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Monitoring indoor climate in a medieval castle

MARJANA SIJANEC ZAVRL*, ROKO ZARNIC AND IVO NEMEC

Civil Engineering Institute ZRMK, Dimiceva 12, 1000 Ljubljana, Slovenia
E-mail: msijanec@gi-zrmk.si

Abstract

The monitoring of indoor climate conditions was organised in the medieval Brezice Castle in Slovenia. The purpose of measuring campaign is to obtain data about the long term changing of indoor climate. The data are needed in process of mitigation of influence of moisture and temperature changing on the large fresco paintings. The campaign will provide data to be used as valuable source to support museum management concerning the future use of castle halls and protection of exhibited objects. They will also help in future decision making about the choice of the most suitable heating and ventilation systems in halls opened to public use. The data collected in the first year give the expected answers and prove the need for continuation of measuring. The special attention is paid to condensation risk analysis in connection to care for preservation of valuable fresco wall paintings in the huge Knight Hall of Castle.

THE PROGRAMME OF MONITORING

The scope of measurement campaign

The Brezice Castle is situated in south-east part of Slovenia. The renaissance castle was erected in 1529 and rebuild in baroque manner in 1694 (see Figure 1). The layout of castle consists of four connected wings that surround the open-air inner courtyard. Each wing consists of ground floor, two additional stories above it and of ventilated attic. In the beginning of the 18th century the most important castle wall paintings were fresco painted on the walls and ceilings of the main castle hall named the Knight Hall, in the stair-case and in the castle chapel. The wall paintings in the Knight Hall are the biggest secular opus in Slovenia. In the past the structure of the castle and paintings were partly damaged due to material deterioration and foundation settlements. The castle and the paintings are under permanent regard and restoration activities.

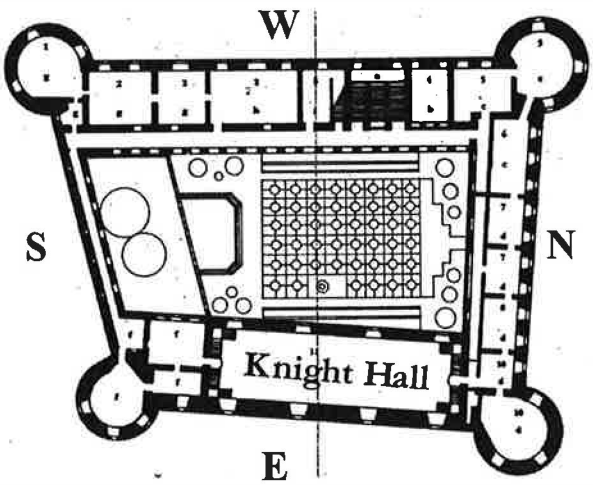

Figure 1. The layout of Brezice Castle in Slovenia

A climate measurement system was installed in an open stairway, which was later fenced by glass in order to moderate outdoor climate influences on fresco. The climate monitoring system was installed to find reasons for intensive deterioration of fresco and covering layer of plaster noticed in the last year's period. Similar fresco deterioration has been noticed also in the castle's Knight Hall.

There is a great interest of the Castle management to open the impressive Knight Hall for the concerts and short term exhibitions. In past, even a flower and gardening exhibition was held during one-week period. In order to analyse possible damages to fresco paintings because of the short-term increased humidity caused by events or uncontrolled ventilation with humid air the microclimate measuring system was installed in the Knight Hall. The microclimatic conditions should be controlled during winter period by a suitable heating system that would not affect the fresco paintings and exhibited objects. A relatively new "Temperierung" approach is taken into consideration to be introduced in the halls of the Castle. "Temperierung" is low temperature wall heating system consisting of pipes that are in-built in the massive wall beneath their inner surface. This system is described in the following paper [1].

Monitoring focused indoor and outdoor air temperature and relative humidity, as well as both in various locations in the massive wall and painted plaster of walls and ceiling.

The investigations presented in this paper are a part of international EUREKA EU 1383 PREVENT project ([2] and [3]). Ministry for Science and Technology of Republic of Slovenia and Civil Engineering Institute ZRMK from Ljubljana granted Slovenian activities in project.

