it over the three month period when the inside temperature is very close to that

Figure 9: The Arnemagnaean Institute is on the second floor of this building of Copenhagen University, designed by KHRAS architects [4]. The windowless area of wall conceals the archive.

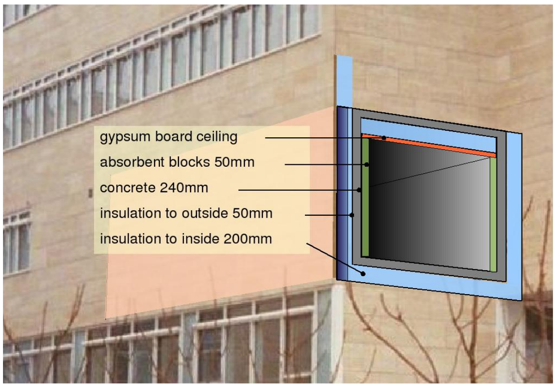

Figure 10: A schematic cutaway drawing of the archive. Notice the thin insulation to the outside and the thick insulation towards the warm building interior.

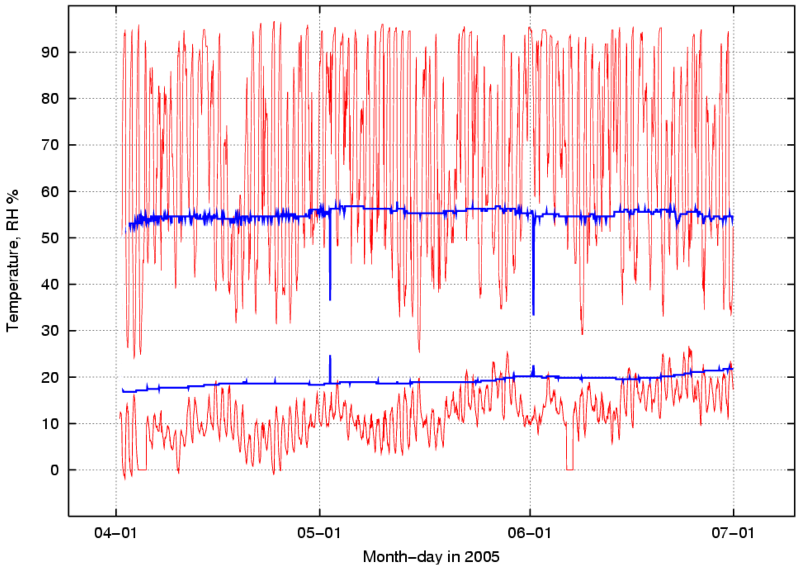

Figure 11: The climate within (blue) and outside the fully loaded archive.

outside. The annual average archive temperature was calculated to reduce the RH to about 50%.

The oddity of insulating a room towards the corridor next to it didn't bother the builders but specifying a reduced thickness of insulation on the outside wall was too big a challenge to their traditional working practices. After the building was finished the measured inside temperature was far higher than the calculated value. We suggested to the supervising architect that the outside insulation was too thick. He assured us that everything was as designed, though photographs of the building process had unaccountably gone missing. We insisted that a travertine facade slab be removed to inspect the insulation, and were proved right. We also had trouble with painters on auto-pilot, who covered our buffer silicate blocks with two layers of acrylic paint where a single thin layer of silicate paint was specified, to allow free movement of water vapour to the absorbent silicate blocks.

Figure 11 shows the inside and outside climate for a three month period.

ACTIVE FINE CONTROL OF RELATIVE HUMIDITY

These passive archives are still few, and there is not enough experience of running them to entirely convince managers, or even designers, of their reliability in the event of persistently unusual weather.

Although the Copenhagen archive is designed to hold the correct climate throughout the year, by entirely passive buffering processes, there is a backup air conditioning device (figure 12). It is designed to suck in outside air when it is, by the chance variation of the weather, of the right water content to correct the archive RH. Such a mechanical corrective system is particularly important in the first few years, because it takes a long time for the thick concrete slabs to reach moisture equilibrium with the archive air. There is an unquantifiable risk of high relative humidity, depending on the porosity and the initial water content of the concrete slabs.

