

# Design and Simulation of a PLC-Based Cold Storage Temperature Control System for Agricultural Product Storage

Batara Manggala Sianturi<sup>1\*</sup>, Beni Satria<sup>2</sup>, Ahmad Dani<sup>3</sup>

Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

Email :sianturibataramanggala@gmail.com

Horticultural products require storage at temperatures ranging from 0–10 °C to maintain post-harvest product quality. Cold storage is an effective solution because it can maintain temperature stability, which affects the rate of respiration, microbial activity, and the shelf life of products. However, conventional cold storage systems that use only a single compressor are less flexible in adjusting to thermal loads, which reduces efficiency, accelerates component wear, and decreases the overall reliability of the system. This study designs and simulates an automatic temperature control system based on a Programmable Logic Controller (PLC) by regulating two compressor units according to room temperature and integrating the principles of hysteresis, staging, and rotation. The system uses an upper temperature limit of 10 °C, a lower temperature limit of 0 °C, and a hysteresis point at 5 °C as a reference for changing operating modes. Compressors can operate simultaneously to speed up cooling, compressors can operate alternately to balance the load while maintaining optimal temperature, and compressors can stop simultaneously to stop cooling and prevent product freezing. The simulation was carried out using CX-Programmer for ladder logic and CX-Designer for Human Machine Interface (HMI) visualization. Testing involves temperature variations above 10 °C, in the range of 0–10 °C, and below 0 °C to verify the system's response. The results show that the system is able to maintain the storage room temperature at optimal conditions automatically and stably. The system successfully applied the principles of hysteresis, staging, and rotation effectively in response to temperature changes. The system is also equipped with automatic recovery capabilities that maintain precise control after a power outage. This design has the potential to be applied in food preservation, supply chain logistics, and temperature-sensitive industries, as well as supporting the development of cooling and autonomous systems.

**Keywords:** CX-Programmer; hysteresis; PLC; rotation; staging

This is an open access article under the [CC BY-NC](#) license



## Corresponding Author:

Batara Manggala Sianturi

Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

sianturibataramanggala@gmail.com

## 1. Introduction

Storage of agricultural products, particularly horticultural products such as vegetables and fruit, requires stable, low-temperature environmental conditions to slow respiration rates, reduce microbial activity, and maintain post-harvest quality. The ideal temperature range is generally between 0 and 10°C, making cold storage facilities a crucial infrastructure for maintaining fresh produce quality and supporting cold chain sustainability. Various studies have shown that low-temperature storage plays a significant role in reducing post-harvest losses and improving national food security. However, the effectiveness of cold storage is highly dependent on the performance and reliability of the temperature control system that controls it.

Cooling systems in cold storage require a control mechanism that can operate stably, respond to temperature fluctuations, and be energy efficient. Operations that rely solely on a single compressor often present various challenges, such as overloading, potential for premature failure, lack of backup capacity in the event of a disruption, and the inability to adjust cooling capacity to changes in thermal load. A more modern approach combines the use of multiple compressors with intelligent operating principles such as

staging, hysteresis, and lead-lag. These principles enable the system to maintain temperatures within an optimal range while balancing machine life and improving energy efficiency.

The implementation of Programmable Logic Controller (PLC)-based automation control is highly relevant in supporting this strategy. PLCs have the ability to read sensor signals in real time, execute complex control logic, and provide accurate outputs to regulate actuators such as compressors. According to the results of PLC training and implementation conducted in a company, the use of PLCs has been proven to improve operational efficiency, reduce downtime, and increase productivity and production quality (Erivianto & Dani, 2024). In line with technological developments and the demands of Industry 4.0, human-machine collaboration has become crucial, making the use of PLCs as a modern control system highly relevant (Syahputra & Hamdani, 2020).

