CFD simulation different inner structure of air heat exchanger

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Abstract. Air heat exchanger is the key equipment to fresh air ventilation system, which is helpful for energy recovery. Hence, how to promote the heat exchanger performance are commonly studied. In the present paper, air heat exchanger thermal efficiency was investigated in an office room in summer and four kinds of difference structure of air heat exchanger performances were simulated by computational fluent dynamics (CFD), and showed the air heat exchanger internal temperature distributions and thermal efficiencies. It was found that inner temperature distributions of difference structure of air heat exchanger were difference. The results showed that increasing inlet velocity from 1.2 m/s to 2.5 m/s, thermal efficiencies declined 25 % and energy recovery decreased, and pressure dropped no more than 20 Pa. The study provided that the thermal efficiency of the heat exchanger was affected by the inner structure of air heat exchanger, and inlet velocity was the most important factor.

1. Introduction
Air heat exchanger has the character of excellent heat efficiency and low energy consumption, which is widely used in air ventilation system[1], and the energy recovery rate about 70% -90%[=]. In order to recovery more energy, air heat exchanger should have a highly efficient heat transfer performance and reasonable pressure drop in practical application [2]. For now, although the heat exchanger has a strong application, all of the factors about material, structure and operation conditions determine the efficiency of heat transfer were studied[3].

Some Literatures show that the performance of air heat exchanger about channel height and operation conditions had been reached. Different channel height, Reynolds number and direction of air flow of air heat exchanger were studier by FLUENT[4]. Wahiba et al. [5]verified that the validity of HRV / ERV system by CFD and the published data, then studied the heat transfer efficiency of heat exchangers in both summer and winter seasons.

In addition difference air heat exchanger material properties had been studied by many scholars. It was found that membrane type and morphological porosity play an important role in the heat transfer efficiency of air heat exchanger[6, 7]. Sabek et al. [8]conducted a series of experiments on different materials and used numerical analysis to analyze the parameters of porous membranes. Lu[9]studied film vibration effect on heat transfer, it was that the effectiveness of air heat exchanger varies from 0.65 to 0.85.

Alberto[10] studied the axial and radial heat transfer process of laminar counter-flow parallel plate heat exchangers. It is found that effect heat transfer efficiency main parameters were airflow average temperature, local conductivity, heat transfer coefficient and outlet average temperature of air heat exchanger. Fernández[11] studied air heat transfer efficiency by changing inlet temperature, humidity and airflow direction. From the Literatures, it was significantly found that airflow velocity has a great effect on heat transfer efficiency.
Muhammad[12] presented the extensive application of CFD in the field of air heat exchangers and enumerated a large number of literatures on the practical application and has an great ability to analyze complex and variable flow fields.

In summary, Literatures focused on changing the material and channel height of air heat exchanger, airflow velocity and direction, thermal conductivity and others operation conditions how should they effect on heat transfer efficiency, pressure drop and energy recovery. Some of them studied on simplified CFD model of exchanger, however, the studies did not involve relation inner structure of air heat exchanger with different velocity. Nothing result showed that changing inner structure whether impact on airflow distribution and thermal efficiency. In this paper, four kinds of different inner structure of air heat exchanger were established and studied by FLUENT. Investigation on the effects of inner structure of air heat exchanger and different inlet velocity were conducted in detail by evaluating thermal efficiency, outlet temperature, pressure drop.

2. Exchanger structure

2.1 3D different inner structure exchanger

Fig.1 gived the diagram of inner structure of air heat exchanger. Heat transfer material is cellulose acetate membrane (CAM), CAM intention to avoid fresh-air and exhaust-air mixing and the parameters are showed on Tab 1.

