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Research Article

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Research on the Effect of the Size of the Wall-Hanging Air-Conditioner Indoor Unit on the Indoor Thermal Comfort

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Abstract

The geometrical dimension of the wall-hanging air-conditioner indoor unit affects the indoor thermal comfort. In this paper, fluent software is used and standard k-e two equation turbulent model is chosen to carry out the simulation of the indoor temperature field and flow field of six different sizes of the single wall-hanging indoor air-conditioner in the room. The temperature distribution, velocity distribution and PMV distribution of the plane which is 1.8m from the ground are given. It can be known that under the condition of six kinds of sizes of the wall-hanging air-conditioner indoor unit, when the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, the temperature variation and velocity variation at the z=1.8m section are relatively small. And the temperature distribution and velocity distribution are more uniform. When the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, PMV at the z=1.8m section is the smallest, which is closest to 0, and the thermal sensation is almost moderate. Therefore, when the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, better indoor comfort can be achieved.

Keywords: Wall-Hanging Air-Conditioner, Size of Indoor Unit, Comfort, Numerical Simulation

Introduction

As people's living standard improves, their demand for thermal comfort of the indoor environment is increasingly higher and higher. Thermal comfort is a feeling of people's physiology and psychology, which refers to a series of activities of the nervous system. These activities make people produce the feeling of pleasure psychologically [1]. The factors that affect the indoor comfort include: the position of the indoor air-conditioner, air supply angle, air supply parameters (air supply temperature, air supply velocity), air distribution modes, indoor heat source and so on. In literature, the effect of air distribution modes on the indoor air distribution was studied and the thermal field and flow field of the indoor air were analyzed [2]. In literatures, the research on the effect of air supply angle on the indoor thermal field and flow field was conducted [3-5]. On the basis of literature, the effect of the position of the indoor air-conditioner on the indoor environment was studied in literature, in which the distribution of the indoor thermal field was mainly analyzed [3-6]. In literature, the effect of air supply parameters on the indoor environment was taken into consideration based on literatures, and the distribution of the indoor thermal field and flow field was analyzed [3-5, 7]. In literature, the research of the effect of air supply parameters on the indoor environment was also carried out with more analysis of the distribution of indoor temperature field [8]. The analysis of the distribution of the indoor thermal field was conducted in literature, in which the appropriate diversion plate angle was determined and the indoor temperature distribution was optimized [9].

In literatures mentioned above, the distribution of the indoor thermal field and flow field is mainly analyzed through the methods of numerical simulation and experiment. The effects of the installation position of indoor air conditioners, air supply angle, air supply parameters and air distribution modes on the indoor environment are studied, nevertheless, there is seldom research on the effect of the size of air-conditioner indoor unit and the arrangement of multiple air-conditioner indoor units. In this paper, the effect of the size of wall-hanging air-conditioner indoor unit on the indoor thermal comfort is studied, with the distribution of the indoor thermal field and flow field analyzed and the evaluation index of thermal comfort PMV introduced.

Analysis of Numerical Simulation

Physics Model

A simplified empty bedroom with a wall-hanging air-conditioner is adopted as the model in the paper in Fig. 1 as follows. The size of the room is 5m×3m×3m(length*width*height), and the design working condition of the model is summer. The wall-hanging air-conditioner indoor unit is located at the position which is 2m from the ground and 1m from the left wall.

