OPTIMIZING FUME EXTRACTION: AN EMPIRICAL STUDY ON THE PERFORMANCE OF LOCAL EXHAUST VENTILATION (LEV) FOR WELDING IN TECHNICAL VOCATIONAL LABORATORIES

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Abstract
This study evaluates the performance of the Local Exhaust Ventilation (LEV) system at the Welding and Metal Fabrication Laboratory, Faculty of Technical and Vocational Education (FPTV), Universiti Tun Hussein Onn Malaysia (UTHM). The objectives were to measure velocity pressure (VP), static pressure (SP), and total pressure (TP) along the duct system, assess air velocity at duct and hood locations, analyze performance variation by duct size, and identify underperforming extraction points. Data were collected at sixteen locations (six ducts and ten hoods) using a digital anemometer, following the Department of Occupational Safety and Health (DOSH, 2008) guidelines. The results showed duct velocities ranging from 14.54 to 21.96 m/s and hood velocities from 1.94 to 3.27 m/s. Two hoods (Hood 9 and Hood 10) recorded velocities below the 2.0 m/s minimum recommended by ACGIH, indicating reduced extraction efficiency. The performance drop was attributed to extended duct length, dust accumulation, and pressure losses due to multiple bends. Optimization strategies were proposed, including regular duct cleaning, airflow balancing, fan performance assessment, and redesigning long ducts or installing booster fans. Implementing these measures can enhance airflow uniformity, improve capture efficiency, and ensure compliance with ACGIH and DOSH standards. The findings provide practical insights for maintaining effective LEV systems and improving occupational safety in Technical and Vocational Education and Training (TVET) welding laboratories.

Keywords: Local Exhaust Ventilation (LEV), air velocity, welding fumes, duct performance, fume extraction efficiency, occupational safety.

1. INTRODUCTION

Local Exhaust Ventilation (LEV) systems are essential engineering controls used to minimize worker exposure to hazardous fumes, vapors, and airborne contaminants in industrial and educational environments. In welding operations, the LEV system functions to capture and remove contaminants directly at their source before they disperse into the breathing zone. Maintaining optimal air velocity at both the duct and hood inlets is therefore critical to ensure the effectiveness of contaminant capture and transport. According to the American Conference of Governmental Industrial Hygienists (ACGIH, 2022), recommended duct velocities for efficient contaminant transport typically range between 10–20 m/s, depending on the type of particulate and duct configuration. Meanwhile, hood face velocities are generally advised to be within 0.5–2.5 m/s, depending on hood design and the characteristics of the contaminant generated. These recommended velocity ranges are essential to achieve adequate capture efficiency and prevent backflow of harmful fumes into the workspace (Amiruddin et al., 2024; Logachev et al., 2024; Szekeres, 2024; DOSH, 2008).

However, despite these guidelines, many educational institutions and vocational laboratories often face challenges in maintaining the recommended performance of LEV systems. Previous studies (Al-Abdullatif & Kim, 2023; Setyawan et al., 2022) have highlighted issues such as uneven air distribution, poor duct design, and low hood velocity, leading to insufficient fume extraction efficiency. In addition, a recent empirical-CFD study in Malaysia (Amiruddin et al., 2024) showed that some hoods yielded velocities of ~1.94 m/s while duct velocities varied between ~14.5–18.5 m/s, reflecting significant differences likely due to pressure losses and duct sizing effects. Studies such as CFD Analysis and Improvement Proposal for the Fume Extraction System in a Welding

Workshop found that existing systems may generate absorption velocities as low as 0.006 m/s, whereas with optimized hood design this could be increased to ~0.78 m/s to meet recommended performance (Cacpata-Bastidas et al., 2024). Meanwhile, Szekeres (2024) conducted a controlled workstation experiment to analyze the capture velocity behavior in LEV systems, reinforcing the importance of hood geometry and inlet velocity control.

