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NUST COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

SMART COLD STORAGE SYSTEM

A PROJECT REPORT

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Sustainable Development Goals

#	SDG	#	SDG
1	No poverty	10	Reduced inequalities
2	Zero hunger	11	Sustainable cities and economies
3	Good health and well-being	12	Responsible consumption and production
4	Quality Education	13	Climate action
5	Gender equality	14	Life below water
6	Clean water and sanitation	15	Life on land
7	Affordable and clean energy	16	Peace, justice and strong institutions
8	Decent work and economic growth	17	Partnership for the goals
9	Industry, innovation and infrastructure		

SDGs mapped with this work

(e.g., if #3, #7 and #9 are mapped)

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ABSTRACT

In an era of environmental awareness and innovative technology, our final year project represents a significant breakthrough in the field of cold storage solutions. We present a smart, eco-friendly cold storage with modern technologies like **Object Detection** and **Adaptive Temperature Control** to increase the storage time and minimize the temperature changes so the fruits and vegetables can be stored and remain fresh for a longer amount of time. We included Object Detection for accurate object identification and intelligent temperature control which will further improve the performance of our system and reduce its carbon footprint. Our cold storage not only reduces carbon emissions but also optimizes energy usage, making it a sustainable and cost-effective option. The Object Detection component of the system uses computer vision to recognize objects within the cold storage and dynamically changes the temperature to ensure optimal preservation based on the kind and number of contents. It will also give us information related to the product (for example the apple is stale or fresh). The AI model was first trained to identify the different objects through number of experiments then the model was tested through different experiments. The whole information will be displayed on the internet so we can access the data of the cold storage any time anywhere. The temperature and state of the fruits will also be displayed on the LCD. Finally, the whole setup will be installed inside the storage for its accurate working. This project combines sustainability, energy efficiency, and artificial intelligence to promise a breakthrough in cold storage technology that will help a variety of industries, including agriculture, food preservation, and healthcare. The smart temperature management system is a key component that distinguishes our project. Traditional cold storage systems sometimes suffer from inefficiencies as a result of continuous temperature settings that do not account for the unique needs of various goods. Our system's dynamic temperature changes ensure that each variety of fruit or vegetable is stored optimally, preventing spoiling and increasing shelf life. This personalized technique not only enhances the quality of stored product, but it also saves energy because the technology avoids excessive chilling. Furthermore, the integration of real-time monitoring and data access via the internet gives consumers unparalleled control and supervision over their storage units. This function is especially useful for large-scale enterprises like commercial farms and food delivery centers, where keeping produce fresh is important. The future of cold storage is here, and it's smart, green, and powered by cutting-edge artificial intelligence technology. Our systematic approach has the potential to alter the cold storage industry by increasing efficiency, lowering environmental impact, and making advanced storage solutions more accessible to a diverse range of consumers. By integrating innovative technology with eco-friendly methods, we want to create a new standard for cold storage systems globally.

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Q Energy/heat, J

T Temperature, T

m Mass, kg

V Volume, m3

H Enthalpy

A Area, m2

h Convection coefficient, W/m2

.K Heat flux, W/s

Qconv Heat transfer due to convection

Qr Heat transfer due to radiation

k Ratio of heat conductivity

PCM Phase change material

HVAC Heating Ventilation and Air Conditioning

TES Thermal Energy Storage

INTRODUCTION:

1.1 Background

Refrigeration systems are critical for preserving perishable goods, and this report details the design, fabrication, and implementation of an advanced cold storage system integrating artificial intelligence (AI). The system's groundbreaking feature lies in its autonomous fruit detection and dynamic temperature adjustment capabilities, optimizing storage conditions. Cold storages are used for this purpose to store different products in bulk amounts before they are transported to different parts of the countries or sent to different countries in which such products are difficult to grow. Fruits covers a large part of these products and some of these fruits are very prone to high or low temperatures and will spoil if not stored at optimum temperatures. Therefor cold storages are used worldwide to store fruits which will be transported to different parts of the world in the future and maintain their quality as long as possible. These fruits export businesses generate a lot of profit and plays an important role in the increasing the export of the country and stabilizing its economy. Modern cold storages are equipped with new technologies to monitor the products stored inside them all the time and also dynamically changing temperature and humidity inside the cold storages to increase the product quality and the performance of the cold storage. In this report a complete methodology is given to make a model of a cold storage with dynamic temperature control, it also includes the qualitative and quantitative analysis of the system by performing multiple experiments on the proposed model. The performance parameters are compared with simple traditional cold storage system to show the products viability in the context of power saving and quality of the apple. To summarize, our improved cold storage technology offers a substantial advancement in the preservation of perishable items. It provides a superior solution for preserving fruit freshness and quality by combining AI, dynamic temperature change, and real-time monitoring. This new strategy not only benefits the fruit export industry by lowering spoilage and improving profitability, but it also promotes environmental sustainability through energy-efficient processes.

1.2 Objective

Our innovative cold storage system has various novel characteristics that distinguish it from typical systems. AI integration provides exact object identification, allowing the system to recognize and categories various varieties of fruits kept within. This item recognition skill is critical since the optimal storage needs for various fruits differ. For example, apples and bananas require various temperatures and humidity levels to remain fresh. By precisely recognizing the fruits, the system can alter the storage settings to ensure that each variety of fruit is preserved in the best possible circumstances. In addition, our system's dynamic temperature adjustment capability represents a considerable breakthrough. Traditional cold storage systems usually keep a consistent temperature, which may not be ideal for all stored materials. In contrast, our technology constantly analyses the conditions within the storage container and changes the temperature in real time based on the observed fruits. This dynamic adjustment aids in maintaining freshness and prolonging the shelf life of products, hence avoiding spoilage and waste. The system also has real-time monitoring and remote access features. Users may check storage conditions from anywhere and at any time thanks to an integrated internet connection. This capability is especially useful for large-scale businesses that require continual inspection to ensure product quality. Users are notified when any parameters vary from the ideal range, allowing them to take rapid action to correct the issue. This proactive strategy helps to avoid potential rotting and ensures that the stored product remains in the optimum condition. This development of a smart cold storage system that optimizes storage conditions and minimizes food spoilage. The system achieves this by integrating traditional refrigeration technology with advanced control systems and artificial intelligence (AI).

- **Design and Fabrication of a Cost-Effective Refrigeration System:** Develop a refrigeration system that balances efficiency and affordability, suitable for the intended storage capacity. This may involve selecting appropriate components such as compressors, condensers, evaporators, and capillary tube.
- **Development of a Comprehensive Control System:** Implement a control system to maintain optimal storage conditions. This includes:
- **Continuous Monitoring:** Utilize a DHT11 sensor to continuously monitor temperature and humidity levels within the cold storage.
- **Compressor power Detection:** Employ a current sensor to monitor compressor operation and identify potential malfunctions for preventative maintenance.
- **Integration of an AI Model for Image Recognition:** Develop an AI model capable of image recognition to differentiate between fresh and stale fruits/vegetables. This may involve FOMO training the model on a well-curated dataset of labeled images capturing the visual characteristics of fresh and spoiled produce.
- **Seamless Integration of Control System and AI Model:** Integrate the developed control system with the AI model for real-time feedback. This allows the AI to analyze the condition of stored produce and inform adjustments to the refrigeration system.
- **Smart Cold Storage System with AI-powered Visual Detection and Dynamic Temperature Control:** Leverage the AI model with camera vision to automatically detect and identify stale or rotten fruits/vegetables. This will enable targeted adjustments to storage temperature based on the specific

needs of the individual produce items. By integrating these elements, the system will create a dynamic and intelligent environment for food storage.

- **Reduced Food Waste:** Early detection of spoilage allows for timely removal of affected produce, minimizing losses.
- **Optimized Storage Conditions:** Dynamic adjustments based on the real-time state of the stored goods ensure optimal temperature and humidity levels.
- **Enhanced Efficiency:** AI-powered monitoring can identify potential equipment malfunctions and enable preventive maintenance, ensuring smooth operation.
- This project aims to contribute to a more sustainable and efficient food storage system, minimizing waste and promoting food security.

1.3 Cold Storage

Materials such as 3mm acrylic sheets, plywood, compressors, condensers, evaporators, and insulation were meticulously chosen to ensure both efficiency and durability. The design phase focused on sizing components and layout considerations, with a frame supporting the 18 by 18-inch cooling storage space strategically housing key elements like compressors, control systems, condensers, thermostats, and evaporators. Challenges in material selection were overcome by strategic solutions like creating a vacuum and adding polyalphaolefin oil to the compressor. Refrigeration systems play a pivotal role in preserving perishable goods, and this report provides a detailed account of an innovative cold storage system with AI integration. The system's standout feature is its autonomous fruit detection and temperature adjustment capabilities, optimizing storage conditions.

Carefully chosen materials, including 3mm acrylic sheets and plywood, contribute to the system's efficiency and durability. Fabrication involved welding and machining, ensuring seamless integration of compressors, control systems, condensers, thermostats, and evaporators. Quality control measures and strategic solutions to challenges in material selection underscore the project's significance in revolutionizing fruit preservation, emphasizing the importance of meticulous design and cutting-edge technology. Materials Used in Refrigeration Systems: The effectiveness and longevity of the refrigeration system were significantly influenced by the scrupulous selection of materials. The foundational structure of the system was crafted from durable 3mm acrylic sheets and plywood, chosen with meticulous care for their robust properties. These materials not only provided structural integrity but also contributed to the overall resilience of the system, ensuring its capability to withstand the rigors of continuous operation. Compressors, condensers, evaporators, pipes, and insulation materials were seamlessly integrated, forming a cohesive unit designed for optimal performance. This comprehensive approach to material selection underscored the commitment to creating a refrigeration system that not only met functional demands but also prioritized efficiency and durability in its design and construction. The project is also more efficient from traditional refrigeration system because it can detect the object inside the storage and then set the temperature according to the type of fruit inside the storage which is based on the ASHRAE standard due to this the storage can result in less power consumption in certain cases and can increase the efficiency of the system also there is further improvement by detecting stale fruits and removing it before it spoils other fruits.

1.4 Control System

The Control system would consist of multiple electronic components and sensor like: Arduino Uno, ESP32 CAM, ESP8266 Wi-Fi Module and DHT11 Sensors. These components and sensors will collect the required data and then control the different actions like turning on the compressor and showing warning signal on the LCD when stale fruit is detected. All of these components were selected after careful consideration and also keeping in mind the requirements of the project dimensions .The system would function as follows:

- First the algorithm running in the ESP-32 CAM microcontroller would use the camera module to recognize the type of fruit/vegetable and analyze if the fruit/vegetable is fresh or stale. After Classification it would pass this information to the Arduino Uno. The Arduino functions would be as follows:
- Measuring the inside and outside Temperature of the compartment using the DHT11 sensor.
- Receiving the classification information of the fruit/vegetable.
- Sending the temperature and classification data to a database via Wi-Fi Module for remote monitoring.
- Sending an alert message to the LCD display and buzzer unit in case of stale product detection.
- Turning the compressor ON/OFF according to inside temperature.
- Displaying the current value on the LCD for the analysis of the system.

The careful integration of these components is necessary for the proper working of the electrical components and receiving data from the sensors and then sending relays the output for turning the compressor ON/OFF. Different software like Arduino and Edge Impulse were for the coding and transfer of data from one controller to another and also displaying the data on LCD and Online platform for the easier accessibility. The important parameters like temperature and humidity are displayed on the LCD for constant monitoring and also to display the warning message in case any stale fruit is detected by the camera inside the cold storage. The current sensor will give us constant results regarding the proper working of the compressor if any maintenance is needed it can be determined.

1.5 AI Integration:

This step is really important for connecting the control system with the electrical components like compressor for its proper working according to the set temperature this step involves the major step like:

- Collecting the data for different types of the fruit that are going to be placed inside the storage.
- Training the algorithm for the different scenarios it could face in terms of type of fruit.
- Then testing this data by checking its performance under different scenarios.
- Inserting the algorithm inside the microcontroller and then integrating the microcontroller with the Arduino to send the output it receives from camera.

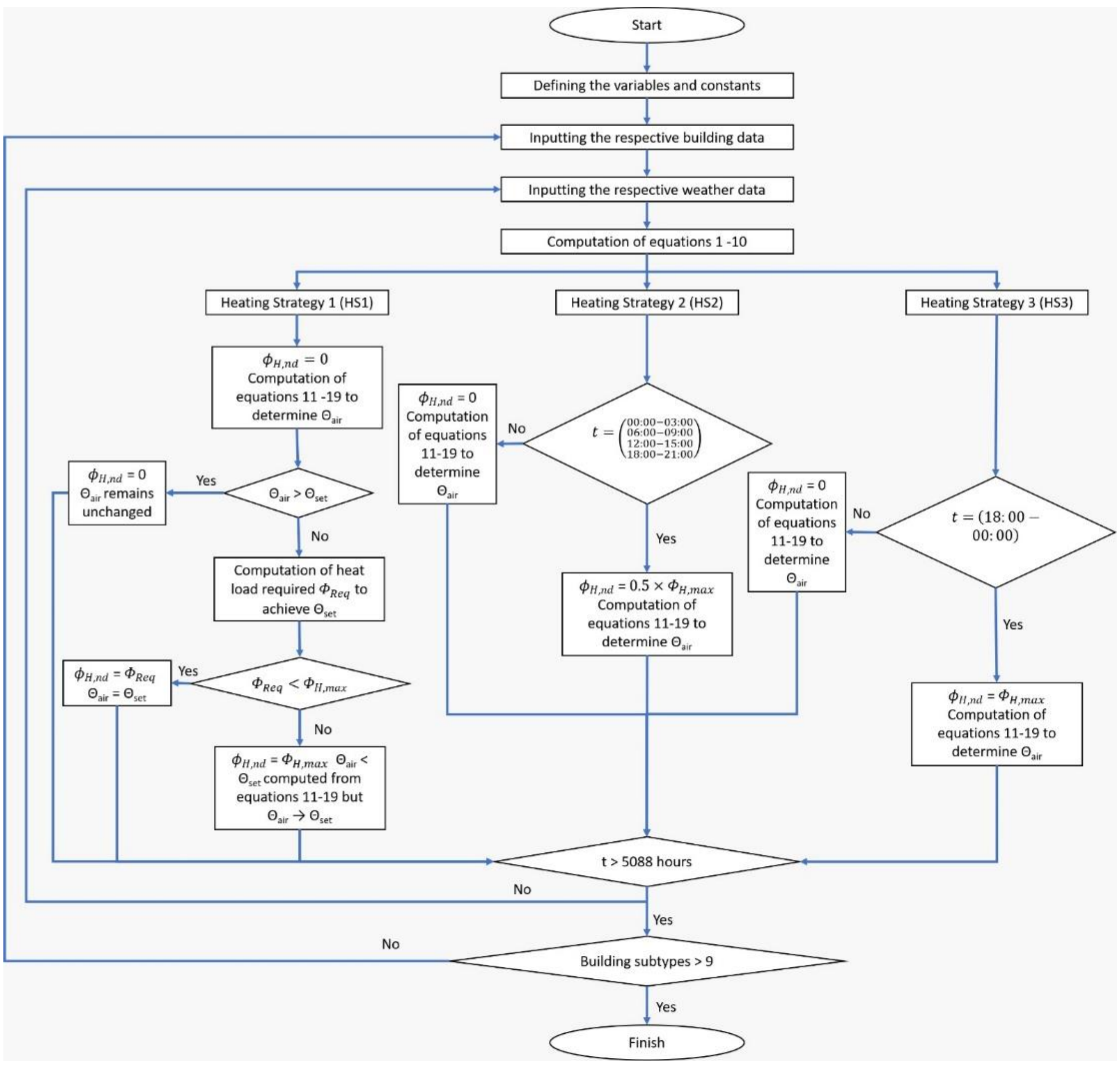

Figure 1: Flowchart explaining the data collection and training process for the algorithm

1.6 Scope

Our innovative cold storage system has various novel characteristics that distinguish it from typical systems with AI integration and provides exact object identification, allowing the system to recognize and categories various varieties of fruits kept within. This item recognition skill is critical since the optimal storage temperature needs for various fruits differ. For example, apples and bananas require various temperatures and humidity levels to remain fresh. By precisely recognizing the fruits, the system can alter the storage settings to ensure that each variety of fruit is preserved in the best possible circumstances. In addition, our system's dynamic temperature adjustment capability represents a considerable breakthrough. Traditional cold storage systems usually keep a consistent temperature, which may not be ideal for all stored materials. This function is especially useful for large-scale enterprises like commercial farms and food delivery centers, where keeping produce fresh is important. The future of cold storage is here, and it's smart, green, and powered by cutting-edge artificial intelligence technology.

