CHEMICAL ENGINEERING TRANSACTIONS

VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216

DOI: 10.3303/CET1651001

Numerical Simulation of Air Distribution's Impact on Indoor Air Quality

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No matter the removal efficiency of indoor pollutants, the distribution of temperature field or human thermal comfort, the use of low grade energy, the form of air distribution of displacement ventilation outperforms other forms of air distribution; the pollutant load of fresh air in the air inlet will affect this pollutant's concentration distribution in room.

1. Introduction

In the air conditioning room, the air is sent into the room from the air supply outlet after a treatment, and the indoor air is expelled from exhaust outlet after the exchange of heat and moisture. It is obvious that the uniformity and stability of temperature field, velocity field and concentration field in air-conditioned room have a close relationship with the flow of indoor air. Different forms of air distribution will engender different distribution effect of the air parameters such as velocity field, temperature field, relative humidity, cleanliness or the concentration of the harmful substances, which directly impact the economy and technology of ventilation and air conditioning system (Elleson, 1991). Inappropriate form of air distribution not only cannot reach the expected effect of air condition, but also may cause the waste of energy and initial investment. Therefore, the task of the design of air distribution in air-conditioned room is to make the indoor airflow flow and distribute rationally, and enable the room's air temperature, humidity, air velocity and contaminant concentration to meet the requirements of the comfort conditions and the technological conditions (Chen, 2009).

There are two basic principles in the form of air distribution in the room: dilution principle and replacement principle. The dilution principle: the treated air is sent out from the upper air supply outlet according to the thermal-humidity load of the whole room, and the surrounding air is inhaled by the use of guide function of jet distribution, and the space where its air is sucked is supplemented by a part of the return airflow, whereupon it form the swirling vortex in which the heat and moisture are exchanged. Due to the exchange of heat and moisture in the form is relatively sufficient, the temperature field, humidity field of indoor air are also reasonably uniform, but for some places where the air cannot reach (such as corner) , they are easy to form a dead angle; The replacement principle: the fresh cold air is sent into the indoor from the bottom of air supply outlet in an extremely low air supply velocity (lower than 0.25m/s), due to the incoming air's temperature is lower than that of the indoor air, and its density is relatively large, it deposit at the bottom of the room to engender an air lake. When faced with heat sources such as a person or an equipment, the fresh air is heated up and begin to rise to form a thermal plume, which brings the heat and pollutants to the upper part of the room and break them away from the person's residence area as the indoor leading airflow. The air outlet is set at the top of the room; the hot, dirty air is discharged from the top of the room. Hence, displacement ventilation forms a flow field where the temperature and pollutant concentration are hierarchical distributed with a low velocity (Yusof et al, 2006).

In addition to the basic form of air supply, the uniformity of indoor airflow also has a relation with parameters of air supply (temperature and air velocity): outlet's form, size and position, return air inlet's position, room's shape and the heat source's position.

2. Research methods of air distribution

The recent researches and experiences show that the indoor airflow has a crucial influence on human thermal comfort and health, the efficiency of room air conditioning ventilation, and building energy consumption. At present, there are three main methods to study indoor air flow: jet flow theory analysis, model experiment and CFD technology. Because the architectural space is more and more complicated, diversified and large-scale, and traditional jet flow analysis method is based on certain standards and ideal conditions or experiments, the proposed jet flow formula is bound to bring large error. Although the model experiment can get all kinds of data that the designers need, it is difficult to be widely used in engineering design due to its long experimental period and expensive experimental cost (Papanastasiou, 2010).

CFD, namely computational fluid dynamics, is the core and important technology of the transfer and combustion of heat, mass and momentum, multiphase flow and chemical reaction studies(Ho and Rosario, 2011). It uses computer to solve the partial differential equations of fluid flow in a variety of control of conservation, which relates to some technologies such as fluid mechanics, calculation methods, computer graphics processing and so on. In the traditional HVAC engineering design, the design is often depends on a large number of tests and designers' experiences, but the application of CFD has completely changed the traditional design process (Li and Meliko, 2011).

Compared with the experimental test, numerical simulation has the following advantages:

(1) The equipment is simple; it can only use the computer and the corresponding external equipment.

(2) The unmeasured working conditions and parameters can be obtained by the simulation.

(3) The same working condition can be reappeared; the similar conditions also can conduct a simple transplant; we needn't to cost manpower and material resources (Yusof and Leman, 2006).

