E3S Web of Conferences 85, 01006 (2019) https://doi.org/10.1051/e3sconf/20198501006
EENVIRO 2018

Simulation and modelling of microclimate in a building with high thermal mass during the winter season

Florin Emilian Ţurcanu[1,*], *Marina* Verdeş[1], *Vasilică* Ciocan[1], *Andrei* Burlacu[1], *Marius Costel* Bălan[1], *Răzvan Silviu* Luciu[1] and *Robert Ştefan* Vizitiu[1]

[1]Gheorghe Asachi" Technical University of Iași, Faculty of Civil Engineering and Building Services, 700050 Iași, Romania

Abstract. This paper presents the simulation method for evaluating the heating system from a church. The inside climate has been evaluated by measures of temperature and humidity taken in the winter season. The aim of the paper is to model and validate the indoor climate measures thought numerical analysis and to evaluate the heating system performance. The paper include a case study over and representative category of buildings, used as worship place that can contain heritage values. Nowadays, to conserve the historical heritage is a fact studied in many countries of Europe.

1 Introduction

The indoor climate in historic churches is a crucial to preserve the cultural heritage. There are others important environmental parameters for cultural heritage buildings, such as light and air pollutants. [1]

Creating an indoor climate, separated from the outside climate is the basic purpose of most buildings. Also, climate provide comfort to the people who live and work in this buildings. Climate induced degradation is one of the major problem that can occur in such buildings. Climate control when is 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 problems lies on establishing the proper climate parameters.

The thermal indoor climate is defined by:

- Air temperature;
- Surface temperature;
- Relative humidity;
- Air velocity for air mases.

Cultural heritage in churches constitute an inestimable wealth of sacred and liturgical items. The church heritage is formed by: tapestry, cope, codex, antiphonary, book, sculpture in wood and ivory, icon, painting on canvas, wooden altar, pew, organ, chalice, and reliquary, fresco, and stained glass windows. This cultural heritage is made up of different materials that are affected by the environment in different ways. This patrimony must be preserved against natural decay and usage. [1]

Simple physics teaches that warm air must rise due to buoyancy-driven convection. No matter what form of heating system is used in any building there will be a tendency for the air be heated and to rise unless there are imposed air movements to prevent it.

The phenomenon of stratification in tall buildings is well known and significant temperature gradients can exist between the floor and roof levels.

Conventional wisdom suggest that in the absence of major currents, the hottest air will be at the highest level.

Churches heat up very slowly and often require long periods of preheating to achieve desired standards of comfort. Many of them are only used intermittently and their maintenance and upkeep are burden for few people.

2 Church of St. Sava from Jassy – case study

Church of St. Sava from Jassy (dates back to 1330, build by Greek monks, who came from the monastery of "St. Sava" in Jerusalem, from which the actual name come. The history of the town is profound marked by the church and the monastery surrounding it, being the first from the capital of Moldavia.

Fig. 1. Exterior view St. Sava Church.

The church has first been made by wood, in 1330, then build from stone in 1390. For many year of different historical periods in ruins and forgetfulness, the church of St. Sava has regained the previous splendour today, after more than 3 years of restoration and consolidation works.

* Corresponding author: turcanufemilian@gmail.com

The church is made in byzantine style, with the overall dimensions of 12,8x32x75 meters (Fig. 2). The thickness of the wall is of 1.8 meters with the maximum height of 16 meters (Fig. 3). The floor covering is made of mosaic concrete and the roof has the coating made from brick tiles.

