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Thermal comfort assessment for different heating system using CFD-modelling inside of an orthodox church

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Abstract. Thermal comfort is a general term that describes the sensation of warm or cold for the occupant, defining the state of mind of humans that expresses satisfaction. Because 90% of our time is spend inside the buildings is essential to achieve a good thermal comfort. In this paper we present two different heating system that are used in more than 90% of the church in our country. The article test two different heating system in order to evaluate the thermal comfort of the occupants and if the climate meet the requirements for the churches where the paints and the artworks must be kept in good condition for future generation.

1. Introduction

The indoor climate in historic buildings such as Metropolitan Orthodox Cathedral form Jassy (figure 1) is a crucial factor in preserving the building and its interiors. Rising of the energy cost and the threat of global climate change has put more focus on indoor climate issues in the recent years. Sustainable management of these buildings demands a balance between preserving cultural heritage and energy efficiency.[1]

Figure 1. View from Metropolitan Orthodox Cathedral form Jassy

Nowadays, we have the possibility of using methods and devices both in terms of computing capabilities and experimental techniques. We have today the opportunity to validate these models by taking into account the variation of several parameters, we also have the opportunity to correct them and to propose new models. [2]

Church has a rectangular shape with the length of approximately 42 meters, the width of 18 meters and the height of 22 meters (figure 2). The volume of air from the space exceed 16000 m^3. Now, the natural indoor environment is created in the cold season with static heaters made of cast-iron with an equivalent power of 3000 Watts. The walls are made from brick with a thick of 1.5 meters.

In cold regions, as the one in which the metropolitan cathedral is placed, with exterior temperature that can be below -18 ^{0}C, when the church is too crowded (or a humidification system is active) and certain surfaces are relatively cold (for ex. Windows, statues, frescoes, walls, ceiling) the excess of water vapour condenses on the cold surfaces. The situation is worsened by certain heating system with combustion of methane, propane, LPG etc., which produce large quantities of water vapour.[4]

Certain warm-air heating systems mitigate the decrease in relative humidity with the addition of vapour. This may do the air good, but it is not always advantageous for the surfaces of artworks, especially the cold ones (i.e. windows) or those with great thermal inertia (i.e. marble statues, walls), on which condensation may take place. [4]

When the RH level in the air and/or the moisture content in materials is high for whatever reason (e.g. crowded room and condensation, percolation, cold surfaces) a number of deterioration mechanisms may be activated. The main ones are: [4]

- oxidation and corrosion of metals (e.g., stained windows, organs, chandeliers);
- bio-decay with deterioration of organic substances (e.g., wood, leather) and/or micro-biological colonization;
- efflorescence's on bricks and plasters due to salt migration; also forced evaporation generates efflorescence.

Condensation depends entirely on two factors: the moisture content in the air (expressed in terms of mixing ratio or dew point temperature) and the temperature of the surface. Condensation can be preceded by moisture absorption if deliquescent salts are present in materials. [5]

1.1. Radiator panel heating

Radiators range from traditional cast-iron to the present pressed steel types. They have different forms: column type, single of multiple panels. Because of the affected esthetical view radiator panel heating is not popular in monumental church. They are used in small monumental churches [3].

Radiators operate as natural convectors (figure 2, figure 3). Air enters at the base of the radiator, is heated and rises for buoyancy, and finally emerges at the top or the front. In traditional radiators, hot water (90°-70°C) carries heat through pipes from the boiler to heaters. Radiators (e.g. panel, column, aluminium-convector radiators) are installed throughout the church, at some distance from, or very close to pews. Mobile radiators are electrically heated and use oil as thermo-convector fluid. Most of the heat is distributed via natural air convection and just a little via long-wave IR radiation. [5]

Benefits: The building is provided with a traditional, basic source of heat. The congregation benefits from the warm air and some people from heat radiated from radiators too. (figure 3)

Problems: Preservation: When in operation, the RH level is low, sometimes too low (figure 4). This is especially true for continuous operation in cold climates. When the system is used occasionally, or with mixed mode, damage is not limited to internal artworks and decorations, but may extends to masonry due to cycles of re-crystallization of soluble salts that follow the heating cycles. Convective motions of warm air develop above the radiators and smoke and pollutants blacken walls and ceiling during operation. Under this respect, the continuous or mixed operation is penalised. [5], [7].

