INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY: APPLIED BUSINESS AND EDUCATION RESEARCH
2024, Vol. 5, No. 4, 1148 – 1162
http://dx.doi.org/10.11594/ijmaber.05.04.03

Research Article

Development and Evaluation of an Optimized Energy Recovery System from Excess Heat of a Compressed Air System

Andrew S. Mañego*

Graduate School, Bulacan State University, Malolos City, 3000, Philippines

---

Article history:
Submission February 2024
Revised April 2024
Accepted April 2024

**Corresponding author:*
E-mail:
andrew.manego@bulsu.edu.ph

ABSTRACT

The aim of this study is to build a bounded optimized energy recovery system from the compressed air system's excess heat. It is important to concentrate on the use of products that satisfy the requirements for performance and sustainability, as well as the need for energy that will be optimized. Purposive sampling is used to select the respondents, using quantitative research, specifically both descriptive and developmental methods. The researcher utilized a decision support tool developed by Kolaitis et al., (2020) as the primary research instrument of the study. The adopted tool was slightly modified to suit the assessment needs of the developed energy utilization system. All the main criteria components are interpreted as highly sustainable. The researcher utilized log sheets to determine the performance of the study. Finally, paired t-test was used to determine whether there was a significant difference in the performance of the study. The performance of the optimized energy after the implementation of the project was statistically higher than the performance of the optimized energy before the implementation of the project. The researcher concluded that the performance of the optimized energy recovery system from excess heat of a compressed air system after the installation and operation was effective and efficient based on the ratings of respondents and descriptive measures on the log sheet. For this kind of innovation, the manufacturing company with the same equipment should adopt and sustain it for potential energy savings and protect mother nature.

Keywords*: Compressed air, Energy efficiency, Energy recovery, Heat recovery, Optimized energy, Waste heat*

Introduction

Energy is one of the most important and necessary needs of every person especially in the age of globalization and modernization. It is often used lighting, running of household appliances, serving a variety of industries, and in other means of transforming electrical energy. There would have been no technology

---

How to cite:
Mañego, A. S. (2024). Development and Evaluation of an Optimized Energy Recovery System from Excess Heat of a Compressed Air System. *International Journal of Multidisciplinary: Applied Business and Education Research*. *5*(4), 1148 – 1162. doi: 10.11594/ijmaber.05.04.03

developments and life, in general, would have remained the same if the theory of electrical energy and the method of making it had not arisen.

Nevertheless, Dincer and Rosen (2021) presented a novel optimization of energy systems that explains the thermodynamic modeling, analysis, and optimization of several types of energy systems in a variety of applications. The optimization of energy recovery systems from excess heat of a compressed air system will bring a wider knowledge of the system and the process of identifying adequate safety functions. This is vital for determining the most appropriate design parameters for increased reliability, functionality, and applicability. Furthermore, Mahmoud (2019) believes that the issues of waste of energy and human needs have advanced, resulting in environmental problems and economic growth. Hence, the private entities had to do some updating and upgrading in terms of the optimization of its energy system.

Coal is the Philippines' primary source of energy. Coal-fired power stations, as sources of non-renewable energy, emit greenhouse gases, having a direct impact on global warming. Resulting in decreased water supplies because of global warming, the power generation capacity of renewable energy sources such as hydroelectric power plants become limited. The drastic solution to this problem is the adoption of the use of renewable energy at home and the optimization of energy in the industry.

Likewise, the most common energy source for industrial compressed air production is electricity. The entire cost of the installation is clearly dominated by energy expenses. As a result, it is essential to concentrate on implementing products that fit the requirements for performance and sustainability, as well as the needs for energy that will be optimized (Atlas Copco 2015).

According to the Department of Energy's 2019 Power Condition Survey, the Luzon grid experienced 46 Yellow Warnings and 16 Red Alerts in 2019. These were mostly caused by high demand, which was exacerbated by the moderate El Niño weather pattern. This raised the demand and reduced the usable capacity of hydroelectric power plants in the grid during the summer months. However, this would influence the country's economy due to a lack of energy capacity. Along with its significant effects on the environment and the economy, the appropriate approach to using resources efficiently and effectively is a very critical process in terms of energy optimization. In the area of electrical technology, innovation plays a major role as private entities, to be specific, are consuming energy in several ways.

There is relevant provision in the Energy Efficiency and Conservation Act, also known as Republic Act 11285, Rule VI. Energy End Users, Section 32. The role was used as a guide in the development of an optimized energy recovery system from the excess heat of a compressed air system. It states that:

> *"All energy end users, including the end users defined under Republic Act No. 9513, otherwise known as the Renewable Energy Act of 2008, shall use every available energy resource efficiently and promote the development and utilization of new and alternative energy efficient technologies and systems, including renewable energy technologies and systems across sectors in compliance with the declared policies of the Act."*

The Act promotes the development and utilization of alternative energy-efficient technologies, energy optimization, and conservation of energy, which provide the need for energy recovery and significant environmental guidance in the undertaking of this study. It is reassuring that when it comes to environmental protection and resource preservation, private entities, as end users, have a major role to play.

Any establishment that utilizes hot water, steam boilers, and compressed air systems, especially industries and manufacturing companies, may benefit from this study. And, where the proponent is presently connected with the same equipment, and it has promoted energy conservation as the centerpiece of its continuous improvements and innovations. In fact, the output of the study may be included in the innovation program of any company, where the current practices may be in consonance with the thrust of the study. Such companies must comply with and sustain an energy management program since the Department of Energy (DOE) has the authority to inspect the establishments, as specified in Section 33 of the Republic Act 11285:

> *"The DOE shall monitor all energy end users' compliance with the relevant standards and requirements under Chapters of the Act, as well as the EEC-IRR. The DOE, through Energy Utilization Management Bureau (EUMB), shall have the authority to visit energy end users to inspect energy-consuming facilities, and evaluate energy management."*

The DOE is working to ensure that energy is well managed for its optimum use that utilizes equipment and technology efficiently in terms of energy recovery systems. A keen analysis was conducted to ensure that a company's energy supplies will be optimized in terms of heat waste recovery from compressed air. This is based on the government's policy declaration that is necessary to be complied accordingly.

