Evaluation of ventilation performance and energy efficiency of greenhouse fans

Zhang Zhi[1], Richard S Gates[2], Zou Zhirong[3*], Hu Xiaohui[3]

(1. *College of Mechanical and Electronic Engineering, Northwest A&F University, Yangling 712100, China*;
2. *Department of Agriculture and Biological Engineering, University of Illinois at Urbana-Champaign, 61801, USA*;
3. *College of Horticulture, Northwest A&F University, Yangling 712100, China*)

Abstract: In order to investigate fan performance in fan-ventilated greenhouses (Urbana, USA), the effects of guard screen and loose belts on fan ventilation airflow and power consumption in greenhouse operations were examined with four belt-driven fans as trial subjects. The Fans Assessment Numeration System was used to measure the airflow rate. Temperature, relative humidity and power consumption were also monitored. Results show there were significant differences in the airflow rate between the fans with a cleaned and uncleaned guard screen (P<0.05). Power consumption also differed significantly even with the same cooling effect in greenhouse. When fan belts were adjusted to the proper tension, the fan speed and airflow rate were 13.1% and 30.1% higher than those of original belts, respectively. The daily average power consumption for the fan with the original loose belts was 20.4% higher than that with the adjusted belts when the pad was not working and 24.2% higher with pad working. The ventilation performance of fans with identical specifications showed a variation by up to 13.0% in terms of the ventilating efficiency ratio. These results demonstrated that fans should be cleaned routinely, and belt tension should be checked to ensure that fan performance meets specifications. This can reduce the power consumption in greenhouses for environmental control. Moreover, reordering fan staging, so that the most efficient fans are used in areas of greatest demand, can also reduce ventilation energy costs.

Keywords: greenhouse, fan performance, airflow rate, power consumption, efficiency ratio
DOI: 10.3965/j.ijabe.20150801.014

Citation: Zhang Z, Gates R S, Zou Z R, Hu X H. Evaluation of ventilation performance and energy efficiency of greenhouse fans. Int J Agric & Biol Eng, 2015; 8(1): 103－110.

1 Introduction

Greenhouses are ideal for controlled crop production. Greenhouse ventilation is used to control temperature, air humidity, carbon dioxide and wind velocity[1,2], which all directly impact plant productivity. Ventilation systems for greenhouses are either naturally or mechanically driven. Fan-pad system is widely used in greenhouse throughout the world[3,4] to control high temperatures in summer, to provide uniform air flow, and maintain acceptable levels of CO_2 concentrations in the greenhouse[5].

Fans are the essential components of mechanically ventilated greenhouse. Fan performance characteristics, especially power consumption, are critical for the optimization of environment controls and energy conservation. Guard screens, shutters and other accessories as well as the aging, affect airflow rate and efficiency[6-8]. These factors can increase energy consumption, even when the same environmental controls are obtained. Studies show that belt-driven fans up to five years old run at nearly rated speeds[9]. Loose and worn

Received date: 2014-08-27 **Accepted date:** 2015-01-08
Biographies: Zhang Zhi, PhD candidate, majoring in agriculture and biological environmental engineering. Email: zhangzhione@126.com. **Richard S. Gates**, Professor, Doctoral Tutor, research interests: agricultural and biological engineering. Email: rsgate@illinois.edu. **Hu Xiaohui,** PhD, associate professor, research interests: greenhouse engineering. Email: hxh1977@163.com.
***Corresponding author: Zou Zhirong**, Professor, Doctoral Tutor, majoring in agriculture and biological environmental engineering. Mailing address: College of Horticulture, No.3 Taicheng Road, Yangling, Shaanxi, 712100, China. Email: zouzhirong2005@hotmail.com.

belts can result in substantial reductions in fan speed, which consequently lowers fan ventilation performance[10].