1.2. Floor heating

In the late seventies of the twentieth century floor heating became popular as the main heating system in weell- insulated dwellings. Furthermore, the 'invizible' heating system was aesthetically sound and made no noise. The degree of thermal comfort was high, a high level of mean radiant temperature, a high thermal contact temperature, even with stone floor systems, and little thermal stratification. Due to these advantages is was also introduced in modern church as well as in monumental church. But due to the lack of insulation of floor heating in monumental church the building have a different behaviour. [5], [6], [7]

Benefits: Quite homogeneous heating with gradual variations. Preferably installed as a basic heating system, with continuous use, especially in mild, humid regions. In the case of continuous operation, all surfaces will be heated although in a different way: the ceiling will remain colder than walls and walls colder than the floor. Warm feet, mild body and thermal comfort. [5], [6]

Problems: Preservation: In cold regions, and in the case of continuous use, the RH may drop below the threshold of sustainability for wood and other organic materials. With intermittent or mixed operation, in the lower part of walls, where heating-cooling cycles are at highest intensity, masonry may be affected by dissolution-recrystallization cycles of soluble salts. A supply of moisture for humidification to mitigate RH may prove effective for air, but condensation and damage may occur on cold surfaces (e.g. windows, ceiling, walls) [5], [6], [7]

2. Case study

This paper described the indoor environment created when is used radiator panel heating or the floor heating system inside the same church in order to compare them. Software used is Autodesk CFD 2017 – capable of solving heat, air and water vapour simulation, the analysis where run in steady state. [7]

