OPEN ACCESS Freely available online

IJESP
International Journal of Environmental Sustainability and Protection

ISSN 2737-5447
Volume 3, Issue 3
https://www.iikii.com.sg/journal/IJESP
International Journal of Environmental Sustainability and Protection

Article

Modification of Energy Saving for Safe Welding Process: Case Study in Manufacturing of SME

Yu-Tzu Chen [1], Rizal Justian Setiawan [1,*], and Nur Azizah [2]

[1] Industrial Engineering and Management, Yuan Ze University, Taoyuan City 320, Taiwan; yuchen@saturn.yzu.edu.tw
[2] International Public Health, China Medical University, Taichung City 406, Taiwan; nazizah169@gmail.com
* Correspondence: rizaljustiansetiawan99@gmail.com; Tel.: +886-3-463-8800#2513

Received: Jul 29, 2023; **Revised:** Aug 29, 2023; **Accepted:** Sep 15, 2023; **Published:** Sep 30, 2023

Abstract: Welding is a popular method for connecting metal in manufacturing. However, welding fumes are hazardous and pose a severe health risk to workers. To provide a safe environment, many manufacturing companies install fume extractors. Even though the air quality is improved in the welding area, fume extractors are always on in non-production hours, which wastes power. Thus, we modified a fume extractor by establishing an automated interconnection system integrated with the Metal Inert Gas (MIG) welding equipment for energy savings. The automated interconnection system was examined for its impact and energy-saving degree. The system includes a relay and timer to connect a fume extractor with MIG welding equipment. The fume extractor is on standby or active modes based on the welding gun operation. The active mode is on when the welding gun is operated, signaling the fume extractor to turn on and vice versa with a 30-second lag to turn off. A case study was conducted in Indonesia's Small and Medium Enterprises (SME) firm. The company's power usage significantly was reduced by more than 25% and operational expenses and CO_2 emissions were also decreased. The system is practical and affordable for SMEs, especially those that rely on MIG welding and fume extractors for their operations.

Keywords: Energy-saving, Welding fume extractor, Fumes, MIG, Occupational safety and health, SDG 3, SDG 12.

1. Introduction

Climate change is a pressing issue for the planet. To ensure peace and prosperity by 2030, the United Nations shared a blueprint with 17 Sustainable Development Goals (SDGs) in 2015 [1]. To maintain competitiveness, the companies must have long-lasting momentum to cope with the challenges and opportunities. With limited resources, Small and Medium Enterprises (SMEs) must find feasible and economical solutions. Therefore, this study was carried out to provide a balanced energy-saving solution for SMEs.

Welding is a popular method for connecting metal in the manufacturing sector. In welding, materials are joined by heating and fusing. Nowadays, welding produces permanent joins with exceptional qualities, outperforming fastening and semi-joining methods. Several welding processes are employed depending on the type of metal and required strength. A fixture maintains the workpiece in the horizontal and vertical orientations during pipe and plate welding [2]. Metal inert gas (MIG) welding is a standard welding process used in the industrial and construction sectors [3]. However, hazardous by-products are produced from the welding process containing fume particles and toxic chemicals that harm workers' health. Inhaling these fumes, the workers may experience occupational asthma and other allergic responses. Thus, it is imperative to use safety technologies to protect workers from the adverse effects of these compounds and particles [4]. A regulated ventilation system filters particles down to 0.4 μm to protect welders since most of the reparable particles in the air are smaller than that size. The welding fume extractor protects workers from harmful fumes during welding operations. The extractor is a crucial safety tool for manufacturing sectors to protect workers from workplace risks [5]. To provide a safe and healthy working environment, SMEs need to align their sustainable goals to SDG 3 Good Health and Well-Being.

A fume extractor improves the work environment, especially in areas where welding equipment is used for fabrication or production. However, a fume extractor wastes energy as it is usually activated continuously during operation hours. "Vampire power," frequently used to describe electric and electronic device usage even when they are not actively carrying out their intended purpose, is wasted for such fume extractors [6]. Welding is not conducted continuously during material preparation, welding machine settings, welding analysis, performing a penetrant test on the welds, and grinding the weld to fix it.

An energy-saving technology is necessary to save vampire power that limits energy utilization [7]. Electrical energy is essential for the survival of humanity [8]. Conserving energy lowers the company's operating expenses and CO_2 emissions, aligning with the global goal SDG 12: Responsible consumption and production. The welfare of the workforce is also crucial for sustainable development. The case study was carried out to verify a safe environment (SDG 3: Good Health and Well-Being) and energy conservation production (SDG 12: Responsible Consumption and Production) in this study with the developed system.

