Optimization of air flows in Orthodox church by numerical simulation

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Abstract. Frequently modern temples have certain problems with heating and ventilation, despite the strict design rules and the installation of religious buildings. There is a necessity to organize proper air exchange and ensure proper heating of the air throughout the space in a complex building. Moreover, to calculate the geometry of natural flows and supply jets, ensure the removal of polluted air bypassing crowded areas and the most important thing is to protect wall paintings and art objects from sedimentation of soot particles and dirt. Using the method of electronic digital modeling, the effectiveness of the proposed model of temple ventilation was confirmed, which is able to provide maximum protection and preservation of the interior decoration and works of art in the room at any mode of operation. Using the created model, specific design characteristics of ventilation and air heating systems were obtained and evaluated. Based on this, it was proposed to develop a project for their reconstruction.

1. Introduction

Currently, Orthodox churches have become an integral part of both architecture and the life of citizens in all cities of Russia. During their operation, it turned out that, despite the strict design and construction rules of religious buildings, regulated by religious principles and building codes, often in modern churches there are certain problems with heating and ventilation, even with quite satisfactory compliance with these standards [1].

The temple building differs from other public buildings in a non-standard form. The complexity of the design and space-planning decisions dictates the basic rules for the design of microclimate systems. The space of the Orthodox Church is stretched up. The building has a large height, but a small area. This form of the building is strictly canonized for religious reasons. However, the canons for the construction of Orthodox churches were created and developed in a warm Mediterranean climate. In Russia, most churches functioned in the summer, and in the winter there were small halls and basement rooms on the lower floors, where it was easy to arrange heating.

2. Research objectives

For the normal functioning of halls of large volumes, it is necessary to: [2]:

- arrange proper air exchange
- ensure proper heating of the air throughout the space,

- calculate the geometry of natural flows and supply jets
- ensure the removal of polluted air bypassing crowded areas
- ensure the safety of the artistic decoration of the temple, which is a unique and valuable heritage.

This is not easy to do, because there are racks with candles in the temple, standing near the icons and placed almost all around the perimeter of the building. Each rack can have 50-100 candles burning simultaneously. A large convective air flow is formed from burning candles (Fig. 1a). This stream has a high temperature and many pollutants that settle on the interior decoration in the form of soot [3].

Currently, in most churches, traditional water heating by radiators or convectors is used. The units are located along the outer walls and increase the power of convective flow, because of this, soot settles more intensely on the walls of the building and frescoes. Icons and wall coverings also suffer from excess heat [4].

a b

Figure 1. Type of a standard rack on 60 candles (a), Traces of soot" in the lower part of the temple wall (b).

One more feature of Orthodox churches is almost total absence of window openings. Usually, only under the ceiling and in the dome space there are small narrow windows that perform an aesthetic function and let in weak sunlight. In modern temples, window openings are often filled with sealed plastic double-glazed windows. Despite a number of advantages such as: aesthetic appearance, durability, ease of use, energy-saving effect, plastic windows significantly reduce the effectiveness of natural ventilation and during a large crowd of people, the channels of organized ventilation cannot cope with the removal of the required amount of air.

The problems described above are very relevant for the Holy Ascension Cathedral of Magnitogorsk - a relatively new building, founded in 1989, and opened in 2004. Despite the relatively short life of the building, the look of its interior is significantly different from the original look (Fig. 1b): the inner surfaces of the temple walls are smoked so much that frescoes and murals are no longer visible in the upper half, instead of light, darkness reigns in the domed spaces. It is impossible to remove soot with wet cleaning, as the drawings are made with gouache, which dissolves in water. The temple loses its beauty and attractiveness. It is urgent to take measures to save him.

To sum up, we can conclude that the solution to the problem of the proper climatization temple buildings with the aim of year-round maintenance the optimal microclimate for people to stay and preserve the artistic heritage located in them is very relevant. There are range of factors which require additional consideration when designing optimal heating and ventilation systems for modern temples such as: complex constructive and space-planning solution, the decoration of the inner walls of the temple, the excess of convective heat fluxes and harmful emissions from candles, frankincense and people, a small number of window openings, the use of sealed double-glazed windows, the number of visitors that is extremely uneven in time, the cost of energy supply of microclimate systems.

3. Results and Discussion

The solution of this problem required theoretical and experimental studies, which were carried out by the authors of this work. The construction of an electronic digital model of air-heat flows in a building was chosen as a method for research. The software package “SolidWorks” was selected as a tool for building the model. The aim of the study was to develop measures to optimize the existing heating and ventilation systems of the building. To achieve the goal, the following tasks were set: to identify the geometric and thermal characteristics of convective and air jets formed during different periods of the temple, to identify stagnant air zones and to reveal the nature of the movement of air containing soot particles in the volume of the building.

Initially, the original graphic documentation was collected, according to the results of which, based on existing plans and sections of the building, a geometric model of the building was created, shown in Figure 2.