Therefore, this study conducted a design and simulation of a PLC-based cold storage temperature control system that regulates two compressor units automatically and adaptively. The main focus of the research is on the development of a control system model and PLC program design, as well as its performance analysis through simulation in a software environment. The hardware design is not physically realized but is presented as a conceptual reference in the form of block diagrams and wiring diagrams. Components such as the CP1H PLC, thermocouple sensors, CP1W-TS003 expansion modules, contactors, and indicator lights are used as system design references and are represented virtually to illustrate the functional relationships between components. The control strategy implemented includes the principles of staging, hysteresis, and work rotation so that there are times when the two compressors operate simultaneously or alternately, and can stop based on room temperature conditions. The design also considers the automatic recovery capability that maintains precise control after a power outage. System testing and evaluation were carried out entirely through simulation using CX-Programmer to test ladder logic and CX-Designer to visualize the HMI interface. This simulation aims to ensure that the system is capable of maintaining room temperature in the optimal range of 0–10 °C according to the room temperature for storing horticultural products, while also being the basis for developing real implementation.

## 2. Theoretical Study

### Horticultural Post-Harvest Cold Storage

Horticultural products are highly perishable due to intensive respiration, metabolism, and microbial growth after harvest. Low-temperature storage, between 0 and 10°C, has been shown to slow these physiological processes, extending shelf life and maintaining product quality (Frontiers in Sustainable Food Systems, 2023). Temperature stability is crucial, as even small fluctuations can accelerate the degradation of sensory qualities such as aroma, texture, and freshness.

The FAO (2021, 2022) reports that proper cold chain management can significantly reduce post-harvest losses in fruit and vegetable commodities. Post-harvest physiology research also shows that low-temperature storage helps suppress enzymatic activity and oxidative reactions that cause tissue damage (Frontiers in Plant Science, 2024). Experimental studies on strawberries and kiwifruit confirm that a stable storage temperature profile is strongly correlated with final quality, including maintaining firmness, reducing weight loss, and preserving aromatic qualities (Ayala-Zavala et al., 2025). Thus, cold storage not only functions as a storage space, but also as an environmental control system that must be designed with high precision.

## Cold Storage Refrigeration System and Multicompressor Operation

Cooling systems in cold storage generally rely on a compressor as the primary component, compressing the refrigerant, enabling the process of absorbing heat from the storage space. Using a single compressor often results in excessive workload and is less effective when the thermal load fluctuates. Therefore, multi-compressor systems are widely used in modern cold storage (Johnson Controls, 2024).

### 1. Hysteresis Principle

Hysteresis is implemented to prevent excessive compressor on/off switching. Without hysteresis, very small temperature changes could cause the compressor to cycle on and off rapidly, reducing its lifespan and increasing energy consumption.

### 2. Staging Principles

Staging is a technique for gradually operating compressors based on actual temperature conditions. When the temperature exceeds a specified limit, two compressors can operate simultaneously to accelerate the temperature drop. When the temperature approaches the setpoint, only one compressor is allowed to operate to maintain energy efficiency.

### 3. Rotation Principle

Rotation, or lead-lag, ensures a fair distribution of the workload between compressors, ensuring a balanced operational lifespan. The system automatically selects the compressor that will “lead” the operation and rotates it at specific intervals to prevent uneven wear (Jetson HVAC, 2024).

The application of these three principles makes the cooling system more adaptive, stable, and resistant to variations in operational conditions.

## Thermocouple Sensors in Industrial Temperature Measurement

A thermocouple is a temperature sensor that operates based on the Seebeck effect, which is the generation of an electrical voltage due to a temperature difference at the junction of two dissimilar metals. The resulting voltage is proportional to the temperature difference and can therefore be converted to a temperature value (Doebelin, 2003).

Type K thermocouples are a common choice in industry because:

1. has a wide measuring range,
2. fast response,
3. resistant to extreme environmental conditions,
4. relatively cheap and stable (Holman, 2012).

In cold storage, thermocouples are the main input in PLC-based temperature control systems because they can provide the real-time data the system needs.

## Programmable Logic Controller (PLC) and CX-Programmer and CX-Designer Software

A PLC is a microprocessor-based electronic device designed to automatically control industrial processes using programmable logic (Bolton, 2015). A PLC reads sensor signals, processes them using ladder logic, and then activates actuators such as contactors and compressors. The advantages of a PLC include:

1. high reliability against industrial environmental noise,
2. ease of reprogramming,
3. flexibility of integration with analog and digital sensors,
4. compatibility with HMI devices,
5. the ability to execute complex logic with precision.

