# Study of the Influence of Air Supply Temperature on Air Distribution in the Run-through Large Space Architecture

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**Abstract:** The article introduces the concept and features of run-through large space. By using CFD technology, the paper simulates a velocity field and temperature field in the important air conditioned zone of China's science and technology museum (new museum) under winter operating conditions. At the same time, the indoor air flow regulations are summarized according to the simulation results. On the above basis, a new solution for airflow control of the connection in a run-through large space is put forward. The conclusion of this paper will offer guidance and reference for the air conditioning design of homogeneous architecture.

**Key words:** CFD, run-through large space, air distribution, air conditioning design

## 1. INTRODUCTION

Air distribution in run-through large space is always an emphasis and difficulty in HVAC academic domain. Predecessors have done a lot of fruitful researches, but they focused mainly on single large space, rarely on multi run-through large space. Run-through large space [1] is the architecture involving multi large spaces with different heights, which are connected with different openings, much heat, mass and momentum at the openings are exchanged by the air flow. This form is a new structural style sprang up recent years. It is difficult to design out reasonable and energy-saving air distribution based on the traditional design experience and design theory. In winter, the warm airflow will be sucked to the high zones because of the chimney effect. And it is hard to achieve the design requirements. In the face of the new problem, we will anticipate winter indoor environment by numerical simulation technology to Study and explore new ways to solve this actual problem.

## 2. PROJECT SUMMERY

China science and technology museum covers 120, 000m$^2$, and it is one of the accessory buildings of 2008 Olympic Games. Fig.1 displays the vertical traffic row of the new museum. In this paper we focus on the hall at the three main inlets, the aisle which connect every large space and the atrium. And West 1 hall covers 557m$^2$ with height of 28.5m . West 2 hall covers 1144m$^2$ with height of 19.0m. South 2 hall covers 145 m$^2$ with height of 28.5m. East 1 hall covers 340 m$^2$ with height of 28.5m. East 2 hall covers 564 m$^2$ with height of 9.5m. East 3 hall covers

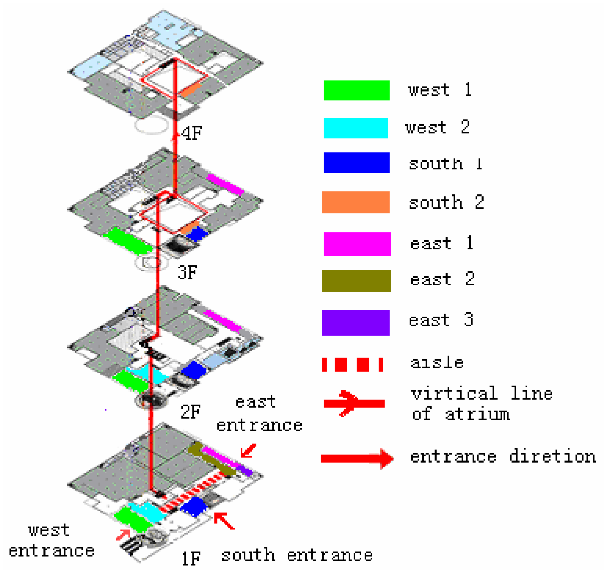



**Fig. 1 Vertical traffic row**

76 $m^2$ with height of 9.5 m. In the picture below, the space where the red lines get through is atrium, and it is 1501 $m^2$ with height of 28.5m. The three halls and the aisle are connected directly. The aisle and the atrium are connected by the opening of the escalator.

## 3. BOUNDARY CONDITIONS AND SETTINGS IN FLUENT

Because of the important influence of inlets and outlets of the indoor air field, the mesh must be adapted to the shape of inlets and outlets. But there are too many complex openings, It is difficult to obtain enough the mesh numbers. Besides, the velocity and temperature profile in all space are paid attention to rather than the flowing characteristics of inflow and outflow air. Thus, the problem is simplified by changing round circle openings into square openings with the same opening area, combining openings of the same size, using the average velocity instead of the openings air velocity[2] and so on. The position and size of model openings are shown in Tab.1, supplied by the designing company. Inlets are the velocity boundaries with constant flow. Outlets are the pressure outlets. The glass walls of the east, west and south hall and the glass roof of the atrium are the mixed heat transfer boundaries combining radiant heat transfer and convection heat transfer. Inside walls are the heat insulated boundaries. Radiant heating floor is the radiant heat transfer boundary with surface temperature 26℃. Indoor heating sources are not considered in winter. The ventilation parameters of hall and atrium are shown below: the designed air conditioning outdoor dry bulb temperature is -12℃, the outdoor average air velocity is 2.8m/s, the designed indoor air temperature is 18℃, the relative humidity is 60%.According to the large space of the China science and technology museum (new museum), Discrete computing area are meshed by mixed mesh and the human active region and openings are refined The number of the model mesh is 1185717. The k－ε equations[3] model is used in simulation of turbulent flow with Boussinesq hypothesis. Finite volume method is used to discrete equations.

