

# Evaluation of Temperature and Humidity Regime in an Orthodox Church

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**Abstract:** This study describes the cult buildings, properties and specifics of the cult building microclimate-related problems, based on the statutory requirements, also considering optimal parameters of the air. This study presents the results of indoor air monitoring in the cult building. The proposed methodology was evaluated in Riga All Saints Orthodox Church. During the evaluation, practical measurements of indoor air quality were taken. The recommendations for improvement of temperature/moisture conditions were presented.

**Keywords:** temperature and humidity regime, monitoring methodology, optimal air parameters, churches

## I. INTRODUCTION

Churches have a unique architectural, historical and spiritual significance. (1) Particular temperature and moisture conditions inside the church must be ensured for long term conservation of such historical items as murals, icons, wood, paper, leather, parchments, etc., but at the same time must be comfortable for visitors (2).

Churches differ from each other in terms of:

- ✓ Structural and architectural appearance;
- ✓ Age;
- ✓ Building materials used and special exploitation features.

Churches as buildings could be divided into:

- ✓ Those used only during the summer time – unheated buildings.

Those used during the entire year including winter time – heated buildings (3).

Church buildings, which are used during the entire year, must be equipped with central or local heating system and with a natural ventilation system with appropriate justification – mechanical ventilation system or conditioning system. (4)

A large number of churches in Russia, which had not had heating before, were reconstructed and heating systems were installed. After making these changes, it has been proved that microclimate in the churches has stabilized, in spite of the fact that the buildings do not have to be used as heated buildings (5).

Churches are unique and this complicates the choice of research methodologies regarding the temperature and humidity levels and the ways of the analysis of the results (6).

Taking into account the topicality of the problem mentioned above, it was decided to develop the methodology of monitoring temperature and moisture conditions and to give recommendations for improvement of these conditions.

## II. OPTIMAL AIR PARAMETERS

Within the scope of the paper two main standards, which regulate optimal air parameters in Orthodox churches, were considered:

- ✓ СНиП 31-103-99 „Orthodox church buildings, structures and complexes”
- ✓ ABOK standart-2-2004 „Orthodox churches. Heating, ventilation and air conditioning”.

The recommended air exchange rates and indoor air parameters according to the above mentioned standards are presented in Table I, Table II and Table III.

TABLE I  
AIR EXCHANGE VALUE IN CHURCH ROOMS (7)

Rooms	Air exchange or amount of supplied/exhausted air (m <sup>3</sup> /h)	
	Supply	Exhaust
Central part of the church	According to the calculations of the assimilation of the harmful discharges produced by the system, not less than 20 m <sup>3</sup> /h of outside air per person	
Altar, vestry, chapel	According to the calculations of the assimilation of the harmful discharges produced by the system, not less than 20 m <sup>3</sup> /h of outside air per person	
Place for baptism	According to the calculations of the assimilation of the harmful discharges produced by the system, not less than 30 m <sup>3</sup> /h of outside air per person	

TABLE II  
ACCEPTABLE AIR PARAMETERS OF THE MAIN INNER CHURCH ROOM (7)

Time of the year	Room	Air parameters		
		Temperature $t_i$ , °C	Moisture $\phi_i$ , %	Speed $v_i$ , m/s
Cold and transition period	Central part of the church	12 – 16	30 – 55	0.2
	Altar	14 – 18	30 – 55	0.1
	Vestry, chapel	14 – 18	30 – 55	0.2
	Place for baptism	22 – 25	30 – 60	0.15
Warm	All rooms	28	75	0.3

TABLE III  
OPTIMAL AIR PARAMETERS OF THE MAIN INNER CHURCH ROOM (7), (8)

Time of the year	Room	Air parameters		
		Temperature $t_i$ , °C	Moisture $\phi_i$ , %	Speed $v_i$ , m/s
Cold and transition period	Central part of the church	14 – 16	40 – 55	0.2
	Altar	16 – 18	40 – 55	0.1
	Vestry, chapel	16 – 18	40 – 55	0.2
	Place for baptism	22 – 24	40 – 60	0.1
Warm	All rooms	20 – 22	50 – 55	0.2

Orthodox churches are not widely spread across Europe. There are no special standards concerning the churches. General European standards on indoor environment can be used for ensuring thermal comfort of the visitors. (9)

### III. DESCRIPTION OF RIGA ALL SAINTS ORTHODOX CHURCH

Riga All Saints Orthodox Church was constructed in mid-16<sup>th</sup> century and until 2010 was used as a summer church.

