# Experimental study on unsteady air terminal

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## ABSTRACT

This paper describes the unsteady terminal and presents its characteristics gained from experiment. The experimental results showed that the fan-coil unit tested in the experiment was able to provide fluctuating airflow and the velocity curve of supply airflow was consistent with the control signal very well. The spectrum of supply airflow is similar to the spectrum of natural wind if the control signal simulating natural wind provided. The supply air temperature is changed when the airflow is changed. Owing to the unsteady air supply, both the airflow rate and the cooling capacity of the unit are decreased up to 3% in the case of dry coil. The airflow rate from the outlet was measured and the turbulence coefficient was found to be 0.097. The distribution of the velocities at a height 1.1 m above the floor was measured. It is found that in the air velocity distribution, the area covered by the high-speed airflow was relatively small, which needs be improved.

## INDEX TERMS

Unsteady fan-coil unit; Fluctuating airflow; Cooling capacity

## INTRODUCTION

Energy saving is the highlight of many researches, especially in recent years. The energy consumed by buildings is almost one-third of the amount that the country consumes. Air conditioning system forms the major part of energy consumption in a building. One reason is that the objective of traditional air conditioning strategy has been to cover the whole room. Another is that the air movement is restricted strictly, that is, the cooling of air movement cannot be used. Questionnaire (Zhao *et al*., 1997) result showed that natural wind is the favourite mode and the indoor set temperature could rise to high levels if the airflow mode is suitable. So a new conditioning strategy, namely unsteady air-conditioning has been presented (Zhao *et al.*, 1997). The main feature of the strategy is to elevate the temperature settings, and to fully use the isothermal or non-isothermal fluctuating air movement in summer. The dynamics of air velocity is a feasible method. In order to investigate a terminal device (fan-coil unit and any other kind of indoor unit) with unsteady supply airflow, a kind of fan-coil unit (FCU) with a swing plate has been designed and manufactured. Furthermore, the performance of the unit has also been tested.

## STRUCTURE OF UNSTEADY FCU

The configuration of the FCU is shown in Figure 1. The unit has two heat exchangers connected with chilled water system in parallel. Each heat exchanger has two rows of fin tubes (length: 500 mm) with a heat transfer area of 3.415 $m^2$. The swing plate is driven by a step motor, which can control the angular motion of the plate according to the simulation program. Therefore, the supply airflow from each outlet will be changed during the course of the plate movement.

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## EXPERIMENTAL ARRANGEMENT

The experiment of the unsteady FCU was conducted in the test chamber of HVAC laboratory of Tsinghua University. The air temperature in the chamber was controlled by RH-DCU-4040 controller, which regulates the electrical heater to keep the temperature within ±0.2°C, while the air relative humidity was controlled by an ultrasonic humidifier.

The experimental schematic diagram is shown in Figure 2. In the experiment, the tested FCU was run at steady or unsteady air supplies by turning the swing plate ON/OFF. In the steady mode, the airflow passing through the heat exchanger was constant, and a frequency converter was used to control the fan speed as well as the airflow rate. In the unsteady mode, for comparison, all parameters in the testing rig were kept as the same level as in the steady case, except that there was movement of the swing plate. Sensors used to measure air and water temperatures are copper–constantan thermocouples. Float meters within the range of 40–250 kg/h measured the water flow rates at both the heat exchanger inlet pipes. Air velocities at two outlets were measured by hot-wire anemometer made by the Laboratory of Meteorological Physics, Beijing University. Data acquisition and processing were done by HP 3852A and a personal computer.

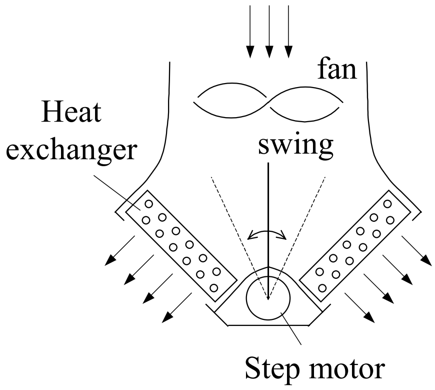
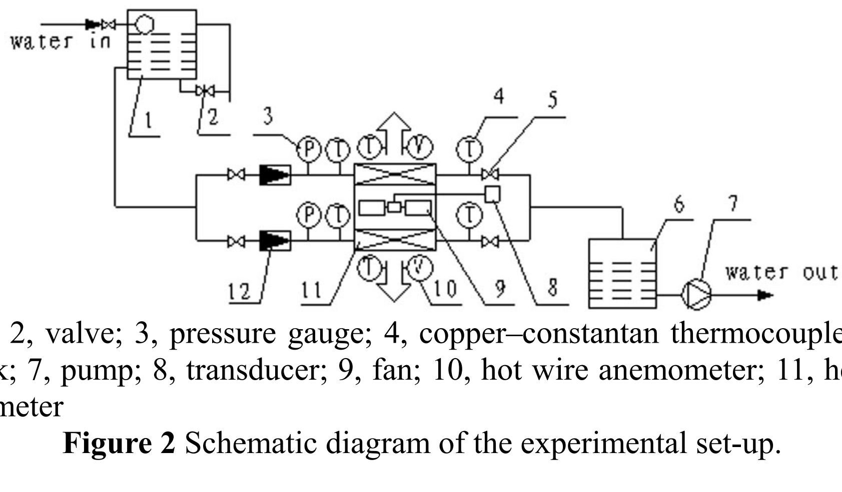