(4) The required funds are few. Because we don't need to set up an experimental platform and arrange experimental equipment, the cost of simulation is frequently lower several orders of magnitudes than the costs of corresponding experimental research. Of course, numerical simulation also has its own limitations:

(1) The user of numerical simulation must fully grasp the relevant knowledge of the turbulence model, computational fluid dynamics, CFD software and programming.

(2) The correctness of simulation depends on whether the selected model can accurately describe the physical phenomena, and any simplicity or hypothesis of the phenomenon may affect the reliability of the simulation results (Li et al, 2012).

(3) The result of numerical simulation should be checked by experiment.

Due to the above characteristics of CFD technology, the development of its application in the field of HVAC is very fast. The computer numerical simulation technology of indoor thermal environment has entered a practical stage in some advanced countries.

3. Physical models of indoor flow field and its simulation methods

Figure 1 is the physical models to be studied in this paper. This paper including four physical models: (1) the model of office's mixing ventilation and air conditioning system (sent from top and return from top), figure 2; (2) the model b of office's mixing ventilation and air conditioning system (sent from side and return from side), figure 3; (3) the model c of office's mixing ventilation and air conditioning system (sent from side and return from side, but the location of air return inlet is different) ,figure 3.

Including: 1 – the ceiling; 2 – floor; 3 – the east wall; 4 – the west wall; 5 – the south wall; 6 – the north wall; 7 - lights; 8 - computer; 9 –human; 10 - desktop; 11 - cabinet; 12 - pollution sources; 13 - air inlet (diffuser); 14 – air return inlet.

3.1 The setting of the physical model's simplification

(1) The medium's continuity

According to molecular motion theory, the idle stroke of gas molecule is 1E-11mm; when compared to the value of the room's characteristic length L, the ratio is a minimum value of higher order, namely $1/L<<1$, therefore we can take the air in the room as a continuum.

(2) steady flow field

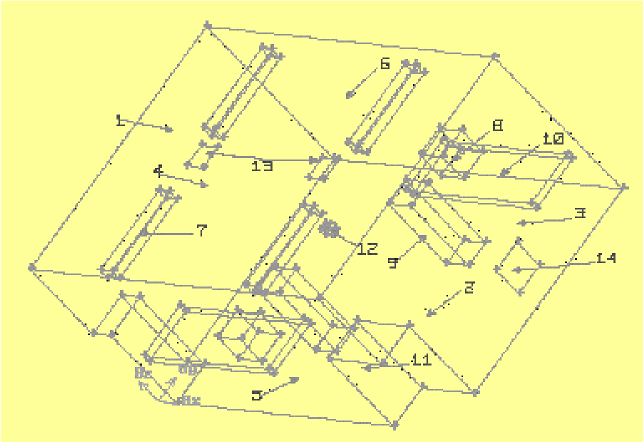

Figure 1: The mixed ventilation air conditioning system model in the office(Beam type last time)

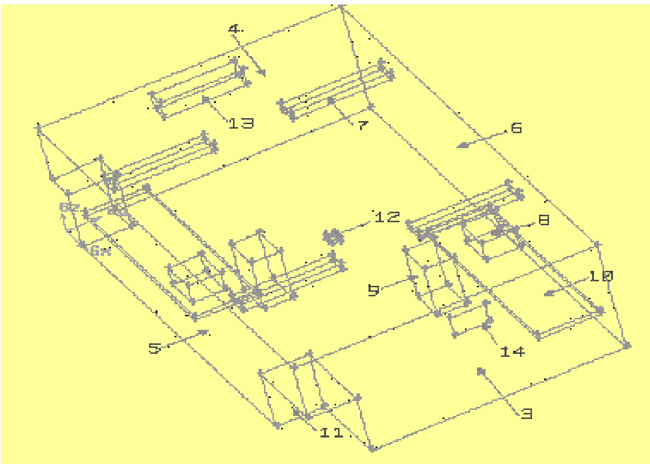

Figure 2: The mixed ventilation air conditioning system model in the office(Side to side back to type)