However, few studies have investigated fan performance and evaluation in greenhouses, since it is difficult to monitor fan airflow accurately[11-13]. Over the past decade, the Fans Assessment Numeration System (FANS), a device for in-situ fan airflow measurement, has been successfully implemented across the United States[14,15]. It provides an accurate method for determining in-situ fan performance. This study used FANS to quantify the airflow from each exhaust fan at different values of static pressure in greenhouses, and also to measure fan power consumption. The purpose of this study was to use FANS for in-field measurement of fan performance in research greenhouses and provide recommendations for maintenance in order to sustain the ventilation performance of the fans. This will increase the efficiency ratio and reduce fan power consumption in greenhouse for environmental controls. Ultimately, findings can be used to save energy and costs by operating fans rationally in greenhouses.

2 Materials and methods

2.1 Greenhouses and fans used in tests

The study was conducted in fan-ventilated greenhouses at the Urbana-Champaign campus of the University of Illinois, USA. Two north-south oriented greenhouses were chosen. The size of greenhouse 1 is 3.2 m×6.25 m (10.5 ft×20.5 ft), with only one fan (H1Fan1). Greenhouse 2 is 8.2 m×12.5 m (27 ft×41 ft), with three fans (H2Fan1, H2Fan2, H2Fan3). The two greenhouses are identical in other structural parameters. The height of the ridges and gutters are 5.3 m, 3 m (17.5 ft, 10 ft), respectively, and both greenhouses are covered with 4 mm (1/8") thick-tempered glass. Evaporative pads are at the north end, and exhaust fans are at the south end. All testing fans were the same type, and had been in operation for more than 30 years. The fan details are described in Table 1.

Table 1 Details of tested fans

Brand	American Coolair
Motor	Baldor
Model	M1321T
Power/W	1103
Voltage/V	208-250 (3 phase)
Fan speed/r·min^{-1}	1725/1140
Drive	Belt driven Drive pulley ϕ 96.5 mm, Axle pulley ϕ 287 mm
Blades	6 steel blades
Shutter	Aluminum louver
Diameter/mm	915
Guard screen	Steel, spacing is 12.7 mm×25.4 mm

2.2 Fan assessment numeration system

2.2.1 Fan Assessment Numeration System (FANS)

The Fan Assessment Numeration System (FANS) was developed by the USD-ARS Southern Poultry Research Laboratory and refined at the University of Kentucky to measure fan air flow in-situ[16,17]. The unit provides the actual fan performance as it is installed and operating, with all accessories in place. FANS (Figure 1[15]) is an aluminum box that utilizes a row of propeller anemometers which traverse the inlet to generate an in-situ velocity profile of a ventilation fan. The device is constructed in six parts: interface panel, electronics enclosure, propeller anemometers, anemometer bar, guide rail and leadscrews. The FANS unit was positioned in front of the fan under testing, and sealed well with tape to prevent air from being drawn around the unit. FANS was controlled by laptop in the testing When the unit works, the anemometers measure air velocity as they are attached to moves up or down the main box unit. Approximately 1.8 million velocity readings are obtained as the anemometers traverse the flow field in about 180 s. The average velocity is calculated based on all of the readings, and this value is multiplied by the cross-sectional area of the fan to get the mean ventilation rate. FANS diameter of 1 220 mm were selected from the typical FANS diameters of 915 mm, 1 220 mm and 1 370 mm for this experiment and it was equipped with five anemometers (Figure 2).

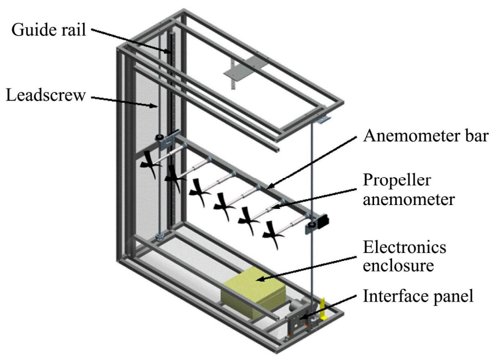

Figure 1 FANS system

Figure 2 Testing in greenhouse 2

2.2.2 FANS unit calibration

FANS unit was calibrated at the fan test chamber at the Bioenvironmental and Structural Systems (BESS) Laboratory of the University of Illinois. FANS unit was placed against the outlet face of the BESS Lab chamber and the gap between the chamber outlet and FANS unit was sealed with Styrofoam (Figure 3). The tests were run within the static pressure range 5-62 Pa. Air flow was read by FANS unit once for each value of static pressure set in the chamber. Also, air flow was calculated based on the pressure difference across calibrated chamber nozzles. Air flow obtained by the FANS unit was regressed as a linear function of the air flow obtained from the BESS Lab chamber. The parameters obtained from the regression, slope, and intercept were inserted into the FANS software.

