Climate stability of historical museums

Research of temperature- and moisture reaction in areas close to outer walls

Consequences regarding the building and the exhibits

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1. Abstract

The determining of the room climate in spaces that are used as exhibition halls is motivated by preserving criteria in the first place. Especially in art galleries, the preserving climate-demands only allow an extremely limited variation as far as the room air temperature and the relative room air humidity are concerned. Particularly the breadth and quantity of variation of the relative room air humidity do have great influence on the ageing process of the exhibits and can ultimately damage them – providing that the damaging is appropriately severe.

The general way of looking at things in the planners' practice takes one room air temperature as well as one relative room air humidity as a starting point. These consist of locally determined climatic results which one can naturally come across in the middle of the room. Often, however, the more difficult to preserve areas – e.g. areas where problems may arise due to existing outer walls or ventilation systems – are not taken into account and consequently lead to cases of damage although the climatic conditions of the room seem to be acceptable. Within the context of a building-physical planning and consulting activity of the modernisation and preservation of the ‚Herzog-Anton-Ulrich Museum' in Brunswick, the above mentioned difficulty of paintings being fixed to cold walls was closely thought about. Accordingly, the micro-climatic consequences especially on the exhibit, but also on the construction itself, were initially examined with the help of calculations.

Describing the conditions of the transmission as well as the current of heat in areas close to exterior walls mathematically, amongst other things proves to be difficult due to the determining of the convective heat transfer coefficients at the restriction areas of wall and painting and air current gap. In case of free convection it is the theory of similarity that can be fallen back upon. In this particular case, however, there is not only a thermally caused output current at the cold wall, but also an enforced convection caused by the ventilation and heating system. As far as this particular case is concerned – especially in consideration of the air velocity and gap

geometry – the author is not familiar with any reliable models of similarity so that a mathematical determining of the processes of the transmission of heat remains indefinite.

In order to improve the simulation of currents of heating and material in such places where paintings are fixed to outer walls and to make estimations regarding the preserving and building-physical risks of damage in case of the ‚Herzog-Anton-Ulrich-Museum' easier, measurements of temperature and humidity were taken parallel to the theoretical examinations. These amongst other things also helped to verify the results of the calculation.

2. Introduction

First and foremost, the fixation of the room climate in spaces that are used as exhibition halls is motivated by preserving criteria. Especially in art galleries, the preserving climate-demands only allow an extremely limited variation as far as the room air temperature and the relative room air humidity are concerned. Particularly the breadth and the quantity of variation of the relative room air humidity have a considerable influence on the aging process of the exhibits and can ultimately damage them.

In practice, the planners generally start out from the idea that there is *one* room temperature as well as *one* relative room air humidity. The prevailing degrees of moisture are measured in the area of the discharged air stream or somewhere else in the room. Often, however, the more difficult to preserve areas – e.g. such areas where problems may arise due to existing outer walls or ventilation systems – are not taken into account and consequently lead to cases of damage although the room's climatic conditions seem to be acceptable.

Besides the question to what extent the climate in areas that are situated near the outer walls differs from the climate in the middle of the room, the question to what extent the risk of damage(s) due to humidity with regard to the building materials as well as the exhibit itself increase, also has to be answered. As far as the professional group of restorers is concerned, all the processes and phenomena that are related to this problem are classified under the term of the so-called *cold-wall-problem* (Ranacher 1995).

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3. Calculation of the temperature reaction of outer walls covered with exhibits

In order to obtain a general applicable assessment of the influence of outer walls that are covered with exhibits on the heat storage and the temperature reaction of an outer wall and this way also on the different layers of material of a painting, it is necessary to record the thermally caused air current between the wall-covering and the reverse side of the painting in dependence upon the geometrical and thermal marginal conditions.