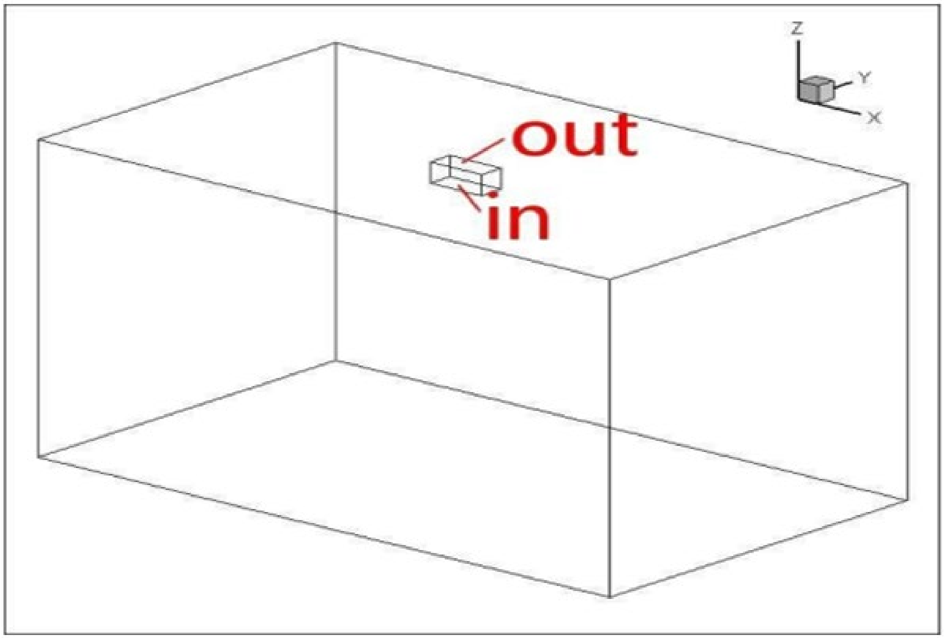


Figure 1: The Simplified Diagram of the Room with Wall-Hanging Air Conditioner

Mathematics Model and Basic Assumption

The application of computational fluid dynamics in the indoor environment is based on the discretization of the continuity equation, momentum conservation equation and energy conservation differential equation of in-compressible air and numerical analysis [10]. The equations which need solving are continuity equation, momentum conservation equation and energy conservation equation. In this paper, the standard k-e two-equation model is used as the turbulent model, and the control volume method is employed to discretize the whole solution area. In order to simplify the problem, the assumptions that can be made include: (1) the air in the room is treated as the continuous in-compressible fluid; (2) both the flow process and heat transfer process in the room are steady, and the air flow is turbulent; (3) heat transfer in the room is convective heat transfer with no consideration of conduction and radiation heat transfer; (4) the room is sealed and there is no air leakage; (5) wall thickness is neglected in the indoor convective heat transfer; (6) the effect of heat source on the indoor environment is not considered.

Settings of Solution Parameters and Boundary Conditions

For control variate method is employed to carry out the research on the effect of the size of wall-hanging air-conditioner indoor unit on the indoor thermal environment, the air supply temperature is 21℃, the difference of air supply temperature is 5℃, and the design temperature of the indoor air-conditioner in summer is chosen as 26℃. It is determined that the mode of air supply in the room is air supply downwards and air return upwards. The cooling load is constant and the air supply volume is constant, as to the single wall-hanging air-conditioner, with the change in the size of the indoor unit, the air supply velocity also changes. Six kinds of sizes of wall-hanging air-conditioner indoor units are chosen for numerical calculation, which are listed in the table 1 as follows.

Table 1: The Size of Air-Conditioner Indoor Units and Air Supply Velocity

Working Condition	Size of Indoor Unit	Air Supply Velocity
1	0.4m×0.2m×0.2m	3.75m/s
2	0.5m×0.2m×0.2m	3m/s
3	0.45m×0.25m×0.2m	2.67m/s
4	0.6m×0.2m×0.3m	2.5m/s
5	0.5m×0.25m×0.4m	2.4m/s
6	0.5m×0.3m×0.5m	2m/s

Discrete parameters are the same under six working conditions. In order to gain a more accurate solution, the second order upwind scheme is used for momentum, energy, turbulent kinetic energy and turbulent dissipation rate, whose relaxation factors are set by default. They are 0.7, 1, 0.8, 0.8 respectively. Residuals of every quantity are set by default too, where the residual criterion of energy is 10-6 and the residual criterion of other terms is 0.001. Since the air supply velocity is known and the flow is regarded as in-compressible flow, the boundary condition at the inlet is velocity inlet boundary condition, and the air supply temperature is 21℃. For pressure and velocity at the outlet are not known, the outlet boundary condition is outflow boundary condition [11]. Walls of the room are all stationary walls without slip, whose boundary conditions are the boundary conditions of convective heat transfer, and the heat transfer coefficient and free stream temperature on the wall are 10W/(m2*K) and 30℃ respectively. Standard wall function is employed as the wall function.

Division of the Mesh

In order to gain the correct solution, meshes of high quality should be chosen. In the paper, hexahedral structured mesh is chosen here to discretize the whole room. The conditions that need to be satisfied are: (1) the minimum orthogonal quality is near to 1; (2) For the heat transfer of the indoor air is studied here, the hexahedron of the air-conditioner is not included in the calculation area, the mesh is divided only in the whole room [11]. The mesh diagram of the second working condition is shown in Fig. 2, and cell numbers of mesh under six working conditions are shown in table 2.

