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Performance Analysis of Industrial Ventilation Systems: A Case Study of Exhaust Fan and Roof Cooling Fan Installations in a Textile Manufacturing Area

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Abstract

This study presents a performance analysis of industrial ventilation systems using exhaust fans and roof cooling fans in a textile manufacturing environment. The research was conducted as a case study in the Preparation and Processing areas of a textile factory located in Cimahi, West Java, Indonesia, under actual operating conditions. Air temperature and relative humidity (RH) were measured and compared with recommended textile industry standards (20–30°C and RH 55–75%). Two mechanical ventilation alternatives were evaluated: an exhaust fan system (1.46 × 1.46 m) and a roof cooling fan system (1.82 × 1.45 m). The results show that areas equipped with exhaust fans exhibited lower indoor temperatures by approximately 2–3°C and more stable RH levels (50–52%) compared to areas without mechanical ventilation, where temperatures reached up to 42°C and RH dropped to 25–30%. Both systems required 0.75 kW per unit, with monthly operating costs ranging from IDR 7–10 million. Volumetric efficiency analysis indicates that exhaust fans achieved 60,000 m³/kWh, while roof cooling fans produced 46,667 m³/kWh, indicating a 28% difference in airflow efficiency. These findings provide empirical evidence on the thermal and energy performance characteristics of industrial ventilation systems in textile production areas.

Keywords: Exhaust fan, industrial ventilation, energy performance, temperature and humidity, textile industry

1. Introduction

Textile manufacturing is characterized by intensive production processes that generate substantial internal heat loads and moisture due to the continuous operation of machinery, high spindle speeds, and dense equipment layouts. These conditions often result in elevated indoor temperatures and relative humidity levels that, if not properly controlled, can negatively affect textile quality, machine performance, and workers' health and safety (ASHRAE, 2016). Ensuring adequate thermal comfort and indoor air quality is therefore a critical requirement in textile production facilities, particularly in tropical regions such as Indonesia where high ambient temperatures prevail throughout the year.

To address the challenge, ventilation systems play a strategic role in mitigating excessive heat and moisture by facilitating heat removal and maintaining sufficient air exchange rates. According to ASHRAE guidelines, effective ventilation design not only improves thermal comfort but also supports productivity, occupational well-being, and energy optimization in industrial buildings (ASHRAE, 2016). Mechanical ventilation systems, such as exhaust fans and roof-mounted cooling fans, are commonly applied in manufacturing environments due to their operational simplicity, adaptability to existing buildings, and lower capital investment compared to centralized air-conditioning systems (Elhadary et al., 2021).

In the context of industrial ventilation, *performance analysis* refers to a systematic evaluation of how effectively a ventilation system achieves its intended functions under actual operating conditions. This evaluation typically involves multiple performance elements, including thermal comfort improvement (temperature reduction and humidity control), airflow effectiveness (air exchange rate and distribution), energy efficiency (power consumption relative to airflow capacity), and operational cost effectiveness (Elhadary et al., 2021; Izadyar & Miller, 2022). A comprehensive performance analysis is essential to determine whether a ventilation system provides adequate environmental control without imposing excessive energy demand.

Previous studies have demonstrated that well-designed exhaust ventilation systems can reduce indoor temperatures by approximately 2–5°C and maintain relative humidity within recommended industrial limits, while consuming significantly less energy than conventional cooling systems (Elhadary et al., 2021). Other research highlights that ventilation performance is strongly influenced by factors such as fan capacity, installation location, airflow patterns, and the actual thermal load generated by production processes (Izadyar & Miller, 2022). However, many existing studies rely on numerical simulations or controlled experimental settings and often focus on a single ventilation configuration, limiting their applicability to real industrial environments.

In practice, many textile industries in Indonesia still employ empirical or experience-based approaches when selecting and installing ventilation systems. Fan specifications and quantities are frequently determined without detailed assessments of heat generation, required air change rates, or energy performance indicators. As a result, ventilation systems may operate below optimal performance levels, leading to inadequate thermal comfort and unnecessary energy consumption. Furthermore, direct comparative analyses between different ventilation alternatives, such as exhaust fans and roof cooling fans, based on actual field measurements remain scarce. Therefore, this study aims to perform a comprehensive performance analysis of exhaust fan and roof cooling fan installations in a textile manufacturing area, focusing on thermal comfort, humidity control, energy consumption, operational cost, and volumetric efficiency under real operating conditions.

