Climate stability of historical museums I:
Building physics calculations of the Herzog-Anton-Ulrich Museum of Brunswick

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ABSTRACT
In addition to the fact that the serviceability of building constructions used as exhibition halls has to be ensured, the climate stability of the whole structure has to be increased. Exemplary building physical calculations with transient boundary conditions (simulations) were set off by the aim to modernize the " Herzog-Anton-Ulrich-Museum" in Brunswick. With the help of these calculations it has been possible to develop not only a standard for correct reconditioning, but also to raise the security of planning.
The thorough simulation of the thermal performance, the humidity- and energy situation in exposition rooms makes an optimum air-conditioning concept feasible, depending on different requirement profiles for the indoor climate and the expenditure for the installation. In this context, practicable discharges were discussed.

1. INTRODUCTION
The "Herzog-Anton-Ulrich-Museum" in Brunswick is one of those few buildings, which were planned and erected at the end of the 19th century with the intention of creating a pure museum or art gallery.
The aim was not only to have rooms for representing art objects, but also to create optimum climatic reservoirs for storing.

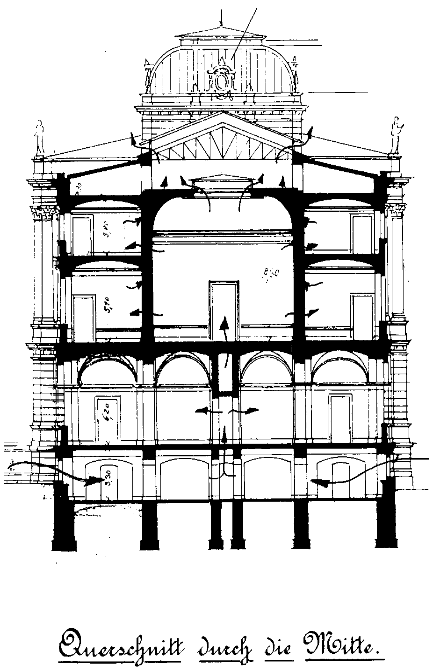

Illustration 1: Historical heating- and airing-system of the 'Herzog-Anton-Ulrich-Museum'

The suitability of the indoor climate in historical museums has always been overestimated and still is. At present, climatic research on historical museums like the "Herzog-Anton-Ulrich-Museum" have to be carried out, as damage caused by humidity in outer and inner rooms as well as on the art objects themselves, could be observed.
The majority of climatic damage at exhibited art objects can be attributed to the following problems:

1. Brief fluctuations of the indoor climate, especially the relative room-humidity lead to premature aging of organic material and can also cause irreversible damage. (⇒Organic material changes its hygroscopic moisture content if the relative room-humidity changes, too). Therefore fluctuations of the relative ambient dampness bring about a change of moisture content and consequently a change in volume (swelling and shrinking).In this context strain generates inside the material structures, which causes damage particularly with brief repeated swelling and shrinking. Air-conditioning is not the ultimate solution for preventing cyclic changes of indoor climates.

2. Faulty thermal insulation combined with an adverse arrangement of the art objects increase the risk of damage for the building and its exhibits. Humidity or fungus damage may be the cause of furniture, artworks, canvasses (or similar things), being placed directly at a non-insulated external wall. Further on, the air carrying fungus spores enlarges the risk of damage on the exhibits.
3. Often soiling at ceiling-arts or frescos can be observed in historical churches. This phenomenon is called ′Thermodiffusion′ (thermo-diffusion). During thermo-diffusion fine dust is transported by the air molecules towards the temperature differentials on cold surfaces, e.g. on non-insulated outer parts of the building.

2. CONSTRUCTIVE REQUIREMENTS ON THE STRUCTURE

Physical requirements on the structure can be divided into these fields:

- Minimum insulation – and climate moisture- protection
- Energy saving thermal insulation
- Designing the structure referring to climatic viewpoints.

By means of the minimum requirements on the structural thermal insulation- and moisture- protection the construction is to be prevented permanently from climatic stress from outside due to different weather conditions and inside due to the use of the building. The requirements are supposed to save the structure from moisture damage. Condensation water is able to develop on building surfaces as well as in the inner structure of the building.
The following characteristics affect the thermal stability of the building (and parts of this, e.g. exhibition-rooms):

- Quantity of windows and sun-protection
- Intensity of airing
- Faculty of heat storage
- Hygroscopic qualities of the building elements.