Instrumentation of the Knight Hall

The big Knight Hall is 31.1 m long, 9.6 m wide and 7.8 m high (see Figure 2). It stretches over the first and second floor of the eastern wing of the castle. The ground floor under the Knight Hall is used as a vine cellar. The castle walls are built of massive stone masonry. Their thickness is gradually lowering from ground floor up to roof (see Figure 3). Outer walls are thicker than walls oriented to the courtyard. The roof construction and ceilings above the Knight Hall are made of timber. The timber beams of ceiling are plated with wooden boards thatched with reed that carry about 40-mm thick multi-layered plaster.

To preserve the fresco painting quality, several preventive activities have been undertaken in the last decade. Since in the last years progressive fresco deterioration has been

Table 1. Minimal and maximal temperatures measured in the Knight Hall expressed in [°C]

Date	Time	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
April 26, '97	4:00:53	5.2	12.2	12.5	8.4	8.7	8.7	8.6	8.9	9.1	9.4	9.6	10.7
April 26, '97	7:41:19	9.5	7.4	8.4	8.2	8.3	8.2	8.3	8.4	8.2	8.3	8.2	7.4
May 18, '97	12:13:06	33.7	21.5	21.1	16.4	17.9	17.5	17.4	17.2	18.4	19.1	20.5	28.8
May 28, '97	20:46:28	12.0	18.9	24.2	19.9	24.0	21.7	21.6	19.6	22.9	24.6	15.6	21.3

Table 2. Relative humidity measured in the Knight Hall expressed in [%]

Date	Time	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8
April 26, '97	4:00:53	87	73	71	64	64	66	64	63
April 26, '97	7:41:19	64	73	70	64	64	66	64	63
May 18, '97	12:13:06	32	87	75	68	71	70	69	63
May 28, '97	20:46:28	84	83	70	69	69	67	71	68

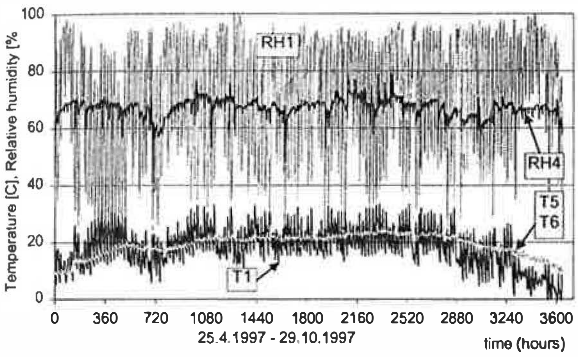

Figure 5: The results of measuring of temperature and relative humidity in the 6 months period

The results of relative humidity measurements show the stable conditions in the Knight Hall. It can be concluded that microclimate in large hall responds slowly on the changing of external climatic conditions due to massive masonry walls and relatively tight windows. Therefore in the normal conditions when the occupancy of hall is moderate there are no severe influences that may cause decay of fresco wall paintings or exposed objects.

Microclimatic conditions during events in the Knight Hall

The microclimate conditions are changed in presence of a large group of people or objects that excrete humidity, gasses or radiate heat. This fact was proved by results of temperature and relative humidity measurements. In August 1997 evening concerts were performed each second day with audience of about 300 persons. Each person radiates about 100W and excretes a significant quantity of humidity.

Before the concert start the air temperature in the mid-height of hall was about 24°C and beneath the ceiling about 25°C. The relative humidity of indoor air was in the same time about 75%. The mid-day outdoor temperature was 32°C and outdoor relative humidity in the time of concerts was about 94%. Due to presence of audience the indoor air temperature rose up for about 2°C at the mid-height of hall and for about 5°C below the ceiling. The relative humidity in the mid-height of hall rose up for about 10% and beneath the ceiling for about 12%. Better insight in temperature and relative humidity changes during the events can be obtained from diagrams presented Figures 6 and 7. These data shows how sensitive can be even a large indoor volume on the short time presence of large audience. In the cases of flower exhibitions the influence on microclimate is expected to be much higher.