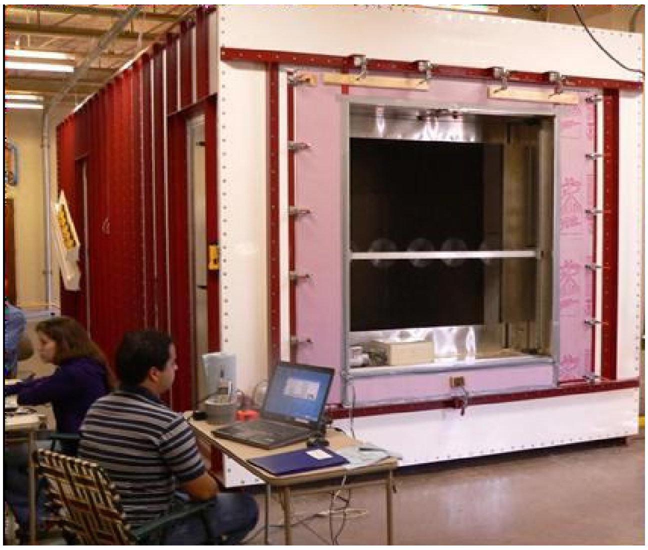

Figure 3 FANS calibration running

Figure 4 illustrates the calibration curve for the FANS unit (48-0014). The calibration equation was $Q_{Actual}(\mathrm{m^3 \cdot h^{-1}})=0.985Q_{\mathrm{FANS}}+171$.

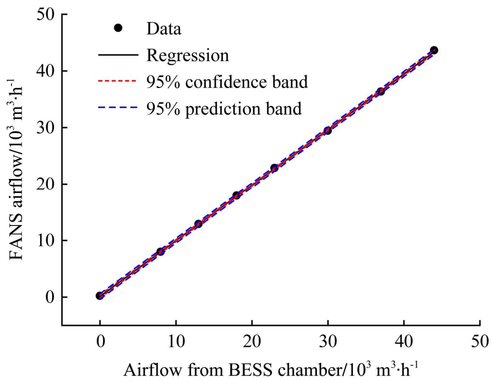

Figure 4 Calibration curve for FANS

2.3 Methods

2.3.1 Airflow rate and fan speed measurement

In the test, static pressure was controlled by adjusting the opening angle of the ridge vent. Once the static pressure is stable, FANS begins to run. Evaluation of the performance characteristics of each fan over a range of static pressures from 5 Pa to approximately 62 Pa takes about 45 min. For each fan, FANS ran 3 times, and the average ventilation rate was used to evaluate fan performance. The software of FANS system, written in Visual Basic, can record static pressure, airflow rate, fan speed and other measurement parameters. Test conditions are described, with fans at high speed, exhaust fans 100% open, all inlet dampers closed, and the ridge vents open adjust.

2.3.2 Energy consumption measurements

The fan power, as well as the supply voltage and current, were recorded during fan operation to determine fan energy consumption for different treatments. Power consumption was determined with a power analyzer (model: OSI Model EW5-20B Transducer). Voltage and current were measured by digital multi meter (model: Fluke model 89 digital multi-meter).

2.3.3 Temperature and humidity measurements

Indoor temperature and relative humidity were monitored by temperature and humidity sensor (model: MicrologPRO). Outdoor temperature and solar radiation were collected by weather station (model: Hobo H21).

2.4 Data analysis

Origin 8.0 (OriginLab Inc,) was used for drawing. Fitting of models and statistical analysis were performed using statistical software, SPSS 18.0 (SPSS Inc, Chicago).