In Malaysia, empirical data on the performance evaluation of LEV systems in Technical and Vocational Education and Training (TVET) laboratories remain scarce. This gap limits the ability of educators and facility managers to ensure compliance with occupational safety standards and to optimize system design for practical training environments. The current LEV system installed in the Welding and Metal Fabrication Laboratory at Universiti Tun Hussein Onn Malaysia (UTHM) has been in use for several years without detailed performance assessment. Initial observations indicate possible variation in suction efficiency among hoods, potentially due to differences in duct size and static pressure losses along the system. Therefore, a systematic evaluation is required to determine whether the existing LEV system provides adequate ventilation performance in accordance with international and local standards such as the Department of Occupational Safety and Health (DOSH, 2008) guidelines.

Despite substantial evidence of the effectiveness of LEV systems, several persistent challenges remain. First, airflow instability and static pressure losses commonly occur in complex duct systems with multiple elbows, dampers, or long duct runs, leading to reduced hood suction performance (Flynn & Susi, 2012; Logachev et al., 2024). Second, hood design and positioning relative to the welding arc significantly influence capture efficiency, as demonstrated by Sabzehali et al. (2023), where the bell-shaped hood yielded superior results. Third, there is a lack of empirical performance data in educational and vocational welding laboratories, where LEV systems are often shared across multiple workstations (Ngali et al., 2023; Rosli et al., 2021). Most prior studies have focused on industrial workshops rather than instructional environments, though recent work such as the Malaysian CFD-empirical validation by Amiruddin et al. (2024) begins to fill this gap. Finally, limited integration between Computational Fluid Dynamics (CFD) simulations and actual field measurements has resulted in insufficient validation of theoretical LEV performance models; for example, the discrepancy in absorption velocity from 0.006 m/s (existing) to 0.78 m/s (proposed hood) in Cacpata-Bastidas et al. (2024) underscores this gap.

Given these gaps, the present study aims to provide a comprehensive empirical evaluation of LEV performance within a Technical and Vocational Education and Training (TVET) welding laboratory setting. The findings are expected to contribute to improved system design, maintenance practices, and occupational safety compliance within similar institutions. Accordingly, this study aims to:

i. Measure the velocity pressure, static pressure, and total pressure along the LEV duct system.
ii. Evaluate the air velocity at selected duct and hood locations to assess fume extraction efficiency.
iii. Identify underperforming extraction points and propose optimization strategies to improve system performance.

This empirical investigation contributes to enhancing safety management practices in vocational laboratories and supports the development of a data-driven framework for maintaining effective LEV systems in technical education institutions.

2. LITERATURE REVIEW

Local Exhaust Ventilation (LEV) systems have been widely studied as an effective engineering control to reduce workers' exposure to airborne contaminants in various industrial operations such as welding, grinding, and chemical processing. In the context of welding laboratories within Technical and Vocational Education and Training (TVET) institutions, the issue becomes more complex. Unlike industrial setups with fixed workstations, educational laboratories often accommodate multiple welding booths connected to a shared duct network. Ngali et al. (2023) observed that when several hoods operate simultaneously, air velocity tends to decrease due to airflow competition among ducts. Furthermore, Jiang et al. (2025) reported that maintenance issues, such as clogged filters or unbalanced fan speeds, exacerbate performance inconsistencies across different hoods. Similar studies by Amiruddin et al. (2024) emphasized that proper duct design and airflow optimization are essential to achieve effective fume extraction performance in welding environments.

2. 1.Health Impacts and the Importance of Welding Fume Control

Welding fumes consist of complex mixtures of metallic oxides and fine particles containing elements such as manganese, chromium, nickel, and iron, all of which pose serious health hazards (Amiruddin et al., 2020). Halbach et al. (2015) found that workers performing arc welding are exposed to fumes generated by the joining of metals, including manganese. Prolonged exposure to these airborne contaminants can cause chronic respiratory diseases, neurological disorders, and potential carcinogenic effects as classified by the International Agency for Research on Cancer (IARC). Effective engineering controls such as Local Exhaust Ventilation (LEV) systems are therefore crucial to maintaining air quality and ensuring worker safety in welding environments.

