Performance test & analysis on fan coil unit and improved induction air unit system

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Abstract. Induction air unit was improved by decreasing the induction ratio and adding the rectifier. Performance test on fan coil unit and improved induction air unit system was carried in the model houses. Test results showed: (1) Induction air unit system could meet the temperature requirement of room. It had a strong dehumidifying ability and much uniformity air velocity in the range of comfortable. (2) Induction air unit system had little temperature gradient and difference. (3) The unit was energy efficient combined with the extensive air handling unit and medium temperature chiller. Improved induction air unit would be used in the high quality air conditioning spaces.

1. Introduction
Global buildings are responsible for approximately 40% of the total world annual energy consumption [1]. Almost all buildings need Heating, Ventilation and Air-Conditioning (HVAC) systems to improve indoor air conditions. Energy consumption of HVAC systems accounts for a large proportion of building energy consumption. Nowadays, more and more people focus on thermal comfort and energy performance of HVAC systems. Most common HVAC systems applied in buildings are fan coil units (FCU) systems, variable air volume (VAV) systems and constant air volume (CAV) systems. In addition, some engineers would like to design green buildings with a more effective HVAC system.

Chilled beams have been proven to be a reliable solution for HVAC system and it has been successfully utilized in Europe for more than 20 years due to favorable performance regarding energy efficiency, thermal comfort and economy [2-3]. The chilled beam system can be generally classified into Active Chilled Beam (ACB) system and passive chilled beam system according to whether there is forced primary airflow [4-5]. There are some research related to chilled beam system.

Farhad Memarzadeh et al. [6] concluded that the total energy consumption of the chilled beam system was 42.5% lower than that of the traditional air-conditioning system. Rhee et al. [7] compared the ACB system with other conventional HVAC systems and concluded that ACB system achieved a better thermal uniformity and with less air flow rate than other conventional air distribution systems.

Gaolin Liang et al. [8] and Zhiyi Wang et al. [9] presented that induction air unit system is a form of semi-central air conditioning system. It could save construction space and meet the requirements of the system fresh air demand as it used a lower supply air temperature and a smaller air duct.
2. Experimental setup

2.1. Improved induction air unit system

Induction air unit is the terminal unit of the air conditioning system where the conditioned air is discharged into the occupied place. It is composed of stamping parts, a nozzle, a plenum chamber, and primary air pipe, as it is shown in figure 1. Induction air unit indoor load was entirely removed by the primary air. The terminal could increase the supply air volume and reduce the temperature difference of the air supply by inducing a certain indoor air. The inducer induction ratio could be calculated as:

\[ n = \frac{G_2}{G_1} \]  

where \( G_2 \) is secondary air volume \([\text{m}^3/\text{s}]\); \( G_1 \) is primary air volume \([\text{m}^3/\text{s}]\). The general induction ratio is between 2.5 and 5, while the improved inducer induction ratio is approximately 1.5.

The improved inducer used rectifier (figure 2), the air velocity of the outlet was controlled at 0.2 m/s-0.8 m/s, creating a better airflow and temperature distribution. Due to the decrease of the supply air temperature, the intensive air handling unit (AHU) used the oval tube heat exchanger to generate 13°C air supply to the inducer system to induce indoor air.

![Induction air unit system](image1)

![Rectifier](image2)

2.2. The test room and measurement points distribution

The measurements were carried out in full-scale mockup of two identical office rooms (see figure 3). The dimensions of the room are 6.4m×3m×3.3m (L×W×H). The temperature, relative humidity, air velocity and PPD index were tested in the middle of two terminals and right below the air opening at the level of 1200 mm from the floor.

Considering the symmetry of the room, the temperature is tested on one side covering nearly half of the room. 36 (6×6) points are measured with a height of 400 mm, 840 mm, 1280 mm, 1720 mm, 2160 mm, 2600 mm.
2.3. Measurement device
The measurements were carried out on August 16, 2013. The room temperature was measured by a platinum resistance thermometer. The room relative humidity, air velocity and PPD index were tested by a thermal environment analyzer (PMV and PPD indices meter). The unit and system power were tested by a clamp-type power meter.

2.4. The equipment comparison of improved induction air unit and fan coil unit
The system diagram of cooling & heating water system was shown in figure 4. The detailed equipment comparison was shown in table 1.

| Equipment                  | Improved Induction air unit                                                                 | Fan coil unit                                                                 |
|----------------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Air source heat pump unit  | Medium temperature air source heat pump unit: water temperature : inlet 20°C, outlet 10°C | Air source heat pump unit: water temperature : inlet 12°C, outlet 7°C           |
| Terminal                   | AHU: water temperature: inlet 10°C, outlet 20°C, supply air temperature: 13°C, rated air flow rate: 275m³/h | FCU: water temperature: inlet 7°C, outlet 12°C, supply air temperature: 13°C, rated air flow rate: 680 m³/h |
| Circulating pump           | Water flow rate: 0.35t/h, pump head: 3.5m                                                   | Water flow rate: 0.7t/h, pump head: 3.5m                                      |
| Fan                        | Air flow rate: 275 m³/h, pressure head: 50Pa                                                | Air flow rate: 680 m³/h, pressure head: 30Pa                                 |
| Air supply opening         | Area: 1685mm×638mm                                                                          | Area: 400mm×150mm                                                            |
3. Results

3.1. Comparison of supply air thermal comfortable

The data of temperature, relative humidity, air velocity, PPD index were collected for each point. The horizontal axis stands for the timeline, while the vertical axis represents temperature, relative humidity, air velocity, PPD respectively (see figure 5).