**Figure 1** A sketch of the unsteady FCU structure.

The temperature sampling frequency was 1 Hz and the sampling frequency of air velocity was 10 Hz. The testing conditions were: converter frequency: 16, 24, 32, 40 Hz; water flow rate: 100, 150, 180, 210 kg/h; inlet air temperature: 28°C; relative humidity: 25–40%; inlet water temperature: 14°C.

The experimental procedure was to start the testing system at a certain fan speed and water flow rate first, and then to measure the parameters (air and water temperatures, water flow rate and pressure drop across the exchanger). When every parameter measured came to a constant value, air velocity measurement started from the steady to the unsteady mode.




1, water tank; 2, valve; 3, pressure gauge; 4, copper–constantan thermocouples; 5, valve; 6, collection tank; 7, pump; 8, transducer; 9, fan; 10, hot wire anemometer; 11, heat exchanger; 12, float flowmeter

**Figure 2** Schematic diagram of the experimental set-up.

## RESULTS AND ANALYSES

### Unsteady Airflow Characteristics

As the swing plate stopped in the middle of the unit throat, the coming airflow was separated into two branches passing through the heat exchangers constantly. As the plate started to move, the airflow was separated by the plate position. The higher flow rate at the right side, the lower flow at the left, simultaneously. Figure 3 gives a comparison of the curves of one outlet velocity and the control signal. It is clear that they are consistent with each other. So, a different airflow mode can be attained by changing the control signal.

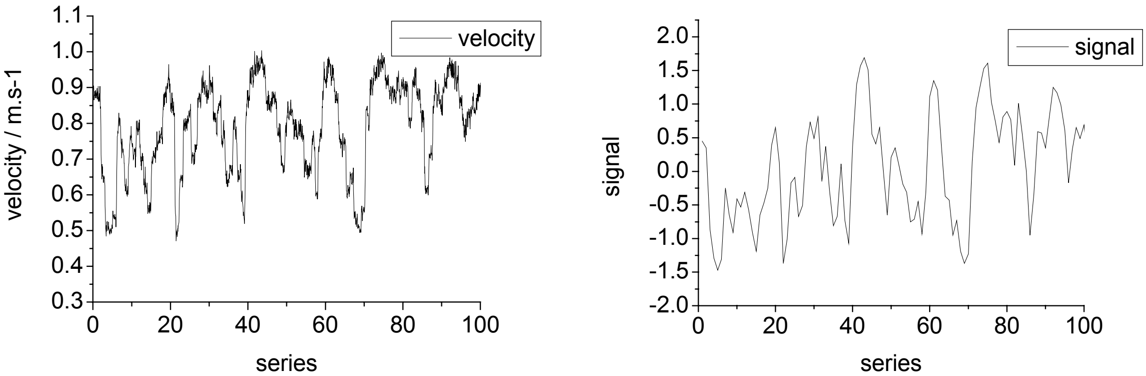



**Figure 3** The curves of outlet velocity (left) and the control signal (right).

Figure 4 shows the difference between mean air velocities in the steady and unsteady modes. It should be noticed that the mean air velocity in the steady mode is slightly higher than that in the unsteady mode. At the same time, the outlet air temperature is varied with the airflow change (shown in Figure 5). It is seen that the average temperature of airflow is also slightly higher in the steady mode than in the unsteady mode. So, the supply airflow not only gives fluctuating air movement, but is also non-isothermal. The effect of exposure to such an air jet on human subjects needs to be studied.

The swing plate, which changes the resistance characteristic of the air passage, causes the decrease of mean air velocity in the unsteady mode. This decrease will also affect the heat transfer of the coils.