2. Literature Review

Industrial ventilation systems have been extensively studied as a critical component of environmental control in heat-intensive manufacturing facilities, including textile industries. Rather than being evaluated solely as air-moving devices, ventilation systems are increasingly analyzed based on their performance in achieving specific operational objectives, such as thermal comfort regulation, indoor air quality improvement, energy efficiency, and cost-effectiveness. In textile manufacturing, where processes continuously generate heat, moisture, and airborne particulates, the performance of ventilation systems directly influences both production stability and occupational health outcomes (ASHRAE Research, 2021; Anders & Santaram, 2021).

One of the primary elements of ventilation performance is thermal comfort effectiveness, which refers to the system's ability to reduce indoor air temperature and maintain relative humidity within acceptable industrial standards. Studies on mechanical ventilation systems indicate that effective exhaust and roof-mounted fans can significantly lower ambient temperatures and mitigate heat accumulation when airflow rates are appropriately matched to the thermal load of the space (Ikpe, 2024). In textile production areas, inadequate thermal control has been empirically linked to increased heat stress, worker fatigue, and productivity decline, highlighting the importance of performance-based ventilation evaluation rather than capacity-based selection alone (Fallah & Mashuri, 2025).

Another critical element of performance analysis is airflow efficiency and distribution, which determines how effectively fresh air replaces contaminated air within the production zone. Exhaust fan systems are widely implemented due to their capability to create directed airflow paths that remove hot air, dust, and fibers from work areas. Research by Fawwaz and Tjahjanti (2025) demonstrated that strategically placed exhaust fans improve air circulation patterns and reduce stagnant zones, leading to measurable improvements in thermal comfort. Similarly, earlier studies in textile environments emphasized that insufficient air exchange and dust accumulation contribute to respiratory health risks, reinforcing the need for ventilation systems that perform effectively in contaminant removal (Yulindra, 2011).

From an energy performance perspective, ventilation systems must be assessed based on the relationship between airflow delivery and electrical power consumption. Performance indicators such as airflow rate per unit power input and operational energy intensity are commonly used to evaluate ventilation efficiency in industrial buildings. Wang et al. (2019) reported that suboptimal airflow management can significantly increase energy demand without proportional thermal benefits, underscoring the importance of evaluating ventilation performance beyond nominal fan capacity. More recent studies have explored the application of inverter-based control strategies to enhance energy efficiency, with Anh et al. (2025) demonstrating that multi-level inverter-controlled exhaust fan systems allow adaptive airflow regulation and reduced energy consumption under varying operational conditions.

Despite advancements in ventilation performance assessment, many textile industries in developing regions continue to implement ventilation systems based on empirical judgment rather than systematic performance analysis. Thermal load calculations, airflow efficiency metrics, and operational cost evaluations are often overlooked during system selection and installation. Consequently, ventilation systems may fail to deliver optimal thermal comfort or operate at unnecessary energy costs. Addressing this gap, the present study conducts a comparative performance analysis of exhaust fan and roof cooling fan systems in a textile manufacturing environment, focusing on thermal comfort effectiveness, airflow efficiency, energy consumption, and operational cost under real operating conditions.

3. Methods

3.1. Research Site

This research was conducted in two main production areas, namely the Preparation and Processing sections, of a textile manufacturing plant located in Cimahi, West Java, Indonesia. These areas are characterized by high thermal loads and fluctuating humidity levels due to continuous production activities. This study evaluates the effectiveness and energy efficiency of two mechanical ventilation systems, namely exhaust fans and roof cooling fans, installed in the production areas. The data collected included air temperature, relative humidity (RH), room dimensions, ventilation system specifications, electrical power consumption, and operational costs.

3.2. Data Collection

Data collection was conducted under actual operating conditions in the Preparation and Processing areas. Environmental parameters measured included air temperature (°C) and relative humidity (RH, %) recorded during morning, afternoon, and evening periods to capture daily thermal variations. Room dimensions (length, width, and height) were measured to determine the total room volume for airflow analysis.