The provision relevantly reiterates the importance of this study since it concentrates on increasing the outlet temperature of the water supply before it reaches the feed-water tank of a steam boiler, using excess heat from an air compressor to optimize the energy recovery system while supplying additional heat transfer. Growth will be attributed to the constant flow and heat transfer of water, with a direct effect on the cooling system. Thus, this study may also serve as a reinforcement to the cooling tower.

On the other hand, failing to utilize the waste heat energy properly will lead to high operational costs and, as an inevitable fact of life, energy prices will continue to rise. In this age that is dominated by industries, factories, and manufacturing companies around the world, it is vital that energy will be used sparingly and efficiently as possible for the sake of both the economy and the environment.

Therefore, recovering the heat energy will have a large impact on the industry in terms of energy-saving initiatives. The pipe and heat exchangers can be used as heat recovery systems by analyzing the appropriate information by designing the pipe layout and electrical control system to maximize the recovery of heat energy study. Furthermore, it is a thermodynamic fact that approximately 10% of the electricity consumed in the industry accounts for the use of an air compressor for manufacturing processes, with the remaining energy converted into waste heat. Heat energy released by compressed air systems can be addressed naturally by using cooling fans, but with an additional cost. However, some processes in the factory can use power to generate heat for hot water processes and heating applications. This latter principle serves the purpose of this study.

The proponent investigated the process of recovering waste heat to conserve energy and minimize carbon dioxide emissions in the company's operations through this research. The study implemented a modification in the control system and piping layout to achieve the desired result by interconnecting the constituent components. Spare parts such as electrical, electronic, and instrumentation devices were also used. The researcher pursued this present investigation to contribute to the body of knowledge, particularly in waste heat recovery systems.

Relevant Theory and Related Literature

Innovation is the conversion of a concept into something useful to produce new things or its development as used in the optimization of energy recovery systems. The theory seeks to describe users' intent to utilize an information system as well as eventual use behavior. In a private company like Froneri Philippines, passion for excellence is one of the core values.

Acceptance behavior, on the other hand, explains many other variables such as user satisfaction and user involvement. These are vital to provide an overall theory in order to explain acceptance behavior and system implementation success of the unified theory of acceptance and use of technology. Following that, the attempt to establish a relationship between this theory and personal innovativeness and user involvement as antecedents by presenting certain arguments (Williams et al. 2015). Therefore, by combining these ideas that describe technology use behavior in this research will be substantial in terms of energy efficiency.

In this case, the researcher's firm was optimizing energy recovery systems from excess heat of compressed air systems as in line with the company's core values. According to Sengupta et al., (2014), the economic theory of innovation focuses on the technological component and its implications for economic growth. The business paradigm has shifted drastically in today's world due to advances in technology and the understanding of new concepts.

Dincer and Rosen (2021) presented a novel optimization of energy systems that explains in detail the thermodynamic modeling, analysis, and optimization of several types of energy system. Luo et al. (2017) support that a novel heat recovery device has been developed to recuperate the heat that is removed from the surface of equipment. This study would reduce carbon dioxide emissions and avoid global warming.

When an inventor knows nature's rules, he can make greater use of them. Deeper understanding may lead to new ideas that might not be apparent at first glance. For example, thermodynamics' fundamental law must be revealed in the field of applications to appreciate its functions. After that, the person who experiences these fresh concepts and convincing arguments will emerge. New information will be created and enhanced in performance. It would result in innovation (Struchtrup, 2014).

Energy recovery is an instrument to improve fuel consumption in thermal engines (Sciubba et al., 2016). All the energy provided to a compressor system is transformed into heat. The better the system's efficiency, the more energy may be recovered and used in other operations. Energy recovery is simple to implement with standard oil-free compressors. This air compressor is excellent for use in a hot water heating system as it maintains the appropriate temperature for effective energy recovery (Atlas Copco, 2015).

According to Pesiridis (2014), the issue of fuel economy and pollution reduction has a timely impact on both diesel and gasoline engines regarding emission management and exhaust energy recovery. Xu et al. (2019) assume that the waste heat recovery applications in automotive, as well as residential and industrial zones, are highlighted. According to studies, optimizing heat recovery systems results in considerable energy savings. Moreover, Jouhara et al. (2018) postulated that industrial waste heat is energy created in industrial operations that are not used and are lost, squandered, or thrown into the environment. Various waste heat recovery systems may be used to collect waste heat and provide important energy sources while reducing total energy usage.

Warnes (2017) states that the electrical and mechanical system or unit must first be connected to an electrical circuit and mechanical modification before it can be used. In addition, Irwin and Nelms (2020) propounded that circuit analysis expertise can only be attained via practice. Also, complex devices can be modeled by basic components that, when assembled into the correct circuit, can be evaluated, and thereby predict the machine's behavior. As a result, circuits are at the heart of every analysis of electrical and mechanical technology. The research begins by describing basic circuit components, then integrating them into electrical circuits and mechanical modifications for study using a variety of laws and theorems.

Luo et al. (2017) presented a novel heat recovery device developed to recuperate the heat that is removed from the surface of the equipment. The provision of the development of such a study from waste heat is to recover and reuse that energy, as this study would reduce carbon dioxide emissions and avoid global warming. In another study, Sandre-Hernadez et al. (2017) supported the solution in optimizing the performance of industrial processes by means of continuous improvement in the design and method used in the development of a waste heat recovery system in order to increase its energy efficiency. Since then, these studies have been hypothesized, implemented, and tested using the Model Predictive Control MPC in a laboratory-based prototype to determine the performance and accuracy in terms of energy savings.