After the first year of exploitation in winter, the following problems were detected:

- Damages of dome inner surface (Fig. 1);
- Damages of the murals (Fig. 1);
- Appearance of the condensate on the inner building surfaces;
- Discomfort of the visitors and the clergy.



Fig. 1. Damages of dome inner surface and murals.

Corrosion of the inner surface of the cupola was found during inspections in the summer time. The appearance of corrosion is accompanied with increased humidity, which is caused by insufficient air exchange, it can also occur due to the lack of thermal isolation, which causes condensate formation on the surface. It is suggested that heat insulation is enhanced.

### IV. TEMPERATURE AND HUMIDITY MONITORING METHODOLOGY

In many sources different approaches to the evaluation of the condition of the places of worship are described, based on the evaluation of the construction's condition (10), (11) or evaluation of the inside temperature and moisture regime (12), (13).

Nevertheless, full-fledged evaluation of the condition of the places of worship (monumental paintings) needs special approach, which could be based on the detailed research connected with the temperature of the construction of the buildings and on the investigations of moisture inside the buildings (14). In order to estimate air regime at the places of worship and consider the formation of different specific conditions, the climatic factor and actions under taken by the renovator (architectural and constructional actions, controlled airing, etc.) should be analyzed (15).

For the evaluation of the temperature and humidity parameters the following monitoring methodology was applied:

1. Measurement of the indoor air temperature, relative humidity and CO<sub>2</sub>;
2. Church thermography in combination with BlowerDoor test.

The measurements of indoor air temperature, relative humidity and CO<sub>2</sub> were done in the altar zone and at the top of the dome, close to the exhaust valve. That gives the opportunity to evaluate air distribution along the dome.

Measurement of temperature and moisture content with loggers gives the opportunity to evaluate the compliance of these parameters with the appropriate standards and to identify the temperature and moisture excitation values and their exposure times.

The application of thermovision together with BlowerDoor test allows finding out air infiltration/exfiltration points and over-moisturized spots in the structure. Air permeability test gives the possibility to determine air exchange parameters and to evaluate the conformance of these parameters to the standards.

The structure was checked for air-tightness with the help of a fume generator, which allows identification of the complex airflow trajectories and air leak and entry points.

The research was divided into two stages: summer and autumn-winter of 2011/2012.

The aim of the summertime research was to determine air exchange parameters and to assess the compliance of those parameters to the standards. Thermovision survey of the structure and determination of its faults using BlowerDoor pressure distance forming tool were also performed during this period.

During the autumn/winter period of research, the indoor air quality and thermal properties of the building envelope were evaluated.

The comparison of the results obtained from the surveys in different weather conditions allows assessing the compliance of the measured properties to the appropriate standards and working out the range of measures to improve the maintenance of the church, provide safe storage of the valuables and ensure comfortable visits for the visitors.

During the summer time research period, the following measurements were performed:

- Creation of the forced increased pressure (+50 Pa) in the heated part of the building and acquisition of the airflow data for air exchange calculations;
- Creation of the forced decreased pressure (–50 Pa) in the heated part of the building and acquisition of the airflow data for air exchange calculations;
- Survey of the building facade next to the forced increased pressure (+50 Pa) for determination of the air exfiltration spots;
- Survey of the building inner surfaces next to the forced decreased pressure (–50 Pa) for determination of the air infiltration spots;
- Gradual exclusion of the zones for the assessment of air-tightness of the area and determination of the areas with abnormal characteristics;

- Identification of carbon monoxide ingress routes from the building with the installed heating system to the altar with the help of the fume generator next to the forced increased or decreased pressure.

Autumn/winter research period included the application of the following methods:

- Creation of the forced increased pressure (+50 Pa) in the heated part of the building and acquisition of the airflow data for air exchange calculations;
- Creation of the forced decreased pressure (−50 Pa) in the heated part of the building and acquisition of the airflow data for air exchange calculations;
- Survey of the building facade next to the forced increased pressure (+50 Pa) for determination of the air exfiltration spots;
- Survey of the building inner surfaces next to the forced decreased pressure (−50 Pa) for determination of the air infiltration spots;
- Continuous measurements of the church inner climate conditions by means of the installed temperature, carbon dioxide concentration and relative moisture loggers;
- Assessment of the effectiveness of the measures undertaken to improve the structure.