1.7 Deliverables and End Goals

- Design and fabricate a working prototype of the smart cold storage system.
- Create an AI-powered object detection system that uses computer vision to reliably identifyand monitor things in the cold storage unit.
- Adaptive temperature control based on the information from the AI model.
- Analyze the energy efficiency and environmental effect of the smart cold storagetechnology vs conventional approaches.
- The AI model will make sure that the different objects inside the freezer are at their optimal temperature and preserved perfectly.
- Finally, the research aims to show the market feasibility and scalability of this new cold storage solution across a variety of industries, including agriculture, food storage, and healthcare. The initiative aims to contribute to environmental sustainability by optimizing energy utilization.
- This project aims to lower the carbon footprint of the new cold storage system and increase the efficiency of the project. The initiative seeks to contribute to a considerable decrease in food and product waste through accurate temperature control and monitoring, benefiting both consumers and companies.
- To increase the Quality of the fruits by constantly monitoring them and also changing the environment inside the cold storage according to requirements.

LITERATURE REVIEW:

Cold storage system in Pakistan is used for the preservation of a variety of fruits and vegetables. These cold storages require electricity for their working and because most of the areas in Pakistan where these fruits or vegetables are grown. Post-harvest diseases destroy 10-30% of the total yield of crops and in some perishablecrops especially in developing countries, they destroy more than 30% of the crop yield [1], [2]. Pakistan is the developing country, where 35-40 percent post-harvest losses are in fruits and vegetables. In these losses 15-20 percent are at the time of management harvested crop, 5-8 percent at harvesting and 10-12 percent loss in vegetable and fruits when ittransports [3].

Now the problem of electricity shortage can be solved through solar panels which is a promising technology, the advancement of solar PV technology, along with the high cost oftraditional energy, has resulted in a 20-25% rise in solar PV installation globally over the previous 20 years [4]. So solar energy is convenient for remote areas where conventional energy is difficult to avail [5].Our project is based on this idea to create a cold storage is used for maintaining temperatureinside the storage. This will solve the problem of energyefficient. Further we are adding an AI algorithm that detects the fruit or vegetable inside the storage and set temperature accordingly. This will result in further increasing the efficiency ofthe system and will reduce the carbon footprint and environmental effects of this project.

2.1 Fruits production in Pakistan

Fruit production in Pakistan significantly contributes to the country's agricultural sector and economic growth. Benefiting from diverse climatic conditions, Pakistan cultivates a wide array of fruits such as mangoes, citrus fruits, dates, and apples. Beyond meeting domestic demand, fruit cultivation plays a pivotal role in bolstering exports, thereby bolstering foreign exchange earnings. Visual representations, in the form of graphs, detailing fruit production across Pakistan's four provinces - Punjab, Sindh, Khyber Pakhtunkhwa, and Baluchistan - offer indispensable insights. These graphs illuminate regional disparities, production trends, and the proportional contributions of each province to Pakistan's overall fruit output. Understanding these dynamics is imperative for policymakers, agricultural stakeholders, and researchers, enabling informed decision-making and strategic planning to foster sustainable agricultural development nationwide.[21][22][23][24]

Table 1: Area under fruit - Pakistan

					Hectares
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	183849	181650	156321	152371	152716
Mango	167899	158659	158512	159240	159247
Banana	30031	29730	32847	32918	33197
Apple	88589	82041	75772	77429	72894

Table 2: Production of fruit- Pakistan

					Tones
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	2351386	2468671	2367308	2573045	2321802
Mango	1735000	1722683	1638858	1713812	1844706
Banana	140415	135660	157377	141973	215570
Apple	564693	543645	572558	671756	732287

Table 3: Production of Fruit-Punjab

					Tones
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	2289140	2397306	2297847	2500254	2246473
Mango	1329343	1330165	1304349	1321461	1450444
Banana	884	682	437	226	190
Apple	3579	3590	3515	0	0

Table 4: Area under fruit-Sindh

					Hectares
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	4035	5536	5633	5691	5818
Mango	62062	59150	59109	59152	59158
Banana	28092	27956	31149	31738	31963
Apple	0	0	0	0	0

Table 5: Production for fruit-Sindh

					Tones
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	25003	31613	32867	33555	34059
Mango	400483	387884	329300	386973	387401
Banana	109472	110503	122874	123263	189954
Apple	0	0	0	0	0

Table 6: Area under fruit-Khyber Pakhtunkhwa

					Hectares
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Percimen	3060	3103	2895	2994	2919
Melons	3826	3597	3497	2078	1881
Banana	365	362	353	44	18
Guava	1575	1555	1757	1638	1764
Mango	343	342	365	372	365
Apple	7540	5976	3027	5512	1556

Table 7: Production of fruit-Khyber Pakhtunkhwa

					Tones
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Percimen	25083	25714	23136	22893	21799
Melons	44063	42891	41197	20179	20547
Guava	27127	26810	28024	25224	25696
Banana	10467	10233	10181	1241	423
Mango	3004	3323	3545	3603	3498
Apple	69287	57236	22488	52264	46011

Table 8: Area under Fruit-Baluchistan

					Hectares
FRUIT	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Citrus	1702	1695	1707	1780	1790
Mango	670	678	689	702	711
Banana	1101	979	979	1020	1054
Apple	80669	75684	72366	71917	71338

Table 9: Production of fruit-Baluchistan

FRUIT	2017-18	2018-19	2019-20	2020-21	2021-22
Citrus	6910	8420	8644	10000	10887
Mango	2170	1311	1664	1775	3363
Banana	17013	11663	21811	16597	24145
Apple	491827	482819	546555	619492	686276

2.2 Statics of the Export Fruit Production

Within Pakistan's fruit export sector, two notable varieties stand out: bananas and apples. These fruits represent significant economic potential for the country's export industry. However, realizing the full benefits of exporting bananas and apples necessitates prioritizing measures aimed at minimizing losses and upholding stringent quality standards throughout the supply chain. A pivotal element in achieving this objective is the establishment of an efficient cold storage infrastructure. Cold storage facilities play a crucial role in preserving the freshness and quality of both bananas and apples, ensuring they reach international markets in prime condition. By mitigating spoilage and prolonging shelf life, cold storage not only enhances the market appeal of these fruits but also reinforces Pakistan's reputation as a dependable supplier. Furthermore, investment in cold storage infrastructure underscores Pakistan's commitment to adhering to global standards, reinforcing its competitive edge in the international fruit trade arena. Thus, by emphasizing the preservation and quality assurance of bananas and apples through cold storage, Pakistan can further solidify its position in the global fruit export market and stimulate sustained economic growth.

Table 10: Export Fruit, Vegetable and Condiments country Wise

			Quantity=Kg Value=000Rs	
Country	**2021-22**		**2020-21**	
	QTY	**VALUE**	**QTY**	**VALUE**
APPLE	**71,338**	**7,130**	**529,818**	**37,371**
Afghanistan	21,200	835	127,034	5,092
Bahrain	-	-	33,196	3,211
Malaysia	30	10	2	1
Oman	42,000	5,561	59,880	5,302
Saudi Arabia	24	12	-	-
Singapore	-	-	10	4
USA	8,084	713	309,696	23,761

2.3 Cold Storage System

2.3.1 Cooling System:

The cooling system is a crucial component in various applications, including air conditioning and refrigeration. Its primary function is to remove heat from an enclosed space and release it outside, thereby lowering the temperature of the interior space. This process involves the circulation of a refrigerant through a series of components that manipulate its state and pressure to achieve the desired cooling effect. The system operates on AC electricity, which powers its components and ensures continuous and efficient operation. Depending on the specific application, the design and complexity of the cooling system can vary, but the fundamental principles remain the same.

- **Compressor:**

The compressor is the heart of the cooling system. It is responsible for pressurizing the refrigerant gas, a process that significantly raises its temperature. The compressor takes in low-pressure, low-temperature refrigerant gas from the evaporator and compresses it to a high-pressure state. This compression increases the temperature of the gas due to the work done on it by the compressor. The high-pressure, high-temperature refrigerant gas is then pushed through the system to the condenser. The efficiency and performance of the compressor are vital, as they directly affect the overall effectiveness of the cooling system. Modern compressors come in various types, including reciprocating, rotary, and scroll compressors, each with specific advantages and applications.

- **Condenser:**

The condenser plays a pivotal role in the cooling cycle by dissipating the heat absorbed by the refrigerant. In the condenser, the high-pressure, high-temperature refrigerant gas releases its heat to the surrounding environment. This heat dissipation process is facilitated by passing the refrigerant through a network of coils or fins, where it is cooled by air or water. As the refrigerant releases heat, it condenses into a high-pressure liquid. The efficiency of the condenser in expelling heat is crucial, as it ensures the refrigerant is adequately cooled before it moves to the next stage of the cycle. Effective condensation is essential for maintaining the overall energy efficiency and performance of the cooling system.

- **Expansion Valve:**

The expansion valve is a critical control device in the cooling system. Its primary function is to regulate the flow of the high-pressure liquid refrigerant into the evaporator. As the refrigerant passes through the expansion valve, it undergoes a rapid pressure drop. This pressure reduction causes the refrigerant to cool significantly and expand. The expansion valve is designed to maintain a specific rate of refrigerant flow, ensuring the optimal amount enters the evaporator to absorb heat efficiently. Proper functioning of the expansion valve is essential for achieving the desired cooling effect and maintaining the stability and efficiency of the cooling cycle.

- **Evaporator:**

The evaporator is the component where the actual cooling of the air or space occurs. The now-cool, low-pressure refrigerant flows into the evaporator coils, where it absorbs heat from the indoor air or the refrigerated space. As the refrigerant absorbs heat, it evaporates, transforming back into a low-pressure gas. This heat absorption process cools the surrounding air or space, providing the desired cooling effect. The evaporator must be designed to maximize heat transfer efficiency, ensuring that the refrigerant absorbs as much heat as possible. Proper air circulation over the evaporator coils is also crucial for maintaining consistent cooling performance. The evaporator's role in the cooling system is fundamental, as it directly affects the comfort and preservation of the cooled environment.

The cooling system, powered by AC electricity, relies on a series of interconnected components to achieve efficient cooling. The compressor pressurizes the refrigerant gas, increasing its temperature. The high-temperature gas then releases heat in the condenser, turning into a high-pressure liquid. This liquid undergoes rapid cooling and expansion in the expansion valve before entering the evaporator, where it absorbs heat from the indoor air or refrigeration space, effectively cooling the environment. Each component plays a vital role in the overall functionality and efficiency of the cooling system, ensuring optimal performance and energy efficiency.

2.3.2 Working of the cold storage:

The working of a cold storage system revolves around a series of interconnected components designed to regulate and maintain specific temperatures critical for preserving perishable goods. Beginning with the compressor, its primary role is to pressurize the refrigerant gas, thereby significantly elevating its temperature to initiate the cooling process. This high-pressure, high-temperature refrigerant then enters the condenser, where it undergoes a crucial transformation by releasing heat to the surroundings. This process causes the refrigerant to condense into a high-pressure liquid state, preparing it for the subsequent stages of cooling. From the condenser, the refrigerant moves through the expansion valve, which serves as a pivotal control mechanism in the system. As the refrigerant passes through the expansion valve, there is a rapid reduction in pressure. This sudden drop causes the refrigerant to cool rapidly and expand, transitioning it back into a low-pressure state. This cooled refrigerant then enters the evaporator, where the actual cooling of the environment takes place.

In the evaporator, the low-pressure refrigerant absorbs heat from the indoor air or the refrigerated space. This heat absorption causes the refrigerant to evaporate, returning it to a low-pressure gas state. As the refrigerant evaporates, it effectively cools the surrounding environment, ensuring that the temperature within the cold storage unit remains stable and suitable for preserving perishable items. The continuous circulation of refrigerant through these components—compressor, condenser, expansion valve, and evaporator—constitutes the core operation of the cold storage system. This cyclic process of compression, heat release, pressure reduction, and heat absorption is essential for maintaining consistent and efficient cooling performance. By carefully controlling these stages, the cold storage system can effectively regulate temperatures, ensuring optimal conditions for the storage and preservation of sensitive products such as food, pharmaceuticals, and other perishable goods. The cooling system, powered by AC electricity, relies on a series of interconnected components to achieve efficient cooling. The compressor pressurizes the refrigerant gas, increasing its temperature. The high-temperature gas then releases heat in the condenser, turning into a high-pressure liquid. This liquid undergoes rapid cooling and expansion in the expansion valve before entering the evaporator, where it absorbs heat from the indoor air or refrigeration space, effectively cooling the environment. Each component plays a vital role in the overall functionality and efficiency of the cooling system, ensuring optimal performance and energy efficiency.

