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NUMERICAL INVESTIGATIONS OF THE AIR FLOW PATTERNS AND TEMPERATURE DISTRIBUTION IN A MUSEUM SHOWROOM, KING TUTANKHAMEN'S GALLERY, EGYPTIAN MUSEUM

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ABSTRACT

The use of numerical simulation methods for the Cultural Heritage is of increasing importance for the analysis, conservation, restoration and appreciation of works of art. This is particularly important when their preservation and planned maintenance is the primary aim [1, 2]. King Tutankhamen's gallery at the Egyptian museum is chosen for our study. The conservation of such artworks requires precise control of the indoor microclimatic conditions. Thus, a suitable HVAC system with reliable control is often necessary for a museum, to maintain acceptable indoor thermal-hygrometric parameters and air velocity and also to minimize the deviations of these parameters from the design values. An investigation of airflow characteristics inside King Tutankhamen's gallery at the Egyptian museum is studied. The effect of visitors within the gallery space is discussed. Lighting is mainly neglected and its effect is shown in a limited procedure. The variability of inlet air velocities and the grills location in the gallery is studied to achieve a better understanding of the closest solution for air distribution within the gallery.

KEYWORDS: Air Conditioning, Historical Buildings, Museums, CFD, Simulation

INTRODUCTION

Cultural heritage is significant to each country since it represents its own existence through history. The national Egyptian heritage is considered to be one of the most significant historical marks all over the world thus preserving such monuments has not only became a local need but also an international one.

Museums as places where heritage is displayed should be well preserved and comply with planned maintenance. The Egyptian museum established 1902, contains many important pieces of ancient Egyptian history. It houses the world’s largest collection of Pharaonic antiquities, and many treasures of King Tutankhamen.

Conservation of such artworks requires precise control of the indoor microclimatic conditions. Thus, a suitable HVAC system with reliable control is often necessary for a museum, to maintain acceptable indoor thermal-hygrometric parameters and air velocity and also to minimize the deviations of these parameters from the design values [3].

The study of air conditions within museums is not widely investigated and differs from an environment to another thus the research aims to find an optimum system design through the use of computational fluid dynamics (CFD) simulation software for a better understanding to the problem [4, 5]. It can be very useful for defining measures of preservation for monuments, developing new techniques for maintenance and identifying the effects of air inlets and outlets. The predictions of such simulation can be also used to study the effect of number of visitors in the gallery. A case study is presented for the temperature and velocity patterns and ascertaining the conditions that satisfies the museum standards.

THE CASE STUDY

King Tutankhamen's gallery is considered a significant mark which is located at the northern part in the Egyptian museum. The gallery is conditioned with air grills as shown in figure 1. The gallery model shown has a maximum height of 10.0 meters, depth of 12.0 meters and width of 15.1 meters. The inlet velocity is about 2 m/s and the inlet temperature is 16^{o}C. The number of air grills is 14, 8 inlet grills and 6 outlets. The grills are located at the top centre of the gallery. Each side has 3 outlets and 4 inlets. The 3 outlet grills are surrounded by 2 inlets at each side. The air grills are of 0.75 m in length and 0.4 m in width. The entrance/ exit doors are kept open as shown. Standard $k-\varepsilon$ model is used in such study for its compliance, simplicity, wide validity and establishment.

The velocity within the gallery is at range from 0.01 to 0.03 m/s which satisfies both the human comfort and the museum standards. While it ranges from 0.18 to 0.36 m/s near the inlet regions and some parts of the walls. The inlet boundary conditions for the gallery are calculated according to ASHRAE standards 62.1 [6] and ASHRAE journal [7].