3 Results and discussion

3.1 Effects of fan guard screen on ventilation performance

Dust accumulations of fan guard screen impose an extra resistance that the fan must operate against, thereby reducing its airflow. H1Fan1 and H2Fan2 were used as test subjects. In the test, cotton cloth supplied with detergent was used to clean the guard screens which were left air dry. Airflow rate was measured when the fan operated with the original guard screen, with the cleaned guard screen and with no guard screen. Results of the field evaluation for fan airflow performance and power consumption are summarized below. Determination the general relationship between air flow and static pressure is essential to assess fan performance. Nearly identical pattern of changes were observed when fan worked with three different status of guard screen.

The second order polynomial regressions were fitted to the data to indicate airflow drops clearly with static pressure climbing. ($R^2 > 0.99$) (Figure 5 and Figure 6). For H1Fan1, the airflow rate was reduced by 32.7% and 43.5% when static pressure rose up to 30 Pa and 40 Pa, respectively. And for H2Fan2, 31.7% and 40.5% reduced in airflow rate when static pressure reached 30 Pa and 40 Pa. The characteristics of the response to guard screen for two fans were the same, which demonstrate that airflow rate was the lowest when the fan operated with a guard screen. A slightly higher airflow rate was obtained after the guard screen was cleaned, and the highest fan airflow rate was obtained without the guard screen (Figure 5 and Figure 6).

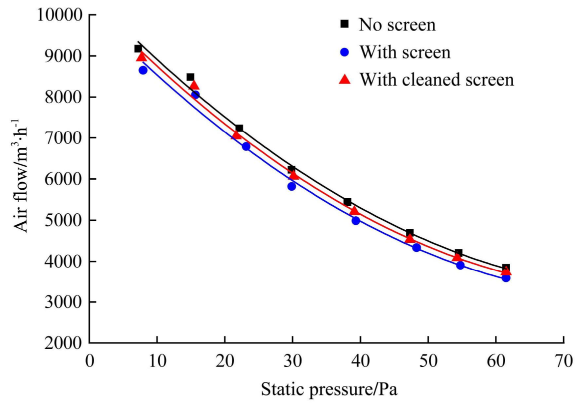

Figure 5 Performance characteristics of H1Fan1 with screen, cleaned screen and without screen

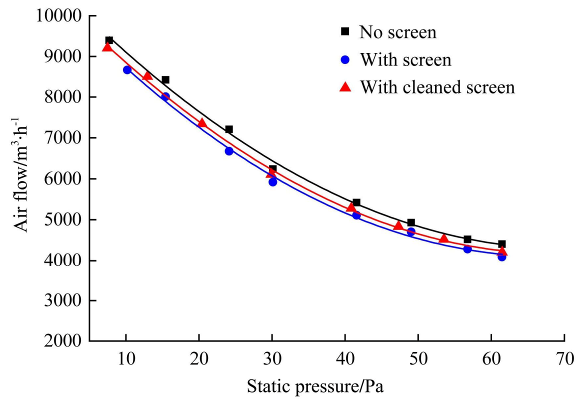

Figure 6 Performance characteristics of H2Fan2 with screen, cleaned screen and without screen

Using second order polynomial regressions for these three test conditions of H1Fan1, the ventilation rate of these three groups were calculated at eight nominal static pressures (Table 2). There were significant differences in fan airflow rate among the three test conditions when static pressure was higher than 30 Pa. In contrast, significant differences were only observed between fans with original screen and with cleaned screen when static pressure was less than 30 Pa (P<0.05).

