Hygrothermal Simulations of Energy-saving Measures to Stabilize the Internal Environment of an Archive Depot

Dr. Martin Krus[#1], Doris Rösler[#2], Lars Klemm[#3]

Fraunhofer Institute for Building Physics, Holzkirchen, Germany

[1]martin.krus@ibp.fraunhofer.de

[2]doris.roesler@ibp.fraunhofer.de

[3]lars.klemms@ibp.fraunhofer.de

Abstract

In archives the indoor climate should be kept as constant as possible. Attention is focused primarily on the avoidance of short-term moisture and temperature fluctuations. Seasonal climate changes represent a lower risk. An air conditioning system (full climate control) is not optimal from an energy and financial point of view. Stable indoor climate conditions are mainly influenced by the heat storage capacity and the hygroscopic properties of the components, the air exchange with outside air, the humidity and heat from internal sources. Because of the interaction of all these parameters, it is often difficult to assess their impact on the indoor climate. By hygrothermal calculations the influence of design, ventilation, internal moisture sources and the inventory have been studied. The aim of this study is, to get an optimal climate with minimal technical equipment on an energy-saving way. The calculations show that it is essential to reach a low air exchange rate, a high standard of insulation, to avoid solar gains by windows and to achieve low humidity and heat loads. In addition it is substantial to avoid built-in moisture. The calculations also show that the so-called "Kölner Modell" with its extremely massive outer walls is not suited for archive depots. This is because the large quantities of archive material take over both the thermal and hygric buffering.

Hygrothermal calculations, archive depot, energy saving

1. Background

Without any doubt it is important to allow people access to historically precious collections to take part of our past. However, the part in museums open to the public is only very small compared to the permanently stored collections. Ca. 70 % of the surface area of the museums is available to exhibit objects, which make up only approx. 20 % of our cultural heritage. In contrast, only ca. 10 % of the real storage area is available for ca. 80 % of the cultural assets. Collections are frequently entrusted to municipal archives or museums so that the amount of cultural assets to be stored is constantly increasing. Therefore, it is not surprising that precious collections are frequently stored under unfavorable storage conditions due to the lack of adequate depot spaces.

Thus, there is a demand for adequate depot buildings, which comply with current requirements of sustainability and energy efficiency as well as the requirements for preservation. Unfortunately, financial means are lacking to realize expensive depot buildings to fulfill the high requirements of an indoor climate secured by complex and energy-intensive air-conditioning systems. The Fraunhofer Institute for Building Physics IBP made a study in cooperation with Südhausbau GmbH and k3-artservices, both in Munich, to realize a zero energy depot for works of art and cultural assets [1]. Within this project the following hygrothermal calculations have been performed.

2. Climatic Requirements and Current Concepts for Depots

DIN ISO 11799 [1] contains the requirements for the storage of archives and libraries and gives reference values for depot rooms, where people work occasionally. Table 1 shows limit values for archive depots and depots of paintings. These limit values are related to the current version of the British Standard BSi PAS 198:2011 Specification for environmental conditions for cultural collections as well as average requirements of loan contracts of several museums predominantly active in the international loan business.

Table 1 Optimal temperature and humidity for archive materials and paintings.

Material	Temperature (°C)	Tolerable daily fluctuation (°C)	Relative humidity (%)	Tolerable daily fluctuation (%)
Archive material	14 – 18	± 1	35 – 50	± 3
painting	16 – 22	± 3	40 – 55	± 5

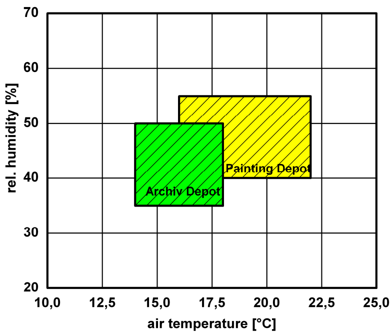

Figure 1: Presentation of given hygrothermal area for archive depot and depot of paintings.

