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THE IMPACT OF UNDERFLOOR HEATING IN A HISTORICAL CHURCH: A CASE STUDY

F. E. ȚURCANU[1] C.F. POENARI G.C. CHIRILĂ
M. VERDEȘ M. C. BALAN I. ȘERBĂNOIU

Abstract: *The aim of this project is to study the thermal conditions of a fairly typical elderly Romanian stone church, by creating its appropriate model, using a CFD modelling program. At the beginning and for many years, there was not any heating system in these buildings so the indoor environment was basically defined by the outdoor conditions. Wide walls, small windows, the huge indoor air volume and the restricted natural ventilation, caused the indoor climate to be more invariable compared to the outdoor climate. As a result of large heat and moisture capacity of indoor air, conditions were very different inside and outside the building. During summer, indoor conditions were colder than outdoors but during winter indoor air climate was warmer. Concluding, it is difficult to design a heating system for a church, since it has to compensate the thermal comfort and energy needs while it is respectful with preservation and aesthetics.*

Key words: *underfloor heating, indoor climate modelling, conservation.*

1. Introduction

Creating an indoor climate, separated from the outdoor climate, is the basic purpose of most buildings. On one hand, the climate is meant to provide comfort for people who live and work in the buildings. On the other hand, climate induced degradation is one of the major hazards to our cultural heritage. The best conservation strategy is to act in order to prevent damages and degradation rather than reacting afterwards. Climate control, when properly used, is an efficient and cost-effective method for preventive conservation. Too often the discussion on climate control is focused on the technical solutions whereas the real difficulty lies in establishing proper climate criteria.

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 describes to what extent humans find the indoor climate acceptable. People are very

[1] Faculty of Civil Engineering and Building Services, University of Gheorghe Asachi from Jassy.

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 12–15ºC. [1]

Relative humidity matters to humans only when it is very high >80% or very low <30%.

• Conservation of materials in the building require 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. [2]

For materials, relative humidity is often the most important climate parameter.

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

2. Underfloor Heating System Evaluation

Underfloor heating system is reasonable, comfortable and safety only if is operated continuously, if the building is well insulated and thermal power source is properly sized for a high inertia building.

Underfloor heating system requires hours to heat the building and to reach the standards, so it must to be put into operation several hours ahead of the liturgical service. In order to reduce the costs of these systems are often combined with other faster systems. A great advantage of floor heating system consists that the air movement is greatly diminished. For tall buildings, underfloor heating can reduce cost maintenance costs by 50% compared to the other heating systems, ensuring a high level of comfort, with positive effects on the construction elements by reducing the inner streams of air, reducing air stratification. These advantages make the system to be used throughout the cold season, especially in churches where services had been several days of the week. [3]

3. Church – Case Study

Church of St. Sava from Jassy (Fig. 1) dates back to 1330, originally being made of wood, then build from stone in 1390. The church is made in byzantine stile, with overall dimensions of 12.8 x 32.75 meters (Fig. 2). The thickness of the wall is of 1.8 meter, and the maximum height is of 16 meters. The floor covering is made of mosaic concrete; the roof has the coating made from steel tiles.

Fig. 1. *Image of St. Sava Church from Jassy*

The church has been under an intense program of rehabilitation. The frescoes and paintings from the church have been remade to their original form. Also the church has been rehabilitated from the structural point of view. The envelope of the church suffered intervention, during which the thermal conductivity has been ameliorated to make the heating system more efficient and to lower the cost of maintenance. The heating system is composed from static heaters, underfloor heating system and radiant panels. In this paper is evaluated only the case of underfloor heating of the church.

4. CFD – Numerical Modelling

The numerical model is realized using Ansys-Fluent software, in steady state regime. The type of flowing is the laminar.

