THERMOVISION AS A COMPLEMENTARY METHOD FOR ANALYSES: MUSEUM PARAMETERS FOR THE PRESERVATION OF GLASS OBJECTS

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ABSTRACT

Exposed glass can be affected by many existing environment parameters. Historical glass being preserved in museum show-cases, has been brought some unsolved problems, due to corrosion process.

The main topic of this paper is focused on the analyzing thermo-humidity parameters inside museums' show-cases, to establish suitable values for exposed glass objects.

They were realized by dataloger system. For better interpretation complementary infrared maping, obtained from thermovision camera pictures was done.

These obtained results pointed some reasons of deterioration glass objects presented in museum showcases.

INTRODUCTION

The fact that historical glass objects can be artificially deteriorated has been proven in many tests and experimental works.

The process of mutual reactions between glass and re-agents influence many elements and physical parameters.

The presence of certain species in solutions, which are chemically different from the original glass, include the re-arrangement of chemical bonds, which can provide some part of the energy. Moreover, the next part of the energy can be delivered to the object (glass) from the surroundings.

Energy, called activation energy is necessary to start any reaction [1]. Energy can be supplied to the object by heat. Heat is defined by the temperature value. Changes of this parameter induce different expansions in the material and tensile strengths between the surface and the subsurface structure. Temperature is the requisite that determines the direction of the net flow movement of heat between two bodies. Temperature can induce a number of mechanical weathering mechanisms and accelerate fatigue failure in susceptible materials.

Because of temperature changes the conditions inside show case can be differentiated. In sunny days glass objects inside case can become overheated by the sun's radiation and effected by changes in the surrounding temperatures. We can talk about: the temperature gradient or so called overheating point. The situation drastically changes after sun-sat and cooling.

In a closed room hot air rises, but its ascent is stopped by the ceiling. The air, distributes, according to its density: 1. the relativity hot and less dense to the top of the ceiling and 2. the relatively cold and more dense to the bottom. Moreover, it must be said, that even a small change in temperature can result in several effects.

Temperature change is not as important as humidity change. For example: internal sources of moisture in historic buildings can cause trouble during the whole year.

Humidity can even increase the deterioration rates in several ways. First of all, the presence of water can favour some chemical reactions.

THE EXPERIMENTAL PROCEDURE

The problem of adjustable suitable temperature (T) and relative humidity (RH) for the historical glass objects, taking into consideration its own history is very important. Glasses preserved by long time at stable parameters, became in equilibrium of internal tensions with structure changes. But, sometimes after staying in acceptable conditions are moved to other places, for example, next to the museum or to another showcase. As a result they can lose their elasticity and have trouble adopting to new conditions, including daily irregular temperature cycles.

Taking into consideration the above mentioned considerations, temperature and relative humidity measurements have been registered in chosen museum showcases in the National Museum in Cracow during different times throughout the year. This was done by datalogers, type S3 120, with measuring range –30 to $+70^0$C and 0 to 100%RH, and measurement accuracy $\pm 0{,}4^0$C, ±2,5 RH at 23^0C. The exposed historical glass objects were in a different state, and placed without any criterion of selection of the objects.

Our testing was started from measurements of temperature and relatively humidity in the museum exposition hall. The first stage of testing was done by collecting values of temperature and relatively humidity in selected showcases. Because of the limited number of datalogers, they were displayed at the same time on the top and inside of the showcases. After collecting data, it was found that the file contains a great deal of different information.. Moreover, actually obtained one value did not refer to the whole volume. The next step was to put the dataloger on each shelf inside of the showcases. Complimentary measurements were done.

To point to the real objects' temperature thermovision measurements were included. They were done by a thermovision camera -THERMA CAM S 60 PAL nr 21803275 – FLIR - which has a measurement accuracy of $0{,}1^o$C. The standard thermometer measures only the temperature of its bulb, which is not necessarily the same as the temperature of the object under investigation. The temperature is a consequence of the present and past energy balance which also includes advective contributions due to the transport of air masses, and only in rare cases is it homogeneous in a body or in a room [7].

