Thermal performance of the new hall of the historical hospital in Florence

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Abstract: The main aim of the present work is the study of the energy performances of the new hall of the Old *St.Maria Nuova* Hospital in the center of Florence (Italy). In particular this study aims to evaluate thermal, energy and environmental performances of the refurbishment project for the new hall of the historical hospital and to evaluate the significant reductions of energy consumption obtained. Transient simulations were carried out of the 3D model of the hall to analyse the air flow patterns, distribution and velocity, provided by an existing typical fan-coils air system. The present study highlights the importance of CDF-FEM simulation to predict and analyse the energy and thermal performance of the system (thermal buffer called *hot room*), when experimental measurements cannot be carried out due to high costs and time needed.

Keywords: thermal buffer, CFD-FEM simulation, energy saving

1. Introduction

The fundamental objective of the European Union's energy policy is to ensure implementation of sustainable energy systems by supporting and promoting secure energy supplies of high service quality at competitive prices. There are wide possibilities of application of energy saving strategies in buildings with a focus on hospital and health care building structures with architectural integration of passive solar technologies applied to energy building retrofitting and old building refurbishment.

The indoor comfort of the hospital hall is guaranteed by an air-conditioning ventilation system, in controlling temperature, humidity, pressure. The S.*Maria Nuova* Hospital is the oldest still operating hospital in Florence, the only one in the historical centre, with the main entrance in the homonymous square. It is the first example of a building and plant refurbishment on a protected historical building. The new hall of the hospital that is the object studied is a bioclimatic greenhouse made of triple low emissive glazed façade used as thermal buffer.

The hospital was founded in 1288 by Folco Portinari. The hospital was recently subjected to some refurbishment intervention to respect to functionality and indoor air quality requirements and functional and equipment and plant standards. During October of 2009 the first portion of the building, concerning rooms for hospitalization, was completed together with all the HVAC plants and equipments. At the end of 2010 the new first aid of the hospital was completed and inaugurated, with the new department of intensive care, dialysis sectors and the new pharmacy. The hospital has a catchments area of about 80 thousand residents more than 300 thousand people, including tourists and other workers for a total of about 38 thousand people who present to the first aid each year.

The access to the new first aid, located in the west side of the lodge, the object of present study, is realized with a steel structure and glass and equipped with two portals of access to the ambulance service and transportation of sick and a pedestrians. This new hall fits into the Buontalenti's porch with respect, preservation and protection for the architectural, historical feature and cultural value of the building (Fig. 1).

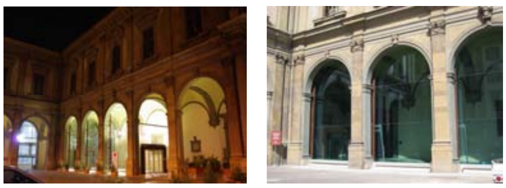

Figure 1. The *hot room* of S.M. Nuova Hospital.

Consequently the project for the new hall had to be justified by a rigorous conservative restoration and conservation of the historical building due to the intention and rules of the Superintendence.

The objective of CFD-FEM simulations of the present work were to define the influence of the new hall structure on the internal thermal comfort and on the cooling plant energy consumption.

2. The solid model

A three dimensional model of the hall of the first aid of the hospital starting from the geometric, architectural and existing plant data, was carried out (Fig. 2). The 3D model concerns the new hall that is inside of the Buontalenti's arcades. The hall is 114 m^2 and its total interior volume is 980 m^3. The main glazed façade is oriented at South-West and it is 135 m^2; two side windows are exposed to the NW and SE, both of 56 m^2, are provided by two sliding doors with motion sensor. The wall at the entrance to the first aid of the hospital building is plastered by mixed stone. The thermo-physical properties of the different materials are shown in Tab.1. This thermal buffer, actually called *hot room*, was considered as one-zone model made by the large glazed surfaces supported by steel profiles connected to the structure (Fig.1).

In particular for the 3D model the N-W sliding door was kept closed, but the S-E and the first aid sliding doors were considered opened. At this condition the one-zone 3D model was assumed to have a boundary faced to the first-aid indoor ambient and an external boundary defined by the external ambient, characterised by the hourly values of temperature and solar radiation variations, that concerns the three N-W, S-W and S-E walls.

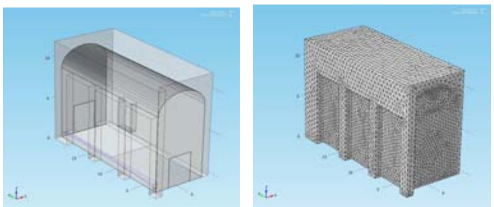

Figure 2. The 3D solid model (sx); the mesh (dx).

The first-aid indoor ambient is kept at a constant temperature of 26°C by an air conditioning VAV system (variable air volume) combined with a floor radiant panels system.

This is the reason because this internal boundary of the 3D model studied was assumed at the fixed constant temperature and at slight over total pressure. The three fan coils (with a four pipes system) located in the floor, with their grilles adjacent to the S-W glazed façade, were modelled assuming an initial inlet constant velocity and inlet temperature values.