The transmission of heat between the reverse side of the painting and the front side of the wall takes place by transmission, convection, and heat radiation. Thus, the following model of a heat balance can be drawn up:

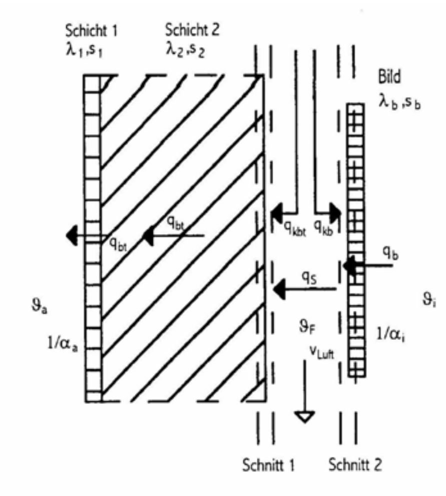

Figure 1: Heat currents in the system *wall – air gap - painting*

Transforming the above mentioned complex processes of heat transmission into an energy balance, one obtains a nonlinear ninth-grade equation. The solution of the energy balances with regard to the system *painting – air layer – cold exterior wall* leads to the following complex processes of heat transmission:

- heat radiation from the reverse side of paintings in the direction of the cold wall. The intenseness of the heat radiation increases as much as the outer wall's inner surface gets colder
- convective heat output from the reverse side of the paintings to the air gap and convective transfer to the outer wall. The intenseness of the heat convection increases as much as the outer wall's inner surface gets colder and the air current in the air gap intensifies. As far as the air current itself is concerned, it equally intensifies together with the decreasing temperature of the inner surface of the outer wall.
- Furthermore, the unhindered, purely thermally caused convection is additionally super positioned by a forced convection that comes from the ventilation system or the air heating installation.
- Both processes of heat transmission lead to a cooling of the reverse side of the painting and a warming of the inner surface of the outer wall, whereas the latter effect is rather marginal due to the high heat storage capacity of the wall.

In the sequence from the front side of the painting, air gap to the outer side of the outer wall one cannot assume a constant density of a heat current q since a convective heat exchange takes place between the above mentioned system and its surrounding. The difficulty lies in the determination of the convective coefficient of he heat transfer h_{cv}. Describing the heat transfer between the surface of the building material or the surface of the painting and the air gap, this coefficient depends on a variety of changeable factors, especially the temperature, the speed, the viscosity, the heat conductive capacity and the kind of air current in the gap as well as on the geometry, the temperature, and the roughness of the surface of the solid body. Coefficients of the heat transfer have to be determined by carrying out experiments and can be generalized with the help of the theory of similarity.

In order to assess the thermal reaction in this area, the temperatures above the cross-section of the compound unit were calculated with different suppositions and compared with the measurements (also compare the experiments that were carried out in the HAU, chapter 3).The following calculated or measured data served as the starting parameters:

- the exterior temperatures ϑ_α are changed in the range from -15 °C to 10 °C in 5 K-steps.
- the maintaining of an indoor range of temperature from 18 °C to 20 °C is demanded (BBS Institute 1999). At the same time calculations are carried out in the case of a failure of the air-conditioning during winter time (ϑ_ι = 13 °C).
- the temperature in the gap between the wall and the painting is on average 1 K below the room temperature (result of the experiment)
- as far as the coefficient of the transfer α_k is concerned, an analysis of the measurement data and the solution of the equation system the value a = α_k = 2.26 was determined. In order to take account of the dispersion of data, the following cases a = α_k = α_k [2.26] + 3 und a = α_k = α_k [2.26] – 3 were examined.

In addition to the wall temperature ϑ_W and the surface temperature of the protective layer of the reverse side of the painting ϑ_O, the surface of the front side as well as the reverse side ϑ_{Bv} und ϑ_{Br} of the painting's layer are calculated. As a comparison the case of the "standing air space" is looked at. Figures 2 and 3 illustrate the comparison of the measured temperatures together with the calculations` results.