## 4. THE CONTENT AND RESULT OF SIMULATION

In this paper we simulate the winter indoor environment of the run-through large space。During the simulation process of three cases, the air temperature of the aisle is respectively 30□, 25□ and 20□ and the air temperature of other space is 30□ without any change. Fig. 2 is the model of winter condition simulated. In this paper, we focus on analyzing the air distribution at the openings and

**Tab. 1 dimension and position of openings in model**

| Room name | Inlet name | Air velocity (m/s) | Opening number | Opening size (m2) | Setting Height (m) | Outlet name | Opening number | Opening size (m2) | Setting height |
|---|---|---|---|---|---|---|---|---|---|
| West 1 | Win1 | 5.2 | 3 | 1 | 27.0 | Wout1 | 1 | 7 | 27.0 |
| West 2 | Win2 | 4.0 | 4 | 0.36 | 19.0 | Wout2 | 1 | 11 | 19.0 |
| aisle | Ain1 | 1.8 | 4 | 1.5 | 9.5 | Aout1 | 2 | 6.5 | 7.0 |
| South 1 | Sin2 | 4.9 | 1 | 1 | 10.0 | Sout2 | 1 | 4.5 | 7.0 |
| South 2 | Sin1 | 2.7 | 2 | 1 | 12.0 | Sout1 | 1 | 4.5 | 7.0 |
| East 1 | Ein1 | 4.1 | 3 | 1.5 | 9.5 | Eout1 | 1 | 7.5 | 7.0 |
| East 2 | Ein2 | 1.3 | 4 | 0.36 | 9.5 | Eout1 | 1 | 7.5 | 7.0 |
| East 3 | Ein3 | 1.1 | 1 | 1 | 7.5 | Eout2 | 1 | 1 | 5.0 |
| atrium. | Atin1 | 3.6 | 4 | 0.7 | 8.0 | Atout1 | 1 | 16 | 6.5 |
| atrium. | Atin2 | 3.6 | 4 | 0.7 | 8.0 | Atout2 | 1 | 16 | 6.5 |

study the influence of the change of the aisle design parameter to the large space indoor parameters connected with. We choose the section of x=6.0m which connected the south hall, aisle and the atrium, the section of y=-8.5m which connected the east hall, aisle and west hall as the typical surfaces. Fig. 3 displays the location of the origin O and the typical surfaces.

