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IMPROVEMENT OF THE INDOOR CLIMATE CONDITIONS INSIDE ORTHODOX CHURCHES

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Abstract: *In this paper is presented a numerical approach of the improvement of indoor climate conditions inside Orthodox churches. First step was to propose a solution to reduce the risk of condensation for an implemented hot air heating system at Three Holy Hierarchs Monastery in Iasi. The improved case consisted in introducing local ventilation at towers level that activates air circulation in these zones. This configuration was a good one and the numerical results are highlighting this effect. The proposed local ventilation was also studied for two other heating solutions that are largely used in this type of buildings, under floor heating and static heaters. The comparative results showed that the local ventilation is the most appropriate combined with the hot air heating.*

Key words: *place of worship, indoor climate, heating strategies, numerical modeling*

1. Introduction

Churches constitute an inestimable wealth, consisting of sacred and liturgical items as well as the patrimony preserved in museums and historical buildings. They also preserve many kinds of valuable artworks, each of them with a specific vulnerability: paintings on canvas and wooden panels are subject to cracking, swelling, blistering, and soiling; frescoes mostly to efflorescence and blackening; wooden artifacts to cracking; metals to corrosion; textiles to fading and soiling [1]. Therefore, the HVAC system has an important role in order to preserve these values.

The thermal indoor climate is defined by:

- Air temperature
- Surface temperatures
- Relative humidity
- Air movements

In order to control the indoor climate we need a physical and quantitative understanding of the complex interaction in the building between air, the building structure, objects and interiors and people.

The proper indoor climate is determined with respect to:

- **Comfort** is a subjective parameter that

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describes to what extent humans find the indoor climate acceptable. People 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 18–22ºC. Relative humidity matters for humans only when it is very high, over 80%, or very low, fewer than 30% [2].

• **Conservation** of materials in the building requires an indoor climate that minimizes ageing and degradation of the materials that are to be preserved. This depends on the materials and the type of degradation processes that are prevalent in the building. For materials, relative humidity is often the most important climate parameter [2].

• **Costs** are always a limiting factor and we must consider this from the beginning. A solution that is too expensive is useless [2].

Ulf Christensen from Norway said that after developing some theories he and his team got some experiences with the following types of heating systems and products:

• Direct electrical heating with traditional pipe-heaters under benches, low temperature electrical sheets or cables built in ceilings and floors and panel-heaters at walls or newer types of bench-heaters and mobile radiant heaters

• Gas radiant heating in older and in newer churches

• Water-based heating with some different types of heating centrals and distributions [3].

Also, **Diana Piksriene from Lithuania** presented the peculiarities of heating-ventilation systems installed in 4 Lithuanian churches and their impacts.

The principle of ***blowing out warm air*** with gas heat has been applied for heating-ventilation process at the Cathedral of Sts. Apostles Peter and Paul. A gas boiler-room, ventilation pipes and other equipment for air intake, warming and warm air sending have been installed in the unemployed space of the cathedral's attic. The automatic control of the system allows warming up the Cathedral premises objectively to the temperature desired before the service or other ceremony, and later to keep it to a minimum and to maintain the standard relative air humidity as well. Thus the economic effect has been achieved and the damages in this church were minimally [4].

Electrical under-floor heating has been installed at the church of St. Virgin Mary's Visit Convent and the church of St. Trinity. On the first case the maintenance of this heating system was extremely expensive and has not been used for several years, until they have found some sponsors. They intend to use the heating system the following winter adjusting the intensity of heating accordingly to the rites and ordinary periods of time. On the second case the church was heated during the cold season continuously and the economical effectiveness has been achieved controlling heating intensity during events and by heating separate floor areas according to the demand. In both cases the electrical under-floor heating system has not damaged the space of interiors of the churches [4].

Radiant heating using gas has been installed at the church of St. Virgin Mary. The glass pipe of the heating device, which has been fitted in a pad of curve of arch in central nave, gives warmth while the gas is burning. This heating system has damaged the space of the interior of the church and did not produce the desired thermal effect in local places of people's presence. For these reasons this heating system has not been used in the church [4].

The present paper presents a Romanian place of worship: "Sfinții Trei Ierarhi" (Three Holy Hierarchs) Monastery from

Iasi – demonstrates the concerns in this regard since the 1880s when, during the capital restoration was equipped with hot air central heating system, which is partially functional in present.

The solution has been designed in the Engineering Office of F.R. Richnowski of Lemberg, between 1885 and 1886. Indoor premises heating was made with 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. Air circulation is achieved gravitationally, through channels of stone and brick masonry laid under the floor to which air intake and discharge ports are connected, arranged on a perimeter basis at the floor level and distributed evenly in the middle of the church ("pronaos"), in front ("naos") and inside the altar. The importance of ventilation and heating system, from an operational point of view and especially for the conservation of unique ceremonial objects and works of art housed inside the cathedral, is such as to justify the technical interest in the cutting-edge solution proposed by the restorer as well as for its efficiency.