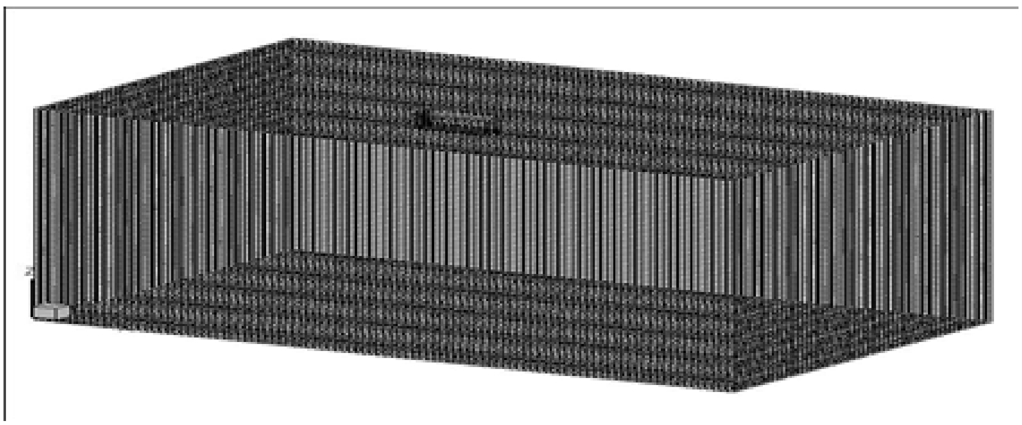


Figure 2: The Mesh Diagram of the Room with Wall-Hanging Air-Conditioner Indoor Unit

Table 2: The Number of Grid Cells for Every Working Condition

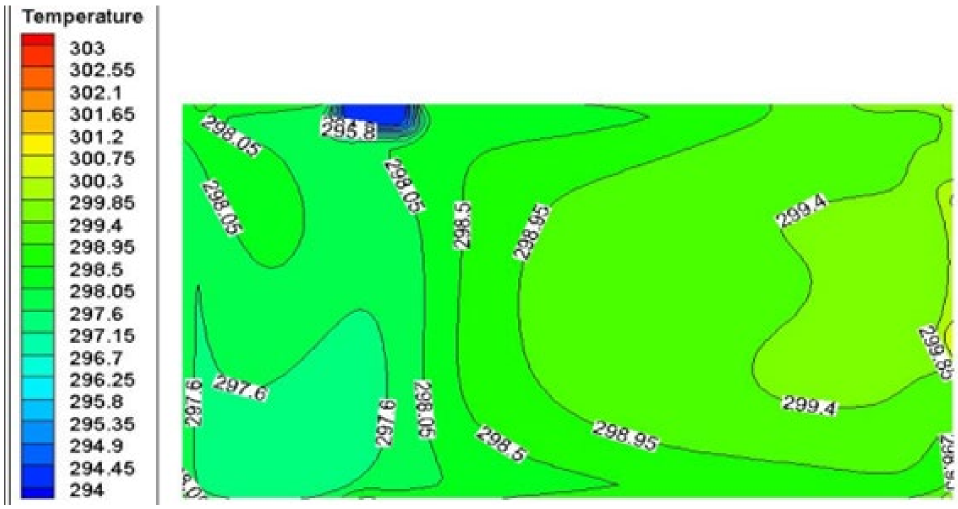
Working Condition	Cell Numbers of Meshes
1	359872
2	359840
3	359856
4	359712
5	359680
6	359600

Calculation Results and Analysis

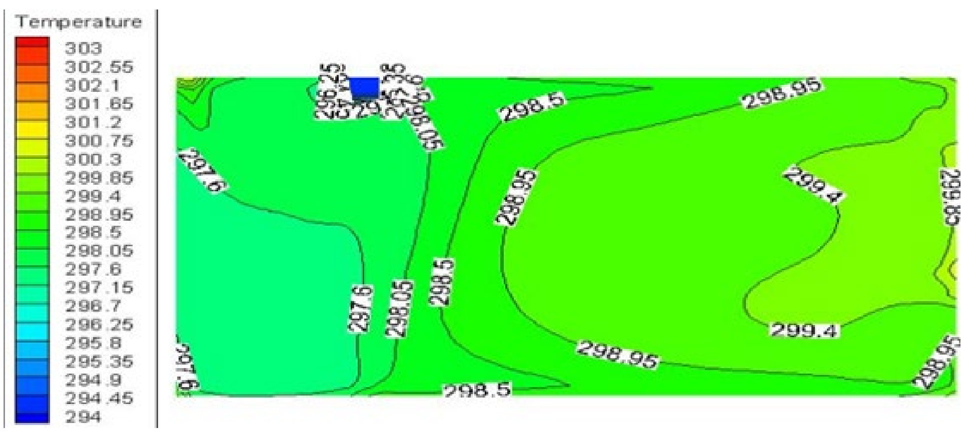
In this paper, the effect of the size of wall-hanging air-conditioner indoor unit on the indoor environment is studied. Control variate method is used for numerical calculation. The thermal field and flow field of the indoor air at the section z=1.8m are analyzed here, and the index PMV is used here to evaluate the indoor thermal comfort.