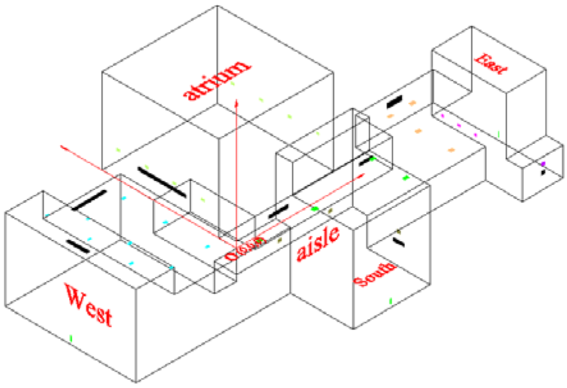



**Fig. 2 Modle in winter condition**

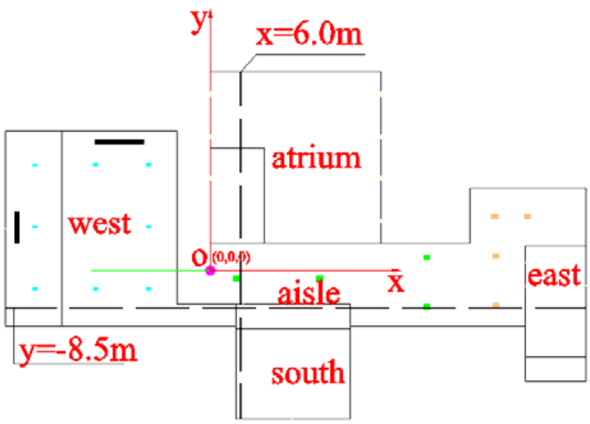
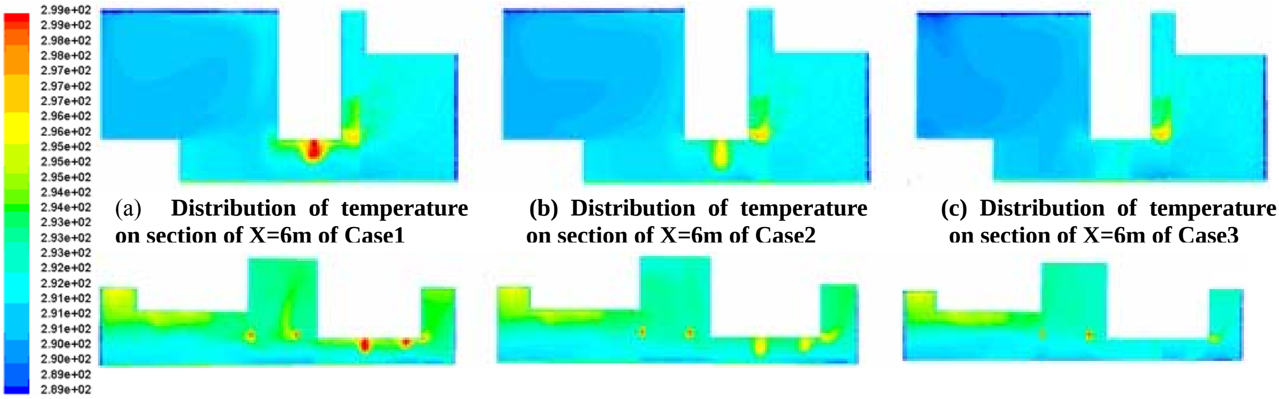



**Fig. 3 positions of typical surfaces**

4.1 The Study of Typical Surfaces Temperature Field

From Fig. 4, we can see that, in winter when we serve warm wind, the simulation result of run-through space is similar to the single large space[4]. At the vertical direction there are thermal demixion and they are very obvious at the west hall. At the roof there are much heat accumulation. In the aisle, south and east halls, there are some thermal demixion but is not as obvious as the west hall. The atrium temperature ascends along with the increase of the height. Near the glass roof, the temperature descends rapidly because of the heat exchange. The temperature remains steady at the vertical direction. But at the horizontal direction, the temperature is not uniform. There are many reasons, for the single large space, the thermal demixion are mainly caused by heat buoyancy force which make the hot air ascending and cold air descending. And the horizontal temperature is uniform mainly caused by the large wall which loses too much heat, and the temperature in inner zones become higher than outer zones. However, for the run-through large spaces, there are more complicated reasons. If there are obvious exchanges of heat, mass and momentum at the joints, the phenomenon will be more obvious. From Fig. 4 we can see that, at the openings of the large space heat transmit is obvious. The height of the atrium roof is 38m, since it is higher than the near spaces, the hot air will be sucked away by the atrium. Furthermore, since the atrium openings get through human active regions, the influence of the aisle to the atrium is the most serious. From (a), (b) and (c) we can see that with the descending of air supply temperature, the heat transmitted from aisle to the atrium is also decreased. When it is 20□, the difference of temperature between the aisle bottom and roof should be restricted within ±1□, then the heat transmit is almost avoided, so temperature distribute uniform. At vertical direction, the thermal demixions is also decreased. From (a), (b) and (c) we can also get that the south hall temperature descends along with of the aisle temperature descent. When the aisle air supply temperature is 20□, the horizontal temperature of the south hall and the aisle human active region is uniform and the vertical difference of temperature is decreased. From (d), (e) and (f), we also can see that, with the descent of the air supply temperature, other halls temperature is also descended. The horizontal temperature of the human active region is more uniform,.From the Fig. 5, we can see that at the three operating conditions the design temperature of the west halls is 18-19□ which

Temperature ( K )



