Natural ventilation and aerodynamics of orthodox churches

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Abstract. The paper devoted to introducing of theory and practice results of natural ventilation and properties of external aerodynamics of orthodox churches research. The features of the movement of air flows inside the temple are considered. On the example of the Transfiguration Cathedral, the analysis of the fields of aerodynamic coefficients is introduced.

1. Introduction
The use of natural ventilation systems in orthodox churches can achieve significant savings in electrical energy, installation and maintenance costs and reduce noise during operation. Natural ventilation both the easiest way to control the indoor air quality for ancient architects and the only available technology for ages. Depending on the architectural features of orthodox churches will change [1,2,3] the values of the field of aerodynamic coefficients which affect the size of the supply and exhaust windows called transoms. At the same time, the amount of air supplied and removed will be influenced by action of space heating system, heat from the inhabitants, from candles, from icon-lamp [1,4,5].

2. Research method and results
Taking into consideration the architectural and design features of orthodox churches, it is necessary to arrange sufficient tests for air movement outside the facility. During these tests could be indicated and proved the values aerodynamic coefficients. The main points for air movement research is places near windows and air inlets and outlets. It should be noticed that aerodynamic coefficient does not depend on climatic conditions. For the same purpose, aerodynamic coefficients are measured at each characteristic point where supply and exhaust openings could be located. Such an approach make possible to choose the most effective design solution for the location and position of natural ventilation system parts. It will depend on the prevailing wind directions, outdoor temperature and other climate features and season of a year.

3. The movement of air flows inside an Orthodox church
When studying the air movement inside an Orthodox church, a number of special features should be taken into consideration. On the vertical walling of religious buildings in the prayer hall there are no ceilings separating one tier of window openings from another. Icons or murals are usually located vertically between the windows, so it is not possible to place a heater under each window, as is done in
civilian buildings. As a rule, only one heating device is located under several window openings located vertically on the outer fence (Fig. 1).

![Diagram of air currents inside an orthodox church](image)

**Figure 1.** The movement of air currents inside an orthodox church: 1 - heater, 2 - supply transoms, 3 - exhaust transoms.

Thus, the upward convective flow above the heater moves along the window opening, and then along the wall section separating the tiers of the window openings and so on. Depending on the design of the orthodox church, on the number of tiers of window openings and on the possibility of removing air through the reels of the temple, the nature of the flow of air flow may change, for example, in the presence a partition between the drums and the prayer hall, air will be removed through the upper tier of window openings [4].

For ordinary civilian buildings the distance from the heater to the windowsill can be not more than 0.2 m, but for orthodox churches, it can reach the distance from 0.5 to 1 m. In the temples there are also significant heat emissions from visitors and burning candles. It is not similar for churches in other countries. For example in Montenegro and Greece could be arranged separate rooms for candles and frescoes and icons. The upward convective flow from the heater involves soot from candles, which subsequently remain on the wall. This leads to damage to frescoes or icons located above the heater. Therefore, it is recommended to install a partition at a distance of 0.2 m from the heater. This measure could protect from soot sedimentation any of church furniture and equipment located above the heating device.

4. **Studies of the external aerodynamics of temples**

To determine the aerodynamic coefficients, we tested four religious building in the wind tunnel located in Nizhny Novgorod, which differ from each other in geometric parameters and architectural
styles: the church of the Zhen-Mironosits (Women-Myrrh-Bearers) 1649 year of construction on Dobrolyubova street, Krestovozdvizhenskiy temple (the Holy Cross Church) 1823 year of construction on Lyadov Square, the Rozhdestvenskaya church (Nativity Church) 1653 year of construction on Rozhdestvenskaya street, and the Spaso-preobrazhenkiy temple (Transfiguration of the Savior Cathedral) 1903 year of construction in Sormovo.

All models were made taking into account the similarity criteria of 2 mm thin plastic (Fig.2), with installation of five-millimeter tubes at the characteristic points of the window openings and tested in a closed subsonic wind tunnel with an open working area in eight wind directions.

According to the studied literature [1, 6, 7], the best option for the location of supply and exhaust openings¹ in Orthodox churches is the lower tier of windows² and window openings in drums, respectively.

The most interesting of the studied orthodox churches is the Transfiguration Cathedral, built in the Neo-Byzantine style. The number and positioning of supply and exhaust transoms in that church could be considered as optimal for both ventilation and heating purposes. And good enough to provide safety of church relics and decoration.

It was conceived by architects and developers as a very spacious temple for the rapidly growing industrial area with high density in population. Now this area became a part of Nizhny Novgorod city. The architect of this temple was Piotr Malinovsky. He is well knows as a person who made a great input in arranging of All-Russian Industrial and Art Exhibition which was held in 1896 at Nizhny Novgorod.

The first brick of the temple was put on in September 1900. This was really tremendous facility for that period of time. With height from ground to the top of the cross up to 43 m and dimensions of the layout up to 47x30 m. The huge dome was supported by half-domes placed around. All the construction transmits the pressure from the top of the temple to the corner parts reinforced with masonry. The centricity of the composition is emphasized by the lower bell tower.

**Figure 2.** The study of external aerodynamics of the Transfiguration Cathedral

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¹ AVOK Standard – 2. 2004. Orthodox churches. Heating, ventilation and air conditioning. - Since 2004-06-09. - M.: AVOK, 2004. - 14 p.
² MDS 31-9.2003. Orthodox churches. T. 2. Orthodox churches and complexes. - M.: Arkhram, 2003. - 182 p.
Figure 3. The aerodynamic coefficients for the Transfiguration of the Savior: Cathedral northeast wind direction.

In the Transfiguration Cathedral, the shape of the drums differs from the Holy Cross Cathedral and the Nativity Church with very unique hexagon shape basis. There are 9 windows available in the side drums for the exhaust windows. And none of them are practically blocked by other drums or other constructions.

In the Transfiguration Church, 51 characteristic points of research were completed, of which: 22 air inlets made in the lower tier of the windows of the Orthodox church (5 - south, 4 - west, 5 - north, 9 - east); 29 exhaust openings, 5 openings in each of the side drums and 9 openings in the main drum.

The greatest differences in the values of aerodynamic coefficients for eight wind directions are observed in the altar of this temple: with direct exposure (east) they are +0.98; with angular impact (southeast and northeast) -1.38; in other cases, vary from -0.13 to -0.29.

5. Conclusions
When designing natural ventilation systems, it is necessary to take into account factors such as architectural and structural features of orthodox churches, the power of heating systems, heat generation from parishioners, candles and church lamps [2, 8].

The values of the aerodynamic coefficients obtained as a result of tests for all possible options for the location of the supply and exhaust transoms in different wind directions (Fig.3) allow us to determine the most effective ratio between the areas of the inflow and exhaust transoms and the number of window openings involved in the natural ventilation system [9]. The thermal and air humidity conditions of ancient time facilities could be the issue of saving the unique interiors [10] and the whole constructions [11, 12, 13]. And for sure for space heating capacity and heat consumption of historical buildings of different type [14, 15].
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