Next the measurements of temperatures inside of the exposition hall were done. The data indicated that there were many differences among them. The walls are made of bricks and one of four has many big windows. Obtained thermogram from the wall with few heat and ventilation openings pointed difference in temperature values is qual to 9,7 ^{o}C (between top and the bottom).

On the opposite one with the big windows there are part- time functioning radiators. In this wall the differences in temperature are in the range: 6,5 ^{o}C for the upper part and 3,9 ^{o}C at the

top of the curtain level. In the middle part of that wall T is equal from 19,1 to 19,5 ^{o}C while on the bottom of the floor the T level is about: 15,0 ^{o}C. This information was found due to thermovision camera measurements – Fig.1. As the data shows in one hall there are very many different thermal parameters.

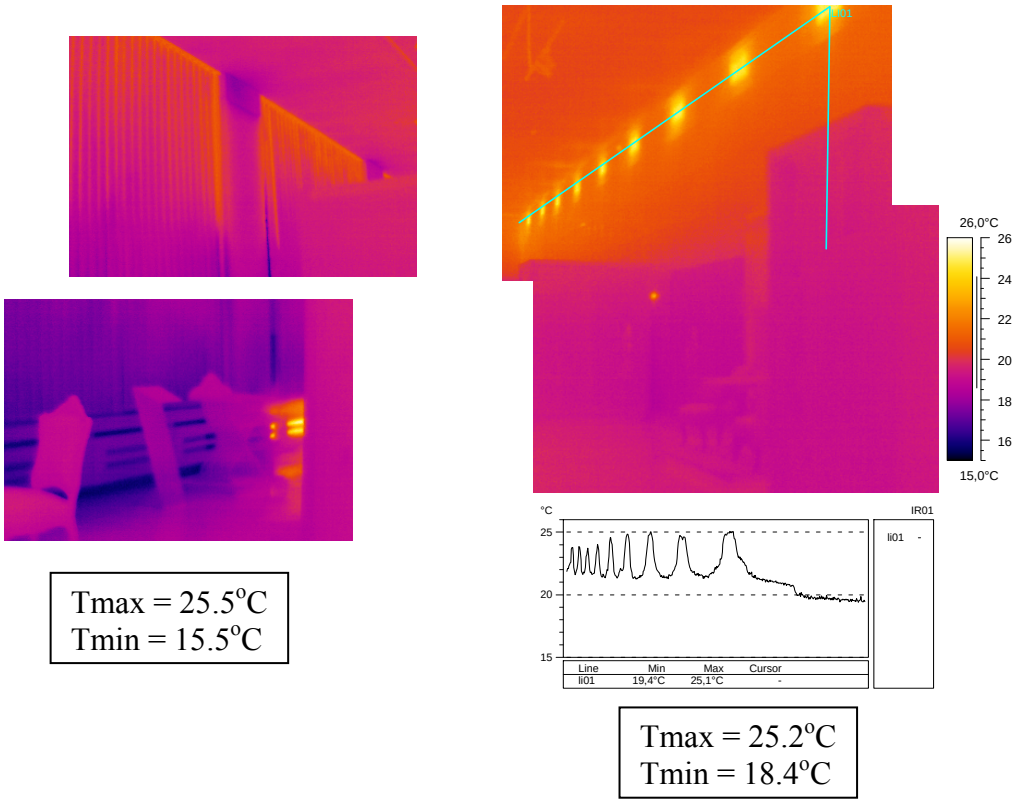

Fig.1. Temperature profile from wall in exposition hall nr 228 January 10:35a.m.

Selected for monitoring two show cases were in opposite corners of the hall. Inside the showcase standing by the window the temperatures are different at each level of the shelves as well as different between left and right side of the showcase. Case nr H-1 has five shelves for object exposition. The temperature gets lower from the top to the bottom. For example, there are the following measurements: 20,2 ^{o}C, 19,8 ^{o}C, 19,5 ^{o}C, 19,4 ^{o}C to 19,1 ^{o}C. According to the thermovision data the average temperature in the whole room was calculated at ca 20,0 ^{o}C.

