Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2506 – 2511

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

A numerical simulation of air distribution in an office room ventilated by 4-way cassette air-conditioner

Oluleke Bamodu [a] , Liang Xia [a,*], Llewellyn Tang [a]

[a]Department of Architecture and Built Environment, The University of Nottingham,Ningbo 315100, China

Abstract

The work in this paper involves the investigation of an office room in cooling mode ventilated by a 4-way cassette air-conditioner, which is increasingly being installed in Eastern China. A comparison of the 4-way cassette AC is made against a typical wall-mounted mixing ventilation system based on ADPI calculations as well as difference in air temperature and velocity. The results in this paper, which are carried out by computational fluid dynamics (CFD) simulation, indicate that a superior air distribution performance is achieved by the 4-way cassette AC when compared to the wall-mounted system. The results also show potentials for energy saving using the 4-way cassette AC.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Air distribution; ADPI; indoor environment; 4-way cassette AC; ventilation; CFD

1. Introduction

Increasing use of HVAC (heating, ventilation, and air conditioning) systems in buildings especially in developed and developing countries have a major impact on the amount of energy consumed in buildings, which in turn account for over 40% of total energy consumption worldwide.

Owing to depleting energy sources, stricter energy policies and drive towards sustainability, various types of ventilation and air distribution systems have been used and researched, such as mixing ventilation, displacement ventilation, hybrid air distribution, personalised ventilation [1, 2] amongst others in order to balance the conflicting relationship of improving the indoor quality while reducing energy consumption. A high-quality ventilation system

* Corresponding author. Tel.: +86-574-8818-9839; fax: +86-574-8818-0175.
E-mail address: Liang.Xia@nottingham.edu.cn

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.722

is required to be energy efficient in addition to being able to achieve good thermal comfort and distribute clean air at appropriate temperature and flow rate within the indoor space where needed, these form the core of many researches involving HVAC system performance [3, 4].

One of the earliest and most widely used system is the mixing ventilation (MV) which has been in existence for over a century and is well defined in international standards [5, 6].One commonly utilized MV systems in China is the wall-mounted air-conditioners, however a new type of MV systems (4-way cassette air-conditioner) are approved and are widely deployed in offices in recent years in Eastern China [7]. Despite numerous research studies covering mixing ventilation such as Lin et al.[8] and Jouini et al.[9], studies focused on the 4-way cassette air-conditioner such as Noh et al. [10] or comparison between it and the wall-mounted AC are limited.

In this paper, a numerical simulation would be carried out using CFD to compare the air distribution of a 4-way cassette AC with a traditional wall-mounted AC. To evaluate the effectiveness of an HVAC in an indoor space, it is crucial to investigate the climate conditions, airflow and air distribution within the indoor space. This is because the air distribution in the room to a great extent affects the performance or the amount of warm or cold air supply needed to meet same comfort satisfaction or requirement; and by extension, the quality of the indoor space. Such numerical study can be carried out by CFD simulation which can aid in predicting the indoor environment condition and visualising airflow and temperature [3, 11].

Nomenclature

N_o	test points meeting the effective draft temperature requirements
N	total test points
T	local air temperature
T_{ac}	average test zone temperature
v	local air velocity (m/s)

2. Numerical model

2.1. Model description

A three-dimensional model of the office room used in this study is shown in Fig. 1 below. The room is modelled using dimension of an office room at the University of Nottingham, Ningbo Campus equipped with the 4-way cassette AC. Fig 1b and c show similar rooms using the wall-mounted AC.

The dimension of the room is 6.8 ×3.8 × 3m. The window is 3.4 × 2.4m and is located on the upper portion of an external east wall. The simulation used here is that of summer conditions, with cool air supplied into the room through the inlets of the 4-way cassette AC, while warm air is evacuated through the exhaust of the 4-way AC (Fig. 2a). In the case of the conventional MV system (Fig 2b), cool air is supplied through the inlet at the top of the west wall and evacuated at the lower part of the room on the east (Fig 1b) or west wall (Fig 1c).

Each of the simulated configurations is shown in Fig 1 below. The temperature of the window is set to 31^0C, while the walls, floor and ceiling are assumed to be adiabatic non-slip. Six fluorescent lamps (14W) are located on the ceiling of the room. Other conditions and considered cases are contained in the case studies section.

The airflow in the room is three-dimensional; steady state, incompressible and turbulent, hence the governing incompressible, Navier-Stokes and continuity equation in Cartesian coordinate are described by the energy, mass and momentum conservation equations.