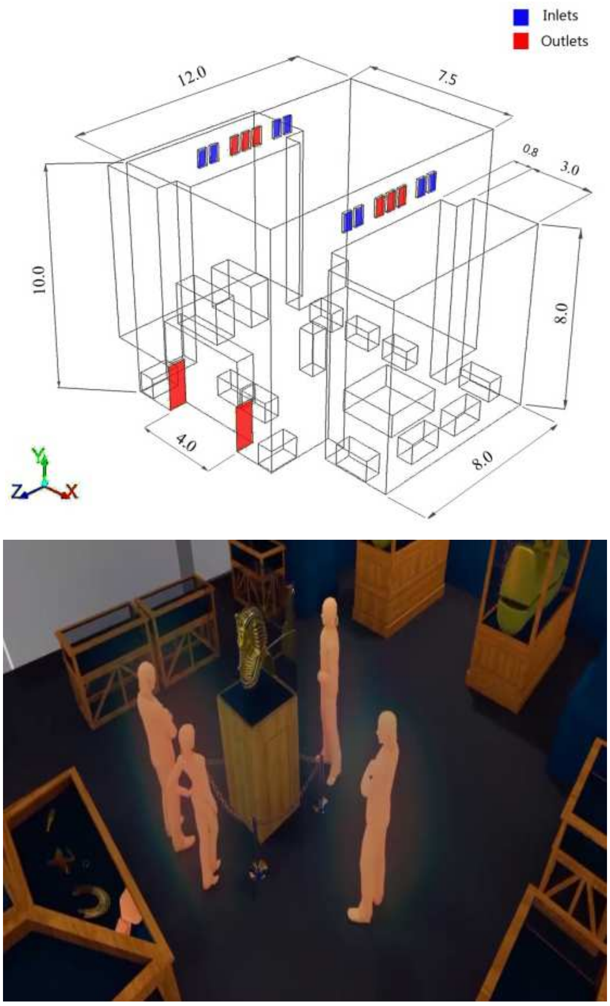

Figure 1: King Tuat's Gallery

Table 1: Boundary Conditions

Boundary Conditions		
Property	**Supply Grills**	**Exhaust Grills**
Velocity	2 m/s	Pressure Outlet
Temperature	16 °C	Back flow
Turbulence Intensity	3.86 %	temperature
Hydraulic Diameter	0.52 m	(t= 27 °C)

Figure 2 shows a Sectional Plan at the Inlet and Outlet Grills at Nine Meters High While the Gallery is Empty. The air is withdrawn from the upper central region where the grills are located to the entrance/ exit doors which cause some losses. Figure 3 shows the velocity contours inside the empty gallery at height 0.7 meter where it is notably high at the doors.

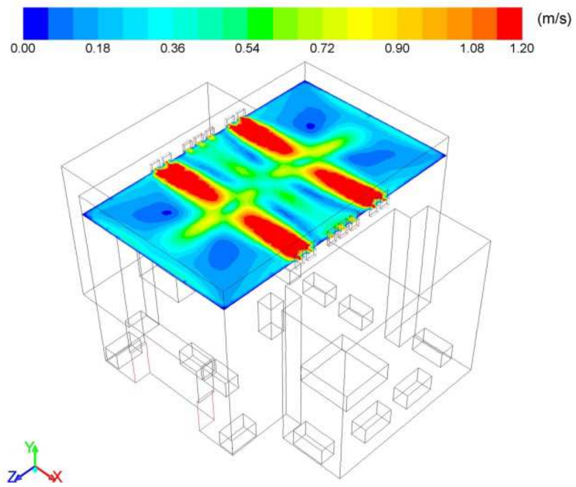

Figure 2: Velocity Contours at the Inlets

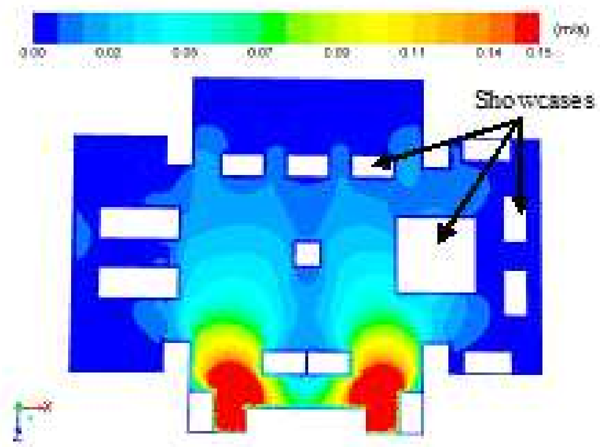

Figure 3: Velocity Contours at y=0.7 m

RESULTS AND DISCUSSIONS

Visitors' Effect

The visitors' effect is studied within the gallery at different cases. The temperature and velocity variations are changed according to the number of visitors inside the gallery. The effect is studied while neglecting other loads as lighting and at constant walls temperature. The scope of such study is to attain ASHRAE museum standards.

The temperature generally increases as the number of visitors increase within the gallery. Figure 4 shows the four cases of visitors occupation inside the gallery from a top view at y=1.5 m.