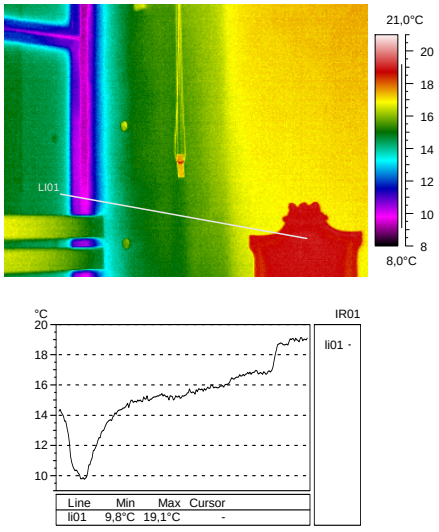

Fig.2Termogram from room corner in hall nr 202 Januarz at. 11:16

But, it should be mentioned here that our measurements were done at the moment which could be drastically changed because of such things as: turning off the heat, the sun setting, turning off the warm air blower shutting down the ventilation openings, for. They were regulated from a different place, far from this hall.

Moreover, looking at the set of temperatures in December, January, February and March (Tab.1.), it can be concluded that temperatures inside were changing due to the outside conditions. A strange situation from physical point of view is presented on thermogram – Fig 2. The chair is placed close to the window where temperature of the frame was 14 ^{o}C but outside of it due to the wrong sealing it was only 10 ^{o}C. The temperature in the hall in October was 20 ^{o}C, but in January it was only 19 ^{o}C.

The temperature differences on the wall with the windows are visible on the Fig.3. Large sized windows covered by curtains have a temperature of ca 21,0 ^{o}C in the inside part. Between the windows there is a brick pillar where the temperature is ca 19,0 ^{o}C. It was the reason to undertake another set of temperatures.

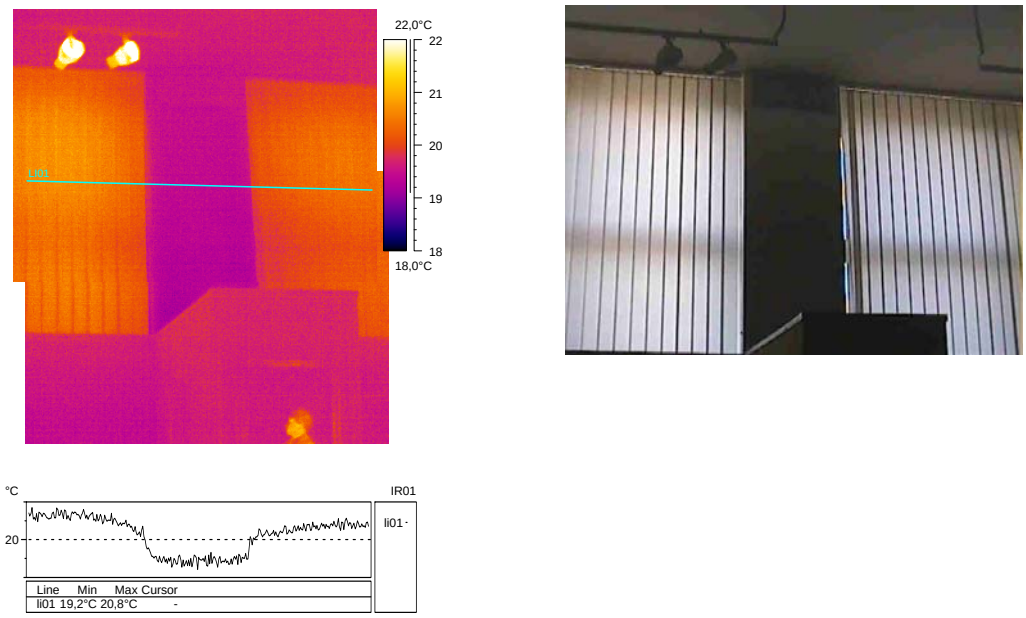

Fig.3. Temperature profile from the wall October noon

Datalogers were put in selected showcases (nr H-1) on each of the shelves and outside of the showcase, at the top. Actually, we tried to prove influence of lighting time on the accumulated heat inside of the case and increase the temperature inside, with suitable higher relative humidity.

