COMPARATIVE ANALYSIS OF HVAC SYSTEM FUNCTIONALITY IN "VASILE ALECSANDRI" NATIONAL THEATRE OF JASSY

BY

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Abstract. The present work investigates the behaviour of the implemented HVAC system at "Vasile Alecsandri" National Theatre of Jassy, for different external conditions. A 2D model of the building was realized by using ANSYS-Fluent software, simulating the functionality of the HVAC system for winter and summer season. For the studied scenarios, the external conditions of Jassy and the indoor conditions of the theatre, when the entire spectacle hall is occupied were considered. The main aspects evaluated for each case were the air temperature, air velocity and relative humidity. The results are presented comparatively as plots and spectra of the interest parameters. It was established that the HVAC system is providing adequate conditions for both studied seasons.

Key words: comfort; indoor climate; HVAC system; numerical simulation.

1. Introduction

The "Vasile Alecsandri" National Theatre, an important objective of Iasi, was submitted to rehabilitation and consolidation recently (Project & Execution, 2012). These works were realized for the architecture, strength

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structure requirements and also for the building services. One of the most important building installations, for these types of buildings is the HVAC system. During execution, the new installed equipment was necessary to fit into the old architecture and it was also subjected to some dimensioning constraints, due to the old channels of heating and ventilation system.

The initial system was designed in 1896 by Koerting brothers (National Archives, 2007), and it realized only the ventilation and heating of the building. Taking into account the large amount of heat dissipation and humidity from occupants, an air conditioning system was necessary. Therefore, the modernized system realizes this task both in winter and summer season.

The capacity of the theatre is about 800 places, which are often occupied during spectacles. This agglomeration determines a very quick change of the interior climate parameters. Instead, the HVAC system must operate with the same reaction speed in order to eliminate the excess of heat and humidity and maintain an optimal level of comfort inside building.

The ventilation of the Main Hall, Fig. 1, is realized by using three independent systems for introducing the fresh air in different zones: stall, lodge and balcony. The exhaust air is evacuated through one system, placed in the ceiling. Total airflow in the auditorium Main Hall is of 21,000 m^3/h. The ventilation is balanced, meaning that the introduced airflow is equal with the evacuated one.

A total of 229 inlet grilles are placed in the floor in stall, under the seats, providing the required fresh air for this zone. For lodges, the inlet grilles are placed in the vertical air channels, while the balconies are connected through channels with the overpressure room, and the inlet grilles are in the tiers. The evacuation of the air is carried out by twelve circular outlet grilles, symmetrically placed in the circular ceiling (Project & Execution, 2012).
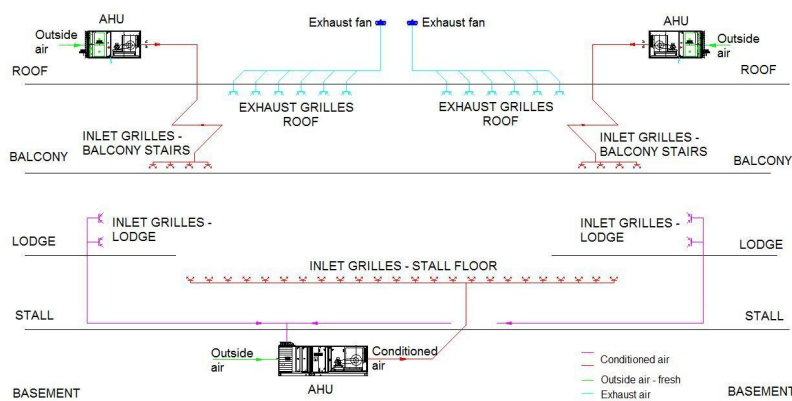

Fig. 1 – Functional scheme of the HVAC system for – Main Hall.

The most important goal of the HVAC system is to provide a proper indoor climate, characterized by: comfort of occupants and conservation of paintings and architectural elements.

Comfort, which is a subjective parameter, describes the perception of occupants when they 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. The typical range is 18 – 24ºC. Relative humidity has important effects over humans only when it is very high, above 80%, or very low, lower than 30% (Bronström, 2004). The preservation of materials, paintings and architectural elements in the building requires an indoor climate that minimizes ageing and degradation. For materials, relative humidity is often the most important climate parameter (Bronström, 2004).

