Control of Temperature and Humidity Conditions of Church Buildings-Architectural Monuments as a Method of Preservation

V Dorokhov1, N Pintelin1

1Laboratory of museums climate and architectural monuments, State Research Institute for Restoration, Ministry of Culture of the Russian Federation (GOSNIIR), Russia, Moscow,107014, Gastello st., 107014, 44, 1.

Abstract. Adjustment of indoor climate inside the monument and temperature and moisture conditions of the building envelope are important measures for reliable preservation of wall paintings in an architectural monument. Adjustment of indoor climate inside the monument and temperature and moisture conditions of the building envelope are important measures for reliable preservation of wall paintings in an architectural monument. These measures are especially important when a church architectural monument is being used for worship purposes. Temperature fluctuations and high humidity facilitate active biological deterioration of painting components, as well as physical and mechanical degradation and chemical corrosion of painting materials. Extensive studies of monument microclimate and temperature and moisture conditions for preservation of the Cathedral constructions covered with unique paintings were conducted in Dormition Cathedral in the town of Vladimir. The studies were conducted in 2011 – 2015. The reasons of occurrence of climatic conditions that have a negative impact on preservation of monumental paintings were identified. Results of the study were used as the basis for preparation of an assignment for modernization of the Cathedral heating, ventilation and air conditioning system. After development of the project the modernization project has passed expert evaluation and was implemented – a number of technical and construction activities were conducted, and the system was modernized. Monitoring of the preservation conditions inside the monument continued after modernization of the system. Wall paintings and iconostasis preservation conditions were analyzed. Monitoring results were used for adjustment of the climate control system control algorithm. Thus, monitoring of temperature and humidity allows for optimization of the temperature and moisture conditions for preservation of the Cathedral wall paintings when it is being used for worship.

1. Introduction

Equipment of church architectural memorial buildings with modern climate control systems should be considered as one of the main methods of their preservation [1], [2]. When monuments are being used for church or museum purposes in Russian climate, creation of an efficient inside air humidity and temperature control system is a significant aspect of ensuring long-term preservation of a monument [3], [4]. This article describes studies and optimization of temperature and humidity aspects of preservation of wall paintings and icons in Dormition Cathedral in the town of Vladimir – a unique 12th century monument protected by UNESCO.

2. Problem definition
In 2011-2012 specialists from the State Research Institute for Restoration have studied the temperature and humidity parameters of inside air and constructions, as well as specifics of air exchange in Dormition Cathedral in the town of Vladimir – a 12th century architectural monument. The studies were carried out using methods developed together with the authors [1], [2], [3], and [4]. The studies included recording of temperature and relative humidity values in different areas and at different heights of the Cathedral. Also, thermal camera studies of temperature fields were carried out on the Cathedral constructions and wall paintings. The studies and analysis of their results have shown that the existing climate control system that combines ventilation with air heating does not ensure the climate conditions required for preservation of wall paintings and iconostasis of the Cathedral. The thermodynamic analysis of climate conditions in the town of Vladimir and analysis of humidity conditions [5], [6], [7] and [8] have also shown that the existing air heating with forced ventilation ensures the required climate parameters only during some climatic seasons [1], [5], [9], [10].

3. The experimental research results and their practical value

Our studies of the Cathedral environment before modernization of the heating, ventilation and air conditioning system have identified the following microclimate specifics that have an adverse impact on preservation of ancient wall paintings and iconostasis of the Cathedral:

1. High temperature and relative humidity in the Cathedral during the summer period. A 10-day period in July of 2012 was selected as a representative period. The graph on Figure 1 shows the values recorded every three hours, and the graph on Figure 2 – daily averaged values of parameters. These parameters reach combinations of values past which the risk of microbiological deterioration of wall paintings and iconostasis sharply increases. The issue of microbiological deterioration of wall paintings and iconostasis were studies in detail by biological laboratory of the State Research Institute for Restoration. According to different estimates the critical combination of temperature and relative humidity is 22-24 °C and 65-68 % [11], [12];

2. Low relative air humidity during the winter period, disrupting the sorption equilibrium of paintings drawn on capillary-porous materials. In our case these are wall painting in the Cathedral made using fresco technique, painting on icons and iconostasis, as well as iconostasis structure [5], [13], [14], [15], [16]. The graph in Figure 3 shows dependence of average daily parameters for 10-day winter period in December of 2012. The relative humidity reaches 17-27 % at 14-18 °C, which is critical for its preservation;