The museum is open to visitors from 10.00 a.m. to 3.00 p.m., and in a few days until 6.00 p.m. Collected data according to the highest and the lowest temperatures in a few chosen weeks from three months of monitoring are presented in Tab. 1.

Time	Outside		Inside showcase					
			Number of shelf					
			1 – top		2 – middle		3 - bottom	
	Temp	Hum	Temp	Hum	Temp	Hum	Temp	Hum
	[°C]	[%]	[°C]	[%]	[°C]	[%]	[°C]	[%]
08:00 05-12-2007	19,9	47,2	19,0	47,2	18,8	47,8	18,6	47,9
15:00 05-12-2007	22,6	41,0	22,0	42,2	21,1	44,3	20,4	46,0
00:00 16-12-2007	20,1	41,3	19,4	44,9	19,1	45,4	19,0	45,2
13:00 16-12-2007	22,4	34,2	21,0	41,6	20,1	43,4	19,8	43,2
06:00 21-12-2007	20,2	39,2	19,3	42,7	18,9	43,2	18,8	43,3
16:00 21-12-2007	22,7	34,3	21,4	38,9	20,4	40,8	19,9	41,4
02:00 22-12-2007	20,1	37,8	19,1	41,6	18,8	42,1	18,6	42,1
15:00 22-12-2007	22,9	30,3	21,4	37,1	20,4	38,9	19,8	39,0
07:00 23-12-2007	20,3	31,5	19,3	37,9	18,9	38,3	18,7	37,9
15:00 23-12-2007	23,1	29,7	21,4	34,4	20,5	36,0	19,9	36,8
15:00 26-12-2007	23,0	31,8	21,6	36,4	20,6	38,1	20,1	38,8
21:00 26-12-2007	20,4	37,6	19,5	39,7	19,2	40,1	19,0	40,4
05:00 27-12-2007	20,4	34,8	19,4	38,9	19,0	39,3	18,8	39,5
15:00 27-12-2007	23,1	31,0	21,6	35,5	20,6	37,1	20,1	38,0
15:00 28-12-2007	22,8	33,5	21,6	36,9	20,6	38,6	20,1	39,4
22:00 28-12-2007	20,4	39,6	19,5	40,4	19,2	40,9	19,0	41,4
15:00 29-12-2007	23,1	36,4	21,9	37,5	20,9	39,2	20,4	40,0
23:00 29-12-2007	20,1	38,6	19,2	41,0	18,9	41,2	18,8	41,4
00:00 30-12-2007	20,3	38,7	19,2	40,8	18,9	41,2	18,8	41,5
14:00 30-12-2007	22,9	34,2	21,4	37,7	20,4	39,4	20,0	40,2
14:00 02-01-2008	22,1	35,0	21,0	41,0	20,2	42,6	19,8	42,8
22:00 02-01-2008	20,3	38,6	19,4	41,9	19,1	42,3	19,0	42,4
00:00 03-01-2008	20,4	37,9	19,4	41,9	19,1	42,3	19,0	42,2
15:00 03-01-2008	22,8	31,3	21,7	37,1	20,7	38,7	20,3	38,9
15:00 09-01-2008	22,4	40,1	21,5	42,2	20,6	44,2	20,1	45,2
23:00 09-01-2008	20,0	46,2	19,2	46,4	18,9	46,8	18,9	47,1
15:00 11-01-2008	22,4	43,8	21,6	43,7	20,6	45,8	20,2	47,0
22:00 11-01-2008	19,4	48,3	19,0	49,0	18,8	49,2	18,8	49,1
15:00 15-01-2008	Because of technical reason this temperature was not registere		22,0	43,1	20,1	47,9	19,6	48,7
22:00 15-01-2008			19,0	49,3	18,6	49,9	18,4	50,4
08:00 25-01-2008			18,9	46,1	18,4	47,0	18,1	47,7
18:00 25-01-2008			22,0	41,0	20,0	45,3	19,6	46,4
06:00 26-01-2008			18,5	44,2	18,0	45,3	17,7	45,9
18:00 26-01-2008			21,8	39,4	19,8	43,9	19,3	44,9
01:00 27-01-2008			18,6	42,8	18,1	43,7	17,8	44,3
16:00 27-01-2008			21,5	40,2	19,5	44,7	19,0	45,8
05:00 03-02-2008			19,1	46,4	18,6	47,6	18,3	48,1
15:00 03-02-2008			21,9	41,0	20,0	45,5	19,4	46,7
10:00 04-03-2008			18,4	45,9	17,8	46,6	17,6	47,5
16:00 04-03-2008			20,9	39,8	19,1	43,3	18,6	44,7
09:00 05-03-2008			18,7	44,3	18,2	45,1	18,0	45,8
17:00 05-03-2008			22,1	38,4	20,1	41,7	19,6	43,2
03:00 06-03-2008			18,5	42,5	18,0	43,2	17,8	43,9
17:00 06-03-2008			22,5	34,9	20,4	39,0	19,9	40,1
01:00 08-03-2008			19,0	42,6	18,7	42,6	18,6	43,0
16:00 08-03-2008			22,0	38,2	20,2	41,4	19,9	42,2