2. Literature Review

The metal inert gas (MIG) welding machine is mostly used. In MIG, a continuous electrode is introduced into the welding pool, and a trigger-controlled apparatus is employed to regulate this wire feed [9]. MIG welding requires various components, including gas cylinders and regulators to use argon and helium. These gases are distributed through interconnected hoses. In the process, metal wires are used as electrodes. An electric arc is created between the electrode and the weld as a heat source, which subsequently melts and solidifies the metal wire and the weld. The result is a weld generated using a MIG torch [10]. While MIG welding is a pivotal tool within the manufacturing industry, it carries potential health hazards. The International Agency for Research on Cancer (IARC) states that the welding fumes produced fall under Group 2B, indicating a potential carcinogenicity. These fumes comprise particles and gases (such as CO, CO_2, O_3, NOx, phosgene, and other harmful substances) that emanate from the breakdown of ambient air, surface residues, or even the disintegration of metal coatings [11]. The primary health concerns associated with welding fumes include sporadic and brief respiratory issues, symptoms including coughing and chest tightness, and common complaints like headaches, dizziness, eye irritation, and dry, chapped skin [12]. Welders' susceptibility to the emissions generated during soldering poses risks to the workforce [13]. The function of a fume extractor is to suction in the fumes from the welding area, filter them, and then release them into the air. It helps workers maintain health in the company [14]. Overall, a fume extractor is a solution to reduce fume exposure during and after welding but it relies on a power source [15]. This device is equipped with a motor and fan to suction the fumes and gases, which requires substantial electrical power [16,17].

Energy serves as the central driving force in the manufacturing process. The key to achieving sustainability and maintaining business competitiveness often hinges on improved control and efficient energy management. An energy-saving system is typically crafted to curtail energy consumption in residential and industrial environments by eliminating unnecessary power usage. 'Vampire power' contributes significantly to energy wastage and environmental issues [18]. The main vampire power for welding is the lack of linkage between the welding gun and the fume extractor. It is more productive to add another procedure to the existing Standard Operation Procedure (SOP) and train workers to turn on and off the fume extractor when needed. However, if workers fail to follow the SOP, energy conservation and the protection of the worker’s health are not realized. Therefore, we created an automatic control system that connects a welding machine gun with a fume extractor as a sustainable solution for the welding process. The concept of this energy-saving solution is to emulate the behavior of a personal computer (PC). A PC is powered off with its peripheral components such as speakers, monitors, mice, printers, and scanners, or is automatically powered down. The principle can be used for effectively managing the vampire power of the fume extractor [19]. Efficient use of electrical energy will save operational costs and indirectly reduce the company's CO2 emissions. Based on this, it is very necessary to make improvements to equipment to be able to work efficiently [20].

3. Research Methodology

This study was conducted in six stages: problem identification, background data collection, machine modification, modification, testing, and evaluation using the conventional R&D method [20] as shown in Fig. 1.

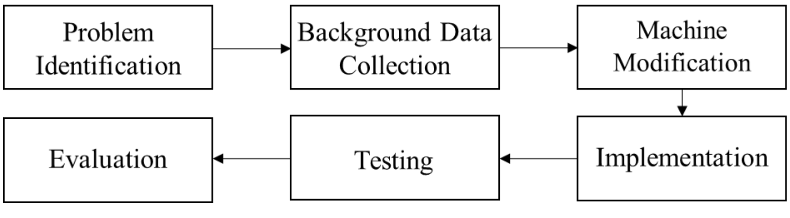

Fig. 1. Research process.

We surveyed to determine the issues in the welding operation with a fume extractor in Indonesia. Based on the survey, we discovered that the fume extractor was used for 14 hours using 8 KWh from 8 AM to 11:59 PM (with a 2-hour break time). It was only shut off for 40 minutes during the lunch break and dinner at 7 PM. Additionally, there was a 20-minute rest for each shift. The welding process was not carried out continuously for seven hours per shift. It was not used during material preparation, setting welding machine parameters, weld analysis, a penetrant test on the welds, and grinding the weld. However, 2 systems were running separately. The fume extractor continued to function even when no welding activity was conducted. Additionally, once welding was completed, the welder engaged in other activities unrelated to welding. The fume extractor operated continuously with or without welding works. The fume extractor blower operated even after the workers left the welding area. This caused the ineffectiveness of energy utilization.

3.1. Data Collection

The data were collected from June 9 to 24, 2023 for 14 working days (excluding Sunday). The fume extractor consumed 1.586 kWh for 14 hours for two weeks, or an average of 112 kWh daily. Fig. 2 demonstrates how daily energy was wasted when the fume extractor was used.