2. 2.Principles and Effectiveness of Local Exhaust Ventilation (LEV)

LEV systems are among the most effective engineering controls for capturing and removing air contaminants directly at their source before they disperse into the breathing zone. Zaidi et al. (2023) observed that when several hoods operate simultaneously, air velocity tends to decrease due to airflow competition among ducts. Furthermore, Meeker et al. (2014) reported that maintenance issues, such as clogged filters or unbalanced fan speeds, exacerbate performance inconsistencies across different hoods. Similar studies by Mahaki et al. (2021) emphasized that proper duct design and airflow optimization are essential to achieve effective fume extraction performance in welding environments.

2. 3.Empirical Studies in Welding Laboratories

In the Malaysian context, Zaidi et al. (2023) conducted an efficiency study of LEV systems in a technical college welding workshop and found that several hoods failed to meet ACGIH capture velocity standards due to poor maintenance and unbalanced airflow distribution. The study emphasized the need for periodic inspections and recalibration of the LEV system to ensure consistent performance. Similarly, Knott et al. (2023) compared three fume control methods—LEV hood extraction, on-gun extraction, and respiratory protective equipment—and reported that LEV hoods reduced respirable fume concentrations by up to ninefold, while on-gun extraction achieved reductions up to twelvefold compared to no control. These findings reinforce the critical role of properly designed and maintained LEV systems in welding safety management.

3. METHODOLOGY

3. 1. Research Location

This experiment was conducted at the Welding and Metal Fabrication Laboratory, Faculty of Technical and Vocational Education (FPTV), Universiti Tun Hussein Onn Malaysia (UTHM). The laboratory is equipped with a Local Exhaust Ventilation (LEV) system designed to extract hazardous welding fumes. The system comprises ten (10) LEV hoods connected to round ducts of three different diameters: 203 mm, 154 mm, and 102 mm.

3. 2. *Research* Design

This study adopted a quantitative experimental research design, emphasizing direct measurements of airflow parameters. The main objective was to analyze the efficiency of the LEV system in capturing and removing welding fumes under real laboratory operating conditions. Data were collected following the procedures recommended in the Guidelines on Occupational Safety and Health for Design, Inspection, Testing, and Examination of LEV Systems (DOSH, 2008).

3. 3. Instruments and Equipment

A digital anemometer was utilized to measure air velocity, velocity pressure (VP), and static pressure (SP) at selected points within the LEV system. The instrument is equipped with a statistical data logging function, which automatically records the minimum, maximum, and average readings during each measurement session. All recorded data were automatically stored in the device's internal memory and subsequently downloaded to a computer for further analysis and documentation. The use of this instrument ensures precise and consistent measurement of airflow characteristics in accordance with the Guidelines on Occupational Safety and Health for Design, Inspection, Testing, and Examination of LEV Systems (DOSH, 2008).

3. 4. Data Collection Procedure

Measurements were taken at sixteen (16) different points within the LEV system:
Six (6) locations along the ductwork (Duct 1 to Duct 6)
Ten (10) locations at the LEV hoods (Hood 1 to Hood 10)
For duct locations:

i. Computing average velocity from velocity pressure readings.

According to Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH, average velocity, V of LEV system can be computed from Velocity Pressure (VP) readings using equation as shown:

$$V=4005\times \sqrt{VP}$$

Where:

V is velocity value of LEV system.
VP is velocity pressure readings.
Static pressure (SP) was also recorded, and total pressure (TP) was calculated using:
TP=VP+SP

For hood locations:
Air velocity (V) was measured directly at each hood (with a duct diameter of 102 mm) using the anemometer probe.

ii. Measurement of Velocity Pressure (VP)

To obtain VP readings according to Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH, the number and placement of measuring sites within the duct rely on the duct size and shape, which are round and rectangular. The concept is to divide the duct into enough equal-area zones to get accurate findings. VP is measured in meter per second (m/s). The following are the proper procedures for measuring VP:

a) For a round duct where ever horizontal or vertical traverse insertion depths can be evaluated as indicated inFigure 4.1 and Table 4.1.