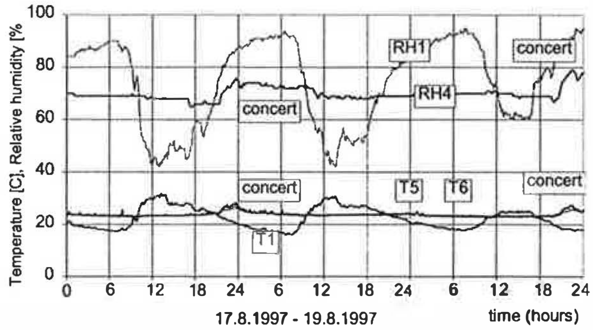

Figure 6: The results of measuring of temperature and relative humidity at wall surface 2.5 m above floor of the Knight Hall in the days of concert performance

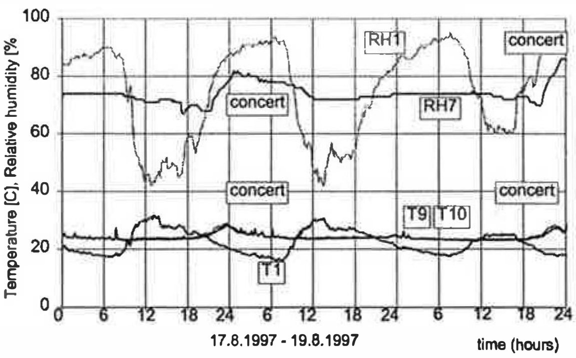

Figure 7: The results of measuring of temperature and relative humidity beneath the ceiling of the Knight Hall in the days of concert performance

The condensation risk analysis

The main concern related to preservation of fresco wall paintings was water condensation on plaster surface. It can lead to the capillary penetration of water solutions of agents beneath the surfaces of paint and cause deterioration and damaging of frescoes. Two potential condensation cases were assumed: the 100% relative humidity of air close to wall surface and the 75% relative humidity of air close to

found in area of stairways the main idea was to assess the impact level of the following factors:
•Outdoor air temperature and relative humidity
•Indoor climate changes because of the events
Outdoor air quality.

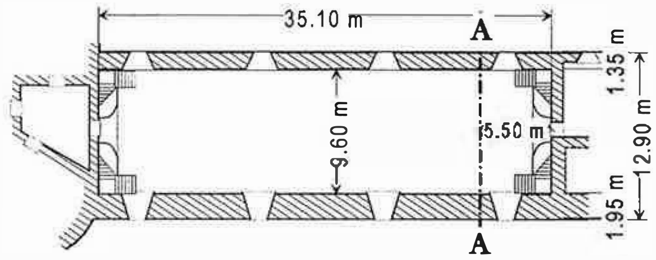

Figure 2. The layout of the Knight Hall in the eastern wing of Brezice Castle in Slovenia

Humidity fluctuations and water transport through walls are necessary condition for activation of other decay factors like frost, soluble salts, and corrosive gases from polluted air and biodegradation. Decay caused by these factors usually severely develops at the wall surface or beneath it. In the case of wall paintings the paint layers suffer most of damages. In the case of paintings of the Brezice Castle the most possible decaying factor is water. The paintings are sufficiently high above the ground level and therefore they are not affected by raising damp. The roof is regularly maintained so the leakage of rain over the walls is not the case. The only source of water that can harm the paintings is humidity caused by the wall surface condensation.

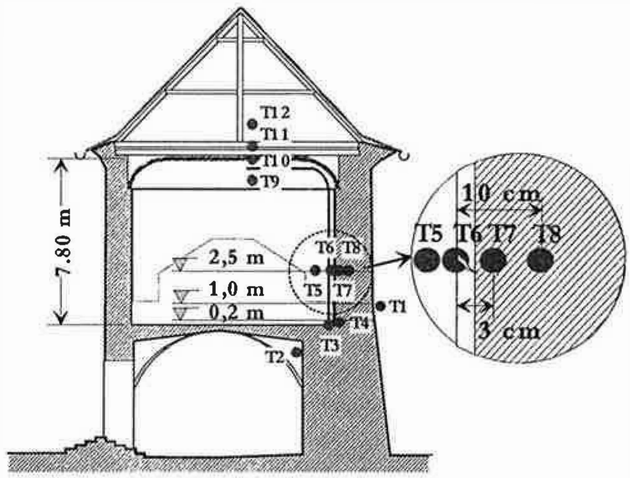

Figure 3. The temperature measuring points in the A-A cross-section of the Knight Hall

This assumption is proved by the development of damages of wall paintings on the walls of staircase. In the first period when the staircase was opened to the influence of atmospheric agents the wall paintings deteriorated relatively fast. After closing of staircase by glass fences the painting deterioration stabilised because of diminishing the impact of the outer air influence. The most influencing factors were changes in temperature and relative humidity in the surrounding of painted walls.

