System of maintaining parameters of air conditioning in orthodox cathedrals

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Abstract. Calculating air exchange according to existing methods, dilutions of all heat surpluses and other hazards are taken into account. This leads to a significant overestimation of the amount of supply air and saving unreasonable costs. To solve the problem of cost optimization, the authors propose a displacement ventilation and air conditioning system. In this case, the supply air is supplied to the lower zone, where the congregation is located. In this case, it is proposed to calculate the air exchange for the assimilation of only part of the heat surplus and other harmful substances entering only the lower zone, up to 2.5 meters high from the floor level. The rest of the hazards are displaced by convective flow and supply air to the upper zone and removed to the outside. The proposed solution to the problem allows you to optimize the cost of ventilation and air conditioning in the halls of worship of Orthodox churches.

1. Introduction

In this regard, the authors of the article to solve the problem propose to use a displacing ventilation and air conditioning system and a “bottom-up” air exchange system in Orthodox cathedrals [3, 12]. With this scheme, the supply air is fed directly into the lower area of the worship hall where the parishioners are. In this case, it is proposed to calculate air exchange to assimilate only part of the excess heat and other harmful substances entering only the lower zone, up to 2.5 meters from the floor. The rest of the harmful substances are displaced by a convective flow into the upper zone of the worship hall and removed outside through a system of natural or mechanical exhaust ventilation. The analysis made allows us to conclude that the existing methods for calculating air exchange do not take these features into account, and therefore cannot be used for optimal calculation of air exchange in relation to the developed displacement ventilation and air conditioning system and the "bottom-top" air exchange scheme in the halls of worship of Orthodox cathedrals. In this case, it is recommended to use classical formulas and dependencies for calculating air exchanges when diluting hazards and maintaining the required microclimate parameters [9]. At the same time, the authors propose to include indicators that clarify the amount of harmful substances entering the lower zone and removed from the upper zone of the worship hall into the known methods. As a result of the analysis carried out by the authors of the existing recommendations and methods for calculating air exchange for Orthodox...
cathedrals, it can be concluded that at this time the designers of ventilation and air conditioning do not have a standard industry method for calculating the optimal air exchange. When calculating air exchange in worship halls according to the “top-down”, “bottom-up”, “top-up” scheme using the existing calculation methods and air exchange schemes, it is supposed to take into account the dilution of all heat surpluses and other specific hazards emitted in the halls for worship. This leads to a significant overestimation of the amount of supply air and economically unreasonable costs for its preparation and purchase of equipment.

2. Materials and methods

2.1. Materials

These harmful effects have a negative effect on the microclimate in the worship hall and on the decoration of the cathedral [5, 7, 9, 11]. Climate control in the halls of worship must be designed in accordance with the requirements of regulatory documents for the design of heating, ventilation and air conditioning [1, 2, 6, 10]. Ventilation and air conditioning in the halls of worship is provided to ensure acceptable and optimal climatic standards for indoor air.

The calculation of the ventilation and air conditioning system is proposed to be carried out based on the maximum air changes obtained for the assimilation of the harmfulness entering the worship hall. It was found that in the warm season, air exchange is calculated based on the total heat surpluses.

2.2. Methods

The supply air flow rate for diluting the released heat from various sources is calculated by the formula (1) [1, 4, 6]:

\[ L_{pr} = \frac{36 \sum Q}{(i_y x - i_{pr}) \cdot \rho_v} \quad (1) \]

In any period of the year, the calculation of the supply air for the assimilation of water vapor is recommended to be determined by the formula (2) [7, 8, 10]:

\[ L_{pr} = \frac{\sum G_{w}}{(d_y x - d_{pr}) \cdot \rho_v} \quad (2) \]

The supply air flow rate for diluting the carbon dioxide emitted in the church hall of the cathedral is calculated according to the formula (3) [6, 7, 8, 10]:

\[ L_{pr} = \frac{\sum G_{co2}}{(C_0 - C_{pr})} \quad (3) \]

According to formula (3), it is proposed to determine \( L_{pr} \) for assimilation of soot, soot and other harmful substances, at known values of their concentration.

