Influence on the Microclimate of the Number of People at Different Occupancy Temples

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Abstract. Heat, water and gas supply in temples and churches are considered, taking into account the different number of people present at the Liturgy and burning candles. The formulas for determining the above-listed proceeds from paraffin candles depending on the mass of single instances. For the reconstructed Church of St. John, the Baptist at Holy Protection Cathedral in the city of Voronezh is designed of harmful emissions, and air exchange for their assimilation at different occupancy rates and given the average statistics of bought room of candles. Expressions for summary determine the total heat and moisture depending on the number of parishioners. It is recommended to use split and multi-split air conditioning systems in re-constructed and restored churches without disturbing the aesthetics of frescoes and the location of icons. The cooling capacity of such installations should be selected to ensure the required parameters of the microclimate with the occupancy of temples less than 75 % of the calculated taking into account the regulatory requirements for individual volume.

1. Introduction
The main attention in the construction or restoration of religious buildings is paid to the architectural preservation of historical heritage as well as the preservation of existing traditions in new buildings of this purpose. There is a problem that at the first stages not enough attention is paid to the design of engineering systems. This situation leads to changes and transfer of equipment, as well as to a violation of the microclimate of the premises, and, subsequently, in the heat and humidity conditions of external fences. These factors have a negative impact on the further operation of buildings.

Cathedrals, temples and churches, being the highest level of development of architecture and national culture of construction. The domed shape of the roof is optimal in terms of wind load and heat loss. The design of external barriers contributes to durability and minimum fuel consumption during the heating period. In the temples there is a rational combination of amplifying and muffling acoustics, effective natural ventilation, organized taking into account the convective air flows. All of the above was aimed at creating structures that affect the hill and massiveness, splendor and beauty, warmth in winter and cool in hot summer.

The applied technical solutions were primarily based on the required capacity of temples. Previously, this figure in terms of one person was taken from 0.25 to 0.6 m². Generally accepted in the Church building area per person was 0.3 m². In case of a large congregation of parishioners, the individual area of parishioners can be reduced to 0.17 m². All the above mentioned areas have an understated limit, which ultimately does not contribute to a comfortable stay at the Liturgy. Currently, the standard indicator of individual volume for a person in the temple is not less than 4 m³ [1], which with the stan-
2. Description of the terms decision

The main factors influencing the parameters of the microclimate in the premises of cathedrals and temples: climatic conditions of operation of buildings, aerodynamics of churches and complex building structures, resistance to heat transfer of external fences, the location of heating devices and regulation of heat transfer, the presence of natural and mechanical ventilation systems, as well as air conditioning, the number of parishioners, the number of lighted candles and lamps.

Window openings have a significant impact on the microclimate of the premises. Their main purpose is to maintain the required illumination and the possibility of visual contact with the environment. Unorganized air exchange is provided by opening the window flaps [2, 3, 4]. It is necessary for ventilation or for fresh outside air with a significant number of people present. The area of glazing in the temples is 2-3 % in relation to the enclosing structures. Therefore, the influence of solar radiation penetrating through the Windows on the thermal balance of the premises in the summer months is insignificant [5].

All these factors together form the temperature and humidity regimes of churches and churches, which must be maintained at a given level [6], comfortable not only for parishioners, but most importantly for the preservation of frescoes and icons. To ensure the required performance of the indoor air environment, the design process should be solved and agreed tasks and issues, among which should be noted in the first place:

- to establish the influence of climatic influences on the building and possible negative consequences manifested during long-term operation;
- to predict aerodynamics and convection of air flows in a limited volume of premises and outside the building;
- to identify possible changes in the laws of heat transfer processes through the external fencing of buildings and engineering systems to ensure the microclimate;
- to consider the modes of operation of the building to regulate the operation of heating, ventilation, air conditioning, including taking into account the unsteadiness of weather conditions and occupancy in the winter and summer periods of the year;
- to justify the required security and optimization of the microclimate in the construction.

