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A dynamic air supply device used to produce simulated natural wind in an indoor environment

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ABSTRACT

Natural ventilation is the most pleasant and suitable ventilation mode. Many researchers have claimed that they have produced simulated natural wind (SNW) using artificial devices. However, the characteristics of these kinds of SNW have been shown, through spectral analysis, to be clearly different from true natural wind (TNW). In this study, a dynamic air supply device based on direct-current (DC) motor control was designed to produce SNW, and the spectral characteristics of the airflow produced by this device were very close to those of TNW. To verify the application potential of this SNW, an experiment on thermal sensation and thermal comfort with regard to the SNW was conducted in both a climate chamber and a real office. Twenty-one subjects were exposed to five conditions: a constant neutral environment at 26 °C; a warm environment at 28 and 30 °C with constant mechanical wind (CMW), and a warm environment at 28 and 30 °C with SNW. In addition, twelve subjects used the device during work in a real office. The data of their thermal sensations was analyzed. The results suggested that the SNW was more effective in improving thermal comfort than the CMW in the warm environments. It was demonstrated that using SNW in a warm environment could result in almost the same thermal comfort as in a constant neutral environment.

1. Introduction

A large number of field measurements and studies have shown that thermal comfort is different in AC and NV environments [1–3]. In a warm NV environment, the TSV value of subjects has been shown to be lower than their PMV; in addition, the acceptable mean velocity of airflow was much higher than that in a stable neutral environment, and the comfortable air temperature was higher, too. Therefore, it is feasible to raise the air temperature and use airflow to improve thermal comfort, especially for SNW [4–7]. In this case, AC energy consumption would be decreased. In previous research, when the indoor designed temperature in summer was raised from 24 °C to 28 °C, the maximum cooling load could be reduced by 15% and the AC time could be reduced by 22% according to simulated calculations [8]. The use of SNW would also reduce the temperature disparity between indoor and outdoor environments, which could help to reduce the risk of getting sick. Thus, using SNW could help buildings save dramatically on energy costs and create a healthier and more comfortable [9–11] indoor environment.

Previous studies have found that there are obvious differences between TNW and CMW, especially with regard to spectral characteristics. It has also been shown that different kinds of natural wind have similar spectral characteristics. Table 1 lists the characteristic parameters of several samples of natural wind collected at different locations [12]. The β value is the negative slope of the double logarithmic power spectrum curve (Fig. 1), and Tu is the value of airflow turbulence intensity. As Table 1 shows, the values of β and Tu of the different samples are similar regardless of the wind's environment, location, and mean velocity.

Recently, many researchers have been developing various types of dynamic air supply devices to create SNW [13–17]. The author's group has been studying on these relevant topics for a long time. The earliest trial of producing a natural wind generator is by Jia [18]. He used a semi-circular turntable as the shunt valve to control the air velocity. Zhou et al. also controlled an axial fan based on motor frequency conversion control to produce dynamic airflow [19]. But the response speed of both devices was slow so that some natural wind signals were anamorphic. Besides, they are too large and need more and 2 m distance to evolve the jet into SNW, so they are quite inconvenient to be applied in the office as the personal ventilator.

In fact, some manufacturers have claimed that their products can produce SNW. However, performance test proved that there

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Nomenclature

SNW	simulated natural wind
TNW	true natural wind
CMW	constant mechanical wind
AC	air-conditioned
NV	naturally-ventilated
TSV	thermal sensation vote
PMV	predicted mean vote
TCV	thermal comfort vote
NAC	not air-conditioned
Tu	the value of airflow turbulence intensity
Greek symbols	
β	the negative slope of the double logarithmic power spectrum curve

were still huge differences between TNW and the SNW created by these devices in terms of spectral characteristics [20]. One example is the "X-type" fan (Fig. 1). The β value of the SNW it produced reached 1.1, much higher than that of CMW. Nevertheless, this is still lower than that of TNW (its β value equals about 1.5). According to Fig. 1, there is an obvious main frequency in the power spectrum curve. Because of the existence of this main frequency, its power is enhanced and its β value is improved as well. It also shows that the SNW has an obvious periodic frequency. This fan is only capable of creating dynamic wind over a very short period of time and then repeating this dynamic process again and again to simulate natural wind.