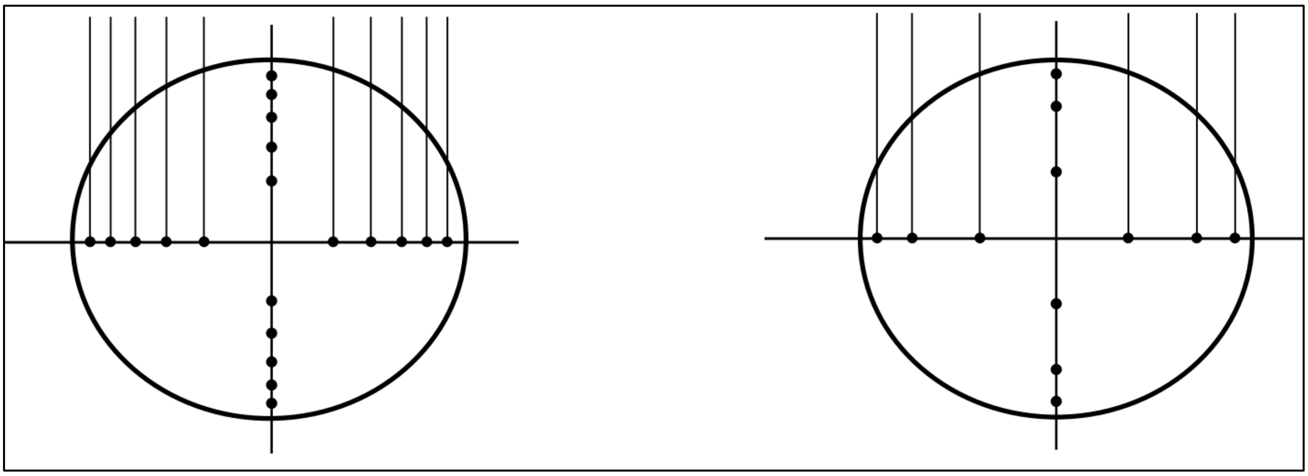

Figure 4.1: Measuring location for a 10 and 6 points pitot travers (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

Table 4.1: Depths to insert pitot tube for traverse readings on round ductwork (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

Diameter of duct (inch)	Distance from wall in fraction of a duct diameter, log-linear rule traverse position (mm) multiple by Diameter, D of round duct									
	1	2	3	4	5	6	7	8	9	10
4	-	-	-	0.043	0.290	0.710	0.957	-	-	-
6	-	-	0.032	0.135	0.321	0.679	0.865	0.968	-	-
8	-	0.021	0.117	0.184	0.345	0.655	0.816	0.883	0.979	-
10	0.019	0.077	0.153	0.217	0.361	0.639	0.783	0.847	0.923	0.981
12	0.019	0.077	0.153	0.217	0.361	0.639	0.783	0.847	0.923	0.981

b) For a rectangular duct - The cross-section is divided ducts into equal parts and a reading is taken at the centre of each area. There should be at least 16 readings obtained, however the interval between measuring point should not exceed 6
inches.

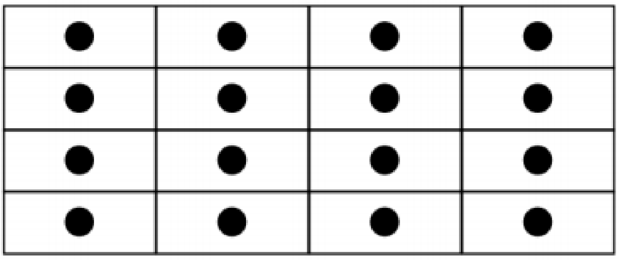

Figure 4.2: Measuring location for rectangular duct (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

3. 5. Data Analysis

The data collected from the digital anemometer were analyzed using descriptive and comparative methods to evaluate the performance of the Local Exhaust Ventilation (LEV) system. The analysis focused on interpreting the measured values of air velocity, velocity pressure (VP), static pressure (SP), and total pressure (TP) across different locations within the system. All measurements obtained from the six (6) duct points and ten (10) hood points were tabulated and averaged to determine airflow characteristics at each sampling location. This analysis provides a comprehensive understanding of the LEV system's performance by quantifying airflow characteristics, identifying inefficiencies, and aligning results with established safety and ventilation standards.