2.4 Object Detection:

Table 11: Object detection and control

No.	Title	Outcome	Reference
1	Esp32 cam-based object detection & Identification with opencv	The paper used Esp32 Cam module to detect objects using YOLOv3 algorithm.	[7]
2	Internet of things based (IOT) inven tory monitoring refrigerator using Arduino sensor. Network.	Paper used Arduino Uno, Weight sensorsand Camera to monitor and maintain freshness of items in Refrigerator.	[8]

2.4.1 YOLO Algorithm:

The YOLO (You Only Look Once) algorithm stands out as a one-step detector that enablessingle-algorithm detection, gaining popularity due to its remarkable performance comparedto other object detection methods. The ESP32 CAM is a cost-effective camera-equipped device, utilizing the ESP32 processor and is cheap. It includes GPIOs for connecting the OV2640 camera to peripherals and a micro-SD card slot for storing images captured by thecamera and client-accessible files [7].

2.4.2 Arduino UNO and YUN:

Smart refrigerators are being used to develop the use of appropriate storing of food. However, this device is not economically friendly because it is expensive. Thus, this study [8] presents an Internet of Things-based smart refrigerator using sensor network and Arduino YUN Microcontroller that is suitable to any individual that usually spends more time at work and has difficulties monitoring their food. The proposed system monitors thestocks remaining and deficient remotely and in real-time. Also, it will notify the user the inventory update on his/her fridge through Internet. Arduino Uno is used for receiving data from the sensor network and an Arduino Yun for receiving and processing images from the camera to implement an Internet of Things (IoT)application. The sensor network initially collects data from each compartment and transmits it to the Arduino Uno. The Arduino Uno and Arduino Yun are connected throughthe I2C communication protocol, allowing the data received by the Uno to be transferred to the Yun. Once all required data is received, the Arduino Yun captures images using thecamera and uploads both the received data and the captured image directly to Dropbox. Subsequently, an Android application displays the data and image from Dropbox.

2.4.3 Sensors:

The system comprises several sub-modules, including the sensing module, control module, and transmission module. The sensing module incorporates gas, humidity, and temperaturesensors. The control module consists of a microcontroller and a power supply unit. Lastly,the transmission module comprises an LCD module and a Wi-Fi module. These interconnected modules collaborate to assess the contents' status within the refrigerator andinform the user about product conditions via SMS or email notifications [8].

In general, following steps will be used for this project:

- Detection of fruits using Computer Vision Technology.
- Data acquisition like temperature, humidity of fruits inside compartment.
- Real time monitoring of fruits and vegetables.
- Control of HVAC system using micro controllers.
- Optimization of parameters by data analysis.

2.5 Overview of Control System:

The overall system consists of the following six components:

1. Arduino Uno
2. ESP32 CAM
3. DHT11 Sensor
4. Relay
5. LCD Display Unit
6. AC712 Current Sensor

The system functions as follows:

Fruit/Vegetable Recognition: The algorithm running in the ESP32 CAM microcontroller uses the camera module to recognize the type of fruit/vegetable and analyze if it is fresh or stale.

Data Transmission: After classification, this information is passed to Arduino Uno.

Temperature Measurement: The Arduino measures the inside and outside temperature of the compartment using the DHT11 sensor.

Alert System: In case of stale product detection, an alert message is sent to the LCD display and the buzzer unit. Temperature Control: The Arduino regulates the temperature of the compartment by controlling the compressor through a relay. Current Monitoring: The AC712 current sensor measures the current draw of the compressor to ensure efficient energy use.

1. Arduino Uno:

The Arduino Uno is a popular microcontroller board based on the ATmega328P processor. It is the go-to choice for many beginners and hobbyists due to its simplicity and versatility. The board features digital and analog pins, allowing it to interface with a variety of sensors and actuators. Arduino Uno is widely used in DIY electronics projects, offering an open-source platform for programming and experimenting with different applications, from robotics to home automation.

2. ESP32 CAM:

The ESP32 CAM is a compact and powerful development board that integrates the ESP32 chip and a camera module. This module enables IOT (Internet of Things) projects with image and video processing capabilities. It supports Wi-Fi connectivity and has various GPIO pins for additional sensors or peripherals. The ESP32 CAM is particularly useful in applications such as surveillance cameras, image recognition, and smart home devices due to its wireless capabilities and onboard camera.

3. ESP8266 Wi-Fi Module:

The ESP8266 Wi-Fi module is a low-cost, compact device that provides Wi-Fi connectivity to microcontrollers and other embedded systems. It gained popularity for its ease of use and affordability. With built-in TCP/IP protocol stack, it allows devices to connect to the internet. The ESP8266 is widely used in IOT projects, enabling devices to communicate over Wi-Fi networks and access cloud services. Its small form factor and simplicity make it a popular choice for adding wireless capabilities to various electronics projects.

4. DHT11 Sensor:

The DHT11 is a basic digital temperature and humidity sensor commonly used in electronics projects. It consists of a humidity sensing component and a thermistor for temperature measurement. The sensor provides a simple interface, usually through a single-wire digital communication protocol. Despite its low cost and simplicity, the DHT11 is reliable for obtaining temperature and humidity data, making it suitable for applications like weather stations, climate monitoring, and home automation projects.

5. Firebase:

Firebase is a comprehensive mobile and web application development platform provided by Google. It offers various services and tools, including real-time database, authentication, hosting, and cloud functions. Firebase facilitates the development of scalable and feature-rich applications by providing a backend infrastructure with easy-to-use APIs. The real-time database is particularly useful for applications that require instant updates and synchronization across multiple devices. Firebase is widely adopted for its seamless integration with both Android and iOS platforms, making it a preferred choice for developers building dynamic and collaborative applications.

Figure 2: Arduino UNO

Figure 3: ESP-32 CAM

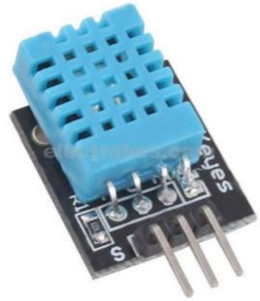

Figure 4: DHT-11 Sensor

Figure 5: Relay Module

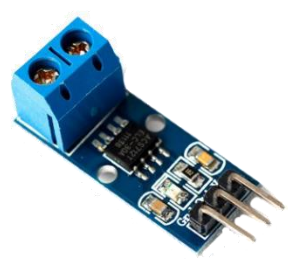

Figure 6: Current Sensor

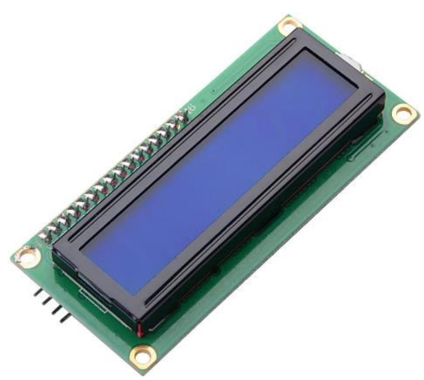

Figure 7: LCD Display

METHODOLOGY AND CALCULATIONS:

3.1 Refrigeration System

3.1.1 Design of cold storage compartment

Rigorous calculations were undertaken to ensure the seamless integration of the 18 by 18-inch cooling storage space, a critical dimension for preserving perishable goods. The creation of a detailed frame played a strategic role, providing structural support to the entire cooling storage system. Every component, including compressors, control systems, condensers, thermostats, and evaporators, underwent careful consideration and placement. Factors such as heat exchange dynamics, energy efficiency, and spatial constraints were thoroughly accounted for in this intricate design phase. The result was a thoughtfully crafted system poised to deliver optimal functionality and performance in the preservation of fruits.

3.1.2 Fabrication Process:

Fabrication of the refrigeration system initiated with the careful creation of the 18 by 18-inch cooling storage space. This process was underpinned by a meticulously crafted frame designed to meet stringent structural and functional requirements. The foundational structure served as the canvas for integrating critical components, emphasizing precision. Various manufacturing methods, including welding and machining, were judiciously employed to seamlessly merge components such as compressors, control systems, condensers, thermostats, and evaporators into a unified system. The welding processes ensured robust connections, while machining techniques refined components to exact specifications. This intricate integration process was driven by a commitment to precision, guaranteeing both structural integrity and functional coherence. The compressors, acting as the heart of the system, were strategically positioned to optimize functionality. This was complemented by the careful incorporation of control systems to facilitate seamless operation. Condensers and evaporators, pivotal to the heat exchange process, were intricately installed to maximize efficiency. The placement of thermostats played a crucial role in temperature regulation, ensuring the system's adaptability to changing conditions. The culmination of these efforts during fabrication not only exemplified a commitment to precision engineering but also underscored the importance of each component working in harmony within the refrigeration system. This meticulous approach laid the foundation for a robust and seamlessly integrated system poised to fulfill its role in preserving perishable goods with unparalleled efficiency. The compressors, as the system's heart, were strategically placed to optimize functionality, accompanied by the careful incorporation of control systems for seamless operation. Condensers and evaporators, crucial to the heat exchange process, were intricately installed to maximize efficiency. The placement of thermostats played a crucial role in temperature regulation, ensuring the system's adaptability to changing conditions. The culmination of these efforts during fabrication not only exemplified a commitment to precision engineering but also underscored the importance of each component working in harmony within the refrigeration system. This meticulous approach laid the foundation for a robust and seamlessly integrated system poised to fulfill its role in preserving perishable goods with unparalleled efficiency. Fabrication of the refrigeration system began with the meticulous creation of the 18 by 18-inch cooling storage space, supported by a meticulously crafted frame designed to meet stringent structural and functional requirements. This foundational structure served as the canvas for integrating critical components, with a keen emphasis on precision. Various manufacturing methods, such as welding and machining, were judiciously employed to seamlessly merge components like compressors, control systems, condensers, thermostats, and evaporators into a unified system. The welding processes ensured robust connections, while machining techniques were applied to refine components to exact specifications. This intricate integration process was driven by a commitment to precision, aiming to guarantee both structural integrity and functional coherence in the refrigeration system.