(a) Distribution of temperature on section of X=6m of Case1

(b) Distribution of temperature on section of X=6m of Case2

(c) Distribution of temperature on section of X=6m of Case3

(d) Distribution of temperature on section of y=-8.5m of Case1

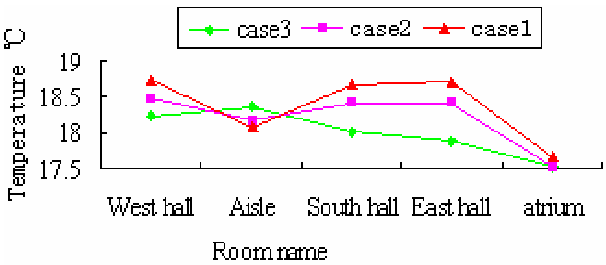
(e) Distribution of temperature on section of y=-8.5m of Case2

(f) Distribution of temperature on section of y=-8.5m of Case3

**Fig. 4 Distribution of temperature on sections of x=6.0m and y=-8.5m of Case1, Case2 and Case3**

meet the design requirements. When the supply air temperature is 20□, the human active region temperature is 18.38□, which is 0.3□ higher than case 1. The temperature of

south halls is also 18-19 ℃ . The east hall temperatureat case 1 and case 2 is higher than 18℃. The case 3 temperature is 17.9℃, which is somewhat lower than design requirements. The atrium temperatures under the three conditions are all between 17.5□ and 18□, which are lower than the design requirements. For the entire space, the average temperature of west hall, south hall and the aisle are between 18□and 19□, which also meet the design requirements. But the average temperature of east hall and atrium are all lower than design temperature. Because the designer didn't consider the heat bring by humans and light. Therefore in reality the indoor temperature will somewhat ascend.

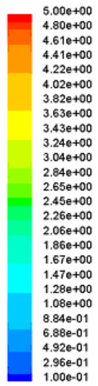


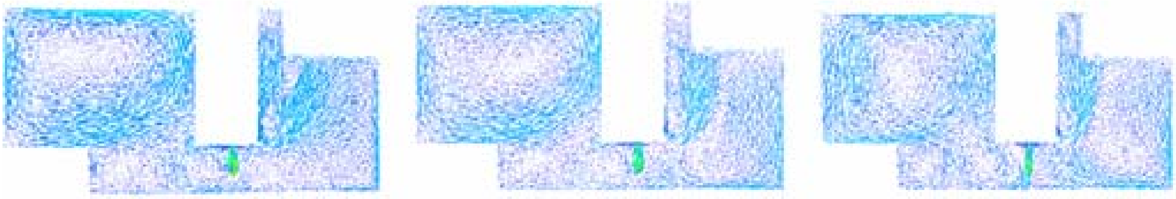

**Fi g. 5 Average temperature of active region for all spaces in three cases**

4.2 The Study of Typical Surfaces Velocity Field

From Fig. 6 we can see the exchange of momentum and mass happened at the openings of the large space. The hot air provided by lower aisle will flow to other higher space. From (a), (b) and (c) we can see that because of the buoyancy lift, the wind from the aisle will ascend towards the roof of the atrium along the left. From Fig.4 we can see the northern wall is relatively lower, so the cold air from the atrium roof will descend along the northern wall, then the ascending hot air and the descending cold air will format a big burble. Along with the descent of the aisle supply air temperature, the burble centre will turn to right-down of the atrium. The change can be seen from the velocity chart at x=6.0 m .when the burble centre turns to the right-down of the atrium, the ascending hot air at the aisle opening will decrease obviously. So the air distribution at the atrium and the aisle has been well controlled. Because the west glass wall connects with the air outdoor, around which the temperature is low, so the cold air descends along the glass wall. In contrary, the northern area of the south hall connects with the aisle and the supply air outlets are located there, so in the north there is hot air ascend. And in the south hall the ascending hot air and descending cold air form a large burble. Along with the descent air supply temperature, the burble centre turn to left down of the south hall. The volume of the hot air from aisle through opening to the south hall is greatly decreased, so the air distribution of the atrium and aisle has been

Velocity (m/s)