![Figure 5. Test results comparison of thermal environment analyser.](image)

Where, FCU represents fan coil unit, IAU represents induction air unit; subscript 1 represents the measuring point in the middle of two terminals, subscript 2 represents the measuring point right below the air opening.

As can be seen from the figures, the indoor temperature could be well adjusted at a higher outdoor temperature regardless of the FCU system or the IAU system, which was shown in figure 5 a). The IAU had a stronger dehumidification capacity due to take on the 13 °C air supply temperature, which was shown in figure 5 b), the relative humidity in the room which used IAU was lower than that used FCU. In figure 5 c), the air velocity was about 0.20m/s in the room used FCU, which was in the comfortable air velocity range. But the air velocity right below the air opening was 2.03m/s, which was exceeding the upper limit air velocity for comfort 0.38m/s. The air velocity was about 0.13m/s in the room used IAU, and the air velocity right below the air opening was 0.14m/s, both in the range of comfortable. The IAU system has a better air velocity uniformity and higher PPD index (see figure 5 d)).

3.2. Comparison of temperature distribution

The horizontal axis stands for the height of the measuring points, while the vertical axis represents temperature (figure 6). The measuring bars number are shown in figure 3.
In the text room used FCU, the lowest temperature at the same height is located at the right below the air opening (measuring bar 3), and the maximum temperature difference in the horizontal direction of the personnel activity area is 4.2°C. In the text room used IAU, the maximum temperature difference in the horizontal direction of the personnel activity area is 1.9°C. The temperature difference is smaller than that used FCU. Thus, the temperature distribution in the horizontal direction is more uniform when used the IAU.

In the text room used FCU, the maximum temperature difference in the vertical direction is 4.2°C, and the maximum temperature difference in the vertical direction of the personnel activity area is 2.4°C. In the text room used IAU, the maximum temperature difference in the vertical direction is 3.9°C, and the maximum temperature difference in the vertical direction of the personnel activity area is 2.2°C. Thus, the temperature distribution in the vertical direction is relatively uniform.

3.3. Comparison of energy consumption
The horizontal axis stands for the timeline, while the vertical axis represents power consumption (figure 7). The results showed that the energy consumption of the IAU system was around 20% lower than that of the FCU system.

Where, the subscript c indicates the power consumption of the chiller, and the subscript t indicates the total power consumption of the system.

4. Conclusions
Compared to the FCU system, improved IAU system is suitable for places with high requirements of comfort and air velocity. It could be promoted depending on the following advantages.

1. The improved IAU system has a low air velocity with no draft sensation on human body, it has much uniformity temperature distribution and high comfort.
2. Energy consumption of the improved IAU system combination with medium temperature chillers and extensive air handling units is lower than energy consumption of the FCU system.
3. The improved IAU system can supply fresh air and has no condensation water that guarantee the indoor air quality.
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References
[1] Omer, A.M. (2008) Energy, environment and sustainable development. Renewable and Sustainable Energy Reviews, 12: 2265-2300.
[2] Chen, C., et al., (2014) Performance comparison of heat exchangers with different circuitry arrangements for active chilled beam applications. Energy and Buildings, 79: 164-172.
[3] Filipsson, P., et al. (2017) A thermal model of an active chilled beam. Energy and Buildings, 149: 83-90.
[4] Wu, B.J., Cai, W.J., Chen, H.R., Ji, K. (2018) Experimental investigation on airflow pattern for active chilled beam system. Energy and Buildings, 166: 438-449.
[5] Filipsson, P., et al. (2016) Induction ratio of active chilled beams – Measurement methods and influencing parameters. Energy and Buildings, 129: 445-451.
[6] Memarzadeh, F., Jiang, J., Manning, A. (2007) Numerical investigation on ventilation strategy for laboratories: An approach to control thermal comfort and air quality using active chilled beams. In: Energy Sustainability Conference. 409-416.
[7] Rhee, K.-N., et al., (2015) Thermal uniformity in an open plan room with an active chilled beam system and conventional air distribution systems. Energy and Buildings, 93: 236-248.
[8] Liang, G.L., et al., (2006) Study and performance evaluation of induction-unit of cold air distribution system. Contamination Control & Air-conditioning Technology, 3: 12-14.
[9] Wang, Z.Y., Wang, G.Y., Liu, S.Q., Xu, J. (2015) Performance test of medium temperature chiller with induction air unit system applied to office buildings. HV&AC, 11: 58-61.