3. High speed of changes in the current and mean daily values that especially accelerates during holiday church service (Figure 1, 2 and 3);

4. Spatial variations of temperature and relative humidity gradients between the front and back sides of iconostasis (Figures 1, 2 and 3). Presence of such gradients is not regulated in the official documents, but it is generally acknowledged that such gradients should be reduced for paintings made on wood surfaces;

5. Also, the studies have addressed other factors affecting preservation of wall paintings, although their analysis lies beyond the scope of this publication – low thermal resistance of air environment and the Cathedral dome drum elements, as well as high level of pollution of the Cathedral air environment related to conduction of worship services.

The terms of reference for modernization of the heating, ventilation and air conditioning system was prepared on the basis of the results of microclimate parameters studies in the Cathedral over a year cycle of parameters’ variations. The main requirements for modernization of the system are:

1. A technical solution was recommended for the project with possibility of air drying, moistening, heating and cooling.

2. Possibility of relative air humidity control during the entire annual cycle of variation of weather conditions in the town of Vladimir;

3. During the cold season it should be possible to adjust temperature from +7 °C to +18 °C and relative humidity from 35 % to 60 %;

4. Possibility of air cooling in the summer period to +22 °C and relative humidity reduction to 60%
5. After studies of the actual thermal protection properties of fragments of the building envelope a system control algorithm should be developed for the periods with outside air temperature below 10°C. Such algorithm is necessary for prevention of condensation on the Cathedral walls and wall paintings;

![Graph showing temperature and humidity data]

**Figure 1.** Town of Vladimir, Dormition Cathedral, data recorded with 3 hour intervals during 4-14.07.2012

![Graph showing mean daily values of parameters]

**Figure 2.** Town of Vladimir, Dormition Cathedral, mean daily values of parameters during 4-14.07.2012

![Graph showing mean daily values of parameters]

**Figure 3.** Town of Vladimir, Dormition Cathedral, mean daily values of parameters during 16-25.12.2012

6. Considering the importance of reduction of sooth depositing on the painting’s surface, the Cathedral should be provided for with overventilation mode for periods after the service – for example, by installing exhaust fans in upper windows of the Cathedral.
In this publication we describe the studies related to the first four recommendations from the list above.

Observations were continued after modernization of the heating, ventilation and air conditioning system in autumn of 2013. The observation results have shown significant improvement of the main Cathedral microclimate parameters:

1) It became possible to control relative humidity in the summer period. Figure 4 shows the graph of mean daily values of relative humidity and temperature in the selected period – July 2015. Compared to Figures 1 and 2 (summer period of 2012 before modernization of the system), you can see overall reduction of relative humidity and stabilization of the temperature and humidity conditions. Relative humidity spike on 27 - 28 July 2015 was caused by off-design conditions – preventive replacement of air drying and humidifying units;

2) Modernization of the system allowed for achievement of the main task – maintenance of air humidity in the winter period. Compared to impermissible low humidity in winter before the system modernization, it became possible to control the air humidity in 35 – 60 % range. Figure 5 shows the graph of mean daily values of relative humidity and temperature in the selected period – January of 2014. The parameters lie in the range favorable for preservation of paintings. Instability is caused by continuing setup of the modernized system (the system was commissioned 2 months before the period in consideration).

Figure 4. Town of Vladimir, Dormition Cathedral, mean daily values of temperature and humidity during 21-31.07.2015

Figure 5. Town of Vladimir, Dormition Cathedral, mean daily values of temperature and humidity during 22-31.01.2014

4. Conclusions

The preservation conditions were studied on the basis of the complaints of restoration artists on bad preservation of wall paintings. Results of studies of the temperature and humidity conditions of air environment and construction in Dormition Cathedral have shown the reasons of deterioration of wall paintings and icons. After that terms of reference were developed for modernization of the climate
control system. The objective of modernization was improvement of the temperature-humidity and climatic conditions for preservation of wall paintings and iconostasis. Observation of the temperature and humidity parameters of air environment and constructions continued after development and practical implementation of the modernization project. The observations results have shown efficiency of the climate control system modernization – namely, improvement of preservation conditions of paintings and icons in the iconostasis. The experience in technological and hardware solutions accumulated during development of the climate control system can serve as a reference model for development of climate control systems in ancient church buildings being actively used as temples and museums.