Operational data of the ventilation systems were also collected, including electrical power consumption per unit, the number of installed units, operating hours, and estimated monthly operating costs. These data were used to evaluate the energy efficiency and cost performance of the ventilation systems.

3.2.1. Ventilation System Alternatives

Two mechanical ventilation systems were evaluated in this study: an exhaust fan system and a roof cooling fan system. The comparison was based on key technical parameters, including fan dimensions, air capacity, electrical power consumption, and the number of installed units. The technical specifications of both systems are summarized in Table 1.

Table 1: Two Alternative Mechanical Ventilation Systems

Alternative	Dimensions (m)	Air Capacity (m^3/h)	Power (kW/unit)	Number of Units
Exhaust Fan	1.46 × 1.46	45,000	0.75	38
Roof Cooling Fan	1.82 × 1.45	35,000	0.75	27

3.2.2. Formula / Equation

The total air flow rate was calculated using Equation (1):

$$Q = n \times V$$

where Q is the total air flow rate (m^3/h), n is the air exchange rate (h^{-1}), and V is the room volume (m^3).

4. Results and Discussion

This section presents the results of field measurements and discusses the performance of the installed ventilation systems under actual operating conditions. The analysis evaluates thermal comfort, relative humidity control, and energy-related aspects, including power consumption and operating costs, as key indicators for assessing the overall performance and efficiency of the ventilation systems in the textile production areas.

4.1 Temperature and Relative Humidity Performance

Table 2 presents the measured air temperature and relative humidity (RH) in the Preparation and Processing areas under actual operating conditions, along with the corresponding target values based on textile industry standards. This comparison provides an initial assessment of the deviation between existing indoor environmental conditions and the recommended comfort ranges.

Table 2: Measured air temperature and relative humidity (RH)

Area	Temperature (°C)	RH (%)	Target (°C/RH%)
Preparation	38.01	49.41	27 / 60
Processing	36.82	49.25	27 / 60

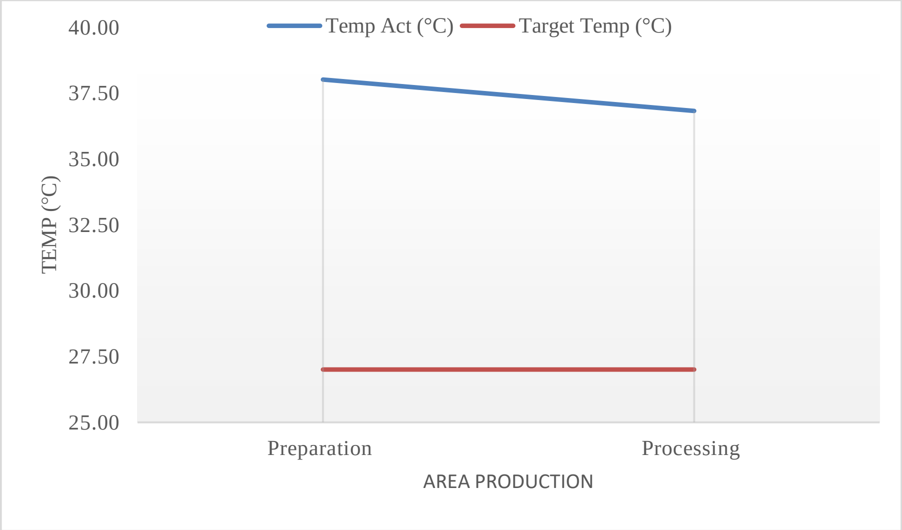

Figure 1: Shows a comparison between actual temperatures and the target standard.

Figure 1 illustrates the comparison between actual and target temperatures in the Preparation and Processing areas. The measured temperatures in both areas significantly exceed the recommended target of 27°C, with the Preparation area reaching 38.01°C and the Processing area 36.82°C. Although the Processing area shows a slightly lower temperature than the Preparation area, both values indicate a substantial deviation from the desired thermal comfort range. This result confirms the presence of excessive heat accumulation in the production areas and highlights the need for effective mechanical ventilation to reduce indoor temperature and improve thermal comfort conditions.

