Energy-Saving Effects of Novel Air Inlet in Spinning Workshops

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Abstract—**This paper introduces a novel air inlet to replace the traditional slit air inlet for achieving a more uniform airflow distribution in spinning workshops. Numerical simulations and comparative analyses were conducted to assess the energy-saving effect of the proposed air inlet. First, an experimental platform was constructed to validate the numerical simulations results. The difference between the experimental and simulated values at the measurement points did not exceed 8%, confirming the reliability of the numerical simulations. Next, numerical simulations were performed to evaluate the air supply effects and energy-saving effect of the novel air inlet. Analyses based on the air-conditioning effect parameter, defined in accordance with GB/T 50481, indicated that the proposed air inlet could reduce both in the air supply volume and energy consumption by approximately 10.6%. According to measurements from two large spinning workshops, the air-conditioning effect parameters for the conventional slit air inlet and proposed design were 0.51 and 0.71, respectively. Specifically, the implementation of the proposed design resulted in improved temperature and humidity uniformity within the workshop. Lastly, the energy analysis of a 30,000-spindle textile factory revealed that the electricity savings associated with the novel air inlet accounted for 1.8% of the total electricity consumption of the factory. Overall, the proposed air inlet is well-suited for spinning workshops, offering significant advantages in terms of uniform air supply and energy savings.**

Index Terms—**Air inlet; Spinning workshop; Numerical simulation; Energy-saving effect; Air-conditioning effect**

I. INTRODUCTION

ACCORDING to ANSI/ASHRAE 70-2023 [1], an air inlet is a device used to either remove or return air from a conditioned space. Air inlets are used in various applications, such as heat sinks [2], desiccant wheels [3], and lithium-ion batteries [4-5]. Moreover, air inlets represent a crucial component of air-conditioning systems in spinning workshops, characterized by high temperatures and humidity levels [6]. Specifically, air inlets provide a significant supply of cold air to support spinning production and ensure worker thermal comfort [7]. Most buildings utilize roof-mounted air inlets [8-9], and below-grade air inlets are less commonly used [10-11]. Notably, the effectiveness of mechanical air supply is superior to that of natural ventilation [12-13], and this principle is also true for air inlets in textile workshops [14]. To enhance thermal comfort for textile workers, air inlets in spinning workshops are typically positioned on the roof above the operative channel. Treated air is directed through the air inlet into the operative area before being introduced into the production area, where it absorbs waste heat and regulates humidity levels before returning to the air-conditioned room [15]. Given the considerable length of spinning machines, often exceeding ten meters, the operative channel, typically one meter wide, relies on air inlets to supply air directly to the operative area. Although the airflow may be somewhat non-uniform, turbulence typically ensures that the temperature and humidity distribution in spinning workshops can meet process requirements [16].

The conventional slit air inlet is widely used in spinning workshops to ensure air supply [17]. Such inlets typically have a rectangular shape, with dimensions ranging from 500 to 3000 mm in length and 30 to 150 mm in width [14]. Fig. 1 illustrates the slit air inlet design. Horizontal and vertical adjustment plates afford control over the airflow direction. However, the absence of auxiliary jet mechanisms results in high airflow rates beneath the inlet and vortex formation in certain areas. These conditions can degrade the production efficiency and quality of high-count yarns. Furthermore, to ensure the thermal comfort of textile workers, the slit air inlet delivers cold air to the operative area rather than the primary heating area. Thus, energy consumption increases, as additional air supply is required to maintain the required production conditions [14].

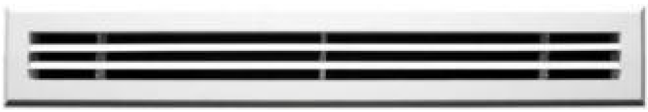

Fig. 1. A traditional slit air inlet.

As spinning equipment has increased in size and automation level, the yarn quality has improved [18]. However, the drawbacks of the traditional slit air inlet, specifically, its uneven air supply, have become increasingly evident, making it less effective for air delivery in spinning workshops [14]. Therefore, this paper introduces a novel air inlet (Fig. 2), derived from the traditional slit air inlet, to enhance air supply performance in spinning workshops.