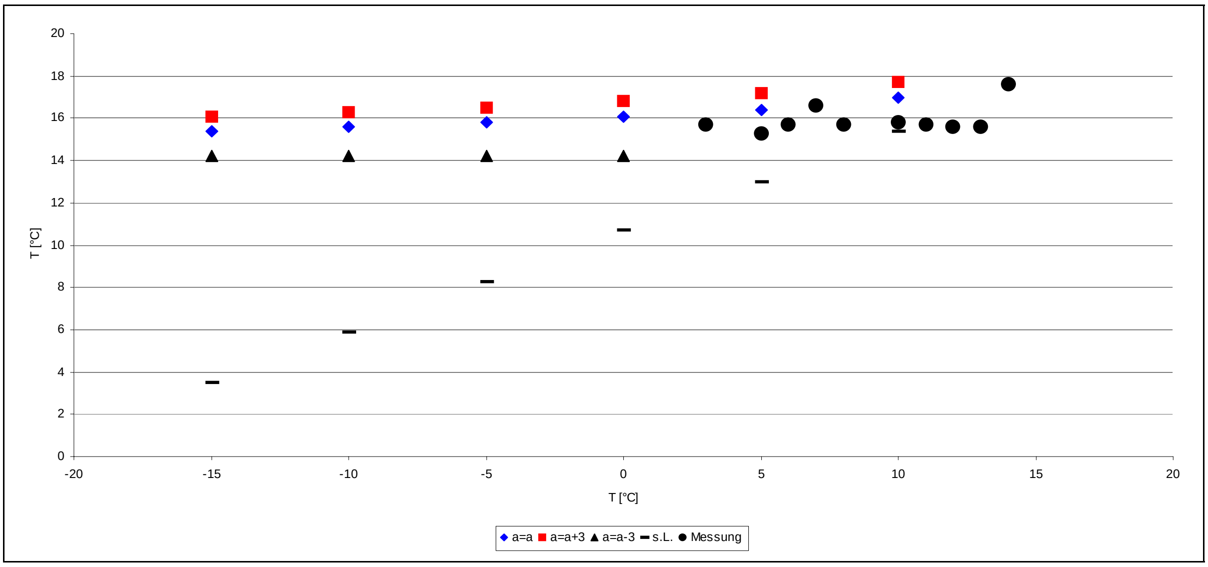

Figure 2: Temperatures of the surface of the wall ϑ_W with an indoor temperature ϑ_i of 20 °C

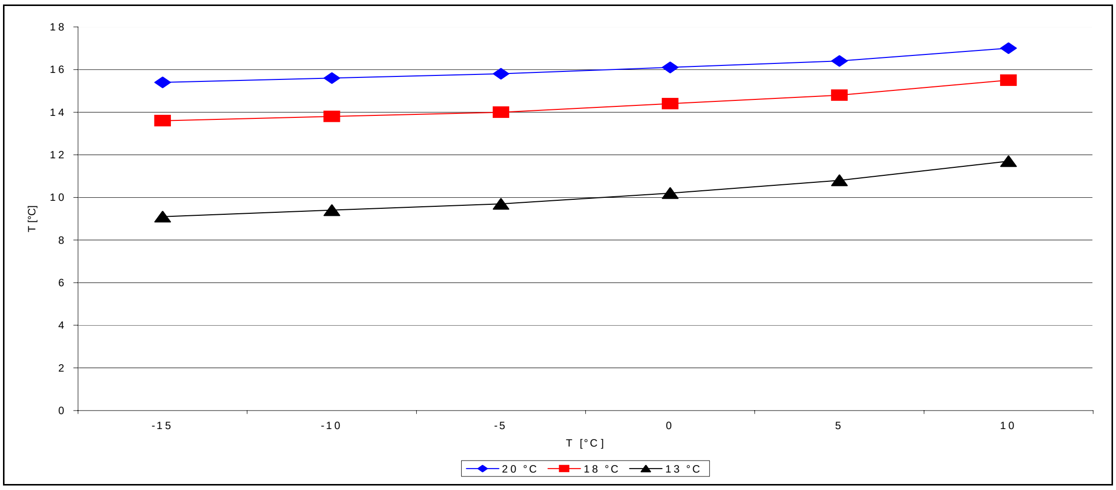

Figure 3: Temperatures of the surface of the wall ϑ_W with different indoor temperatures ϑ_i

4. Measurements of the limiting layer of temperatures of a painting hanging on the outer wall

The measurements were carried out at the painting *Nymphs and Satyrs* by Louis de Silvestre (1675-1760) in the so-called *French Hall*, a northern side gallery in the first floor of the Herzog-Anton-Ulrich Museum in Brunswick..