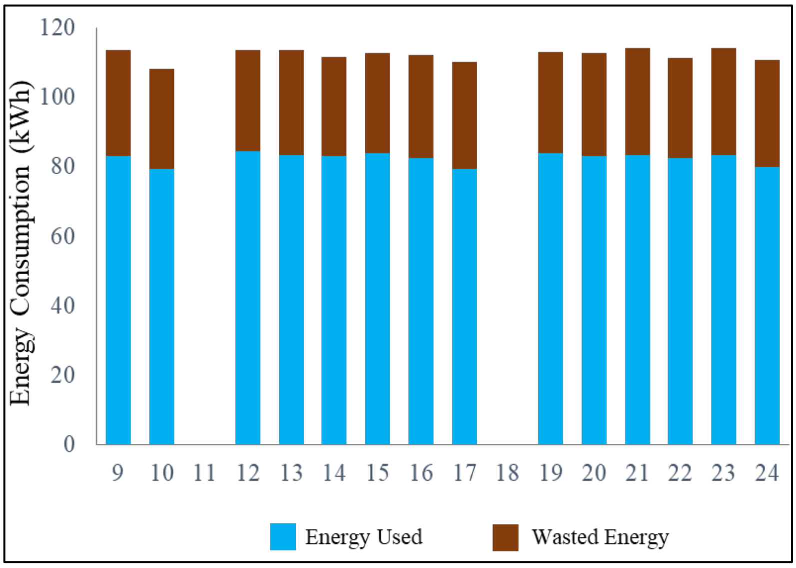

Fig. 2. Energy consumption of fume extractor before improvement.

The time and energy lost throughout the two shifts were analyzed, too. The time for operating the fume extractor and MIG welding in two shifts is depicted in Fig. 3. According to the data, there was no activity related to the welding process during the 120 minutes between shifts. As a result, in 240 minutes, the fume extractor ran continuously with no MIG welding activity.

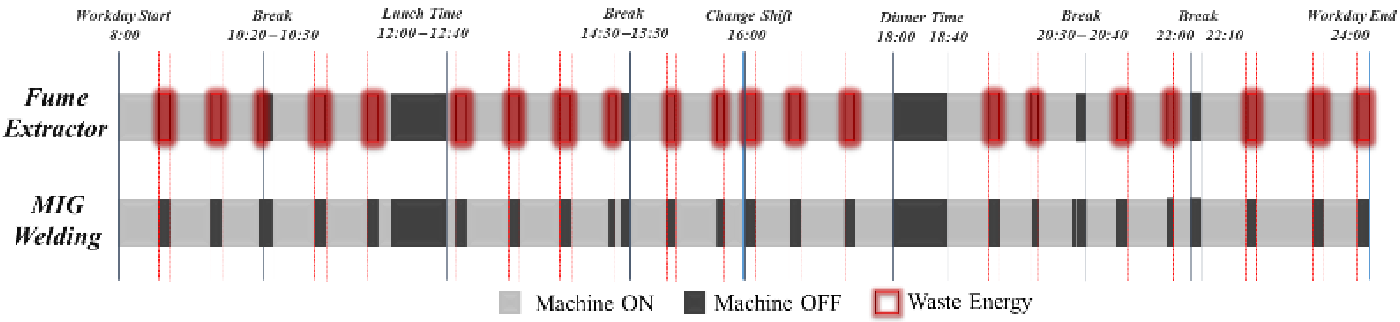

Fig. 3. Time-based MIG welding and fume extractor usage.

When using a fume extractor, the blower of the fume extractor sucks up all the welding fume for 20 s. We added 10 s to ensure that all fumes are sucked in and turned it off after 30 s of completing the welding process. A manual method can be an option to eliminate the waste of energy. However, turning off the fume extractor manually after 30 seconds was not easy due to the lack of employee awareness and supervision, the location of the fume extractor, the demands for completing the work quickly, and the unavailability of designated personnel to operate the fume extractor. Thus, an automated process is required to operate more efficiently, faster, and more accurately [21,22].

3.2. Machine Modification

The MIG welding and the fume extractor were operated manually and separately. Even though workers turned off the fume extractor by adding an extra step in the existing SOP, workers were not aware of turning off the fume extractor while not in use. In Fig.4 there is an illustration of the use of a fume extractor in the welding area. The function of this equipment is to suck fume from the welding output and direct it to a filter which will then throw clean air outside the building. The fume extractor control panel was located far from the workplace so it was not easy to turn it on or off. In addition, the use of a fume extractor that is not integrated with a MIG welding machine like in a SME case study site has the potential to cause employees to forget or not be aware of turning off the fume extractor after welding. Based on this, a lot of energy will be wasted if the fume extractor continues to be on when there is no welding activity.