Meanwhile, Cai et al. (2019) assumed that the energy-saving and emission-reduction (ESER) plan is a critical approach for increasing manufacturing industry sustainability in the green transition. This study presents a novel concept called lean energy-saving and emission-reduction (LESER) and a strategy to efficiently enhance energy efficiency and reduce waste emissions by analyzing current practices and limits of ESER in the manufacturing industry. In addition, Gao et al. (2017) supports that the individual energy-saving behaviors at the workplace are significant for reducing energy usage and carbon emissions. A manufacturing philosophy is primarily concerned with reducing waste. Nowadays, various manufacturing industries must keep pace with all new technologies, innovations, and equipment to compete successfully and efficiently in the worldwide economy (Nallusamy et al., 2015).

On the other hand, Sapingai (2017) states that the nature of the information requested as well as the manner of entry are carefully chosen and is called the data collection log sheet. A data collection log sheet is a structured form that must be filled out with certain details. Moreover, Lawson (2014) pointed out that the method of sampling and collecting data parameters is reliable for monitoring the system of several pieces of equipment in running conditions that will be determined in the operational log sheet. The parameters of machinery will also be measured with the use of the aforesaid log sheets.

The quantitative method answers research problems by using numbers, quantity, and statistics. It entails measuring and quantifying abilities, efficiency, points of expertise, aptitude, and commitment. The gathered information is then examined with statistical techniques, and the results are utilized to generate study findings (Roever and Phakiti 2017). However, the utilization of statistical techniques and how quantitative research results are conveyed leaves much to be desired. In contrast, Kothari (2020) states that the importance of research is determined by its quality rather than its inquisitiveness. Those involved in research must pay close attention to creating and sticking to a suitable approach. It is envisaged that this modest effort may aid in the completion of exploratory and result-oriented research investigations.

Statement of the Problem

The general problem of the study is: How may an optimized energy recovery system from excess heat of a compressed air system be developed and evaluated? Specifically, this study sought answers to the following questions:

- How may an energy recovery system from the excess heat of a compressed air system be developed?
- How may the level of sustainability of the optimized energy recovery system be evaluated in terms of applications; safety; functionality; environmental impact; industry/company approval; and financial requirements?
- What is the performance of the system before and after the installation and operation of the equipment based on the optimized energy?
- Is there a significant difference in the performance of the optimized energy recovery system before and after the implementation of the project?

Hypothesis of the Study

From the problem stated, the following hypotheses were formulated:

- Ho1: There is no significant difference in the performance of the optimized energy recovery system before and after the installation and operation of the equipment.
- Ha1: There is a significant difference in the performance of the optimized energy recovery system before and after the installation and operation of the equipment.

Assumption of the Study

The following assumptions guided the researcher in correctly drawing conclusions from the analysis of the results:

- Energy recovery system can be optimized from compressed air system's excess heat. Specifically, reducing the steam injection for preheating of the feed water tank will have a direct impact on reducing fuel consumption as the fuel was utilized to produce steam.
- The optimum technology regarding energy utilization system can be best assessed by a support tool consisting of the following criteria: application, safety, functionality, environmental impact, industry / company approval and financial requirements.

The effectiveness of the developed optimized energy recovery system can be determined if a significant difference in the performance of the equipment is detected before and after its installation and operation using the optimized energy as parameter.

Methodology

The study utilized the quantitative method of research where numbers, quantification, and statistics are used to solve research challenges. It comprises assessing and measuring skills, effectiveness, areas of competence, ability, and dedication. Here, the data obtained is then analyzed statistically, and the outcomes are used to develop scientific studies. As presented in this study, quantitative methods are analytical, mathematical, and computing tools that help researchers solve a wide range of problems, notably those in private enterprises. Moreover, both the descriptive and developmental research methods were also used in this study. In using the developmental and descriptive research methods, the researcher seeks to develop and evaluate the optimization of an energy recovery system from excess heat of a compressed air system. Development is the act of revealing what is uncertain; a progressive development process in which everything will be constructed, such as a plan or technique. Descriptive, on the other hand, are represented by information resources or descriptions.

The study was conducted at the Bulacan State University-Main Campus with selected faculty experts in Electrical Technology and company experts from Froneri Philippines, Incorporated, where the study was implemented. The participants in the study consisted of five (5) management staff, seven (7) associates, and eight (8) instructors in electrical technology. The respondents were purposively selected considering the expertise to evaluate the developed system of the study. The following attributes characterized the respondents: (a) the faculty experts; minimum of five years of experience in their field of specialization, experts in the field of industrial technology and graduates of either master's or doctoral degree; and (b) company experts; bachelor’s degree holder and licensed electrical technology or mechanical engineering. The survey respondents were asked to respond to an evaluation form that defines the sustainability of the energy recovery system that was developed and optimized. The responses consisted of the data that were used in the last section of the report for data processing. The adopted and modified evaluation tool were sent to each respondent. The researcher also utilized log sheets to determine the performance of the energy recovery system in terms of the operational parameters such as outlet temperature, pressure differential, and optimized energy, as these would serve as the indicating factors for future references of the study.

The researcher utilized a decision support tool developed by Kolaitis et al. (2020) as the primary research instrument of the study. The adopted tool was slightly modified to suit the assessment needs of the developed energy utilization system. The slightly modified evaluation tool was content validated by two (2) faculty experts unrelated to the study and two (2) company experts unrelated to the project. The specific criteria adopted in the selection procedure have been selected to highlight the contribution of each proposed technology based on the concept of sustainability. As previously mentioned, the set of factors to be used in the evaluation of the innovation consists of the following: applications; safety; functionality; environmental impact; industry approval; and financial requirements.

The Optimized Energy Recovery System from Excess Heat of a Compressed Air System was evaluated quantitatively. The data that were collected for the study were processed statistically to produce the desired outcome.In rating and assessing the level of sustainability of the Optimization of Energy Recovery System from Excess Heat of a Compressed Air System, the weighted average of each factor was computed and interpreted using the five-point Likert scale developed for the purpose. Finally, a paired sample t-test was used to determine whether there is a significant difference in the performance of the optimized energy recovery system before and after the implementation of the project.