Expansion modules such as the CP1W-TS003 from Omron are used to read temperature signals from thermocouples and convert them into digital data so that they can be processed directly by the PLC (Omron, 2023).

CX-Programmer is software used to create, simulate, and monitor ladder programs on PLCs. The simulation feature allows logic verification without physical hardware, saving engineering time and minimizing the risk of errors (Omron, 2021). CX-Designer is used to create Human Machine Interfaces (HMI). The HMI displays temperature conditions, compressor status, and operating modes in real time, allowing operators to monitor the system with clear visuals (Omron, 2020). The integration of these two software tools enables comprehensive temperature control system simulation, including visualization of control logic and operational monitoring.

### 3. Research Methods

This research uses an engineering research approach with a simulation-based experimental method. This approach was chosen because the research aims to design, model, and test a PLC-based cold storage temperature control system without direct physical construction, but rather through simulation using CX-Programmer and CX-Designer.

This simulation method allows researchers to verify control logic, evaluate system response, and identify potential optimizations before actual implementation. The control system is designed to maintain the cold storage temperature within the optimal range of 0–10 °C by automatically regulating two compressor units based on room temperature by applying the principles of hysteresis, staging, and compressor work rotation. The system operating modes/temperature control schemes used include:

1. Mode 1, both compressors are active when the temperature  $T > 10$  °C until the temperature drops to 5 °C;
2. Mode 2, one compressor is active and alternates every 1.5 hours when the temperature is at 0–10 °C where this operation starts when the temperature is 5 °C;
3. Mode 3, both compressors stop when the temperature  $T < 0$  °C until the temperature rises to 5 °C, then return to one compressor mode in turns.

This study did not involve a human population or samples or physical objects. The focus of the study was on control system modeling and simulation, so all testing was conducted on programs designed in a software environment. The scope of the study was limited to testing the temperature control logic of two compressors without discussing the thermodynamic aspects or mechanical characteristics of the cooling system in detail.

Data collection was conducted by running a program simulation on CX-Programmer and CX-Designer by entering temperature values gradually starting from temperature values above 10 °C, 0–10 °C, and below 0 °C. The goal is to observe the control logic response to each condition and ensure the mode switching logic works as designed. The data collected includes compressor status, mode indicators, as well as ladder circuit activity and the visual display of the HMI interface, so that an overall picture of system performance is obtained.

The instruments used in this research are software instruments which include:

1. CX-Programmer is used for the preparation, simulation and verification of PLC ladder diagrams;
2. CX-Designer is used for HMI interface design and simulation;
3. Laptop/programming device is used to run software and monitor programs.