Tab.1.Temperature and Relatively Humidity outside and inside of showcase H 1

The changeable outside situation caused temperature gradients on all of the shelves. Observing data it was concluded that the ambient temperature in the museum usually is a little higher than the temperature on the top shelf. Overheated moments have happened a few times every 24 hours. According to the literature [2, 3, 4, 6] and some own experiences, such a situation is not desirable to preserve good conditions for glass. Actually, the average temperature on the top shelf is about 19,5 ^{o}C, however, during the day there were some moments when the temperature was much higher and reached 22,6 ^{o}C.

The most probable reason for this phenomenon is a change in the outside conditions of the museum. It could be caused by short or long time of sun – shining, central heating, the air condition system, visitor movement. On the basis of the data shown in Tab.1. it was found that the highest temperature appeared between noon and 2.00 p.m. However, in a few cases the biggest T value was between 5.00 p.m. and 6.00 p.m. It was during the days with longer open hours. It happened in February and it is shown in Tab.1. It can be assumed that it was due to longer heating time in the museum. After reaching its highest value, the temperature immediately decreased. In accordance with this occurrence the value of the relatively humidity also changed. The value for the outside humidity drastically changed accordingly to the temperature changes. On the other hand, inside the showcase increasing humidity was created differently. It was found that the highest amount humidity was collected on the bottom of the show- case. It happened because of limited space inside the showcase and lack of ventilation. Moreover, the construction of the showcase is very favourable for creating such a RH value. The bottom of the case is made of chip-board with specific features that allows it to accumulate moisture. It has happened because of organic compound concentration in the board which easily attracts water or vapour. For decorative reasons this board was covered by some kind of fabric that helps to keep moisture [5]. These facts create a dangerous situation because they influence the created mutual reactions between glass and moisture, as well as high and low amounts of moisture.

In general, it was found that the warmer it was outside the hall, the warmer it was inside. It looks like the lighting case lamps do not have an influence on the drastic changes inside. They give some part of heat (look at Tab.1) which is reduced gradually reaching the lowest level of the shelf in the case. It is important to pay attention to the distance between the upper part of case with lamp and the first shelf. Moreover, lamp must have the protection, so called “mat shutter” to reduce passing light radiuses by the glass shelves - Fig.4.

Fig.4.Temperature profile from outside of showcase nr E8 October noon

It is visible on the thermovision camera pictures that the lighting lamps provide visible heating only on the upper part of the showcase. To better visualize situation inside the

showcases the diagrams of temperature and relative humidity changes in some chosen period of time are presented below – Fig.5.