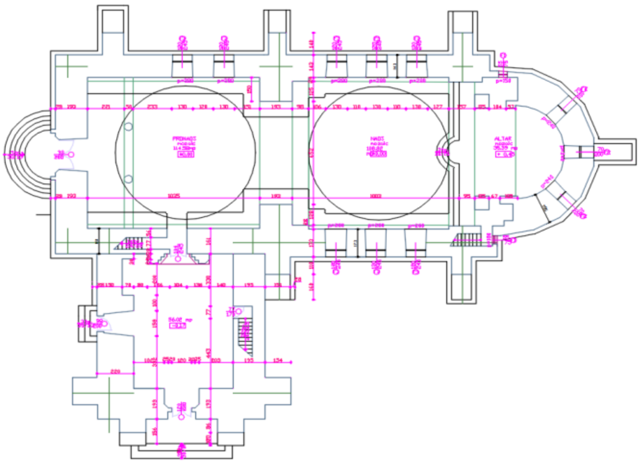


Fig. 2. Plan view St. Sava Church.

The church has been under an intense program of rehabilitation. The frescos and paintings from the church have been remade to their original form. Also the church has been rehabilitated from the structural point of view.

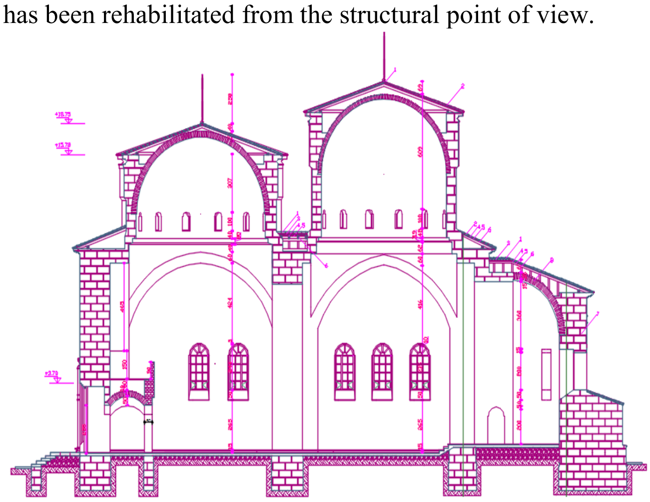


Fig. 3. Longitudinal section of St. Sava Church.

The envelope of the church suffered intervention, during which the thermal conductivity has been increased to make the heating system more efficient and to lower the cost of maintenance. [2]

2.1 Heating system

The heating system is composed from static heaters (Fig.4) and underfloor heating system (Fig.5). The aim of the paper is to evaluate the indoor climate from the point of view of heritage conservation, also the see the level of thermal comfort created for the churchgoers. Another analysis that we made was to validate the plan of measurements with the simulation of indoor climate done in Autodesk CFD 2019 software.

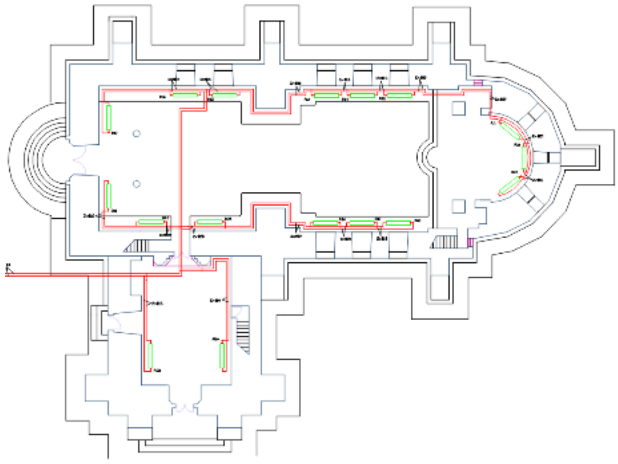


Fig. 4. Placement of static heaters in the church.

Nowadays, there are two heating methodologies:

- Heating the whole volume - central heating (Fig. 4);
- Local heating – keeping the church cool and warming churchgoers with local heating system (Fig.5).