Figure 1 shows the indoor climate requirements for temperature and relative humidity. The greater temperature corridor of the depot of paintings as well as the lower amount of relative humidity in the archive depot is clearly visible. These values shall be considered as reference values. Furthermore, the depot stock consists of a great variety of materials with different storage conditions so that compromises are necessary. Specifications on the necessary air change rates cannot be found in DIN ISO 11799. However, the necessity of clean air, even distribution and the discharge of harmful gas emissions are emphasized. Lighting, daylight or artificial light, should be generally kept as small as possible [2].

Climate regulation according to the „Kölner Modell“ applies the principle of free ventilation. The condition is a massive wall structure made of solid brick masonry, insulation and ventilated façade with optimal thermal properties [3]. The indoor climate shall be exposed to seasonal fluctuations concerning temperature and humidity as little as possible in this way. The indoor climate is regulated only by window ventilation, by skylights at best allowing cross ventilation via space heater or wall tempering.

3. Hygrothermal Investigations

By means of indoor climate simulation with WUFI®-Plus [4, 5] the climatic conditions in the depot room are investigated depending of the designed building structure. The calculations exclusively refer to the depot room and not to the total building of the depot. Hygrothermal calculations are carried out over a period of five years with the outdoor climatic conditions of Würzburg. The long-term behavior independent of the initial state is assessed by evaluating the fifth year. To observe the influence of the built-in moisture the initial period is examined. Besides the outdoor climatic conditions, the structure of the building envelope with regard to construction and material parameters as well as boundary conditions to be defined for heating, cooling, ventilation and lighting also hygrothermal, thermal and CO_2-sources are taken into consideration. Material parameters are derived from the WUFI®-Plus – material database or were determined by experiment. Since the thermal and hygric masses of the archive material and the storage system are of significant importance for the indoor climate, they are taken into account (Table 2).

Table 2 Definition of the depot stock and the storage system as well as of the times of utilization and of lighting of the archive depot and the depot of paintings

Depot type	Archive depot	Depot of paintings
Depot stock	4700 archive cardboards (70 % filling)	4800 paintings
Mass/Volume	282 m³ paper	2500 kg wood, 1000 kg canvas
Storage system	10 modular shelves, each 12 m with 14 shelves each	48 mobile partitions
Mass	10 t steel	10 t steel
Time of utilization	3 x daily 2 persons for 20 min; Monday – Friday	3 x daily 2 persons for 20 min; Monday – Friday
Lighting	when present 12 W/m² ➔3372 W; safety lighting 32 W continuously	when present 12 W/m² ➔3372 W; safety lighting 32 W continuously

Table 3 Versions of the depot integrated in the calculations.

Versions	Basic version	Improved building envelope	Built-in moisture reduced building envelope
Floor	10 cm XPS, 30 cm concrete, bitumen sheet, 6 cm parquet U-value: 0.276 W/m²K	20 cm cellular glass, 30 cm concrete, bitumen sheet, 6 cm hardwood U-value: 0.177 W/m²K	As basic version
External wall	6 cm concrete, 14 cm EPS, 18 cm concrete U-value: 0.214 W/m²K	6 cm concrete, 14 cm phenolic foam, 10 cm concrete U-value: 0.151 W/m²K	28 cm cellular glass slabs U-value: 0.132 W/m²K
Roof	Roof sheeting, 16 cm mineral foam sheet, 25 cm aerated concrete U-value: 0.153 W/m²K	Roof sheeting, 16 cm phenolic foam, 25 cm aerated concrete U-value: 0.098 W/m²K	As basic version
Internal walls	10 cm phenolic resin, 13 cm concrete U-value: 0.274 W/m²K	As basic version	As basic version

Calculations are based on three versions with various structures of the components as concerns the insulation materials. Two versions have an external wall structure with composite elements made of pre-cast concrete elements. One version has an insulation layer with expanded polystyrene foam (basic version) and the other with phenolic foam. For the assessment of a construction without built-in moisture a version with external walls of the depot room consisting of cellular glass is calculated. Table 3 gives a list of the essential characteristics of the three versions.