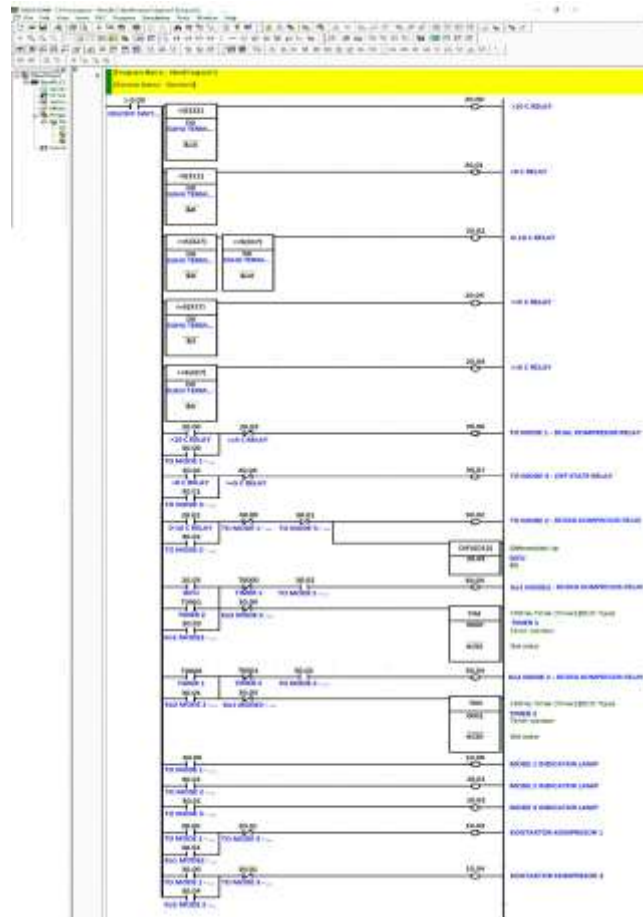


Figure 3. Ladder diagram in CX-Programmer

From the ladder diagram that has been created, the details of the addresses and names of variables/equipment can be presented in a table.

Table 1. List of Addresses and Variable Names in Ladder Diagram Program

Address	Variable Name	Information
I: 00.00	ON/OFF Switch	Main power control
D0	Data memory (temperature input)	Representation of thermocouple readings
10.00	Mode 1 indicator light	Mode marker
10.01	Mode 2 indicator light	Mode marker
10.02	Mode 3 indicator light	Mode marker
10.03	Compressor 1	Control output
10.04	Compressor 2	Control output

The HMI interface in CX-Designer is presented to show the visual appearance of the system and operator interaction so that readers can understand how to monitor and control the process.

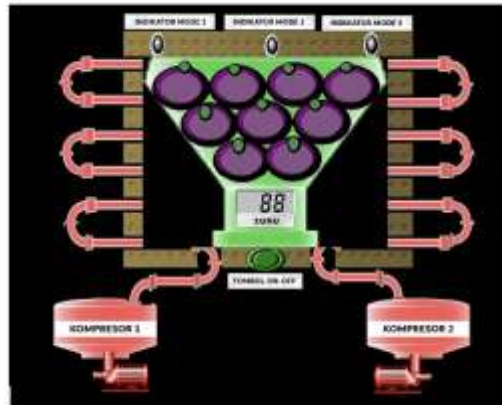


Figure 4. HMI interface on CX-Designer

## 4. Results and Discussion

### Data Collection Process

The data collection process is carried out through control logic simulation testing using the CX-Programmer and CX-Designer software, which are run in an integrated manner within the Work Online Simulation feature. When the CX-Programmer is run, the ladder diagram displays a green path indicating the logic is in an active (energized) state, while a colorless path indicates an inactive logic state. The actual temperature value resulting from the thermocouple sensor reading simulation is displayed at Data Memory address D0.

Simultaneously, when CX-Designer is running, the HMI interface displays the system conditions visually and in real-time. The compressor status is indicated in red when inactive and blue when active. The operating mode indicator lights (mode 1, mode 2, and mode 3) are displayed in gray when inactive and green when active. In addition, the ON-OFF switch button is displayed in green, where the pressed state indicates the system is ON, while the unpressed state indicates the system is OFF.

During the simulation process, temperature values are manually entered into Data Memory D0 and changed gradually over a temperature range above 10 °C, 0–10 °C, and below 0 °C. Each change in temperature value is observed through the logic response of the ladder diagram and changes in the HMI display, then recorded as data to evaluate the suitability of the system performance with the established control design.

### Research Time Range and Location

The research was conducted during the period from September to December 2025 in the laboratory using a computer with CX-Programmer and CX-Designer software installed.

### Data Analysis Results

Mode 1 is designed to have both compressors running when the temperature exceeds 10°C and remain running until the temperature drops to 5°C. Then both compressors (10.03 and 10.04) are active, the mode 1 indicator light (10.00) is ON, the mode 2 indicator light (10.01) is OFF and the mode 3 indicator light (10.02) is OFF. Furthermore, when the temperature from  $T > 10^{\circ}\text{C}$  drops to a temperature of  $5 < T \leq 10^{\circ}\text{C}$  (represented by a temperature of 9 °C), then both compressors (10.03 and 10.04) are still active, the mode 1 indicator light (10.00) is ON, the mode 2 indicator light (10.01) is OFF, and the mode 3 indicator light (10.02) is OFF. This proves that mode 1 functions according to the designed control logic. Mode 2 is designed to have one compressor active and alternating every 1.5 hours when the temperature is between 0 and 10°C, with operation starting when the temperature reaches 5°C. Because this is a simulation, the 1.5-hour test is simplified to 15 seconds.