This innovative design incorporates multiple wind scrapers positioned at the junction of the air inlet and main air duct to ensure uniform air volume; an air-volume-regulating valve, located at the throat of the air inlet; and narrow horizontal guide vanes beneath the air inlet to disperse air in multiple directions, thereby minimizing the likelihood of vortex formation. These design features promote consistent

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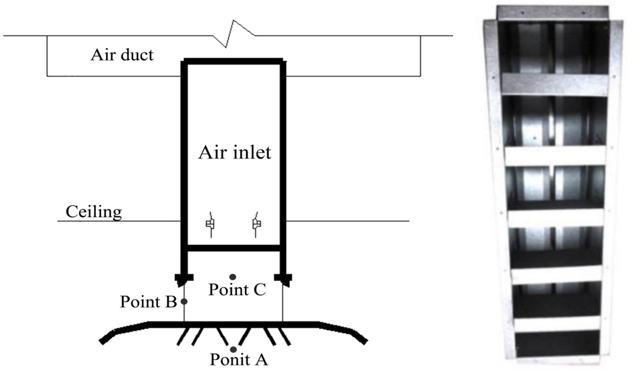
wind speed throughout the production area, ensure uniform temperature and airflow distributions, reduce the accumulation of dust and debris, and improve overall workshop cleanliness.



（a）Schematic diagram (b) Real picture

Fig. 2. A novel air inlet.

The objectives of this study can be summarized as follows: (1) to construct an experimental platform to validate the accuracy of the numerical model and investigate the air supply performance of the novel air inlet; (2) assess the energy-saving effect of the novel air inlet under comparable air supply volumes through numerical simulations; (3) evaluate the air supply performance of the novel air inlet through practical testing in an actual spinning workshop.

II. Methods

A. Construction of Experimental Platform

An experimental platform was established to evaluate the air supply performance of the proposed air inlet and validate the accuracy of the numerical model, as shown in Fig. 3. The platform was constructed in accordance with ANSI/ASHRAE 70-2023 [1]. The air duct was mounted on two steel-angle supports and connected to a compound mixed-flow air inlet. The air supply volume was regulated using a frequency converter, which controlled the SFG3-2 axial flow fan with a nominal air volume of 3000 m^3 /h. To meet the experimental requirements, variable speed flow modulation of the fan was achieved through the frequency converter. Complying with ANSI/ASHRAE 70-2023 [1] specifications, the dimensions of the experimental platform were 10 m (length) × 8 m (width) × 6.3 m (height).

B. Numerical Model for Validation

A simplified model of the air supply system, as shown in Fig. 3, was developed, focusing primarily on the air supply inlet and duct. In general, such simplified models can be solved using customized programs [19] or commercial software such as Fluent. In this study, the numerical model was established using Fluent 19.0, a widely used tool for HVAC simulations. This software includes a robust numerical model generation mechanism capable of addressing various fluid mechanics problems. The primary objective of developing a numerical model for the experimental setup was to accurately represent realistic airflow structures by filtering out extraneous factors. The final numerical model is illustrated in Fig. 4.

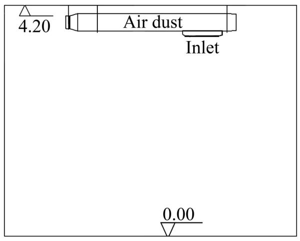


Fig. 3. An experimental platform

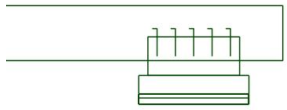
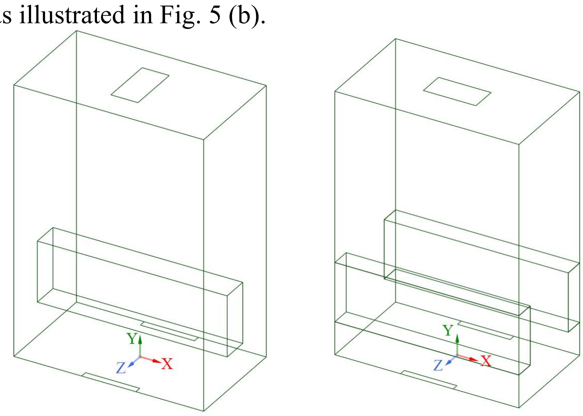


Fig. 4. The numerical model.