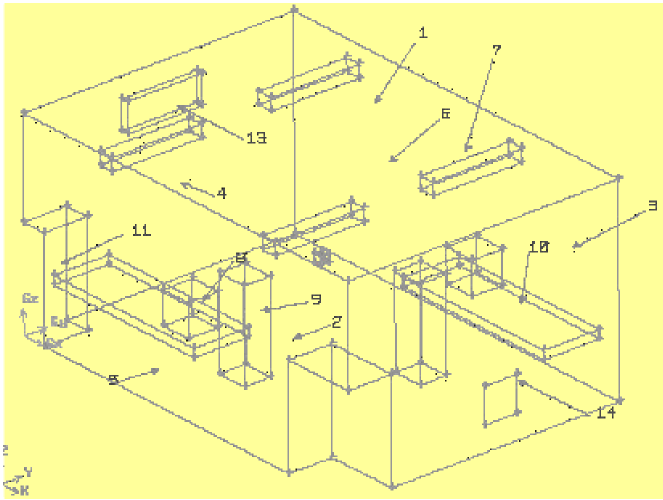

Figure 3: The mixed ventilation air conditioning system model in the office(Side to side back to type, different inlet position)

The case that flow conditions change with the time is called unsteady flow; and the case that flow conditions don't change with the time is called steady flow. In the actual situation, when the air flow is sent into the interior through the air supply outlet at a uniform speed, after a period of time, the coming air is fully mixed with indoor air, and the indoor flow field is in the stable state. At this time, the flow field of room can be regarded as steady flow (without the interference of external air). Of course, the "steady" of the flow doesn't mean the flow field doesn't change; it changes according to a law of development, that is, the vortex is generated and disappeared continually.

(3) Incompressible air

Based on the knowledge of fluid mechanics, if the flow velocity is sufficiently smaller than sound velocity, namely the Mach number $M \leqslant 0.25$, the compressibility of gas can be ignored. The flow velocity of air-conditioned room is within 3 - 5m / s in general, which is far less than the sound speed. In this velocity range, the changes of pressure and temperature in the flow field are very small when compared with the free flow, so the corresponding density changes can be neglected, and the air can be taken as incompressible, and its density is constant.

3.2 physical models of the forms of air distribution

The physical models in this section as shown in the figure 4 and 5; there are illuminating lamps, computers, desks, bookcases and other physical models in the room in order to simulate the room size and indoor items; the number of human, heat source and heating value as shown in table (about the build-ups of physical model and the setting of related parameters). In this paper, we assume that the physical model is located in the centre of the building, so all the walls, ceilings and floors are adiabatic boundary conditions. In this simulation, for the sake of the comparison of the removal efficiency of pollutants in different form of air distribution, we assume that there has the pollution source CO_2 (the breathing from indoor personnel), which release amount is 1.689E-3kg/s; there has organic benzene vapour C_6H_6 (the release from the desk surface), which release amount is 4.25 μ g/m2.h. Because this paper aims to compare the performance indexes of different form of air distribution under the same conditions, only the locations of air supply outlet and air return inlet are different in each model. The total air rate volume of all kinds of air supply mode is 5 times/hour, the air supply temperature is defined as 14.5 ℃, the relative humidity of the air is 60%, and the other indoor models have the same boundary conditions.

The model calculation adopts the RNG model in κ – ε turbulent model, which is a multiple species model where is no chemical reaction between each other. The boundary conditions of each model in the room are shown in table 1:

Table 1: The boundary conditions of each model in the room

Number	Name	Number				Boundary conditions	The required data
		Room1	Room 2	Room3	Room 4		
1	ceiling	1	1	1	1	adiabatic	
2	floor	1	1	1	1	adiabatic	
3	east wall	1	1	1	1	adiabatic	
4	west wall	1	1	1	1	adiabatic	
5	south wall	1	1	1	1	adiabatic	
6	north wall	1	1	1	1	adiabatic	
7	floodlight	4	4	3	4	high heat flux	heat flow
8	computer	2	2	2	2	high heat flux	heat flow
9	human body	2	2	2	2	high heat flux	heat flow
10	desktop	2	2	2	2	high heat flux	burst size
11	cabinet	2	2	2	2	high heat flux	
12	Air inlet	2	2	2	2	high heat flux	
13	Return air mouth	1	1	1	1	high heat flux	
14	CO2 release source	1	1	1	1	high heat flux	burst size