Variation of Air-conditioning

Figure 2 shows the temperature and moisture behaviour for the basic version. In the context, the type of air-conditioning was varied, i.e. free oscillation (no air-conditioning), heating as well as heating and cooling in order to achieve the climatic corridor marked (green area). In case of the archive depot room temperature falls to 5 °C during free oscillation in winter, whereas in summer exceeds 20 °C. Therefore, the strict compliance with the temperature limits requires heating and cooling. Moreover, free oscillation has an unfavorable impact on the relative humidity. If the archive depot is heated to a minimum temperature of 14 °C, the required temperature is achieved. Heating does also reduce the relative humidity at least partially in the first quarter of the year so that the given corridor can be kept. In summer, the same temperature course occurs as for the free oscillation with a slightly lower relative humidity. Only complete air-conditioning guarantees the strict compliance with the climatic corridor. Only heating, the maximum of daily fluctuations amounts to 0.3 K and 0.9 %. Admissible maximum fluctuations of 1 K and 3 % r. H. for depot rooms with archive material fluctuations are met.

The situation is more favorable for the depot of paintings. In case of free oscillation, almost the same behavior occurs concerning the room temperature as with the archive depot. However, the admissible maximum temperature is not exceeded, since it is 22 °C. Therefore, cooling is not necessary. The relative humidity, however, shows higher fluctuations concerning the annual as well as daily cycles caused by the lower humidity-buffering capacity of the depot stock. Maximum daily fluctuations with heating amount to 0.4 K and 1.1 % r. H. for the depots of paintings, but fluctuations of 3 K and 5 % r. H. are allowed.

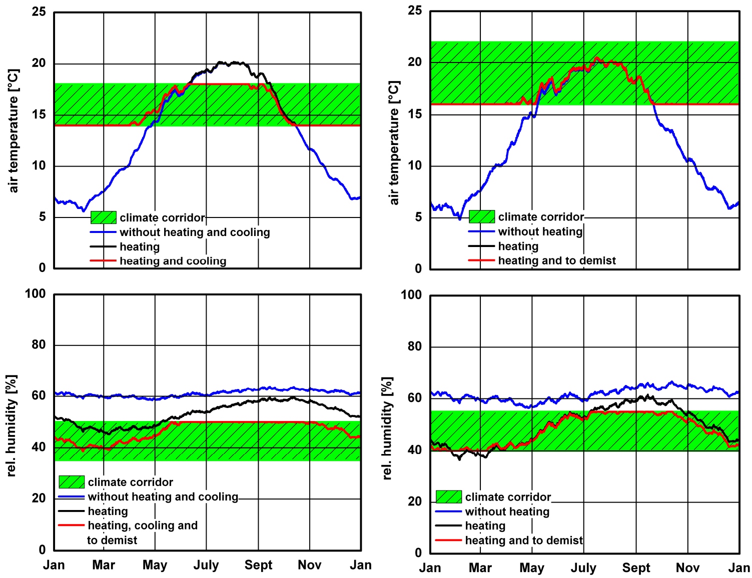

Figure 2 Hygrothermal behavior of basic version for variation of air-conditioning, left for the archive depot and right for the depot of paintings.

It is obvious that the depot of paintings shows a clearly greater potential for a passive building concept due to the greater upward climatic corridor. But heating is more energy-intensive in comparison to the archive depot due to the higher minimum temperatures. However, lower limits for temperature and humidity cause higher requirements of building technology in case of the archive depot.

Constructional Variations

The version „Improved Building Envelope“, described as version „Phenolic Foam“, shall be compared with version „Cellular Glass“ and basic version. Figure 3 shows the comparison for the case of only heating. For the archive depot, the „basic version“ and version „Cellular Glass“ have almost the same effect as concerns temperature. Version „Phenolic Foam“ shows higher temperatures in summer. Humidity behavior is the same as with the basic version. In winter, however, the version with cellular glass shows lower humidity. The humidity corridor, however, is exceeded in summer in this case. Maximum daily fluctuations of 0.3 K and 0.8 to 0.9 % r.H. occur for all versions.