This study is focussed in surveying the indoor climate parameters during the peak load in winter and summer seasons.

2. Case Description

One major problem of socio-cultural buildings, such as National Theatre "Vasile Alecsandri" Jassy, is the high level of heat and water vapour emissions in a very short period and the solutions to evacuate it.

The problem studied throughout this work consist of the functionality of the HVAC system for the real building of National Theatre "Vasile Alecsandri" Jassy, Fig. 2. The subject of this study is the Main Hall – the space where the entire audience is present during spectacles. This represents a voluminous space with 10.7 m height, 18 m width and 21 m length. The model is realized by using the actual dimensions of the existing monument and the air flow of the HVAC system.

The emissions from people were modelled as heat and water mass fluxes, corresponding to maximum capacity of the objective. In literature are reported attempts to simulate air flow inside buildings and its effects over indoor climate (Thiyagarajan & Kumar, 2015) and also for the influence of the outside air circulation over interior climate (Mahu *et al*., 2012). Another field of development is the medical one, where this type of approach provides preliminary information on the surgery or emergency ward climate (Peri *et al*., 2011; Balocco *et al*., 2014).

3. Numerical Modelling

The simulations are achieved in steady state regime, using turbulent flow and *k-ε* model. Therefore, the temperature, velocity and relative humidity

data inside the main hall of the theatre were obtained. Performing numerical simulations carried out by CFD tool, ANSYS-Fluent, the differential equations of heat transfer and fluid mechanics were solved (ANSYS 13):

Momentum equation:

$$\frac{\delta}{\delta t}(\rho \vec{v}) + \nabla(\rho \vec{v}\vec{v}) = -\nabla p + \nabla(\overline{\overline{\tau}}) + \rho \vec{g} + \vec{F} .$$ (1)

Energy conservation:

$$\frac{\delta}{\delta t}(\rho E) + \nabla \left[\vec{v}(\rho E + p) \right] = -\nabla \left(\sum_j h_j J_j \right) + S_h.$$ (2)

Conservation of mass:

.   (3)

The geometry and mesh of the model, Fig. 2, were realized by using ANSYS-Design-Modeller and ANSYS-Meshing. The geometry of the building is a simplified one, for the cross section only, assuming a 2D model. It was determined the mass flow for each grille, taking into account that Fluent uses an auxiliary virtual dimension of 1 m long (ANSYS 13). The mesh was created with refinements near walls, Fig. 2 b, resulting in 5596 nodes, 10418 2D interior faces and 5,322 mixed cells.
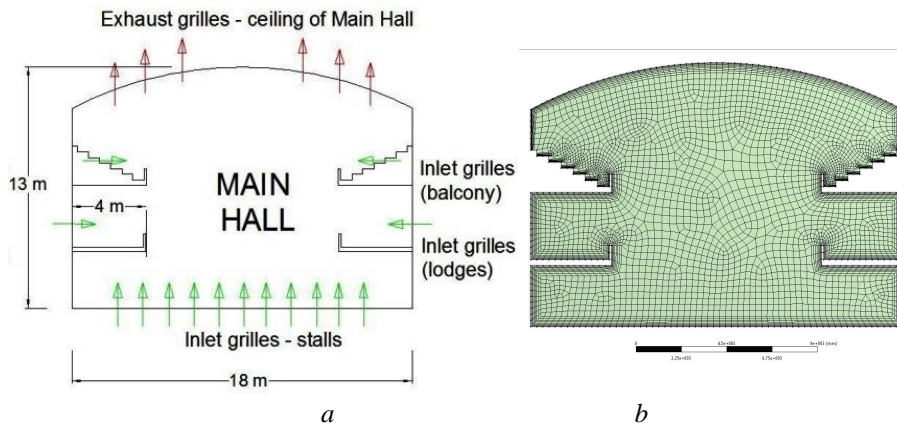

Fig. 2 – Cross section of the Main Hall: a – geometry; b – meshing.