Results and Discussion

For better understanding and interpretation of the data, the results are presented part by part based on the statement of the problem presented in Chapter I.

Development of the Optimized Energy Recovery System from Excess Heat of a Compressed Air System

The development of the system begins by describing basic circuit components, then integrating them into electrical circuits and mechanical modifications by using circuit analysis.

Circuit Analysis. Warnes (2013) states that the electrical and mechanical system or unit must first be connected to an electrical circuit and mechanical modification before it can be used. Furthermore, Irwin and Nelms (2020) propounded that circuit analysis expertise can only be attained via practice. Also, complex devices can be modeled by basic components that, when assembled into the correct circuit, can be evaluated, and thereby predict the machine's behavior. As a result, circuits are at the heart of every analysis of electrical and mechanical technology.

Piping and Instrumentation Diagrams (P & ID) are essential for maintaining and modifying the processes that they graphically describe. During the design stage, the diagram also serves as the foundation for the study's development as illustrated in Figure 1.

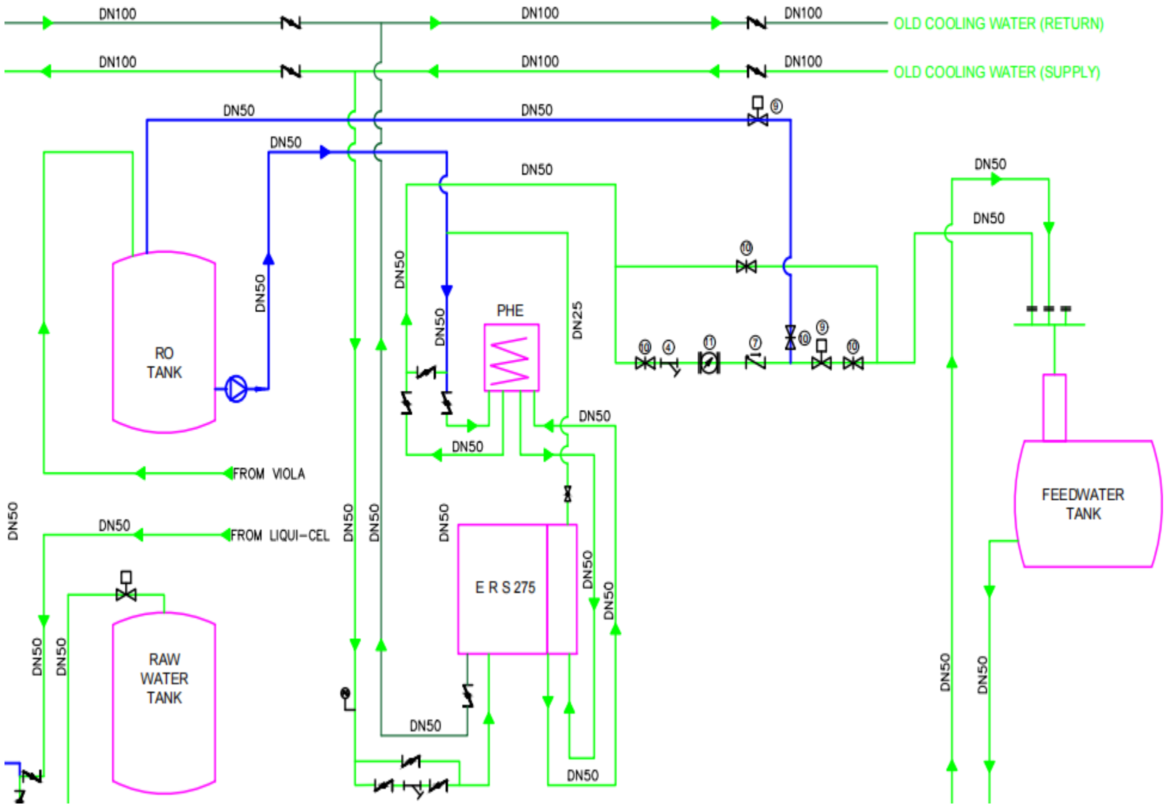

Figure 1. Piping and Instrumentation Diagram P&ID

The Mechanical Scope of Work. The third-party contractor provides the labor and materials necessary to install pipes and fittings locally and easily in accordance with the Piping and Instrumentation Diagram (P & ID) as above-mentioned. Figure 2 depicts the pipework and fittings as they were before the alteration.

Figure 2. Installed Piping and Fittings before the Modification

Figure 3 displays the installation of pipes and fittings following the alteration.

Figure 3. Installation of Pipes and Fittings after the Modification

Electrical ladder diagrams are specialized schematics used to depict industrial control logic systems. The level controller is presented in Figure 4. The power supply is shown in Figure 5 and the automated refilling-recirculating with off-time delay is shown in Figure 6. These are utilized in the research's development.

Firstly, in Figure 4, the level controller contact is shown as the signal in control relay main (KO) connected to 220 Volts of Alternating Current. This wiring connection will be responsible for the sequence operations of recirculating and refilling water before it enters the feed water tank.

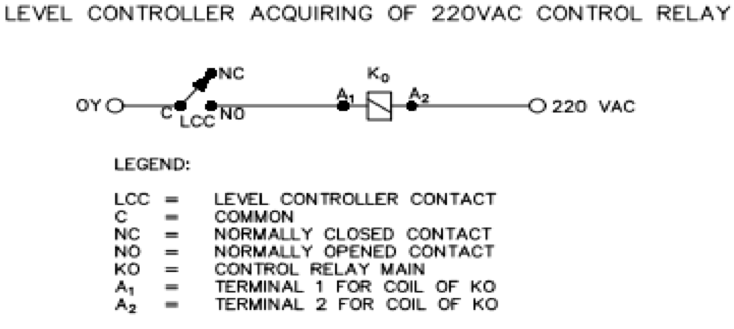

Figure 4. Ladder Diagram of the Level Controller

Secondly, in Figure 5, the full wave; bridge-type connection is shown as the power supply connected to an input of 440 Volts of Alternating Current; a 5 Ampacity Double Pole, Double

Throw (DPDT) Circuit Breaker in the primary coil of a step-down transformer with an output of 24 Volts of Alternating Current in the secondary coil connected to the bridge-type connection of four (4) diodes with two (2) electrolytic capacitors connected in series and parallel connections with the resistor (R1) in order to produce an output of 24 Volts of Direct Current; Full Wave Power Supply.