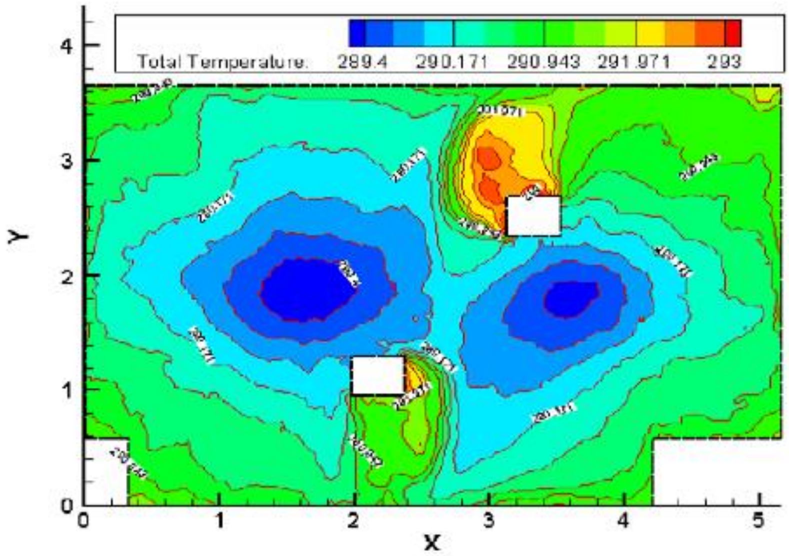

Figure 4: Z = 1.1 m CO2 distribution of pollutant concentration

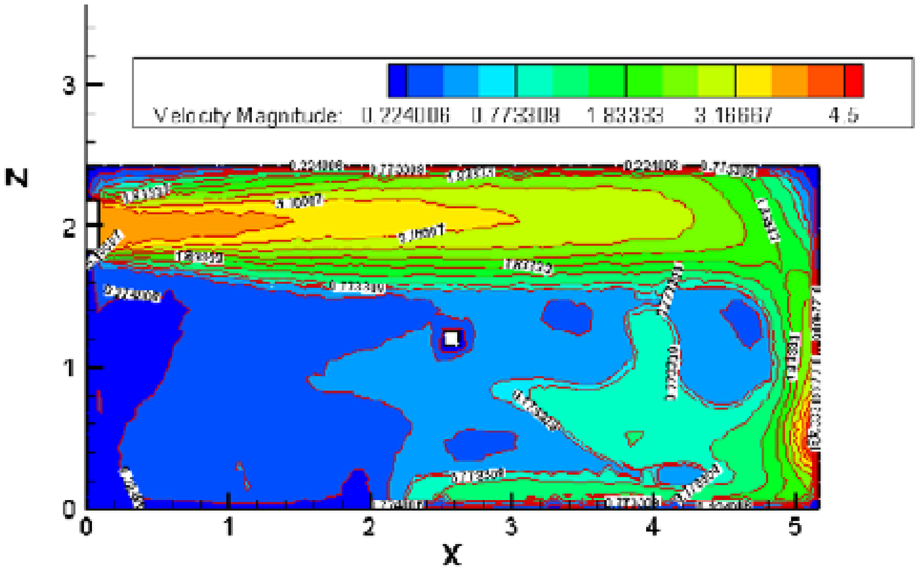

Figure 5: Y = 1.83 m C6H6 pollutants concentration distribution

4. Conclusion

This chapter mainly analyses and compares indoor temperature field, concentration of field distribution under various forms of air distribution, and the indoor air environment, human thermal comfort by the simulation and calculation of indoor airflow. The main research works are as follows:

(1) Analyse the basic principle of ventilation mode, and put forward the basic situation of air distribution in theory.

(2) Establish the physical model of numerical simulation, and propose a more appropriate method of numerical calculation after repeated simulation and testing.

(3) Conduct experiments for the setting of the boundary conditions repeatedly, find out the appropriate boundary conditions and under-relaxation factors by comparing the simulation results and the actual situation.

(4) Compare the performances of air conditioning systems which have different forms of air distribution from different aspects, including (a) temperature field and velocity field; (b) the concentration distribution of indoor pollutants; (c) ventilation efficiency and energy use efficiency; (d) human thermal comfort.

(5) Analyse the simulation results of different kinds of air distribution.
(6) Simulate the distribution of different indoor pollutants, and analyse the reasons for the different results.
No matter the removal efficiency of indoor pollutants, the distribution of temperature field or human thermal comfort, the use of low grade energy, the form of air distribution of displacement ventilation outperforms other forms of air distribution; the pollutant load of fresh air in the air inlet will affect this pollutant's concentration distribution in room.

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