| name                      | Symbol | Parameters       |
|---------------------------|--------|------------------|
| CAM thickness             | δ      | 0.1 mm           |
| path length               | l      | 285 mm           |
| channel height            | d      | 2.4 mm           |
| cross sectional area      | A      | 47.5 mm²*9       |
| CAM Thermal conductivity  | K      | 0.13 W/(m·K)    |
| Air thermal conductivity  | λₐ     | 0.0263 Wm⁻¹      |
| Air viscosity coefficient | ν      | 18.5e-6 m²/s     |
| Hot air temperature       | Th,i   | 35°C             |
| cold air temperature      | Tc,i   | 25°C             |
| Air density               | ρ      | 1.1614kg/m³      |

Fig. 2a (model 1) Original structure of air heat exchanger has eight flow deflectors and divides into nine small channel; Fig. 2b (model 2) showed that inner structure of air heat exchanger was divided by four flow deflectors; Fig. 2c (model 3) showed inner structure of air heat exchanger was divided by tow flow deflectors; Fig. 2d (model 4) showed inner structure of air heat exchanger no flow deflector.
2.2 Assumptions
Structures and boundary conditions were idealized in CFD software package, so some assumptions
should be made during the solving process:
1. The gas has continuity;
2. The thermal conductivity and thermal resistance of CAM was constant;
3. Air ignores the effect of gravity;
4. Ignoring the environmental heat loss and radiation and other factors;
5. The heat transfer coefficients of air heat exchanger passages were equal.

2.3 Governing equation

2.3.1 Continuous equation
According to the law of conservation of mass the differential equation of continuity equation is deduced as:
\[ \frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} = 0 \]

(1)

2.3.2 Momentum equation
The Conservation Equation of Momentum in the Process of Heat Transfer with Constant Viscosity Coefficient as:
\[ u_x \frac{\partial u_x}{\partial x} + u_y \frac{\partial u_y}{\partial y} = \nu \frac{\partial^2 u_x}{\partial y^2} \]

(2)

2.3.3 Energy equation
The law of conservation of energy equation expression as:
\[ \rho_c u_x \frac{\partial T}{\partial x} + \rho_c u_y \frac{\partial T}{\partial y} = k \frac{\partial^2 T}{\partial y^2} \]

(3)

3. Mathematical analysis

3.1 Heat transfer analysis
The process of heat transfer without heat source and physical properties were constant. Thermal conductivity of CAM and convection thermal resistance were in series so the total thermal resistance expression as:
\[ U = \frac{1}{hA} + \frac{\delta}{kA} + \frac{1}{hA} \]

(4)

Air heat exchanger heat transfer rate \( q \) expression as:
\[ q = U \Delta T_{in} \]

(5)

The logarithmic mean temperature as:
\[ \Delta T_{in} = (\Delta T_x - \Delta T_y) / \ln(\Delta T_x / \Delta T_y) \]

(6)

\[ \Delta T_x = T_{h,x} - T_{o,x} \]

(7)

\[ \Delta T_y = T_{h,y} - T_{o,y} \]

(8)

Nusselt number was an important dimensionless dimension of convective heat transfer, The expression of average Nusselt number as:
\[ \overline{Nu} = \frac{\bar{h}L}{k} = 0.664 Re^{1/2} Pr^{1/3} \]

(9)

Boundary Reynolds Number \( Re_c \):
\[ Re_c = \frac{\rho v l}{\mu} \]

(10)
3.2 Efficiency
The heat transfer process of air heat exchanger, the gas density and specific heat capacity change were very small. So the density and specific heat capacity were considered as constant. Therefore, heat transfer process only the temperature was a variable so the efficiency of sensible heat equation can be written as:

$$\epsilon = \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$$  \hspace{1cm} (11)

4. Results and discussion

4.1 Validity
In order to ensure the heat exchanger of actual in thermal efficiency, experiment was designed shown as figure 3.

![Fig. 3 schematic diagram of the experimental setup](image)

In the role of the fan, fresh-air and exhaust-air in the heat exchanger for heat transfer. In the new air and return air into the heat exchanger installed before and after the temperature was shown in the four locations while the use of anemometer to record the entrance speed.