The boundary conditions at inlet sections are the temperature of the conditioned air and the mass flow inlet equivalent to airflow of HVAC system. Temperature of treated air is about 20°C during winter and 24°C in summer. For external walls, a convective heat transfer was considered with $\alpha = 24$ W/m²K,

$T_{ext} = -18°C$ in winter and $\alpha = 12$ W/m²K, $T_{ext} = 35°C$ in summer. The walls are made of reinforced concrete, with high thicknesses of 0.6 m to 1 m and high thermal inertia.

The turbulence was modelled using semi-empirical model k-ε, considered adequate for simulating air flow inside large domains (ANSYS 13). The humidity is modelled with species model tool of Fluent software. The emissions of water vapours are computed assuming that a group of people can be modelled as a mass flow inlet of water inside the interior air. The heat generation rate, in case of full occupancy was imposed as 100 W/m³ and the moisture produced by a sitting person as 70 g H₂0/h (Uyttenhove *et al*., 2004).

4. Results

The results are presented comparatively for the two studied cases. The qualitative data are revealed by contours of velocity, temperature and humidity, while the quantitative ones can be observed in the plots of the same parameters.

Fig. 3 highlights the distribution of temperature in the studied cases. It is noticed that in both seasons the temperature in the occupational zone is maintained almost constant during the spectacles. The higher values during summer are determined by the inlet temperature of conditioned air in addition to the external heat transfer. In both situations, the excess of heat is conducted in the superior zone of the hall where it does not affect the comfort of the occupants.
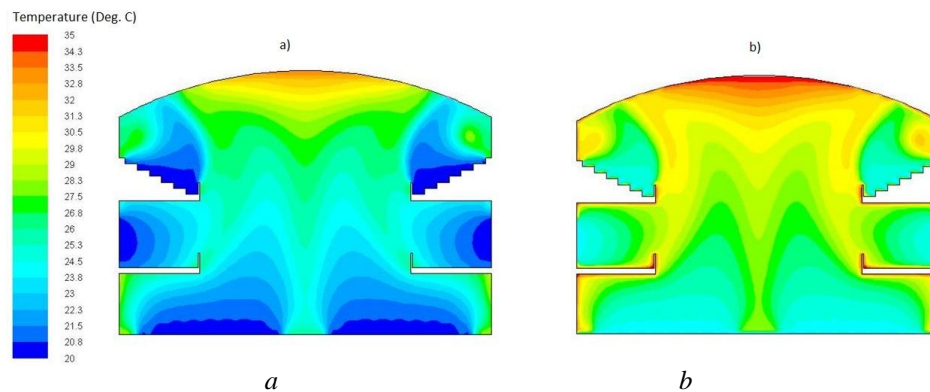

Fig. 3 – Temperature spectra: *a* – winter season; *b* – summer season.

More accurate data is presented in Fig. 4, which offers information about temperature distribution at different height in cross section. The elevation planes were selected as $h = 1$ m, 4 m, 7.5 m, 9 m and 10.7 m, being most relevant from the point of view of human comfort in occupational zones.

Temperatures of interior air reach values of 20 – 28°C during winter and 24 – 32°C during summer. The high density of people during winter determines a reversed heat transfer balance. In this season, sometimes is necessary to realize the cooling of the audience, while other rooms could need to be heated.

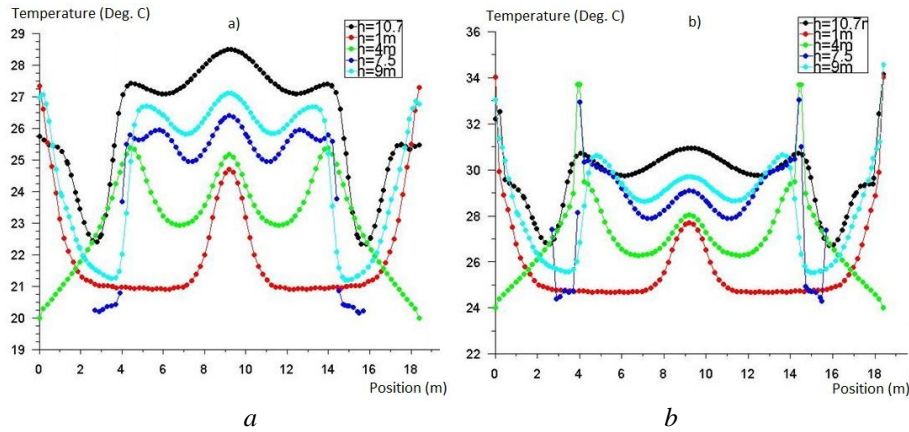*a*   *b*

Fig. 4 – Temperatures at different heights: *a* – winter season; *b* – summer season.