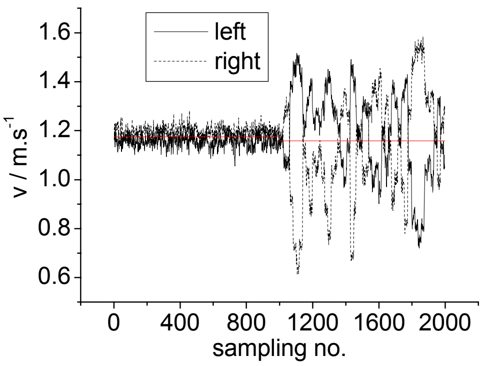



**Figure 4** The unsteady outlet airflow of FCU (180 kg/h, 24 Hz).

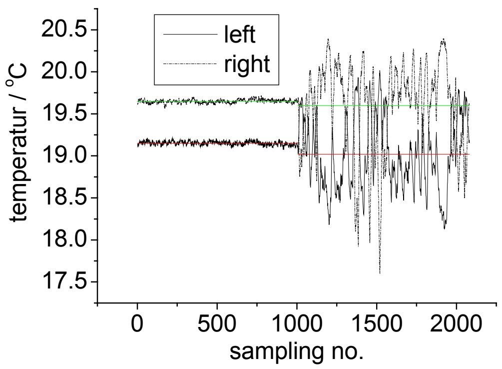



**Figure 5** Outlet temperature curves in the steady and unsteady modes (180 kg/h, 24 Hz).

**Air Velocity Spectrum Analysis**

The spectra of air velocity spectra measured at the outlets of the FCU are different for the steady and unsteady airflows. The unsteady one is similar to the natural wind, (as shown in Figure 6) if the control signal simulates the natural wind. In fact, the fluctuating airflow simulated is to increase the power at lower frequencies, but the same spectrum as the real natural wind is not obtained. According to the previous research on the acceptability of different airflow patterns (constant, sine curve, stochastic and simulated natural), it was approved that the simulated natural wind was selected by over 60% of subjects as the preferable airflow pattern (Jia, 2000). So the supply airflow should be able to reach the occupant zone directly even if its spectrum will have a little change after passing a certain distance.

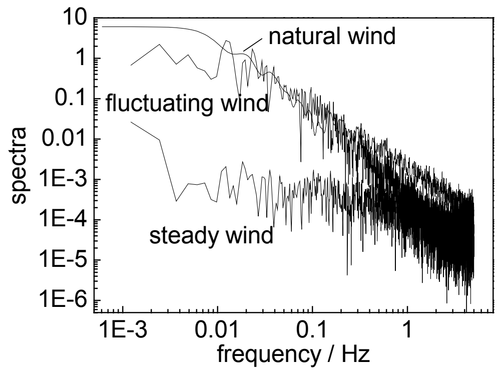



**Figure 6** Analysis of the spectrum of the outlet-air speed (24 Hz).

**Heat Exchange Performance**

At the beginning, it was supposed that the heat transfer of the coil would be enhanced more or less due to the unsteady airflow. As a matter of fact, the measured cooling capacity in the unsteady mode is slightly less than that in the steady mode. The decrease of the cooling capacity is not notable since the difference of capacities in both modes is too small and less than 3% (shown in Figure 7).

Comparing the decrease of the mean air velocity, it is difficult to say if the heat transfer is enhanced, because the decreases of mean air velocity and cooling capacity have the same order of magnitude. For example, the difference of mean air velocities in both modes at the conditions of 24 Hz converter frequency and 180 kg/h water supply is up to 1.228%, and the difference of cooling capacities at the same conditions is about 1.081%.

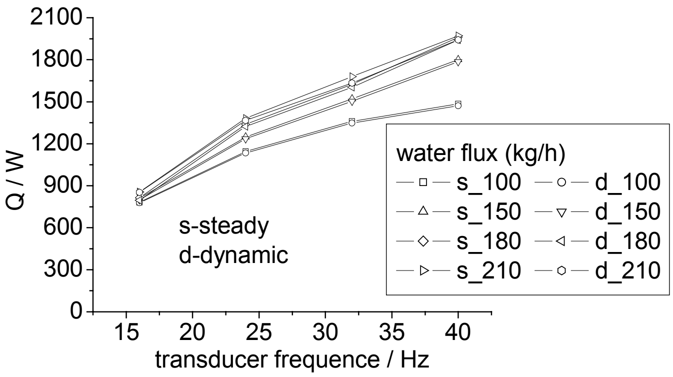



**Figure 7** A comparison between the unsteady and the steady modes of heat transfer.

**Turbulivity**

Turbulivity is an important parameter of fan-coil unit. If its structure is certain, the turbulivity is a constant, and the velocity along the axis will be calculated. In order to obtain the turbulivity of the outlet, the velocities at different distances from outlet were tested. The unsteady FCU outlet is 0.12 × 0.5 m, so the equivalent diameter is 0.1935 m. The centre velocities at each outlet were $V_{0left}$=1.657 m/s, $V_{0right}$=1.945 m/s. The result is calculated in Table 1, and the average turbulence coefficient is found to be 0.097.