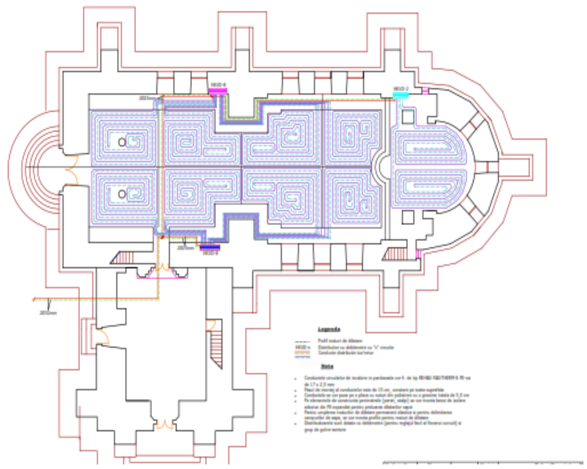


Fig. 5. Plan view with the underfloor heating system in the church.

Central heating has the advantage of using well-known, traditional techniques. On the other hand, has the disadvantage of wasting the energy and deterioration effects to the artworks. [2]

Local heating has a better use of heat, reducing the dissipation and most important is safe for artworks, more convenient for conservation. Also, it has a less common methodology and thermal comfort is generally lower.

Ever since churches first started installing heating, the subject has been one of debate and has needed expert advice. Heating methods, fuels and personal expectation have all changed since then, but the objective remains to improve personal comfort whilst preserving the building. Each church is unique and there is no universal solutions. Heating needs depend not only the church's structure but its location, condition, contents, present heating, usage, the expectations of the congregation and the finance available. Secondly: to assist the decision-making process when changes to heating are being contemplated or when considering systems for a new church or ancillary buildings.

Rarely can one make a simple and unambiguous decision about heating. Inevitably the system chosen will have an impact on the building, what it contains and the people who use it. Each will respond in different ways and compromises are virtually inevitable.

Churches are living entities, for worship and mission. Internal conditions need to help fulfil these purposes at the start of the twenty-one century this often means aiming for higher levels of personal comfort than was the norm one hundred or even twenty-five, years ago. However, over recent years the pitfalls of inappropriate heating have become better understood, which should affect the decisions taken.

Historic churches are an important part of the nation's past. All who care for the, must hand them on in a healthy state to the next generation. Heating systems affect them both directly through their installation and indirectly via the environmental they create. [3]

3 Campaign of measurements in the church of "St. Sava"

Objectives of the side measurements were:

- ➢ to identify the level of thermal comfort;
- ➢ measures for the main comfort parameters temperature (T–^{0}C) and relative humidity;
- ➢ critical analysis of the comfort measured parameters.

For the evaluation of the indoor microclimate in the church of St. Sava, there have been utilized equipment for the main parameters: temperature (T – ^{0}C) and relative humidity (rH - %), also we made investigation with the thermal camera to evaluate the degree of insulation and possible heat leaks. [4]

The equipment are performant from Flir (thermal camera model B200) and USB Data Logger DS 100 that has been placed in the occupied zone of the churchgoers (Fig. 6). [3]

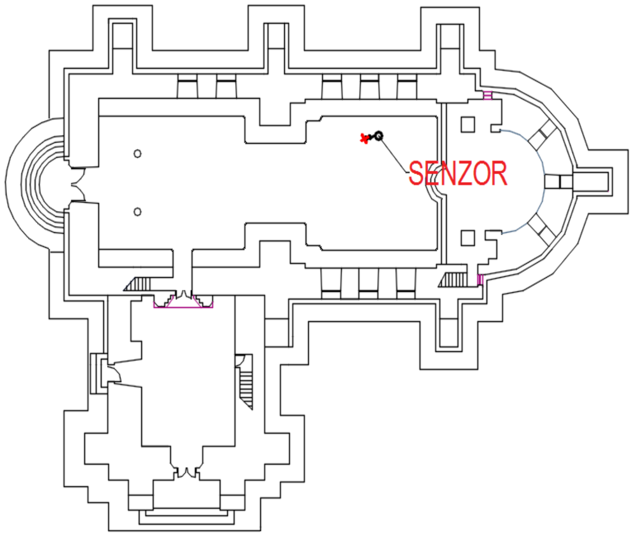
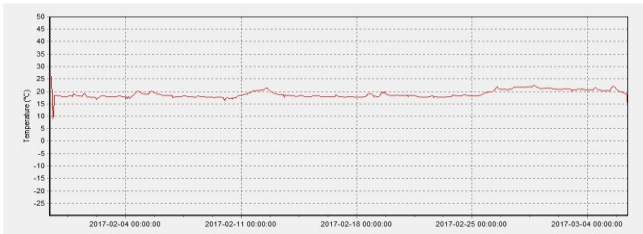