The three diagrams in figure 13 show how the water vapour content of the

Figure 12: The minimalistic air conditioning apparatus, seen from below. Outside air is blown into the archive only when the building control computer senses that it will push the interior RH in the right direction.

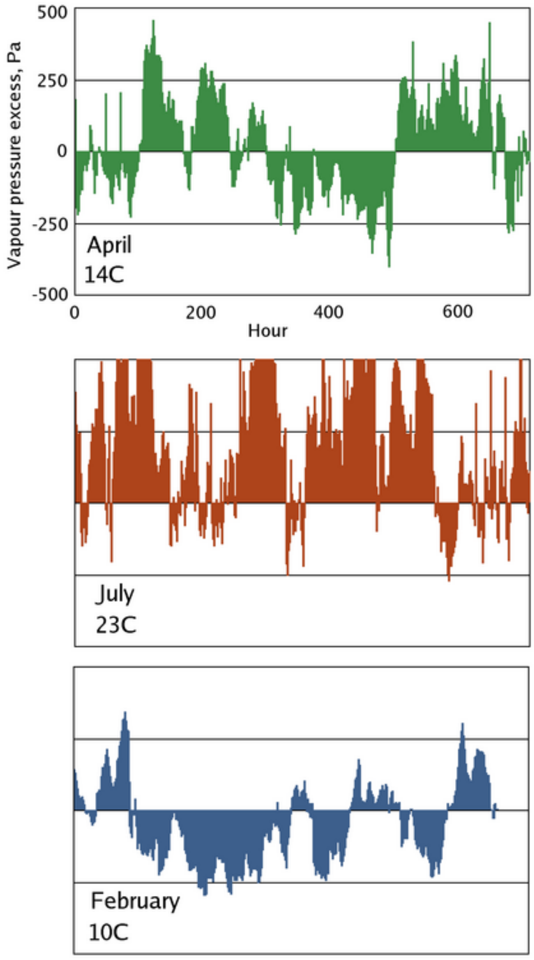

Figure 13: The periods when air can be blown in from outside to correct the inside RH. The outside water vapour concentration, expressed as vapour pressure, during three months in 1999 is compared with the required inside water vapour pressure corresponding to 45% RH in the archive. When the shaded area is above the line, the outside air can be pumped in to humidify the archive.

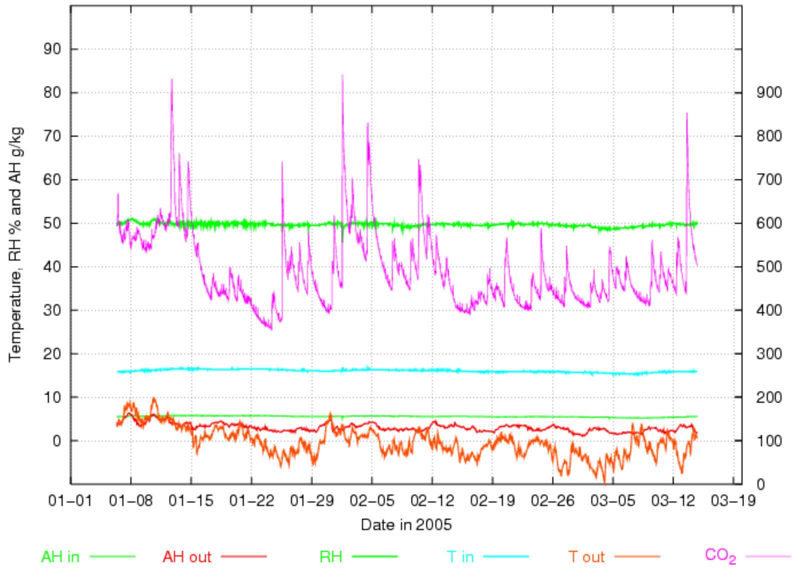

Figure 14: A more detailed climate record. At the beginning of the measuring period there are two events when outside air was blown into the archive. The effect is clearly visible as two bumps in the RH trace, which are rapidly suppressed by buffering from the archive. During the rest of the period the outside absolute humidity (AH) was always below the inside AH, so there was no injection of outside air. Nevertheless the interior RH remained stable. The air exchange rate of the closed archive can be deduced from the decay in carbon dioxide concentration over the weekends. The exchange rate is about once per day.

outside air compares with the inside water vapour content for a single month in three seasons. In spring, and autumn, the outside air often has a water vapour content that allows pushing the inside RH either way by blowing air in. In winter it is seldom possible to humidify and in summer there are few occasions for dehumidification, but if the buffer capacity of the archive is sufficient, the correction can wait for the spring or autumn window of opportunity.