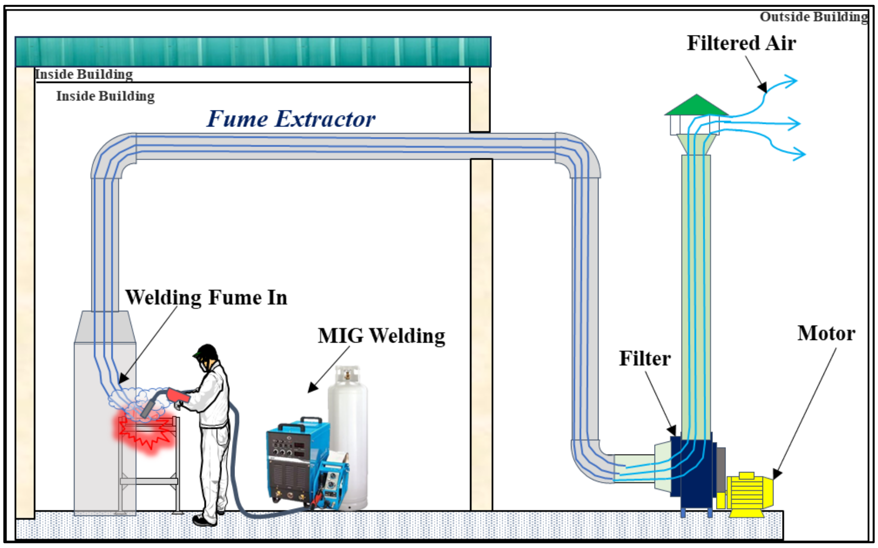

Fig. 4. Fume extractor in case study

To save energy for welding, especially for fume extractor, authors reviewed several methods to lower energy usage for fume extractor and improve the efficiency. It was necessary to automatically link the fume extractor and the MIG welding machine. Table 1 shows the four options using a timer switch with a contact relay, interlock system, programmable logic controller, and Internet of Things (IoT). All the ideas proposed are to integrate the operational equipment of the fume extractor and MIG welding machine with the aim of creating effective energy use in the fume extractor during welding activities.

Table 1. Proposed solutions.

Requirements	Timer Switch and Relay		Interlock System		Programmable Logic Controller		Internet of Things	
	Description	Score[2]	Description	Score[2]	Description	Score[2]	Description	Score[2]
Low Cost for Components[1]	US$ 47.5	4	US$ 118	3	US$ 336.9	2	US$ 772.2	1
Low Components Replacement Required	Component replacement ± 3y	2	Component replacement ± 1y	1	Inverter replacement ± 4y	3	Controller replacement ± 5y	4
Time estimation to achieve Break Even Points	±1 month	4	±3 months	2	±6 months	3	14 months	1
Duration required for modification and installation	3 working days	3	2 working days	4	7 working days	2	12 Working days	1
Total Score		**13[3]**		**10**		**10**		**7**

[1] Exchange Rate: US$ 1 = IDR 14,933 (July 2023); [2] The option that most meets the requirements among all the options will get 4 score and the option that least meets the requirements will get a 1 score; [3] The option that gets the highest total score.

After evaluation costs for components and components replacement, time to achieve break-even points, and duration required for modification and installation, authors chose to use a timer switch with a contact relay. In Table 1, the use of Timer Switch and Relay gets the highest score. The contact relay transmits a signal from the MIG wire feed motor at MIG welding to the controller on the fume extractor's main panel. At the same time, the timer switch controls how long the fume extractor is allowed to run before shutting off (delay 30 s after the welding gun is released). 30 seconds were selected to ensure for the blower of the fume extractor to completely suck in the welding fume in the area. A framework for the modifying the fume extractor is shown in Fig. 5.