#### V. TEMPERATURE AND HUMIDITY CONDITIONS: RESEARCH RESULTS

##### A. Air Exchange rate

Evaluation of the air exchange rate was done during the summer season using the blower door equipment.

The average value of the air flow at  $\pm 50$  Pa was  $7,000 \text{ m}^3/\text{h}$ , which allowed calculating the air exchange rate to be  $1.05 \text{ h}^{-1}$ . This does not correspond to the demand for air exchange of  $20 \text{ m}^3/\text{h}$  per person, i.e. if there are 600 people (on average), the required air exchange volume must be  $12,000 \text{ m}^3/\text{h}$ , especially taking into account that the instantaneous visitor capacity of the church is 2,000 people.

The current mechanical ventilation system with maximal airflow of  $3,400 \text{ m}^3/\text{h}$  does not fulfill the requirements of the standards.

The reasons why the normal air exchange was interrupted might be shut ventilation openings and low permeability of other openings.

In order to obtain standard compliant air exchange parameters in the building, it was advised to perform detailed temperature and moisture monitoring during the exploitation of the building. It was planned to be done by installing temperature and relative moisture measuring devices (loggers) in the places with the biggest survey significance: at the central part of the church, floor and arch levels and the altar. Data acquisition period should have included the period of time with maximum visitor number.



Fig. 2. Ventilation channels.

##### B. Air Parameters

Compliance of the inner climate conditions to the СНиП standard 31-103-99 of the Riga All Saints Orthodox Church (Orthodox church buildings, structures and complexes) was assessed on the days of the presence of the greatest number of worshippers (04 December, 2011 and 07 January, 2012) with the help of temperature, carbon dioxide concentration and relative humidity loggers.

The overrun of the relative humidity upper limit was observed, which reached 75 % on 04 December, 2011, as well as overrun of the carbon dioxide concentration upper limit, which reached 3,300 ppm on 07 January, 2012

Temperature, relative humidity and  $\text{CO}_2$  measurement results, which are presented in the graph below (Fig. 3), show  $\text{CO}_2$  concentration reduction efficiency of the mechanical ventilation during the public worship time. The suggested solution to the problem is installation of a mechanical ventilation system with low noise level.

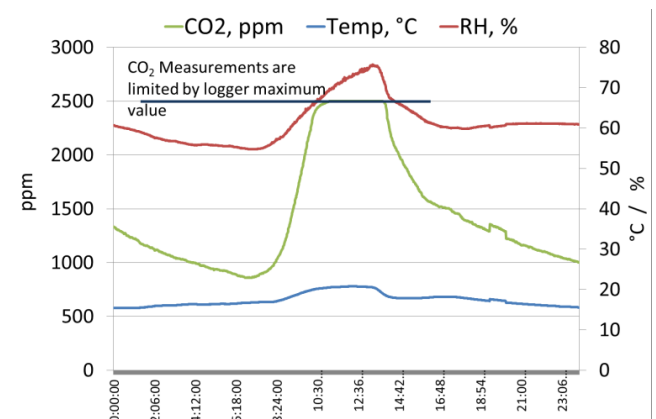


Fig. 3. Indoor air quality parameters during maximal occupancy on December 4, 2011.



In order to get more precise data on CO<sub>2</sub> concentration, the loggers with higher maximum values were used during the period of celebration of the Orthodox Christmas in January 2012. Figure 4 shows indoor air quality during the Orthodox Christmas.

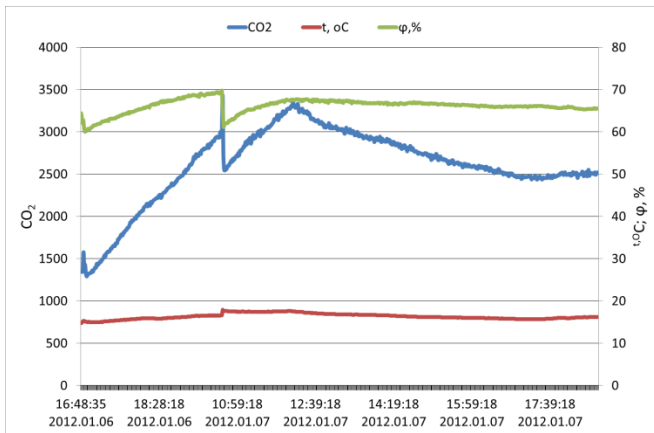


Fig. 4. Indoor air quality parameters on January 6–7, 2012.