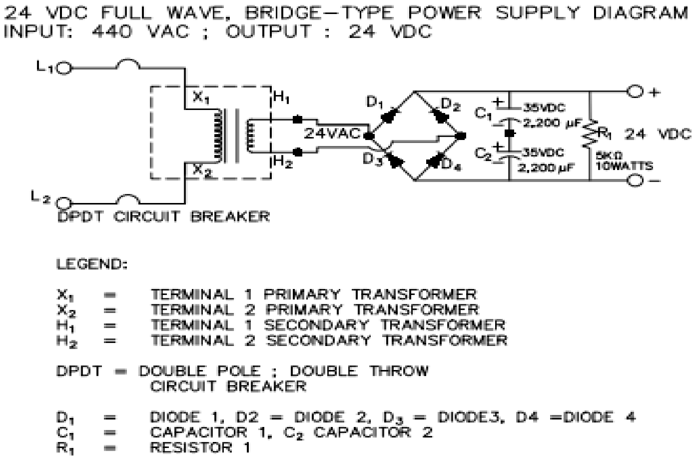

Figure 5. Ladder Diagram of the Power Supply

This power supply will be responsible for reducing the voltage for safety purposes to utilize low-voltage equipment.

Thirdly, in Figure 6, the automatic refilling of the feed water tank and recirculating of water by means of two (2) solenoid valves with an off-time delay is shown as the main electrical interlocking system to optimize energy recovery system from excess heat of a compressed air system.

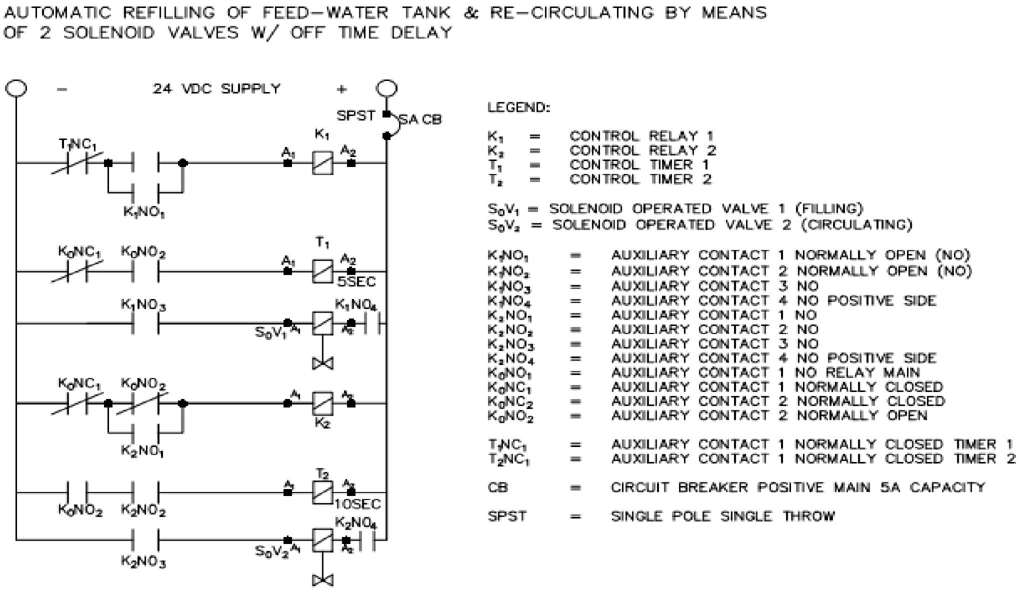

Figure 6. Automatic Refilling and Recirculating with Delay Timer Ladder Diagram

Automatic Refilling of Feedwater Tank Interlocking System. The positive supply of the main circuit is connected to a 5 Ampacity Single Pole, Single Throw (SPST) Circuit Breaker as thermal overload protection. The negative power supply is connected to the normally closed contact 1 of control timer 1 (T1NC1), which is connected in series to the normally open contact 1 of control relay main (KONO1) and in parallel connected to control relay 1's normally open contact 1 (K1NO1) as a holding coil connected to negative coil A1 and coil A2 to the positive supply of control relay 1 (K1). The negative power supply is connected to the normally closed contact 1 of control relay main (KONC1), which is connected to the normally open contact 2 of control relay 1, (K1NO2), which is connected to negative coil A1 and coil A2 to the positive supply of Timer 1 (T1). Timer 1 (T1) Off Delay is set to 5 seconds. The negative power supply is connected to control relay 1's normally open contact 3 (K1NO3), which is connected to negative coil A1, and coil A2 is connected to control relay 1's normally open contact 4 (K1NO4) to the positive supply of solenoid operated valve 1 (SoV1).

Automatic Recirculating Water Interlocking System. The positive supply of the main circuit is connected to a 5 Ampacity Single Pole, Single Throw (SPST) Circuit Breaker as thermal overload protection. The negative power supply is connected to the normally closed contact 1 of control timer 2 (T2NC1), which is connected in series to the normally closed contact 2 of control relay main (KONC2) and in parallel connected to control relay 2's normally open contact 1 (K2NO1) as a holding coil connected to negative coil A1 and coil A2 to the positive supply of control relay 2 (K2). The negative power supply is connected to the normally open contact 2 of control relay main (KONO2), which is connected to the normally open contact 2 of control relay 2, (K2NO2), which is connected to negative coil A1 and coil A2 to the positive supply of Timer 2 (T2). Timer 2 (T2) Off Delay is set to 10 seconds. The negative power supply is connected to control relay 2's normally open contact 3 (K2NO3), which is connected to negative coil A1, and coil A2 is connected to control relay 2's normally open contact 4 (K2NO4) to the positive supply of solenoid operated valve 2 (SoV2).