Heat transfer efficiency of heat exchanger was calculated by using the formula (11). Then, the convection coefficient of heat exchanger calculated by the formula (9) and (10), the result was showed in Tab. 2.

| velocity m/s | heat transfer coefficient w/(m²·k) |
|--------------|-----------------------------------|
| 1.2          | 37.4                              |
| 1.5          | 41.8                              |
| 1.8          | 45.8                              |
| 2            | 48.3                              |
| 2.5          | 54.0                              |

Simulation result was compared with the experimental result. The comparison of the two results was shown in Fig. 4. The result showed that experiment result and simulation result error was less than 5%. Hence, It was concluded that the model 1 structure of the air heat exchanger was valid.
4.2 Temperature distribution

Measurement air heat exchanger performance, outlet temperature was an important parameter. In this paper, changing the number of flow deflectors inner structure of air heat exchanger and inlet velocity studied how outlet temperature various. Under the same boundary conditions (fresh-air inlet temperature was 35 °C, exhaust-air inlet temperature was 25 °C, velocity was 1.2 m/s), FLUENT was used to simulate four different structural air heat exchanger and deals with results.

Different structure of air exchanger inner temperature distribution were shown in Fig. 5. It was found that model 1-3 outlet temperature the same due to flow deflectors. After entering the heat exchanger, the air is along the small passages which split by the baffle plate. But model 4 have no flow deflectors, it can’t direct the air flow.

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**Fig. 4 Experiment and Simulation heat efficiency**

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Different structure of air exchanger inner temperature distribution were shown in Fig. 5. It was found that model 1-3 outlet temperature the same due to flow deflectors. After entering the heat exchanger, the air is along the small passages which split by the baffle plate. But model 4 have no flow deflectors, it can’t direct the air flow.
The mean outlet temperature of the models correlation with inlet velocity were show in Fig.6. Compared with the same speed, increasing velocity result in changes of temperatures between model 4 and models 1-3 were limited. When increasing velocity from 1.2 m/s to 2.5 m/s, changing of temperature from 0.5 ℃ to 0.75 ℃. But Comparison of the model itself, the outlet temperatures rised 2.5 ℃. It was obvious that velocity has a great effect on thermal efficiency and baffle plates play a few important role in model 1-3.

**4.3 pressure drop**
In the ventilation system air volume was an important factor, but pressure drop would affect air volume. Fig. 7a showed that all pressure drop of different structure of air heat exchanger were less than 16 Pa when the inlet velocity was 1.2 m/s, and no flow deflector structure air heat exchanger press drop was only 10 Pa. The others were consistent. Fig. 7b, it was illustration that the pressure drop increase effect by inlet velocity. Model 1-3 are small difference, but drop pressure faster than the model 4. Therefore, Minimize pressure drop, using a heat exchanger with flow deflectors should control inlet velocity.

4.4 efficiency and energy recovery

Fig. 8 showed the thermal efficiency of outlet position of different structure of air heat exchanger and inlet velocity effect on thermal efficiency.
Fig. 9 relationship between recovery and inlet velocity

The higher inlet velocity the higher heat transfer rate, according Eq. (5) the energy recovery at different inlet velocities was shown in Fig. 9.

5. Conclusions
In this paper, a simulation study of air heat exchanger had been presented. Using CFD software package simulated different inner structure of air heat exchanger, which related with thermal efficiency, pressure drop and energy recovery. The primary conclusions were given below:

1. Inner structure flow deflectors of air heat exchanger would affect outlet temperature and heat transfer efficiency. It was found that without flow deflectors exchanger outlet temperature was higher than the others.
2. The temperature distribution of the flow uniform related with flow deflectors. The more flow deflectors addition the uniform temperature distribution.
3. The number of flow deflectors would affect pressure drop but not a major factor. It was found that Fig. 2a-2c structure pressure drop were the same.
4. Inlet velocity played an essential role in the heat transfer process. Increasing inlet velocity the thermal efficiency was descend, but the pressure drop and energy recovery were increased. Increasing inlet velocity from 1.2 m/s to 2.5 m/s, the result indicated that thermal efficiencies declined about 25%.

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