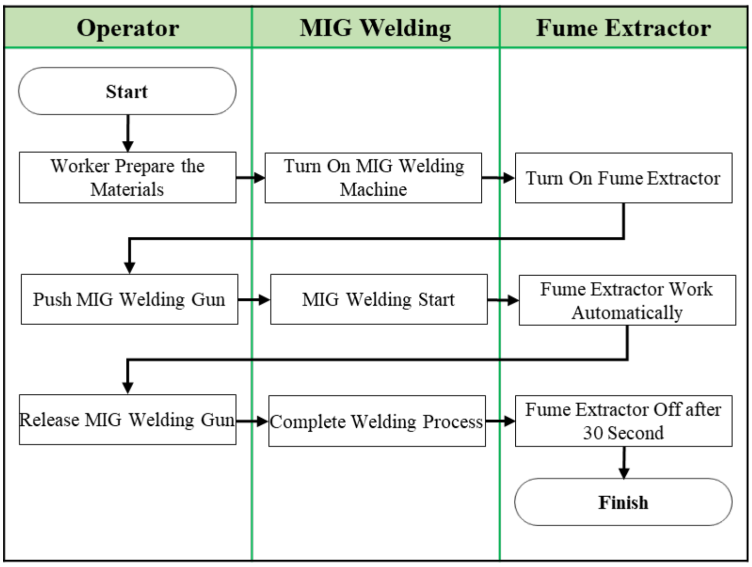

Fig. 5. Conceptual modified fume extractor.

3.3. Modification

To check the feasibility of the mechanism, an integrated system between a welder, MIG welding machine, and fume extractor was fabricated. When using MIG welding, the welder pushes the welding gun. In the modified system, the welding gun's trigger automatically turns on the fume extractor. In contrast, the fume extractor stops working 30 s after the user releases the trigger. 30 s delay is for the automatic turn-off fume extractor system to suck in and filter the fume completely. We used commercially available components for the fume extractor modification. The additional control panel was assembled as shown in Figs. 6 and 7.

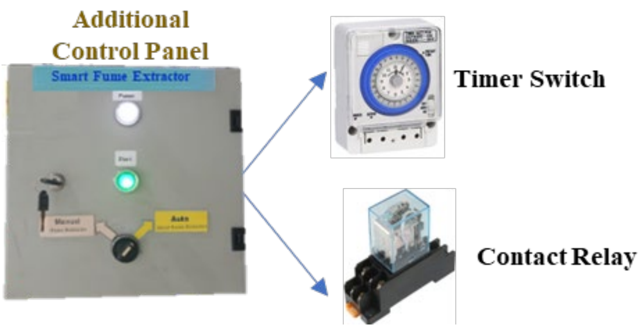

Fig. 6. Components on additional panel.

Fig. 7. Components of modified fume extractor.

The additional control panel was assembled and then connected to the MIG Welding gun and Fume extractor Panel as shown in Fig. 8.

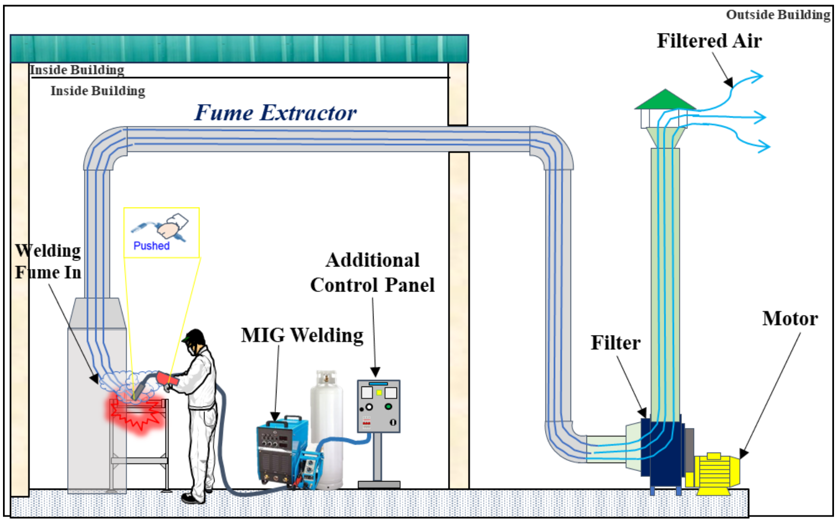

Fig. 8. Modified fume extractor.

3.4. Testing

When the gun was operated, the welding machine turned on and sent a signal to the control panel to operate the fumw extractor. When the gun was removed and the welding machine stopped, a signal was sent to the control panel. The fume extractor turned off automatically after 30 seconds. The testing was conducted for 14 days from June 29 to July 14, 2023. Fig. 9 demonstrates the result. The energy use was decreased by more than 90%. The vampire energy was not reduced entirely because the fume extractor did not turn off directly till the welding gun was stopped and was operated to clear the air. The assessment of the modified fume extractor was conducted for energy consumption, emission reduction, and financial analysis [23,24].