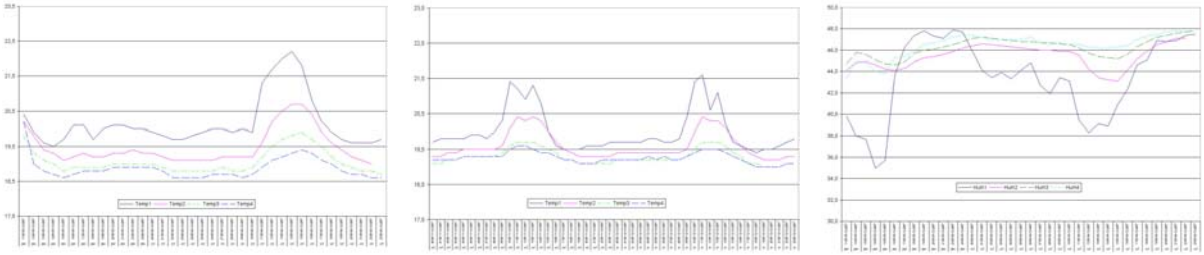

Fig.5. Examples of two - three day monitoring of T and RH inside and outside showcase

They point to the maximum increased value of inside temperature and humidity level. It is indicated that the processes are not undergoing in the same way outside as inside. Once more it is confirmed that the changing temperature is induced by ambient thermal parameters. Humidity out of the case is spread out easier and quicker, without any limitations to volume. The situation inside is favourable to keep similar temperatures on the first two top levels, but the deeper, the bigger changes are observed. It could happen, because of a smaller amount of light rays going through the lower glass shelves, and according to physical rule that warm air is at the upper parts. In that situation the bottom is the coolest and preserves more moisture. Accumulated moisture is facilitated by the chip board feature. Its high organic compound concentration helps to ease the reaction with water. Obtained data were applied to calculate correlation coefficients, among shelves. They were presented in Tab.2.

Correlations coefficient. Marked correlations are significant at p < ,05000 N=1007 (Casewise deletion of missing data)				
	TEMP_Out	**TEMP_1**	**TEMP_2**	**TEMP_3**
TEMP_Out	1,0000	,8768	,8182	,6810
	p= ---	p=0,00	p=0,00	p=0,00
TEMP_1,	,8768	1,0000	,9767	,8794
	p=0,00	p= ---	p=0,00	p=0,00
TEMP_2	,8182	,9767	1,0000	,9469
	p=0,00	p=0,00	p= ---	p=0,00
TEMP_3	,6810	,8794	,9469	1,0000
	p=0,00	p=0,00	p=0,00	p= ---

Tab.2.

On the bases of these calculations, the outside temperature does not have very high correlation with the top shelf and low with the bottom shelf. However, it was found that there is a higher correlation between the first and second shelf, than it was obtained for the second on the third shelf. Above data are presented on the following diagrams presented as scatter plot, which better visualized influences between local parameters (inside of case) Fig 6.