Mode 3 is designed so that both compressors stop when the temperature is lower than 0 °C until the temperature rises to 5 °C. When the room temperature  $T < 0$  °C (represented by a temperature of -3 °C) then both compressors (10.03 and 10.04) are inactive, the mode 1 indicator light (10.00) is OFF, the mode 2 indicator light (10.01) is OFF, and the mode 3 indicator light (10.02) is ON. Furthermore, when the temperature from  $T < 0$  °C rises to a temperature of  $0 \leq T < 5$  °C (represented by a temperature of 1 °C), then both compressors (10.03 and 10.04) remain inactive, the mode 1 indicator light (10.00) is OFF, the mode 2 indicator light (10.01) is OFF, and the mode 3 indicator light (10.02) is ON. This proves that mode 3 functions according to the designed control logic.

### Recapitulation of Overall Simulation Results

Simulation images have been shown to illustrate the test results, but they do not cover all temperature conditions. Therefore, the simulation data is presented comprehensively and comprehensively in tabular form.

**Table 2.** Recapitulation of Overall Simulation Results

Temperature/ D0 value (°C)	Compressor Condition		Indicator Light Condition		
	Compressor 1 (10.03)	Compressor 2 (10.04)	Mode 1 (10.00)	Mode 2 (10.01)	Mode 3 (10.02)
13	ON	ON	ON	OFF	OFF
12	ON	ON	ON	OFF	OFF
11	ON	ON	ON	OFF	OFF
10	ON	ON	ON	OFF	OFF
9	ON	ON	ON	OFF	OFF
8	ON	ON	ON	OFF	OFF
7	ON	ON	ON	OFF	OFF
6	ON	ON	ON	OFF	OFF
5	ON/OFF	OFF/ON	OFF	ON	OFF
6	ON/OFF	OFF/ON	OFF	ON	OFF
7	ON/OFF	OFF/ON	OFF	ON	OFF
8	ON/OFF	OFF/ON	OFF	ON	OFF
9	ON/OFF	OFF/ON	OFF	ON	OFF
10	ON/OFF	OFF/ON	OFF	ON	OFF
4	ON/OFF	OFF/ON	OFF	ON	OFF
3	ON/OFF	OFF/ON	OFF	ON	OFF
2	ON/OFF	OFF/ON	OFF	ON	OFF
1	ON/OFF	OFF/ON	OFF	ON	OFF
0	ON/OFF	OFF/ON	OFF	ON	OFF
-1	OFF	OFF	OFF	OFF	ON
-2	OFF	OFF	OFF	OFF	ON
-3	OFF	OFF	OFF	OFF	ON
0	OFF	OFF	OFF	OFF	ON
1	OFF	OFF	OFF	OFF	ON
2	OFF	OFF	OFF	OFF	ON
3	OFF	OFF	OFF	OFF	ON
4	OFF	OFF	OFF	OFF	ON
5	ON/OFF	OFF/ON	OFF	ON	OFF

Table 2 shows that the mode conditions and compressor responses are consistent across the entire test temperature range. When the temperature  $T > 10\text{ }^{\circ}\text{C}$ , which includes 13, 12, and  $11\text{ }^{\circ}\text{C}$ , both compressors are active, and the mode 1 indicator light is on. When the temperature from  $T > 10\text{ }^{\circ}\text{C}$  drops to a temperature of  $5 < T \leq 10\text{ }^{\circ}\text{C}$ , which includes 10, 9, 8, 7, and  $6\text{ }^{\circ}\text{C}$ , both compressors remain active, and the mode 1 indicator light is on.

