Pressure Differential Analysis of a Laboratory Animal Room[1]

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Abstract: This paper simulated and analyzed the pressure differential of a laboratory animal room by CFD software. Under a certain wind speed, the windward side pressure distribution of laboratory animal room was studied, and the windward side pressure differential distribution function was drawn. The corresponding distribution law and maximum wind pressure point were found. At the same time, the indoor pressure among the laboratory rooms was studied and simulated when the door opened, to learn what pressure differential can prevent air flow from a low pressure region to a high pressure region. We tested whether the differential pressure is reasonable to regulate the code between the indoors and outdoors, and among laboratory animal rooms, so as to provide a certain reference for code, construction and design, and to decrease positive pressure air change and save energy based on inside air environment requirements.

Key words: laboratory animal room, pressure differential, simulation, save energy

1. LABORATORY ANIMAL ROOM PRESSURE DIFFERENTIAL

In order to guarantee the laboratory animal room air environment security, the laboratory animal room must keep a higher (lower) pressure differential to the next room; this is one of the most important characteristic for the laboratory animal room air conditioning to the common air conditioning system, and its also one of the most important part of its cleanness. Table 1 is the pressure differential request of the laboratory animal.

1 Supported by the scientific research project of Hunan Provincial Education department of China(04C537)

2. PRESSURE DIFFERENTIAL SIMULATION BETWEEN INDOORS AND OUTDOORS

When the wind flow on the windward side, the wind pressure would be form on it, reference [2、3] was made some study on it, the aim of this simulation is that through the study on building windward side pressure, find the change rule of the windward side pressure.

2.1 Physical Model

As shown in Fig.1 below, it is the physical model, the building is in center of the area, the volume is $4m\times5m\times15m$. it can be known that the width is 5 times of the building and the length is the 10 times of it for the simulation area, it can simulate wind flow to the building in the infinitude space[2、3]. Base on this conditioning, the calculation area can be set as $80m\times20m\times80m$. The distance between building and calculation area left border is 38m, take the origin on the left bottom, the coordinate nearest corner to the origin is (38.0, 5.5, 0.0), inlet in the left and outlet in the right.

2.2 Mathematics Model and Boundary Condition

This research is the relate to low velocity of flow , it can be described by turbulent $k-\varepsilon$ equation[4], the vector quantity of differential equation is expressed as follows :

Continuous equation:

$$\frac{\partial u_i}{\partial x_i}=0 \tag{1}$$

Momentum equation:

ESL-IC-06-11-134

$$\frac{\partial u_i}{\partial \tau}+\frac{\partial}{\partial x_j}(u_i u_j)=-\frac{\partial p}{\rho \partial x_i}+\frac{\partial}{\partial x_i}[v_{eff}(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_i}{\partial x_j})]+A_r T\delta_{z,i} \quad (2)$$

Tab. 1 **the pressure differential request of the laboratory animal.**

Environment	cleanness corridor	rooms	Contaminated corridor	outdoor
barrier	+60	+40	+20	0
isolation	+120	+80	+40	0

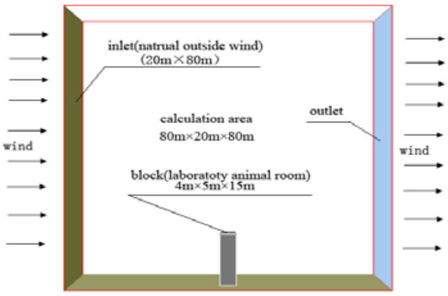


Fig.1 Physical model of the outdoor pressure differential simulation

Turbulent energy supply equation

$$\frac{\partial k}{\partial \tau}+\frac{\partial (u_j k)}{\partial x_j}=\frac{\partial(\gamma_{keff}\frac{\partial k}{\partial x_j})}{\partial x_j}+v_t(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\frac{\partial u_j}{\partial x_i}-\frac{\sigma_\mu k^2}{v_t} \quad (3)$$