Fig. 6. Plan view of the sensor placement in St. Sava Church.

The church of St. Sava are the home for the relics of the St. Marina. The sensor for temperature and relative humidity was placed on top of the relics as shown in the Fig. 7.

Fig. 7. Longitudinal section of St. Sava Church.

The campaign measurements take place during the winter season between 30.01.2017 - 06.03.2017. During this period the outside temperature has a minim of T= -16,2ºC and maximum of T=+19,2ºC.
The graphical variation of the comfort parameters are show in Figure 8.



a)

b)

Fig. 8. a) Graphical variation of temperature b) Graphical variation of relative humidity.

It can be observed from the fig.8 that the temperature in church microclimate has high value for the winter season, particularly for the time when the measurement were taken. The humidity has value between rH=45%-65%. [4]

For a better understanding of the microclimate, there was made a statistical interpretation of the measured parameters of thermal comfort. The statistical analysis refers to show the standard deviation and the trusted values been exemplify trough histograms and boxplots.
In measurement made in the microclimate of St Sava church shows (fig. 9) that the temperature are in a large scale between 13-24 ^{0}C, with a mean value of temperature around 18,90 ^{0}C, with a standard deviation of 1,438, given by the histogram plot in figure 10. [3]

Also, it can be seen a good variation of humidity without peak loads in a quick time. The mean value of humidity is around 54,17 % rH with a standard deviation of 3,407 (Fig. 11, Fig.12).

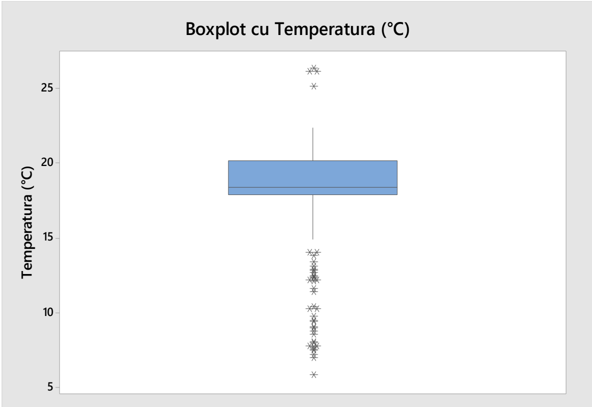


Fig.9. Temperature boxplot in St. Sava Church.

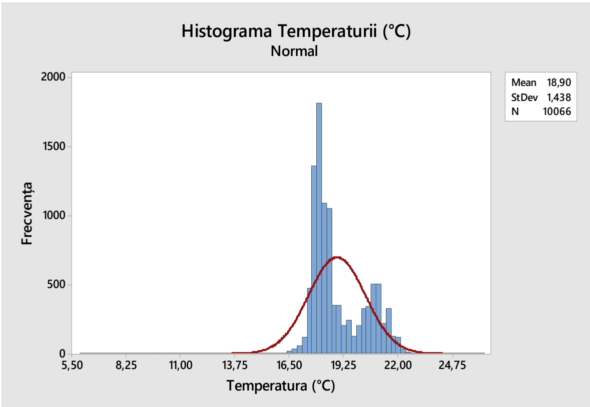


Fig. 10. Temperature histogram in St. Sava Church.