4. FINDINGS AND DISCUSSIONS

4. 1. Objective 1: to measure the velocity pressure, static pressure, and total pressure along the Local Exhaust Ventilation (LEV) duct system.

Before any actual experimental measurements could be taken, the physical condition of every component of the Local Exhaust Ventilation (LEV) system had to be assessed. The goal of this inspection is to ensure that the LEV system is in good condition. During the measurements, any obstructions to the airflow of the LEV inlet hood were removed. Before taking any anemometer observations, the fan that produced air suction was switched on for at least fifteen minutes. This step is critical for ensuring the LEV system's stability. As a result, data collecting is solid and precise.

Regardless of duct shape, the optimal location to execute a traverse is at least 7.5 diameters downstream of any major disturbance, such as dampers or elbows. This is done to ensure laminar airflow at the measuring site. If the traverse ends at a place with a diameter less than 7.5, another traverse must be performed at a different place and the results compared. The results are acceptable if the calculated volumetric flow rates are within 10% of each other. At the Welding and Metal Fabrication Laboratory, researcher has been determining the duct shapes of the LEV system, which are spherical ducts. This LEV system has three distinct circular duct sizes. As a result, the researcher employs Table 3.1 as a reference in conducting this research.

Table 3.2: An example of how insertion depths of pitot tube were determined for round ducts using 10 insertion pitot point travers at 203.2mm diameter of round duct

Traverse Point	Ratio of Depths, R	Diameter of Duct, D (mm)	Insertion Depths of Pitot Tube, R x D (mm)
1	0.019	203.2	3.86
2	0.077	203.2	15.65
3	0.153	203.2	31.1
4	0.217	203.2	44.1
5	0.361	203.2	73.36
6	0.639	203.2	129.84
7	0.783	203.2	159.11
8	0.847	203.2	172.11
9	0.923	203.2	187.55
10	0.981	203.2	199.34

Table 3.2 illustrates how Figure 3.1 was used for round ducts of the LEV system at the Welding and Metal Fabrication Laboratory, FPTV, with eight (8) insertion points. Pitot tube was inserted into the duct at varied depths using the identical insertion points, and measurements were taken until travers point 8. To obtain reliable readings of velocity pressure and static pressure using the pitot tube, the traverse points were selected at a minimum distance of 7.5 times the duct diameter downstream from any disturbances (e.g., elbows or dampers). The duct at the Welding and Metal Fabrication Laboratory was confirmed to be circular, and three different duct diameters were identified: 203 mm, 154 mm, and 102 mm. Table 3.2 illustrates the insertion depths for the pitot tube at each of the 10 traverse points in a 203.2 mm diameter duct. The insertion depths were calculated by multiplying the ratio of depth (R) with the duct diameter (D), producing exact points ranging from 3.86 mm to 199.34 mm. These precise locations ensured a representative velocity profile across the duct cross-section.

4. 2. Objective 2: Evaluate the air velocity at selected duct and hood locations to assess fume extraction efficiency.

A total of 16 measurement locations were selected throughout the LEV system: six (6) along the ducts and ten (10) at the hoods. There are three (3) distinct sizes of round ducts in this laboratory, with diameters of 203mm, 154mm, and 102mm. A total of ten (10) LEV hoods are attached to the LEV system at UTHM's Welding and Metal Fabrication Laboratory, FPTV. Measurement of the velocity pressure was performed at six (6) locations along the duct and ten (10) locations were calculated on the hood of LEV system. The results of the experiment are displayed in the table below.

Table 4.1: The results of air velocity along ducts were actual experiment performed

Location	Velocity Pressure, VP ("wg)	Velocity, V (m/s) V=4005 X √VP	Static Pressure, SP ("wg)	Total Pressure, TP ("wg) TP=VP + SP
Duct 1	0.825	18.49	-2.850	-2.025
Duct 2	0.896	19.26	-2.040	-1.144
Duct 3	0.773	17.89	-1.123	-0.35
Duct 4	0.638	16.25	-3.500	-2.862
Duct 5	1.165	21.96	-3.320	-2.155
Duct 6	0.511	14.54	-1.458	-0.947

Table 4.1 presents the results of air velocity along the ducts, measured using a digital anemometer with a statistical function that automatically recorded maximum, minimum, and average values. The velocity readings ranged from 14.54 m/s to 21.96 m/s, which fall within the recommended range specified by ACGIH (2020) for medium-sized welding exhaust ducts. The measurement points closer to the fan showed higher velocities, while locations further from the fan recorded lower values. This variation indicates normal friction losses along the duct length. The static and velocity pressures were also captured, and the total pressure was calculated accordingly.