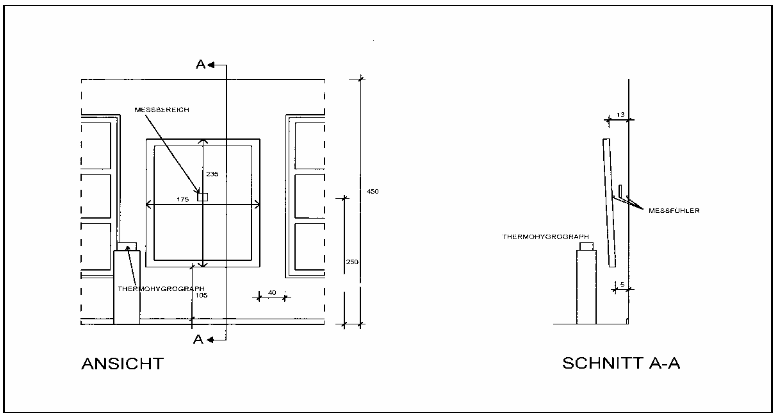

Figure 4 Setting up of the measurement equipment in the area of the painting in the *French Hall*

The painting hanging in front of the outer wall (?) consists of the following elements (beginning with the reverse side):

- protection of the reverse side made of cardboard (d = 0.5 cm)
- wedge frame (d = 3.5 cm)
- double canvas

- priming coat
- coat of paint
- layer of oil-varnish

The painting is not glazed and there are separators at the reverse side of the painting (distance on top: 13 cm, at the bottom: 5 cm).

Comparative measurements were carried out in an undisturbed wall area in a room that is used as a restoration workshop in the northern side gallery on the first floor.

Pictures 5 and 6 show the results of the temperature measurements (duration: 10th November until 1st December 1999) in the *French Hall* and the restoration workshop.