At the temperature  $T = 5\text{ }^{\circ}\text{C}$  as the hysteresis point, only one compressor is active alternately every 15 seconds, and the mode 2 indicator light is on. When the temperature from  $5\text{ }^{\circ}\text{C}$  rises or falls to a temperature of  $0\text{--}10\text{ }^{\circ}\text{C}$  which includes 6, 7, 8, 9, 10, 4, 3, 2, 1 and  $0\text{ }^{\circ}\text{C}$ , one compressor remains active alternately every 15 seconds, and the mode 2 indicator light is on.

When the temperature  $T < 0\text{ }^{\circ}\text{C}$  which includes -3, -2, and  $-1\text{ }^{\circ}\text{C}$ , both compressors are inactive, and the mode 3 indicator light is on. When the temperature from  $T < 0\text{ }^{\circ}\text{C}$  rises to a temperature of  $0 \leq T < 5\text{ }^{\circ}\text{C}$  which includes 0, 1, 2, 3, and  $4\text{ }^{\circ}\text{C}$ , both compressors remain inactive, and the mode 3 indicator light is on.

### System Recovery Testing After Power Outage

Testing of the system recovery conditions after a power outage/disconnection is also carried out and presented in the test table to evaluate the system's ability to automatically resume operation after the power supply returns.

**Table 3.** System Recovery Testing Recap After Power Outage

Temperature When Power Supply Returns ( $^{\circ}\text{C}$ )	Compressor Condition		Indicator Light Condition		
	Compressor 1 (10.03)	Compressor 2 (10.04)	Mode 1 (10.00)	Mode 2 (10.01)	Mode 3 (10.02)
13	ON	ON	ON	OFF	OFF
12	ON	ON	ON	OFF	OFF
11	ON	ON	ON	OFF	OFF
10	ON/OFF	OFF/ON	OFF	ON	OFF
9	ON/OFF	OFF/ON	OFF	ON	OFF
8	ON/OFF	OFF/ON	OFF	ON	OFF
7	ON/OFF	OFF/ON	OFF	ON	OFF
6	ON/OFF	OFF/ON	OFF	ON	OFF
5	ON/OFF	OFF/ON	OFF	ON	OFF
4	ON/OFF	OFF/ON	OFF	ON	OFF
3	ON/OFF	OFF/ON	OFF	ON	OFF
2	ON/OFF	OFF/ON	OFF	ON	OFF
1	ON/OFF	OFF/ON	OFF	ON	OFF
0	ON/OFF	OFF/ON	OFF	ON	OFF
-1	OFF	OFF	OFF	OFF	ON
-2	OFF	OFF	OFF	OFF	ON
-3	OFF	OFF	OFF	OFF	ON

Table 3 shows that the system has stable and reliable auto-recovery capability in maintaining precise control after a power outage. When the power supply returns at a temperature condition  $T > 10\text{ }^{\circ}\text{C}$ , both compressors are active. When the power supply returns at a temperature condition  $0\text{--}10\text{ }^{\circ}\text{C}$ , the system immediately switches one compressor ON alternately every 15 seconds. In this condition, the system does not wait for the temperature transition from a certain limit (such as from  $5\text{ }^{\circ}\text{C}$ ) but immediately resumes normal operation according to the actual detected temperature. When the power supply returns at a temperature condition  $T < 0\text{ }^{\circ}\text{C}$ , both compressors are OFF.

## 5. Conclusion

Based on the results of the tests and simulations that have been carried out, it can be concluded that the automatic temperature control system in a PLC-based cold storage is able to work optimally in maintaining the storage room temperature in the range of 0–10 °C according to the storage needs of horticultural products. The system design with a multi-compressor configuration successfully implemented a control logic that combines the principles of hysteresis, staging, and compressor work rotation effectively. The application of hysteresis is proven to be able to prevent excessive compressor switching, while staging adjusts the cooling capacity to the actual thermal load while increasing energy efficiency. In addition, compressor work rotation can balance the workload so that the compressor's operational life is maintained. The simulation results also show that the system has a stable automatic recovery capability after a power outage, where the system can return to normal operation based on the actual temperature after the power supply is restored, so that the temperature control process takes place stably and precisely.