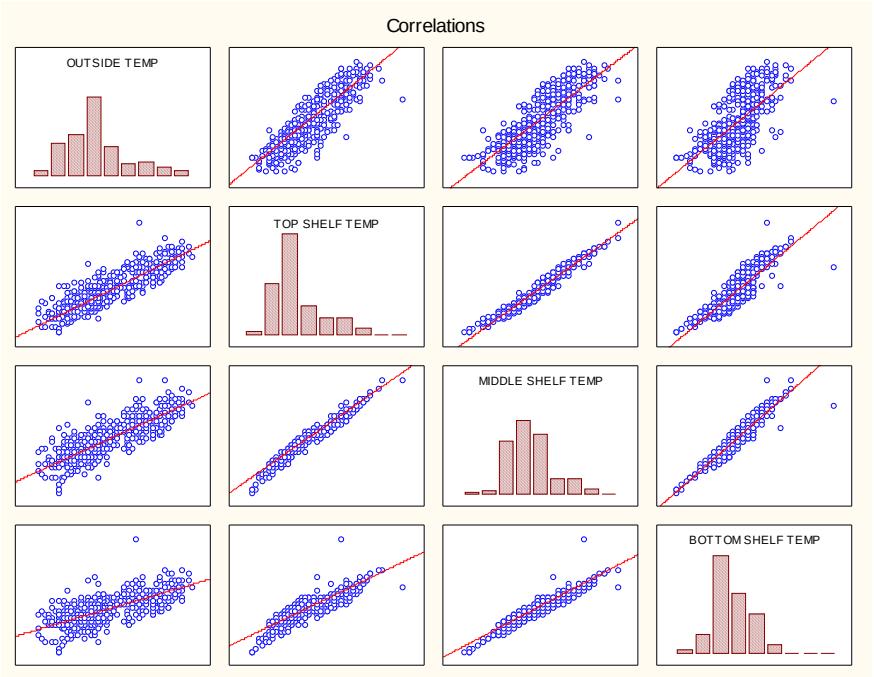

Fig.6. Correlations among outside and inside shelves.

According to humidity – calculated coefficients presented in Tab.3 pointed that the biggest correlation is between second and the third shelf. Outside humidity has some influence on internal case conditions, but the actual relationship among shelves seems to be are more effective. This relationship is between the second and the third shelves, and the third one always has the highest amount of moisture.

Correlations coefficient. Marked correlations are significant at p < ,05000 N=1007 (Casewise deletion of missing data)				
	HUM_Out.	**HUM_1**	**HUM_2**	**HUM_3**
HUM_Out.	1,0000	,9201	,9123	,9221
	p= ---	p=0,00	p=0,00	p=0,00
HUM_1	,9201	1,0000	,9937	,9833
	p=0,00	p= ---	p=0,00	p=0,00
HUM_2	,9123	,9937	1,0000	,9952
	p=0,00	p=0,00	p= ---	p=0,00
HUM_3	,9221	,9833	,9952	1,0000
	p=0,00	p=0,00	p=0,00	p= ---

Tab.3.

Another statistically calculated comparison presented in Tab.4, allows to conclude that temperature differences create a situation which is not acceptable for glass. Generally the inside showcase temperatures are mainly dependent on the ambient temperature out of the showcase, but the lighting lamp gives enough heat to rise temperature on the top. Moreover, due to the physical feature, hot air is lighter than cool air. That is why the warmer part of the air accumulates in the uppermost level of the showcase.

Descriptive Statistics (Diagrams for outside and 3 shelves)							
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Range**	**Std.Dev.**
TEMPout	1007	20,58620	20,40000	18,70000	23,40000	4,700000	0,915494
TEMP_1	1007	19,76971	19,60000	18,40000	22,60000	4,200000	0,646297
TEMP_2	1007	19,34062	19,20000	18,00000	21,10000	3,100000	0,460755
TEMP_3	1007	19,17021	19,10000	18,00000	21,30000	3,300000	0,374147

Tab.4

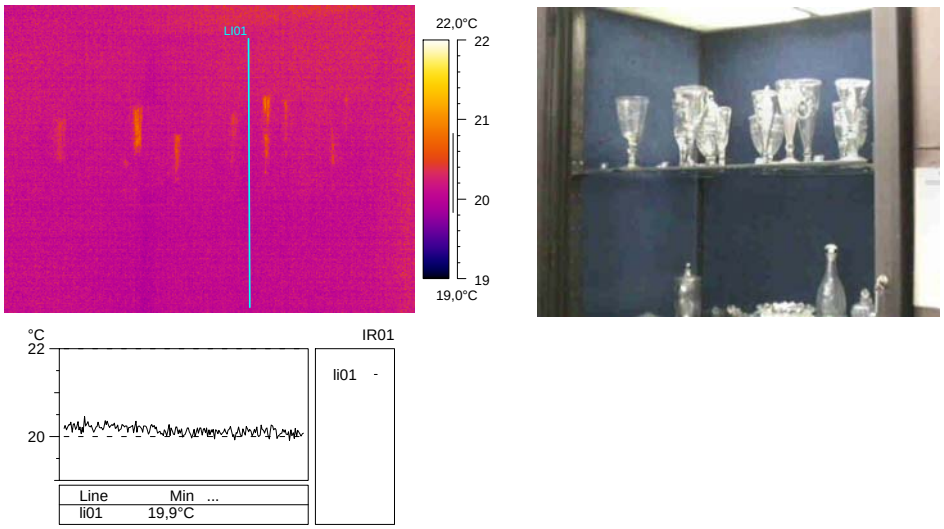

Fig.7.Temperature profile along chosen line in showcase F-9.