Turbulent energy distributes the flowing rate equation:

$$\frac{\partial \varepsilon}{\partial \tau}+\frac{\partial (u_j \varepsilon)}{\partial x_j}=\frac{\partial(\gamma_{seff}\frac{\partial \varepsilon}{\partial x_j})}{\partial x_j}+\sigma_1\sigma_\mu k(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\frac{\partial u_j}{\partial x_i}-\frac{\sigma_2 \varepsilon^2}{k} \quad (4)$$

among them, u is velocity, m/s; τ is time, s; x is weight of the coordinate axis; $\delta_{z,i}$ is Kroneckev arithmetic operators; k is turbulent energy; ε is turbulent energy viscosity dissipating rate; ρ is density, kg/m^3; p is pressure, Pa; μ is Kinematic viscosity, m/s^2; A_r is Archimedes value; v_{eff} is efficiency coefficient of turbulent viscosity; γ_{keff} is turbulent energy efficiency diffusion coefficient; γ_{seff} is turbulent energy viscosity dissipating rate efficiency diffusion coefficient; v is coefficient of molecule viscosity; σ_u, σ_1, σ_2, σ_k, σ_ε are coefficient of $k-\varepsilon$ turbulent model. And other coefficients are defined as follow:

$$v_{eff}=v+v_t, \gamma_{keff}=v+\frac{v_t}{\sigma_K}, \gamma_{seff}=v+\frac{v_t}{\sigma_\varepsilon}, \quad v_t=\frac{\sigma_u k^2}{\varepsilon}$$

The Boundary conditions treat as follow:

(1). Boundary condition of the wall

For the wall, boundary condition can be take as: $u=0, v=0, w=0, k=0, \varepsilon=0$.

(2). Boundary condition of the inlet

The supply air is outdoor wind, it is a variables with the h, the function[2] is:

$$u=u_{10}\times(\frac{h}{10})^a \quad (5)$$

In accordance with the geographical location, mean wind velocity of the standard height (always take 10m) is $6\,m/s$, the roughness coefficient of the ground is 0.333[2]. So formula(5) can be taken as

$$u=6\times(\frac{h}{10})^{0.333} \quad (6)$$

$v=0 \qquad w=0$

k、ε of the inlet affected by many factor, always confirmed by experiment, the value in this simulation as follow[5]: $k=0.04$, $\varepsilon=0.008$.

(3). Boundary condition of the outlet:

Can know base on the law of conservation of mass:

$u=-1, \ v=0, \ w=0.$

For the boundary condition k、 ε, it fit on the second category boundary conditions:

$$\frac{\partial k}{\partial n}=0, \quad \frac{\partial \varepsilon}{\partial n}=0$$

2.3 Results and Discussion

Fig.3 is velocity and pressure distribution of outdoor pressure differential simulation, the left figure is the supply air velocity distribution, right figure is the pressure distribution; Fig.4 is the velocity and pressure distribution of the building windward side. From the Fig.3, we can see the velocity of building windward side become faster and faster along the height direction, the data can be obtain from the software. We also can see from Fig.3, in the calculate area, mostly area keep the pressure at 1Pa, as far as nearby the building, the pressure change rate become bigger. From Fig.4, we can see, about on the height of 1m, when the wind dash to the wall, it be detached