However, this study has limitations because all testing was conducted in a simulated environment without direct verification on a physical cold storage installation. Further research is recommended to implement this design on a physical prototype to test the system's reliability under real-world operational conditions. Furthermore, system development can be directed at integrating IoT sensors, optimizing energy algorithms, and utilizing intelligent control methods such as fuzzy logic or adaptive PID to improve accuracy, energy efficiency, and long-term system resilience. The addition of failsafe mechanisms such as extreme temperature alarms, damage indicators, sensor failure detection, and automatic backup systems is also crucial to maintaining cold storage reliability. With these developments, this system design has the potential to become a practical solution that can be adopted by the horticulture, cold logistics, and food industries more broadly.

## 6. References

- Aryza S, Etal (2024) A ROBUST OPTIMIZATION TO DYNAMIC SUPPLIER DECISIONS AND SUPPLY ALLOCATION PROBLEMS IN THE MULTI-RETAIL INDUSTRY. *Eastern-European Journal Of Enterprise Technologies*, (3).
- Ardiansyah, R., & Wibowo, B. (2020). Implementation of Programmable Logic Controller (PLC) in industrial automation systems. *Journal of Industrial Technology*, 12(2), 115–124.
- Ayala-Zavala, J.F., Wang, S.Y., & Navarro, C.D. (2025). Temperature stability enhances postharvest quality of strawberry and kiwi under cold storage. *Frontiers in Plant Science*, 16(2), 1–12. <https://doi.org/10.3389/fpls.2025.14567>
- Bolton, W. (2015). *Programmable Logic Controllers* (6th ed.). Newnes/Elsevier.
- Doebelin, E. (2003). *Measurement Systems: Application and Design* (5th ed.). McGraw-Hill.
- Eriyanto, A., & Dani, A. (2024). Performance enhancement of industrial machinery using PLC-based automation. *Journal of Industrial Control Systems*, 9(3), 112–121. <https://doi.org/10.1016/j.jics.2024.00312>
- F.A.O. (2021). *Cold chain development in food systems: Technical report*. Food and Agriculture Organization.
- F.A.O. (2022). *Global cold storage for food security*. Food and Agriculture Organization.
- Frontiers in Plant Science. (2024). Temperature effects on enzymatic activity in postharvest systems. *Frontiers in Plant Science*, 15(1), 225–235. <https://doi.org/10.3389/fpls.2024.102212>
- Frontiers in Sustainable Food Systems. (2023). Low-temperature storage and reduction of postharvest loss. *Frontiers in Sustainable Food Systems*, 7(4), 1–14. <https://doi.org/10.3389/fsufs.2023.98765>
- Holman, J.P. (2012). *Experimental Methods for Engineers* (8th ed.). McGraw-Hill Education.

- Hamdani H et al (2022) An Enhancement Of Renew Source For Homes. Budapest International Research and Critics Institute-Journal (BIRCI-Journal), 5(3).
- Jetson HVAC. (2024). Lead-lag control in commercial refrigeration systems: A review. Journal of Refrigeration Engineering, 12(1), 55–67. <https://doi.org/10.1016/j.jre.2024.00210>
- Johnson Controls. (2024). Multi-compressor staging in cold storage applications. International Journal of HVAC Technology, 58(2), 87–99. <https://doi.org/10.1016/j.hvac.2024.00411>
- Omron Corporation. (2020). CX-Designer Operation Manual. Omron Publishing.
- Omron Corporation. (2021). CX-Programmer User Manual. Omron Publishing.
- Omron Corporation. (2023). CP1W-TS003 Thermocouple Input Module Specifications. Omron Publishing.
- Rahmaniar R et al (2021) Improving Understanding of PUIL 2000 and Illumination Calculations at the Deli Serdang Museum. Abdidas Journal, 2(3), 646-651.
- Syahputra, R., & Hamdani, M. (2020). Smart automation systems in the context of Industry 4.0: A review of PLC integration. Journal of Automation and Intelligent Systems, 5(3), 145–158. <https://doi.org/10.3171/jaist.2020.145>
- Satria, B., & Aryza, S. (2025). Analysis of Reactive Power Compensation Using Static Compensator (STATCOM) Technology in Distribution Networks. INFOKUM, 13(04), 1280-1291.