With the improvement of the characteristic features, the proportion of the building's own air conditioning has to be set to the maximum and at the same time the proportion of the installed equipment (which is required to achieve a particular climate in rooms) has to be reduced.
In this way, high expenditures on the plants, like investment- and operating costs, can be avoided. Employing these measures helps to decrease the preserving risk of damage.

3. REQUIREMENTS ON THE INDOOR CLIMATE

Preserving criteria mainly characterize the requirements on the indoor climate of museums. For saving art objects, durable limited values of the room temperature and the relative room-humidity and their variations have to be kept, for example:

- Room temperature: ϑ_{RL} = 18…20°C
- Relative room-humidity: ϕ_{RL} = 50…55%.

These standards inevitably entail large investments in the plants and their equipment. As a result of this narrow climatic range the what is a called and feared 'Zweipunktverhalten' (two-points behaviour) of air conditioning systems, occurs.(Commonly accepted climatic requirements⇒[3],[4],[5],[6])

4. TASK

The most important intent of modernisation is to improve the existing dissatisfying climatic circumstances in the exhibition rooms and to create optimum conditions for preserving the art objects.
The planning, regarding thermal building physics, can be divided in two fields of duties:

1. The physically correct structure restoration
2. Helping to develop a suitable climate concept.

5. THE MODEL OF CALCULATION

The indoor climate calculations [1] are based on a so-reference test year [2] (real case). As far as the thermal stability of the structure is concerned, the summer period represents the more critical case. The reason for this is that extensive fluctuations of the outer temperatures and sun radiation during one day provoke a de-stabilisation of the inner climate.
In addition to that, the summer period is more interesting, because the air conditioning functions 'Cooling' and 'Dehumidifying', are very expensive and a reduction or the avoidance of these functions are an important part of planning. Due to this, simulations and calculations of extreme hot, sunny and humid summer days are carried out (worst case).

6. BUILDING-CONSTRUCTIVE REFLECTIONS

The thermal insulation of the existing outer walls can be evaluated as follows:

- The minimum requirements of the thermal insulation (regarding to DIN 4108) as well as the recommended minimum requirements of outer-walls (u ≥ 1.20 [m^2*K]/W) generally cannot be evaluated as ‘fulfilled’.
- The requirements of the energy-saving thermal insulation regarding to the ‘Thermal Insulation Order’ cannot be met.

With historical buildings a supplementary installing of heat insulation layers is often very complicated because of the regulations concerning the preservation of monuments.
A more suitable method of improving the thermal insulation of the outer walls is to fix an inside plaster system.
Protection against condensation water is to prevent a harmful moistening of interior structures. The respective requirements have been written down.

The following statements can be deduced from the simulations results:

1. A reduction of natural drafts through window-joints together with a matching ventilation results in a stabilization of the temperature. The effects on the relative room humidity are even more remarkable, with non-insulated windows uncontrolled joint-drafts amount to about 20% in midsummer, where as the fluctuation with insulated windows the fluctuations are less than 10%.
2. The employment of a high-quality solar control glass connected with a shading cause a reduction of the room temperature.
3. The uncontrollable drafts through window-joints have to be replaced by controllable mechanic venturing. This replacement has positive effects on the heating costs, as heat losses become less. Presupposed an outside draft of V=20m^3 /(h*person) (without heat recovery) and insulated windows, about 60% of the heating energy can be saved.
4. Solar control glass and shading have to reduce the transmission heat loss during the winter-period, and they have to eliminate infra-red radiation and to filter out the UV-radiation as much as possible due to a reduction of incoming radiation in summer. Concurrently high colourlessness and a certain transparency towards the world outside have to be strived for.

7. CONTEMPLATION OF DIFFERENT CLIMATE CONCEPTS

Due to the demanded air-tightness of the windows (⇒to improve the climatic stabilization of the exhibition rooms), a mechanical venturing (called ‘RLT’-plant) is needed to guarantee the hygienically necessary airing. In this way it is possible to let a controllable airing into the exhibition rooms. Obviously, the installed plant has to be entrusted with other necessary climatic tasks like cooling, heating, moistening and de-moistening.

All calculations are based on the condition after the restoration.
The selected climate concepts differ from one another in the following ways:

- the selection of the thermal-dynamic functions of airing (air-heating, -moistening, -cooling and –de-moistening) and
- the fixing of the preserving requirements on the inner climate.