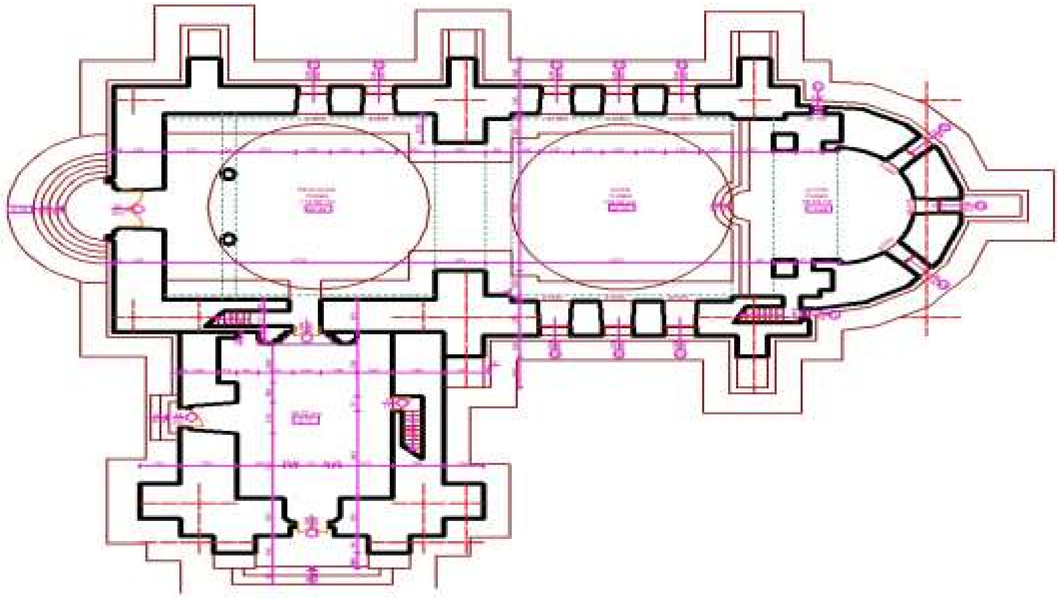

Fig. 2. *Plan view of the church, Jassy*

Having the section drawing it was created a 2d model for the longitudinal section of the church. The geometrical dimensions were those of the real building. There were created 1 model of simulation, one with underfloor heating. The external conditions imposed to the walls and windows in simulation were the temperature of air -18 ^{0}C the convective heat transfer coefficient of 24 W/m^{2}K for the exterior walls and of 12 W/m^{2}K for the interior walls. The columns and internal walls were modeled as conducting walls. Also the heat flux for the underfloor heating system is has been determined using STAS 6648 – church heating demand [1] [4]:

$$Q = \Sigma K_F S_F (t_i - t_e) + \Sigma S_P \, a_p (t_i - t_0) [W] \quad 1.1$$

t_i - interior demand temperature
t_0 – interior temperature at what the heating system start

Modelling using CFD requires the input of initial or boundary conditions on which the calculations are based. Common boundary conditions for the system is:

- external air temperature
- wall surface temperature
- internal air temperature

The discretization scheme employed in the construction of the church is illustrated in Figure 3. It can be seen that a body-fitted grid was used with more grids close to the window surface and to the heating system terminal. [5]

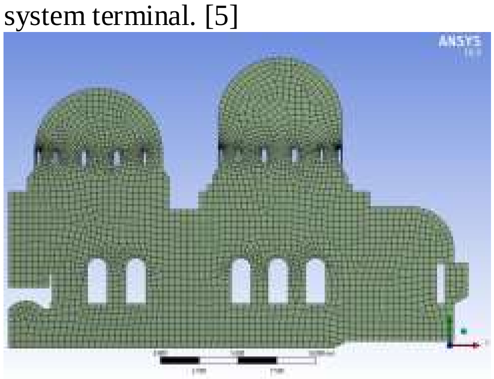

Fig. 3. *Discretization scheme of St. Sava Church, Jassy*

5. Modelling Results and Discussion

The numerical results were obtained as a temperature spectrum and curved profiles that represents temperature variation along the height of the church. It can be observed the difference in temperature and distribution of temperature in the occupation zone. First 2 m from the height of the church are the most important because is this occupation zone in which the human's activities take place. The static heaters heat the whole volume of air and in the case of underfloor heating the first 2 meters are heat but the rest have a low and constant temperature (Fig.4).