The experiences gained from measuring of microclimate conditions in the staircase helped in the planning of measuring campaign in the Knight Hall. It was decided to measure the temperature changes and relative humidity changes in one cross-section of hall (see Figures 3 and 4).

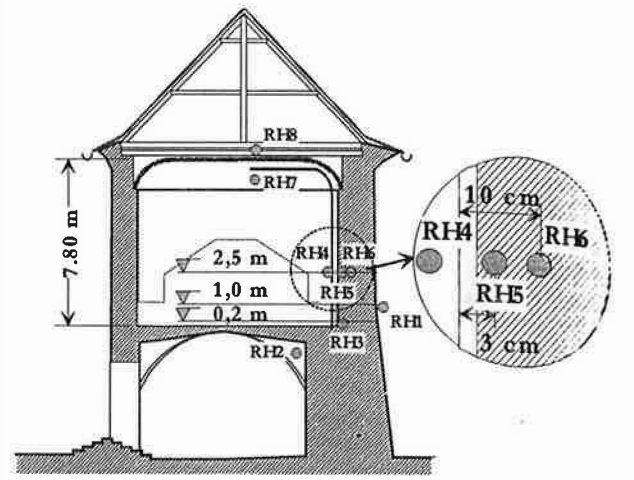

Figure 4. The relative humidity measuring points in the A-A cross-section of the Knight Hall

The steel mast provides the supporting construction for the instruments. Altogether 12 temperature measuring points and 8 relative humidity measuring points are installed. Temperature sensors are thermocouples Cu-Con, Ni-NiCr. Relative humidity sensors are capacitating thin-film polymer sensors BMC Type GHTU. Their measuring range is 0 to 100% of relative humidity with linearity of 2% in recommended measuring range between 30% and 80% of relative humidity. Sensors are connected to the data acquisition system that constantly samples results in ten minutes intervals. They are placed in three levels inside the hall: 0,2 m above the floor, 2.5 m above the floor and beneath the ceiling. Instruments are also installed in the wine cellar beneath its floor and in the attic above the hall's floor. One pair of instruments is installed outside the building to measure temperature and relative humidity of outer air. The temperature and relative humidity is measured on the wall surface and few centimetres beneath the surface of wall (see Figure 3 and 4). Temperature is also measured in the plaster of wall and in the plaster of ceiling.

THE RESULTS OF MONITORING OF THE KNIGHT HALL INDOOR CLIMATE

The microclimate conditions in normal use of hall

The measuring campaign started in the last week of April 1997 and is continuing with speed 6 readings per hour. The data are collected by a data acquisition system and stored on disk. In Figure 5 are presented results of collecting data on selected points (see Figures 3 and 4) obtained in the first six months.

The diagram shows that increasing of wall temperature (T5) followed the increasing of outdoor temperature (T1) with the delay of about 10 days due to heat accumulation in masonry walls. Table 1 shows indoor temperatures during the minimal and maximal outdoor air temperature. Table 2 shows relative humidity measured in the same time as temperatures that are shown in Table 1. The differences between indoor temperatures in the Knight Hall, in cellar and in attic can be clearly seen. There are also differences between temperatures measured on the wall surface and deeper inside the wall. The layouts of measuring points are shown in Figures 3 and 4.

wall surface in conjunction with presence of salts in plaster and therefore intensified humidity suction. The late phenomenon is the result of complex mechanism that depends on very local microclimatic conditions in the surface region combined with the material properties of plaster and extension of its porosity and micro-cracks.

The condensation risk can appear even in the short summer periods if the indoor humidity significantly increases. Such a case is presented in Figure 9 where the measured temperatures in the time of concerts are compared with dew point temperatures The dew point temperature was calculated from relative humidity and indoor air temperature following the expressions:

$$T_d = \frac{T_0}{1 - \frac{R_v T_0}{L_{av}} \ln\left(\frac{e}{e_{w0}}\right)},$$

$$e = U \cdot e_w \qquad e_w = e_{w0} \cdot e^{\frac{L_{av}(T-T_0)}{R_v \cdot T \cdot T_0}} .$$

T_d is a dew point temperature, T is air temperature, T_0 is temperature of triple point. U is relative humidity (from 0 to 1), R_v is vapour gas constant, L_{av} is latent evaporation heat, e is vapour pressure, e_w is saturated vapour pressure and e_{wo} is vapour pressure in triple point.