8. SUMMARY AND PROSPECT

The results of the calculations made can be summarized as shown below:

1. The external walls of exhibition rooms at existing museums generally need an improvement of the thermal insulation. A good physical variant is to fix an inside plaster system. Thus the risk of damage due to humidity on surfaces and fungus-formation can be reduced noticeably. Simultaneously, costs for building and using the heating plants, can be cut.
2. External windows weaken the thermal stability of exhibition rooms. Improving the tightness of joints and the shading has a very positive effect on the inner-climate and the heat development (with northern windows, too).
3. Additionally, shading at skylight windows and roof glazing is not very effective regarding the inner-climate. With the help of a not yet specified airing-concept for roof-trusses, surplus heat can dispense through the skylight windows.

The influence of the number of visitors on the development of the climate inside is relatively insignificant if there is a proportionate distribution of visitors in place and time). Only big events give rise to drastic deteriorations of the climatic situation.
In this context the question, if a technical improvement for brief events is economic, has to be asked (and answered).

Different climate-concepts were analysed exactly concerning the inner climate and energy consumption. These concepts differ from one another in the following ways:

- the selection of the thermal-dynamic functions of airing (air-heating, -moistening, -cooling and –de-moistening) and
- fixing the preserving requirements on the inner climate.

According to the technical, climatic outline conditions it is obvious, that there is a great chance to economize, especially regarding the reduction of drafts.

This publication is the result of a (building-) constructive and (building-) climate analysis with the prime aim of finding a decision basis for a useful climate concept.

We have to deal with these following tasks, too:
- Calculation of drafts in skylight halls to check the temperature-layers and the air-speeds.
- Daylight studies including simulations about the light spreading in the exhibition rooms.
- Checking the possibility of employment of ‘area-heating and area-cooling’ in walls and floors.
- A detailed analysis of temperature- and moisture- behaviour near the walls and their influence on canvas

9. LITERATURE

[1] TRNSYS, Version 14.2
A Transient System Simulation Program; Solar Energy Laboratory University of Wisconsin-Madison, Madison WI 53706 U.S.A.; 04/97

[2] Testreferenzjahr TRY 2: Nord- und westdeutsches Tiefland mit Repräsentanzstation Hannover-Langenhagen (Klimaregion 2); Deutscher Wetterdienst Offenbach – Geschäftsfeld Klima- und Umweltberatung; Datum der Erstellung: 11/84

[3] Hinweise zur Planung und Ausführung von Raumlufttechnischen Anlagen für öffentliche Gebäude (RLT-Anlagen-Bau-93); Aufgestellt und herausgegeben vom Arbeitskreis Maschinen- und Elektrotechnik staatlicher und kommunaler Verwaltungen (AMEV); Bonn 1993

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[6] Hilbert, G.S.: Sammlungsgut in Sicherheit; Teil 2: Lichtschutz – Klimatisierung; Gebr. Mann Verlag Berlin 1987

TABLE I: Variants of calculations

Variant	Thermal dynamic conditioning	range of the inner climate
1a	Heating	$\vartheta_{RL} \geq 18$ °C
2a	Heating Moistening	$\vartheta_{RL} \geq 18$ °C ϕ_{RL} = 50 % ... 55 %
2b		$\vartheta_{RL} \geq 20$ °C... 22 °C (saisonal gleitend) ϕ_{RL} = 50 % ... 60 %
3a	Heating Moistening Cooling De-moistening	ϑ_{RL} = 19 ° C ± 1 K ϕ_{RL} = 50 % ... 55 %
3b		ϑ_{RL} = 21 ° C ± 1 K ... 23 ° C ± 1 K (saisonal gleitend) ϕ_{RL} = 45 % ... 55 %
ϑ_{RL} ... temperature of the room ϕ_{RL} ... relative room-humidity		