Unsteadiness of both external factors and internal conditions can lead to negative consequences. The first manifestation is the deterioration of the microclimate, tangible for the people present. This is primarily due to the large number of parishioners at the Liturgy, which according to statistics can occur once or twice a week. The reduction of oxygen concentration, as well as the arrival of excess heat and moisture is not only due to the presence of people, but also due to the abundance of burning candles and lamps.

Oxygen consumption, heat and moisture release by a person depending on his age and type of activity are well studied, and therefore there are extensive data [7, 8, 9], allowing to determine changes in the overall performance depending on the occupancy of the halls. The complexity arises in the calculations of the impact on the internal environment of open flame temples of a large number of burning candles of different masses [10].

The technology of production of the most popular products from paraffin and wax regulates the number of candles produced from 1 kg of raw materials depending on the size and weight of single copies (table. 1) [11]. The lowest heat of combustion of paraffin is 46.81 MJ/kg [11, 12]. The size and weight of the batch of candles produced from 1 kg, affect the burning time, this leads to different heat dissipation per unit of production (table. 2). In addition, the combustion of 1 kg of paraffin produces 1.3 kg/kg of moisture and 1650 l/kg of carbon dioxide [11, 12]. Since information on the time of burn-
ing is available for the most widely used in Church service candle numbers (table. 1), then approximating these data in terms of a single product and getting the following dependencies, you can determine the heat, moisture and gas emissions by weight sold in the temples of candles

\[ q = 23.074 + 13.681m - 0.938m^2 + 0.0207m^3, \]  

\[ g = 2.7126 + 1.218m - 0.0778m^2 + 0.0016m^3, \]  

\[ g_{CO_2} = 2.9776 + 1.7145m - 0.1167m^2 + 0.0026m^3, \]  

where \( q \) – heat flow from a burning candle, W; \( g \) – moisture released by burning one candle, g/h; \( g_{CO_2} \) - the amount of carbon dioxide produced by burning a candle, l/h; \( m \) – the mass of candles, g.

### 3. Description of technology

In order to assess the impact on the microclimate of the possible increase in the number of parishioners and, accordingly, burning candles during the Liturgy, consider the occupancy forecast for the reconstructed Church of St. John the Baptist at the intercession Cathedral in Voronezh (Fig. 1, 2, 3). Let us take several variants of the number of parishioners at the Liturgy in accordance with table. 3. The occupancy rate reaches 100%, determined based on the individual regulatory capacity of 4 m³[1] per person. In this case, the average height of the ceiling of the hall per person is 0.79 m² of floor space. In a crowded temple, corresponding to 150 %, per person accounts for 0.52 m² of floor space, which usually occurs no more than 10 times a year. The number of candles given in table. 3, taken on the basis that each person on average buys four candles with the numbers, in the total amount determined as a percentage: № 20 – 5 %, № 40 – 15 %, № 80 – 20 %, № 120 – 25 %, № 140 – 35 %.

Table 1. Parameters of candles produced from 1 kg of paraffin.

| № candle | Number of candles in a pack, pcs | Weight of one candle, g | Height, cm | Burning time, min |
|----------|-------------------------------|-------------------------|------------|------------------|
| 20       | 50                            | 20                      | 30         | 180              |
| 40       | 100                           | 10                      | 26         | 90               |
| 80       | 200                           | 5                       | 18         | 55               |
| 120      | 300                           | 3.3                     | 15.5       | 45               |
| 140      | 350                           | 2.86                    | 15         | 40               |

Table 2. Indicators of the process of burning Church candles.

| № candle | Heat release during combustion, W 1 kg 1 candle | Flagovedeniya, kg/h 1 kg 1 candle | Carbon dioxide intake, l/h 1 kg 1 candle |
|----------|-----------------------------------------------|-----------------------------------|--------------------------------------|
| 20       | 4334                                          | 0.433                             | 550                                  |
| 40       | 8669                                          | 0.867                             | 1100                                 |
| 80       | 14185                                         | 1.418                             | 1799                                 |
| 120      | 17337                                         | 1.733                             | 2200                                 |
| 140      | 19504                                         | 1.949                             | 2474                                 |

Table 3. Heat and moisture at different occupancy of the temple.