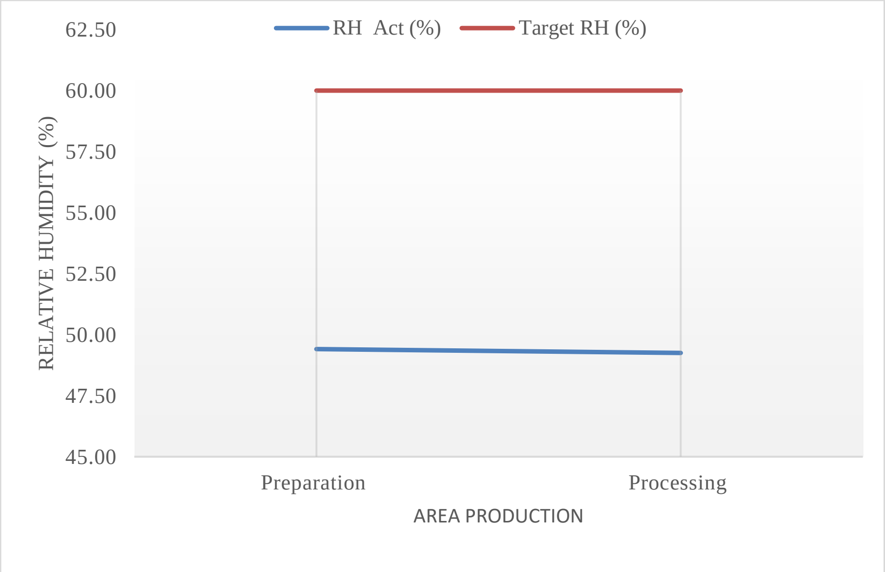

Figure 2: Presents the comparison of actual RH values and the target RH.

Figure 2 shows the comparison between actual and target relative humidity (RH) levels in the Preparation and Processing areas. The measured RH values in both areas are relatively stable, ranging from 49.41% in the Preparation area to 49.25% in the Processing area; however, these values remain below the recommended target of 60%. This deviation indicates that, despite acceptable stability, the indoor environment is drier than the optimal range for textile production. Such conditions may influence material handling and increase the risk of static electricity, highlighting the importance of ventilation strategies that not only remove heat but also help maintain adequate humidity levels.

The installation of exhaust fans resulted in an average temperature reduction of approximately 2.5°C and improved RH stability in the range of 50–52%. In contrast, areas without mechanical ventilation reached temperatures up to 42°C with RH levels as low as 25–30%.

4.2 Energy Consumption and Operating Cost Analysis

Table 3 summarizes the energy consumption and monthly operating costs of the two alternative mechanical ventilation systems evaluated in this study**.**

Table 3: Summarizes the energy consumption and monthly

Alternative	Power (kW/unit)	Units	Monthly Cost (IDR)
Exhaust Fan (1.46 × 1.46)	0.75	38	10,218,960
Roof Cooling Fan (1.82 × 1.45)	0.75	27	7,260,840

Although the exhaust fan system requires approximately 40% higher operational costs, it provides superior air capacity and cooling effectiveness compared to the roof cooling fan system. This difference highlights the trade-off between energy expenditure and thermal performance in industrial ventilation design. A system with lower operating costs does not necessarily deliver optimal airflow distribution or sufficient heat removal, particularly in high-thermal-load environments such as textile production areas.

To further assess energy performance, volumetric efficiency (η) was calculated as the ratio of air capacity to electrical power input. The exhaust fan achieved a volumetric efficiency of 60,000 m^3/kWh, while the roof cooling fan reached only 46,667 m^3/kWh. This result indicates that the exhaust fan system is approximately 28% more efficient in terms of air movement per unit of energy consumed.

The higher volumetric efficiency of the exhaust fan system suggests a more effective utilization of electrical energy for ventilation purposes, enabling greater heat removal and improved thermal comfort despite higher operating costs. Therefore, from an energy-performance perspective, the exhaust fan system represents a more suitable solution for production areas with high heat generation, where thermal comfort and process stability are critical to operational efficiency.