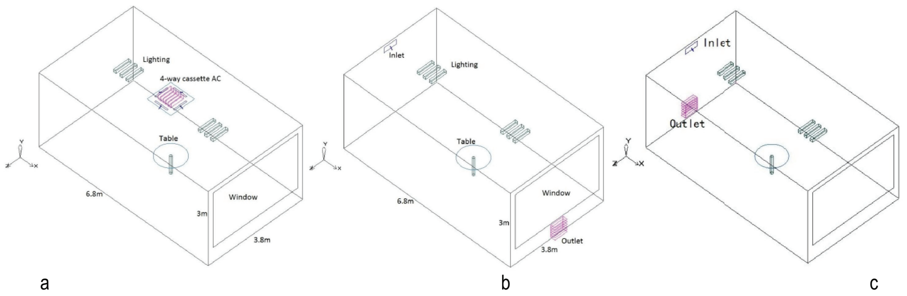


Fig. 1. Model of office room with: (a) 4-way cassette air-conditioner; (b) air supply inlet and outlet on opposite sides of wall; (c) air supply inlet and outlet on same side of wall.

Fig. 2. (a) 4-way cassette air-conditioner; (b) typical wall-mounted air-conditioner.

2.2. Case studies and solution method

A total of 9 cases are considered in this study to compare the air distribution performance of the 4-way cassette AC against conventional wall-mounted ones, with the three basic layout configurations shown in Fig 1(a, b, c). With other conditions being same including the supply air velocity and air volume, the supply angle is varied between 30^0 and 45^0, while the temperature is set to 16^0C or 18^0C. The simulated cases are shown in table 1 below.

Table 1. Configuration conditions for simulated cases.

Case	Layout type	Supply temperature (°C)	Supply outlet angle (°)	Supply velocity (m/s)
1	A	16	30	1.055
2	B	16	30	1.055
3	C	16	30	1.055
4	A	16	45	1.055
5	B	16	45	1.055
6	C	16	45	1.055
7	A	18	30	1.055
8	B	18	30	1.055
9	C	18	30	1.055

The modelling, meshing and simulations in this study are carried out using Airpak 3.0.16, which is an HVAC specially designed CFD software from Ansys. SIMPLE algorithm is used for the coupling between velocity and pressure, while the finite volume solver numerically simulates the temperature; airflow based on standard $k-\varepsilon$ model and calculates the corresponding ADPI. The convergence criterions used in these simulations are less than 10^{-6} for energy conversion normalised residual, while others are set to be less than 10^{-3}.

The whole simulations are carried out on an Intel ® Core ™ i7-3770 CPU 3.4GHz computer with 16GB of internal memory. For improved accuracy, fine grid settings as increase of the total number of grids are used with further refinement at the air inlets and outlets.

3. Simulation results and discussion

3.1. ADPI

The ADPI (air diffusion performance index) is a function of effective draft temperature and air velocity commonly used to evaluate the performance of an air distribution system in a room or space. The ADPI can be calculated as the percentage of test points obtained in the measuring zone that meet the ASHRAE requirement where effective draft temperature (EDT) is between -1.7 °C and 1.1 °C, and air velocity of 0.35m/s or less by the total measuring point [2, 12].

$$ADPI = \frac{N_O}{N} \times 100 \quad (1)$$

$$EDT = (T - T_{ac}) - 8(v - 0.15) \quad (2)$$

Comparing the performance of the 4-way cassette AC and the wall-mounted AC (two different layouts; Fig 1b and 1c), the ADPI are calculated for the simulated cases and presented below in Fig 3.

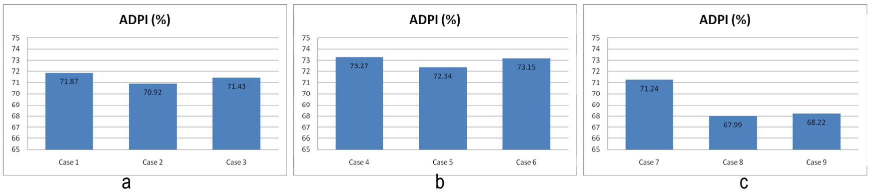


Fig. 3. Chart of ADPI calculations comparing: (a) case 1, 2, 3; (b) case 4, 5, 6; (c) case 7, 8, 9.