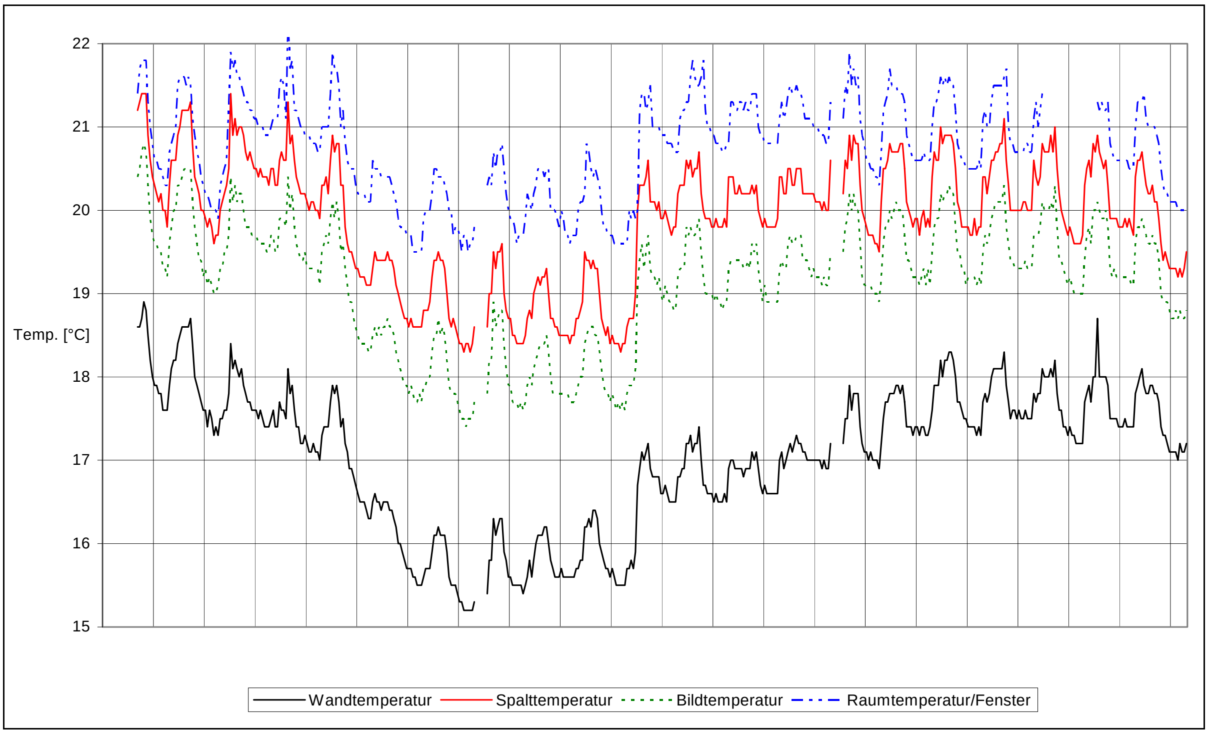

Figure 5: Temperature gradient in the painting’s area – French Hall

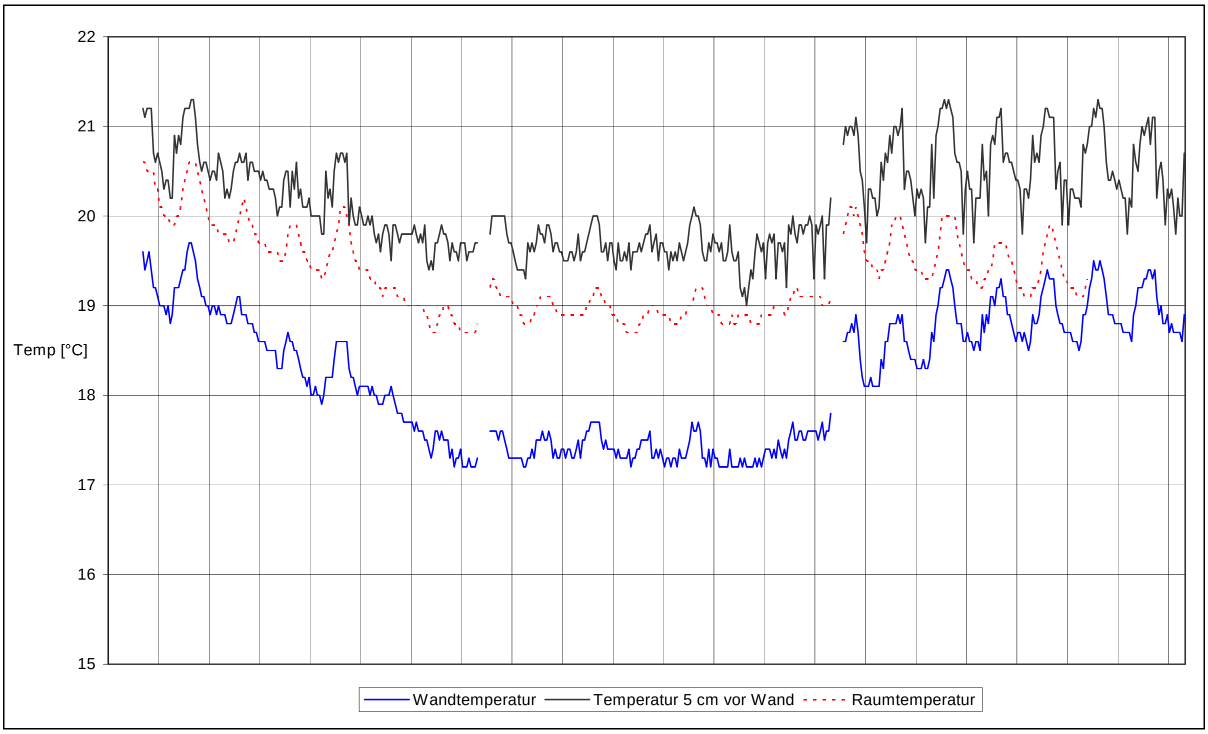

Figure 6: Temperature gradient in the undisturbed area - restoration studio l

The analysis of the temperature measurement show:

- The difference of the painting's surface temperature, which is decisive regarding the stress onto the painting, is 2 K on average
- The difference of the exterior wall's surface temperature, which is decisive regarding the safety of the building construction, is 4 K on average
- The difference of the exterior wall's surface temperature, which is also decisive regarding the relative air humidity in the air gap, is 1 K on average

below the normal room-air temperature.

The affects of the temperature differences concerning to the relative air humidity, consequently o the sorption as well as to the shrinkage- and swelling- behaviour of the paintings, are explained in chapter 4 and the following chapters.

5. Measurements of the relative air humidity of the Herzog- Anton- Ulrich- museum

Not only the temperature, but also the relative air- humidity were recorded in the period of 10th of November till the 1st of December in 1999 in line with the technical measurement analysis. Illustration 5 shows the conversion of the relative into the absolute air- humidity.