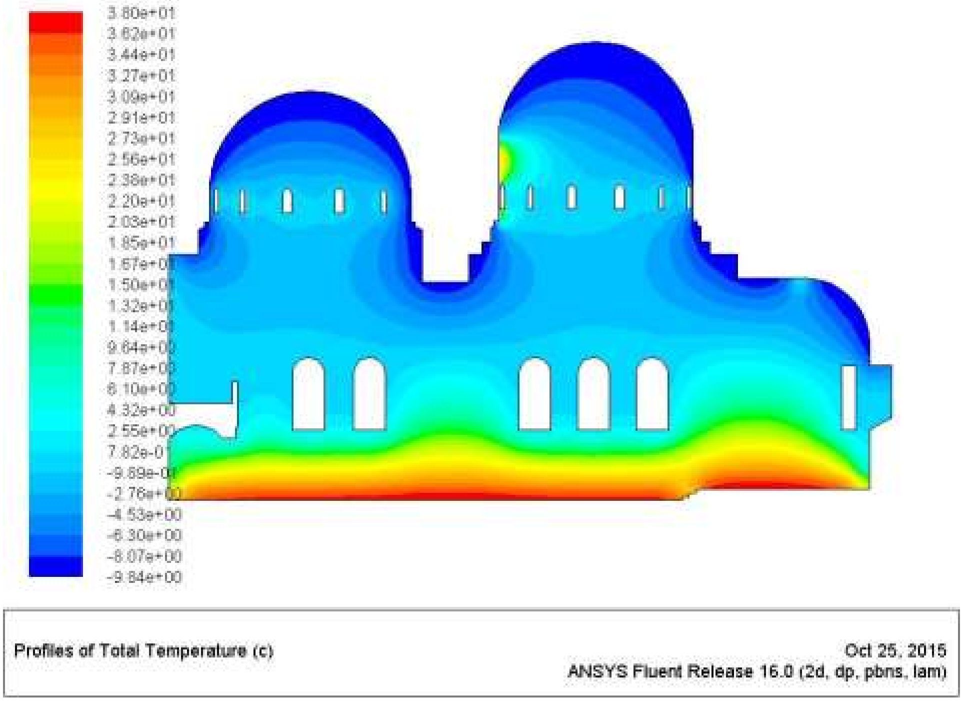

Fig. 4. *Church with underfloor heating system, Temperature profiles*

In figure 4 it can be seen the temperature variation on a vertical plane along the height of church. It can be observed that the temperature has the maximum temperature in the activity zone of 2, 2.5 meters.

In figure 5, a cut made through church in a vertical plan shows that in case of underfloor heating there is a strong variation of temperature. The maximum been in the occupation zone and the minimum in the ceiling area.

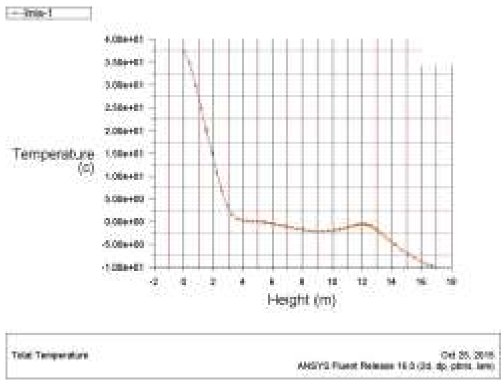

Fig. 5. *Temperature variation on a vertical plane, Temperature variation*

Figure 6, shows another cut in vertical plane throughout the church and temperature variation. The temperature at the floor is of 38 ^{0}C, temperature of the thermal agent in the heating system, and drops to minus because the church is uninsulated, and the exterior temperature has the value of -18^{0}C.