C. Numerical Model for Comparison

To evaluate the air supply effectiveness of the proposed and traditional slit air inlets, a typical region of a cotton spinning workshop was selected. This region measured 5 m × 2 m × 4.2 m and contained one air inlet in each section. The spinning machine was assumed to contain a uniform heating element (5 m × 0.8 m × 1.2 m), set to a constant heat flux density, with its bottom positioned 0.3 m above the ground. The proposed air inlet was located in the upper part of the spinning machine, centered within the area, as shown in Fig. 5 (a). In contrast, the traditional air inlet was situated above the aisle, resulting in a configuration where the calculation area contained two and a half spinning machines, as illustrated in Fig. 5 (b).



(a) Model of a novel air inlet (b) Model of a split air inlet

Fig. 5. Models of two air inlets in a typical spinning workshop

III. Results and Discussion

A. Comparison of Experimental Values and Numerical Simulated Values

In the meshed simplified numerical model, refinement was applied mainly in the region surrounding the air inlet. Figs. 6 and 7 show the trace and velocity vector diagrams of the outflow, demonstrating a uniform air supply.

A rotating frequency converter was used to adjust the wind velocity at the air inlet throat, setting speeds of 2, 2.5, 3, and 3.5 m/s. The wind speed was then measured at three distinct locations (Fig. 8) and compared with the numerical simulation results. Consistency between the simulation data and experimental results was assessed to determine whether the numerical model could accurately analyze the air supply effectiveness of the air inlet [20]. Fig. 9 presents the experimental and numerical results for the three measurement points at different throat wind speeds. The measured and simulated results were closely correlated, with a maximum deviation below 8%. Thus, the proposed numerical model could effectively evaluate the operational efficiency of the proposed air inlet.

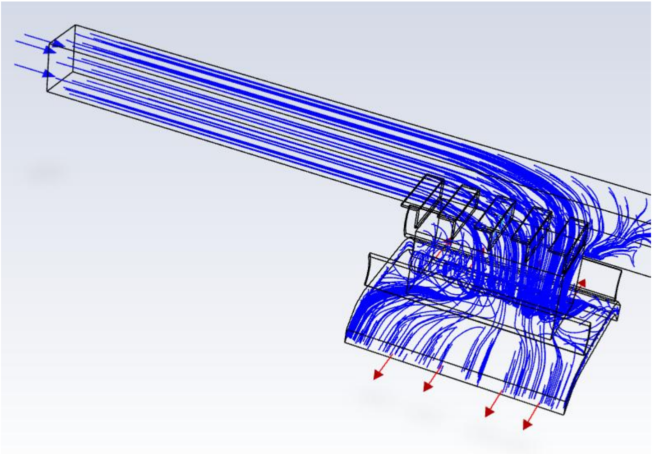


Fig.6. Outflow trace.

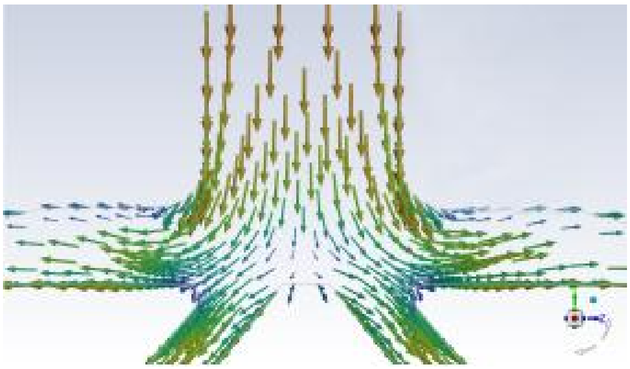


Fig. 7. Outflow velocity vector diagram.

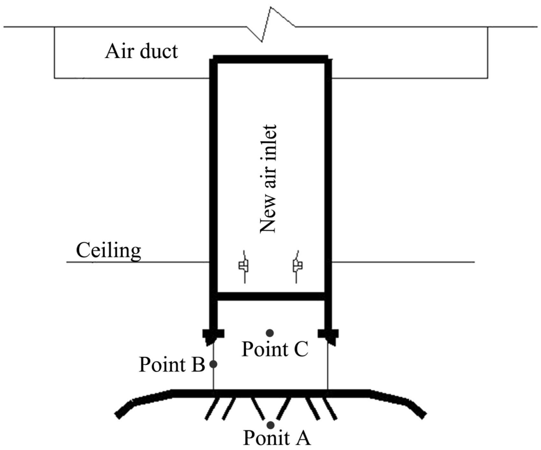


Fig. 8. Measuring point location.