3. Transient simulation

To investigate the development of the ventilation flow and the air temperature distribution inside the system studied, a time dependent simulation based on general heat transfer combined with the turbulent k-ε flow model, was performed using Comsol Multiphysics. Hourly climatic data of the hottest day provided by the standard year of Florence, were used. For the South-West glazed façade the external air temperature was corrected taking into account the incident solar radiation. After many attempts, a good quality of the mesh was obtained by 200000 degrees of freedom with 197000 triangular and tetrahedral elements. The linear system solver *PARDISO* was used.

The initial conditions for transient computation were obtained by running the simulation starting from the steady state analysis, assuming for the initial indoor climatic conditions, a uniform internal air temperature of 26°C and 50% of relative humidity, as literature suggested. Simulations performed for the model needed a computational time for convergence of 7 days using 6 GB Ram. The sub-domain setting equations used for the general heat transfer and turbulent k-ε flow model are the following:

Air

$$\rho\frac{\partial u}{\partial t}+\rho(u\cdot\nabla)u=\nabla\cdot\left[-\rho I+(\mu+\mu_T)\left(\nabla u+(\nabla u)^T\right)-\frac{2}{3}(\mu+\mu_T)(\nabla\cdot u)I-\frac{2}{3}\rho kI\right]+F$$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho u)=0$$

$$\rho\frac{\partial k}{\partial t}+\rho(u\cdot\nabla)k=\nabla\cdot\left[\left(\mu+\frac{\mu_T}{\sigma_k}\right)\nabla k\right]+p_k-\rho\varepsilon$$

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho(u\cdot\nabla)\varepsilon=\nabla\cdot\left[\left(\mu+\frac{\mu_T}{\sigma_\varepsilon}\right)\nabla\varepsilon\right]+C_{\varepsilon1}\frac{\varepsilon}{k}\rho_k-C_{\varepsilon2}\rho\frac{\varepsilon^2}{k},\varepsilon=ep$$

$$\mu_T=\rho C_\mu\frac{k}{\varepsilon^2},P_k=\mu_T\left[\nabla u:\left(\nabla u+(\nabla u)^T\right)\right]$$

Walls

$$\rho C_p\frac{\partial T}{\partial t}+\nabla\cdot(-k\nabla T)=Q-\rho C_p u\cdot\nabla T$$

where:

P absolute pressure (Pa)
k thermal conductivity (W $m^{-1}K^{-1}$)
ρ density (kg m^{-3})
c_p heat capacity (J$kg^{-1}K^{-1}$)
μ dynamic viscosity (N s m^{-2})

The boundary conditions used for the general heat transfer are the following:

a) at the initial conditions the air thermal conductivity, density and heat capacity were considered constant and respectively 0.026 (W$m^{-1}K^{-1}$), 1.2 (kg m^{-3}) and 1000 (J $kg^{-1}K^{-1}$);

b) thermo-physical properties of all the building materials were considered constant (Table 1);
c) hourly values of the external sun-air temperature were used as boundary conditions for the main South-West oriented glazed façade;
d) hourly values of the external air temperature were used as boundary conditions for the lateral glazed façades respectively S-E and N-W oriented;
e) "temperature" linked to the fan coils surface with inlet air temperature assumed at 18°C;
f) "temperature" linked to the indoor constant surface temperature for all the surfaces (ceiling and vertical wall) of the hospital facing the zones with the air cooling set-point temperature value (26°C);
g) "Outflow" thermal flow condition for one sliding door and the first aid considering the boundary condition for the open door, and the connected heat transfer between indoor and outdoor;
h) "Thermal insulation" for the surfaces of the external columns and floor;

The boundary conditions used for the turbulent k-ε flow model are the following:

a) "outlet-pressure" for the S-E sliding door and the first-aid door, fixed at the initial atmospheric pressure (1.013 kPa);
b) normal inflow velocity field used as inlet velocity condition (z-directed) assumed equal to 0.15 m s^{-1} for the air inlet initial condition provided by the air conditioning fan coil system;
c) outside pressure without pressure stress for the open door (placed on the South-East façade);
d) referring to the turbulent k-ε flow model, in the air sub-domain, the air density and dynamic viscosity were considered as function of the air temperature and the volume force due to the buoyancy and function of air density following the Boussinesq approximation.
e) all boundaries of the computational domain, walls, ceiling, floor and the internal surface of the glazed façades were modelled as *wall function* boundaries.

Table 1. Thermal properties of different materials.

Components	s (m)	λ ($Wm^{-1}K^{-1}$)	ρ (kgm^{-3})	c (J $kg^{-1}K^{-1}$)
mixed stone (walls, ceiling and columns)	0.9	2.3	2700	385
S-W and N-E glazed façade	0.032	1.26	2500	795
South-East glazed façade	0.050	1.53	2500	795
floor	0.40	0.51	2700	400

4. Results and discussion

Simulation results highlight the thermal flow and the surface temperature distribution, air temperature and air velocity field in the *hot room* connected to climatic external stress. The internal pressure scheme was also evaluated taking into account the fan-coils air system operating condition (from 7 a.m. until 18 p.m.), and the closed-opened doors conditions.