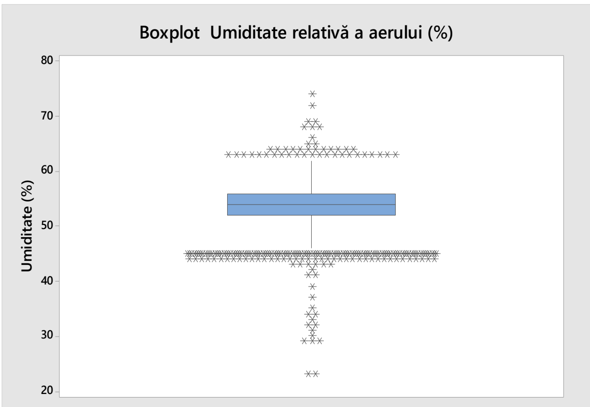


Fig. 11. Relative humidity of air boxplot in St. Sava Church.

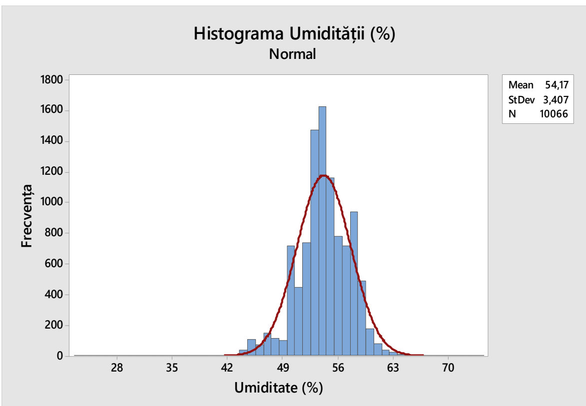


Fig. 12. Relative humidity of air histogram in St. Sava Church.

The minim value of relative humidity measured is 42 % and the maxim is 63 % rH (Fig. 12).

There were calculated the comfort index PMV and PPV for the indoor microclimate based on the activity and data taken from the measurement (Fig.13).

Parameters for thermal comfort	Dates
Thermal insulation of clothes (clo)	1,00
Air Termperature (°C)	18,8
Mean radiant temperature (°C)	19,7
Metabolic rate (met)	1,2
Air speed (m/s)	0,07
Relative humidity of air (%)	54,2

Parametri care indică confortul	Results
Index of comfort (°C)	**19,25**
PMV	**-0,5**
PPD	**10,2**

Fig. 13. Parameters need to evaluate the level of comfort based on the comfort index PMV and PPD in St. Sava Church.

The comfort graph is show in the figure 14.

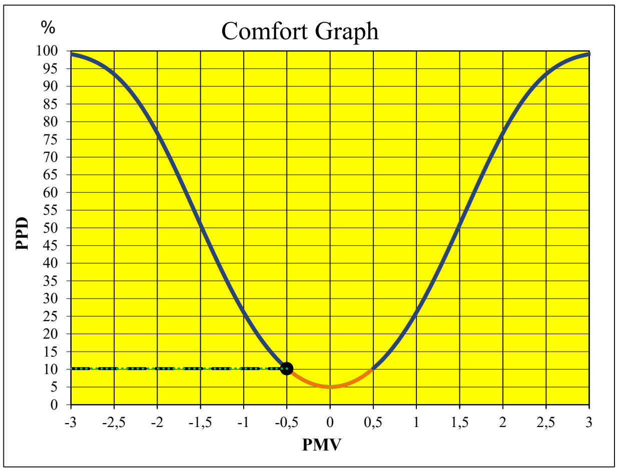


Fig. 14. Comfort graph of PMV and PPD index in St. Sava Church.

From the figure 12 and 14 it can be observed that the level of comfort is high with a height degree of satisfaction, approximately of 90 %, this showing that the heating system is succeeding to maintain a comfortable environment for the churchgoers.