The materials and equipment needed to install the electrical and instrumentation parts came from the company because those are considered slow-moving or non-moving stock items, so the researcher found a way to utilize them.

Testing and Validation of Measuring Instruments. Without a well-planned testing effort, the development will surely fail and have an influence on the overall operational performance of the solution. Validation studies assist researchers in identifying mistakes that occur while examining thoughts and behaviors, allowing these faults to be mitigated or removed for research studies to deliver more precise and valid results.

All the activities, inputs, materials, methods, and information above are used for the development of the optimized energy recovery system from excess heat of a compressed air system.

Evaluation of the Sustainability of the Optimized Energy Recovery System from Excess Heat of a Compressed Air System

This part presents the evaluation of the sustainability of the research in terms of the following main criteria: (1) application; (2) safety; (3) functionality; (4) environmental impact; (5) industry/company approval; and (6) financial requirements.

Presented in Table 1 is the summary of the respondents' responses in the evaluation of the sustainability of the optimized energy recovery system from excess heat of a compressed air system.

Table 1. Summary of the Responses.

Main Criteria	Mean	Interpretation
1. Application	5.00	Highly Sustainable
2. Safety	4.92	Highly Sustainable
3. Functionality	4.85	Highly Sustainable
4. Environmental Impact	4.93	Highly Sustainable
5. Industry/Company Approval	5.00	Highly Sustainable
6. Financial Requirements	4.90	Highly Sustainable
Overall Mean	**4.93**	**Highly Sustainable**

It can be gleaned from the summary of the responses in table 1 that all indicators of the sustainability of the optimized energy recovery system from excess heat of a compressed air system were rated favorably by the respondents, with mean ratings ranging from a high of 5.0 to a low of 4.85. Two (2) of the six (6) main criteria were scored identically with a perfect mean rating of 5.0, and they were Application and Industry Approval, followed by Environmental Impact, Safety, Financial Requirements, and Functionality with a mean rating of 4.93, 4.92, 4.90, and 4.85, respectively. All the main criteria components are interpreted as highly sustainable. Overall, the optimized energy recovery system from excess heat of a compressed air system was rated "Highly Sustainable," as evidenced by a grand mean of 4.93. The project study is strongly recommended for adoption and future improvement, according to the company and faculty experts' responses.

Performance of the Optimized Energy Recovery System Before and After the Installation and Operation of the Equipment

Table 2 displays the number of days, the equivalent mean values of the outlet temperatures, optimized energy, and the weighted mean of the performance of the system before and after the inclusion of the equipment based on the optimized energy. The mean optimized energy in mega-joules prior to installation and operation of the equipment is 365.20, while the mean optimized energy after implementation of the developed equipment is 730.15. There was a significant increase of 364.95. This implies the efficiency of the developed and optimized energy recovery system.

Table 2. Distribution of the Optimized Energy Recovery System Before and After the Installation and Operation of the Equipment.

Day Number	Oultlet Temperature (°C)		Pressure Dfferential (bars)		Optimized Energy (Megajoules)	
	Before	After	Before	After	Before	After
1	31.3	39.0	0.5	0.5	382.89	647.9
2	31.5	39.0	0.5	0.5	459.80	627.0
3	31.5	39.0	0.5	0.5	376.20	627.0
4	31.5	40.0	0.5	0.5	418.00	710.6
5	31.5	39.0	0.5	0.5	334.40	627.0
6	31.0	40.0	0.5	0.5	334.40	752.4
7	31.0	40.0	0.5	0.5	334.40	752.4
8	32.0	39.0	0.5	0.5	418.00	585.2
9	32.0	40.0	0.5	0.5	334.40	668.8
10	32.0	41.0	0.5	0.5	334.40	752.4
11	32.0	40.0	0.5	0.5	334.40	668.8
12	31.0	40.0	0.5	0.5	334.40	752.4
13	31.7	41.0	0.5	0.5	334.40	780.0
14	32.0	40.5	0.5	0.5	334.40	710.6
15	32.0	41.0	0.5	0.5	334.40	752.4
16	32.0	40.0	0.5	0.5	334.40	668.8
17	31.0	40.0	0.5	0.5	334.40	752.4
18	31.0	39.0	0.5	0.5	334.40	668.8
19	31.0	40.0	0.5	0.5	418.00	752.4
20	31.0	40.0	0.5	0.5	334.40	752.4
21	32.0	40.0	0.5	0.5	334.40	668.8
22	32.0	40.5	0.5	0.5	501.60	710.6
23	31.0	41.0	0.5	0.5	418.00	836.0
24	30.0	41.0	0.5	0.5	334.40	919.6

Day Number	Oultlet Temperature (°C)		Pressure Dfferential (bars)		Optimized Energy (Megajoules)	
	Before	After	Before	After	Before	After
25	31.0	42.0	0.5	0.5	418.00	919.6
26	30.0	41.0	0.5	0.5	334.40	919.6
		Average			365.20	730.15

Moreover, Figure 7 shows the summarized graphical presentation to visualize the trend and comparison of optimized energy recovery from excess heat of a compressed air system before and after installation and operation.