Analysis of Temperature Distribution under Different Sizes of Air-Conditioner Indoor Units

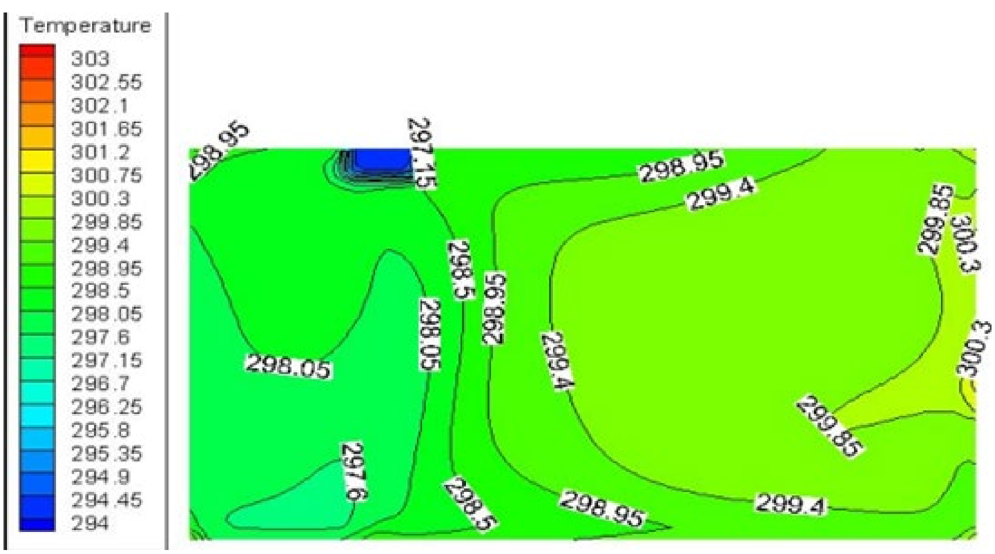
When the size of the air-conditioner indoor unit is 0.4m×0.2m×0.2m, 0.5m×0.2m×0.2m, 0.45m×0.25m×0.2m, 0.6m×0.2m×0.3m, 0.5m×0.25m×0.4m, 0.5m×0.3m×0.5m, graphs of temperature distribution at the z=1.8m section are shown in Fig. 3, and the line diagram of temperature difference with the size of the air conditioner indoor unit is shown in Fig. 4.



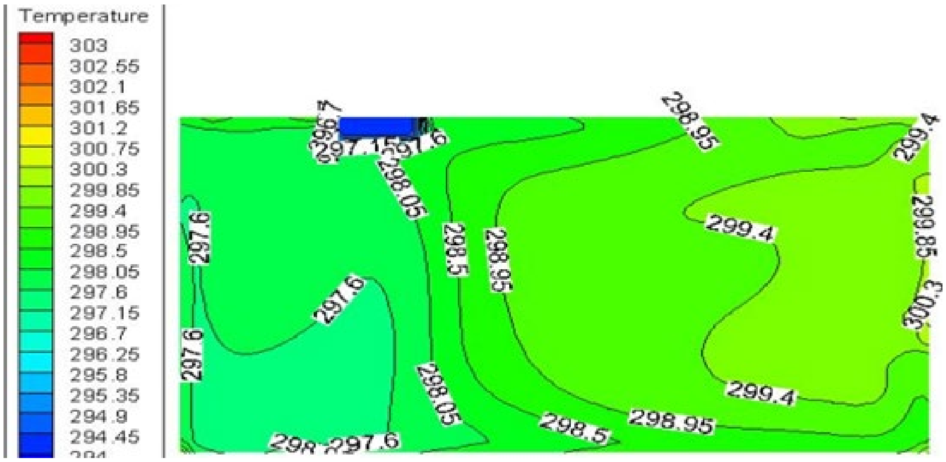
(a) size of indoor unit is 0.5m×0.2m×0.2m