Unfortunately, the lack of written documents does not allow us to obtain further information on the subsequent operation of the installation

2. Case Description

The problem studied in the base case is taking into account the present HVAC system of the Three Hierarchs Monastery. This situation is presented in Figure 1.

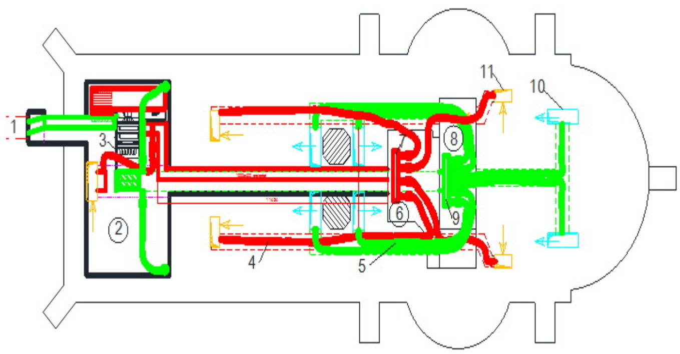

Fig. 1. *Networks existing air channels under the floor: 1-fresh air intake channel; 2-basement of porch; 3- air handling unit; 4-flexible pipe connected to the suction grid; 5- flexible pipe connected to the outlet grid; 6- suction chamber;7- exhaust air collector; 8- pressure side chamber; 9- treated air collector; 10-outlet grid; 11-suction grid*

The second one is obtained by improving the actual situation. The third and fourth cases are created in order to compare another two largely used heating systems for this type of building.

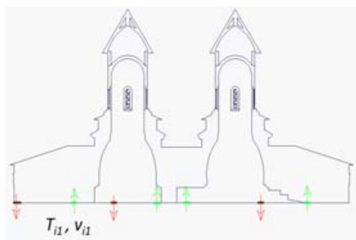

Fig. 2. *Base case*: *air heating system - without tower ventilation*

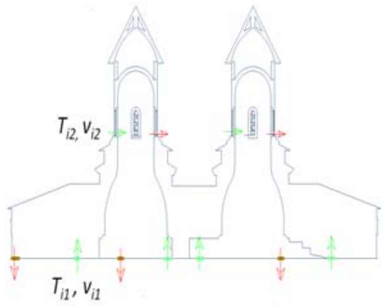

Fig. 3. *Improved case: air heating system - with tower ventilation*

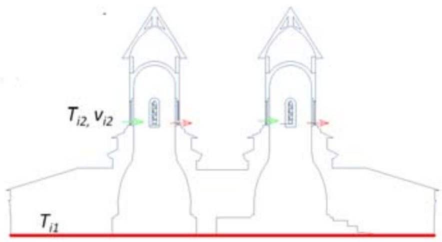

Fig.4. *Under floor heating*

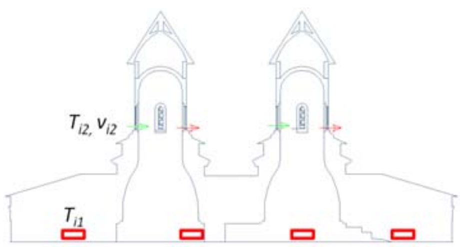

Fig.5. *Static heaters*

3. Numerical modeling

The numerical model is realized using ANSYS-Fluent software, in steady state regime. The type of flowing is the turbulent one: - k- ε RNG model.

A 2D model was created for the longitudinal section of the building. The geometrical dimensions used were those of the real building. 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/m^{2}K.

4. Results

The numerical results were obtained as temperature and velocity spectra and profiles. The qualitative information on the flowing can be observed in the following images - Figures 6-10.

For obtaining the quantitative data in figure 10 are concentrated the values of velocity at 1 m height from the floor in the studied cases.