As it can be seen, the CO<sub>2</sub> level reaches 3,500 ppm that is 3.5 times higher than the recommended values.

#### Autumn–winter research:

- Thermovision inspection of the cupola was carried out after heat insulation had been improved as suggested after the summertime period of research. The results have shown minor thermal bridge in the places, where arch is connected to the ceiling (Fig. 5). The reason behind the presence of the thermal bridges is insufficient insulation thickness across the ceiling and arch.
- Existing thermal bridges do not contribute towards condensate formation, but it is advisable to eliminate those during the thermal heating improvement works.

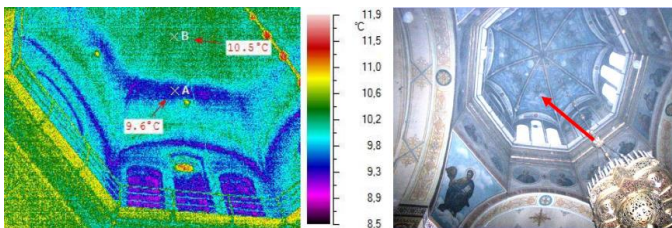


Fig. 5. Thermovision inspection of the cupola after heat insulation has been improved. Minor thermal bridge in the places, where the arch is connected to the ceiling.

#### C. Thermographic analysis

##### Summer research:

- Many defects of the structure were identified during the thermographic analysis using pressure distance forming tool (Fig. 6), i.e. air exfiltration and infiltration places as well as spots of increased humidity levels (Fig. 7).

##### Autumn–winter research:

- Repeated thermographical analysis of the inner part of the church confirmed the presence of defects discovered during the summer research. These were caused by

increased humidity levels in the ceiling and abnormal infiltration and exfiltration of the air through the window and door frames, as well as the points of contact of the walls with the floor.

- It is recommended to remove the air infiltration through the door and windows as well as to conduct a study to determine the reasons of the temperature anomalies in the northern and southern walls of the cathedral as well as in the altar arches and to find out the moisture ingress ways into the structure.



Fig. 6. BlowerDoor pressure distance forming tool.

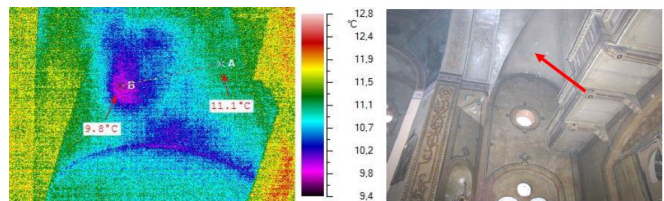


Fig. 7. Spots of increased humidity levels.

#### VI. CONCLUSIONS AND RECOMMENDATIONS

- The reason for condensate formation and consequent arch's inner surface corrosion could be the lack of thermal insulation. To prevent condensate formation, which is the primary reason for destruction of the paintings on the walls, it is necessary to improve the thermal insulation level of the cupola. This problem is common to the churches, which move from summer exploitation regime to the year-round regime.
- To assess the air condition in the building, continuous measurements of humidity, temperature, CO<sub>2</sub> have to be obtained with the special attention paid to the times of greatest occupancy in the church both in summer and winter. The analysis of the obtained data has to be used to assess the conformance of the air conditions to the building standards. To ensure acceptable air conditions, heating and ventilation systems have to be provided. To get optimal air conditions, air conditioning system has to be provided.
- There is a high possibility of carbon monoxide inflow in the churches with firewood-based heating systems. Structure's air-tightness must be assessed using the fume generator and creating the pressure difference between different church rooms. In the case of leak, civil works have to be carried out in the building to eliminate leak points. Carbon monoxide measurements have to be done to determine the compliance with the building standards.
- The indoor air temperature in the church should be controlled at the altar zone in order to ensure the comfort

of the priest. Special attention to CO<sub>2</sub> concentration is necessary in parishioners' area. Special attention to relative humidity should be paid in order to prevent formation of dew points on the internal surfaces of the external envelope.

- Places of air infiltration and exfiltration as well as spots with increased humidity levels have to be determined by means of thermovision surveys and pressure difference-creating device. These places can be a cause of condensate and corrosion formation, destroying the priceless wall paintings.

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