(b) size of indoor unit is 0.4m×0.2m×0.2m

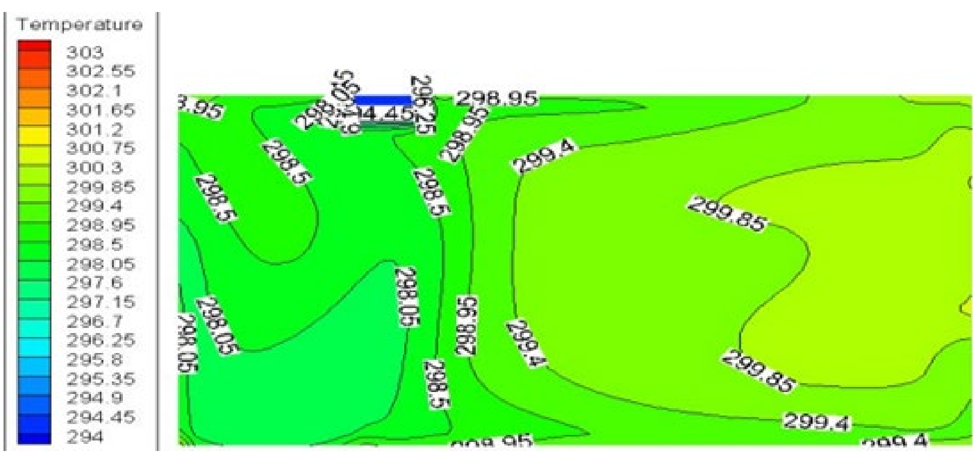


(c) size of indoor unit is 0.45m×0.25m×0.2m



(d) size of indoor unit is 0.6m×0.2m×0.3m

(e) size of indoor unit is 0.5m×0.25m×0.4m



(f) size of indoor unit is 0.5m×0.3m×0.5m

Figure 3: Cloud Pictures of Temperature Distribution at the Section z=1.8m

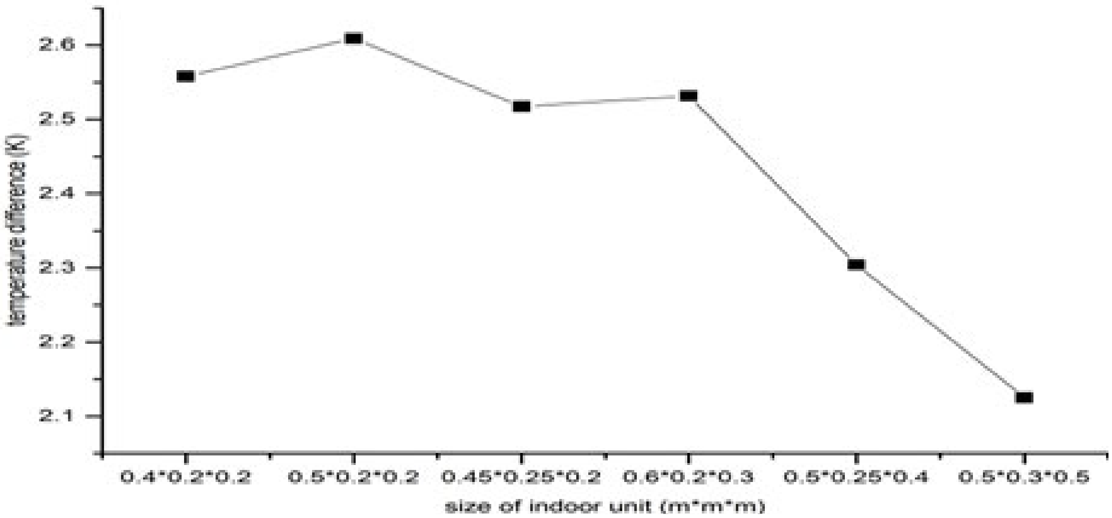


Figure 4: Line Diagram of Temperature Difference at the Section z=1.8m

It can be seen from Fig. 3 that temperature near the air-supply vent of the air-conditioner indoor unit is lower. The further the air is from the air supply vent, the higher the temperature is. As can be seen from Fig. 4. Before the size of the indoor unit 0.6m×0.2m×0.3m, temperature difference at the section z=1.8m increases first, decreases then and increases again. After the size of the indoor unit 0.6m×0.2m×0.3m, there is a gradual decrease in temperature difference at the z=1.8m section with the increase in the size of indoor unit. It can be seen from Table 3 that when the size of the air-conditioner indoor unit is 0.4m×0.2m×0.2m, temperature difference at the z=1.8m section is 2.5579K; when the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, temperature difference is 2.6091K; when the size of the air-conditioner indoor unit is 0.45m×0.25m×0.2m, temperature difference is 2.5175K; when the size of the air-conditioner indoor unit is 0.6m×0.2m×0.3m, temperature difference is 2.5316K; when the size of the air-conditioner indoor unit is 0.5m×0.25m×0.4m, temperature difference is 2.3043K; when the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, temperature difference is 2.1251K. By comparison, it can be seen that when the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, temperature difference is smaller, thus temperature distribution is more uniform.