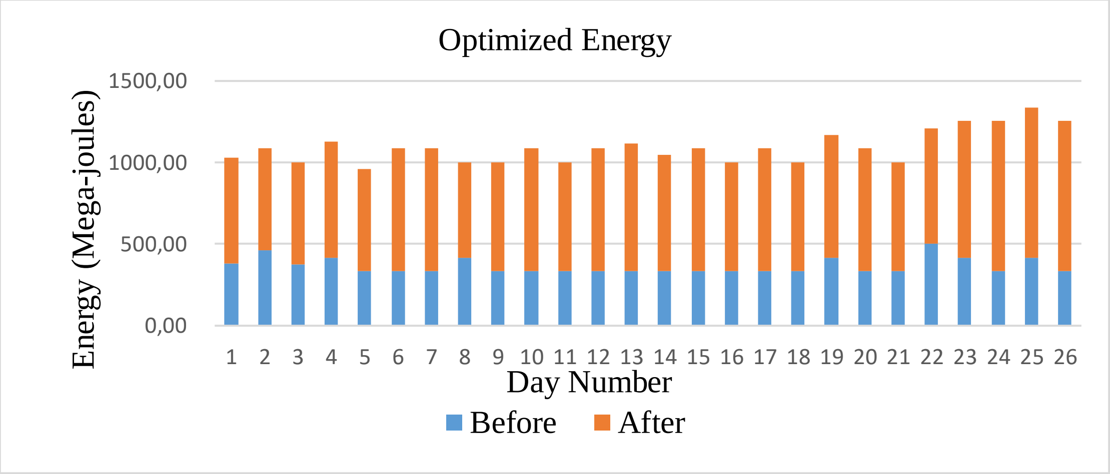

Figure 7 The Summary of Graphical Presentation of Optimized Energy

Meanwhile, Table 3 shows the descriptive measures of the optimized energy recovery system from excess heat of a compressed air system before and after the implementation of the study.

Table 3. Descriptive Measures of the Optimized Energy Before and After the Installation and Operation of the Equipment

Optimized Energy	N	Mean	Std. Deviation
After	26	730.15	90.55
Before	26	365.20	48.19

Table 3 simply shows that the variance of the optimized energy after the implementation of the system is greater than the variance of the optimized energy before the system was installed.

Significance of the Performance of the Optimized Recovery System

Table 4 shows the results of a paired-samples t-test conducted to compare the optimized energy before and after the utilization of the developed equipment. The mean difference of 364.95 was found to be significant between the two measures; the optimized energy before (M = 365.20, SD = 48.19) and the optimized energy after (M = 730.15, SD = 90.55); t(25) =-17.384, p = 0.000, which is less than. It means that the t-value of -17.384 is less than the p-value of 0.00.

Table 4. Differences Between the Optimized Energy Before and After the Utilization of the Equipment.

Parameter	Mean	SD	Mean Difference	t -value	Df	p - value
Optimized Energy Before	365.20	48.19	364.95	-17.384	25	0.00
Optimized Energy After	730.15	90.55				

These findings suggest that the null hypothesis stating that the optimized energy before and after the utilization of the developed equipment is not significantly different is thus rejected. The performance of the optimized energy after the utilization of the equipment was statistically higher than the performance of the optimized energy before the utilization of the developed equipment.

Conclusion

The study was developed in line with the circuit analysis, by combining the mechanical and electrical modifications, creating a log sheet and procedures, installing instrumentation components, and coming up with an effective and efficient system. The optimized energy recovery system from excess heat of a compressed air system was rated "Highly Sustainable" by the company and faculty experts. It provides the potential for energy savings and energy efficiency, resulting in less pollution in terms of environmental impact, thereby benefiting the environment significantly. There is a significant difference in the performance of the optimized energy recovery system before and after the installation and operation of the equipment.

The researcher concluded that the performance of the optimized energy recovery system from excess heat of a compressed air system after the installation and operation was effective and efficient based on the ratings of respondents and descriptive measures on the log sheet. For this kind of innovation, the manufacturing company with the same equipment should adopt and sustain it for potential energy savings and to protect mother nature.

Recommendations

The study found that the development of an optimized energy recovery system from compressed air system excess heat revealed the following recommendations, which are now presented: Since the optimized energy recovery system from excess heat of a compressed air system was effective and efficient. It may apply to any establishment that utilizes hot water, steam boilers, and compressed air systems, especially manufacturing companies and industries. The results of the study may give the company experts: the management and the associates who served as respondents to this research, another insight on how to further improve the efficiency of machinery in the process. The study may be used as part of the learning materials for the students who will be taking the fundamentals of heating. It may serve as an example of how heat energy transfers and how to modify electrical control systems interact with one another in a complex process used in industrial applications. The faculty experts may use the findings of the study as basis on how to further improve the efficiency of machinery in terms of electrical control systems, as in line with industry**.** The research output may be used to promote energy efficiency and conservation, thereby benefiting the environment significantly. The study may provide add-on information to guide future studies associated with energy management systems. The study may contribute significantly to the body of knowledge on waste heat recovery systems for future researchers.

Acknowledgement

The researcher wishes to express his gratitude to the following individuals, without whom this work would not have been possible.

Engr. CHRISTOPHER E. MONTEMAYOR, Engineering Manager of The Pacific Meat Company Incorporated, served as a mentor, providing encouragement, technical support, and indispensable suggestions and recommendations without which improvements would not have been possible. His valuable guidance paved the way for the completion of this study;

Engr. MICHAEL O. BUQUIRON, Engineering Manager of Froneri Philippines, Incorporated, for sharing his technical expertise in instrumentation systems and supplying materials that made the project possible and successful. His insightful advice opened the door for the completion of this research;

Dr. TEODY C. SAN ANDRES, Executive Vice President and OIC-Dean, Graduate School and research paper expert, organized the contents of this study. His significant guidance opened up the way for the study to be completed;

The manuscripts for this study were organized by **Dr. EUGENE B. MUTUC**, Secretary of the Graduate School, and a research paper expert. His considerable counsel paved the road for the study's completion;

Dr. WARLITO GALITA, his adviser and research paper specialist, provided direction and ideas that allowed for advances in the final revisions;

For organizing the contents of his study, **Dr. DOLLY P. MAROMA,** his panel chairperson and research paper specialist, organized it;

Dr. EDGARDO M. SANTOS, whose statistical expertise in determining the significance of this project and the level of sustainability of his study was invaluable;

Dr. ALLEN N. MAROMA, his critic reader/editor, whose writing and editing abilities had much supported in the concept and refinement of this research;