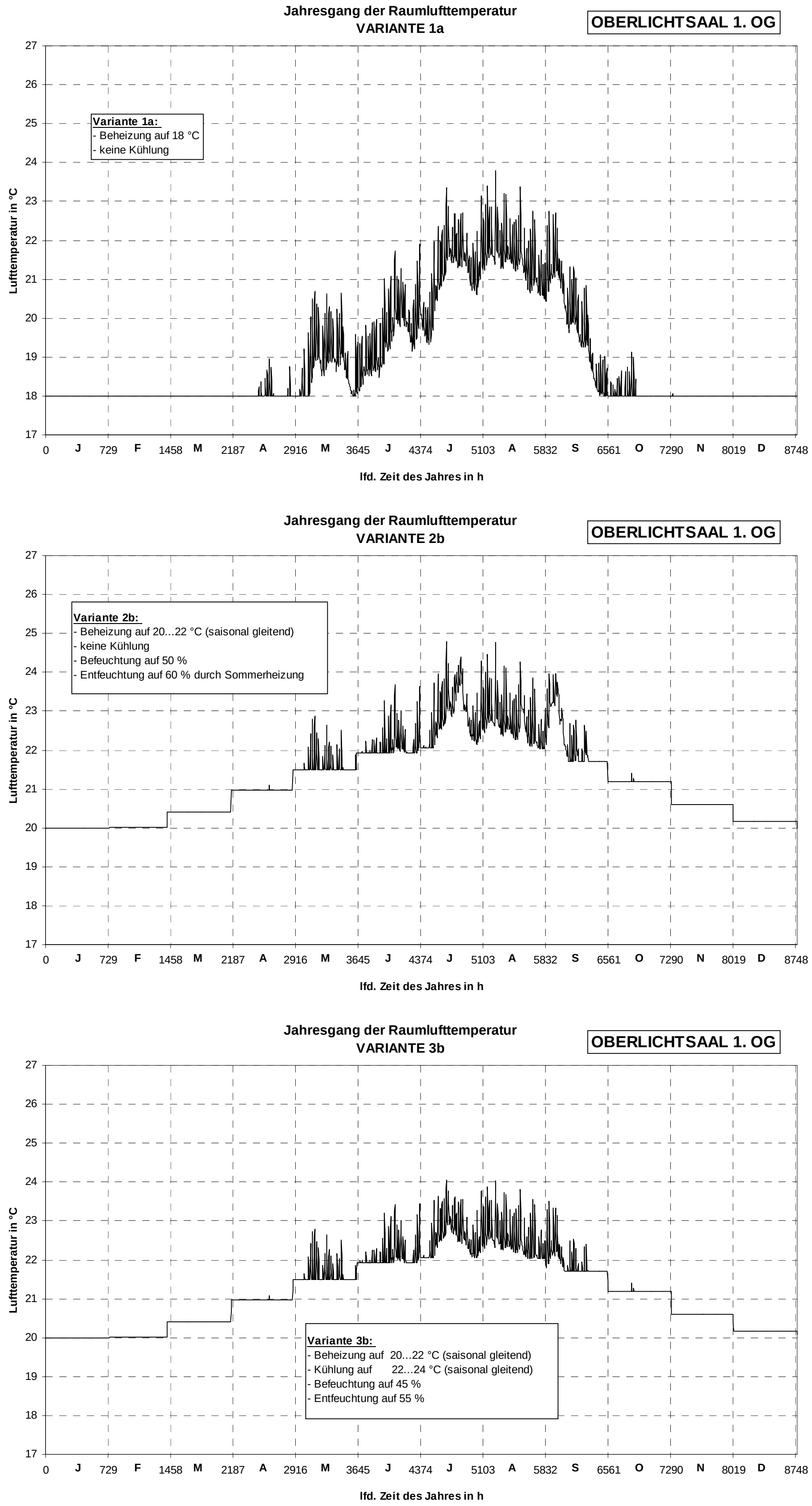
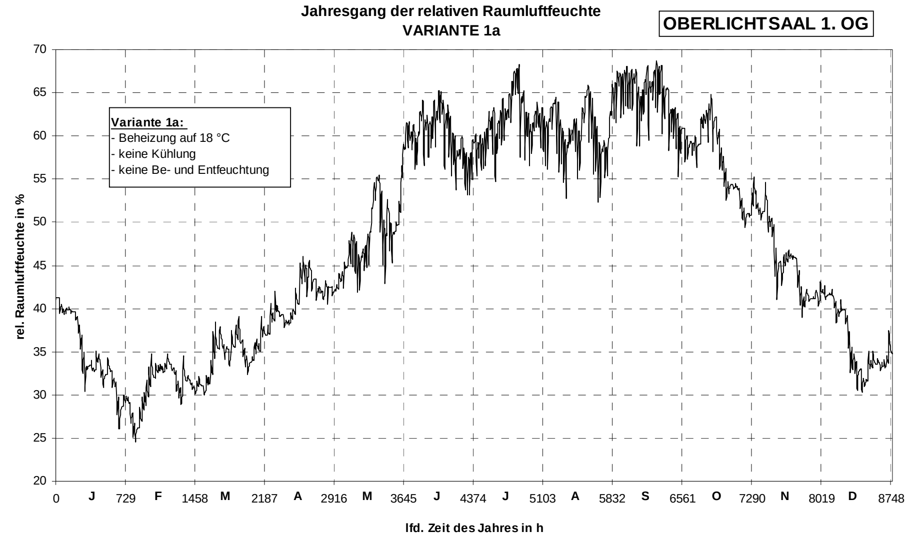
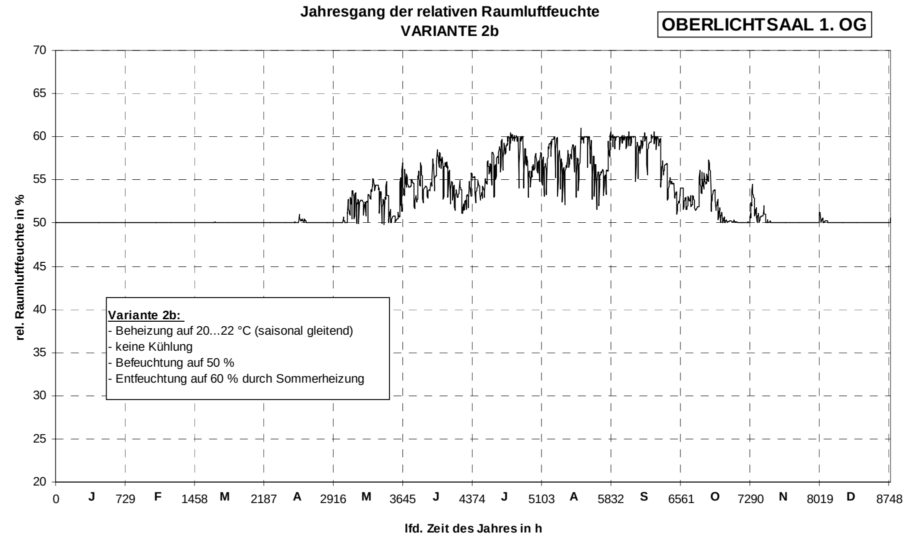