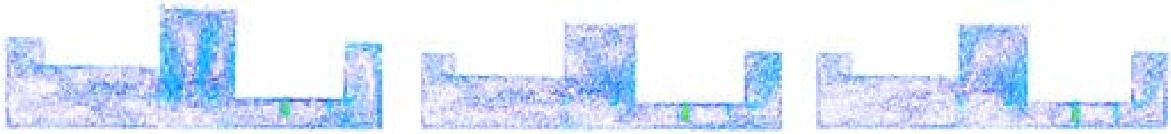


**(a) Distribution of velocity on section of X=6m of Case1**

**(b) Distribution of velocity on section of X=6m of Case2**

**(c) Distribution of velocity on section of X=6m of Case3**



**(d) Distribution of velocity on section of y=-8.5m of Case1**

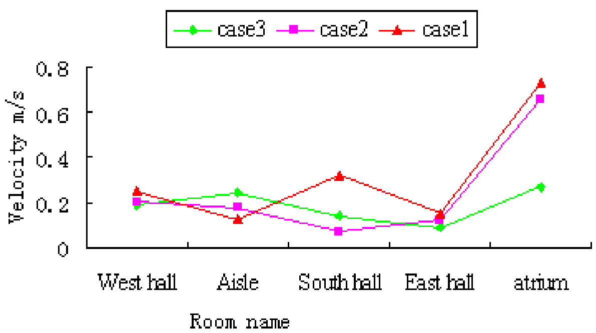
**(e) Distribution of velocity on section of y=-8.5m of Case2**

**(f) Distribution of velocity on section of y=-8.5m of Case3**

**Fig. 6 Distribution of velocity on sections of x=6.0m and y=-8.5m of Case1, Case2 and Case3**

well controlled. From (d), (e) and (f) we can obviously see that, because of the buoyancy lift, the hot air flow to the west 2 hall through west 1 hall along the aisle. When the air temperature of supply decreased, the situation will be well controlled. And (e) just certifies this. When the supply air temperature is 20℃, the Fig.(f) shows the airflow that penetrates every hall will dissipated, and the air units can work at the normal condition.

From Fig. 7, we can see that the change of the aisle temperature have different influence to the hall velocity field. The west hall adopts the air supply way of roof- supply roof -return. And the wind velocity of the human active region is less influenced by the supply air temperature. Under the three cases, the velocities are all lower than 0.3m/s, and it meets the design requirements. When the supply air temperature is 20□, the velocity is lowest, which is 0.19m/s. The air supply way of the aisle is also roof-supply roof-return, and under the three cases, the supply air velocities of the human active region are all lower than 0.3m/s. But when it is 20□, the velocity reaches 0.247m/s, this is because with the air temperature descends, the air density also gets greater, and the descending distance is also longer . So the air reached to the bottom is also greater. There are many different air flows interact in the south hall, so the air distribution is rather complicated. From the simulation result, we can see when the supply air temperature is 30□, the wind velocity reaches the summit that is 0.315m/s still can't meet the design requirements. While the other two cases all meet the requirements. The average velocities of the east hall human active region are all less than 0.3m/s and meet the design requirements. The air distribution of the atrium is influenced by the aisle upply air. Higher supply air temperature is, greater the wind velocity is. When the supply air temperature is 30□, the wind velocity reaches the summit that is 0.729m/s.When the supply air temperature is 25□, the wind velocity is 0.653m/s. But neither of them satisfies the design requirements. When the supply air is 20□, the velocity is 0.269m/s,which caters to the requirements well. To the whole, only when the supply air is 20□,the velocity of the human active region can meet the design requirements.




**Fi g. 7 Average velocity of active region for all spaces in the three cases**

## 5. CONCLUSION

5.1 Compared with the single large space, the run-through large space is large in size and their configurations are complicated. So it is more difficult for numerical simulation. In order to simulate the real condition, in this project, we hold the real dimensions of the architecture without any simplification. The computer internal storage is elevated, at the same time, the grids of the emphasis study area and the human active regions are complicated. And the grid of the higher space are enlarged at some extent.

5.2 Through the numerical simulation of the run-through space we can find that air distribution is rather complicated. It is difficult to anticipate the air distribution and mutual interaction only by traditional design measure and experience. So it is difficult to give reasonable design parameters. In this project, when the aisle temperature is 20℃, the exchange of heat, mass and momentum at the openings can be better controled. And it can satisfy the parameter standards of temperature and wind velocity. Compared with the other cases, it can save more power. For the run-through space with the opening under the human active region, e.g. atrium and aisle, we should control the difference of temperature between the aisle roof and the atrium bottom within 1℃.So the mutual interference between two rooms will be controlled. If the opening locates beyond the human active region, e.g. the aisle, the west and south hall, when the difference in temperature of supply wind is 10℃, we can well restrain the air mutual interference between different height rooms. Through adjusting the temperature difference of different height rooms, run-through large space problems can be perfectly solved. Thus, the breach for architectural style caused by the traditional ways, such as segmentation measure and air curtains often used before, will be avoided.

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