3.1 Thermography analysis

Non-invasive methods have become very popular, fast and accurate, making it possible to be used in a wide range of applications. Among the non-invasive methods used today, thermography was quickly noted in the thermos-physics of buildings. [4]

With the help of thermography it was able to evaluate and to see the convection currents created by the static heaters placed on the exterior walls under the windows (Fig. 15). Also it could be analysed the thermal bridges for the exterior walls and heat loss thought the windows (Fig. 16).

Thermo-vision analysis show that the static heaters that operate as natural convectors make the air at the bottom to heat and to rise because of buoyancy to the top. This system cause the deterioration due to suspended particle deposit. Also cause blackening above the heated areas and on cold surface, especially the ceiling, frescos and paintings in general, organs stuccoes, tapestry.

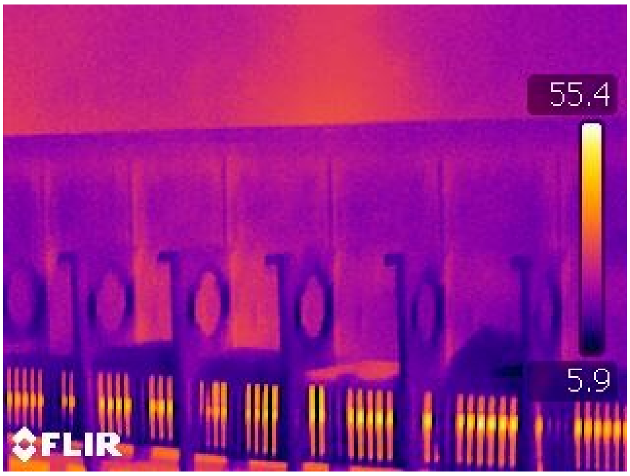


Fig. 15. Convection current caused by static heaters in St. Sava Church.

Thermal images at the exterior show the heat loss at the intersection of walls and at the section changes. Also from fig. 16 it can be see heat loss thought the roof and at the intersection between walls and roof. [5]

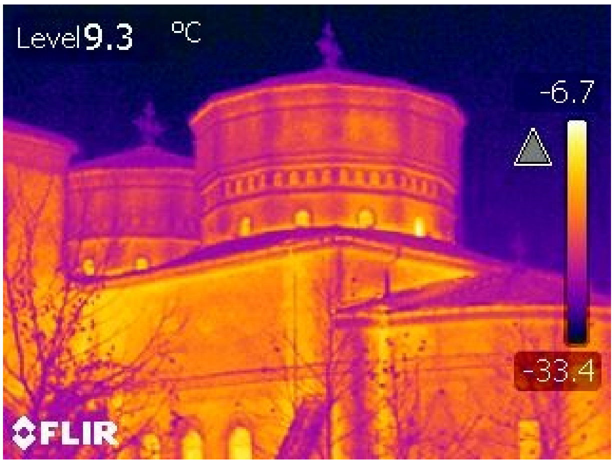


Fig. 16. Thermal bridges of the exterior walls and heat loss through windows for St. Sava Church.

4 Microclimate modelling

This paper describes the indoor environment created when used static heaters and underfloor heating systems. We used the measurements made on the site to validate the simulation of the microclimate done in CFD environment. Software used is Autodesk 2019 – capable of solving heat, air and water vapour simulation, the analysis was run in steady state. The model was made in Autodesk Inventor 2019 in 3D space (Fig. 17), in order to have a model closed to the investigation site. [5]

The boundary conditions imposed for the analysis is presented in the table 1.