Velocities spectra, Fig. 5, are almost similar for both studied cases, caused by approximately the same airflow during winter and summer season. The average velocity in occupational zone reaches a maximum of 0.3 m/s and does not affect the comfort of the occupants.
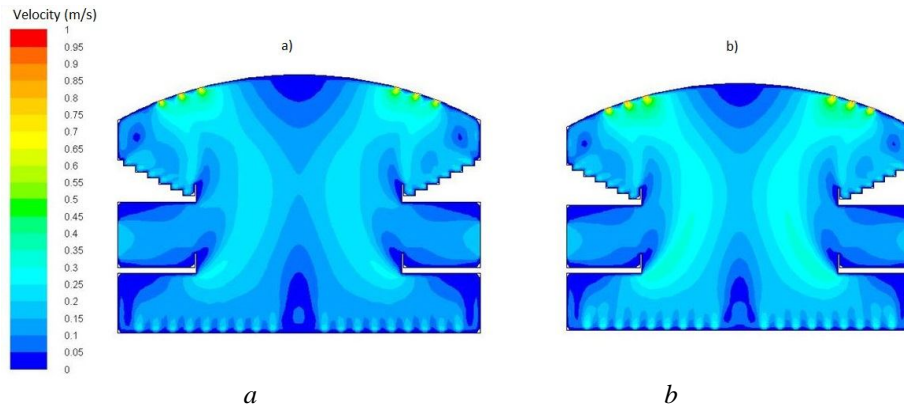

a   *b*

Fig. 5 – Velocity spectra: *a* – winter season; *b* – summer season.

Analysing information from Fig. 6, there are recorded higher values of velocity in summer season. This phenomenon is caused by the higher temperatures and air density gradient on vertical. However, the average

velocities in comfort areas are 0.1 – 0.2 m/s, while the maximum values of 0.35 m/s are recorded in the opening of the hall or in the upper zone of the studied building.
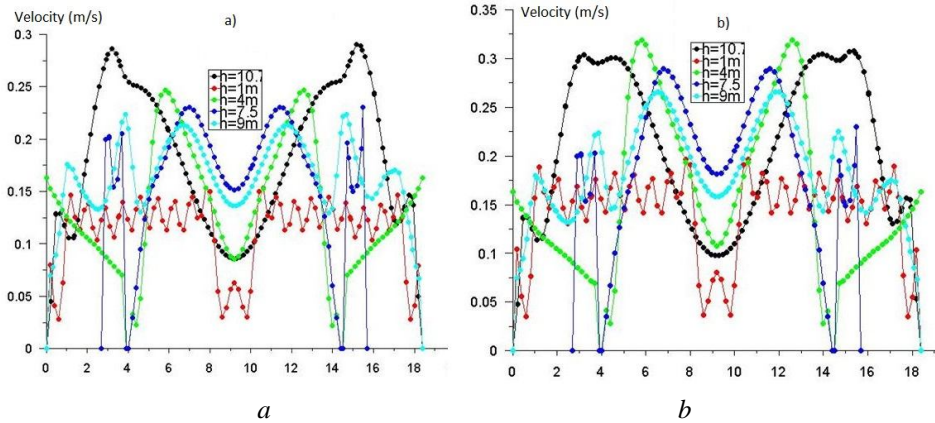

a   *b*

Fig. 6 – Velocity at different heights: *a* – winter season; *b* – summer season.