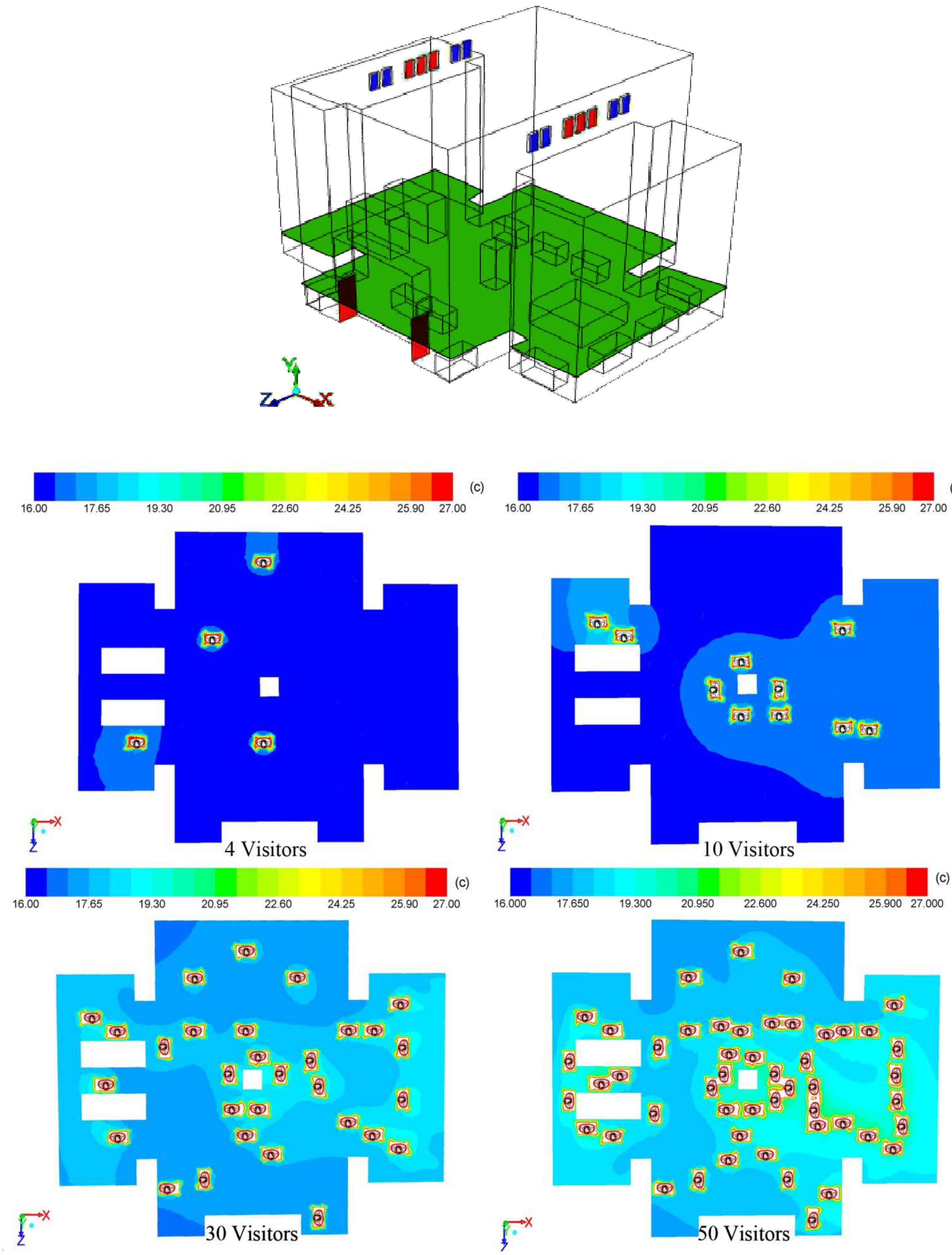

Figure 4: Temperature Effect at Different Occupation Capacities at y= 1.5 m

The visitors' effect is significantly notable as the temperature increases with the increase of the number of visitors. Figures 5 and 6 show the relation between temperatures along the x and z directions of the gallery as the number of visitors increase.

Light Effect

The lighting is studied at 30 visitors' occupation and compared with the primary condition without lights at the same number of visitors.

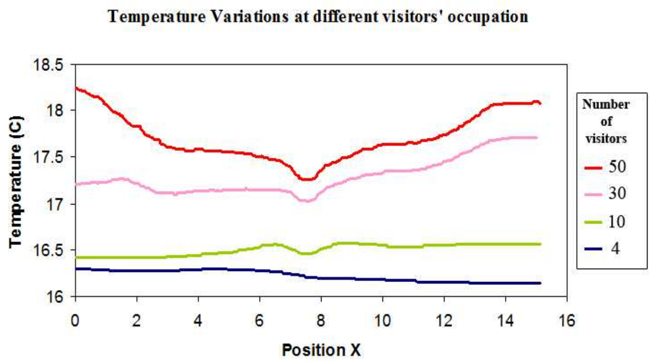

Figure 5: Temperature Visitors' Effect in X Direction

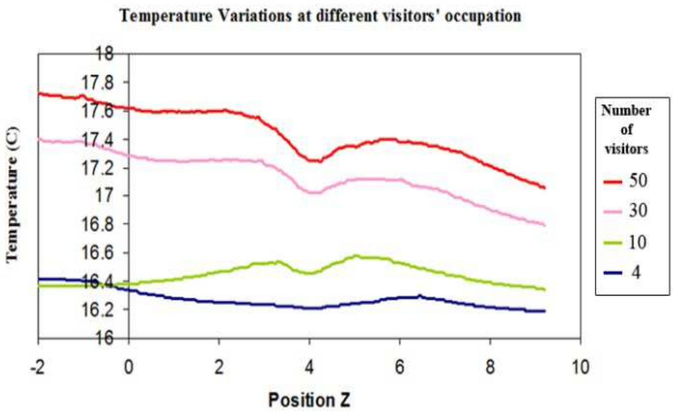

Figure 6: Temperature Visitors' Effect in z Direction

There are mainly two sources of light inside the gallery, corner lights which are set at each corner of the gallery and centre lights that are hanging at a height of eight meters at the central zone of the gallery, above the golden mask. Figure 7 shows a simulated image for the sources of lights located in the gallery.