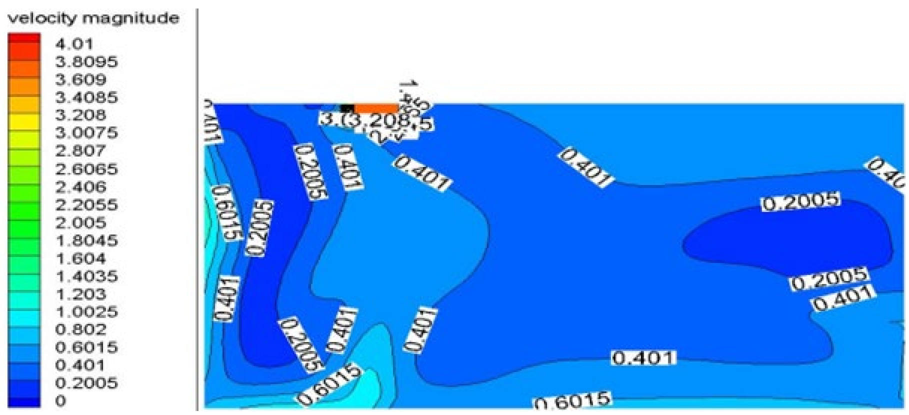
Table 3: Size of Indoor Unit and Temperature Difference at the Section z=1.8m

Size of Indoor Unit	Temperature Difference at the Section z=1.8m
0.4m×0.2m×0.2m	2.5579
0.5m×0.2m×0.2m	2.6091
0.45m×0.25m×0.2m	2.5175
0.6m×0.2m×0.3m	2.5316
0.5m×0.25m×0.4m	2.3043
0.5m×0.3m×0.5m	2.1251

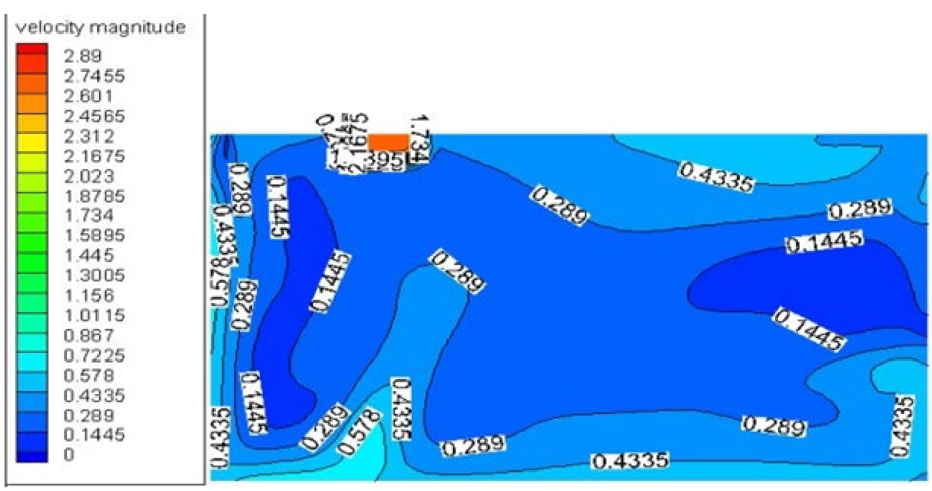
Analysis of Velocity Distribution Under Different Sizes of Air-Conditioner Indoor Units

When the size of the air-conditioner indoor unit is 0.4m×0.2m×0.2m, 0.5m×0.2m×0.2m, 0.45m×0.25m×0.2m, 0.6m×0.2m×0.3m, 0.5m×0.25m×0.4m, 0.5m×0.3m×0.5m, graphs of velocity distribution at the z=1.8m section are shown in Fig. 5, and the line diagram of velocity difference with the size of the air conditioner indoor unit is shown in Fig. 6.

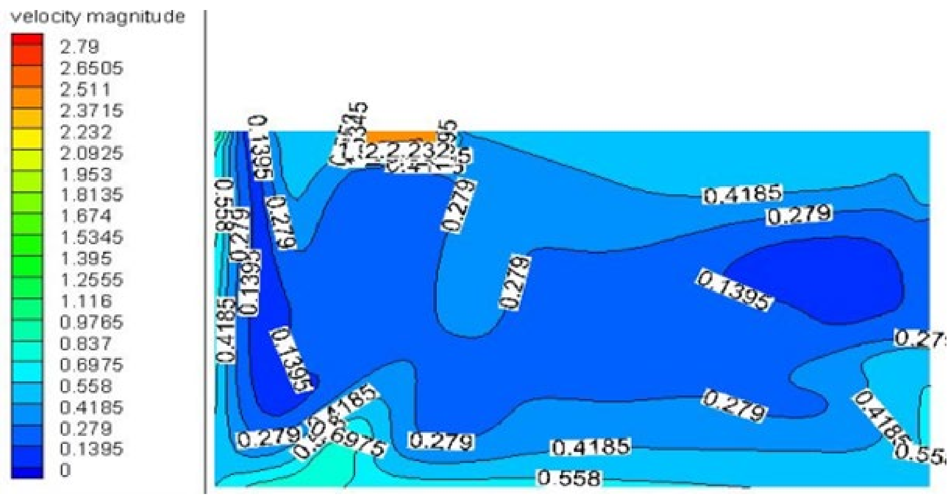
(a) size of indoor unit is 0.5m×0.2m×0.2m