Table 2 Airflow rate of H1Fan1 with guard screen, cleaned guard screen or without screen over different static pressures

Test conditions	Airflow rate/m^3·h^{-1}							
	Static pressure/Pa							
	7	15	22	30	38	47	56	61
With screen	8991.6±99.6^a	7813.4±91.2^a	6645.5±92.3^a	5957.6±90.8^a	4976.5±88.7^a	4268.6±83.1^a	3832.8±72.4^a	3582.9±70.3^a
With cleaned screen	9216.1±105.2^b	8020.4±99.7^b	7083.7±100.2^b	6138.4±95.6^b	5111.4±90.5^b	4428.2±81.6^b	3987.9±61.8^b	3736.0±67.3^b
No screen	9372.9±106.3^b	8185.3±87.9^b	7251.3±101.3^b	6304.0±93.1^c	5299.9±73.4^c	4567.4±82.0^c	4109.8±69.7^c	3842.9±68.5^c

Note: Each value represents the mean (standard errors are shown as well) calculated based on the regression equation established from 3 independent experiments. Different letters indicate significant differences between treatments (P<0.05).

In order to contrast the fan power consumption under these three conditions, daily average consumption was surveyed in nearly identical outdoor weather conditions. The temperature in the greenhouse was set between 26 and 27℃. Fans start working when indoor temperature rises above 27℃ and stop working when indoor temperature drops below 26℃. Experimental was divided into two groups: with and without the pad working[18], and all the environmental factors were monitored from 9:00-17:00 each day. When the pad was in non-working state, power consumption of the fan with screen was 2.6% more than the fan with clean screen, and 4.8% more than the fan without screen. Significant differences in power consumption were observed among the three fan working conditions (P<0.05), as shown in Table 3. When the pad was working with the fan together, power consumption of the fan with screen was 3.2% and 5.3% more than with cleaned screen and without screen, respectively. There were also significant differences among these three conditions (P<0.05), as shown in Table 4.

Table 3 Comparison of daily power consumption of the fan with screen, with cleaned screen and without screen when pad was in non-working state

Fan conditions	Environmental Conditions				Power consumption /kW·h·d^{-1}
	Outdoor temperature/℃	Outdoor relative humidity/%	Solar radiation/W·m^{-2}	Indoor temperature/℃	
With screen	25.4±0.09	61.6±1.2	728±8	26.6±0.10	7.03±0.08^{a}
With cleaned screen	25.5±0.10	60.9±1.0	737±5	26.6±0.08	6.85±0.07^{b}
No screen	25.4±0.07	58.7±2.0	733±7	26.5±0.07	6.71±0.03^{c}

Note: Each value represents a mean ± standard error of 3 independent experiments (n=3). Different letters indicate significant differences between treatments (P<0.05).

Table 4 Comparison of daily power consumption of the fan with screen, with cleaned screen and without screen when pad was in working state

Fan conditions	Environmental conditions				Power consumption /kW·h·d^{-1}
	Outdoor temperature/℃	Outdoor relative humidity/%	Solar radiation/W·m^{-2}	Indoor temperature/℃	
With screen	26.6±0.12	54.6±2.1	748±10	26.4±0.10	5.49±0.06^{a}
With cleaned screen	26.6±0.08	56.3±1.8	755±7	26.5±0.06	5.32±0.05^{b}
No screen	26.7±0.04	55.7±1.6	753±9	26.5±0.01	5.18±0.06^{c}

Note: Each value represents a mean ± standard error of 3 independent experiments (n=3). Different letters indicate significant differences between treatments (P<0.05).

3.2 Effects of belt tension on ventilation performance

Loose and worn belts can result in substantial reductions in fan performance, since air flow is proportional to fan speed. H1Fan1 worked as test subject, and the fan belt was adjusted to proper tension in this experiment. The fan can run either at high speed or at low speed, so airflow rate and fan speed were measured in the two tranches of speed respectively when the fan worked with the original belt and the adjusted belt.