ILLUSTRATION 2: Temperature development during one year





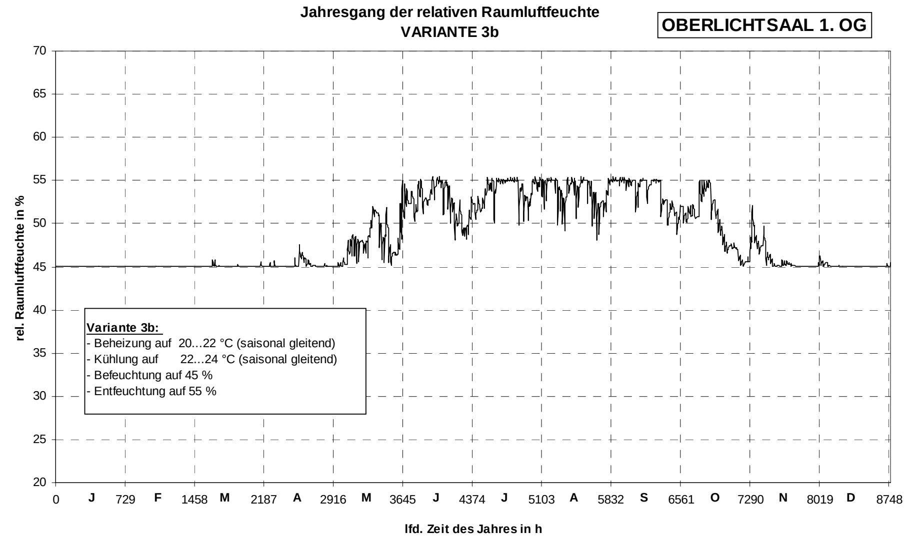


ILLUSTRATION 3: Development of the relative room-humidity during one year