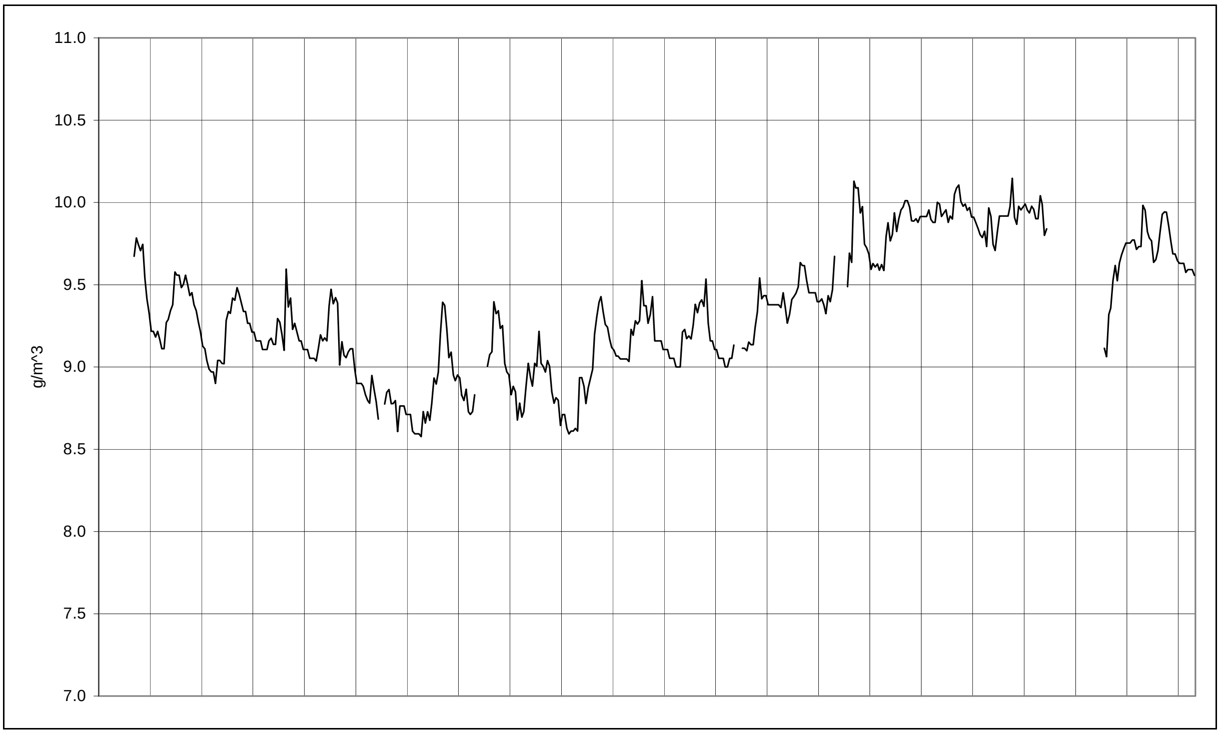

Figure 7: Gradient of the absolute air- humidity in the “French- Hall”

6. The danger of condensate at the exhibits fixed on the exterior walls

To make a statement regarding the danger of condensate at the exhibits at the exterior walls of the Herzog- Anton- Ulrich- museum, the walls’ surface temperatures ϑ_{wall} and the paintings’ back sides $\vartheta_{painting}$ in the crack have to be compared with the temperature of dew point $\vartheta_{dew\ point}$, which can be calculated with the help of the rooms’ ambient data.

The aim of all building climatic tasks in museums is the compliance with the room air temperature and the room air- humidity with following data:

- room air temperature ϑ_i : 18-20 °C
- room air humidity φ_i : 50-55 % relative humidity (r.h.)

These data are based on following dew point temperatures:

1. Normal case $\vartheta_{dew\ point\ (dp)}$ (18°C, 60% r.h.) = +10.1°C
2. Normal case $\vartheta_{dew\ point\ (dp)}$ (20°C, 60% r.h.) = +12.0°C
3. Collapse of the air conditioning $\vartheta_{dew\ point\ (dp)}$ (13°C, 80% r.h.) = + 9.6°C

Table 1 shows the comparison of the dew point temperature and the surface temperatures concerning to different heat- transfer coefficients.