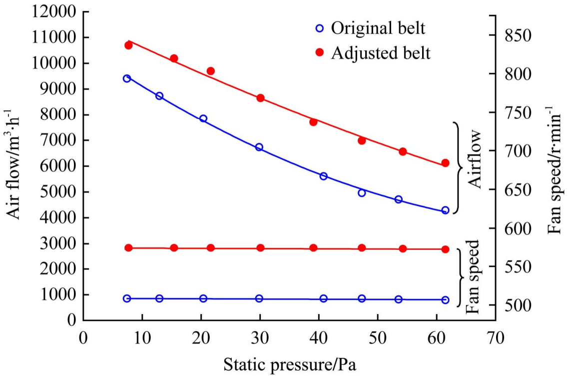

Figure 7 Performance characteristics of fan with original belt and adjusted belt at high speed

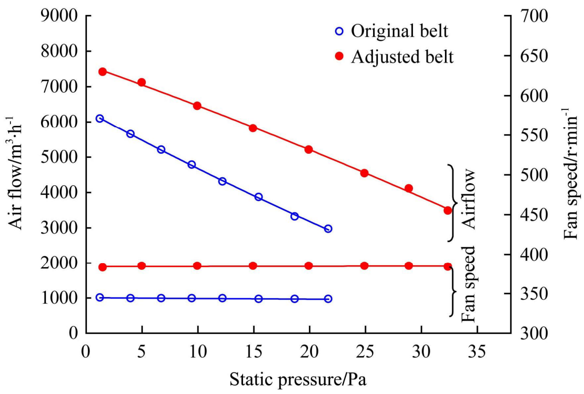

Figure 8 Performance characteristics of fan with original and adjusted belt at low speed

Both airflow rate and fan speed of the fan worked with the original belt and the tightened belt at fan high speed are shown in Figure 7. The maximum difference of airflow at the same pressure point between the fan before and after belt adjustment was about 2 200 m^3/h. Fan with the adjusted belt moved an average of 30.1% more airflow rate than fan with the original belt at eight nominal static pressures. Figure 7 also shows fan speed measurements under two belt conditions during the fan characterization procedure. The fan speed tested with the adjusted belt was 574 r/min, which is approximately 13.0% faster than for the original belt. It was also evident that the rotational speed of individual fan shows almost no change. Also, when fan ran at low speed, fan with adjusted belt delivered an average of 36.6% more airflow rate than fan with the original belt since fan speed was increased by 13.9% (Figure 8). Therefore, timely replacement of belts is essential to keep fan performance closer to original specifications. Measuring fan speed may be necessary to diagnose ventilation problems, since air flow is proportional to fan speed.

What's more, nearly identical outdoor weather conditions were chosen in order to contrast fan power consumptions at the same cooling effect of greenhouse between the fan with adjusted and original belt. And also, fan ran at high speed in each test. Results are presented in Tables 5 and 6. When the pad did not work, daily average consumption surveyed in the same environments for the original belt was 20.4% higher than for the fan with the adjusted belt, and 24.2% higher when the pad worked with the fan simultaneously.

Table 5 Comparison of daily power consumption of the fan with original belt and with adjusted belt when pad was in non-working state

Fan conditions	Environmental Conditions				Power consumption /kW·h·d^{-1}
	Outdoor temperature/℃	Outdoor relative humidity/%	Solar radiation/W·m^{-2}	Indoor temperature/℃	
Original belt	27.4±0.12	54.6±2.1	748±10	26.4±0.10	5.49±0.06
Adjusted belt	27.4±0.16	58.1±2.9	736±11	26.4±0.07	4.42±0.05

Note: Each value represents a mean ± standard error of 3 independent experiments (*n*=3).

Table 6 Comparison of daily power consumption of the fan with original belt and with adjusted belt when pad was in working state

Fan conditions	Environmental Conditions				Power consumption /kW·h·d^{-1}
	Outdoor temperature/℃	Outdoor relative humidity/%	Solar radiation/W·m^{-2}	Indoor temperature/℃	
Original belt	25.4±0.09	61.6±1.2	728±8	26.6±0.10	7.03±0.08
Adjusted belt	25.5±0.03	58.9±2.5	723±5	26.5±0.07	5.84±0.08

Note: Each value represents a mean ± standard error of 3 independent experiments (*n*=3).