It was used a single flow model k-epsilon standard and the mesh size was increased to check if the results get more accurate. The meshing discretization was made in Autodesk CFD Simulation software. Without adjusting the size based on local curvature and having both fluid and solid zones we have a first mesh of 1.5M elements. [6]

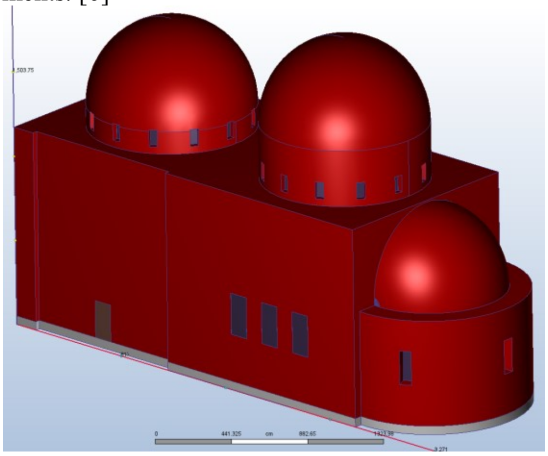


Fig. 17. Thermal bridges of the exterior walls and heat loss through windows for St. Sava Church.

For the next three simulation we increased the refinement resulting a number of 5.4 M elements (Fig. 18).

Table 1. Boundary condition.

Boundary condition	Symbol	Value
Heat flux for static heaters	Q_s	280 W/m^2
Heat flux for underfloor heating system	Q_u	120 W/m^2
Temperature for exterior walls, windows, roof door	T_e	-16 ^{0}C
Temperature for floor on the ground	T_s	10 ^{0}C
Film coefficient for walls	U_w	0.492 W/m^{2}K
Film coefficient for floor on the ground	U_g	0.31 W/m^{2}K

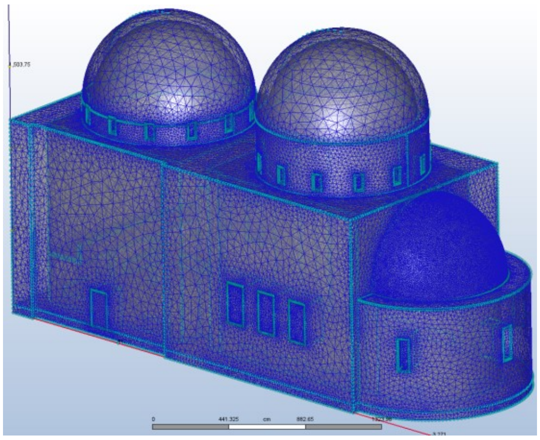


Fig. 18. Mesh discretization of the St. Sava Church at 5.4M elements.

4.1 Results

After the numerical model has been generated and the CFD calculus has run the result are represented through section plans from the church.

Result are in the form of fields for temperature and air speed but also in the form of graph of variation the same parameters in the area where the sensor have been set.

In Fig. 19 it can be seen that the temperature have a uniform distribution and that in the influence zone of the heaters the air has higher speed.

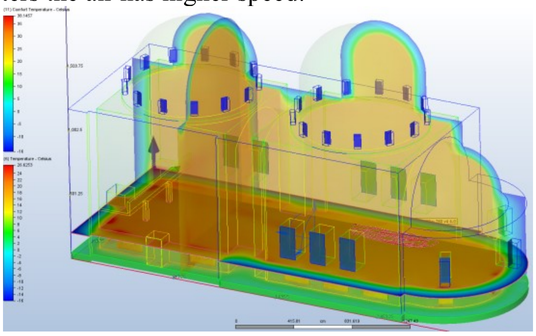


Fig. 19. Temperature in the section plans of St. Sava Church.

From the Fig. 20, in the centre of the church it can be seen that the air velocity has higher speed, generated by the underfloor heating system

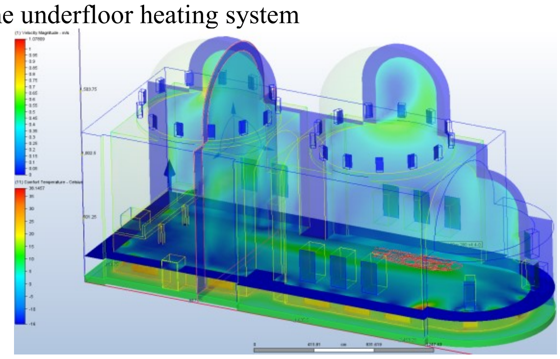


Fig. 20. Air speed velocity in the section plans taken in St. Sava Church.