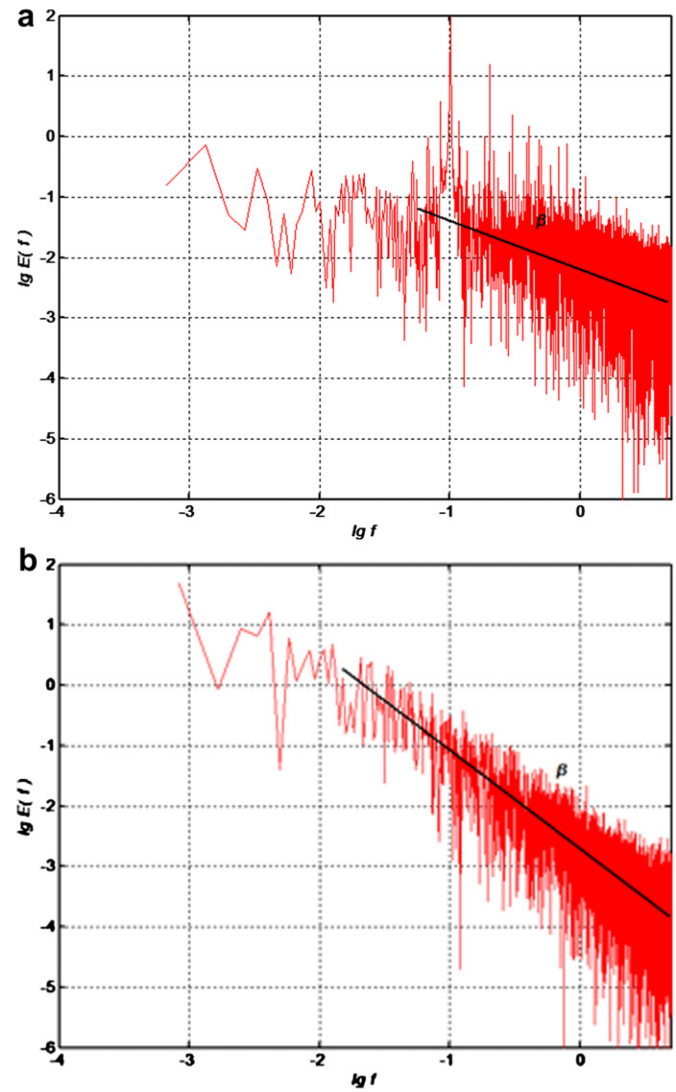

Fig. 1. Double logarithmic power spectrum curve of TNW (left) and SNW (right).

2. Methods

2.1. The components and theory of the device

At present, the design of dynamic air supply devices utilizes two main approaches: turntable control and motor control. Both methods have successfully produced SNW in the laboratory.

Jia [18] introduced turntable control in 2000. Its main objective is to adjust the air velocity by controlling the opening of the shunt valve in the device, in which a semi-circular turntable is used as the shunt valve. Motor frequency conversion control is another effective way to produce dynamic airflow [8]. Computer gives control signals to the frequency converter, and then the motor would rotate at variable speeds.

Zhou et al. [19] simulated natural wind by controlling an axial fan based on motor frequency conversion control. They found that dynamic airflow similar to that of natural wind was formed farther away from the outlet (more than 2 m) instead of less than 1m away. According to further analysis, the main reason why the SNW near the outlet could not reach the dynamic airflow level of natural wind was that the motor response time was too long.

Based on this finding, a new device, called the Personalized Natural Wind Fan, was designed (Fig. 2). It included air deflector, brushless DC motor, outlet, operation panel and shelf, etc. Air flowed from the air deflector to the outlet through the DC motor. Users could control the device through the operation panel easily. There were several types of airflow for users to choose. Depending on the frequency and voltage signals given by the driving circuit, the brushless DC motor could rotate at variable speeds and dynamic airflow was produced and sent to the workspace (Fig. 3). The brushless DC motor was used to improve the response speed, and the computer was replaced by a Single-Chip Microcomputer (SCM) to complete the miniaturization of the device.

Table 1
Average β and *Tu* values of natural wind in several building environments.

	Open air	Roof	Neighborhood	Indoors
Average β	1.61	1.55	1.45	1.49
Average *Tu*	0.54	0.59	0.46	0.62

2.2. Response times

The newly designed device represents a significant improvement compared to the device used in the experiments by Zhou et al. [19]. To get SNW, the distance from the outlet of Zhou et al.'s device to the measuring point had to be longer than 2 m, and then the average velocity of the SNW would be very low. Because of its length and low velocity, its practical use was restricted. However, this problem was solved by the new device. In comparison, the accelerating and decelerating response times of the new device are much shorter.

Fig. 4 shows the time series curve of the response time test. Fig. 5 shows an amplification of the accelerating and decelerating segments of the curve in Fig. 4. The accelerating response time is about 0.5 s and the decelerating time is about 1.1 s. This performance