From the above charts (Fig 3), it is observed that the room equipped with the 4-way cassette AC, perform slightly better in all cases considered based on the ADPI calculations than the room equipped with the typical wall-mounted AC type. Since uniform distribution of air can be represented with the ADPI, it can be deduced that the 4-way cassette AC perform better in terms of air distribution than the conventional AC. Considering the fact that ADPI is dependent on the room geometry, supply airflow rate, and room thermal load amongst other factors; the 4-way cassette air-conditioner is expected to achieve even better performance in a square-shaped room due to the four way equal distribution of air than the conventional wall-mounted system in similar shaped room.

3.2. Vertical air temperature and velocity difference

Choosing the best performance configurations based on ADPI (Fig 3b), Fig 4 (a, b, c) represents charts showing the difference in temperature between y = 0.1m (knee) level & y = 1.1m (head of seated person) level, and also the difference between y = 0.1m & 1.7m (head of standing person) level. From the charts, it is shown that Case 4 (Fig 4a) which is that of the 4-way cassette AC produces less difference in temperature between the 0.1m & 1.1m and 0.1m & 1.7m levels along the room length, i.e., x coordinate.

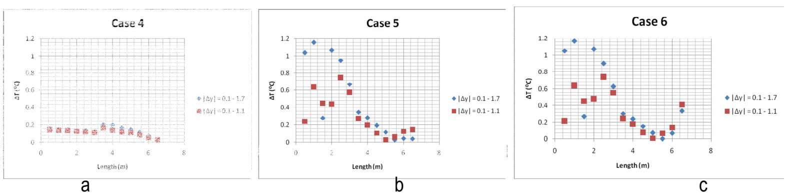
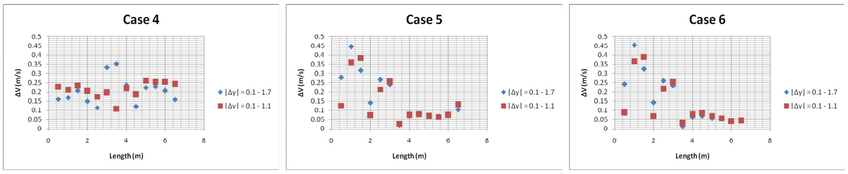


Fig. 4. Chart of difference in temperature between level 0.1 & 1.7, and 0.1 & 1.1 for: (a) case 4; (b) case 5; (c) case 6.

The highest difference observed is approximately 0.2 ^{0}C for the 4-way cassette AC in case study 4, while a difference of almost 1.2^{0}C is observed for the conventional AC system in Case 5 and 6. As expected, the locations of the highest difference are noticed close to the air supply position in all cases (i.e. close to the centre of room for the 4-way cassette AC and close to the wall for the conventional AC).



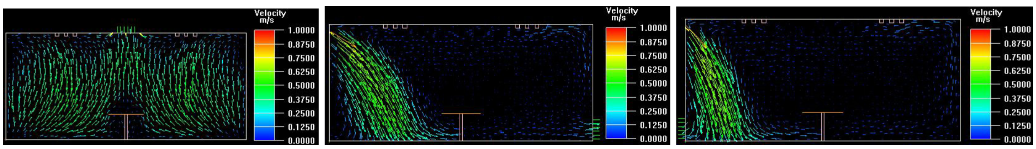
a b c

Fig. 5. Chart of difference in air velocity between level 0.1 & 1.7, and 0.1 & 1.1 for: (a) case 4; (b) case 5; (c) case 6.

Similar conditions with the temperature difference can also be observed from the velocity air velocity difference. The 4-way cassette AC maintains lesser difference in air velocity with the highest variation of approximately 0.35m/s located close to the centre of the room (Fig 6a), while a value of approximately 0.45m/s is recorded for the typical AC in Case 5 and Case 6 (Fig 6b, 6c). The locations of these maximum difference points are similar to those of the maximum temperature difference.

3.3. Airflow and temperature patterns

The air velocity and temperature patterns taken at cross section Z = 1.9m (centre of room) are shown in Fig 6 and Fig 7 below. As can be seen in Fig 6, the airflow pattern for Case 5 and Case 6, the vectors have a downward fall before proceeding along the room length in an anticlockwise direction. In both cases, there is also a significant amount of stagnation of airflow. The slight difference between the 2 patterns is the short circuiting (approach towards the exhaust before movement along room) of airflow observed in Fig 6c. The 4-way cassette AC on its part produces a different airflow pattern, with the vectors moving back towards the centre of the room and pointing upwards due to the location of the exhaust.