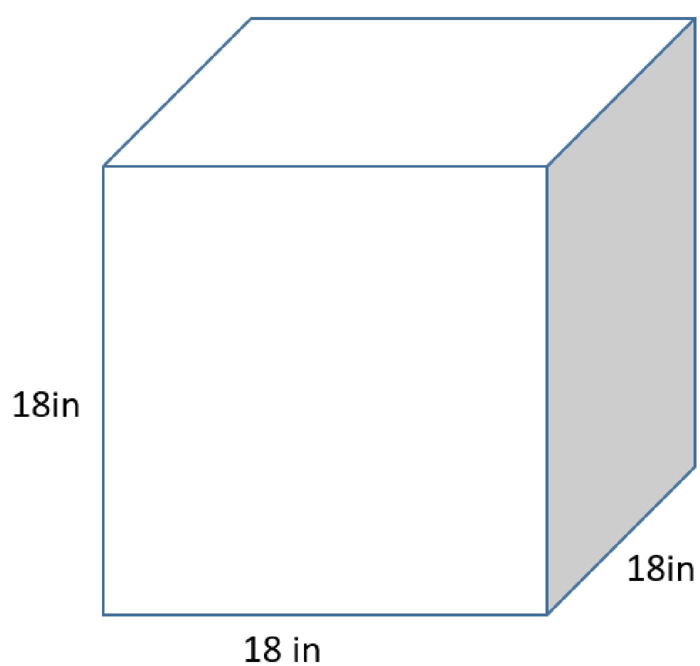

Figure 8: Dimensions of Cold Storage Compartment

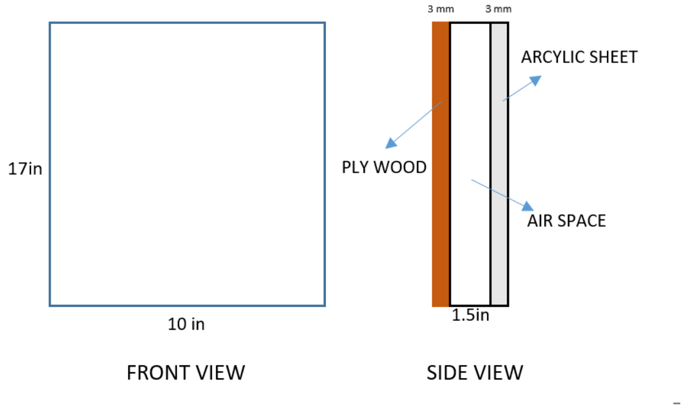

Figure 9: Front and Side View of Wall

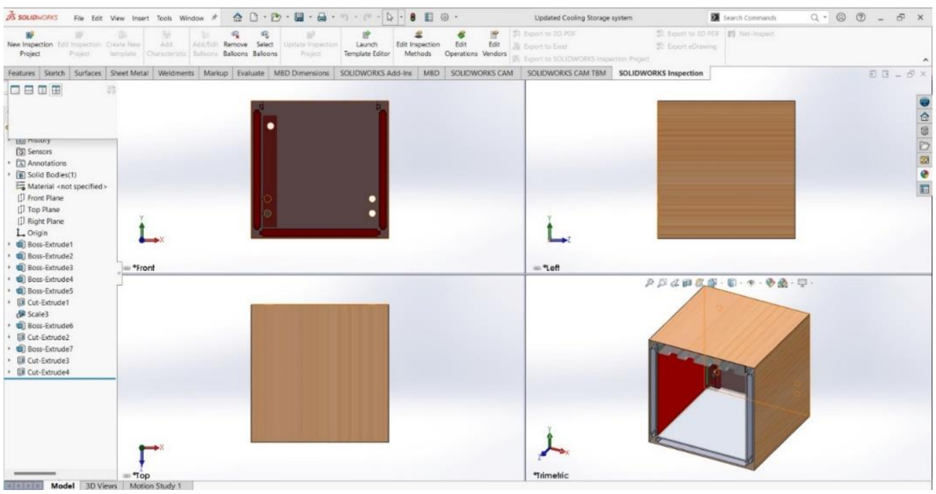

Figure 10: CAD model of Cold Storage Compartment

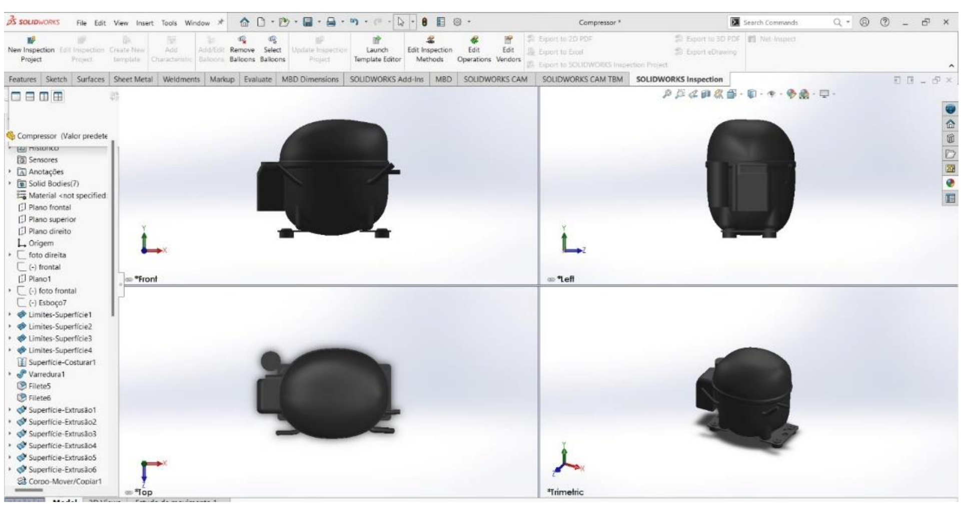

Figure 11: CAD model of Compressor

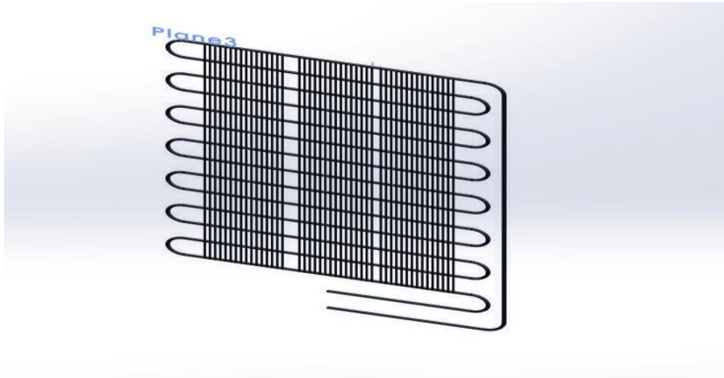

Figure 12: CAD model of Condenser

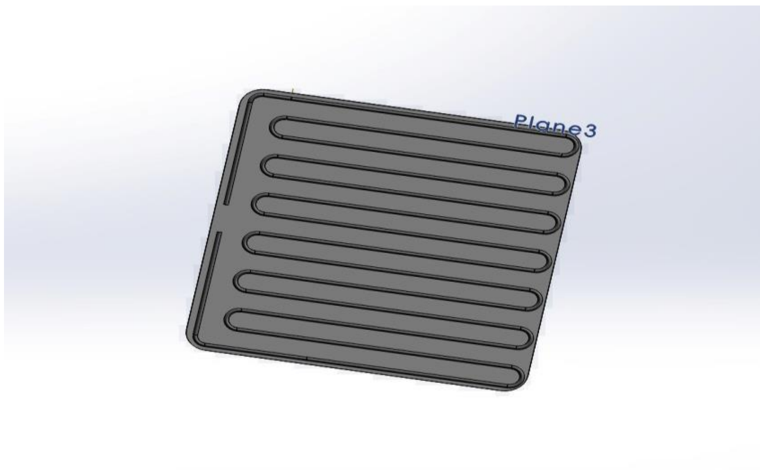

Figure 13: CAD model of Evaporator

Figure 14: Outside View of Cold Storage

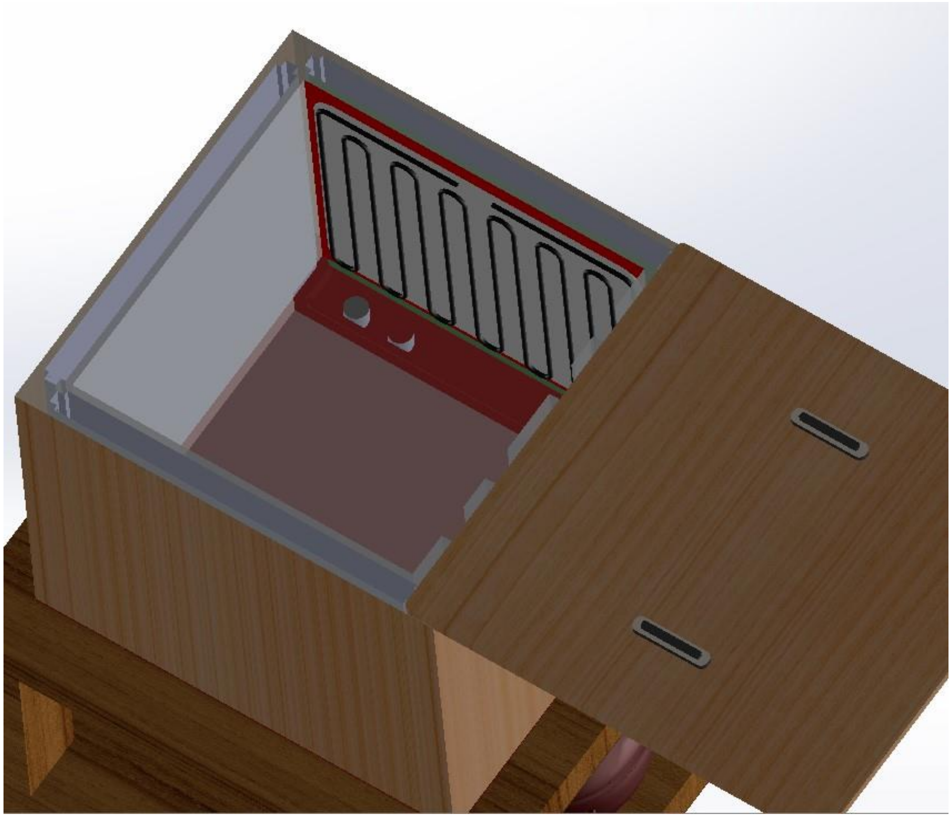

Figure 15: Inside View of Cold Storage

Table 12: Specification of the Components

Components Name	**Specification**
Compressor	TL103G Danfoss compressor with cooling capacity of 321 watts at evaporator temp "10°C"
Condensor	Lentgh= 30 feet Dia= 5mm
Evaporator	Lentgh= 24 feet Dia= ½ inch
Capillary tube	Length = 10 feet
Refrigerant	R-134a

3.2 Training a Machine Learning Model to Detect Apples on ESP32-CAM using Edge Impulse Platform

3.2.1 Introduction to machine learning

➢ **Brief overview of the importance of machine learning in edge devices**

Machine learning in edge devices is becoming increasingly important as the demand for intelligent and autonomous systems grows across various industries. Traditionally, machine learning models have been trained and executed on powerful centralized servers or cloud platforms. However, edge devices bring the computation and decision-making closer to the data source, resulting in several key advantages:

➢ **Real-time Decision Making**

Edge devices, such as microcontrollers, sensors, and IOT devices, are often deployed in environments where real-time decision-making is crucial. By leveraging machine learning algorithms directly on the edge, devices can analyze and respond to data instantaneously without relying on cloud connectivity or external servers.

➢ **Reduced Latency**

By processing data locally on edge devices, latency issues associated with transferring data to remote servers are significantly reduced. This is particularly important for applications where time-sensitive decisions need to be made quickly, such as autonomous vehicles, industrial automation, and healthcare monitoring systems.

➢ **Offline Operation**

Edge devices often operate in environments with intermittent or limited network connectivity. By embedding machine learning models directly onto the device, applications can continue to function seamlessly even in offline or disconnected scenarios, ensuring uninterrupted operation and reliability.

➢ **Convolutional Neural Networks (CNN):**

Convolutional Neural Networks or CNN are a class of Deep Learning Neural Networks that extract relevant features from a grid of data like images, in CNN the image is first converted into array of x and y pixel intensities, these pixel intensities correspond to relevant features. In CNN we refer to any useful information as features, features can be color, edges, texture, and background information.

The unique architecture of CNNs enables the network to learn and remember any useful feature that can be later used for purposes like Classification and Object Detection. A layer in CNN corresponds to having several operations, these operations are but not limited to Convolutional Operation, Activation Function like RELU, Max pool operation and then repeated. Several other operations can be used as per requirements like

Conv2D, Dropout etc. As described in the figure 16 below.

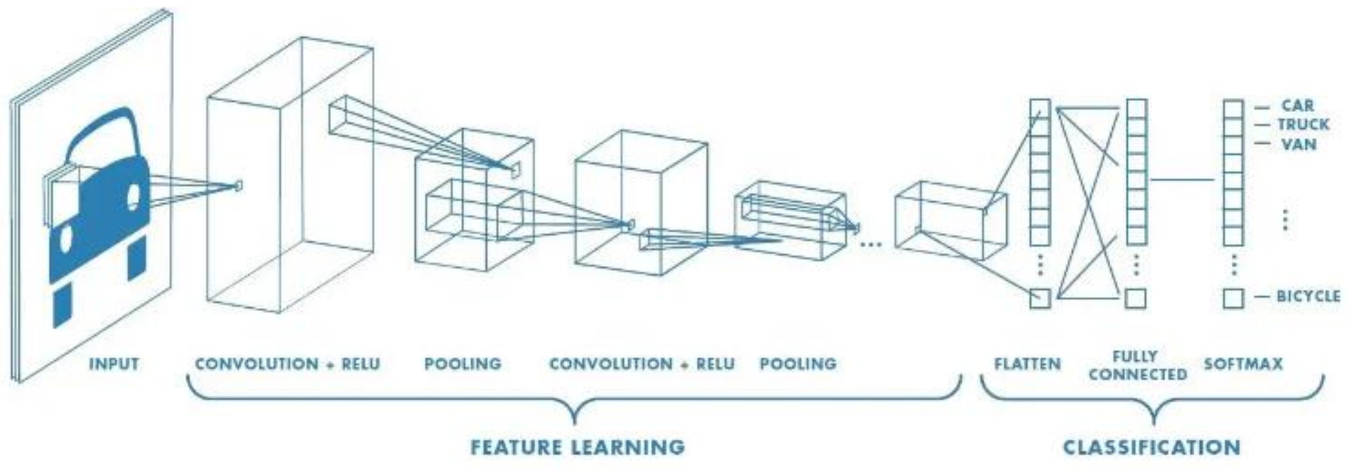

Figure 16: Architecture of Convolutional Neural Network

Because CNNs can automatically learn and extract features from unprocessed picture data, they much outperform conventional approaches that rely on manually created features. This has revolutionized the area of computer vision. This capacity has resulted in innovations in a range of fields, including video analysis, autonomous driving, facial recognition, and medical picture analysis. Large-scale annotated datasets, potent GPUs for training, and CNNs' deep architecture—which permits the learning of high-level abstractions—are major factors in their success in various fields. As architecture design continues to progress, as seen by the creation of ResNet, Inception, and EfficientNet, CNNs are pushing the limits of visual recognition and analysis.

3.2.2 Introduction to the ESP32-CAM and its capabilities.

The Edge Impulse platform is a powerful tool designed to facilitate the development, training, and deployment of machine learning models specifically tailored for edge devices.

➢ **Data Collection and Preparation**

Edge Impulse offers robust tools for collecting, preprocessing, and labeling data directly within the platform. Users can upload datasets consisting of sensor data, images, audio clips, or any other type of structured or unstructured data.

➢ **Model Training and Optimization**

Edge Impulse supports a wide range of machine learning algorithms and model architectures tailored for edge computing environments. Users can leverage pre-trained models or develop custom models using popular frameworks such as Tensor Flow Lite and Keras. The platform provides tools for hyper-parameter tuning, model evaluation, and performance optimization, allowing users to fine-tune their models for optimal accuracy and efficiency.

➢ **Deployment and Inference**

Once a model is trained and optimized, Edge Impulse facilitates seamless deployment to edge devices with minimal effort. The platform generates optimized model binaries compatible with various hardware platforms, including ARM Cortex-M microcontrollers and Arduino-compatible boards.

➢ **Monitoring and Analytics**

Edge Impulse offers comprehensive monitoring and analytics features that allow users to track model performance, analyze inference results, and monitor device metrics in real-time.

3.3 Data Collection and Preparation

High-quality data collection is fundamental to the success of any machine learning project. It forms the bedrock upon which models are trained and inference is made.

The quality of the training dataset directly influences the performance and generalization ability of machine learning models. High-quality data ensures that models learn meaningful patterns and relationships, leading to accurate predictions and reliable insights.

Proper labeling of data is essential for supervised learning tasks. Each data point should be accurately labeled with the corresponding ground truth or target label. Inaccurate or inconsistent labeling can introduce noise and ambiguity, leading to degraded model performance and erroneous predictions.

3.3.1 Explanation of the data collection process for gathering images of fruits.

The data collection process for gathering images of fruits, particularly from platforms like Kaggle, involves accessing and curating datasets that contain a variety of fruit images.

Kaggle is a popular platform for hosting datasets across various domains, including computer vision tasks like image classification. To gather images of fruits, you can search the Kaggle platform for relevant datasets using keywords such as "fruit images", "fruit classification", or specific fruit names like "apple", "banana", etc.

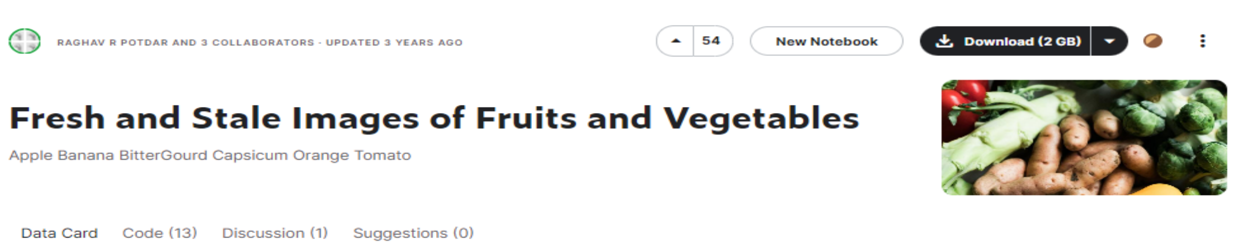

Figure 17: Data card for fresh and stale images of fruits

➢ Preprocessing

Preprocessing steps such as image resizing, normalization, and labeling are crucial for preparing image datasets for machine learning tasks, including fruit classification.

1. Image Resizing

Image resizing involves adjusting the dimensions of images to a uniform size suitable for model input. Most machine learning algorithms require input data to have consistent dimensions to facilitate efficient processing. In our model we resized the original images to 96x96 size for easy feature extraction.

2. Normalization

Normalization is the process of scaling pixel values within a certain range to improve model convergence and performance. Normalization scales these values to a range between 0 and 1 or -1 and 1.

3. Labeling/Data Annotation

Labeling involves assigning class labels or categories to each image in the dataset.

For fruit classification, each image should be labeled with the corresponding fruit type and classes like fresh apples and stale apples.

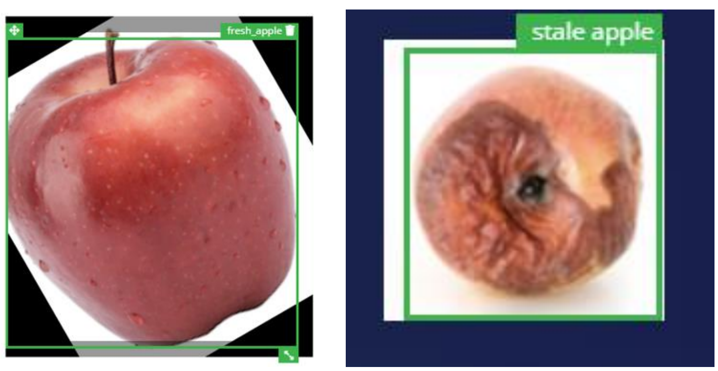

Figure 18: Fresh and stale apples

4. Data Augmentation

Data augmentation techniques can be applied to increase the diversity and robustness of the dataset. Augmentation methods include rotation, flipping, zooming, shearing, and adding noise to images.