The calculations carried out by the authors showed that in the cold period of the year, the maximum supply air flow \( L_{pr} \) is required for the assimilation of carbon dioxide emitted into the church hall from various sources.

To determine the air exchange in order to dilute the heat input from artificial lighting, it is necessary to determine the amount of heat from the lighting \( Q_{osv} \) if the energy power of illumination \( N_{osv} \) is known, then the value of \( Q_{tp} \) is proposed to be determined by the formula (4):

\[ Q_{osv} = 1000 \cdot N_{osv} \quad (4) \]
3. Results
The numerical values of the heat transfer coefficients are determined experimentally and characterize the amount of heat entering the lower zone up to 2 meters from the floor, respectively, from equipment, lighting, solar radiation through walls, coverings and glazing, as well as from people and candle burning.

Then, the total amount of supply air $L_{pr}$ required for assimilation and displacement of heat from the lower to the right zone of the worship hall and ensuring the required microclimate parameters is determined by the formula (5):

$$L_{pr} = \frac{3.6(k_1Q_{obor} + k_3Q_{osv} + k_3Q_{radvert} + k_4Q_{radpokr} + k_5Q_{radost} + k_6Q_{lud} + k_7Q_{sv} + Q_{pr})}{Ke(t_{yx} - t_{pr})}$$

The coefficient $Ke$ for the developed displacement air conditioning system is determined by the formula (6):

$$Ke = \frac{t_{yx} - t_{pr}}{t_{u} - t_{pr}}$$

The studies carried out by the authors have shown that for a displacement-type air conditioning system, the value of the $Ke$ coefficient is significantly greater than unity and can reach parameters 2.5 - 4, which confirms the high efficiency of the developed displacement-type system and the scheme of supplying air to the lower zone and its removal from the upper zone hall of worship.

The averaged values of the coefficients of heat input $K_i$, obtained by the authors experimentally for warm and cold periods, are shown in Table 1. When calculating air changes, $L_{pr}$ in the warm season is taken into account in formula according to the values of $k_1, k_2, k_3, k_4, k_5, k_6, k_7$, in the cold period - only $k_1, k_2, k_6, k_7$.

The developed engineering methodology makes it possible to calculate air exchange for assimilation of heat surpluses using an air conditioning system of the type of displacement ventilation and a "bottom-up" air exchange scheme in the worship halls of Orthodox cathedrals.

4. Discussion

Table 1. Averaged numerical values of heat gain coefficients.

| Heat gain in the room | Heat gain coefficients, $K$ | The lower area of the hall | The upper area of the hall |
|-----------------------|-----------------------------|----------------------------|-----------------------------|
|                       |                            | $k_1$ | $k_2$ | $k_3$ | $k_4$ | $k_5$ | $k_6$ | $k_7$ | $1-k_1$ | $1-k_2$ | $1-k_3$ | $1-k_4$ | $1-k_5$ | $1-k_6$ | $1-k_7$ |
| The lower area of the hall | 0.55 | 0.45 | 0.4 | 0.2 | 0.35 | 0.65 | 0.55 | - | - | - | - | - | - | - |
| The upper area of the hall | - | - | - | - | - | - | - | 1-0.45 | 1-0.55 | 1-0.6 | 1-0.8 | 1-0.65 | 1-0.35 | 1-0.55 |

The following is a methodology for calculating air exchange for the cold period of the year to dilute the carbon dioxide supplied to the worship hall of the Orthodox cathedral from the parishioners and staff of $G_{lud}$, burning candles $G_{sv}$, lamps $G_{lam}$ and other sources of $G_{pr}$ [4, 5, 7].
For this, a similar approach is proposed as for the assimilation of excess heat. In this case, the formula (3) and the specifying coefficients of carbon dioxide (C) entering the lower zone of the worship hall at a level up to 2 meters from the floor level are used: $C_1$, $C_2$, $C_3$, $C_4$, $Q_{pr}$. The other part ($1 - C_i$), together with the convective flow, is displaced into the upper zone of the hall and then removed into the atmosphere.