The variation of the temperature is represented in Fig. 21, with a mean temperature of approximatively 18^{0}C, which is appropriate to the temperature from the temperature sensor of $18{,}90^{0}$C.

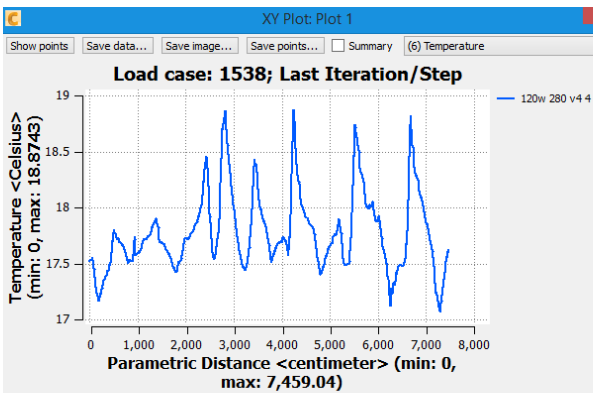


Fig. 21. Temperature graph in St. Sava Church.

In Fig. 22 the air velocity from simulation in the area where the sensor was set, has value between 0,25-0,55 m/s. This value are quite high, probably due to the underfloor heating systems that can cause such speed in the tall buildings.

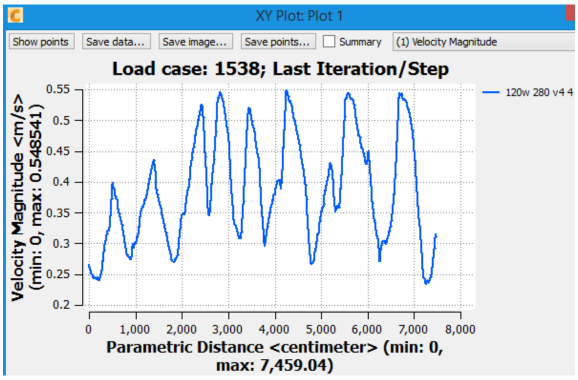


Fig. 22. Air speed graph in St. Sava Church.

4 Conclusion and further developments

The research represents a new approach for the microclimate in churches from Romania. The research can be the set to evaluate new heating systems in the heritage churches.

The solution of heating spaces with static heaters and underfloor heating system needs further evaluation, due to the lack of understating of heat and mass transferrin tall buildings especially in churches.

Also, the research can evolve in setting an algorithm for choosing the proper heating system in heritage buildings and particularly in churches that house heritage objects.

References

[1] Corgnati, P. S., Fabi, V. & Filippi, M.,. A methodology for microclimatic quality evaluation in museums: Application to a temporary exhibit. Build Environ, pp. 1253-1260 (2009)

[2] Camuffo, D., Pagan, E., Schellen, H. & Limpens-Neilen, D., A practical guide to the pros and cons of the various heating systems with a view to the conservation of the Cultural Heritage in Churches. Results of the European Project Friendly Heating EVK4-CT-2001-00067, (2014)

[3] Cheng, Y., Niu, J. & Gao, N., 2012. Thermal comfort models: a review and numerical investigation.. Build Environ, **47**, pp. 13-22.

[4] de Dear , R. J., Ring , J. W. & Fanger, P. O.,. Thermal sensation resulting from sudden ambient. Indoor Air, **3**, pp. 181-192 (2013)

[5] Delgado, J. M., de Freitas, V. P. & Guimarães, A. S. Hygrothermal Risk on Building Heritage. Springer. 2015

[6] Kramer, R., Jos, v. S. & Schellen, H.,Inverse modeling of simplified hygrothermal building models to

predict and characterize indoor climates. Build Environ, **68**, pp. 87-99. (2013)