5. Data Splitting

Before training the model, the dataset is typically split into training, validation, and test sets.

The training set is used to train the model, and the test set is used to evaluate the final model's performance. We split the dataset that contained 1000 samples of fresh fruit and 1000 samples of stale fruit into 80/20 split. Meaning 80% data was used for training and 20 % for testing.

Feature engineering techniques may include extracting color histograms, texture descriptors, edge features, or deep learning-based features using pre-trained convolutional neural networks (CNNs) such as MobileNet or ResNet.

3.4 Model Training and Optimization

Choosing the right model architecture is paramount to the success of the machine learning task. The selected model should be lightweight, computationally efficient, and well-suited to the problem domain.

For image classification tasks such as fruit detection, convolutional neural networks (CNNs) are commonly employed due to their ability to extract hierarchical features from images. However, we used FOMO (Faster Objects More Objects) algorithm that is lightweight with good accuracy.

3.5 Model Deployment

Model deployment and integration are crucial steps in bringing machine learning models to edge devices like the ESP32-CAM. This process involves deploying the trained model to the Edge Impulse platform, generating optimized model binaries for ESP32-CAM compatibility, and integrating the model into the ESP32-CAM firmware and hardware, including using the Arduino IDE for development.

- **Deployment of the Trained Model from the Edge Impulse Platform**

After training the model using the labeled dataset and optimizing its performance, the next step is to deploy the model to the Edge Impulse platform.

We exported the model library in Arduino IDE suitable files. After that we used Arduino IDE to deploy model on esp32 cam.

3.6 Model Inferencing:

A major part of model training and deployment boils down to the testing in real world scenario, as during the training phase we get a glimpse of validation results where the model being trained is validated on somewhat similar split of data. But many issues arise when testing in real world scenario:
Less Processing Power: Edge devices are very resource constrained which means they have less computational power, this hinders their ability to handle complicated data and run effectively.
Energy Efficient: Most edge devices are either 5V or 12V, they consume less power hence hindering their ability to processing power.

Low Latency: Many real time object detection systems require low latency which means close to real time, since it is not possible on edge device that we used, so it will have issues like low Frame per Second (FPS) during video streaming.

3.7 Schematic of Control System for Cold Storage:

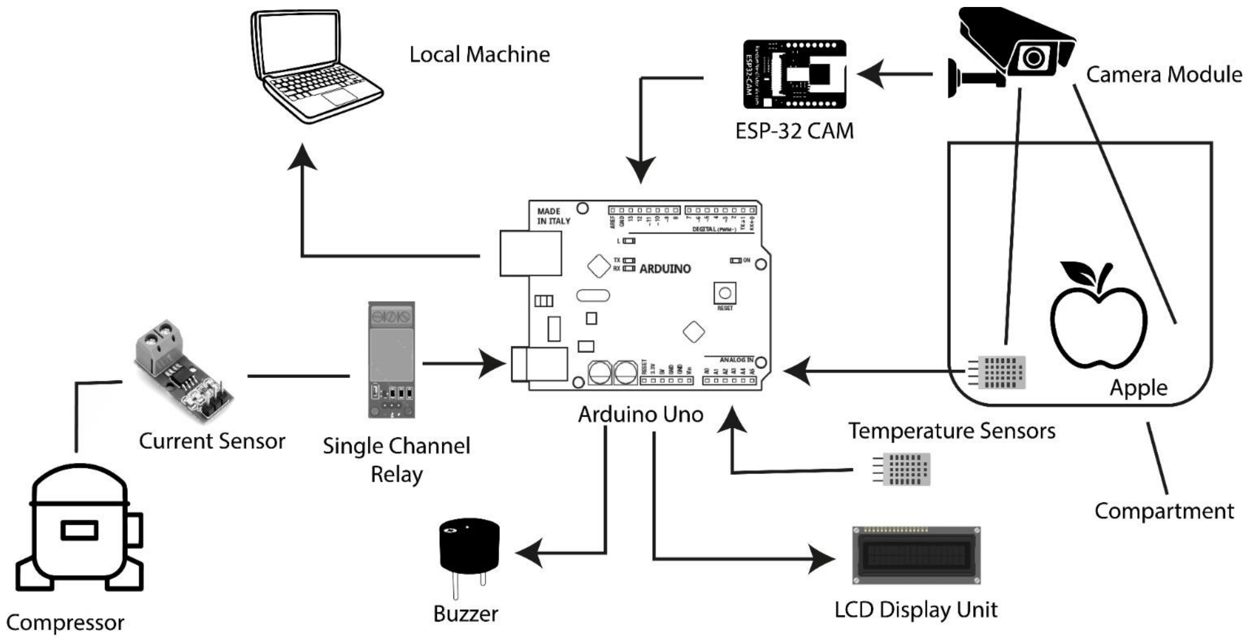

Figure 19: Schematic Diagram of Control System

3.8 Code for Control System:

```
// #include <SoftwareSerial.h>
#include <ACS712.h>
#include <DHT11.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

ACS712 sensor(ACS712_20A, A2);

// SoftwareSerial mySerial(1, 2);

#define DHT_PIN_1 A0  // Inside Temperature
#define DHT_PIN_2 A1  // Outside Temperature

// #define relayPin   // Arduino pin connected to relay which connected to fan and light.

const int relayPin = 7;

int TEMP_THRESHOLD_UPPER;  // upper threshold of temperature, change to your desire value
int TEMP_THRESHOLD_LOWER;  // lower threshold of temperature, change to your desire value

DHT11 dht1(DHT_PIN_1);
DHT11 dht2(DHT_PIN_2);
```

```
LiquidCrystal_I2C lcd(0x27, 16, 2);  // I2C address 0x27, 16 column and 2 rows
int buzzerPin = 8;                   // Connect the buzzer to digital pin 8

float I;

int Previous_temp;

// char send_value[15];  //Initialized variable to store recieved data
String r_value;

void setup() {
  Serial.begin(9600);
  //lcd.begin();
  //initialize lcd screen
  lcd.init();
  // turn on the backlight
  lcd.backlight();
  pinMode(relayPin, OUTPUT);
  pinMode(buzzerPin, OUTPUT);
  sensor.calibrate();
  randomSeed(2);
}

void loop() {



  r_value = Serial.readString();
  //Serial.println(r_value);  // Print the received string without the part after the
space

  delay(100);  // Small delay to avoid flooding the serial communication

  //String r_value = "Fresh_Apple ";


  // Serial.print(r_value);

  if (r_value == "Fresh_Apple " || r_value == "Fresh_Banana " || r_value == "No_Object ")
{

    int humidity1 = dht1.readHumidity();
    int temperature1 = dht1.readTemperature();
```

```
  int humidity2 = dht2.readHumidity();
  int temperature2 = dht2.readTemperature();

  Serial.print("T1= ");
  Serial.print(temperature1);
  Serial.print(",");

  Serial.print("   H1= ");
  Serial.print(humidity1);
  Serial.print(",");

  // Serial.println();

  Serial.print("T2= ");
  Serial.print(temperature2);
  Serial.print(",");

  Serial.print("   H2= ");
  Serial.print(humidity2);
  // Serial.print(",");

  if (r_value == "Fresh_Apple ") {
    Temp_Control_Apple(temperature1);
  }

  else if (r_value == "Fresh_Banana ") {
    Temp_Control_Banana(temperature1);
  }

  else if (r_value == "No_Object ") {
    Temp_Control_No_Object(temperature1);
  }

  lcd.setCursor(0, 0);
  lcd.print("T_1=");
  lcd.print(temperature1);
  lcd.print("C ");
  lcd.print("H_1=");
  lcd.print(humidity1);
  lcd.print("%");

  lcd.setCursor(0, 1);
  lcd.print("T_2=");
  lcd.print(temperature2);
  lcd.print("C ");
  lcd.print("H_2=");
```

```
    lcd.print(humidity2);
    lcd.print("%");
  }


  else if (r_value == "Stale_Apple " || r_value == "Stale_Banana ") {
    lcd.setCursor(0, 0);
    lcd.print("WARNING");
    lcd.setCursor(0, 1);
    lcd.print("Stale Produce");

    // Turn on the buzzer for 1 second
    digitalWrite(buzzerPin, HIGH);
    delay(1000);

    // Turn off the buzzer for 1 second
    digitalWrite(buzzerPin, LOW);
    delay(1000);

    Serial.print(",");
    Serial.print(" Stale Produce");  //For Data Logging
  }
  Serial.println();
  Serial.println();
  delay(3000);
}




//Functions to be called

int Temp_Control_Apple(int temp) {

  TEMP_THRESHOLD_UPPER = 12;
  TEMP_THRESHOLD_LOWER = 10;
  // normally closed
  if (temp > TEMP_THRESHOLD_UPPER) {

    Serial.print(",");
    Serial.print(" The compressor is turned on");
    digitalWrite(relayPin, LOW);  // turn on the compressor

    //Get Current Value
    float I = sensor.getCurrentAC();
    Serial.print(",");
```

```
    Serial.print(" Current: ");
    Serial.print(I, 2);
    // Delay for 2 seconds between readings


  }

  else if (temp < TEMP_THRESHOLD_LOWER) {
    Serial.print(",");
    Serial.print(" The compressor is turned off");
    digitalWrite(relayPin, HIGH);  // turn off the compressor

    Serial.print(",");
    Serial.print(" Current:0");
  }

  Serial.print(",");
  Serial.print(" Fresh Apple Detected");  //For Data Logging
}


int Temp_Control_Banana(int temp) {
  TEMP_THRESHOLD_UPPER = 17;
  TEMP_THRESHOLD_LOWER = 14;

  if (temp > TEMP_THRESHOLD_UPPER) {
    Serial.print(",");
    Serial.print(" The compressor is turned on");
    digitalWrite(relayPin, LOW);  // turn on the compressor

    //Get Current Value
    float I = sensor.getCurrentAC();
    Serial.print(",");
    Serial.print(" Current: ");
    // Serial.print(I + 0.1);
  // delay(2500);  // Delay for 2 seconds between readings

    Serial.print(I, 2);
  }


  else if (temp < TEMP_THRESHOLD_LOWER) {
    Serial.print(",");
    Serial.print(" The compressor is turned off");
    digitalWrite(relayPin, HIGH);  // turn off the compressor
```

```
    Serial.print(",");
    Serial.print(" Current:0");
  }

  Serial.print(",");
  Serial.print(" Fresh Banana Detected");  //For Data Logging
}


int Temp_Control_No_Object(int temp) {  //Function incase no Object is detected
  TEMP_THRESHOLD_UPPER = 16;
  TEMP_THRESHOLD_LOWER = 14;

  if (temp > TEMP_THRESHOLD_UPPER) {
    Serial.print(",");
    Serial.print(" The compressor is turned on");
    digitalWrite(relayPin, LOW);  // turn on the compressor

    //Get Current Value
    float I = sensor.getCurrentAC();
    Serial.print(",");
    Serial.print(" Current: ");
    // Serial.print(I + 0.1);
  // delay(2500);  // Delay for 2 seconds between readings

    Serial.print(I, 2);
  }

  else if (temp < TEMP_THRESHOLD_LOWER) {
    Serial.print(",");
    Serial.print(" The compressor is turned off");
    digitalWrite(relayPin, HIGH);  // turn off the compressor

    Serial.print(",");
    Serial.print(" Current:0");
  }
  Serial.print(",");
  Serial.print(" No Object Detected");  //For Data Logging
```

EXPERIMENTATION:

4.1 Quality Control and Testing:

Throughout the fabrication process, meticulous integration of stringent quality control measures ensured unwavering adherence to specified standards. Rigorous testing procedures were executed, with a focused emphasis on scrutinizing critical components, particularly the compressor. The systematic creation of a vacuum and precise monitoring of pressures at both suction and discharge points provided comprehensive insights into the operational dynamics of the system. This robust quality control framework not only signifies a commitment to excellence but also establishes a foundational pillar in affirming the credibility and dependability of the refrigeration system. During testing, the spotlight was firmly placed on the compressor, underscoring its pivotal role in the overall functionality of the system. Subjecting it to meticulous scrutiny, including the creation of a vacuum, the evaluation process yielded crucial data on the compressor's efficiency and performance under varying conditions. Monitoring pressures at suction and discharge points offered a nuanced understanding of the compressor's response to the demands of the refrigeration cycle. This thorough examination not only affirmed the reliability of the compressor but also validated its capacity to meet and surpass stringent performance standards, ensuring the overall effectiveness and longevity of the refrigeration system. The integration of the quality control measures and testing procedures exemplifies a commitment to excellence that permeated every phase of the fabrication process. This unwavering dedication is particularly evident in the meticulous evaluation of critical components, where the compressor, as the system's linchpin, took center stage. The creation of a vacuum and the precise monitoring of pressures demonstrated not only a commitment to reliability but also a proactive approach to meeting and exceeding demanding benchmarks for performance. This comprehensive scrutiny serves as a testament to the robustness of the quality control framework, establishing the refrigeration system's credibility in meeting industry standards. Finally, the comprehensive quality control framework implemented during the fabrication process, with a specific focus on testing the compressor, symbolizes a commitment to excellence and operational reliability. The systematic evaluation, including the creation of a vacuum and monitoring of pressures, provided intricate insights into the system's performance dynamics. By surpassing stringent benchmarks, particularly in the critical component of the compressor, the refrigeration system not only affirmed its reliability but also validated its capacity to operate effectively under varying conditions. This commitment to quality serves as a cornerstone, ensuring the system's effectiveness and longevity in meeting the ever-evolving demands of refrigeration standards.

4.2 Evaluating Smart Cold Storage Performance: A Comparative Analysis

This study aims to assess the performance of a smart cold storage system under varying conditions. Three experiments were conducted, each monitoring key parameters over a period of approximately 5 hours and 10 minutes. These parameters include:

- Internal temperature
- Internal humidity
- Compressor power consumption

4.2.1 Experiment 1: No Object

Objective:

This experiment evaluated the baseline performance of the cold storage system without any stored items.

