Comparative analysis of heating systems used in Orthodox churches

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Abstract. This work displays a numerical examination of the improvement of indoor atmosphere conditions inside an Orthodox church of Iași. The objective consists in proposing a solution for reducing the risk of condensation for the case of the real heating system with hot air, used in Three Holy Hierarchs Monastery of Iași. The solution was to use the local ventilation at towers, that generates air flow in these zones and evacuate humidity. This configuration was tested numerically and the results highlighted its effects. For comparison, the local ventilation was studied for two other heating solutions that are largely used in this type of buildings, underfloor heating and static heaters. The simulations demonstrated that the local ventilation represents a suitable solution when it is combined with the hot air heating.

1. Introduction

The importance of churches consists in their wealth in sacred and liturgical items, as well as the patrimony preserved in museums, historical and heritage buildings. It is specific for the churches to preserve many kinds of valuable artworks, many of them with high vulnerability, like paintings on canvas or wooden panels, which are subject to cracking, swelling, blistering, and soiling. The frescoes are mostly exposed to efflorescence and blackening, while wooden artefacts to cracking, metals to corrosion and textiles to fading and soiling [1]. Therefore, the ventilation and air conditioning system have a decisive role in preserving this worth.

For heritage buildings, the thermal indoor climate is influenced by following parameters: air temperature, temperature of surfaces, relative humidity and air velocity.

For controlling the indoor climate, there is important to have physical and quantitative understanding of the complex interaction in the building between air and the building elements, objects and people.

The comfort represents a subjective and debatable factor that describes if the occupant precept the indoor climate acceptable. Usually, the occupants are very sensitive to temperatures, but not so sensitive to relative humidity. The comfort temperature range depends mainly on clothing, activity and duration of stay in the building; a typical range is 18–22°C. Relative humidity is important for humans when it is very high, over 80%, or lower than 30% [2].

The indoor climate assures the conservation of materials in the building and minimizes aging and degradation of the materials that are to be preserved. These effects are influenced by the materials and the type of degradation processes that are prevalent in the building. In the case of the materials inside heritage buildings, the relative humidity is often the most important climate parameter [2].

Another important aspect is the cost of a solution, which is a limiting factor and must be taken into account from the beginning, because a solution that is too expensive is most often useless [2].

In reference [3], Ulf Christensen presented several theories and tests referring to the traditional heating systems and products/components, such as electrical heating, low temperature electrical sheets, panel-heaters at walls or more recent ones, like bench-heaters or mobile radiant heaters. Another solution for newer or older churches is the gas radiant heating or water-based heating, with some different sorts of heating sources or distribution networks [3].
The literature also presents the particularities of HVAC systems installed in four Lithuanian churches and their impacts [4]. An example of the principle of blowing out warm air with gas heating system has been applied for heating-ventilation process at the Cathedral of Sts. Apostles Peter and Paul. An automatic control system allows the warming up the Cathedral up to the comfort temperature during ceremonies, and to maintain the standard relative air humidity as well when necessary. Thus, an economic efficiency was assured and the degradations inside this church are minimally [4].

An electrical underfloor heating system has been introduced at the St. Virgin Mary church and the church of St. Trinity. The churches were continuously heated during the cold season and the electrical underfloor heating system has not damaged the interior of the churches [4]. The radiant heating system, which has been installed at the church of St. Virgin Mary, has damaged the interior of the church and did not produced the desired thermal effect in local places of people’s presence. Therefore, this heating system has not been utilized in the church any longer [4].

The present work presents the analysis of the heating system of the Romanian place of worship “Three Holy Hierarchs” Monastery from Iasi. Since 1880, when a capital restoration was achieved, the building was equipped with hot air central heating system, which is partially functional in present. The analysed solution has been engineered by F.R. Richnowski of Lemberg, between 1885 and 1886. Indoor heating was provided by air heated in a central station powered by wood, located in a specially designated place in the church basement. The fresh air intake and the flue were located outside the building. The natural air circulation was assured, through channels of stone and block brick work laid under the floor. In this area, there are connected the air intake and discharge gates, with a perimeter arrangement at the decking and distributed evenly in the middle, in front of the church and inside the altar [5].

The importance of the HVAC system in the conservation of unique ceremonial objects and works of art housed inside the cathedral is determinant, because the heat and humidity managed by these systems are the most aggressive factors of destroying paintings and other valuable works [6-9].

The main objective of the paper consists in proposing a technique to decrease the risk of condensation for the case of the actual heating system (by hot air) used in the Three Holy Hierarchs Monastery of Iasi. The solution consists in using the local ventilation at towers that generates an air circulation in this area and evacuate humidity. This configuration is numerically tested and the results are highlighted as temperature and velocity spectra and profiles.

2. Case description

The current HVAC system implemented in the Three Hierarchs Monastery consists the base case of the study. In figure 1 is presented the system and its main components.