3.3 Difference analysis in ventilation performance of otherwise identical fans

There was considerable variation in both airflow and power consumption among otherwise identical fans. All four fans in two greenhouses were tested. The ventilation performance of otherwise identical fans was shown to vary by up to 10.1% during the whole range of static pressure. The average difference in airflow rate was higher when static pressure was lower than 30 Pa, which was 11.4% (Figure 9).

The energy efficiency of ventilation fans is typically expressed as a volumetric airflow rate per Watt of power consumed, at expected operating static pressure. Values for these fans are provided in Table 7 for the 8 nominal static pressures. Current recommendations for ventilation fans are to select those with efficiencies greater than about 34 m^3/h·W at 25 Pa[19]. By contrast, these fans displayed a range of 7.0 m^3/h·W to 8.0 m^3/h·W only at about 22 Pa, since they had operated for more than 30 years. Thus, the fans were not considered to be energy efficient. The ventilation efficiency ratio of four otherwise identical fans was found to vary by up to 13.0%. Not all fans always operated for the same period of time in greenhouse. It may reduce ventilation energy costs to reorder the fan staging so that the most efficient fans in a batch of similar fans is used where the greatest demands for run time are necessary.

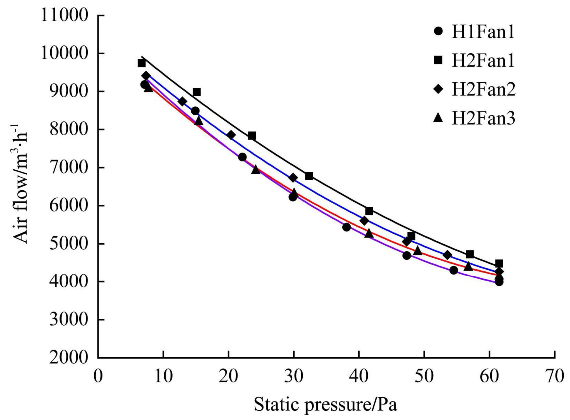

Figure 9 Performance characteristics of four identical fans

Table 7 Ventilating efficiency ratio of four identical fans

Fan	Ventilation efficiency ratio/$m^3 \cdot h^{-1} \cdot W^{-1}$							
	Static pressure/Pa							
	7	15	22	30	38	47	56	61
H1Fan1	9.4	8.0	7.0	5.9	5.2	4.5	4.0	3.8
H2Fan1	10.3	9.0	8.0	6.8	5.9	5.2	4.5	4.2
H2Fan2	10.0	8.6	7.5	6.4	5.6	4.9	4.3	4.1
H2Fan3	9.5	8.2	7.1	6.2	5.4	4.7	4.2	4.0

4 Conclusions

1) Regular cleaning and maintenance of fan accessories is essential to maintaining fan performance. Accumulated dirt and corrosion of guard screen imposes extra resistance, thereby reducing airflow. Although the reduction in ventilation rate was found to be less than 5%, there were significant differences in power consumption between fans before and after cleaning the guard screen, even with the same environmental controls in greenhouse.

2) Maintenance of proper tension on drive belts and replacement of worn belts were found to be very important in maintaining fan performance. A small reduction in fan speed from a slipping or loose belt has a large effect on airflow, which increases power consumption and costs.

3) The ventilation efficiency ratios of four otherwise identical fans were shown to vary. Reordering fan staging may address this challenge, by placing the most efficient fans in a batch of similar fans in the areas of greatest demand. This would reduce ventilation energy costs in greenhouses with environment controls.

4) Power consumption fluctuates slightly as fans operating, and ventilation efficiency significantly decreases as static pressure climbs. For ideal ventilation rates and efficiency, static pressure should be controlled at less than 30 Pa by operating a limited sunroof in greenhouse.

Acknowledgements

We acknowledge that this work was financially support by the Public Welfare Trade (Agriculture) Research Project, China (201203002), and the Technology Co-ordination Innovation Project of Shaanxi. Province, China (2011KTDZ02-03-02). We would also like to thank the staff of the Bioenvironmental and Structural Systems (BESS) Laboratory, Agricultural and Biological Engineering, University of Illinois.