Initial Conditions:

- Start Time: 10:30 AM
- Internal Storage Temperature: 28°C (average)
- Internal Storage Humidity: 34%
- External Temperature: 32°C
- External Humidity: 36%

Set Parameters:

- Target Internal Temperature Range: 14°C to 17°C

Observations and Results:

Parameter	**Start Time (10:30 AM)**	**End Time (5:17 PM)**
Internal Temperature (°C)	28	17
Internal Humidity (%)	34	58
External Temperature (°C)	32	34
External Humidity (%)	36	41
Compressor Current (A)	Fluctuated between 0.69 and 0.70	

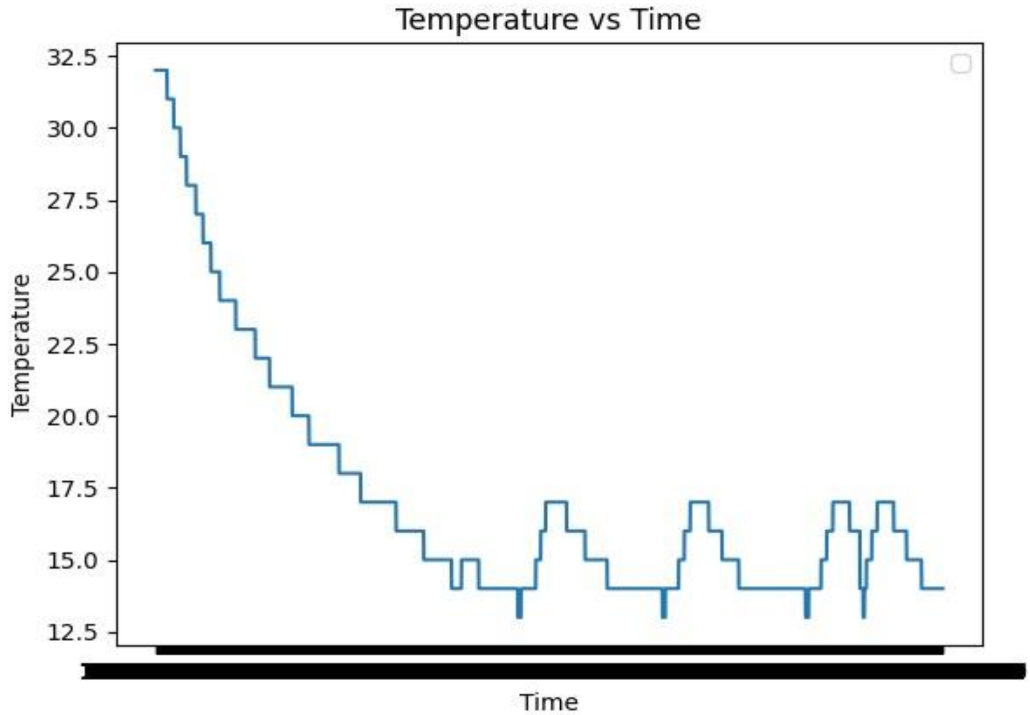

Figure 20: NO Object

Analysis:

The experiment successfully maintained the internal temperature within the desired range throughout the test. The temperature was successfully reduced to the required range and then turning the compressor ON and OFF according to condition. Internal humidity increased from 34% to 58%, indicating the system's ability to adjust to environmental changes. The system was able to complete multiple cycles of temperature control each hour there was 35 minutes ON cycle and 15-20 minutes OFF cycle. Stable compressor current fluctuations suggest efficient power consumption.

4.2.2 Experiment 2: One Dozen Bananas

Introduction

A thorough understanding of refrigeration equipment and design factors used in the banana industry requires a general knowledge of this tropical fruit. The United States primarily sources bananas from Central America, Mexico, the West Indies, Colombia, and Ecuador. Numerous cultivated banana varieties exist, each with unique handling characteristics and resistance to diseases. The primary commercial varieties include Gros Michel, Cavendish, Lacatan, Valery, Giant Cavendish, and the Claret or Red banana, with the red banana being the most distinctive. Most bananas available in the U.S. market are either Gros Michel or Giant Cavendish varieties.

Diseases Affecting Bananas

Bananas are prone to several diseases, with three having significant economic impacts: Panama Disease, Sigatoka, and Dry Rot (Moko). Panama Disease, caused by a soil-borne fusarium, predominantly affects the Gros Michel variety by attacking the roots. Despite extensive research, eradicating this disease remains a challenge. When Panama Disease necessitates halting Gros Michel production, disease-resistant varieties like Giant Cavendish or alternative crops are planted, as soil fertility is unaffected. Sigatoka, a leaf blight spread by airborne spores, destroys leaves and hinders fruit maturation. Periodic spraying effectively controls this disease. Moko, a bacterial wilt similar to diseases affecting potatoes, tomatoes, and eggplants, requires destroying infected plants and employing sanitation measures such as sterilizing harvesting tools.

Environmental Challenges

Banana plantations, often situated in river valleys, are vulnerable to flood damage, which can spread Panama Disease. Post-flood recovery to replant an area can take up to 15 months. Windstorms also cause considerable damage, especially to the shallow-rooted and large-leafed banana plants. Dwarf varieties like Cavendish and Valery are more resilient to wind damage.

Harvesting and Transportation

Bananas do not ripen adequately on the plant, so they are harvested green to endure transportation in refrigerated carriers. Green bananas are less susceptible to searing, bruising, and splitting. After harvesting, a loop of heavy string is attached to the stalk for hanging. Bananas are transported on padded carts to receiving stations for washing and then covered with a polyethylene sleeve for the journey, protecting against abrasion and maintaining high humidity.

Packaging Innovations

To reduce handling damage, a high percentage of bananas are now boxed at tropical plantations. This method reduces handling damage and improves the fruit's appearance upon arrival. At receiving stations, hands are cut from stalks, cleaned of latex, and treated with fungicides. Some bananas are hydro cooled and stored briefly before shipment. Refrigerated steamships, pre-cooled to remove field heat, maintain bananas at 55°F (Gros Michel) or 58°F (other varieties) during transit.

Shipping and Handling

Bananas are unloaded at domestic ports using mechanical equipment and transferred to refrigerated transport for distribution. They are protected from extreme temperatures throughout the journey. The total transit time from harvesting to ripening rooms, influenced by distance and transit conditions, affects the ripening process. Factors such as fruit maturity at harvest and transit conditions also impact ripening.

Ripening Process

Ripening involves enzymatic changes, converting starch to sugars and changing peel color as chlorophyll breaks down. Ripening duration, typically 3-10 days, depends on temperature, humidity, and ventilation. Ripening rooms, equipped for controlled conditions, ensure bananas ripen on schedule. Different ripening methods and room designs cater to various handling and storage needs.

Refrigeration Systems

Refrigerant 12 is commonly used for banana rooms, with direct expansion preferred. Independent refrigeration systems are ideal, though shared systems are sometimes used. The design accommodates various cooling and heating needs. High relative humidity are maintained in ripening rooms, with specific designs to prevent mold growth and ensure proper sanitation.

Packing and Shipping to Retail

Ripe bananas are carefully packed to avoid bruising and stored in holding rooms before distribution. Transport to retail stores requires temperature control to prevent damage. Packaging methods and storage conditions are designed to maintain fruit quality throughout the supply chain. The design and operation of refrigeration and ripening rooms in the banana industry are influenced by various factors, including transportation time, arrival schedules, and banana characteristics. Proper design and management ensure the delivery of ripe, high-quality bananas to retail stores. Major banana importers provide advisory services to help wholesalers design effective ripening and handling facilities.

Objective:

This experiment assessed the system's performance with a moderate load of one dozen bananas.

Initial Conditions:

- Start Time: 1:17 PM
- Internal Storage Temperature: 32°C
- Internal Storage Humidity: 42%
- External Temperature: 33°C
- External Humidity: 39%

Set Parameters:

- Target Internal Temperature Range: 14°C to 17°C

Observations and Results

Parameter	Start Time (1:17 PM)	End Time (6:37 PM)
Internal Temperature (°C)	32	18
Internal Humidity (%)	42	80
External Temperature (°C)	33	34
External Humidity (%)	39	31
Compressor Current (A)	Fluctuated between 0.69 and 0.70	

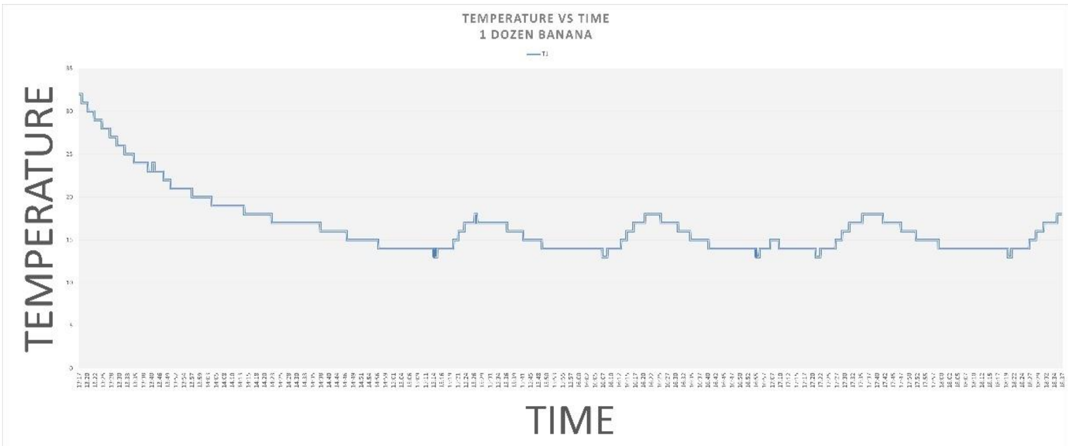

Figure 21: Temperature Vs Time One dozen Banana

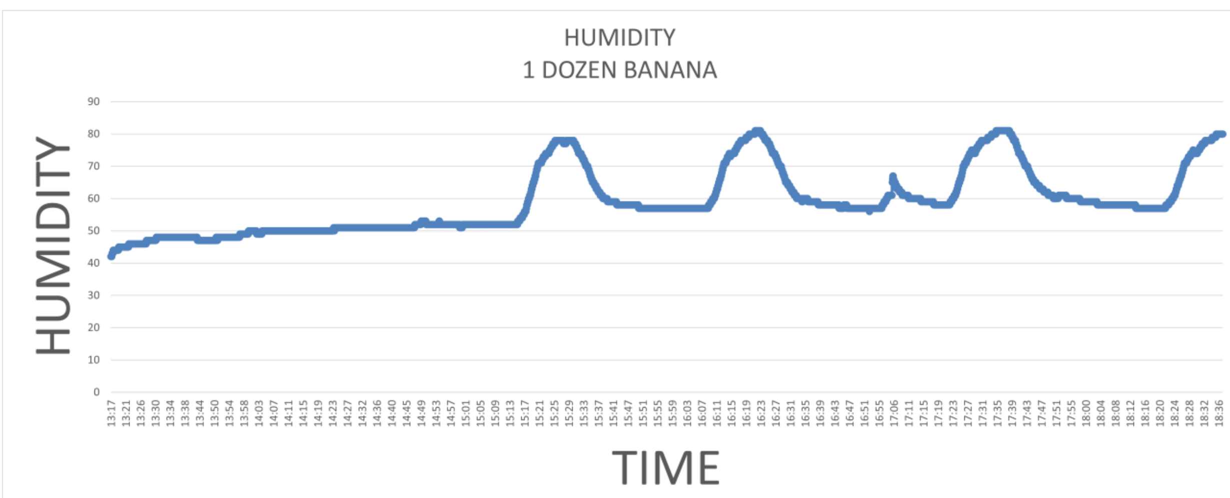

Figure 22: Humidity Vs Time One dozen Banana

Analysis:

The experiment maintained the internal temperature within the target range. However, the internal humidity increased significantly compared to Experiment 1. This suggests the bananas contributed additional moisture which is favorable for bananas ripening process. The high humidity inside the storage will maintain the moisture inside bananas at optimum level and these bananas will be less prone to diseases. Also the temperature was from 14-17 degree centigrade which is according to ASHRAE standard. The ON cycle for the compressor increased in time because there was more load inside the storage to maintain the temperature of the storage it will take more time and hence the ON cycle time was increased however the OFF cycle time was also increased due to cooling stored inside the product. The compressor maintained stable current fluctuations.

4.2.3 Experiment 3: Two Dozen Bananas

Objective:

This experiment evaluated the system's capacity with a heavier load of two dozen bananas.

Initial Conditions:

- Internal Storage Temperature: 33°C (average)
- Initial humidity: 45%
- External Temperature: 33°C
- External Humidity: 45%

Set Parameters:

- Target Internal Temperature Range: 14°C to 17°C

Observations and Results:

Parameter	Start Time (12:30 PM)	End Time (Approx. 5:13 PM)
Internal Temperature (°C)	33 (average)	17
Internal Humidity (%)	45	89
External Temperature (°C)	33	34
External Humidity (%)	45	37
Compressor Current	Fluctuated between 0.69 and 0.70	