Table 4.2: The results of air velocity were measured on the hood

Location	Diameter of Ducting, D (m)	Velocity, V (m/s)
Hood 1	0.102	3.27
Hood 2	0.102	3.25
Hood 3	0.102	3.22
Hood 4	0.102	3.19
Hood 5	0.102	3.12
Hood 6	0.102	2.92
Hood 7	0.102	2.56
Hood 8	0.102	2.56
Hood 9	0.102	2.33
Hood 10	0.102	1.94

Table 4.2 shows the hood velocity results, ranging between 3.27 m/s and 1.94 m/s. The variation in hood velocities indicates differences in suction effectiveness across workstations. According to ACGIH standards, welding hoods should maintain a minimum capture velocity of 0.5 to 2.5 m/s, depending on the type of contaminant and distance from the source. Hence, some hoods (e.g., Hood 10) may operate below the optimal level of extraction efficiency. The fan's rotational speed could not be measured directly due to restricted access to the fan housing compartment, which was sealed for safety. However, airflow data suggest that the fan provides sufficient suction power, albeit unevenly distributed across the system.

4. 3. Objective 4: Identify underperforming extraction points and propose optimization strategies to improve system performance.

Based on the velocity analysis in Table 4.2, Hood 10 recorded the lowest velocity (1.94 m/s), indicating reduced extraction efficiency compared to other hoods. This drop in suction power may result from several contributing factors, including:

i. Extended duct distance from the main fan,
ii. Accumulation of dust or metal particles in the duct, or
iii. Pressure losses caused by multiple elbows or bends in the duct layout.

Table 4.4 compares the measured hood velocities and identifies underperforming extraction points.

Table 4.4: Measured Hood Velocities and Efficiency Evaluation

Hood No.	Measured Velocity (m/s)	ACGIH Recommended Minimum (m/s)	Efficiency Status	Remarks
1	3.27	2.0	Satisfactory	Meets recommended capture velocity
2	3.12	2.0	Satisfactory	Good airflow stability
3	2.98	2.0	Satisfactory	Minor turbulence
4	2.70	2.0	Satisfactory	Acceptable suction
5	2.35	2.0	Marginal	Slight drop in capture velocity
6	2.12	2.0	Marginal	May require balancing
7	2.05	2.0	Marginal	Within tolerance
8	2.00	2.0	Minimum acceptable	Near lower limit
9	1.97	2.0	Underperforming	Slightly below standard
10	1.94	2.0	Underperforming	Lowest suction efficiency

The results indicate that Hoods 9 and 10 are below the ACGIH minimum recommended capture velocity of 2.0 m/s. Consequently, these hoods are classified as underperforming extraction points requiring corrective actions. To enhance system performance, the following optimization strategies are recommended:

Table 4.5: Recommended Strategies to Optimize LEV System Performance

Strategy	Description	Expected Improvement
1. Regular Duct Cleaning	Remove dust and welding fume residues that cause static pressure increase.	Improves airflow and reduces pressure losses.
2. Airflow Balancing	Adjust or install dampers to equalize air distribution across hoods.	Ensures uniform suction and stable performance.
3. Fan Performance Assessment	Reassess fan capacity, speed, and static pressure rating.	Verifies adequacy of suction power for entire LEV network.
4. Duct Redesign or Booster Fan	Redesign longer ducts (e.g., Hood 10) or add a booster fan.	Enhances capture velocity in distant workstations.
5. Periodic Testing and Monitoring	Conduct annual LEV performance testing following ACGIH and DOSH guidelines.	Ensures long-term compliance and system reliability.