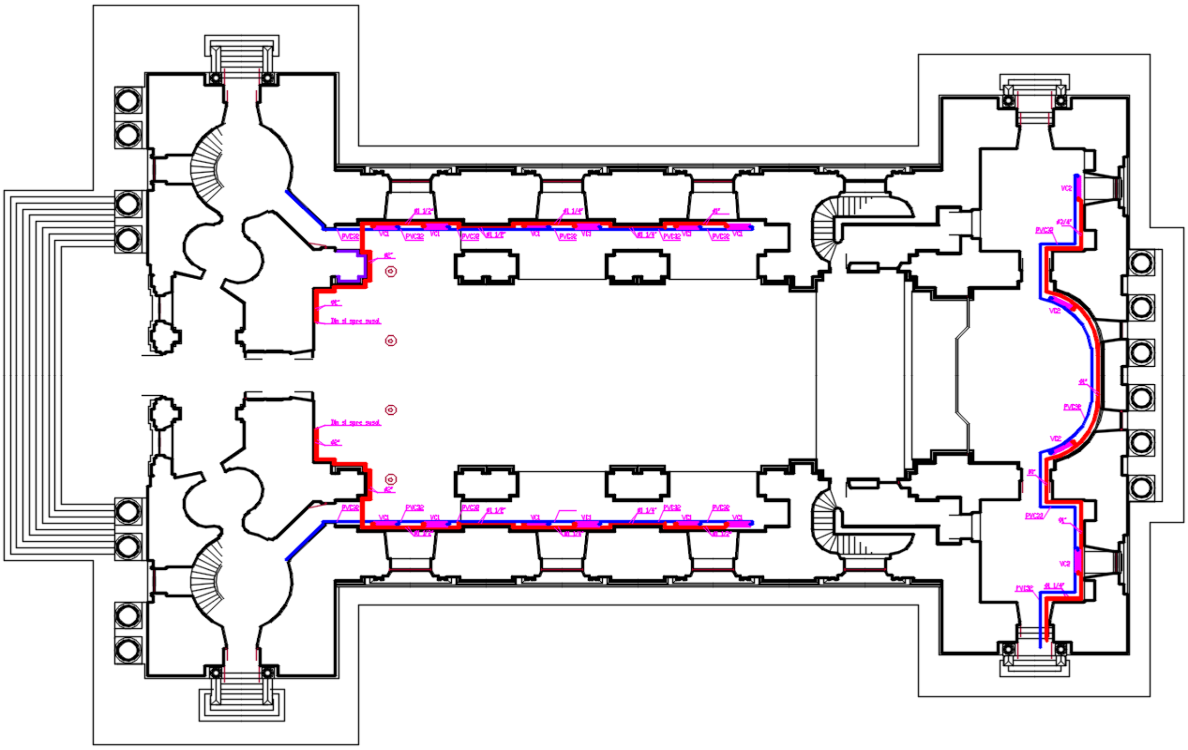

Figure 2. Metropolitan Orthodox Cathedral – Plan View with the hot water heating system