References

[1] Devina R A et al. 2000 Microclimate of Church Buildings (Principles of Normalization of Temperature and Humidity Conditions in Cult Architectural Monuments. M.: RIO, State Research Institute for Restoration.

[2] State Standard R 55567-2013 “National Standard of the Russian Federation. The order of the organization and conducting technical engineering studies on researches on objects of cultural heritage. Monuments of history and culture. General requirements”.

[3] Dorokhov V, Zotov A and Illarionova I. 1990 Use of nondestructive methods for assessment of the temperature and moisture of the envelope of the Spaso-Preobrazhensky Cathedral of Mirozhsky monastery. Proceedings of Scientific-Practical Conference “Pskov Land, Ancient and Modern”, (Pskov) pp. 17-20

[4] Zotov A and Dorokhov V 1991 Experience with nondestructive control methods of temperature and moisture conditions in architectural monuments. Museum storage and equipment. (Informkultura GBL. Express-inform. M.) pp.24-30

[5] Bogoslovsky V Sizov B 1988 Principles of temperature and humidity condition parameters selection for ancient buildings ensuring their preservation. Scientific Research in Protection of Monuments. Collected works. (Warsaw) pp. 297-300

[6] Gagarin V and Zheldakov D 2017 The method of accounting changes of climatic data in determining the number of cycles of the transition temperature of zero in the cross section of the outer wall of the building as part of a program on adaptation to climate change. Journal Bulletin of Construction Machinery, Nauka 2.0 No. 6, pp.17-20

[7] Gagarin V, Kozlov V and Zybarev K 2016 Analysis of Location of Maximum Humidity Zone in Building Envelopes with Different Thicknesses of Thermal Insulation Layer, Residential Construction vol. 6, pp. 8–12.

[8] Gagarin V and Pastushkov P 2015 Determination of Design Humidity of Construction Materials Industrial and Civil Construction Vol. 8, pp. 28–33.

[9] Umnyakova N 2016 Climatic Parameters of Standard Year for Heat Technical Engineering Calculations. Bulletin of Construction Machinery Vol. 8, pp. 48-51.

[10] Umnyakov P, Umnyakova N and Aldoshina N 2017 Provision of Thermal Conditions for Preserving Ancient Masterpieces of Russian Icon Painting of the Trinity Cathedral of the Holy Trinity-St. Sergius Lavra, Residential Construction Vol. 8, pp. 25-29 (in Russian)

[11] Rebrikova N and Manturovskaya N 1996 Maintenance of Microbiological Safety of Artifacts in Different Conditions of Storage: From Show-case to Open Air ICOM Committee for Conservation, 11th Triennial Meeting, Edinburgh, Scotland, 1-6 September 1996, Preprints. Paris, Vol. I. pp. 83-86

[12] Rebrikova N and Ponizovskaya V 2015 Extremely Xerophilous Fungi Found in Museum Collections, Modern Mycology in Russia Vol. 4, Dyakov Yu T and Sergeyev Yu V, Proceedings of III International Mycology Forum, Moscow, 14-15 April 2015, (National Mycology Academy, Vol. 4), pp. 298-300.

[13] Hoadley R 2000 Understanding wood: a craftsman's guide to wood technology, (Taunton Press, Newton), p. 83.
[14] Mecklenburg M and Tumosa C 1991 Mechanical behavior of paintings subjected to changes in temperature and relative humidity. *Mecklenburg M. F. Art in transit: studies in the transport of paintings. (International conference on the packing and transportation of paintings, London)*, pp. 173–216.

[15] Erhardt D and Mecklenburg M 1994 Relative Humidity Re-examined *Preventive conservation: practice, theory and research.* Preprints of the contributions to the Ottawa congress 12-16 September 1994, pp. 32-38.

[16] Michalski S 1996 Environmental guidelines: defining norms for large and varied collections *The American Institute for Conservation of Historic and Artistic Works: preservation of collections*, pp. 18-33.