![Figure 1. Current heating and ventilation system of the Three Hierarchs Monastery.](image-url)
The following cases are also studied in the paper. The second configuration, figure 2b, is obtained by improving the base case. The third and fourth cases, figure 3a and figure 3b, were analysed in order to compare the proposed solution with another two largely used heating systems suitable for this type of buildings. In these figures, $T_i$ and $v_i$ represent the inlet temperature and velocity for each admission zone.

3. Numerical analysis
The numerical analysis is achieved by using ANSYS-Fluent software. The fluid flow in steady state regime is used, while the type of flowing is the turbulent one: k-ε RNG model.

The numerical analysis was realized for a 2D geometry of the entire longitudinal section of the building. The mesh of the model and the operating conditions are presented in figure 4.

The external conditions imposed to the walls and windows in simulations were the temperature of air of -18 °C and the convective heat transfer coefficient of 24 W/m²K.
4. Results
The results obtained from numerical simulations are represented as temperature and velocity spectra and profiles. The values for qualitative analysis of the flowing are presented in the following images - figures 5-15.

The currently implemented solution that consists of heating and ventilation of the church by air represents the base case (Case1 – figure 5a), with the inlet and outlet air grilles placed at the floor level. The air recirculation at the lower zone of the church leads to a homogenous temperature, determined by the three air inlets and two outflows. The inlet velocities were of 0.5 m/s, while the outflow velocities reach a maximum of 1.4 m/s. Simultaneously, the poor air circulation inside the two towers is influencing this zone, determining a high danger of condensation. Thus, the local ventilation is recommended for moisture evacuation and condensate removal, figure 5b. This configuration represents the Case2 of the presented analysis. Under the effect of ventilation, the velocities raise inside the towers and evacuate the excess of humidity.

The other two cases studied are taking into account two heating solutions that are largely used in churches: Case3 – Underfloor Heating (figure 7a) and Case4 – Static Heaters (figure 7b), combined with the solution of ventilation the towers. In terms of air circulation, the two solutions are almost the same. The quantitative data are merged in figure 11 for the velocity at 1 m height from the floor in all studied cases.

![Figure 5. Spectrum of velocity (a) base case; (b) proposed solution.](image1)

![Figure 6. Profiles of velocity (a) base case; (b) proposed solution.](image2)

![Figure 7. Spectrum of velocity (a) underfloor heating; (b) static heaters.](image3)
Figure 8. Profiles of velocity (a) underfloor heating; (b) static heaters.

The same behaviour of the air flow can be observed in figure 9 and figure 10, which represent the velocity vectors.

Figure 9. Vectors of velocities (m/s) (a) base case; (b) proposed solution.

Figure 10. Vectors of velocities (m/s) (a) underfloor heating; (b) static heaters.

The analysis of the velocities for the studied cases revealed some important particularities. In the base case, when the heating and ventilation of the church consists in air-based solution, the air recirculation at the lower part of the building leads to a more uniform temperature. In the three inlets grids the velocities reach values of 0.45 m/s, while for the three outlets the maximum velocities are of 1.45 m/s. The low air circulation within the two towers is influencing this area, creating a high danger of condensation, figure 12a and figure 13a.

Thus, the local ventilation of the towers is justified, for removing the excess of humidity and eliminate the risk of condensation. The results for this configuration are presented in figure 12a and figure 12b. Under the effect of ventilation, the velocities rise inside the towers and evacuate the excess of humidity.
Figure 11. Velocity profiles at 1 m height from the floor.

Figure 14 presents the other two heating solutions that are largely used in churches: figure 14a – underfloor heating and figure 14b – static heaters. These configurations are combined with the ventilation solution of the towers. The results showed that the global air circulation for the last two solutions is almost similar, while the temperature profiles are slightly different, figure 15.

Figure 12. Spectrum of temperature (a) base case; (b) proposed solution.

Figure 13. Profiles of temperature (a) base case; (b) proposed solution.

Figure 14. Spectrum of temperature (a) underfloor heating; (b) static heaters.
The effect of the air flowing for each case is emphasized by the temperature distribution. The major deficiency is registered in the base case, when a lower temperature of the air in the towers and their walls is recorded. Instead, for the second case, the advantage of using the local ventilation can be noticed in the raise of temperatures adjacent to these zones.

The underfloor heating system is characterized by lower velocities at the church’s external walls, that determines lower temperatures on their surface. In the case of static heaters, it can be observed a non-uniform distribution of temperatures, especially in the occupied zone.

For the first three cases studied, the temperature at 1 m height has approximately the same value of 15 °C, figure 16. The graph of temperatures for the static heater case shows the influence of their presence. However, the mean value of the temperatures in the occupation zone is also about 15 °C.

5. Conclusions

The new configuration of the HVAC system, with local ventilation in towers, enhanced the exhaust of humidity and also reduces the risk of condensation on the walls and paintings.

An important aspect consists in the small effect of the tower ventilation over the distribution of temperatures and velocities on the occupied zone.

When underfloor heating system and static heaters are used together, the tower ventilation creates some recirculation zones below them which determines a gradient of temperatures that rises towards the sides of the church.

The main conclusion is that the second case studied, the hot air HVAC system, is the most appropriate for assuring the comfort parameters in the occupational zone of this church.
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