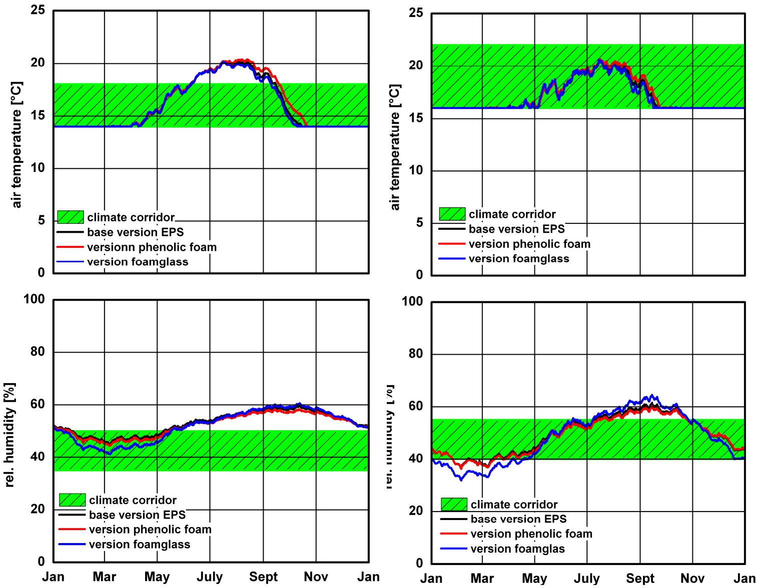

Figure 3: Comparison of the hygrothermal behavior of the three constructional versions, left for the archive depot and right for the depot of paintings.

For the depot of paintings, version „Phenolic Foam “ shows higher late-summer temperatures compared to the other versions. The course of r.H. is also almost the same compared to the „basic version“. With „Cellular Glass“ lower r.H occur in winter compared to the archive depot so that humidification is necessary. In summer, the higher climatic corridor contributes to the compliance with humidity limit values. In midsummer, however, the limit of 55 % is permanently exceeded. The r.H. with „Cellular Glass“ is slightly higher compared to the other versions in summer, since a smaller amount of humidity can be absorbed due to the slightly lower room air temperatures. Max. daily fluctuations amount to 0.4 °C and 1.1 % r. H. for the basic version and the phenolic foam version, and to 0.8 °C and 1.2 % r. h. for the cellular glass version.

Hygrothermal Variations

In addition, the impact of built-in moisture, air change, amount of archive material and the floor slab was investigated for the archive depot. For the basic version the impact of the built-in moisture is presented in Fig. 4, left side. It is obvious that clearly higher humidity occurs in the depot room. Due to the very low infiltration air change rate (acr) of 0.05 1/h, this effect is reduced only very slowly, thus a clearly negative influence can still be seen even after five years. Since concrete is drying very slowly a very long drying period must be taken into consideration before the archive material is stored.

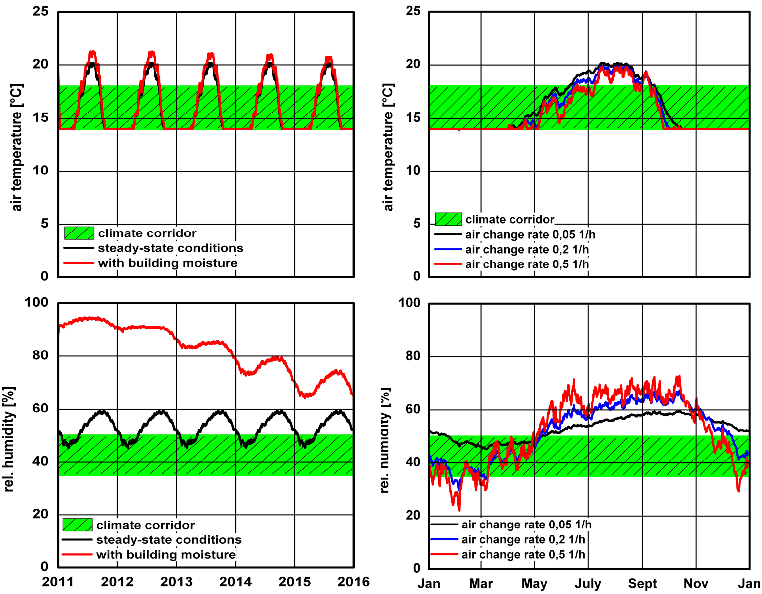

Figure 4 Hygrothermal impact of built-in moisture (left) and of the air change rate (right)