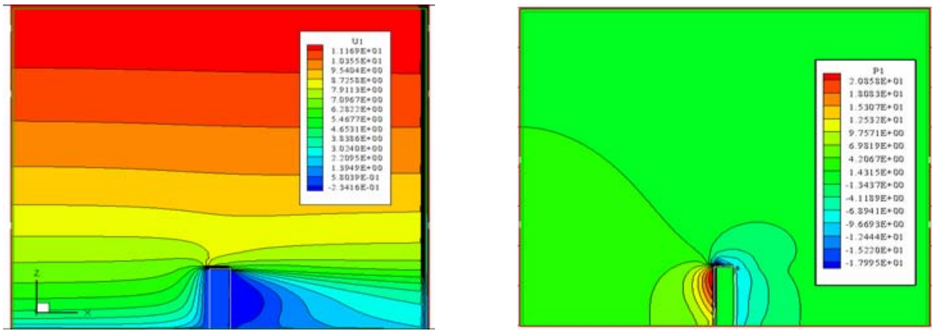


Fig. 3 **the distribution of outdoor velocity and pressure differential**

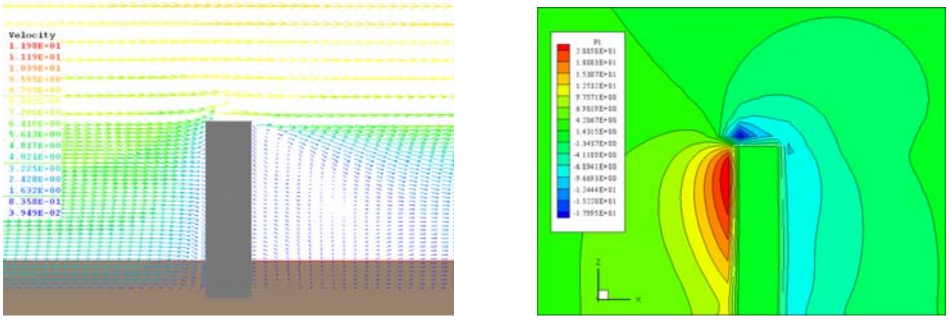


Fig. 4 **Zoom in the distribution of outdoor velocity and pressure differential**

two part, a part walks along the wall to underside, the boundary layer separation phenomenon appear at the wall from the top. In the figure can be clearly seen, a forming a whirlpool in the bottom, Another part continuing walk along the wall to upside, then crossed top of the boundary layer (h=15m), speed of airstreams suddenly increased, it changed into a negative pressure point. The phenomenon of boundary layer separation, the more detailed description can be found in reference[6]～[8].

According to simulation results, fitting a function of windward side pressure distribution:

$$P = -0.0408h^3 + 0.7663h^2 - 2.4746h + 12.1428 \quad (7)$$

According to function (7), the location of minimum pressure is in $h = 1.90m$, he location of maximum pressure is in $h = 10.62m$, and the value is $P_{\max} = 23.42Pa$.

3. PRESSURE SIMULATION AMONG THE INDOOR ROOMS

When the laboratory animal room is running, as the activity result of personnel, windows and doors, the animals can be overlapping infection. In order to prevent this kind of phenomenon, a differential pressure between the rooms need to establish, prevents the air flow to the low cleanness room from the high cleanness room. Can know from table 1, the differential pressure gradient in the barrier environment interior is 20Pa, and the isolation environment is 40Pa. presently simulated two rooms under the differential pressure 20Pa, two rooms differential pressure change rate when the door is opening.

3.1 Physical Model

As shown in Fig.6, a door connect room 1 and room 2, take three probes in two rooms—probe 1, probe 2 and probe 3[10,11], recorded the parameter change rate such as velocity and pressure. The red one is high pressure room and white one is the low pressure room, and the differential pressure between two rooms are 20 Pa. the trim size of the room is 1.0m