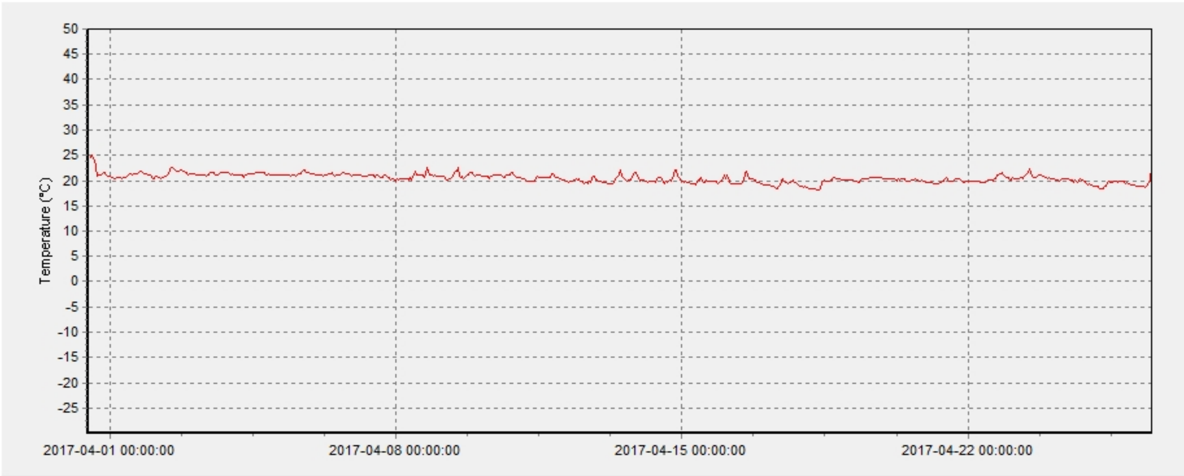

Figure 3. Air temperature variation in Metropolitan Orthodox Cathedral

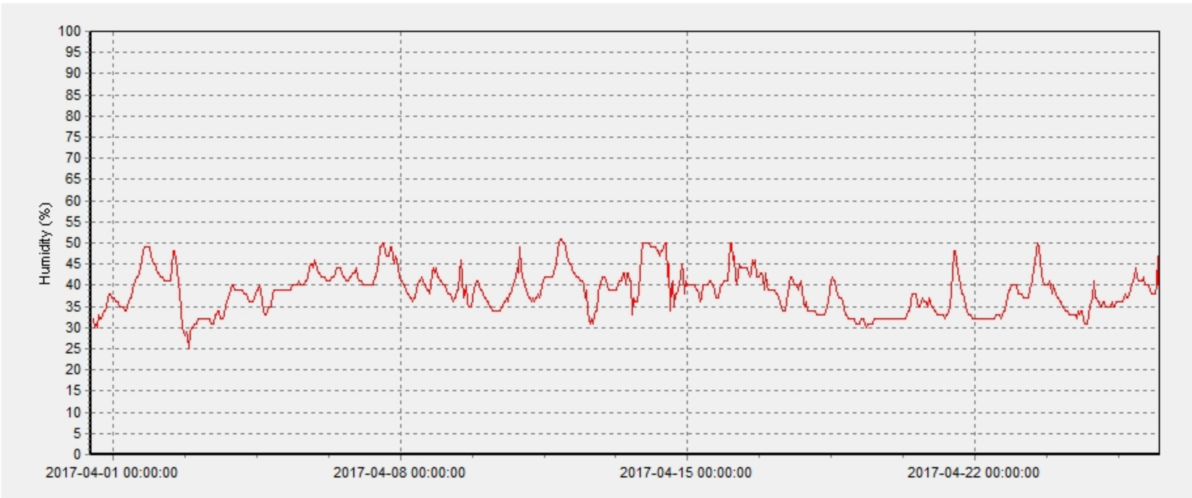

Figure 4. Air humidity variation inside the Metropolitan Orthodox Cathedral

The model has been made in Autodesk Inventor 2017 in 3d space in order to have a model closed to the investigation site. The boundary conditions imposed for walls are:

- the film coefficient for exterior walls is U=0.8 W/m^{2}K
- the film coefficient for interior walls is U=0.6 W/m^{2}K
- the film coefficient for windows is U=0.5 W/m^{2}K
- the film coefficient for floor is U=1 W/m^{2}K

The boundary condition used for static heater are taken from the site, cast-iron material with an approximated temperature of 80^{o}C. Model discretization has a step of 0,5 meter (figure 5) in a volume of air of 16000 m^3. In the case of second modelling the static heaters were removed and replaced with floor heating system, system that had been fixed to 100 W/m^2 heat flux.

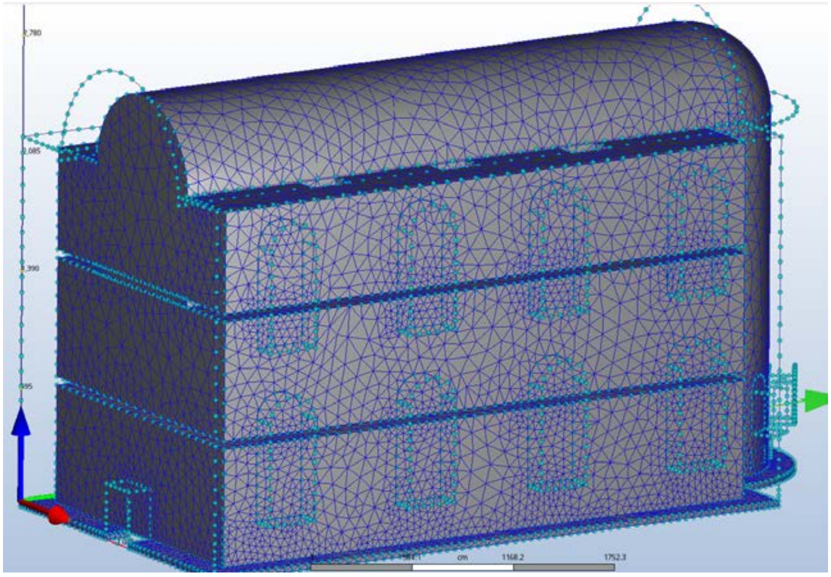

Figure 5. Metropolitan Orthodox Cathedral 3d geometry and meshing

3. Results

The CFD modelling show that the value of temperature that is create inside the church interior environment has a multi-zone variation. Locally, where static heaters are placed is warmer than the other side (figure. 6), also the air distribution in case of floor heating system can be view in figure 8, for comparison. The predicted mean vote (PMV) is in range of +0,5÷-0,5 (figure 7) and the comfort temperature of 15-20°C (figure 6).