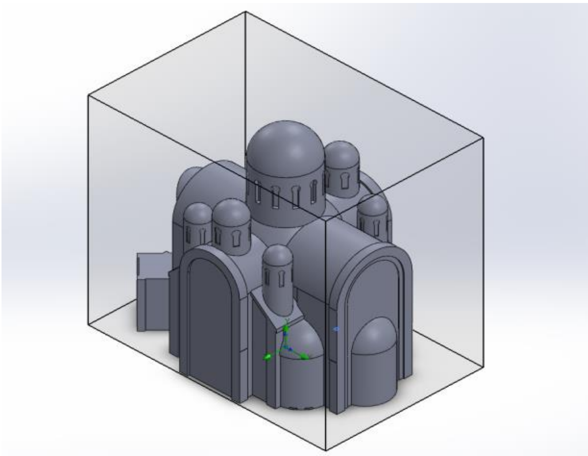
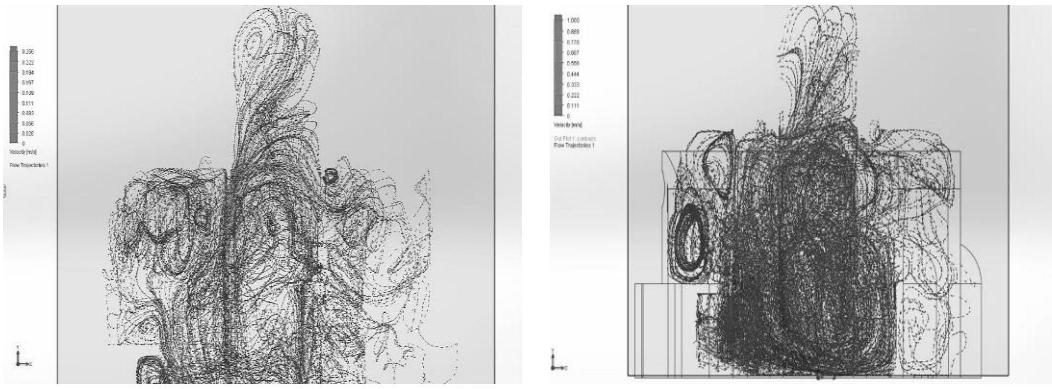


Figure 2. Computational domain of tasks is a geometric 3d model of the temple building.

In the winter of 2017-18, a field survey of air flows in the temple was conducted at various temple opening hours. Initial and boundary conditions were introduced for constructing a model of air flows in speed terms based on the results of a field survey in the calculation complex. The examples of 2-d models of air flow in the longitudinal section of the temple are shown in Figure 3a.



a b

Figure 3. Air flow paths with the existing temple ventilation system (a), trajectories of air flows in a longitudinal section of the temple through a drum design, with use of an additional extract (b).

The model of the existing distribution scheme of air flows graphically shows the minimum mobility in the area of the main drum. Figure 4 shows the presence of closed trajectories located in the

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upper area of the temple, which is the main reason for the deposition of soot on the surface of fences [4,5].

Initially, an option was proposed to supplement the existing scheme of natural ventilation with air check valves installed in the construction of the large drum to improve ventilation and minimize costs. The installation of valves is provided in the lower part of the window openings on four sides, which allows the ventilation system to work regardless of the direction of movement of the external winds. The result of constructing a model of air flows in the longitudinal section of the temple with the indicated option is shown in Figure 3b.

The presented figure 3b also shows the looped trajectories of air flows, indicating the presence of extensive stagnant zones. The total speed of the air mass fluctuates in the range from 0 to 0.11 m / s, while the speed at the inlet of the outdoor air through the open door is about 1 m / s, which exceeds the permissible speed of air movement in the working area, according to existing standards [1].

Thus, the constructed model showed that the use of a natural ventilation scheme when using non-return air valves in the upper zone in combination with a natural inflow through the front door is not an effective solution in the struggle against soot deposition on fences.

To solve the problem, it was necessary to find a different organization for the ventilation in the temple. For analysis, a natural exhaust ventilation option was proposed in the upper area of the room through non-return valves in combination with a mechanical inflow. It is proposed to place supply air openings in the floor around the perimeter of the columns, between the column wall and the candle stand. Such a decision was dictated by the search for the possibility of “deflecting” the convective streams of air formed by burning candles from the columns and walls of the building. Upward air flows are redirected to the central part of the dome, where exhaust openings are installed, therefore mobility in this zone increases, stagnant zones disappear, thereby significantly reducing the likelihood of soot deposition on the surfaces of walls and columns. Outside air supply is controlled by a controlled damper. The results of modeling the operation of the proposed circuit are shown in figures 4-5.

Figure 4 shows a significant change in the trajectories of air flows in the temple space compared to Figures 3a and 3b. Air flows from specially designed distributors are directed vertically upwards. The convective streams raised by the supply air formed during the burning of candles are directed to the upper central part of the drum. Part of the air is redirected to the middle drums located on both sides of the main dome [6-10].