The quantitative value of the clarifying coefficients $C_1$, $C_2$, $C_3$, $C_4$ was determined by the authors empirically and are given in Table 2.

### Table 2. Averaged numerical values of the refinement coefficients of carbon dioxide intake.

| The entry of carbon dioxide into the room | The value of the coefficients of carbon dioxide entering the room |
|------------------------------------------|---------------------------------------------------------------|
| Lower zone                              | $C_1$ $C_2$ $C_3$ $C_4$ $C_{np}$                           |
| the hall of worship of the Orthodox cathedral | 0.64 0.45 0.7 0.6 1                                      |

Based on this, the total amount of fresh air supplied to the worship hall of an Orthodox cathedral during the cold period of the year $L_{pr}$ to dilute and displace carbon dioxide from the lower to the upper zones of the hall and ensure the required microclimate parameters is calculated by the formula (7):

$$L_{pr} = \frac{(C_1 \cdot Q_{lad})+(C_2 \cdot Q_{sv})+(C_3 \cdot Q_{kad})+(C_4 \cdot Q_{lam})+Q_{pr}}{C_{in} - C_{prit}}$$

### 5. Summary

The revealed advantages of the air conditioning system by the type of displacement ventilation and the "bottom-up" air movement pattern in comparison with the mixing type system, they include:
- supply air, supplied clean to the breathing zone of the parishioners;
- the supply air does not mix with the internal air in the lower zone of the hall, but displaces it to the exhaust devices;
- the movement of the supply air together with the movement of convective flows;
- a steady convective flow is created in the center of the hall, displacing the polluted air into the upper zone, which prevents the ingress of harmful substances onto walls, icons, frescoes and other decorations;
- air exchange is reduced to 55% or more;
- the parameters of the internal air in the lower zone are ensured with optimal energy consumption, which is reduced to 45%.

These advantages confirm the rather high efficiency of the developed displacement ventilation and air conditioning system and the “bottom-up” air exchange scheme.

For technical solutions of local exhaust ventilation, the umbrella designs proposed by the authors are proposed (Fig. 1).
Figure 1. Types of exhaust hoods above the table top of the lamps for removing the combustion products of candles: the simple umbrella; the umbrella with a canopy; the an umbrella with a pocket; the umbrella with overturned air removal; the effective umbrella with overturned air removal; 1 - conical part; 2 - skirt; 3 - exhaust air duct; 4 - conical part with rounding of the top of the umbrella; 5 - exhaust pipe; 6 - chimney perforated under the umbrella.

A preliminary analysis of the operation of the exhaust hood in natural conditions showed that its configuration, dimensions and height are set above the candlestick depending on a number of factors: the thermal power of the convective flow during the combustion of candles; the volume of air in the convective flow; the speed of movement and air temperature in the convective flow; the presence of external air movement in the worship hall, etc.

In addition, in the course of the study, it was found that the use of displacement ventilation and the "bottom-up" air exchange scheme reduces the concentration of pollution below the stratification level to 70%. As a result, the quality of air improves, since heat, dust, fumes, soot, gases, moisture and other harmful substances are displaced from the lower zone to the upper one, to the places of removal. From the research presented in the article, it can be concluded that the displacement ventilation system and the "bottom-up" air exchange scheme gives an advantage in the quality of internal air and in terms of energy savings for air conditioning of cathedrals and temples in comparison with mixing ventilation and the "top-down" air exchange scheme down”. Therefore, it can be argued that the use of displacement ventilation in combination with air conditioning and natural removal of polluted air from the upper zone is the most effective in order to effectively combat existing hazards in the halls of worship of cathedrals and temples and create comfortable conditions for parishioners.

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