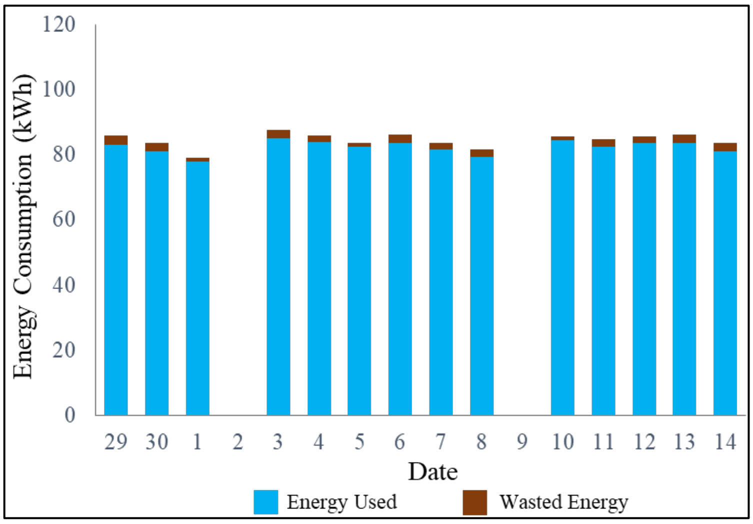

Fig. 9. Energy consumption data on modified fume extractor.

4. Result and Discussion

4.1. Energy Consumption

Data were collected 14 days before the modification and 14 days after it. Table 2 shows energy consumption data before and after modification. The energy usage reduced from 1.586 to 1.161 kWh with 424 kWh saved in total. The vampire power was controlled with the additional control panel.

Table 2. Analysis of Energy Consumption Before and After Modification.

Energy Consumption	Energy / 14 Days
Before Improvement	1,586 kWh
After Improvement	1,162 kWh
Energy Reduction	424 kWh

Fig. 10 illustrates the results, demonstrating that this modified fume extractor decreased energy usage by 26.73% in 14 days.

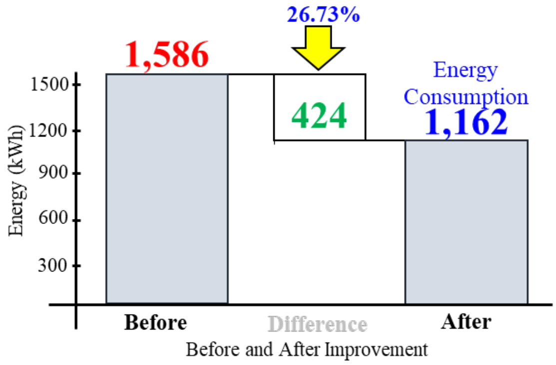

Fig. 10. Energy use before and after modification.

4.2. CO_2 Emission

Energy reductions with the modification also contributed to reducing CO_2 emissions. The energy conversion factor was 0.891 kg/kWh according to the Indonesian Government Regulation stated in the Letter of the ESDM Minister (Ministry of Energy and Mineral Resources of the Republic of Indonesia) No. 3783/21/600.5/2008. Based on this, (1) was used to calculate CO_2 emissions.

$$CO_2 \text{ Emissions} = \text{Energy (kWh)} \times 0.891 \quad (1)$$

A modified fume extractor reduced carbon dioxide (CO_2) emissions by 0.38 tons for two weeks or 14 days, according to the calculation as shown in Table 3.

Table 3. CO_2 Emissions before and after modification.

CO_2 Emission	Energy / 14 Days	CO_2 Emission / 14 days
Before Improvement	1,586 kWh	1.41 Ton
After Improvement	1,162 kWh	1.03 Ton
CO_2 Reduction	**424 kWh**	**0.38 Ton**

The reduction in carbon dioxide emissionsis depicted in Fig. 11. The result shows that CO_2 emission was reduced by 26.95%. Although indirectly decreasing carbon dioxide emissions, the result provides SMEs with a competitive and sustainable solution.

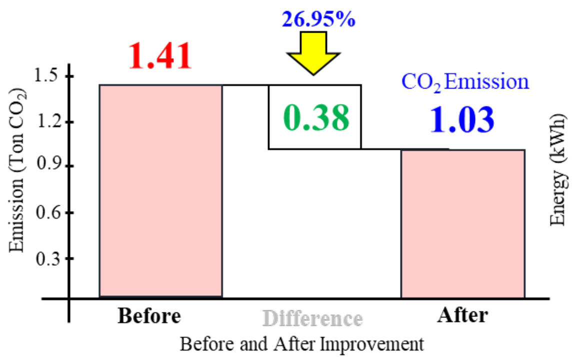

Fig. 11. Carbon dioxide emissions before and after modification.