Results show that the air-inlet from fan-coils, combined with the scheme pressure and the door opened condition does not produce stagnation areas near the ceiling. Figure 3 shows the velocity field and distribution from h 7a.m. to 10.30 a.m.: these are the hottest hours of the day considered with the highest external air temperature and incident solar radiation.

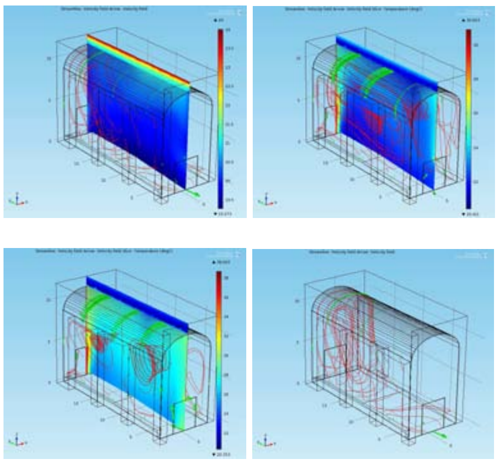

Figure 3. The velocity field and distribution.

When the fan-coils system is running, the air flows from the supply vents move towards the open door through the conditioned space

(Fig,4). Taking into account the location of the open door, a disruption in airflow due to the temperature gradient can cause a more persistent change in the overall static pressure, such as from a direct blockage of the return air flow rate. The internal pressure scheme is rather stable due to the small changes of the pressure variation.

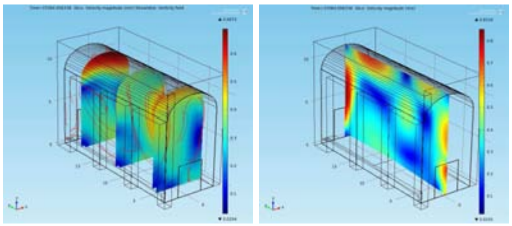

Figure 4. The velocity vertical distribution and magnitude.

The internal air temperature gradients are important and produce a complex air flow distribution due to the mix between the natural convection, connected to buoyancy forces and the air density variation, and the forced convection provided by the operating fan-coils unit (Fig.4). In particular, Fig.5 shows the surface temperature distribution at the hottest hour. It can be seen that the lowest surface temperature values (from 18°C to 25°C) belong to the massive walls with high thermal capacity, the highest belong to the S-W and S-E façades and then respectively of 30°C and 36°C. The mean internal air temperature remains roughly stable, varying between 22°C and 28°C.

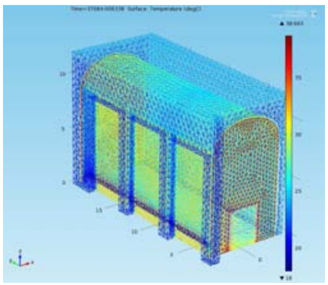

Figure 5. The surface temperature distribution.

The simulation results concerning the air velocity through the S-E *hot-room* door, considered opened, during the hottest hours of the hottest summer day (h 10 - 15), provide its maximum value of 0.8 m/s; on the contrary, during the remaining hours the air velocity is about 0.1 m/s. Taking into account that during the door opening and closing, the passage of a person needs about five seconds, the external air flow rate is 1.4 m^3/s during the hottest hours and 0.19 m^3/s in the remaining hours of the day. In particular, at the h 14 (the hottest hour) when the door is open, the three fan-coils unit needs a cooling peak power of 25.5 kW. For the door closed condition, during the whole day, the cooling peak power requested by the plant is 13.7 kW. From transient simulation results obtained, the effectiveness of the *hot room* as thermal buffer can be analysed. As a matter of fact the air temperature and velocity field inside, produce an important effect as thermal buffer, especially during summer, providing a zone characterized by cooling storage and humidity reduction.

4. Conclusions

We believe that this work can provide important recommendations towards thermal comfort control and careful design and optimization of ventilation in important hall such as of the hospitals. Comsol simulation, that is rather inexpensive compared to monitoring campaigns, is applied to an hall of a historical hospital but could be equally extended to other target mainly connected to building-plant refurbishment and energy retrofitting design.

From the analysis on the air flow patterns, air temperature and air velocity distribution we can draw important indications for the best location of openings and particularly for the sliding doors position and for the best building components (opaque and transparent) solution.

Transient simulation results provide a qualitative and quantitative evaluation of thermal and energy performances of the *hot room* and then to check its effective thermal buffer effect.

Comsol simulation allows to design ventilation strategies, thermal effects on the cooling plant operating conditions but also to indicate the selection of the best type of the air inlet/outlet diffusers in order to minimize the intermixing between the supply air and the air movement in the room due to door opening and closing, in medium-low latitude when climatic stress mainly due to solar radiation is very important.

5. References

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