B. *Air Supply Effectiveness of Proposed and Conventional Slit Air Inlets*

The air inlet leveraged a velocity inlet boundary condition, with a wind speed of 2.5 m/s and supply air temperature of 23 ℃. As expected, higher wind speeds at the air inlet resulted in increased wind speeds in the supply area [21-22]. However, in spinning workshops, the main function of the air supply is to satisfy process requirements. Therefore, a standard air supply speed was used in this study. Additionally, the air inlet involved a pressure inlet boundary condition. Heat transfer from the enclosure accounted for 10% of the cooling load, while the total load from lighting and personnel was 10 W/m².

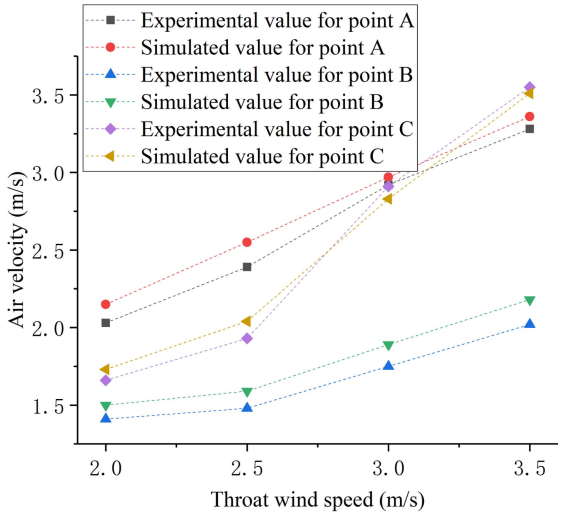


Fig. 9. Comparison of experimental values and CFD.

Figs. 10 and 11 indicate that the proposed air inlet provided more uniform airflow throughout the workshop, whereas the slit air inlet generated stronger airflow in the aisle, leading to uneven airflow in the spinning area. Given that both personnel and spinning machines were positioned in the lower part of the workshop, measurements were obtained from two locations: at a height of 1.5 m in the middle of the aisle, and at a height of 1.5 m positioned 20 cm from the spinning machine. The temperature, relative humidity, and wind speed at these two locations were calculated to compare the air supply effectiveness of the proposed and conventional air inlets (Tables I–III).

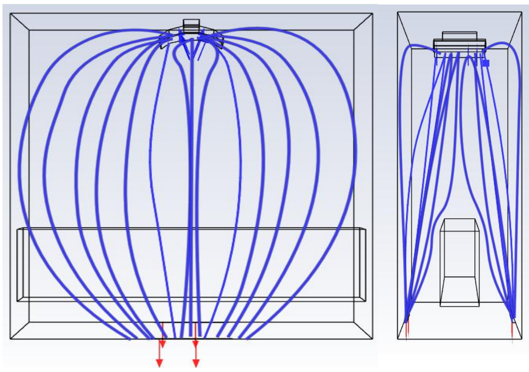


Fig. 10. Airflow field for a novel air inlet.

As indicated in Table I, regardless of the maximum, minimum, or mean values, the wind speed associated with the slit air inlet was significantly higher than that of the novel air inlet. This suggests that in the selected regions, the novel air inlet provided a more uniform air supply and improved airflow distribution.

As shown in Table II, relative to the conventional slit air inlet, the maximum and mean temperatures on the selected surfaces were significantly lower, while the minimum temperature was higher when using the novel air inlet. This suggests that the novel air inlet enhanced the uniformity of the temperature distribution throughout the spinning workshop.

As indicated in Table III, compared with the conventional air inlet, the maximum relative humidity on the selected surfaces was significantly lower with the novel air inlet, whereas the minimum and mean values were higher. This suggests that the novel air inlet led to a more uniform distribution of relative humidity within the spinning workshop, critical for maintaining the high-humidity environment required for the production processes.

