# Airflow Simulation and Energy Analysis in Ventilated Room with a New Type of Air Conditioning[1]

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**Abstract:** Airflow simulation in one ventilated room with radiant heating and natural ventilation has been carried out. Three cases are compared: the closed room, the room with full openings, and the room with small openings. The radiator heating room with small openings is recommended. The airflow and thermal comfort are discussed for the last case. It is suitable for two kinds of civil buildings, housing buildings and office buildings, which take up the largest part of all functional buildings.

**Key words:** Natural ventilation; Radiant heating; Thermal comfort

## 1. INTRODUCTION

Indoor air environment has drawn much attention in recent decades. Davidson found the displacement ventilation was the convenient way to improve IAQ [1]. Chow et al have studied on the indoor airflow in the occupied zone of ventilated and air-conditioned roo m [2]. Chen et al also have done numerical studies on indoor air quality and thermal comfort [3]. Floor heating has been adopted in recent years, due to the over-emphasis on energy saving in these applications, the poor indoor air quality has greatly affected employee's working efficiency as no fresh air or little fresh air is supplied. As the heating load is small, assistance of natural ventilation may be applicable [4]. For the application of radiant heating, the required indoor air temperature drops. Thus, no much heating load increases even with natural ventilation, but high level indoor air quality will be achieved. Our study aims to simulate airflow in the ventilated room with this new type of air conditioning. Radiation is taken into account by the energy conservation in the system. The following section presents algorithm, thermal comport parameters and the simulated results. Later sections discuss the indoor thermal environment.

## 2. MODEL AND NUMERICAL METHODS

As shown in Fig.1, here is a single room of 5.0×3.3m (Length×Height), and the openings on the symmetry in width direction perpendicular to the paper. It has one out forward wall. The rectangular opening on the side is 21.00 cm long. The designed thermal parameters are as follows, the calculated outdoor air temperature is 0℃, the calculated indoor air temperature for engineering computation is 16℃, and the relative humidity of the outdoor air is 75%. The heat source is floor radiation and its designed temperature is 30℃. The outside wall is 24 cm thick and plastered inside and outside. And the inlet opening is 2.00m lower than the outlet opening. The non-heated indoor surfaces are diffuse and gray surface.

The mathematical descriptions of airflow are based on the fundamental laws of physics, i.e. mass, momentum and energy conservation, etc. Then, the governing equations to be solved are the conservation equations for continuity, momentum, and energy as well as the equations for turbulent kinetic energy and its dissipation rate. The buoyancy effect is accounted for by Boussinesq approximation. The basic non-dimensional equations for the steady, turbulent

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airflows are summarized in [5-7].

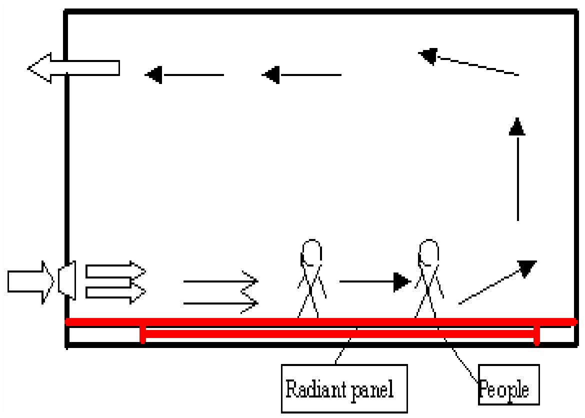



**Fig. 1 Geometric presentation of the system**

As for the thermal radiation of the inner walls, the thermal radiation model should be employed. In this model the fluid (air) is considered radioactively non-participating and the walls are grey and diffuse. The net radiative heat power of a surface element is computed by the net-radiation method for enclosures. The radiation equation can be solved either directly or iteratively. The direct solution is exact and usually needs larger computing expenditure. An iterative solution, e.g., the Gauss-Seidel iteration, requires only a few iterations for intermediate or high wall emissivities. Nevertheless, at low emissivities the direct solution method is more efficient than the iterative method [8]. In this study, the non-slip condition at all solid surfaces is applied for the velocities. In the vicinity of the walls, it will apply wall functions to bridge the core of turbulence and the sub-layer of flow regime. In our paper, in order to compute and compare convenience, the wall functions recommended by Launder and Spalding will be adopted when using the standard $k$-$\varepsilon$ model [7].

The set of governing equations are discretized utilizing a method called practice B that is a control volume based finite difference method [9]. To avoid checkerboard pressure and velocity fields, the non-uniform grid in staggered arrangements, clustered toward the walls, is used for the velocity in the X and Y directions [9, 10]. The convection terms of momentum equations are approximated by means of the QUICK scheme, and those for scalar equations are approximated by means of the upwind scheme. The diffusion terms of all equations are discretized by the second-order central-difference scheme. The resulting algebraic equations are solved iteratively using a line-by-line procedure, combining the tri-diagonal matrix algorithm (TDMA) and the successive over-relaxation (SOR). A SIMPLE-like algorithm developed by Date is used to treat the coupling of momentum and energy equations [11].