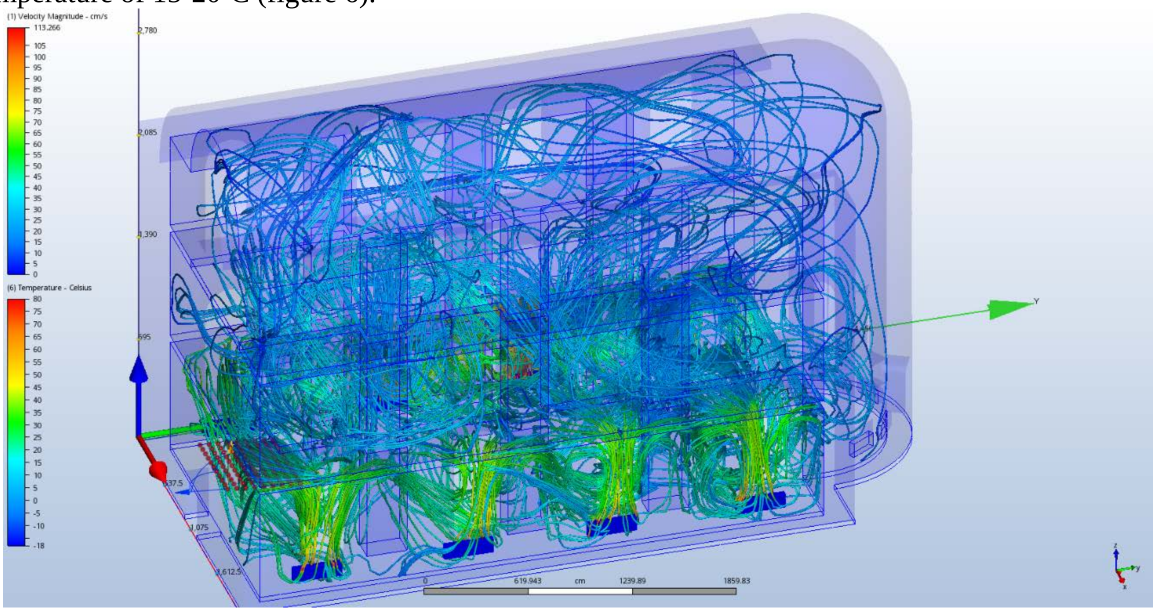

Figure 6. Air temperature distribution and velocity inside the Metropolitan Orthodox Cathedral

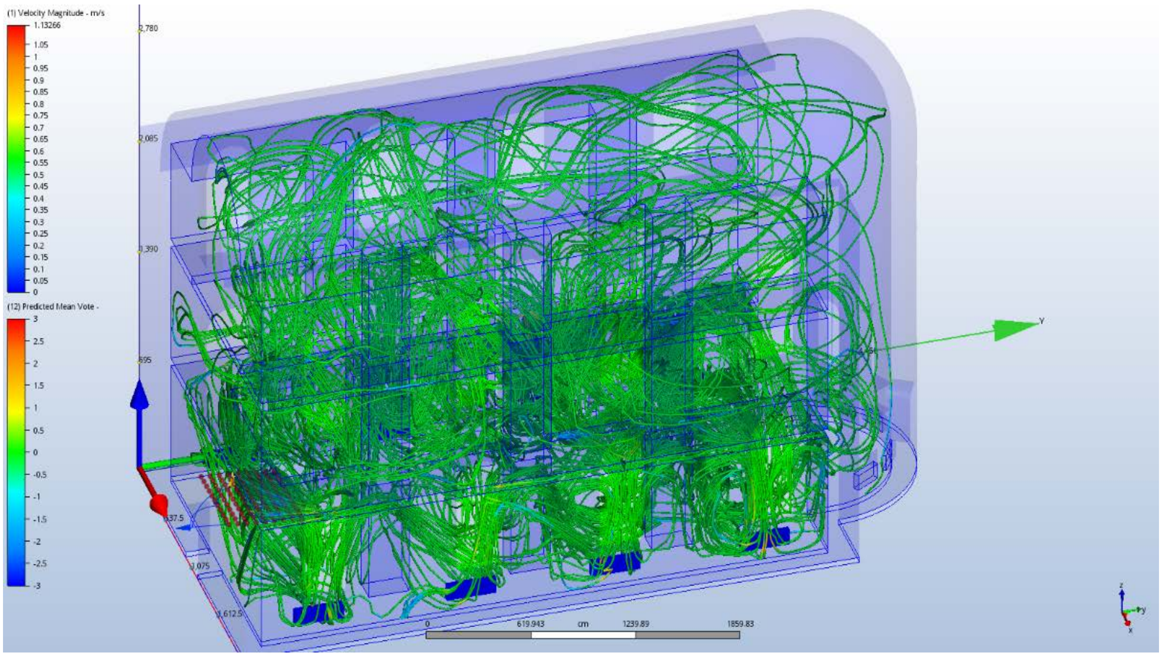

Figure 7. Air velocity and PMV viewed in cross section of Metropolitan Orthodox Cathedral

Convective rise of internal air leads to blackening of surfaces (e.g. paintings, tapestries), especially above the support brackets that trigger turbulence in the uprising airstream (figure 6). Forced air convectors blacken walls all the same, notwithstanding air filters are included (figure 7).