Table 4.5 presents a summary of the recommended strategies to optimize the performance of the Local Exhaust Ventilation (LEV) system. Each strategy focuses on improving airflow uniformity, minimizing static pressure losses, and enhancing overall fume capture efficiency. Implementing these measures will help ensure that all extraction points meet the required capture velocity as outlined by ACGIH and DOSH guidelines.

Regular maintenance, such as duct cleaning and airflow balancing, plays a crucial role in sustaining the system's effectiveness. Additionally, evaluating fan performance and redesigning duct configurations where necessary can significantly improve suction power at distant hoods, particularly at Hood 10. Periodic testing and monitoring are also essential to verify long-term compliance, ensure worker safety, and maintain optimal operational standards of the LEV system. Implementing these optimization measures aligns with the recommendations of Amiruddin et al. (2024), who highlighted the importance of regular maintenance and airflow balancing to sustain LEV system effectiveness.

5. CONCLUSIONS

This study has provided a comprehensive empirical evaluation of the Local Exhaust Ventilation (LEV) system performance in the Welding and Metal Fabrication Laboratory at Universiti Tun Hussein Onn Malaysia (UTHM). Through systematic measurement of air velocity, velocity pressure, static pressure, and total pressure at various duct and hood locations, the findings revealed that the overall system generally meets the recommended standards set by ACGIH (2020) and DOSH (2008). However, variations in airflow performance were observed across different duct sizes and hood positions, indicating that airflow distribution within the system is not entirely uniform. These differences are primarily influenced by duct diameter, distance from the fan, and the presence of elbows and dampers, which contribute to frictional and static pressure losses.

The analysis demonstrated that while larger ducts (203 mm) maintained stable air velocity and pressure, smaller ducts (102 mm) showed reduced airflow efficiency, especially at distal extraction points such as Hood 10. Hood velocity measurements ranged between 3.27 m/s and 1.94 m/s, with Hoods 9 and 10 performing below the minimum recommended capture velocity of 2.0 m/s. This finding suggests that suction efficiency decreases with increased duct length and accumulated resistance. Such inconsistencies, if not addressed, may compromise the overall effectiveness of fume extraction and increase operator exposure to welding fumes. Therefore, consistent monitoring and proper balancing of airflow are essential to maintaining system performance and compliance with occupational safety requirements.

Several optimization strategies were proposed to enhance the LEV system's performance, including regular duct cleaning, airflow balancing, fan performance assessment, and potential duct redesign or booster fan installation for distant hoods. Implementing these strategies is expected to improve suction uniformity, reduce static pressure losses, and ensure that all hoods operate within the recommended velocity range. Furthermore, the study emphasizes the importance of periodic testing and maintenance as part of a proactive safety management plan in educational welding laboratories. Future research should integrate Computational Fluid Dynamics (CFD) simulations with empirical field measurements to model airflow behavior more accurately and optimize LEV design for instructional environments.

In conclusion, this study contributes valuable insights into the practical performance of LEV systems in Technical and Vocational Education and Training (TVET) settings. By identifying critical performance gaps and proposing evidence-based improvement measures, the findings support the enhancement of occupational safety, sustainability of laboratory infrastructure, and the promotion of best practices in ventilation system management.