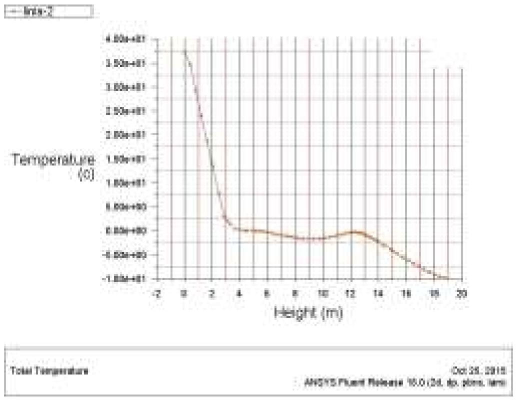

Fig. 6. *Temperature variation on a vertical plane, Temperature variation*

It can be observed from fig.4, fig.5, fig. 6, that in an uninsulated space heated with underfloor heating system the temperature has a strong variation on height. The system has the advantage to heat only the occupation zone.

In a horizontal plane made at the height of 1.4 to 1.7 meters (figure 7) is can be observed the variation of temperature. [6]

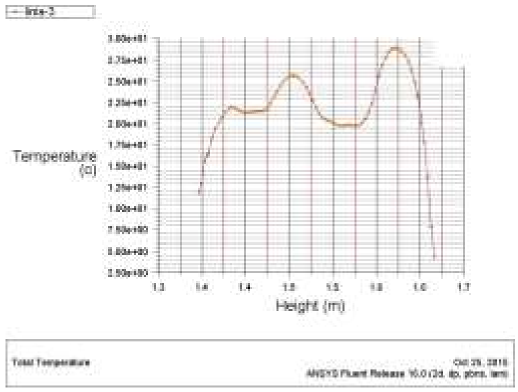

Fig. 7. *Temperature variation on a horizontal plane, Temperature variation*

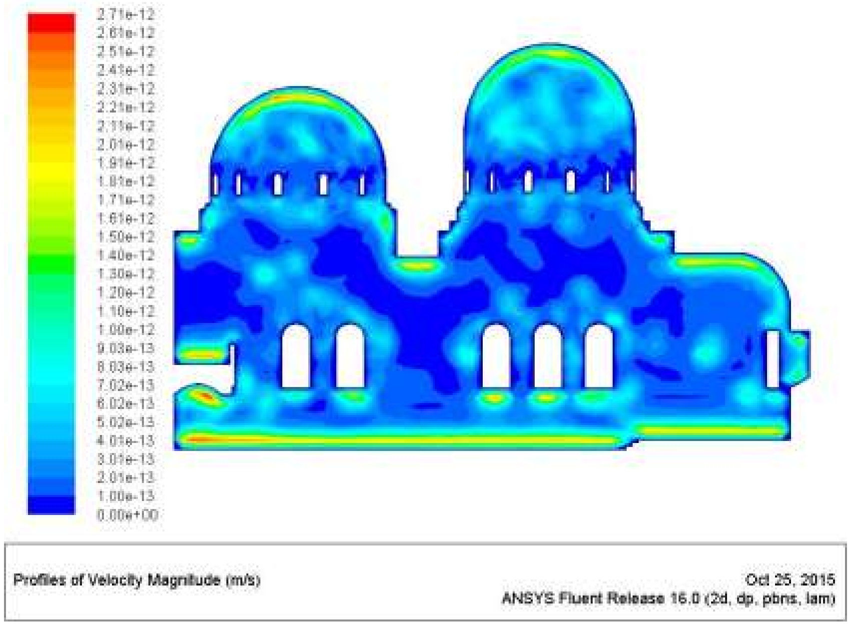

Fig. 8. *Air velocity speed and variation*

Furthermore, figure 6 show the velocity vectors of air speed and movement in the church. This seems to be an acceptable level for providing human thermal comfort. [7] [8]

6. Conclusions

In this case study, the underfloor 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. There are abrupt variations in air temperature (thus also in relative humidity) which could cause damage to monumental objects. And the stratification in air temperature above a height of about 2 m, which existed when operating the hot air heating system, is present with the local heating system. The heat is present in the zone where the people are seated.

From the viewpoint of thermal comfort, more research has to be performed in order to rate the human thermal comfort in the church. The situation is very complex, because it is a quite cold exterior climate (-18°C) in winter.

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