The temperature and velocity variations are studied and are found to be negligible since the lighting in the spacious dark room satisfies the standards to prevent any photochemical or photo physical damage.

Figure 8 shows the temperature effect of the centre lights. The temperature varies 18^{o}C to 20^{o}C at the occupied regions and from 18^{o}C to 22^{o}C close to the central light sources.

The corner lights are slightly higher in temperature since the temperature varies around the corner source from 18^{o}C to 23^{o}C, while at the floor space and occupied regions it varies from 18^{o}C to 20^{o}C. Figure 9 shows the temperature contours of the corner lights.

The light effect increases the temperature within the gallery very slightly that it is neglected in most of the other cases. The velocity is almost constant. Figures 10 and 11 show the temperature effect along the mid sections in x and z directions inside the gallery.

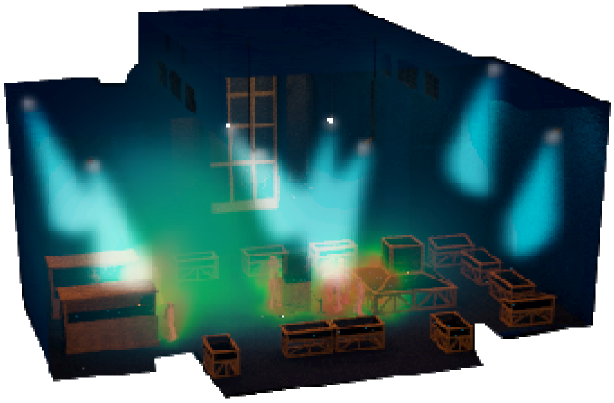

Figure 7: Simulated Image for the Gallery Showing Lighting

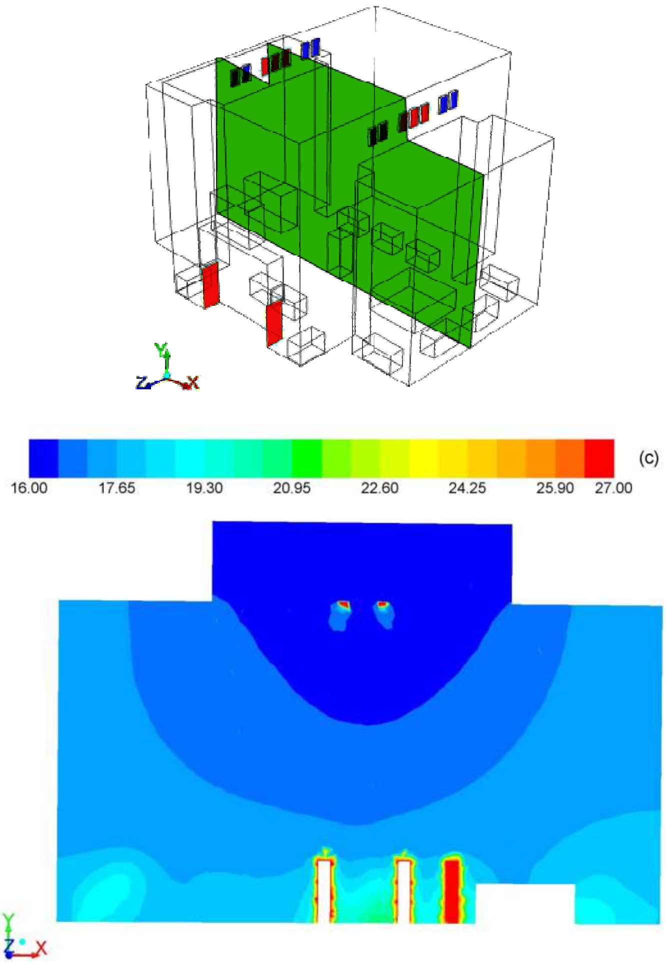

Figure 8: Temperature Contours, Centre Lights at z= 3.6 m

New Grills' Location

Another study is processed by changing the location of the original inlet grills and placing them in another place for better air distribution since the inlet and exhaust grills are aligned beside each other at the top central region of each side, due to such alignment some air flow is reversed from the inlet grills and sucked back to the outlet grills causing some losses.