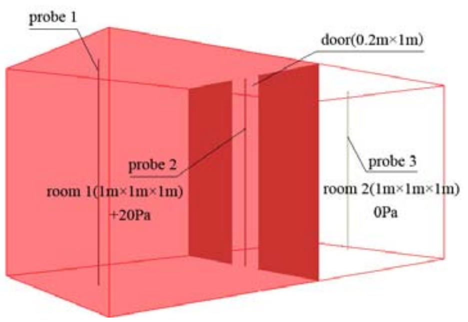


Fig.6 Model of the pressure simulation among the indoor rooms

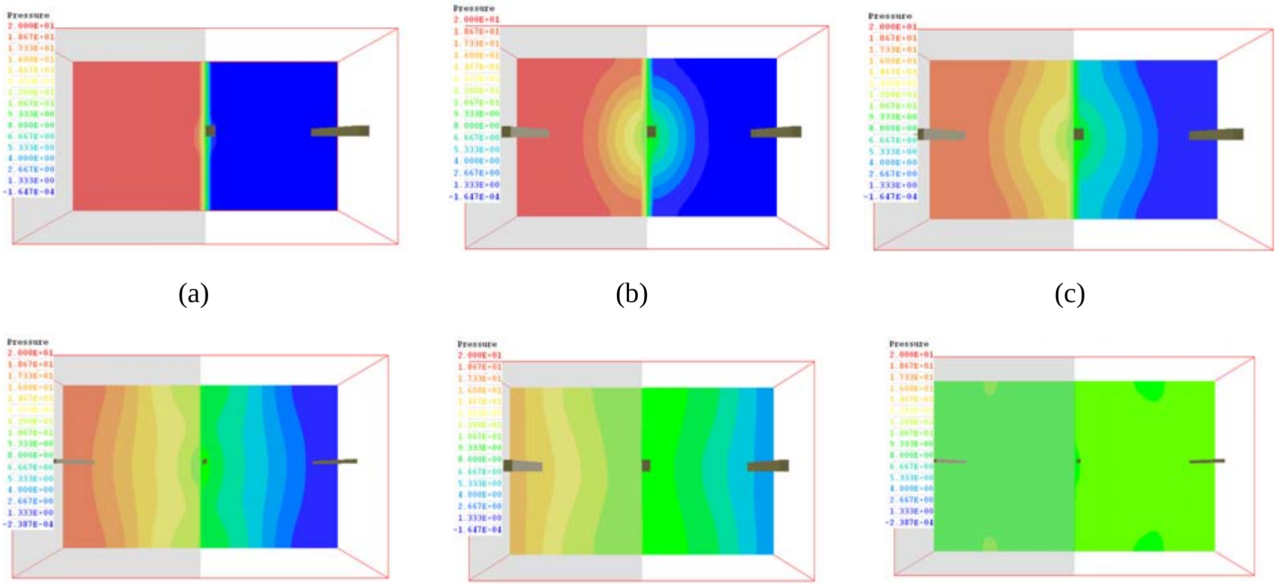
×1.0m×1.0m, and the trim size of the door is 0.2m ×1m, take the origin on the left down basement of the red room, so the coordinates of the three probes are (0.2, 0.5, 0.0), (0.1, 0.5, 0.0) and (1.8, 0.5, 0.0) respective. The turbulent model of the simulation is $k-\varepsilon$ two equation[4]. Boundary condition refer to section 2.2

3.2 Results and Discussion

Shown as Fig.7, Fig.(a)~Fig.(f) is pressure transformation in two rooms, at first, the pressure in room 1 is +20Pa (relative to atmospheric pressure), and the pressure in room 2 is 0Pa, in some time, Pulls out the partition board suddenly, equivalent to opening the door, and air currents driven by the differential pressures, flow from room 1 to room 2, until two rooms balanced.

Figure 8 is probes records pressure changes over time, Fig.8(a) is the pressure transformation record by probe 1, Fig.8(b) is record by probe 2, Fig.8(c) is record by probe 3. The process time is 0.001s, in this process, it is divided into 100, the time step is 0.00001s. can be found the pressure transformation in room 1 and room 2 through observing Fig.8(a) and fag.8(c), the pressure are not high to balance or low to balance, but exist a vibration process. In Fig.8(a), the pressure from +20Pa to balance state, but after balancing, they continue to decline instead of static, still it reach to 0Pa, When falls to 0Pa then toward rise, at the same time room 2 also has a process of 0Pa— balance — 20Pa — balance. Fig.8(b) pressure transformation of the door, at first, the pressure is 0Pa, with the time going, it become 15Pa, fluctuations in the value and maintain.

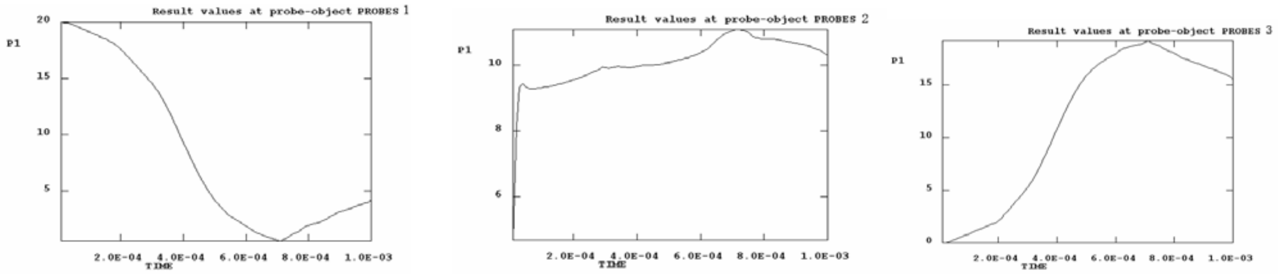
About how much velocity of flow produced by 20Pa differential pressures on the door, Fig.9 show detail, it is the point velocity of flow record by probes. Fig.9(a) is the data record by probe 1 in room 1, Fig.9(b) is the