The diagram to the right shows that an increase in air change rate results in lower temperatures in summer and lower humidities in winter. At the same time, however, higher humidity in summer is to be expected. At acr of 0.2 1/h maximum daily fluctuations are still within the range of limit values, but clearly higher compared to an acr of 0.05 1/h. With an acr of 0.5 1/h considerable daily fluctuations occur with 5.7 °C and 5.5 % r. H., which clearly exceed the admissible values.

The archive material in the depot has a decisive impact on the indoor climate (Fig. 5 left). Temperatures in summer are almost the same with a full as with a half-full depot, whereas significantly higher temperatures occur in case of an empty depot. As concerns humidity, there is also only a slight difference between full and half-full depot, short-term fluctuations, however, are greater in case of the half-full depot. The empty state without archive material shows clearly higher fluctuations in the annual cycle which amount to approx. 38 and 64 % r.H., whereby the impact of the depot stock is obvious in relation to the daily humidity fluctuations. The maximum daily fluctuations of r.H. of 4.1 % in the empty state exceed the admissible values. The investigation of the impact of the floor slab is based on the concept of the Danish depot of works of art and preservation center in Vejle, where thermal insulation of the floor was deliberately avoided. This results in lower temperatures in summer (Fig. 5, right), whereby high relative humidity occurs of up to 70 % requiring a clearly longer heating period. Floor insulation with cellular glass results, compared with the basic version, in a slightly shorter heating period but also in higher temperatures in summer and therefore in a slightly lower maximum humidity.

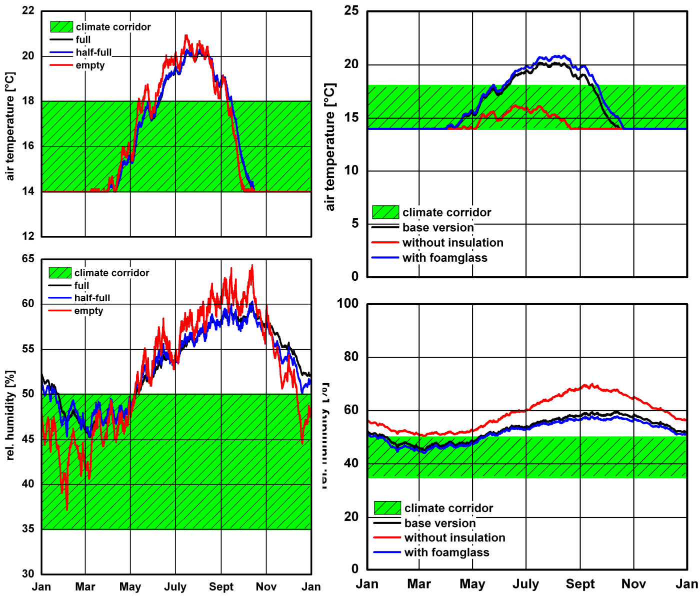

Figure 5: Hygrothermal impact of the archive material (left) and of the floor slab (right)

4. Net Energy Demand Calculated for the Depot Room

Table 5 summarizes the net energy demand calculated for the depot room for heating, cooling, humidification and dehumidification as well as the total demand for the three versions separately for the archive depot (AD) and the depot of paintings (DP). Since the defined minimum temperature for the depot of paintings is 2 K higher than for the archive depot, the result is a higher thermal heat demand for all versions. For the archive depot, however, more cooling and dehumidification is necessary due to the smaller climatic corridor. For humidification only in for the depot of paintings and only in winter an energetic demand is given. Most favourable is version „Phenolic Foam“ showing on average 28 % lower energy demand than the „Basic Version“. The version „Cellular Glass“ with 0.13 W/(m²K) has a slightly worse result than version „Phenolic Foam“ with its clearly better thermal insulation of the floor slab and roof.