The results of a six months measuring campaign starting the spring 1997 show that microclimatic conditions were not critical for surface condensation was. It should be mentioned that critical early spring period of year 1998 is not yet analysed. In the spring 1997 the hall was not used for events. Therefore no additional indoor sources of moisture were present. During the springtime the relative indoor air humidity was in range of 65%. In the same time the wall temperature was still low and outdoor relative humidity was in range of 75%. The significant indoor source of humidity or import of outdoor humidity by extensive natural ventilation could lead to condensation on the surfaces of cold walls. It is expected that the condensation risk is higher in the wintertime.

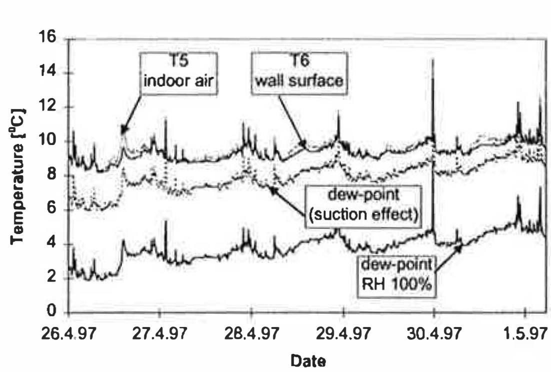

Figure 8: The dew analysis in the area of wall surface 2.5 m above the floor of the Knight Hall in the last week of April 1997

Calculation of the dew point on the surface of walls shows that water condensation conditions are not critical during the springtime if only criteria of 100% RH is taken into consideration and if large audience does not occupy hall (see Figure 8). In the case of event the criteria of 100% RH can near the critical conditions (see Figure 9). In both discussed cases the criteria of "suction effect" is more severe. It is potentially critical in the case of events in hall even in summer time (see Figure 9). The "suction effect" is related to presence of soluble salts in the plaster. Relative humidity over 70 % is high enough to produce water condensation in the material due to hygroscope soluble salts [4]. Therefore the future investigations will be also oriented to detection of salts in painted plasters to obtain information about possibilities of condensation due to "suction effect".

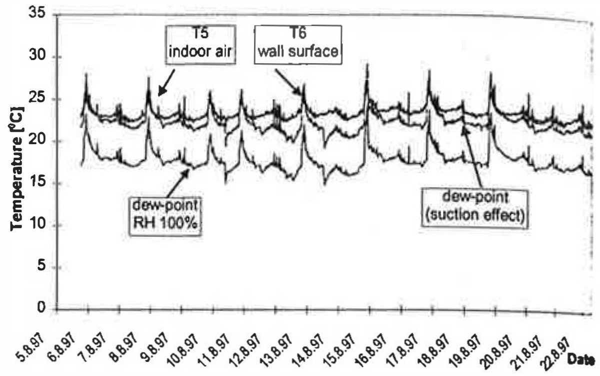

Figure 9: The dew analysis in the area of wall surface 2.5 m above the floor of the Knight Hall in the second and third week of August 1997

CONCLUSIONS

The measurement of indoor clime in the medieval castles can provide valuable sources of data needed for optimal use and management of this type of cultural monuments. The major dilemma is how much can be cultural monument and its interior exposed to visitors. The knowledge about response of monument fabrics and objects on visitors' impact because of the influence on indoor climate conditions is the essential starting point for decision making. One of the major problems is the condensation on the wall surfaces and on the exposed objects. This influence can be moderated in severity by appropriate organisation of planned events and by investment in systems that lower the condensation risk.

The first step in mitigation of condensation is to limit people gathering in the unheated hall during the critical year periods, as is early spring. Even more important issue is to control natural ventilation of hall regarding the outdoor relative humidity. However, the condensation conditions can develop also in other seasons of year. One of the available long-term solutions that can enable using of castle halls for larger events is introduction of controlled low temperature heating system. It can regulate massive wall heat accumulation during the whole year to avoid surface conditions that can lead to condensation. The system of this kind is also "Temperierung" system that is described in the following paper of this Proceedings [1].

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