(a) (b) (c)

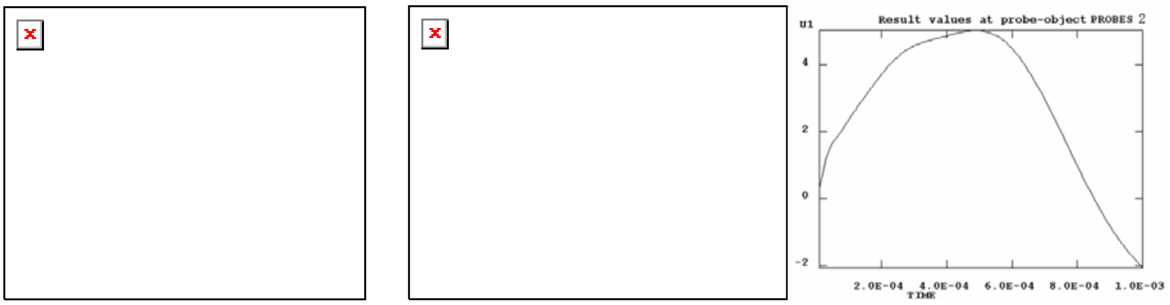
(d) (e) (f)

Fig.7 The pressure transformation in two rooms



(a) (b) (c)

Fig.8 Pressure transformation record by probes



(a) (b) (c)

Fig.9 The velocity value record by probes

data record by probe 2 in room 2, Fig.9(c) is the datarecord by probe 3 in the middle of two room. According to the formula can be described:

$$v_c = \frac{1}{\sqrt{\xi_1 + \xi_2}}\sqrt{\frac{2\Delta P}{\rho}} = \varphi\sqrt{\frac{2\Delta P}{\rho}} \qquad (8)$$

$$= 0.82\sqrt{\frac{2\times 20}{1.2}} = 4.73\ (m/s)$$

Can be see in Fig.9(c), the max velocity of flow is 5*m/s*, And the calculation of the value of the difference is not great. When people walk from the area of low pressure to high pressure zone, air-speed generally is about 0.14~0.2m/s, when the value of the two rooms differential pressures remain in 20Pa, the resulting value of speed is 5m/s, can offset the speed produced by walking person. Fig.9(a) and Fig.9(b) are data record by probe in those room, it can be seen that the rate of change is very similar to two figure, show pressure changes are synchronized, when the pressure diminish room 1, the pressure in room 2 immediately increase, The time difference is very small.

4. CONCLUSION

We can draw a conclusion based on the previous analysis:

(1) when face to uniform natural wind, the max pressure is always on 1/4 to 1/3 height to the top. In that we should increase the pressure on this point for safe of the environment of the laboratory animal room.

(2) When the rate of the coming natural wind is 6m/s, we can calculate the max pressure is around 23.4Pa. The code regulate differential pressures between indoor and outside should be 20~50Pa in n normal situation. Base on calculated result, if the wind velocity greater than 6m/s, the differential pressures between door and indoor should be greater than 25Pa for safe of indoor environment, so that the outside air unable to permeate into indoor through the windward side

(3) When take the indoor pressure differential gradient as 20Pa, can be offset the affect of person activity, prevent pollutants from the area of low pressure to high pressure infiltration.

(4) Pressure changes shocks occur during the simulation, This is because the simulation process can not provide continuous pressure. If continuous pressure can provide by high-pressure area, then continuous air currents can flow from high pressure area to low pressure area, prevent pollutants from the area of low pressure to high

pressure infiltration, laboratory animal room security can be guaranteed.

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