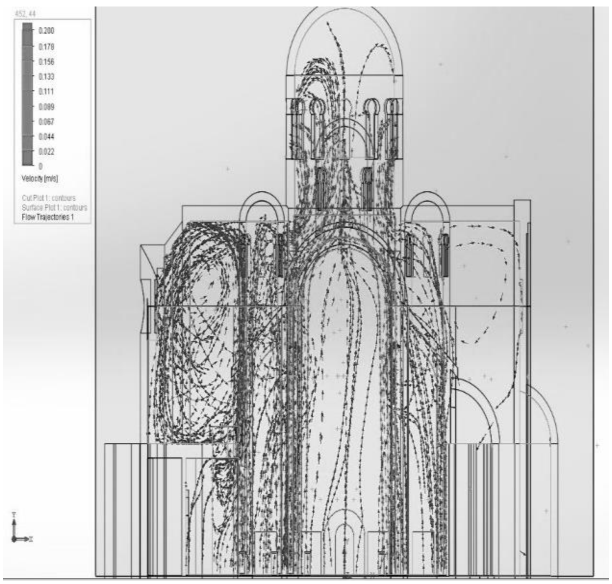

Figure 4. Trajectories of air flow when air is introduced into the space between columns and candle stands.

Together with a change in the direction of air mass flows, their velocities increase, which leads to an increase in the mobility of the air in problem areas. Thus, the formation of stagnant zones is markedly reduced.

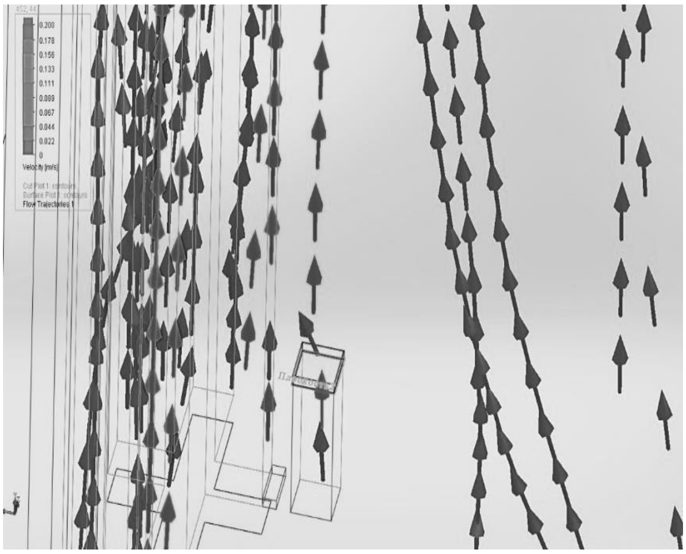

Figure 5. Enlarged diagram of the flow paths: convective from candles and supply air

The assumption of a “deviation” of convective contaminated air flows from the wall surface was confirmed when considering the enlarged diagram of the air flow paths shown in Figure 5. In Figure 5 it is shown how the convective flow from the candlestick (conditionally depicted as a parallelepiped) at the beginning of its path, as it were, tries to head to the nearest column guard (conditionally depicted as a cross). A stream of heated supply air coming from the bottom of the column, with a large initial impulse and flow rate, redirects part of the convective contaminated stream, preventing it from interacting with the enclosing wall, while increasing the speed of the convective stream itself [11-17].

Thus, a clean supply air stream protects the building envelope from polluting airflow. In this case, the heated air from the air handling unit rushes up and allows warming the upper part of the temple space, which increase the temperature of the wall surfaces, while changing the position of the Dew point. The possibility of condensation on the inner surface of the walls is noticeably reduced, which helps to protect wall paintings, icons and wall structures from increased humidity in the premise.

4. Conclusion

The constructed process model has shown that the proposed scheme of temple ventilation allows effectively solving the problem - to evenly distribute air flows and direct them into the exhaust openings, thereby minimizing the possibility of swirling flows that can cause uncontrolled spread of soot throughout the room.

As a result of the research, the following recommendations were made: in order to maintain a year-round optimal microclimate in the premises of Orthodox churches in the middle and northern stripes of Russia and similar to them:

- it is unacceptable to use only natural unorganized air inflow into the building (through windows and doors); year-round mechanical ventilation is necessary to protect the inner surface of the external walls from soot particle deposition; the recommended air supply zones are: floor, side-by-side of columns adjacent to the candle stands;
- a natural exhaust device is required through windows and hatches (grates) in the domed spaces, mechanical extraction is optional, because the supply air will “displace” warm air due to natural convection;

- water heating should be provided only to maintain the minimum permissible air temperature (+ 5-8°C), the rest of the heat loss should be compensated by the overheated air of the supply ventilation, which will contribute to uniform heating of the walls and the inner space of the drums. It is necessary to turn on air heating in advance, 1-2 hours before the arrival of visitors, i.e. before the active burning of candles.

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