Table 1:
Differences regarding the surface- and dew point- temperatures at a controlled operation and an event of fault

	ϑ_i [°C]	$\Delta (\vartheta_{Wall} - \vartheta_{dp})$ [K]	bei ϑ_a [°C]	$\Delta (\vartheta_{painting} - \vartheta_{dp})$ [K]	bei ϑ_a [°C]
$\alpha_k = \alpha_k$ [2.26]	18.0	3.5	-15.0	6.1	-15.0
$\alpha_k = \alpha_k$ [2.26] + 3	18.0	4.1	-15.0	6.4	-15.0
$\alpha_k = \alpha_k$ [2.26] - 3	18.0	2.4	-15.0	5.0	0.0
$\alpha_k = \alpha_k$ [2.26]	20.0	3.4	-15.0	6.1	-15.0
$\alpha_k = \alpha_k$ [2.26] + 3	20.0	4.1	-15.0	6.4	-15.0
$\alpha_k = \alpha_k$ [2.26] - 3	20.0	2.2	-15.0	4.8	-15.0
$\alpha_k = \alpha_k$ [2.26]	13.0	-0.5	-15.0	1.8	-15.0
$\alpha_k = \alpha_k$ [2.26] + 3	13.0	0.1	-15.0	2.0	-15.0
$\alpha_k = \alpha_k$ [2.26] - 3	13.0	-1.5	-15.0	1.2	0.0

The comparison of the dew point temperature and the surface temperatures points out, that there is no danger of an arising condensate at the walls' surface as well as at the paintings' back sides when having a controlled operation. The minimal differences between the surface- and the dew point temperature concerning to the different assumptions of the convective heat- transfer coefficients α_k in the gap are at least 2 K at the walls' surface and at least 4 K at the paintings' backside.

The collapse of the air conditioning (room climate: 13°C, 80% r.h.) provokes a shortfall of the dew point temperature and consequently an arising condensate on the wall's surface, but there was no condensate on the exhibit itself at each calculated case.

7. Consideration of the paintings' loading caused by shrinkage and swelling

The sorption attribute of the materials affects a shrinkage and swelling. Here the material absorbs and releases the moisture as a consequence of the changing relative air- humidity. These changing volume finally causes the ageing of the exhibits.