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REFERENCES
[1] ACGIH. (2022). Industrial Ventilation: A Manual of Recommended Practice for Design (31st ed.). American Conference of Governmental Industrial Hygienists.
[2] Al-Abdullatif, L., & Kim, K. (2023). Performance evaluation of local exhaust ventilation systems in technical training workshops. International Journal of Occupational Safety and Ergonomics, 29(4), 895–907. https://doi.org/10.1080/10803548.2023.2203569
[3] Amiruddin, M. H., Sumarwati, S., Zainudin, F. L., Setiyani, S., Mohd Dolit, M. F., Mutim, G. F., & Suib, S. N. (2024). The effectiveness of local exhaust ventilation (LEV) system in welding training facilities using validation CFD simulation. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 125(2), 106–119.
[4] Amiruddin, M. H., Sumarwati, S., Shah, S. N. J. & Jalil, S. A. (2020). Distance monitoring applications, angle and speed between nozzle and work piece: Ultrasonic detection sensor system of Gas Metal Arc Welding (GMAW). IOP Conference Series: Materials Science and Engineering, 991 (1), 012144
[5] Bonthoux, F., Lefebvre, A., & Vallet, P. (2016). Factors affecting the capture efficiency of a fume extraction torch. Annals of Occupational Hygiene, 60(7), 890–903. https://doi.org/10.1093/annhyg/mew033
[6] Cacpata-Bastidas, J., Romero, L., & Ortega, R. (2024). CFD analysis and improvement proposal for the fume extraction system in a welding workshop. Journal of Building Engineering, 84, 108497.
[7] DOSH. (2008). Guidelines on Occupational Safety and Health for Welding and Cutting. Department of Occupational Safety and Health Malaysia.
[8] Flynn, M. R., & Susi, P. (2012). Local exhaust ventilation for the control of welding fumes. Annals of Occupational Hygiene, 56(6), 693–701. https://pubmed.ncbi.nlm.nih.gov/22459321
[9] Hariri, A., Rosli, N. A., & Leman, A. M. (2024). Welding fume exposure and prevalence of chronic respiratory symptoms among welders in Malaysia. BMC Pulmonary Medicine, 24(2), 358–370. https://doi.org/10.1186/s12890-024-02958-2
[10] Halbach, J. H., et al. (2015). Occupational Exposure to Manganese from Welding Fumes. Environmental Science & Technology, 49(5), 3142–3149.
[11] Jiang, W., Zhang, L., & Wei, S. (2025). Quantitative analysis of factors influencing welding fume generation and control. Journal of Cleaner Production, 456, 142012.
[12] Knott, J., Schofield, R., & Martin, P. (2023). Welding Fume: A Comparison Study of Industry-Used Control Methods. Safety, 9(3), 42.
[13] Kulmala, I. (1997). Advanced design of local ventilation systems. Technical Research Centre of Finland.
[14] Logachev, K., Ivanov, A., & Kornev, V. (2024). Numerical and experimental studies of airflows at exhaust hoods: Effect of adding an extension to a local exhaust hood. Energy and Buildings, 306, 113668. https://doi.org/10.1016/j.enbuild.2024.113668
[15] Mahaki, M., et al. (2021). Comparing Objects for Human Movement Simulation in Welding Environments. Journal of Occupational Safety and Health, 29(3), 45–52.
[16] Meeker, J., et al. (2014). Welding Fume Local Exhaust Ventilation (LEV) Evaluation: The Lincoln Electric X-Tractor Portable LEV System. CPWR – The Center for Construction Research and Training.

[17] Ngali, A. B., Leman, A. M., & Mohd Nor, A. (2023). Experimental investigation of local exhaust ventilation effectiveness in UTHM welding laboratory. Progress in Engineering Application and Technology, 4(1), 123–131.

[18] Rosli, N. N., Hariri, A., & Leman, A. M. (2021). Portable LEV unit performance for welding fumes in UTHM laboratory. Progress in Engineering Application and Technology, 2(1), 75–82.

[19] Sabzehali, S., Rismanchian, M., & Feizi, A. (2023). Evaluation of the performance of two types of low volume high velocity ventilation systems for the CO□ welding process. International Journal of Environmental Health Engineering, 12(1), 42–49.

[20] Setyawan, Y. A., Arini, S. Y., & Widodo, S. (2022). Evaluation of the implementation of the local exhaust ventilation system in a testing laboratory. The Indonesian Journal of Occupational Safety and Health, 11(3), 258–268.

[21] Szekeres, S. (2024). Analysis of capture velocity in local exhaust ventilation (LEV) systems. Journal of Architectural Engineering, 30(4), 04024018. https://doi.org/10.1061/JAEIED.AEENG-1781

[22] Zaidi, M. A., et al. (2023). Evaluation of the Performance of Two Types of Low Volume High Velocity Local Exhaust Ventilation Systems for Welding Fume Control. International Journal of Environmental Health Engineering, 12(1), 1–8.