Dr. REAGAN GALVEZ, a member of his panel, whose writing and editing talents had greatly aided in the development and polishing of this research;

The Bulacan State University-College of Industrial Technology through its Faculty in Electrical, Mechatronics, and Heating, Ventilation, and Air Conditioning EMHVAC Department for their encouraging remarks that motivated the researcher to complete his research: For their technical assistance and motivation in pursuing his research study; for their encouragement and prodding that motivated the researcher to continue and complete his master's degree;

The Froneri Philippines, Incorporated-Nestle Pulilan Factory Employees Union and Technical Department, through its Management and Associates in Industrial Services, for their encouraging remarks that motivated the researcher to complete his research: For their moral support and drive in pursuing his research study; as well as for their encouragement and prodding that encouraged the researcher to move on and finish his master's degree;

His son, **Andrew Kim**, was a source of courage and motivation for the researcher while he completed his studies;

His partner, **Gina**, whose love and care prompted and inspired the researcher to continue working on this project;

His family members - parents, guardians, relatives, brothers and sisters, nephews and nieces, as well as his pets, which this researcher adores - for their love, motivation, and respect that motivated him to complete this project;

And to the **LORD GOD**, I respectfully present this little endeavor in gratitude for all the benefits and gifts of time, friends, colleagues, and dreams becoming reality...

ASM

About The Contributors

Andrew S. Mañego is an instructor and finished his Master of Industrial Technology Management at Bulacan State University-Main Campus. He is ranked third among Bulacan State University cited researchers in 2023 and first in 2022, according to the AD Scientific Index. He is a member and a former Auditor of the MITM Society. He is a registered master electrician and a certified electronics technician.

References

Cai, W., Lai, K. H., Liu, C., Wei, F., Ma, M., Jia, S., ... & Lv, L. (2019). Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy. *Science of the Total Environment*, *665*, 23-32.

Dincer, I., & Rosen, M. A. (2021). Thermal energy storage: systems and applications. John Wiley & Sons.

Gao, L., Wang, S., Li, J., & Li, H. (2017). Application of the extended theory of planned behavior to understand individual’s energy saving behavior in workplaces. *Resources, Conservation and Recycling*, *127*, 107-113.

Hollnagel, E. (2018). *Safety–I and safety–II: the past and future of safety management*. CRC press.

Https://www.atlascopco.com

Irwin, J. D., & Nelms, R. M. (2020). Basic engineering circuit analysis. John Wiley & Sons.

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. (2018). Waste heat recovery technologies and applications. Thermal Science and Engineering Progress, 6, 268-289

Kolaitis, D., Giannopoulos, D., & Founti, M. (2020). Development of a Decision Support Tool for Sustainability Assessment of Energy Recovery Systems Using Refuse Derived Fuel. In *New and Renewable Energy Technologies for Sustainable Development* (pp. 55-65). CRC Press.

Kothari, C. (2020). Research methodology methods and techniques.

Lawson, Timothy. (2014). Comparison of the species composition of purse-seine catches determined from logsheets, observer data, market data, cannery receipts and port sampling data.

Luo, L., Zhao, J., and Huang, B. *(*2017). Experimental study of enhancing heating performance of the air-source heat pump by using a novel heat recovery device designed for reusing the energy of the compressor shell. *Journal of Energy Conversion and Management.*

Mahmoud, Ayman Elsayed Eltaher (2019). *Architecture Graduate, Standards of Energy Consumption Rationalization in University Building in Egypt,* Helwan University.

Nallusamy, S., Dinagaraj, G. B., Balakannan, K., & Satheesh, S. (2015). Sustainable green lean manufacturing practices in small scale industries-A case study. *International Journal of Applied Engineering Research*, *10*(62), 143-146.

Pesiridis, Apostolos (2014). *Automotive Exhaust Emmissions and Energy Recovery*, Nova Science Publishers, Inc., New York

Power Planning and Development Division PPDD (2019). *2019 Power Situation Report* by Department of Energy DOE, Electric Power Industry Management Bureau (EPIMB). Website: http://www.doe.gov.ph

Republic Act 11285: *Energy Efficiency and Conservation Act*, Implementing Rules and Regulations EEC-IRR was signed by President of the Republic of the Philippines, Rodrigo Roa Duterte on April 12, 2019.

Roever, Carsten and Phakiti, Aek. (2017). *Quantitative Methods for Second Language Research: A Problem-Solving Approach,* Routledge.

Sandre-Hernandez, O., Rangel-Magdaleno, J., & Morales-Caporal, R. (2017). A comparison on finite-set model predictive torque control schemes for PMSMs. IEEE Transactions on Power Electronics, 33(10), 8838-8847.

*Sapingai, Mohamad Azywan (*2017). *Development of Auto Log Sheet Switch for Energy Management.*

Sciubba, E., Tocci, L., & Toro, C. (2016). *Thermodynamic Analysis of a Rankine Dual Loop Waste Thermal Energy Recovery System.* Energy conversion and management, 122, 109-118.

Sengupta, S. F., Mohr, J. J., & Slater, S. (2014). Radical product innovation capability: Literature review, synthesis, and illustrative research propositions. *Journal of product innovation management*, *31*(3), 552-566.

Struchtrup, Henning (2014). *Thermodynamics and Energy Conversion*, Springer Heidelberg New York Dordrecht London.

Warnes, Lionel (2017). *Electronic and Electrical Engineering Principles and Practice,* Third Edition, Palgrave Macmillan, New York: Houndmills, Basingstoke, Hampshire RG21 6XS and 175 Fifth Avenue.

Williams, M. D., Rana, N. P., & Dwivedi, Y. K. (2015). The unified theory of acceptance and use of technology (UTAUT): a literature review. Journal of enterprise information management.

Xu, B., Rathod, D., Yebi, A., Filipi, Z., Onori, S., & Hoffman, M. (2019). A comprehensive review of organic rankine cycle waste heat recovery systems in heavy-duty diesel engine applications. Renewable and Sustainable Energy Reviews, 107, 145-170.