One might think that the injection of air will also change the temperature and so defeat the intention to stabilise the interior climate. This would be true if the insulation were very thick but it is calculated to provide a measure of stability together with a significant heat flow through the walls. The heat capacity of air is very small, so the effect of pumping is mainly to adjust the water content of the interior, without significantly altering the temperature.

Figure 14 is a more detailed climate graph showing two occasions on which outside air was injected to correct the inside RH.

HOLDING A MODERATE RELATIVE HUMIDITY WITHOUT HEATING

In the Arnemagnaean archive we used heat from the permanently occupied building to provide the temperature excess to reduce the RH to 50%. However, the variability of the weather can be used to correct the RH of an archive which is actually running at the average ambient temperature, instead of 5°C above. If uncorrected this would result in about 75% RH indoors, but if the humidity buffer capacity is about a year, one can pump air in every winter to reduce the RH. Getting the archive down to the average ambient temperature can best be done by building underground or by using a heat exchanger with water circulating in pipes buried in the ground. This heat pump is sometimes used for reducing heating bills in inhabited dwellings, but for an archive the heat exchanger can be used directly to control the temperature without using extra energy.

Such an archive would achieve the maximum chemical stability attainable without mechanical cooling. In the UK one could expect an archive to run at about 10°C, if buried or temperature controlled by heat exchange with the underground.

One can confidently build to a specification of 10°C and 50%RH with a very small annual variation, using a very underdimensioned mechanical system. Because it cannot make changes fast, the mechanical system is also fail safe. Such an ideal archive is illustrated in figure 15.

THE IMPORTANCE OF MEASURING AND CONTROLLING THE AIR EXCHANGE RATE

The simplicity of the climate control method described here depends on keeping the air exchange rate low. The designed air exchange rate cannot be relied on: it depends on keeping the door closed, the seals well fitting and the valves in the air injection system well sealed. The normal way of measuring air exchange is expensive and measures only for a short time, when traffic and weather can both be atypical. However, the decay curves of carbon dioxide concentration (see figure 14) after the archive closes for the day can give a repeating rough indication of the air exchange rate during quiet times. This is running at about one air change per day. It must be admitted that a formal, standard test of air exchange rate[5], on just one occasion, gave an exchange rate of once every eight hours. For this test, the protocol demands vigorous air movement with a fan. Either reading predicts a satisfactory performance of the archive, so long as it is not busy. An archive with much traffic would need an air lock.

CONCLUSIONS

Practical evidence is accumulating that it is easy to make archives that maintain a moderate climate without air conditioning. The essential conditions are a massive construction, to give thermal inertia, a humidity buffering inner lining to the walls, to give a reassuring RH stability even in an empty archive, and good air-tightness. The fine adjustment to the RH can be made by occasional injection of outside air, when by chance its water vapour content is suitable.

References

[1] A.R.Urquhart and A.M.Williams, 'Absorption isotherm of cotton', *J.Textile Inst* (1924) 559–572.

[2] Tim Padfield, 'The role of absorbent building materials in moderating changes of relative humidity', Phd thesis, Technical University of Denmark 1998. http://www.padfield.org/tim/cfys/phd/phd-indx.php

[3] Data from Lars Christoffersen, Birch and Krogboe A/S, Teknikerbyen 34, 2830 Virum, Denmark

Figure 15: The ideal archive: underground, with reliable hydroelectricity, water for fire extinguishing, low air pressure, low air pollution and mountain bike rack for the curator.

[4] KHRAS Architects, Teknikerbyen 7, 2830 Virum, Denmark. Consulting engineer: COWI A/S Parallelvej 2, 2800 Kongens Lyngby, Denmark.

[5] Air change rate was measured by Morten Ryhl-Svendsen.

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