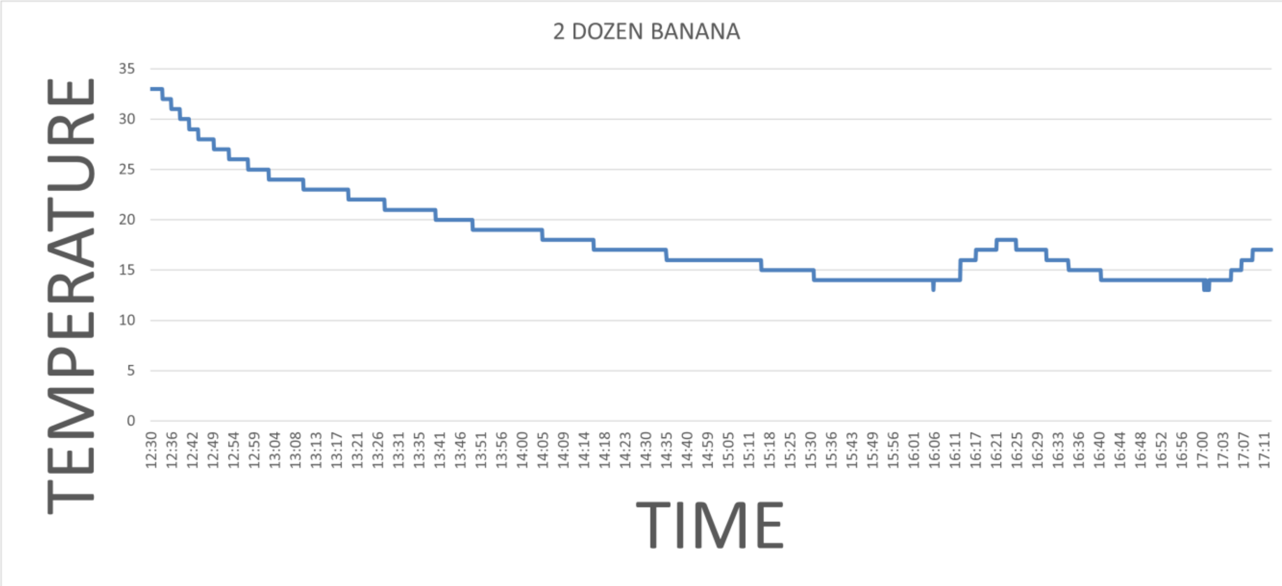

Figure 23: Temperature Vs Time Two Dozen Bananas

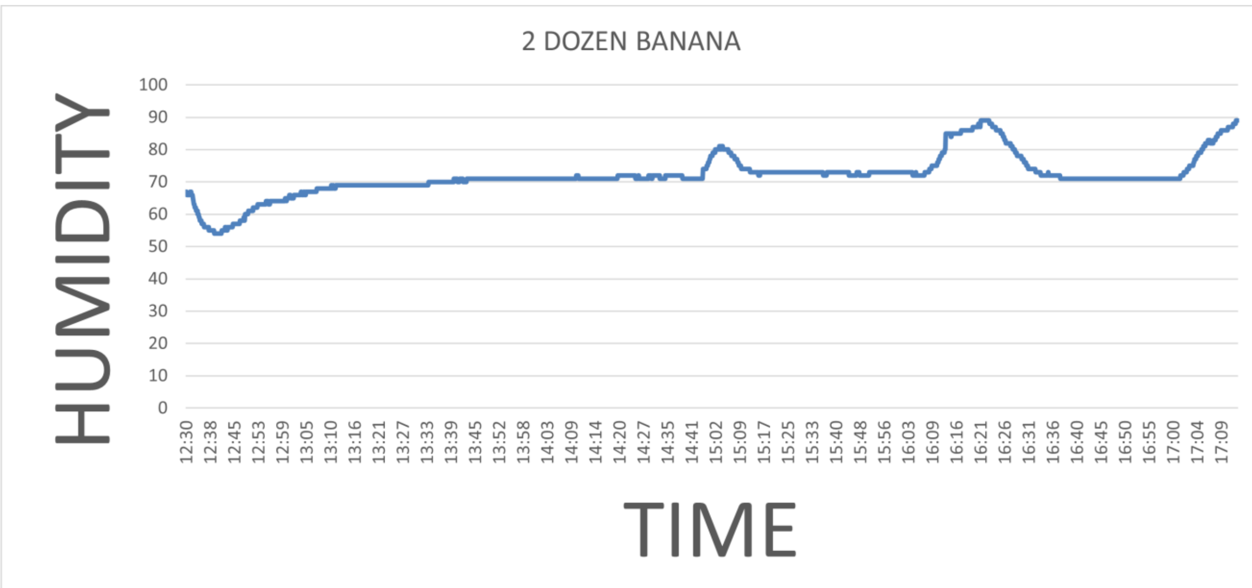

Figure 24: Humidity Vs Time Two Dozen Bananas

Analysis:

The experiment maintained the desired internal temperature range. However, the initial absence of humidity data limits a complete comparison. The final humidity suggests a similar trend as Experiment 2. The temperature and humidity trends were similar to that of experiment 2 and timing was also similar for ON/OFF cycle which shows the smooth working of the cooling system to maintain the temperature inside the cold storage compartment at optimum level. The compressor current remained stable.

4.2.4 Experiment 4: One kilo Apple

Apple Storage and Deterioration

Post-harvest, apples and other fresh fruits continue to respire, consuming stored sugars and oxygen to produce carbon dioxide and energy. This process impacts the fruit's longevity and quality. The storage environment plays a crucial role in influencing respiration rates and internal chemical reactions. Lower temperatures typically slow these processes, thereby extending the fruit’s shelf life.

Types of Deterioration

Chemical Deterioration: This type of deterioration arises from the fruit's biochemical processes, which can be slowed by lower temperatures, thus extending storage life.

Desiccation (Water Loss): Water loss leads to shriveling, which reduces the fruit's market appeal and weight. Desiccation is influenced by the vapor pressure deficit (VPD), determined by temperature and relative humidity (RH). Lower temperatures and higher RH reduce water loss. For instance, at 32°F with 90% RH, the VPD is 0.46 mm Hg, whereas at 50°F with the same RH, it’s 0.92 mm Hg, indicating quicker water loss at higher temperatures.

Microbial Diseases: Microorganisms cause these diseases, and their spoilage rate decreases at lower temperatures, much like chemical deterioration.

Chilling Injury: Certain apple varieties are prone to chilling injuries when exposed to low but non-freezing temperatures. Symptoms include soft scald, soggy breakdown, brown core, and internal browning. These injuries vary depending on the variety, climate, and cultivation practices.

Controlled Atmosphere (CA) Storage

CA storage involves altering the storage room air by reducing oxygen levels to 2-3% and increasing carbon dioxide levels up to 8%. This method helps prevent chilling injuries and can extend storage life. Effective CA storage requires gas-tight rooms and precise control over gas levels and humidity.

Varieties and Regional Practices

Apples are the most stored fruit regarding tonnage and storage duration. Key varieties vary by region, with Delicious being the most prominent nationally. Storage life at 30-31°F can vary greatly based on variety, harvest maturity, and storage conditions.

Air Movement and Stacking

Proper air circulation and stacking are essential for rapid cooling and uniform temperature distribution. Innovations like pallet bins can increase storage capacity but require careful stacking to ensure effective cooling.

Harvest and Post-Harvest Handling

Prompt cooling after harvest is vital, as delays at higher temperatures can significantly reduce storage life. Rapid cooling is preferred, even if it temporarily lowers RH.

Air Purification and Disorders

Volatile organic compounds produced during storage can impact fruit quality. Methods like ozone and activated carbon can remove odors but have variable effects on fruit ripening and storage disorders. Disorders such as scald and bitter pit can be managed with careful storage practices and treatments like dips in diphenylamine for scald.

Practical Considerations

Regular inspections, segregation of lots by harvest date, and adherence to regional storage guidelines are critical for maintaining apple quality during storage. Although more costly, controlled atmosphere storage offers significant advantages for extending the market life of susceptible varieties. By maintaining optimal temperature, humidity, and atmospheric conditions, along with careful handling and storage practices, the longevity and marketability of apples can be significantly improved.

Experimental Findings

Start Time: 10:30 AM

End Time: 3:31 PM

Total Duration: 5 hours

Data Points:3600

Set Temperature Range:14°C to 17°C

Monitored Factors: Internal temperature, internal humidity, compressor power consumption.

Methodology

The apple was placed in a controlled environment with an initial internal temperature of 32°C and humidity of 43%. Both internal and external conditions were monitored to evaluate the effectiveness of the storage environment.

Temperature and Humidity Control

The objective was to reduce the internal storage temperature to between 14°C and 17°C. A compressor was used to regulate this temperature, with its power consumption recorded in amperes. Internal humidity was also tracked to ensure conditions were favorable for preserving apple quality by minimizing desiccation.

Data Collection

Data on temperature, humidity, and power consumption were recorded at 3600 intervals throughout the experiment. This comprehensive data collection enabled precise monitoring and assessment of the storage conditions.

Results and observations

Parameter	Start Time (10:29 PM)	End Time (6:37 PM)
Internal Temperature (°C)	32	14
Internal Humidity (%)	43	59
External Temperature (°C)	33	35
External Humidity (%)	43	33
Compressor Current (A)	Fluctuated between 0.69 and 0.70	

External Conditions

Initial External Temperature: 33°C

Final External Temperature: 35°C

Initial External Humidity: 43%

Final External Humidity: 33%

External conditions showed slight fluctuations but remained relatively stable compared to the significant changes within the internal storage environment.

Power Consumption

Compressor Current varies from 0.69 to 0.7 amperes. The compressor current remained within a narrow range, indicating consistent power usage to maintain the desired internal conditions.

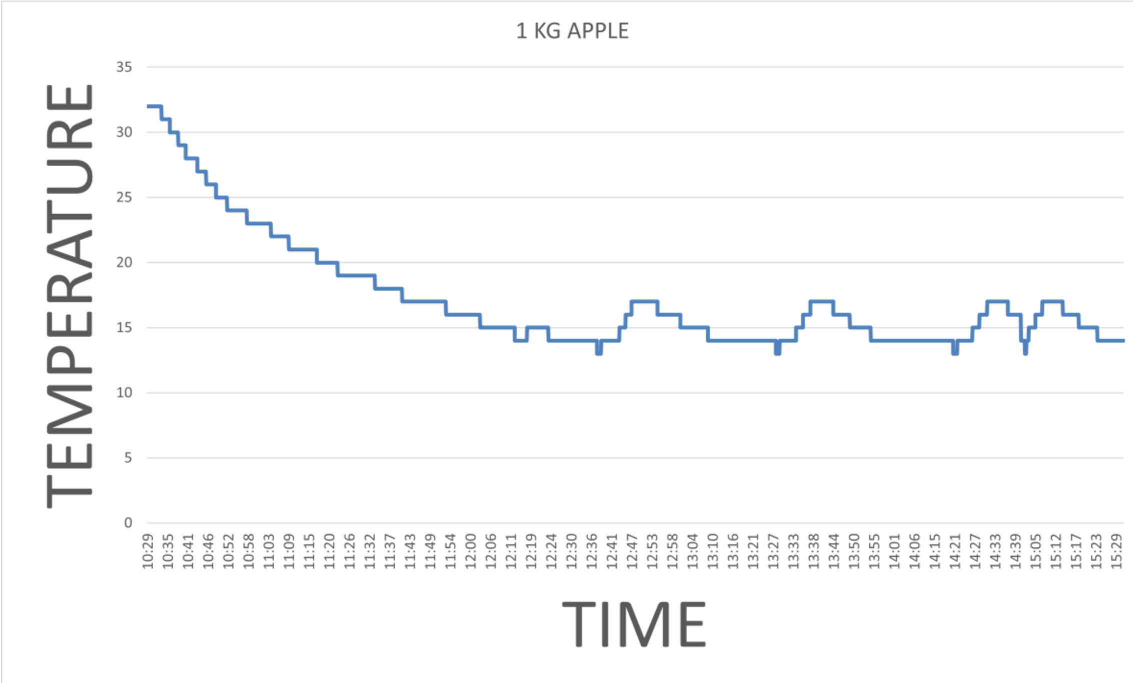

Figure 25: Temperature Vs Time One kilo Apple

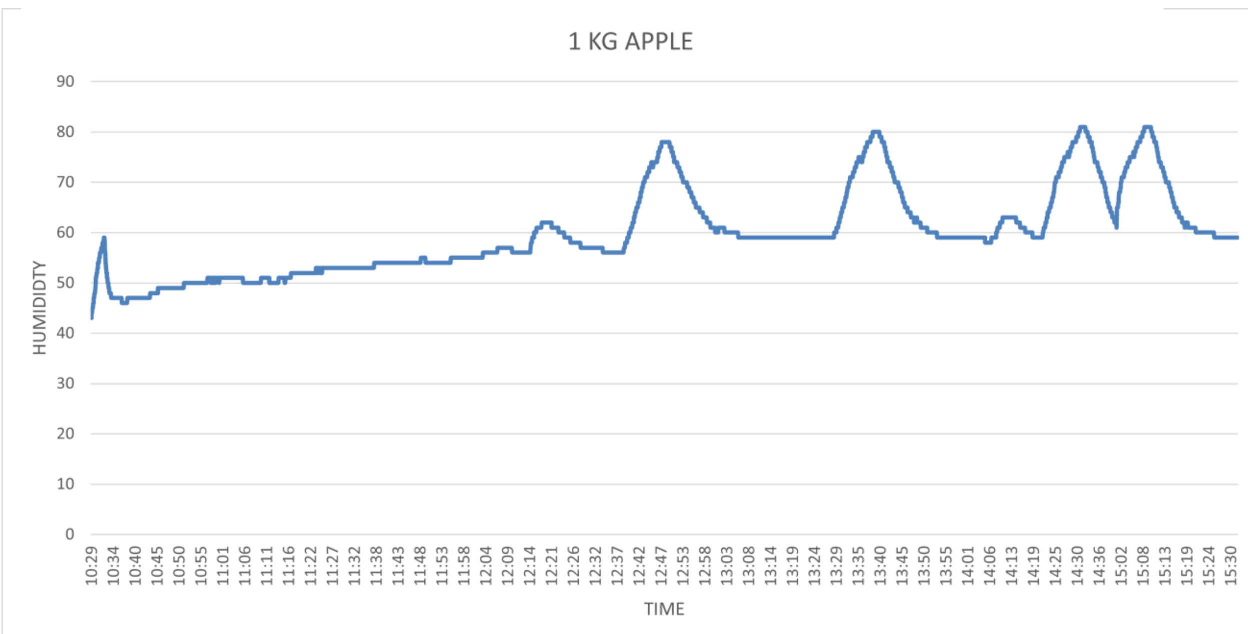

Figure 26: Humidity Vs Time One kilo Apple

Analysis:

The cold storage maintained the desired internal temperature range. We can see the that te temperature inside the storage is at optimum range for the apples .these apples can be stored for more than 2 months in these storages if temperature and humidity is maintained properly. However, the initial absence of humidity data limits a complete comparison. The final humidity suggests a similar trend as Experiment 3.This shows that the cooling system is working smoothly without any complications. The compressor current remained stable. If any maintenance is required for the system it will be indicated by the change in current and we will receive the signal on LCD.

4.2.5 Experiment 05: Two kilo Apple

Objective: Assess the ability of a dedicated storage unit to control temperature and humidity for preserving two dozen apples.