[References]

[1] Al-Helal I M. Effects of ventilation rate on the environment of a fan-pad evaporatively cooled, shaded greenhouse in extreme arid climates. Applied Engineering in Agriculture, 2007; 23(2): 221–230.

[2] Yang S H, Rhee J Y. Utilization and performance evaluation of a surplus air heat pump system for greenhouse cooling and heating. Applied Energy, 2013; 105: 244–251.

[3] Lopez A, Valera D L, Molina-Aiz F D, Peña Araceli. Sonic anemometry to evaluate airflow characteristics and temperature distribution in empty Mediterranean greenhouses equipped with pad-fan and fog systems. Biosystems Engineering, 2012; 113(4): 334–350.

[4] Al-Helal I, Al-Abbadi N, Al-Ibrahim A. A study of fan-pad performance for a photovoltaic powered greenhouse in Saudi Arabian summer. International Agricultural Engineering Journal, 2004; 13(4): 113–124.

[5] Kumar K S, Jha M K, Tiwari K N, Singh A. Modeling and evaluation of greenhouse for floriculture in subtropics. Energy and Buildings, 2010; 42(7): 1075 – 1083.

[6] Zhao Y, Shen J Y, Teitel M. Experiment on microclimate in the greenhouses by fan and pad. Transactions of the CS AM, 2008; 39(8): 109–113. (in Chinese with English abstract).

[7] Person H L, Jacobson L D, Jordan K A. Effect of dirt, louvers and other attachments on fan performance. Transactions of the ASAE, 1979; 22(3): 612–616.

[8] Simmons J D, Hannigan T E, Lott B D. Reduction in poultry ventilation fan output due to shutters. Applied Engineering in Agriculture, 1997; 13(5): 671–673.

[9] Janni K A, Jacobson L D, Nicolai R E, Hetchler B, Johnson V J. Airflow reduction of large belt-driven exhaust ventilation fans with shutters and loose belts. St. Joseph, Michigan: Proceedings of the 7th International Livestock Environment Symposium, 2005; 245–251.

[10] Bottcher R W, Baughman G R, Magura J T. Field measurements of fan speed and power use in poultry houses. The Journal of Applied Poultry Research, 1996; 5(1): 56–62.

[11] Morello G M. Influence of fan operation on Fan Assessment Numeration System (FANS) test results. Lexington: University of Kentucky, 2011.

[12] Gates R S, Casey K D, Xin H, Wheeler E F, Simmons J D. Fan assessment numeration system (FANS) design and calibration specifications. Transactions of the ASAE, 2004;

47(5): 1709–1715.

[13] Calvet S, Cambra-Lo´pez M, Blanes-Vidal V, Estellés F, Torres A G. Ventilation rates in mechanically-ventilated commercial poultry buildings in Southern Europe: Measurement system development and uncertainty analysis. Biosystems Engineering, 2010; 106(4): 423–432.

[14] Hoff S J, Bundy D S, Nelson M A, Zelle B C, Jacobson L D, Heber A J, et al. Real-time airflow rate measurements from mechanically ventilated animal buildings. Journal of the Air & Waste Management Association, 2009; 59(6): 683–694.

[15] Sama M P, Gates R S, Adams W C, Day G B, King C L. Adams. Fan Assessment Numeration System (FANS) Scaling and Upgrades, 2008 ASABE Annual Meeting, Paper Number 084723.

[16] Gates R S, Casey K D, Xin H, Burns R T. Building emissions uncertainty estimates. Transactions of the ASABE, 2009; 52(4): 1345–1351.

[17] Lopes I M. Evaluation of transitions for testing agricultural ventilation fans with the Fan Assessment Numeration System (FANS). Lexington: University of Kentucky, 2012.

[18] Zhao Y, Teitel M. An Experimental Study on Energy Saving in the Greenhouse by VAV Based on VFD. Transactions of the CSAM, 2006; 37(5): 106–109. (in Chinese with English abstract).

[19] Czarick M. The Best Performing Tunnel Fans-2005. Poultry Housing Tip, 2006; 18(5): 1–4.