Actually, it was very well visible in another showcase (nr F-1), which is placed inside the wall. This showcase is surrounded by walls, and the front side, is made up of glass oriented towards exposition hall. After analysing the thermovision camera's pictures, it has been found that temperatures inside are comparative among all shelves inside.

Obtained temperature profile along chosen line pointed stable parameters. It means that objects' temperature and inside parameters are stable.

DISCUSSION AND RESULTS

Trials were carried out to establish very local showcase physical parameters.

Obtained data from long time monitoring of temperature and relatively humidity have not brought us as useful data as we got from thermovision camera pictures.

It was a good possibility to detect temperature from some defined volume (as showcase inside) or from different points, to distinguish the situation among all displayed glass objects. Actually, the tendency of decreasing temperature from top to bottom was visible. It was confirmed in some earlier showcase analyses.

It should be emphasized here that we did not analyse the influence of the glass state on the criteria of degradation development, because of lack information about their situation before placing them into the showcases in the exhibition. On the bases of collected temperature and relative humidity data, it was concluded that temperature gradients were created not only during 24 h, but between the months (December – January). It could happened due to changes of close surrounding weather. Because the hall is oriented to the West, higher temperatures

were reached in this hall mainly in afternoon until 3.00 p.m. (monitoring was done in the winter when the sun sets much earlier than in the spring.

FINAL REMARKS

1. The outside temperature of the showcases is created by central heating (radiators) during the winter, by the air conditioning the whole time, solar radiation and lighting.
2. The glass objects are illuminated from sources installed inside, at the top of the showcases. Between glass objects and so called "cool light" there is w panel of frosted glass.
3. Inside most showcases there are three shelves located at different distances. The highest shelf is situated not far away from the frosted panel that is separate from the source of the light.
4. The distance between the glass object and the light source influences the surface object temperature
5. The glass objects displayed in different showcases are in different conditions.. The degree of the deterioration of the surface was never a criterion of selection of the objects. However, the mutual chemical reactions between glasses might influence the RH inside the showcases.
6. Inside the showcase the highest temperature is at the top shelf. Usually it is about 1°C higher then the temperature on the lower shelves. The temperatures on the lower shelves are similar to each other.
7. Outside the showcases the RH is suitable to the changes of the temperature.
8. Inside showcases there is tendency of accumulation of the humidity at the bottom. The bottom is made of the chip-board (harl), covered by the textile.

RECOMMENDATIONS

- The illumination of the showcases even by so called "cold light" might be damaging for the everyday changing (rising and dropping) of temperatures. In spite of the affirmation that "cold light" does not emit IR, the results of just carried out explorations show the effects of warmness and coolness inside the showcase.
- The nearer glass object is placed to the source of cold "cool light" the higher temperature acts upon it.
- The state of the glass object surface should be very well considered before planned exhibition by curators, to avoid higher rate for development deterioration of vulnerable glasses.
- Neither chip-board nor the textile covers should be taken in to consideration when showcases are prepared for exhibition for susceptibility to humidity as well as organic compounds inside them that just in higher humidity easily react with the glass.
- In order to arrive at a better interpretation of the described phenomenon, some experiments with inducing corrosion of glass sensors should be carried out in changeable physical-chemical parameters. They will emphasize, for example, the dependence of higher temperature on the influence glass object deterioration.
- The conditions inside the showcases should be arranged to avoid the accumulation of moisture on the bottom. (remove chip-board and fabric as a decorative element).

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