5. Conclusion

This study evaluated the performance of two mechanical ventilation systems, exhaust fans and roof cooling fans, installed in a textile manufacturing area under actual operating conditions. The results indicate that high thermal loads in the Preparation and Processing areas caused indoor temperatures to exceed recommended comfort standards, confirming the necessity of effective mechanical ventilation. The installation of exhaust fans successfully reduced indoor temperatures by approximately 2–3°C and improved relative humidity stability to around 50–52%, approaching the recommended range for textile production.

From an energy perspective, the exhaust fan system required approximately 40% higher monthly operating costs compared to the roof cooling fan system. However, volumetric efficiency analysis showed that exhaust fans achieved a higher airflow-to-energy ratio (60,000 m^3/kWh), making them about 28% more efficient in air movement per unit of electrical energy. This superior airflow performance resulted in more effective heat removal and better air distribution within high-thermal-load production areas.

Overall, despite higher energy consumption, exhaust fan–based ventilation systems demonstrate better overall performance in terms of thermal comfort, humidity control, and ventilation efficiency. Therefore, exhaust fans are recommended for textile production environments with intensive heat generation, where improved indoor environmental conditions can enhance process stability, worker comfort, and long-term operational efficiency.

6. Suggestions

Future studies are recommended to incorporate Computational Fluid Dynamics (CFD) simulations to provide a more detailed analysis of airflow distribution, velocity profiles, and heat removal effectiveness within textile production areas. In addition, the implementation of automated ventilation control systems based on real-time temperature and relative humidity sensors is suggested to enable adaptive fan speed regulation. Such systems have the potential to optimize ventilation performance while further reducing energy consumption and operational costs in industrial environments.

References

Amien, F. & Kemenkes Makassar, P. (2025). Exposure to Particulate Matter (PM 10 and PM 2.5) in the Work Environment at the PT Vale Sorowako Smelter Plant, East Luwu. Sulolipu Journal, *25*(2), 301–308.

Anders, B. D., & Santaram, V. (2021). Design of a Ventilation System to Improve IAQ and Thermal Comfort in a Textile Factory. *Indoor Environmental Quality Performance Approaches*, 1–11. www.ashrae.org

Anh, A. T. H. T., Cuong, T. H., & Khoi, T. Van. (2025). Cascaded H-bridge 7-level inverter application for air exhaust fan drive control of Thu Thiem road tunnel. *Bulletin of Electrical Engineering and Informatics*, *14*(1), 108–117. https://doi.org/10.11591/eei.v14i1.8490

Ashrae Research. (2021). *2021 ASHRAE handbook. Fundamentals*. ASHRAE.

Elhadary, M. I., Alzahrani, A. M., Aly, R. M. H., & Elboshy, B. (2021). A comparative study for forced ventilation systems in industrial buildings to improve the workers' thermal comfort. *Sustainability*, *13*(18), 10267. https://doi.org/10.3390/su131810267

Fallah, B. W., & Mashuri, P. (2025). Critical Control Point Analysis of Physical Environment on Work Stress in Textile Industry. *Metode Jurnal Teknik Industri*, *11*(2), 2025.

Fawwaz, R. M., & Tjahjanti, H. P. (2025). Air Circulation Improvement through Exhaust and Fan Installation. In *Procedia of Engineering and Life Science* (Vol. 8, Issue 1).

Ikpe, A.E. (2024). The role of mechanical ventilation systems and their applications in contemporary engineering practices. *Optimality, Vol. 1, No. 2*.

Izadyar, N., & Miller, W. (2022). Ventilation strategies and design impacts on indoor airborne transmission: A review. *Building and Environment*, *218*, 109158. https://doi.org/10.1016/j.buildenv.2022.109158

Verma, A., & Gupta, S. (2025). Numerical simulation of exhaust position for optimized ventilation in a textile manufacturing plant: A CFD study. *International Journal of Engineering Applied Sciences and Technology, 9*(10), 30–41.

Wang, Y., Cao, Y., & Meng, X. (2019). Energy efficiency of industrial buildings. In *Indoor and Built Environment* (Vol. 28, Issue 3, pp. 293–297). SAGE Publications Ltd.

Yulindra, M. (2011). *The Relationship Between Byssinosis Incidence and the Level of Cotton Dust Exposure in Textile Workers at PT ASATEX Yogyakarta*.