4.3. Financial Analysis

The fume extractor modification was proven to save energy, which was related to the decrease in in operational expenses. Table 4 shows the comparison of operating costs of the fume extractor that saved USD 27.6 for 14 days.

Table 4. Electricity expense before and after modification.

Cost	Cost / 14 days (US$)[1]
Before Improvement	US$ 103.23
After Improvement	US$ 75.63
Cost Reduction	**US$ 27.6** [2]

[1] Exchange Rate: US$ 1 = IDR 14,933 (July 2023); [2] Industrial electricity tariff code I-2/TR with a 14,001-200 kVA power is charged at IDR 972/kWH in Indonesia.

The SME can increase the efficiency of its electrical energy use with the modified fume extractor, which saved USD 27.6 for two weeks. The components for the modified fume extractor cost USD 47.5. According to the estimate in Fig. 12, the SME can recover its initial investment in 28 days when USD 55.2 can be saved.

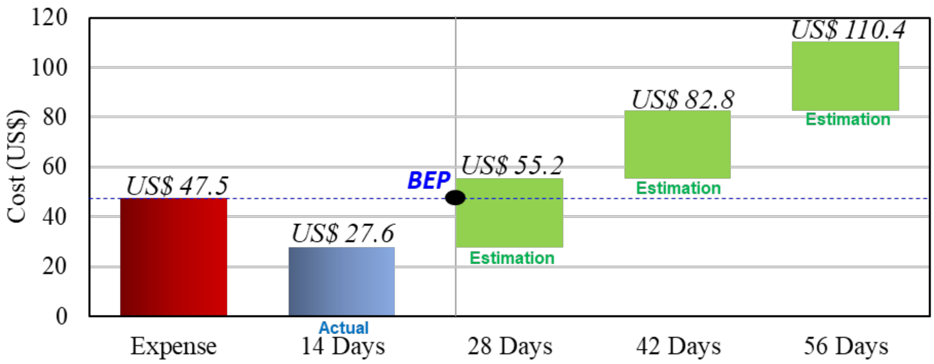

Fig. 12. Modified fume extractor's break even point.

5. Conclusions

Modifications of the safe welding process with the automatic system including a fume extractor and a welding gun were carried out. The modified fume extractor saved 424 kWh of energy, reduced 0.38 tons of CO_2 emissions, and saved USD 27.6 for 14 days. The modified fume extractor achieves SDG3 and SDG12, helps workers maintain healthy conditions, and assisted companies in saving costs.

Author Contributions: Conceptualization, R.J. Setiawan; methodology, Y.T. Chen; validation, R.J. Setiawan; conduct experiment, R.J. Setiawan; data curation, N. Azizah; writing—original draft preparation, Y.T. Chen; writing—review and editing, R.J. Setiawan; translation, N. Azizah. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive external funding.

Data Availability Statement: The data of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UNDP. The SDGs in Action. 2023. Available online at: https://www.undp.org/ (accessed on August 1, 2023).
2. Senthil, S.M.; Kumar, M.B.; Dennison. M.S. A Contemporary Review on Friction Stir Welding of Circular Pipe Joints and the Influence of Fixtures on This Process? *Advances in Materials Science and Engineering* **2022**, *1*(1), 1–25.
3. Els, L.; Cowx, P.; Nordhagen, R.; Komelius, G.; Andrew, N.; Smith. P. Analysis of a Ferromanganese Secondary Fume Extraction System to Improve Design Methodologies. In Proceedings of the Thirteenth International Ferroalloy Congress Kazakhstan, Almaty, Kazakhstan, June 9–12, 2013.