In terms of relative humidity, higher values are noticed during summer season, determined by intense moisture emissions from people that are coming from outside. Despite this, the values of relative humidity of interior air are lies between 55-63 % during winter and 56,...,67% during summer. These values are providing good comfort conditions for occupants. Also, another important aspect is the values registered during winter season, which does not exceed 63% near exterior walls or ceiling, the condensation risk being reduced. The relative humidity of interior air has very reduced range during both seasons because of the controlled parameters of conditioned air.
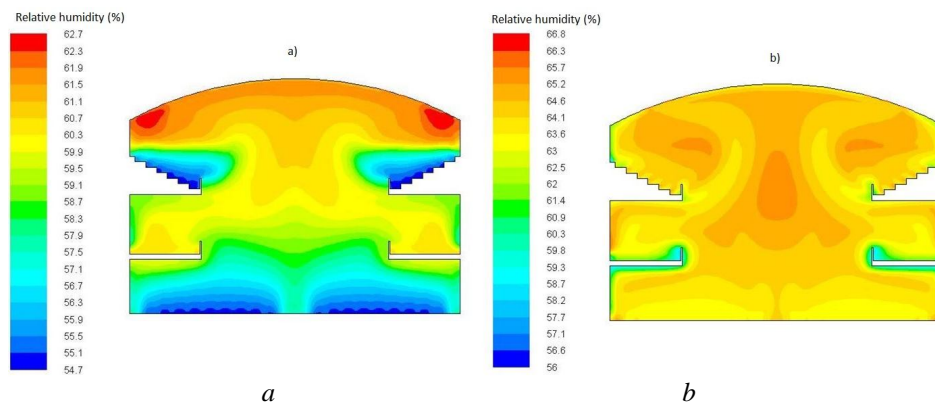

a   *b*

Fig. 7 – Relative humidity: *a* – winter season; *b* – summer season.

5. Conclusions

The HVAC system of the real building was studied by using a 2D model, with specific software ANSYS-Fluent. The HVAC system is subjected to an analysis of its functionality, by evaluating the supplied parameters when operating at maximum load.

After an overall outlook of the results, it can be stated with certainty that the recently implemented HVAC system reaches its task and provides adequate comfort conditions inside the spectacle hall during both seasons.

It must be noticed that in winter the heat transfer balance is sometimes reversed, determining the necessity to realize the cooling of the audience hall, while the other rooms need to be heated.

More general conclusions state that when such important interventions are realized, it must be taken into account the conservation of original architectural elements of the building, limitation of designing air channels and grilles, due to the initial architectural constraints and existing conditions, and also the permanent cooperation between engineering designers and architects.

Such type of analysis can be used for all important building engineering works, even in design phase, to get best results during execution and service of the installation.

Notations

p – Pressure (Pa);
α – convective heat transfer coefficient (W/m^{2}K);
v – Overall velocity vector (m/s);
t – Time (s);
ρ – Density (kg/m^3);
τ – Shear stress (Pa);
g – Gravitational acceleration (m/s^2);
F – Force vector (N);
E – Total energy (J);
h – Enthalpy (J/kg);
h^0 – Standard state enthalpy of formation (energy/mass, energy/mole);
J – Mass flux; diffusion flux (kg/m^2-s);
S_h – Source of heat added;
S_m – Source of mass added to the continuous phase;
T_{ext} – temperature of external air (°C).

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ANALIZA COMPARATIVĂ A FUNCŢIONALITĂŢII SISTEMULUI HVAC LA TEATRUL NAŢIONAL "VASILE ALECSANDRI" IAŞI

(Rezumat)

Scopul studiului constă în investigarea comportamentul instalaţiei de ventilare şi climatizare, implementată recent la Teatrul Naţional "Vasile Alecsandri" din Iaşi. În acest scop, s-a utilizat softul specializat ANSYS-Fluent, pentru realizarea unui model 2D al clădirii şi simularea funcţionalităţii sistemului HVAC în perioada iernii şi a verii. Pentru simulări au fost considerate condiţiile externe specifice oraşului Iaşi, iar pentru interiorul clădirii s-a considerat cazul în care întreaga sală de spectacol este ocupată. Principalele aspecte urmărite în fiecare caz au constat în evaluarea temperaturii aerului interior, vitezei curenţilor de aer şi umiditatea relativă. Rezultatele prezentate comparativ sunt graficele şi spectrele parametrilor urmăriţi.