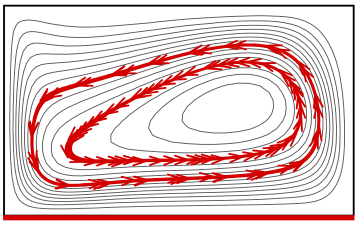
## 3. THERMAL COMFORT PARAMETERS

The temperature of outdoor air is 0℃ and relative humidity of it is 75%, then its humidity content is 2.82 g/kg (dry air). The moisture emitted from one person is about 0.025g/s (light labor or extremely light labor). When scattering in the fresh air, the humidity content of fresh air will increase 1.94 g/kg (dry air). The thermal comforts of several typical thermal conditions in these two heating modes are calculated with the widely used thermal comfort index-PMV (Predicted Mean Vote) and its computational formula [12]. The influence of turbulence on airflow has not been taken into account in the PPD (Predicted Percentage Dissatisfied) and PMV model. Fanger proposed a mathematical model of draft risk including the influence of airflow turbulence intensity [13]. While the mean air speed, mean air speed of the occupied zone and the percentage of people dissatisfied with the air draught in an environment (PD) are proposed by Chow and Fung [2].

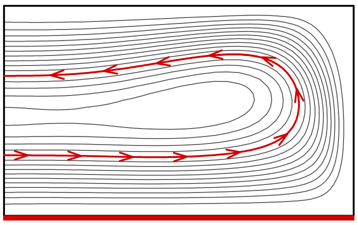
## 4. RESULTS AND ANALYSIS

Numerical simulation of indoor airflow is carried out with those numerical methods and thermal boundary conditions mentioned above. Firstly, the left vertical wall is assumed three cases, i.e., constant cold temperature, full-opening or two-small openings. Fig.2 presents the flow fields under these cases. For the closed room, the left sidewall maintains constant cold temperature. The room with full opening side can provide the enough fresh air, but the energy consumption would be large. The last is the object of this paper. Evidently, it is of the similar flow structures among these. As the first one provides none fresh air, then the third one is recommended.

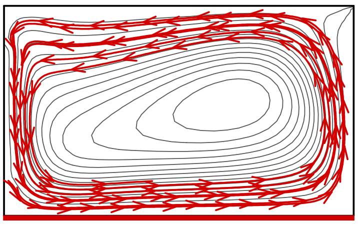
Fig.3 provides the detailed distributions of airflow parameters along the center axis of inlet opening, including that vector of U-directional part, kinetics of turbulence, temperature and index PD.



***A*** *Close room*



***B*** *Partial room*



***C*** *Small openings*

**Fig. 2 Flow structures for three cases (A, B and C)**

The inflow fresh air speed attenuates quickly for the low inlet velocity and high temperature difference between indoor and outdoor. And the radiation temperature tends to uniform along the axis. The detailed distributions of airflow parameters along the center axis of outlet opening, including that U-vector, kinetics of turbulence, temperature and index PD are also provided in Fig.3. The U-vector fluctuates along the line, for the recycled airflow is influenced from thermal driven by radiator and air momentum transfer between indoor and out space.

## 5. CONCLUSION

Radiator heating with natural ventilation is recommended in this paper. Numerical methods and thermal parameters are reviewed, and three cases (close room, partial room and small openings) are compared followed that. At last, the thermal parameter distributions of recommended case are presented and analysed. The radiator heating combined with natural ventilation can provide fresh air.

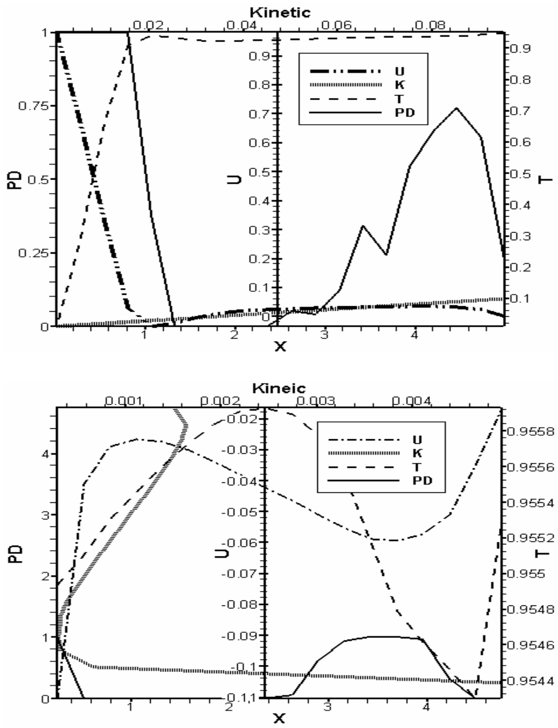



**Fig. 3 Distributions of horizontal velocity, kinetics of turbulence, temperature and PD along the center axis of inlet opening (left) and outlet opening (right).**

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