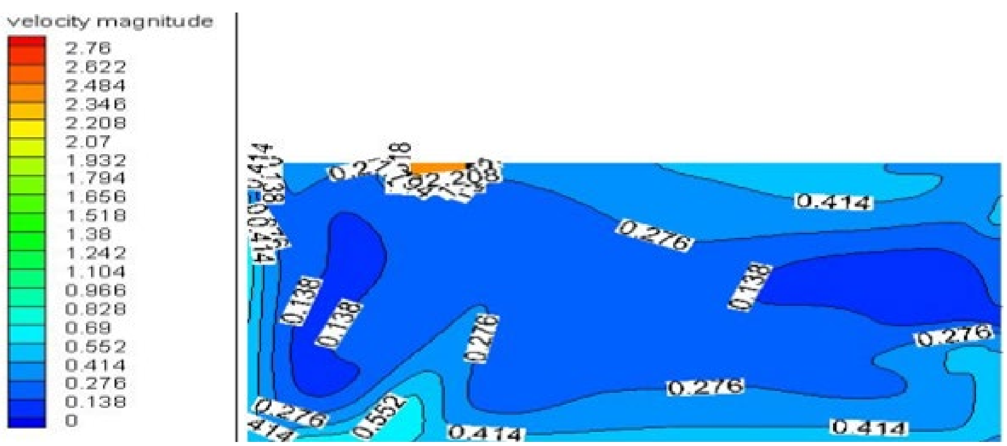
(b) size of indoor unit is 0.4m×0.2m×0.2m



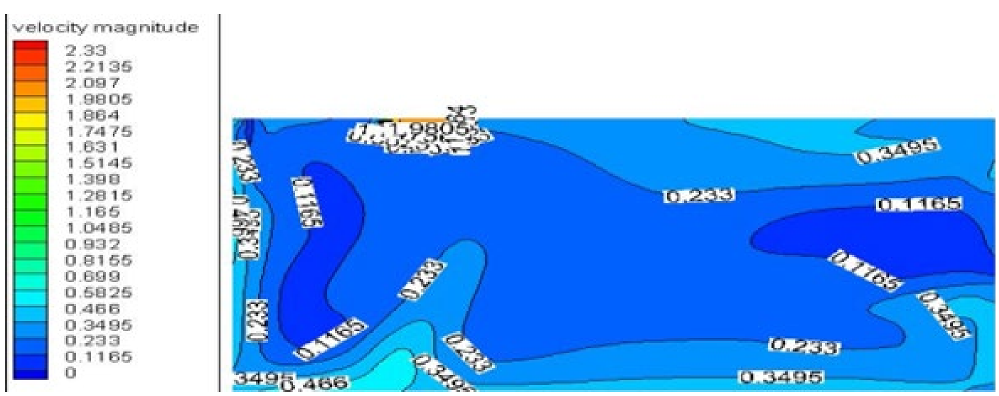
(c) size of indoor unit is 0.45m×0.25m×0.2m