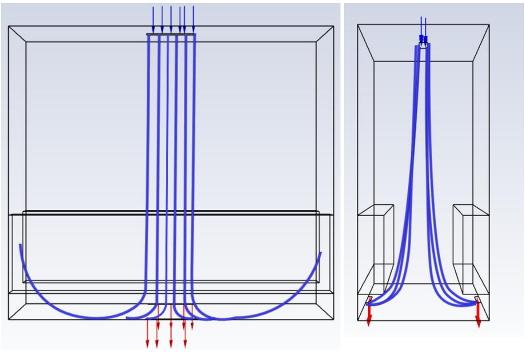


Fig. 11. Airflow field for a split air inlet.

TABLE I
COMPARISON OF WIND SPEED WITH THE NOVEL AIR INLET AND SPLIT AIR INLET (M/S)

	Max1	Max2	Min1	Min2	Mean1	Mean2
Spit Air Inlet	0.745	0.60	0.343	0.35	0.343	0.27
Novel Air Inlet	0.092	0.084	0.052	0.049	0.070	0.065

Note: Max1, maximum wind speed at a height of 1.5m in the middle of the aisle; Max2, maximum wind speed at a distance of 20cm from the spinning machine and a height of 1.5m; Min1， minimum wind speed at a height of 1.5m in the middle of the aisle; Min2, minimum wind speed at a distance of 20cm from the spinning machine and a height of 1.5m; Mean1, mean wind speed at a height of 1.5m in the middle of the aisle; Mean2, mean wind speed at a distance of 20cm from the spinning machine and a height of 1.5m.

TABLE II
TEMPERATURE COMPARISON USING THE NOVEL AIR INLET AND SPIT AIR INLET (℃)

	Max3	Max4	Min3	Min4	Mean3	Mean4
Spit Air Inlet	30.88	31.48	28.54	28.88	29.93	30.38
Novel Air Inlet	29.81	30.06	29.34	29.52	29.60	29.80

Note: Max3, maximum temperature at a height of 1.5m in the middle of the aisle; Max4, maximum temperature at a distance of 20cm from the spinning machine and a height of 1.5m; Min3, minimum temperature at a height of 1.5m in the middle of the aisle; Min4, minimum temperature at a distance of 20cm from the spinning machine and a height of 1.5m; Mean3, mean temperature at a height of 1.5m in the middle of the aisle; Mean4, mean temperature at a distance of 20cm from the spinning machine and a height of 1.5m.

TABLE III
RELATIVE HUMIDITY COMPARISON USING THE NOVEL AIR INLET AND SPIT AIR INLET (%)

	Max5	Max6	Min5	Min6	Mean5	Mean6
Spit Air Inlet	60.88	59.99	53.24	51.75	56.36	55.16
Novel Air Inlet	57.53	57.96	55.87	55.42	56.60	56.3

Note: Max5, maximum relative humidity at a height of 1.5m in the middle of the aisle; Max6, maximum relative humidity at a distance of 20cm from the spinning machine and a height of 1.5m; Min5,minimum relative humidity at a height of 1.5m in the middle of the aisle; Min6, minimum relative humidity at a distance of 20cm from the spinning machine and a height of 1.5m; Mean5, mean relative humidity at a height of 1.5m in the middle of the aisle; Mean6, mean relative humidity at a distance of 20cm from the spinning machine and a height of 1.5m.

In summary, as indicated in Tables I–III, the implementation of the novel air inlet resulted in a more consistent air supply to the workshop. Moreover, the novel air inlet led to more uniform wind speed, temperature, and relative humidity levels throughout the space, with the higher average relative humidity levels particularly beneficial for production. Thus, the novel air inlet is more suitable for textile workshops.