Table 5 Energy demand of the versions (AD = archive depot, DP = depot of paintings).

Energy demand [kWh]	Basic version EPS		Version phenolic foam		Version Cellular glass	
	AD	DP	AD	DP	AD	DP
Heating	6.628	9.870	4.468	7.102	5.856	8.042
Cooling	963	0	895	0	749	0
Dehumidification	500	147	479	118	485	199
Humidification	0	66	0	64	0	144
Total	8091	10083	5842	7284	7090	8385
Related to basic version [%]	100	100	72	72	88	83

5. Summary

Specific requirements and boundary conditions must be taken into consideration concerning the concept of a modular energy-efficient depot for cultural assets, depending on the type of the stored goods. While an indoor temperature of 14-18 °C and a relative humidity of 35-50 % r. H. are required for an archive depot, the required indoor temperature of 16-22 °C and relative humidity of 40-55 %r. H. are higher for the depot of paintings. Furthermore, short-term fluctuations of relative humidity and indoor temperatures should be as low as possible. Therefore it is necessary to improve energy efficiency by means of constructional as well as passive measures, since passive systems can often reduce investments for air-conditioning systems of a building. If the depot room has no windows to minimize the intensity and duration of the influence of light, the result is that there are no solar heat gains. Due to the low indoor temperatures cooling is unnecessary at least for the depot of paintings. If the specifications of the climatic corridor have to be fulfilled, humidification as well as dehumidification is still necessary.

In comparison to the basic version the energy demand can be reduced by almost 30 % by improving the thermal insulation of the external walls, floor and roof. Calculations show that due to a low air change rate built-in moisture can be a serious long-term problem. Therefore, constructional measures are required to avoid built-in moisture to enter the room. As calculations show the infiltration air change must be kept on a low level to reduce greater daily fluctuations. This must be particularly considered, if low thermal and moisture-buffering masses are stored in the depot.

All in all, the calculations show that due to the specified climatic limits the aim of a zero-energy depot cannot be achieved by passive measures, at least for the depot room. The question, however, is, whether these narrow limits are really necessary. The option should be taken into consideration to adjust temperatures and humidity to the seasonal fluctuations as far as possible to keep the energy demand at the lowest possible level [3]. As calculations show temperature changes in the depot would occur in the seasonal cycle, but the relative humidity of approx. 60% r. H. would be constant throughout the year.

6. References

[1] DIN ISO 11799: Information und Dokumentation – Anforderungen an die Aufbewahrung von Archiv- und Bibliotheksgut (ISO 11799:2003)(*Information and documentation – Requirements for the storage of archive and library materials*), Beuth Verlag, Berlin

[2] Glauert, M., Anforderungen an ein Archivmagazin - Eine Checkliste. (*Requirements for an archive depot – a checklist*)http://www.landeshauptarchiv-brandenburg.de/FilePool/Archivmagazin_Glauert.pdf, 08.07.2011

[3] Geller, B., Archivbauten im Klimawandel – Erfahrungen mit der natürlichen freien Lüftung zur Klimaregulierung in Magazinräumen (*Archive depots and the climate change – experiences with natural free airing for climate regulation in magazine rooms*), VDR (Verband der Restauratoren), Heft 1/2, 2007, S. 121 – 125

[4] Holm, A.; Radon, J.; Künzel, H.M.; Sedlbauer, K.: Berechnung des hygrothermischen Verhaltens von Räumen (*Calculation of the hygrothermal Behaviour of rooms*). WTA-Schriftenreihe (2004), H. 24, S. 81-94. Hrsg.: WTA-Publications, München.

[5] Krus, M.; Holm, A.H. Neue Beurteilungsmethode in der Altbausanierung. (New assessment method for refurbishment) In: Venzmer, Helmuth (Hrsg); 19. Hanseatische Sanierungstage 2008, Berlin; ISBN 978-3-8167-7673-4, Fraunhofer IRB Verlag (2009) , S. 29-40.