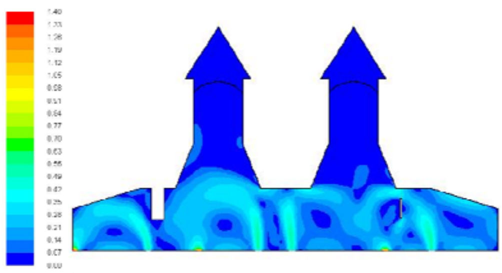

Fig. 6. *Velocity spectrum – base case*

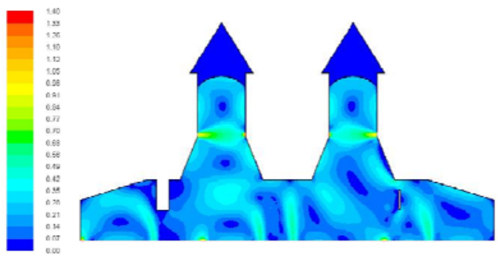

Fig. 7. *Velocity spectrum – proposed case*

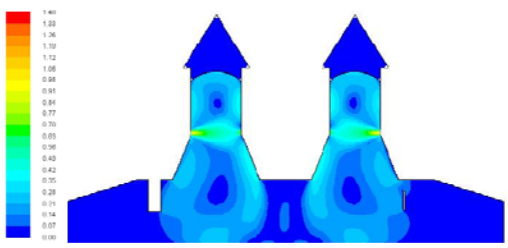

Fig. 8. *Velocity spectrum – under floor heating*

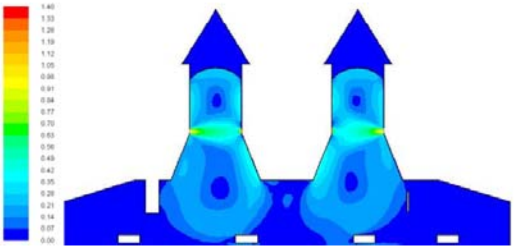

Fig. 9. *Velocity spectrum – static heaters*

Analyzing the velocities in the studied cases some particularities can be remarked. In the base case is presented the currently implemented solution that consists of heating and ventilation of the church by air. In this case the air recirculation at the inferior zone leads to a homogenous temperature.

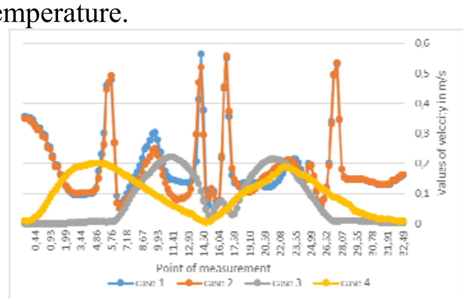

Fig. 10. *Profiles of velocities at 1 m height*

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The 4 air inlets can be observed with velocities of 0.5 m/s and the two outflows with velocities of maximum 1.4 m/s. In the same time, the poor circulation of the air inside the two towers is affecting that zone, with a high risk of condensation.

Therefore, a local ventilation of the towers is proposed in order to evacuate humidity and eliminate condensation. This configuration is presented in Figure 7 of the presented study. Under the effect of ventilation the velocities rise 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: Figure 8 – Under floor heating and Figure 9 – Static Heaters, combined with the solution of ventilation the towers. With respect to the air circulation, the two solutions are almost the same.

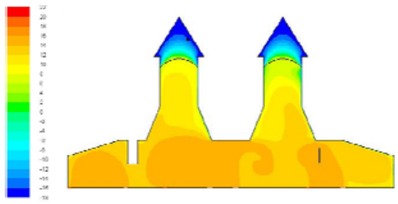

Fig. 11. *Temperature spectrum – base case*

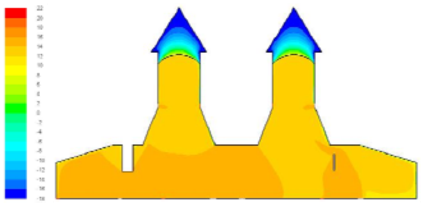

Fig. 12. *Temperature spectrum – proposed case*

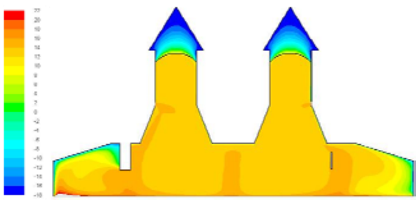

Fig. 13. *Temperature spectrum – under floor heating*

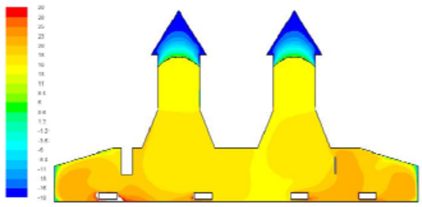

Fig. 14. *Temperature spectrum – static heaters*

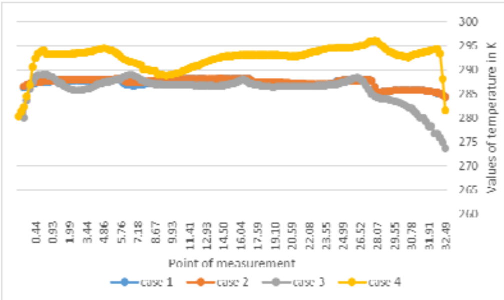

Fig. 15. *Profiles of temperatures at 1 m height from the floor*

The distribution of temperatures underlines the effect of air flow for each configuration. In this way, the main problem is detected for the base case, where is recorded a low temperature of the air in the towers and their walls. For the second case, the effect of using the local ventilation can be seen in the raise of temperatures in these zones.

In case of using under floor heating the low velocities at both extremities of the church determine the decrease of the temperature near the walls.

When static heaters are used it can observed a non-uniform distribution of temperatures, especially in the occupation zone.

In the first three cases – Figure 15, the temperature at 1 m height has similar values of approximate 15 °C. The chart of temperatures in case of static heater is influenced by their presence, but as average value, the temperature in the occupation zone is almost 15 °C.

5. Conclusions

The solution of local ventilation in towers enhanced the evacuation of humidity and reduces the risk of condensation.

In the occupational zone, the use of ventilation in towers does not affect the distribution of temperatures and velocities;

With under floor heating system and static heaters, the use of ventilation in towers generates two recirculation of air below them which creates a gradient of temperatures rising towards the sides of the church;

The second case, with hot air heating, is the most appropriate for keeping the comfort parameters in the occupational zone.

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