When in use, it generates an endless convective motion of the air above the floor, with heavy deposition of pollutants on walls (figure 8) and ceiling. The latter remains colder and is heavily blackened. Cold downdraughts formed on contact with the walls increase blackening. If possible, insulation of the roof is advisable as a preventative measure. The warm floor tends to mobilize underground vapour and in some cases it may generate a capillary rise. Ground water can be stopped by an adequate damp proof base; however, this is not always easy or possible with interventions in historic buildings.

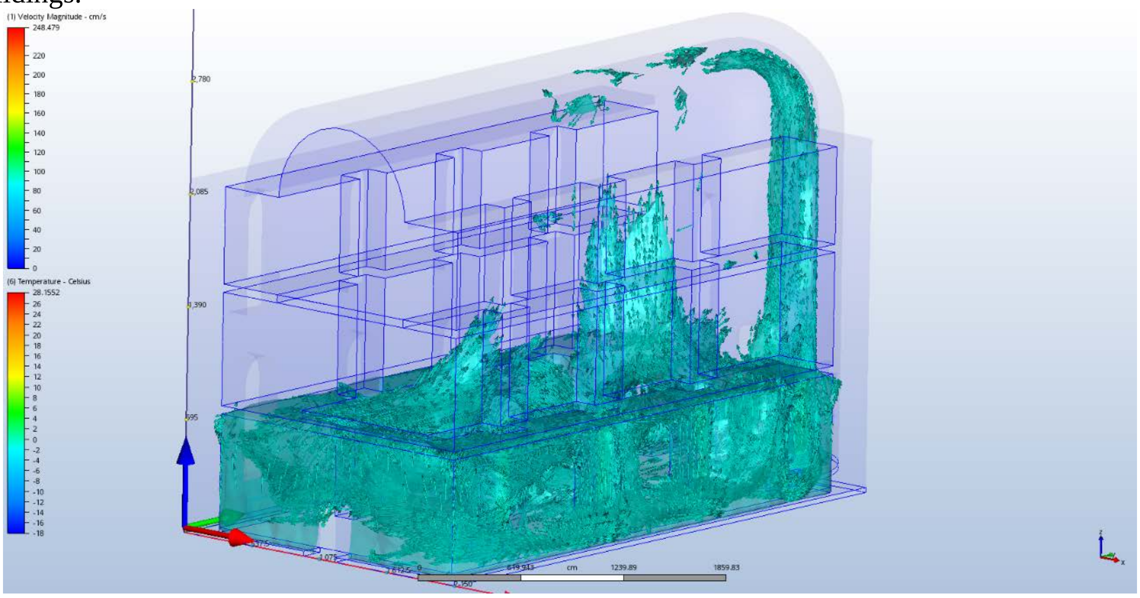

Figure 8. Floor heating system and the air volume characteristics in terms of temperature and velocity

4. Conclusion

In this case study, the local radiant heating system is a nice alternative for the “old” static heating system that heats the whole air volume of the church. First, the heating capacity of the local system is lower than that of the churches static heating system. Secondly, whereas the static heating system needs to be operated for several hours before the service starts, the local heating system needs only to be operated from 15 minutes before the service until the end of it. Therefore, the heating costs of the underfloor heating system will be importantly lower than those of the static heating system.

From the viewpoint of conservation, it is positive that the air convection is relatively small, and also in the whole church, is only heated very slowly and does not reach high temperatures. And the stratification in air temperature above a height of about 2 m, which existed when operating the hot air heating system, is not present with the local heating system. The heat is present in the zone where the people are seated.

5. References

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