| Filling the temple, % | Number of persons | Number of candles, pcs. | Heat Dissipation, W | Moisture, kg/h | Required air consumption, kg/h |
|-----------------------|-------------------|--------------------------|---------------------|---------------|-------------------------------|
| 5                     | 4                 | 16                       | 1418                | 0.3048        | 1042                          |
| 25                    | 20                | 80                       | 7137                | 1,5284        | 4144                          |
| 50                    | 39                | 156                      | 13908               | 2,9795        | 6859                          |
| 75                    | 56                | 224                      | 19993               | 4,2804        | 8568                          |
| 100                   | 78                | 312                      | 27848               | 5,9621        | 10335                         |
Heat release from candles can be determined depending on the number of candlesticks and their nests [4]. Conventionally, we assume that the amount of equipment allows you to install all purchased candles, and since there is no information on the calorific value of wax, we assume that mainly purchased paraffin products. Then heat, moisture and gas from burning candles can be determined by the formulas

\[ Q_{CB} = \sum_{i=1}^{n} n_{i}q_{i}, \]  

(4)

\[ G_{CB} = \sum_{i=1}^{n} 0.001n_{i}g_{i}, \]  

(5)

\[ G_{CO_{2},CB} = \sum_{i=1}^{n} n_{i}g_{CO_{2},i}, \]  

(6)

where \( Q_{CB}, G_{CB}, G_{CO_{2},CB} \) - heat, moisture and gas from burning candles, respectively, W, kg/h, l/h; \( q_{i}, g_{i}, g_{CO_{2},i} \) - heat, moisture and gas emission from one burning candle of a certain number, respectively, W, g/h, l/h; \( n_{i} \) – the number of candles in one room, PCs.

Given the adopted statistics buying a candle, heat and flagovedeniya it is possible to calculate aggregate parameters depending on the number of people expressions, approximating the calculated data table. 3,

\[ Q = 356.93N - 3.6633, \]  

(7)

\[ G = 0.0764N - 0.0003, \]  

(8)

where \( Q, G \) – heat and moisture from people and burning candles, respectively, W, kg/h; \( N \) – number of people in the temple, pcs.
Figure 1. Reconstructed Church of St. John the Baptist at the intercession Cathedral in Voronezh.

Figure 2. The main facade of the Church of John the Baptist.
4. The advantages of the proposed technology
The chosen proportionality of the occupancy of the hall and purchased candles does not change the angle of inclination on the id diagram of heat and mass transfer processes in the hall for the warm period of the year (Fig. 4), but affects the temperature of the removed air. The resulting air flow (table. 3), designed for assimilation of heat, significantly exceed the required sanitary standards. When filling the temple air consumption exceeds the required minimum 3.7 times. Given that the reconstructed and restored temples do not have niches where you can lay the air ducts of the required size, the scheme of assimilation of hazards can not be implemented. Therefore, it is advisable to install split and multi-split air conditioning system (Fig. 3), and if necessary, in the case of a large number of parishioners, to carry out ventilation. Selection of the inner and outer blocks should be performed at the predefined heat input by the formula (7) subject to a maximum of 75% occupancy of the temples, as the capacity of the equipment required for the number of people corresponding to 100%, can be more than 1.5 times, and it happens very rarely popular.

Figure 3. Plan of the second floor of the Church of St. John the Baptist with the location of internal and external air conditioning units for the main hall.

Figure 4. Changing the microclimate parameters of the hall of St. John the Baptist depending on its occupancy by parishioners: Π – supply air with temperature 23 °C; B - the internal temperature of 23 °C and relative humidity 60 %; Y5, Y25, Y50, Y75, Y100, Y125, Y150 - removed air when filling the temple 5 %, 25 %, 50 %, 75 %, 100 %, 125 %, 150 % with temperature 26, 27, 28, 29, 30, 31 и 32 °C, respectively.
5. Conclusion
In the reconstructed and restored temples it is recommended to use split and multi-split air conditioning system, without disturbing the aesthetics of frescoes and the location of icons. Nominal cooling capacity of installations is advisable to select to ensure the required parameters of the microclimate when the occupancy of temples less than 75 % of the calculated taking into account the regulatory requirements for individual volume.

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