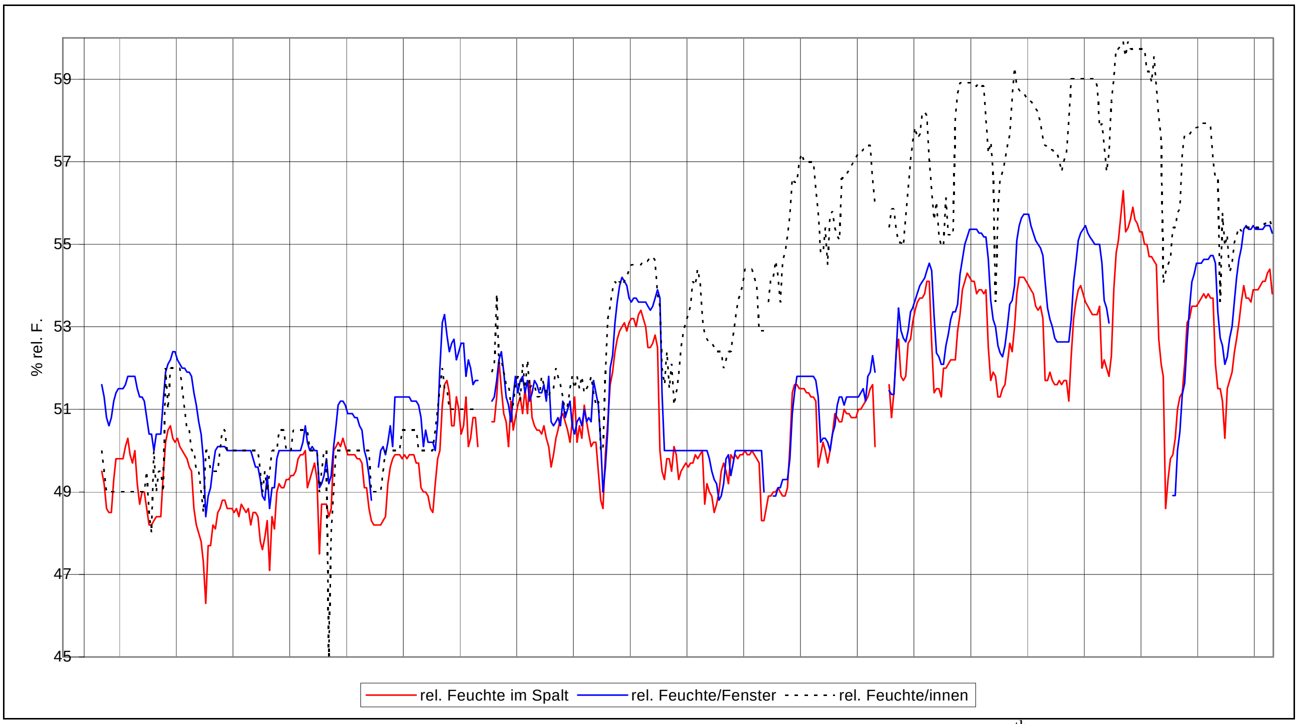

Figure 8: Measurements of the relative air- humidity of the "French Hall" from 10th November until 1st December1999

The basis of all HLT regulations regarding the climate stability und consequently the assurance of the exhibits in museums is the room humidity! This humidity is measured either near the discharged air stream or somewhere else in the room. The relative air humidity are the base of arrangements and assessments. This measured humidity extensively differ from the humidity which can be recognized in the range of the drawings, which are fixed on the exterior walls. Consequently the HLT- regulations have to be carried out on the basis of these measurement of the relative air humidity in the described area!

8. Results

At first following climatic connections in the air gap can be acquired based on the measured air- and surface temperatures as the air humidity in the gap and in the room connected with different versions of calculations:
The connection between the outside temperature and the convective heat transfer coefficient in the air gap is approximately linear.

- The comparison between the surface temperatures with the dew point temperature in the air gap shows, that the inner wall surface's temperature is at least 2 Kelvin and the surface temperature of the painting's backside at least 4 Kelvin greater than the dew point temperature of the bordering air layer.
- The absolute air humidity in the air gap and in the room air is nearly equal. Consequently there is no damp diffusion sloping at the boundary areas of the exhibit. So the intensity of the air circulations in the gap is great enough to prevent so called "Klimataschen".

- The air temperature in the space between the exterior wall and the backside of the exhibit is approximately independent to the outside temperature and is on average 1 Kelvin lower than the room temperature. This can be explained by the fact that on the one hand the heat storage capacity of the massive exterior wall causes a significant amplitude damping of the (from outside) penetrating temperature radiation and on the other hand the interior wall surface's cooling strengthens the thermal conditioned air current. Consequently the convective heat supply of the room air into the air gap is strengthened, too. So the outer temperature and the convection almost compensate each other.
- The difference of the painting's backside and front side is maximal 0,3 Kelvin. With the conditions $\phi_i \approx 20°C$ and $\varphi_i \approx 50\%$ r.h. the humidity difference is about $\Delta\varphi_i \approx 1\%$ r.h.
- Only a malfunction of the air conditioning, but not a changing condition of the outside weather is able to cause a temporary variation of the temperature and in consequence of the relative humidity.
- The basis of all HLT regulations regarding the climate stability und consequently the assurance of the exhibits in museums is the room humidity! This humidity is measured either near the discharged air stream or somewhere else in the room. The relative air humidity are the base of arrangements and assessments. This measured humidity extensively differ from the humidity which can be recognized in the range of the drawings, which are fixed on the exterior walls. Consequently the HLT- regulations have to be carried out on the basis of these measurement of the relative air humidity in the described area.

A hygric thermal decoupling is crucial for not having durable damages of exterior wall constructions and the exhibits. This can be reached if a sufficient air circulation in the gap between the exterior wall and the exhibit can be reached. This air circulation has a more positive effect if the gap is greater. $x_L \geq 0{,}02\ H^{2/3}$ (with x_L = gap width and H = painting's height) is a recommendation of Petzold (1980). This connection between the gap's width and the painting's height could be confirmed in the received case. Additional methods to improve the conservatory comforts are e.g. the fixing of a heat insulation layer on the exhibit's backside and/ or an increasing of the inner wall surface's temperature. This can be reached with the help of a heat insulation or a wall heating system.

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