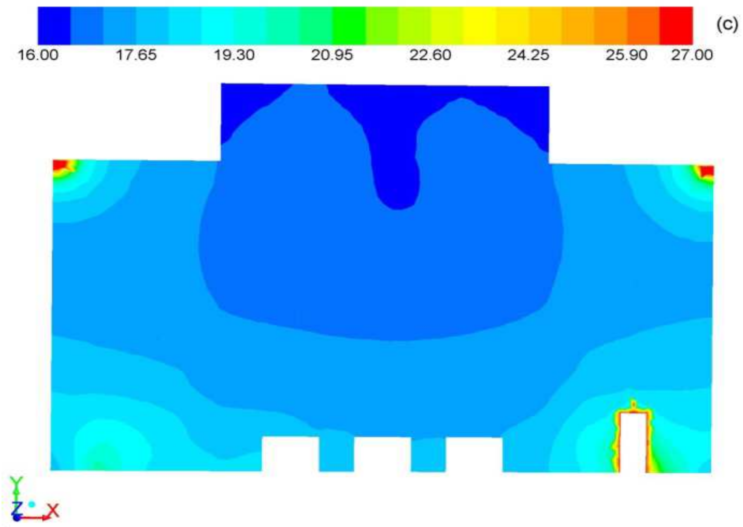

Figure 9: Temperature Contours, Corner Lights at z = 1 m

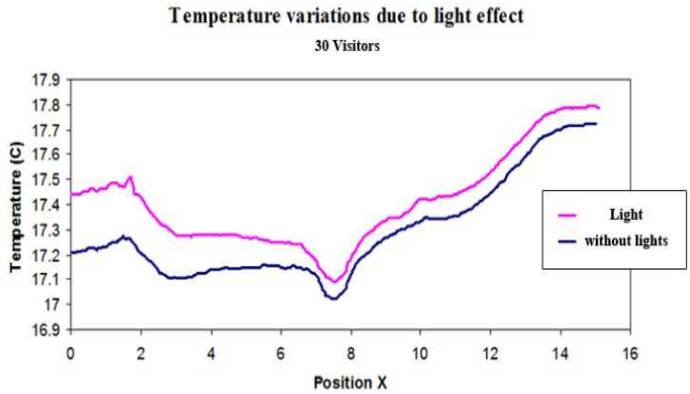

Figure 10: Temperature Variations due to Lighting in x Direction

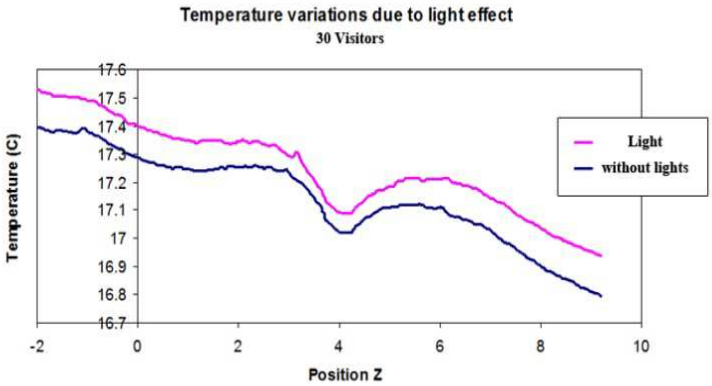

Figure 11: Temperature Variations Due to Lighting in z Direction

There are two case studies for changing the locations of the grills; the first case is by applying the inlet grills at the ceiling sides of the gallery while the exhaust grills remain at the top central side walls. The second case is by aligning both inlet and outlet grills at the side ceilings in a reciprocating manner. Both cases are studied while the gallery is occupied with 30 visitors.

Case One

The new inlet grills, 1st case, are placed at the side ceilings of the gallery at eight 8 high, 4 grills at each side centred. Each grill is 0.6 m x 0.65 m with inlet velocity 1.54 m/s. The exhaust grills (6 grills) are kept at their same location, higher than the inlets at the central region. Figure 12 shows the new location of the inlet grills as described.

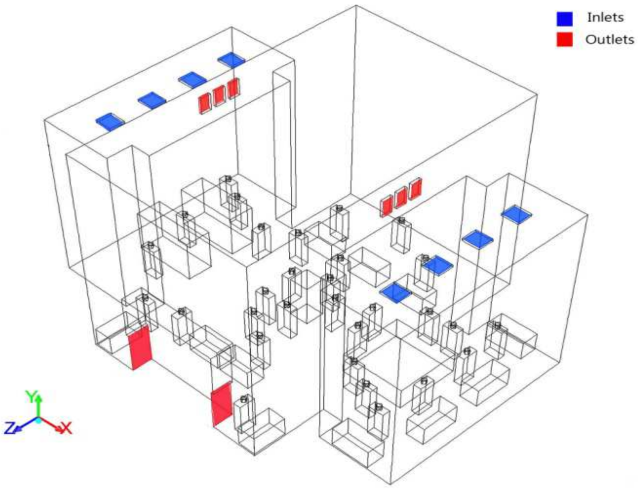

Figure 12: New Grills' Location, 1st Case

The air distribution is generally at higher velocities while the temperature variations are wider than both cases (the base case and the 2nd case) at the same number of visitors. The air losses from the entrance/ exit doors became less.