4. Dhongadi, M.R.; Rokhade, K. Design Modelling and Analysis of Welding Fume Extractor. *International Journal of Engineering Research and Applications* **2020**, *10*(7), 24–29.
5. Omoregie, M.J.; Akilaki, T.I.F.; Kalu, K.E. Design and Fabrication of a Mobile Fume Extractor. *Nigerian Journal of Technology (NIJOTECH)* **2019**, *38*(1), 112–116.
6. Devi, G.C.; Suganya, G.; Savitha, S.; Kanchana, N. Vampire Power Reduction using Microcontroller. *International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)* **2016**, *21*(3), 276–278.
7. Kumar, A.; Fathima, K.; Saranya, T.M.; Hema, S. Methodology to Reduce Vampire Power using PIC Microcontroller. *ARPN Journal of Engineering and Applied Sciences* **2017**, *12*(13), 4027–4031.
8. Atmoko, A.W.; Setiawan, R.J.; Fauzi, I. IoT-Based Electric Vampire Remover to Overcome Electric Vampire On Electronic Equipment. *JTECS* **2021**, *1*(2), 115–123.
9. Madavi, K.R.; Jogi, B.F.; Lohar, G.S. Metal inert gas (MIG) welding process: A study of the effect of welding parameters. *Materials Today Proceedings* **2022**, *51*(1), 690–698.
10. Li, C.; Chen, Z.; Gao, H.; Zhang, D.; Han, X. Numerical simulation of the metal inert gas welding process that considers grain heterogeneity. *SAGE Journal of Materials* **2021**, *235*(1), 42–58.
11. Lehnert, M.; Pesch, B.; Lotz, A.; Pelzer, J.; Kendzia, B.; Gawrych, K. Exposure to Inhalable, Respirable, and Ultrafine Particles in Welding Fume. *Ann. Occup. Hyg. Journal* **2012**, *56*(5), 557–667.
12. Manikandan, C.; Sharon, R.M.; Shethek, A.M.; Durai, A.K.; Vairamani, G.; I.N. Manickam, I.N.; Sulaiman, S.S. Cost Effective Fume and Dust Cleaning System. *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)* **2020**, *9*(2), 14063–14066.
13. Zare, S.; Sahranavard, Y.; Hakimi, H.; Bateni, M.; Karami, M.; Hemmatjo, R. Designing, Constructing and Installing a Local Exhaust Ventilation System to Minimize Welders' Exposure to Welding Fumes. *Archives of Hygiene Sciences Journal* **2017**, *6*(4), 356–362.
14. Kumar, K.V.S.; Dharmaraj, M.; Thangavel, P.; Srikishore, K.A.; Sudharsan, R.; Vimal, M. A Critical Review on Fume Extraction System for Pipe and Plate Welding. *IOP Conference Series: Materials Science and Engineering* **2021**, *1084*, 012064. https://doi.org/10.1088/1757-899X/1084/1/012064
15. Ridwan, M.; Dhongadi, M.; Rokhade, K.K. Design Modelling and Analysis of Welding Fume Extractor. *International Journal of Engineering Research and Applications* **2020**, *10*(7), 24–29.
16. Ramakrishnan, H.; Vinoth, P. Design, Fabrication, and Analysis of Fume Extraction and Filtration Equipment. *Pak. J. Buotechnol.* **2017**, *14*(1), 101–103.
17. Olufemi, B.P.; Oluwayimik, O.M. The Development of Fume Extractor for a Welding Booth. *IOP Conference Series: Materials Science and Engineering*, **2018**, *413*(1), 012018. https://doi.org/10.1088/1757-899X/413/1/012018
18. Ma, M.; Huang, B.; Wang, B.; Chen, J.; Liao, L. Development of an Energy-Efficient Smart Socket Based on STM32F103. *Applied Sciences* **2018**, *8*(11), 2276. https://doi.org/10.3390/app8112276
19. Kumar, A.; Fathima, K.; Saranya, T.M.; Hema, S. Methodology to Reduce Vampire Power using PIC Microcontroller. *ARPN Journal of Engineering and Applied Sciences* **2017**, *12*(13), 4027–4032.
20. Chen, Y.T.; Setiawan, R.J. Energy Saving Solution for Welding Process: A SME Case Study of Fume Extractor. In Proceedings of the IEEE 6th International Conference on Knowledge Innovation and Invention (IEEE ICKII 2023), Sapporo, Japan, August 11–13, 2023; pp. 720–725.
21. Kiss Flow. Manual Process vs. Automated Process. **2023**. Available online: https://kissflow.com/workflow/bpm/manual-process-vs-automated-process/ (accessed on August 4, 2023).
22. Apeks Supercritical. Full automation vs. manual systems: which is better? September 7, 2017. Available online: https://www.apekssupercritical.com/2017/09/07/full-automation-vs-manual-systems-better/ (accessed on August 3, 2023).
23. Setiawan, R.J.; Tarnadi, A.; Surfani, I. Design and Manufacture an Automatic Mushroom Sprinkler based Internet of Things to Increase Oyster Mushroom Productivity. *JMPM* **2021**, *5*(1), 1–9. https//doi.org/10.18196/jmpm.v5i1.12043
24. Suryanto, I.D.; Setiawan, R.J. Hybrid Aerator based on Savonius Wind Turbine and Solar Photovoltaic Technology for Shrimp Pond. *TREnD (Technology of Renewable Energy and Development) National Seminar Proceeding* **2021**, *1*, 82–91.