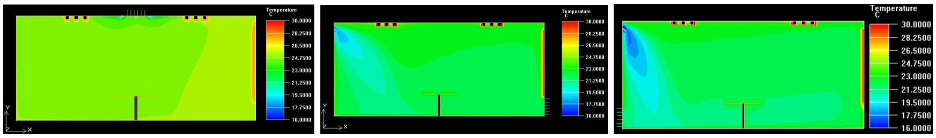


a b c

Fig. 6. Airflow pattern at cross section Z = 1.9m for: (a) case 4; (b) case 5; (c) case 6.

The temperature is more pronounced towards the supply, then becomes uniform moving further into the room. This pattern can also be noticed from earlier analysis of the temperature and air velocity difference, with the max difference located close to the air supply zone, while variations become lesser along the room or in other words, become more uniform.

It is found from the results that ADPI level is more satisfactory for Case 4 compared to both Cases 5 and 6, suggesting the 4-way cassette AC is at least superior in performance to the other two types of wall-mounted AC configurations. Although the indoor thermal comfort involves temperature, humidity and others, ADPI should be included into the consideration of a comprehensive study of indoor thermal comfort and can be used as a starting point. Comparison between Fig 3 a, b and c indicates that an increase in inlet angle may have higher ADPI and can allow for an increase in supply temperature. This concludes that energy saving can be achieved after considering parameters such as temperature, humidity and ADPI etc thoroughly and optimising such parameters.



a b c

Fig. 7. Temperature pattern at cross section Z = 1.9m for: (a) case 4; (b) case 5; (c) case 6.

4. Conclusions

A numerical investigation is carried out in this paper using CFD to simulate the indoor climate in an office room ventilated by a 4-way cassette air-conditioner in cooling mode. A comparison is carried out against two similar rooms but ventilated by different layout configuration of a typical mixing ventilation air-conditioner.

The investigation produced the following observations:

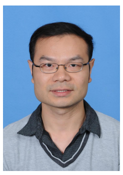
- The 4-way cassette air-conditioner performed slightly better than the typical wall-mounted air-conditioner and provides a better uniformity in air distribution based on the ADPI.
- The 4-way cassette AC produced lower variations in air temperature and velocity than the typical AC.
- It is expected that the 4-way cassette AC will further perform better than the typical MV system in a square-shaped room, although this have to be investigated.
- Optimising the supply air temperature and air supply angle has potential energy saving possibility.

Acknowledgements

The work presented herein is funded primarily by Ningbo Science and Technology Bureau (Grant No. 2015B11011) through the Innovation Team at the University of Nottingham Ningbo China.

References

[1] Seppänen O. Ventilation strategies for good indoor air quality and energy efficiency. International Journal of Ventilation 2008;6: 297-306.
[2] Cao G, Awbi H, Yao R, Fan Y, Sirén K, Kosonen R, Zhang J. A review of the performance of different ventilation and airflow distribution systems in buildings. Building and Environment 2014;73(3): 171-186.
[3] Gan G. Evaluation of room air distribution systems using computational fluid dynamics. Energy and Buildings 1995;23(12): 83-93.
[4] Awbi HB. Energy efficient room air distribution. Renewable Energy 1998;15(9): 293-299.
[5] Boyle & Son R. Natural and artificial methods of ventilation. London; 1899.
[6] ANSI/ASHRAE. Standard 113-2013, Method of Testing for Room Air Diffusion. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers Inc.; 2013.
[7] Ningbo Public Procurement. [Online]. Available: http://www.nbzfcg.cn
[8] Lin Z, Chow TT, Fong KF, Tsang CF, Wang Q. Comparison of performances of displacement and mixing ventilations. Part II: indoor air quality. International Journal of Refrigeration 2005;28(3): 288-305.
[9] Jouini DB, Saïd MN, Plett EG. Measurements of room air distribution in a ventilated office environment. Building and Environment 1994;29(10): 511-521.
[10] Noh KC. Han CW, Oh MD. Effect of the airflow rate of a ceiling type air-conditioner on ventilation effectiveness in a lecture room. International Journal of Refrigeration 2008;31(3): 180-188.
[11] Chen Q, Zhai Z. The use of CFD tools for indoor environmental design. In: Malkawi A, Augenbroe G, editors. Advanced Building Simulation, New York: Spon Press; 2004. p. 119-140.
[12] ANSI/ASHRAE. Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers Inc.; 2004.



Biography

Dr. Liang Xia's research field is in building services engineering and indoor thermal comfort. He has published more than 30 research articles and conference papers in the field. He has secured research funds with total amount more than RMB 0.5 million.