Case Two

The new grills, 2nd case, are placed at the side ceilings of the gallery at eight 8 high, 4 inlet grills at each side centred and reciprocating with other 4 outlet grills, two by two i.e. two inlets followed by two outlets and vise versa. Each grill is 0.6 m x 0.65 m with inlet velocity 1.54 m/s. Figure 13 shows the new location of the inlet grills as described. The air distribution generally does not differ significantly from the 1st case while the temperature variations are wider than the base case and less than the 1st case. The air losses from the entrance/ exit doors became less than both the base case and the 1st modification case. The temperature and velocity contours of the new simulated grills are shown in figures 17 and 18.

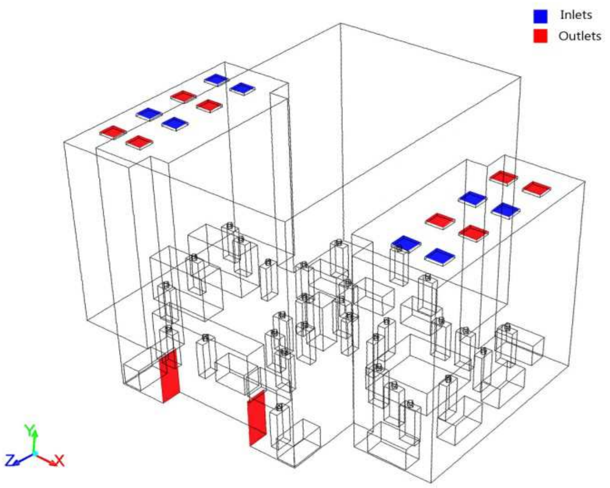

Figure 13: New Grills' Location, 2nd Case

The effect of the new grills is compared with that of the base ones in the following graphs, where the study is performed through x and z directions.

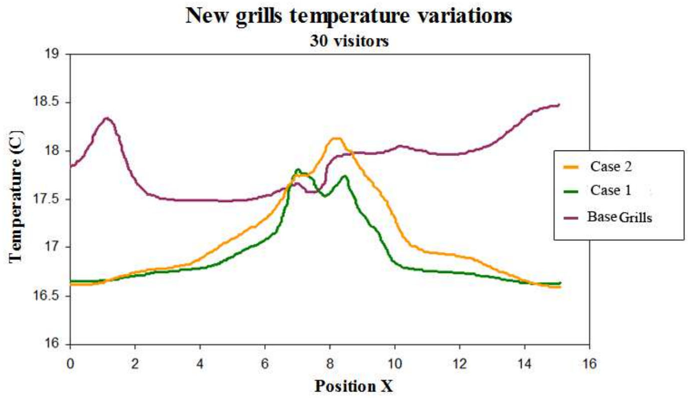

Figure 14: New Grills Temperature Variations in x Direction

Generally the temperature is lower with the new grills although it is higher than that of the primary at the middle centre of the gallery due to the exhaust location in the 1st case and the displacement of exhaust through the middle.

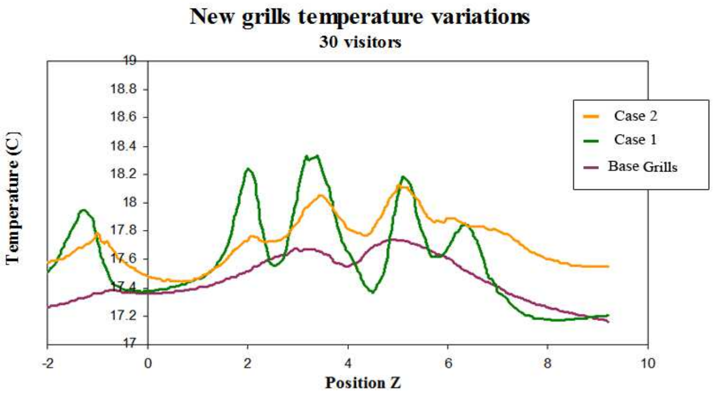

Figure 15: New Grills Temperature Variations in z Direction

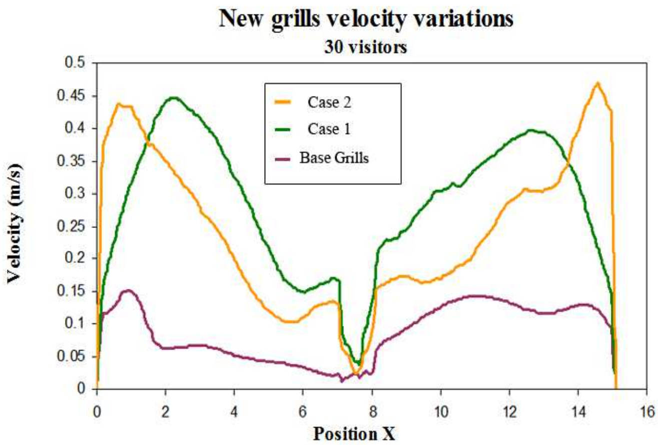

Figure 16: New Grills Velocity Variations in x Direction

At the middle of the gallery along z direction the temperature is higher with the new grills' cases than that of the base ones while there are high fluctuating variations the 1st case.