C. Energy-Saving Effect

1) Air-Conditioning Effect Parameter

Studies show that the optimal relative humidity range for the production processes in a spinning workshop is between 55% and 70% [23]. Furthermore, maintaining a lower workshop temperature during summer enhances the effectiveness of air conditioning for employees [24]. To quantify this air-conditioning effect, we defined an air-conditioning effect parameter as a function of the mean relative humidity, standard deviation of relative humidity, mean temperature, and standard deviation of temperature.

$$\kappa = \begin{cases} \frac{7}{10}\left(\frac{\overline{RH}}{70}-\frac{\sigma_1}{10}\right)+\frac{3}{10}\left(2-\frac{\overline{T}}{30}-\frac{\sigma_2}{10}\right) & \overline{RH} \le 70 \\ \frac{7}{10}\left(2-\frac{\overline{RH}}{70}-\frac{\sigma_1}{10}\right)+\frac{3}{10}\left(2-\frac{\overline{T}}{30}-\frac{\sigma_2}{10}\right) & \overline{RH} > 70 \end{cases} \quad (1)$$

where $RH, \sigma_1, \overline{T}, \sigma_2$ denote the mean relative humidity, standard deviation of relative humidity, mean temperature, and standard deviation of temperature, respectively. The simulated measurement points corresponded to all grid points within the calculation area, positioned 20 cm from the spinning frame, at a height of 1.5 m, and parallel to the spinning frame [7]. A higher value of the air-conditioning effect parameter indicated a more effective air-conditioning system, whereas a lower value indicated suboptimal performance of the air supply equipment [14].

2) Energy-Saving Calculation Process

The energy savings resulting from the implementation of the novel air inlet were calculated through the following process (Fig. 12): First, numerical simulations were conducted for both the proposed and conventional air inlets to determine the discharge coefficients at an equivalent air-conditioning volume. Next, the slit air inlet model was re-simulated with an increased air volume. Using the discharge coefficients obtained from both simulations, interpolation calculations were performed to determine the air supply volume required by the slit air inlet. By comparing the air supply volume of the proposed and conventional air inlets, the actual energy savings were quantified.

3) Assessment

Numerical simulations were performed to evaluate the performances of the novel air inlet and existing slit air inlet. Specifically, the slit air inlet was modeled as a rectangle [25]. For an air supply volume of 1000 m³/h, the calculated air-conditioning effect parameters were $\kappa_1 = 0.85$ for the novel air inlet and $\kappa_2 = 0.62$ for the conventional slit air inlet. Subsequently, a simulation was performed at an air supply volume of 1150 m³/h. The air-conditioning effect parameter for the conventional air inlet was $\kappa_2 = 0.91$, yielding an f value of 1119 m³/h. These results indicated that the implementation of the novel air inlet led to air supply volume and energy savings of approximately 10.6%.

D. Practical Application

The applicability of the air inlets was assessed by implementing them in two cotton spinning workshops, each measuring 71.2 m in length and 58.44 m in width, housing 66

FA506 spinning frames. One workshop was equipped with 216 novel air inlets, while the other was equipped with 216 conventional slit air inlets [14]. Both workshops operated using the same four air-conditioning rooms and maintained identical air supply volumes. The temperature, relative humidity, and wind speed were measured at 216 evenly spaced locations, positioned 20 cm from the spinning frame and at a height of 1.5 m, parallel to the spinning frame. The measured values are summarized in Table IV.

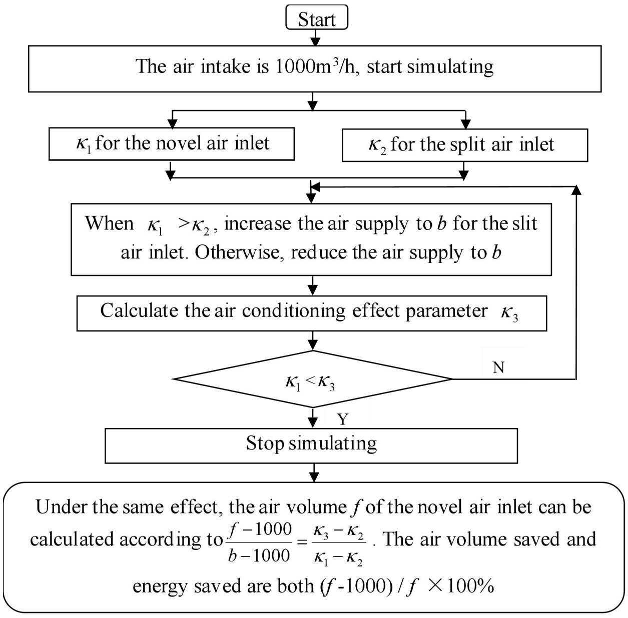


Fig. 12. The energy-saving calculation process for the novel air inlet.