**Table 1** Turbulence coefficient

| $x$ (m) | Right | | Left | |
|---|---|---|---|---|
| | $V_x$ | $\alpha$ | $V_x$ | $\alpha$ |
| 1.273 | 1.079 | 0.090 | 1.081 | 0.109 |
| 2.263 | 0.578 | 0.105 | 0.859 | 0.081 |
| 1.976 | 0.624 | 0.123 | 1.066 | 0.072 |

**Airflow Distribution in the Chamber**

Airflow distribution plays an important role in air conditioning system. It affects the air conditioning quality. In a sitting position the occupants' head is at a height of 1.1 m normally. So it is necessary to know the airflow at this height. Figure 8 shows the dimensions of the FCU in the chamber. The outlet is 2.02 m above the floor. The test grid (4a) is 200 × 200 mm$^2$ and is on the axis of the outlet 1.1 m above the floor.

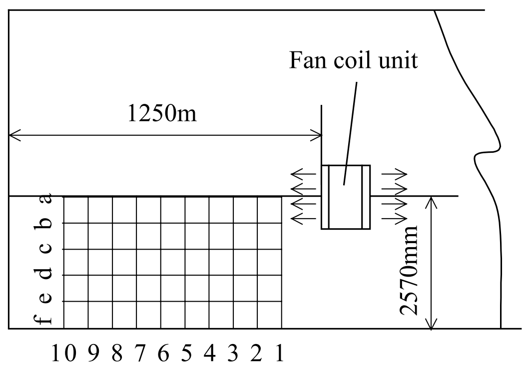



**Figure 8** Test place of airflow distribution in the chamber.

The distribution of airflow at a height of 1.1 m is as shown as Figure 9, where the outlet velocity is 1.657 m/s. The result shows that the velocities on the shoot direction are relatively high. However, the velocities in other parts of the chamber are low. The structure and installation of the unsteady FCU might be amended in order to attain suitable airflow distribution and to utilize fully the cooling effect of airflow in the occupant zone.

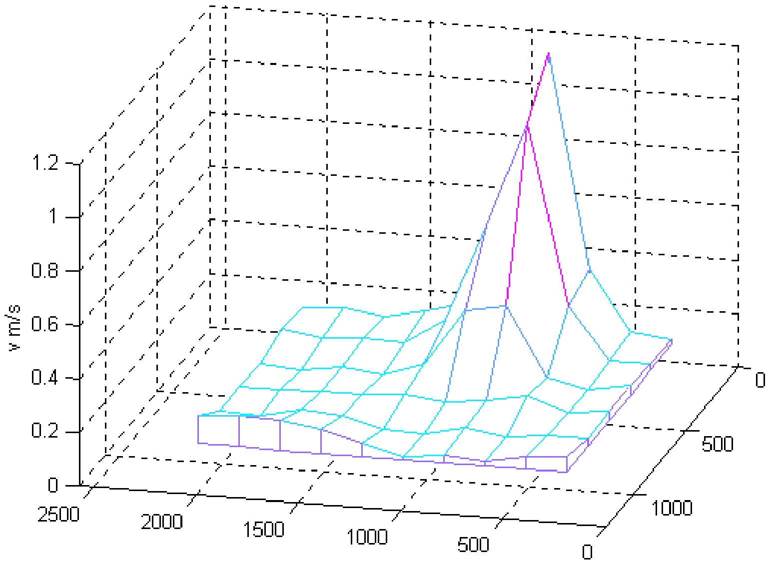



**Figure 9** The airflow distribution at a height of 1.1 m from the floor.

## CONCLUSIONS

The performance of the unsteady FCU is studied in this paper. Considering the experimental results, the following conclusions can be drawn:

1. The prototype of the unsteady FCU can produce a simulated natural wind and its velocity curve is consistent with the control signal. Simulated natural wind has the similar spectrum as natural wind.
2. There is a 3% decrease of outlet mean air velocity in the unsteady mode because of the change of resistance characteristic in the air passage caused by the swing plate.
3. The non-isothermal and fluctuating air movement can be provided by the FCU in the unsteady mode. The air temperature changes when air velocity is changed.
4. The cooling capacity of the FCU prototype is also decreased accompanied by a decrease in the mean air velocity. Enhanced heat transfer of the coil was not found in the experiment.
5. The turbulence coefficient of the airflow from the unsteady FCU is 0.097. The distribution of the velocities at a height 1.1 m above the floor was measured. It is found that in air velocity distribution, the area covered by the high-speed airflow was relatively small.

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