The velocity variations with the new grills' case are noticeably higher than that of the base grills and which deviates from the standards. The velocity is high at the gallery sides while low in the middle.

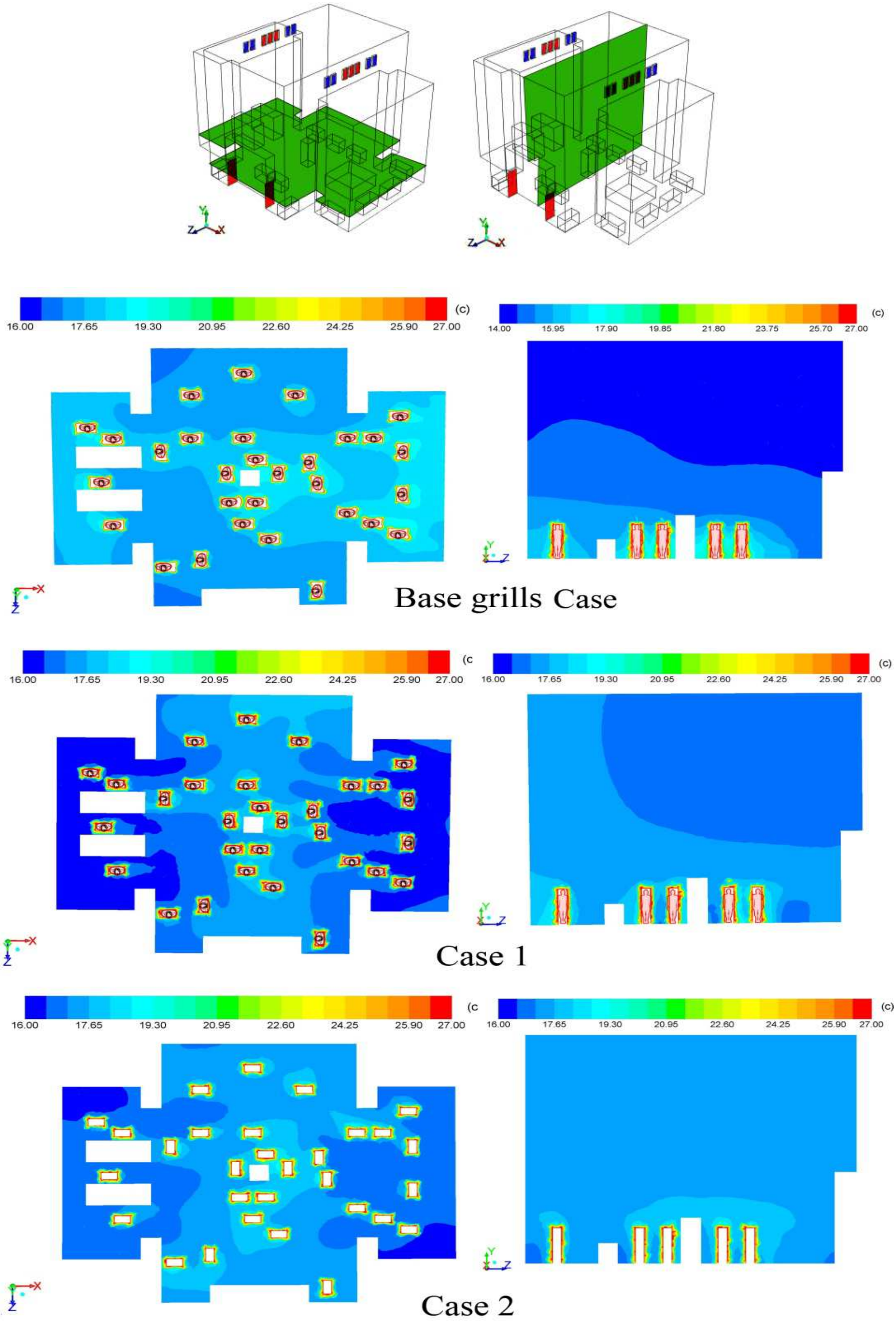

Figure 17: Temperature Contours of Grills' Cases at y = 1.5 m and z = 4 m

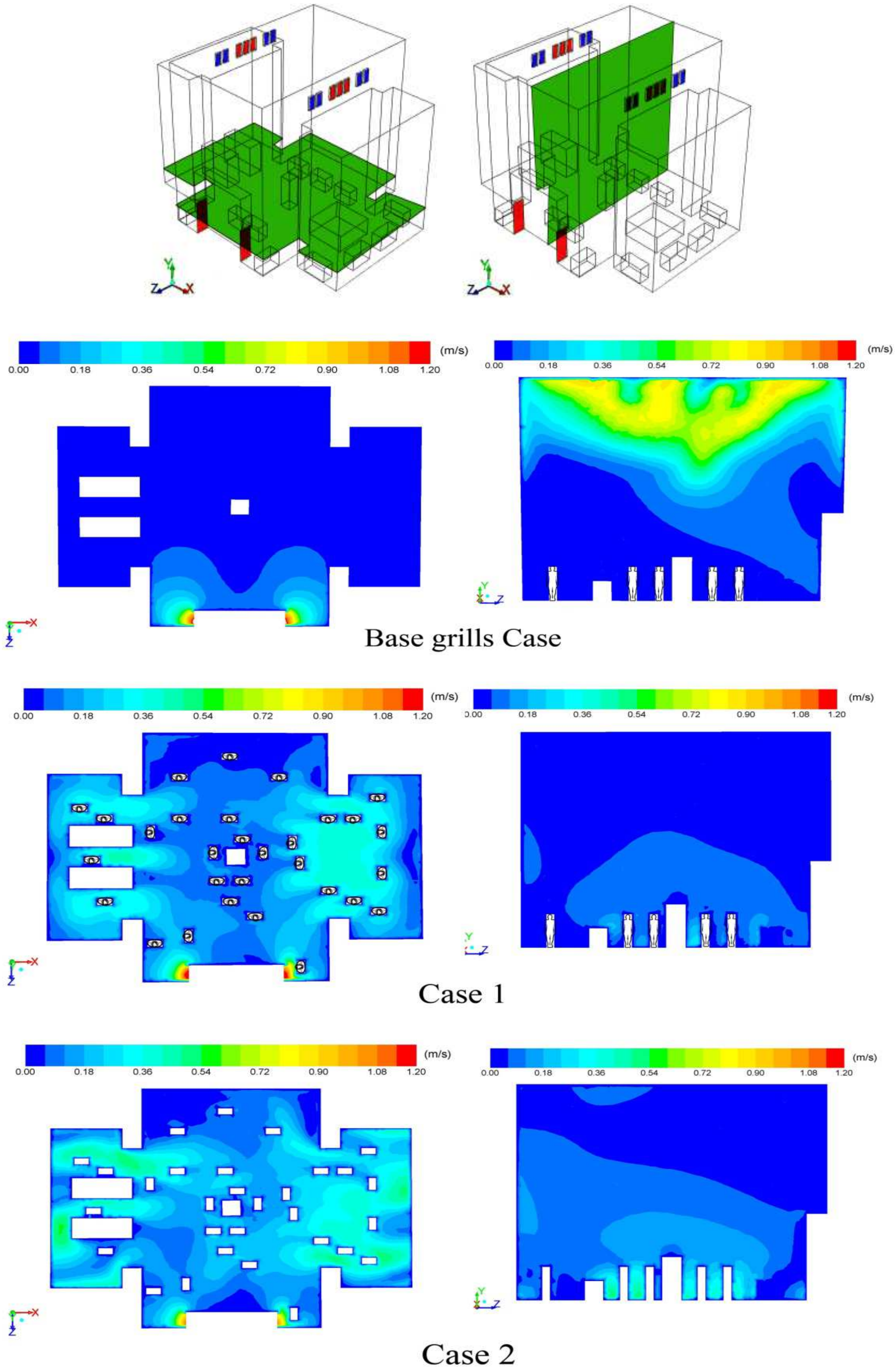

Figure 18: Velocity Contours of Grills' Cases at y = 1.5 m and z = 4 m

DISCUSSIONS AND CONCLUSIONS

Computational fluid dynamics (CFD) has been increasing used as a prediction tool in the design and assessment of the indoor building environment. A significant number of scientific papers exists dealing with the application of CFD models in various indoor environments with considerable success [8]. The use of computational fluid dynamics (CFD) simulation software for a better understanding to the problem is very useful for defining measures of preservation for monuments, developing new techniques for maintenance and identifying the effects of air inlets from photochemical reactions. The gallery is studied under its primary state i.e. the conditions in the museum, then different grills' locations are simulated and studied as well. The effect of variable visitors is studied and was found to be significant as the numbers of visitors increases the temperature and velocity increases. The lighting is simulated as well and studied and was found to be insignificant due to the spacious volume of the gallery.

The grills' locations was calculated and found to be less efficient than the original base grills due to the wide temperature difference and variations which may cause mechanical damage on the monuments. The velocity fluctuations were found to be high while using the new grills' locations which exceed 0.25 m/s at some regions causing human dissatisfaction [7].

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