When the novel air inlet was used, the mean temperature, standard deviation of temperature, standard deviation of relative humidity, and standard deviation of wind speed decreased, whereas the mean relative humidity increased. Additionally, the air-conditioning effect parameter for the novel air inlet was 0.71, higher than that (0.51) for the conventional slit air inlet. These results indicate that the novel air inlet is more suitable for spinning workshops, offering numerous benefits such as a uniform air supply and significant energy savings.

TABLE IV
MEASUREMENT EFFECT COMPARISON USING THE NOVEL AIR INLET AND SPIT AIR INLET

	MT	MRH	MWS	SDT	SDRH	SDWS	κ
Spit Air Inlet	31.4℃	47.7%	0.17	1.66	2.96	0.028	0.51
Novel Air Inlet	29.8℃	54.1%	0.17	0.50	1.64	0.018	0.71

Note: MT, mean temperature; MRH, mean relative humidity; MWS, Mean wined speed; SDT, standard deviation of temperature; SDRH, standard deviation of relative humidity; SDWS, standard deviation of wind speed.

A comparative survey was conducted among personnel working in the two workshops. Of the 39 participants, 37 were frontline workers and two were frontline managers. All participants were familiar with both workshops. Notably, 30 participants perceived an improvement in the quality of yarn produced in the workshop equipped with the novel air inlets, and 28 reported a more comfortable working environment. This feedback indicated that the novel inlets were well-received by the frontline personnel.

E. Energy Analysis

Spinning production is an energy-intensive process with significant potential for energy savings [26-28]. For instance, in a 30,000-spindle textile factory, if eight air-conditioners are used, the relevant electricity consumption is 406 kW. However, because the fans and water pumps in the air-conditioning system are equipped with frequency converters, the energy savings can be converted into electricity savings [12]. Through this approach, the textile factory can save up to 43 kW of electricity, which, at an average electricity price of 0.725 RMB/kWh, translates to daily savings of approximately 748.2 RMB [6]. Given that the total electricity consumption for the entire textile factory is 2357 kW, implementing the proposed novel air inlet technology could yield electricity savings of 1.8%, resulting in substantial energy savings [6].

IV. CONCLUSIONS

This study proposes a novel air inlet design to enhance air supply in spinning workshops, offering an alternative to the conventional slit-type design.

(1) The novel air inlet design features multiple wind scrapers installed at the junction of the air inlet and main air duct, an air-volume-regulating valve at the throat of the air inlet to adjust airflow, and narrow horizontal guide vanes positioned beneath the air inlet.

(2) An experimental platform was established to investigate the air supply effectiveness of the novel air inlet and validate the numerical model. The simulated values closely match the experimental values, with a maximum difference of less than 8%. These findings demonstrate the effectiveness of the numerical model in evaluating the performance of the novel air inlet.

(3) A comparison of the air supply effects of the proposed and conventional air inlets reveals that the proposed air inlet provides a more consistent air supply to the workshop, along with more uniform wind speed, temperature, and relative humidity levels throughout the space, particularly achieving a higher average relative humidity.

(4)The implementation of the novel air inlet results in approximately 10.6% savings in both air supply volume and energy, based on the air-conditioning effect parameters defined in GB/T 50481.

(5) Practical testing was conducted in two identical cotton spinning workshops, each measuring 71.2 m in length and 58.44 m in width, with one using the conventional air inlet and the other using the novel air inlet. The air-conditioning effect parameters of the novel and conventional air inlets are 0.71 and 0.51, respectively. These results indicate that the novel air inlet is more suitable for spinning workshops, offering significant benefits in terms of uniform air supply and energy savings.

(6) A comparative survey revealed that participants noticed better yarn quality and a more comfortable environment in the workshop with novel air inlets, suggesting frontline personnel welcomed the inlets.

(7) An energy analysis was performed for a textile factory with 30,000 spindles, revealing that the electricity saved by using the novel air inlet amounts to 1.8% of the total energy consumption. Thus, the adoption of the novel air inlet can lead to substantial energy and cost savings, highlighting the importance of its widespread implementation.

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