(d) size of indoor unit is 0.6m×0.2m×0.3m



(e) size of indoor unit is 0.5m×0.25m×0.4m



(f) size of indoor unit is 0.5m×0.3m×0.5m

Figure 5: Cloud Pictures of Velocity Distribution at the Section z=1.8m

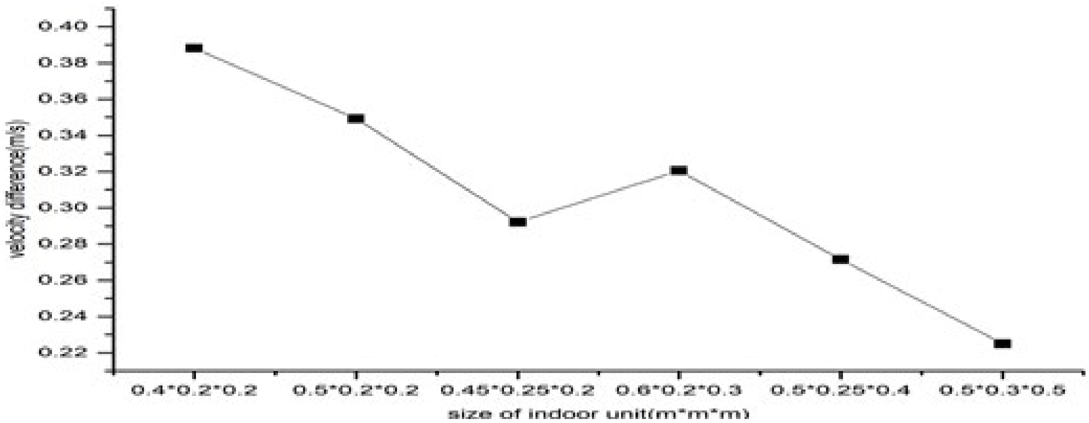


Figure 6: Line Diagram of Velocity Difference at the Section z=1.8m

It can be seen from Fig. 5 that velocity near the air supply vent of air-conditioner indoor unit is larger. When the air is away from the air supply vent, there is a more obvious decrease in velocity. In the indoor activity area, there are local areas where velocity is low. With the increase in the size of the air-conditioner indoor unit, velocity in the local areas where velocity is low gradually decreases, which varies from 0.2005m/s to 0.1165m/s. From Fig. 6, it can be found that before the size of the indoor unit 0.6m×0.2m×0.3m, the velocity difference decreases first and increases then with the increase in the size of the air-conditioner indoor unit. After the size of the indoor unit 0.6m×0.2m×0.3m, with the increase in the size of the air-conditioner indoor unit, there is a gradual decrease in velocity difference at the z=1.8m section. It can be seen from Table 4 that when the size of the air-conditioner indoor unit is 0.4m×0.2m×0.2m, velocity difference is 0.3882m/s; when the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, velocity difference is 0.3493m/s; when the size of the air-conditioner indoor unit is 0.45m×0.25m×0.2m, velocity difference is 0.29216m/s; when the size of the air-conditioner indoor unit is 0.6m×0.2m×0.3m, velocity difference is 0.32049m/s; when the size of the air-conditioner indoor unit is 0.5m×0.25m×0.4m, velocity difference is 0.27146m/s; when the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, velocity difference is 0.22506m/s. Velocity difference is smaller when the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, so velocity distribution is more uniform.

Table 4: Size of Indoor Unit and Velocity Difference at the Section z=1.8m

Size of Indoor Unit	Velocity Difference at the Section z=1.8m
0.4m×0.2m×0.2m	0.3882
0.5m×0.2m×0.2m	0.3493
0.45m×0.25m×0.2m	0.29216
0.6m×0.2m×0.3m	0.32049
0.5m×0.25m×0.4m	0.27146
0.5m×0.3m×0.5m	0.22506

Analysis of PMV Under Different Sizes of Air-Conditioner Indoor Units

Temperature and velocity are two main factors which affect the indoor thermal comfort, but they are not used to evaluate the indoor thermal comfort. In order to evaluate it effectively, the important index--- PMV needs to be introduced. PMV is graded by seven grades, as is shown in table 5 [12]. When the size of the air-conditioner indoor unit is 0.4m×0.2m×0.2m, 0.5m×0.2m×0.2m, 0.45m×0.25m×0.2m,0.6m×0.2m×0.3m,0.5m×0.25m×0.4m, 0.5m×0.3m×0.5m, the average PMV at the z=1.8m section calculated with fluent software is shown in Table 6.

Table 5: PMV Thermal Sensation Scale

Thermal Sensation	cold	cool	slightly cool	moderate	slightly warm	warm	hot
PMV	-3	-2	-1	0	+1	+2	+3

Table 6: PMV at the z=1.8m Section Under Six Different Sizes of Air-Conditioner Indoor Unit

Sizes of Indoor Unit	PMV
0.4m×0.2m×0.2m	0.159429
0.5m×0.2m×0.2m	0.146205
0.45m×0.25m×0.2m	0.23819494
0.6m×0.2m×0.3m	0.15811349
0.5m×0.25m×0.4m	0.23878027
0.5m×0.3m×0.5m	0.29167604

It can be seen from Fig. 6 that for the six different sizes of indoor unit, PMV ranges from 0-0.5, with nobody feeling cold or hot. When the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, PMV at the z=1.8m section is smallest, which is closest to 0, and thermal sensation is almost moderate. Thus, when the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, better indoor comfort can be achieved.

Conclusions

The research on the temperature distribution, velocity distribution and PMV distribution at the z=1.8m section under six different sizes of wall-hanging air-conditioner indoor unit is carried out through the method of numerical simulation. Conclusions are as follows,

1. Under six different sizes of wall-hanging air-conditioner indoor unit, temperature in the activity area of the room is close to the indoor air-conditioning design temperature in summer. When the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, temperature difference is smaller, which is 2.1251K. Thus, the indoor temperature distribution is more uniform.
2. When the size of the air-conditioner indoor unit is 0.5m×0.3m×0.5m, the velocity difference at the z=1.8m section is smallest, which is 0.22506m/s. Thus, the velocity distribution is more uniform.
3. When the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, PMV at the z=1.8m section is closest to 0, and thermal sensation is almost moderate. Thus, when the size of the air-conditioner indoor unit is 0.5m×0.2m×0.2m, better indoor comfort can be achieved.

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