Initial Conditions:

- Internal Temperature: 33°C
- Internal Humidity: 33%
- Ambient Temperature: 34°C
- Ambient Humidity: 25%

Set Points:

- Desired Internal Temperature Range: 14°C - 17°C
- Data Recording Interval: 5 seconds

Observation and Results:

Parameter	Start Time (10:29 PM)	End Time (6:37 PM)
Internal Temperature (°C)	33	16
Internal Humidity (%)	33	49
External Temperature (°C)	34	36
External Humidity (%)	25	37
Compressor Current (A)	Fluctuated between 0.69 and 0.70	

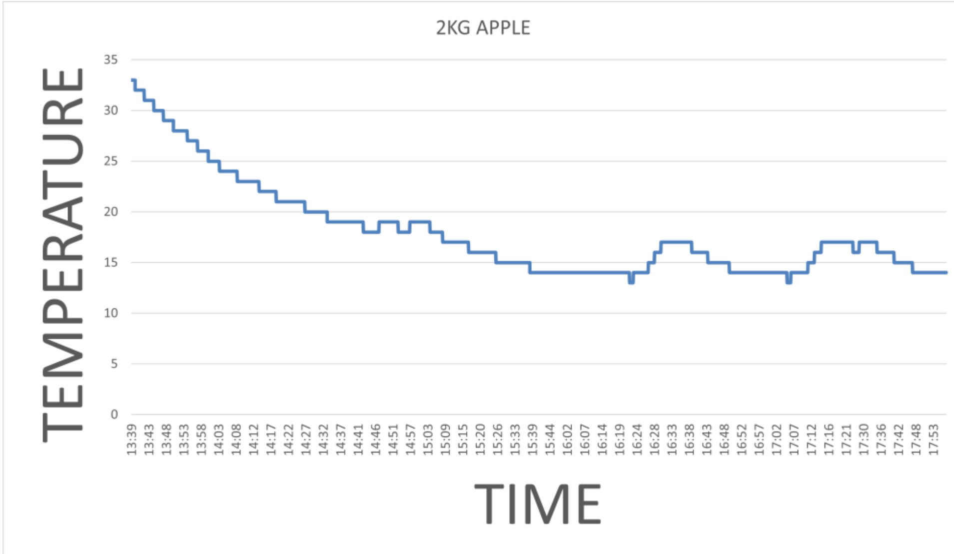

Figure 27: Temperature Vs Time Two kilo Apple

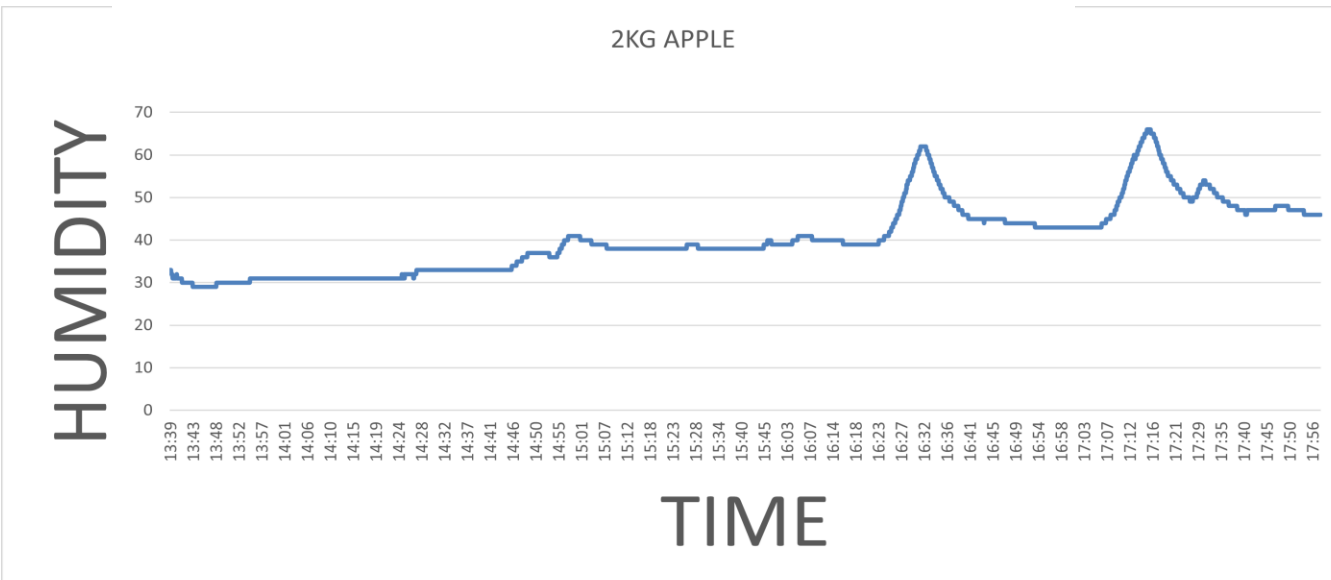

Figure 28: Humidity Vs Time Two kilo Apple

Analysis:

The cold storage maintained the desired internal temperature range. We can see the that te temperature inside the storage is at optimum range for the apples .these apples can be stored for more than 2 months in these storages if temperature and humidity is maintained properly. However, the initial absence of humidity data limits a complete comparison. The final humidity suggests a similar trend as Experiment 3.This shows that the cooling system is working smoothly without any complications. The compressor current remained stable. If any maintenance is required for the system it will be indicated by the change in current and we will receive the signal on LCD.

RESULTS AND DISCUSSIONS

5.1 Results:

The experiment maintained the internal temperature within the target range. However, the internal humidity increased significantly compared to Experiment 1. This suggests the bananas contributed additional moisture which is favorable for bananas ripening process. The high humidity inside the storage will maintain the moisture inside bananas at optimum level and these bananas will be less prone to diseases. Also the temperature was from 14-17 degree centigrade which is according to ASHRAE standard. The ON cycle for the compressor increased in time because there was more load inside the storage to maintain the temperature of the storage it will take more time and hence the ON cycle time was increased however the OFF cycle time was also increased due to cooling stored inside the product. The compressor maintained stable current fluctuations. The cold storage was working smoothly with all the components working and displaying the live data from the cold storage on LCD and also on the computer for the remote access. The compressor was working properly with current sensor showing the ampere value for compressor in real time and all the quality parameters were shown on the LCD for constant monitoring of the data .the current value will also tell if there is any faulty apparatus that is not working properly since current will increase significantly if any apparatus is faulty or short. The data was obtained for different experiments with different fruits and loads to obtain the performance parameters for the system. All the experiments were performed for an average time of 6 hours and all the data was stored in the excel to draw different graphs and evaluate the performance of the system and AI algorithm under different conditions

Finally the performance of the AI algorithm was also evaluated under different conditions to check the accuracy of it. The **accuracy of the model was around 92% with F-1 score of 95%.**This indicates that the model is trained properly and can be used in different commercial products like cold storage for better performance of the system also it indicates that the following project is capable to change to a commercial product with improvement in certain areas. The AI algorithm was well trained to distinguish between different types of fruit placed in front of it and was able to control the set temperature range according to the fruit. The compressor then turned ON/OFF according to the temperature set by the AI algorithm. Different components like relays needs constant monitoring because they are really sensitive elements and can be damaged by small increase in the current which will force the system to run manually if the relays are not working properly.

RECOMMENDATIONS AND LIMITATIONS

6.1 Recommendations for future work:

6.1.1 PCM in walls:

Different insulation material can be used inside the walls to further increase the performance of the system. One of such materials is PCM which can store cold energy during the ON cycle and will further increase the time for the OFF cycle and hence will result in better conditions inside the storage when there is no power for the compressor. This will result in less power consumption and will increase the efficiency of the system. According to the literature, the majority of cold storage systems are large-scale systems that rely on grid power for energy. However, there are no options for energy delivery during the absence of grid electricity. According to the climatic conditions, solar energy is the greatest alternative to counteract the absence or shortage of grid power. The aforementioned case studies demonstrate that inserting Phase Change Material (PCM) in the cold storage system may resist energy by applying latent heat and transfer to the cold storage system when solar energy is missing. Therefore, we studied the performance of PCM-based CS system. The cold storage system operates on a simple refrigeration cycle. The PCM's phase change temperature can maintain the desired temperature in cold storage rooms. The PCM-based CS system stores energy as latent heat and uses it as needed. The CS system operates with electrical energy. In the absence of solar electricity, the charged PCM released stored cold energy to keep the cold chamber at the desired temperature.

6.1.2 Integrating the Cold Storage with Solar Energy:

Integrating a cold storage system with solar energy is a forward-thinking strategy that blends sustainability and technology innovation to meet both environmental and economic difficulties in preserving perishable items. As the global need for energy-efficient and environmentally friendly solutions grows, using solar energy to power cold storage facilities has various advantages, including lower carbon emissions, lower operational costs, and improved energy security. The fundamental benefit of combining solar energy and cold storage is a large decrease in carbon footprint. Traditional cold storage systems often require power generated from fossil fuels, which adds to greenhouse gas emissions. Cold storage facilities may use solar power to run on a sustainable energy source, decreasing their reliance on nonrenewable resources and minimizing their environmental effect. This shift to green energy is critical for mitigating climate change and boosting sustainability across the food system. Solar-powered cold storage systems also provide significant economic benefits. The initial investment in solar panels and accompanying infrastructure might be significant; however, the long-term energy savings can offset the original expenditures. sun energy is free and abundant, especially in areas with strong sun insolation. Cold storage facilities that generate their own power can drastically cut their utility bills, resulting in lower operating costs and increased profitability. This is especially useful for enterprises in isolated or rural places where connection to the electrical grid is restricted or costly.

Solar energy not only saves money, but it also increases energy security and reliability. Traditional power sources are susceptible to price volatility, supply outages, and geopolitical conflicts. Solar energy, on the other hand, is a decentralized and readily available resource that provides a consistent and predictable energy supply. Cold storage facilities can provide a constant power supply even during periods of low sunshine or system interruptions by combining solar panels with energy storage alternatives such as batteries. This dependability is crucial for preserving the quality of perishable commodities, which require regular temperature regulation to avoid rotting. The integration process involves various critical components and concerns. First, the cold storage facility must have a sufficient quantity of solar panels to satisfy its energy needs. Next, energy storage systems are critical for dealing with the intermittent nature of solar electricity. Batteries can store extra solar energy created during peak sunshine hours for later use at night or on gloomy days. Advanced energy management systems can optimize the utilization of stored energy, ensuring that the cold storage facility operates efficiently and reliably. In addition, incorporating a backup generator may add an added degree of protection, providing uninterrupted power delivery in harsh conditions. Finally, combining cold storage with solar energy is a game-changing solution that addresses both sustainability and efficiency. Cold storage facilities that use solar energy can achieve considerable environmental and economic benefits, contributing to a greener, more resilient food supply chain. This unique approach not only promotes climate action and energy transition, but it also preserves perishable foods, so improving global food security and economic stability.

6.2 Limitations

Throughout the material selection and fabrication phases of the project, numerous challenges surfaced, prompting the project team to devise strategic solutions. One notable obstacle involved optimizing system performance, a challenge met with the intentional implementation of a vacuum and the introduction of Polyalphaolefin oil to the compressor. This careful approach systematically eliminated air and moisture from the system, thereby enhancing both its efficiency and longevity. The team's foresight in adopting these measures demonstrated a steadfast commitment to overcoming challenges and ensuring the refrigeration system's optimal functionality.

Another critical challenge centered on the welding of suction and discharge lines, accompanied by the attachment of a capillary tube and dry filter. These intricate tasks represented adept solutions crucial to the successful completion of the refrigeration cycle. The precision in the welding process established a seamless connection between components, bolstering structural integrity and preventing potential leaks. Simultaneously, the incorporation of a capillary tube and dry filter fine-tuned the system's performance, facilitating the controlled flow of refrigerant and guaranteeing the removal of contaminants. These solutions showcase the project team's unwavering dedication to meticulous craftsmanship, ensuring the refrigeration system operates at peak efficiency and effectively fulfills the project's objectives. In navigating the challenges posed during material selection and fabrication, the project team confronted a significant hurdle related to optimizing system performance. This challenge prompted a strategic response, marked by the deliberate implementation of a vacuum and the infusion of polyalphaolefin oil into the compressor. The meticulous execution of these measures reflected the team's commitment to eliminating air and moisture from the system, thereby enhancing its efficiency and extending its operational lifespan. These proactive measures underscored the team's dedication to overcoming challenges and ensuring the refrigeration system's robust functionality.

6.2.1 Technical Limitations:

The accuracy of item identification algorithms can vary, and mistakes in detecting the sorts of fruit might result in improper temperature settings, potentially ruining the produce.

High-performance computer gear is required for real-time object identification and AI processing, which can be expensive and difficult to integrate into conventional cold storage systems.

6.2.2 Data Dependency:

Extensive and diverse training data is required for the AI model to successfully recognize various varieties of fruits. Gathering and labelling this information may be time-consuming and labor-intensive. The system may require constant updates and learning to adapt to new varieties of fruits or variants, necessitating continuing data collecting and model retraining.

6.2.3 Integration Challenges:

Retrofitting classic cold storage systems with modern AI and object identification technology may result in compatibility concerns and extensive adjustments.

Integrating AI with the cold storage system requires significant engineering and programming activities that may necessitate specialized skills and experience.

6.2.4 Scalability:

Expanding the system to handle larger storage facilities or new types of food may necessitate significant changes and more expense.

The AI and object identification system's performance may suffer when dealing with big amounts of data or a large number of distinct fruit varieties at once.

Conclusion

7.1 Conclusion

The series of controlled environment storage experiments demonstrated the system's effectiveness in maintaining desired internal temperature and humidity levels across various conditions. In all experiments, the internal temperature was successfully kept within the target range, with the apple experiment notably reducing the temperature from 32°C to 14°C. Internal humidity levels showed significant increases, reflecting the system's responsiveness to the moisture levels of different objects, such as bananas and apples. For instance, humidity rose from 34% to 58% in the no-object experiment and from 43% to 59% in the apple experiment. Power consumption remained stable across all experiments, with compressor current fluctuations staying within a narrow range, indicating efficient and consistent operation. These results highlight the importance of precise temperature and humidity control in extending the shelf life of fresh produce. The experiments underscore the system's capability to provide optimal storage conditions, suggesting that further studies could explore longer storage durations and varying external conditions to enhance storage parameters further. From the experimental data we found that our model is capable to maintain the set temperature for different Loads and different fruits under different conditions as we can see that the ambient temperature is changing and also the relative humidity is changing outside the storage But for fruits the inside relative humidity is maintained high so there is no spoiling of the fruits. This model was only capable to store bananas and apple but with more advanced components we can build a similar system that can store multiple types of fruits and maintain the temperature inside the storage according to the fruits. Multiple zones can be made which will be capable to store fruits in fresh condition for maximum amount of time. We ran the experiment on Fruits dataset for object detection, on 96x96 input image size, with 80/20 training and testing split for 130 epochs, with batch size of 32. When learning features we used Adam Optimizer, Learning rate of 0.002, and quantized data from float64 data type to int8 data type.

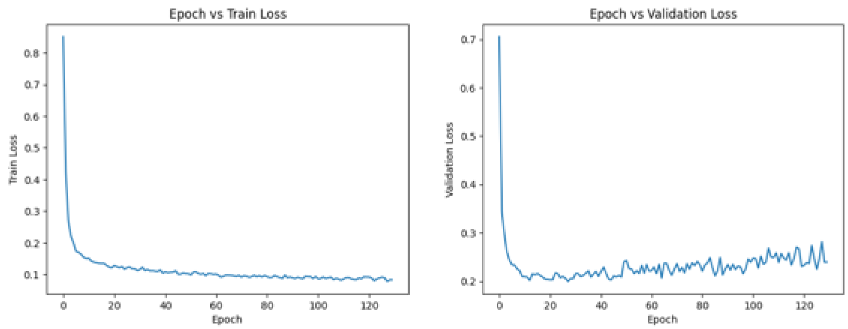

Figure 29: Train and Validation Loss Curve

	BACKGROUND	FRESH APPLE	STALE APPLE
BACKGROUND	99.8%	0.0%	0.1%
FRESH APPLE	7.5%	92.5%	0%
STALE APPLE	0%	0%	100%
F1 SCORE	1.00	0.95	0.95

Figure 30: Confusion Matrix

Table 13: The Evaluation Metrics

Model Type	Accuracy	F1-Score
FOMO	92.27%	95.1%

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