# Development and evaluation of semi-automatic controlled atmosphere storage facility for calamansi (*Citrofortunella microcarpa*)

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**Abstract:** Development and evaluation of semi-automatic controlled atmosphere storage facility for calamansi *(Citrofortunella microcarpa)* was developed with the application of vapor compression refrigeration engineering principles and arduino system to lengthen the fruit shelf-life for commercialization and processing purposes. The prototype's overall dimension is 210 cm in length, 120 cm in width, and 120 cm in height, and has a storage volume of 0.512 $m^3$. It has a storage capacity of about 90-120 kilograms. Maintaining a temperature range of $8^0C$ -$10^0C$, $CO_2$ of 1%-6%, $O_2$ of 7%-12%, and N of 80%-90% atmospheric concentration inside the semi-controlled atmosphere storage facility resulted in a significant decrease in percentage (13.01%) of rotten calamansi fruit as compared to normal storage room (36.39%) from its initial weight. This demonstrates that the facility can reduce the fruits respiration rate and decrease deterioration.

**Keywords:** *calamansi*, vapor compression method, controlled atmosphere storage, Arduino system

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## 1 Introduction

There are lots of different existing storage rooms or refrigeration systems used for extending the shelf-life of fruits but most are not suitable for citrus. Citrus is a non-climacteric fruit that is usually harvested on its physiological maturity and it has poor responses to cold storage, chilling injury and membranosis can develop as a result of improper storage temperature. Additionally, the common stresses and responses exhibited by citrus including *calaman*si under cold storage are pitting, watery breakdown, brown stain or scald, aging, membranosis, albedo browning, and red blotch (Primo-Capella et al., 2021). However, when the fruits are held too long at relatively high temperatures they will be attacked by the decay-producing organism or may undergo changes in flavors and nutrient contents. Furthermore, it induces blue mold and stem-end decay, leading to water loss and shriveling (Patel et al., 2016). But then, the aforementioned problems could be prevented and minimized by inhibiting the respiration process and by retarding or slowing down fruit senescence. This can be done by proper monitoring of oxygen, carbon dioxide, nitrogen, and temperature levels and percentages of relative humidity RH in a controlled atmosphere storage (Brizzolara et al., 2020).

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Controlled atmosphere storage is a system for holding produce in an atmosphere that differs substantially from the normal air with respect to $CO_2$ and $O_2$ levels. Controlled atmosphere storage refers to constantly monitoring and adjusting the $CO_2$ and $O_2$ levels within gas-tight storage or containers. A reduction in $O_2$ and an increase in $CO_2$ have been proven to reduce the respiration rate and extend the storage life of fruit (Yahia et al., 2019)

The respiration process of citrus fruit increases with a higher concentration of 34.1% – 99.1% and increases with a very low concentration from 0.5% to 5% of oxygen. Citrus fruit produces higher ethanol and acetaldehyde at low oxygen and higher nitrogen levels indicating anaerobic respiration. The physiological changes in citrus fruit could definitely be minimized or can be slowed down by means of controlled atmosphere storage from which its main function is to retard senescence or ripening by reducing respiration rate, and ethylene production from where ethylene biosynthesis can be controlled by maintaining low temperature, creating an oxygen deficit environment and increasing carbon dioxide concentration (Ma et al., 2019).

The Calamansi *(Citrus microcarpa)* one of the most important fruit crops grown in the Philippines. In terms of area and production, it ranks fourth to banana, mango, and pineapple (Quijano et al., 2021). Philippine calamansi commonly exported to Hong Kong China, United Arab Emirates and Saudi Arabia. *Calamansi* fruit is known for its beneficial uses and significant products like essential oils, juice, jam, vinegar, herbal medicine, decorative crafts, and firewood making its economic contribution gradually increasing. However, despite its promising economic potential, there is a noticeable decrease in the production of *calamansi* in the Philippines. The industry was further threatened by a lack of production and post-production technologies which include proper storage facilities.

In contribution to the attainment in lengthening the shelf-life of *calamansi* and increasing the export market of *calamansi* of the Philippines, the development of a semi-automatic controlled atmosphere storage facility for *calamansi* fruit with the application of arduino system will aid to achieve the said goal and help the farmers in proper postharvest handling of the fruit by providing the optimum storage condition of the fruit.

## 2 Methodology

### 2.1 Design criteria

The design and fabrication of Semi-Automatic Controlled Atmosphere Storage System for *Calamansi* fruit with the application of arduino system with Short Message Service (SMS) notification is controlled using arduino system to constantly monitor the concentration of carbon dioxide, oxygen and nitrogen gasses and the level of temperature and relative humidity within the storage. While the system was designed to operate from 8℃ to 10℃ temperature, 90% – 95% relative humidity, 1%-6% $CO_2$ and 7%-12% $O_2$ as these are the safe and optimum temperatures for *calamansi* fruit.

### 2.2 Experimental site

The study was conducted at the Mindoro State University – Institute of Agricultural and Biosystems Engineering laboratory facility, 5205, Victoria, Oriental Mindoro, Philippines, $13^0$09'32" N, $121^0$11'22" E on July 2022.

### 2.3 Arduino system

The Arduino system shown in Figure 1 describes the flow of controlling and monitoring the required criteria in lengthening the shelf life of *calamansi.* The required limitation of gases, temperature, and Relative Humidity (RH) for the storage system of citrus was programmed by connecting the Arduino Uno board into a computer device to input the data. A breadboard where the Nitrogen, Oxygen, Carbon dioxide, and Nitrogen temperature and RH sensors module is connected through a jumper wire which is attached to the arduino board. The ultrasonic humidifier and the compressor are connected to the breadboard and to the arduino board by a relay switch module. The Liquid Crystal Display (LCD) screen is connected to the arduino board to display the digital readings of the sensors. The 12 V/3.5 A industrial power supply is plug to the 240 V outlet to serve as the power source of the arduino board. The DC-AC controller is used to reduce the current toward the Global System for Mobile Communications (GSM) module where the network simcard was installed. The GSM module was used to send the notification to the operator once the set conditions meet.

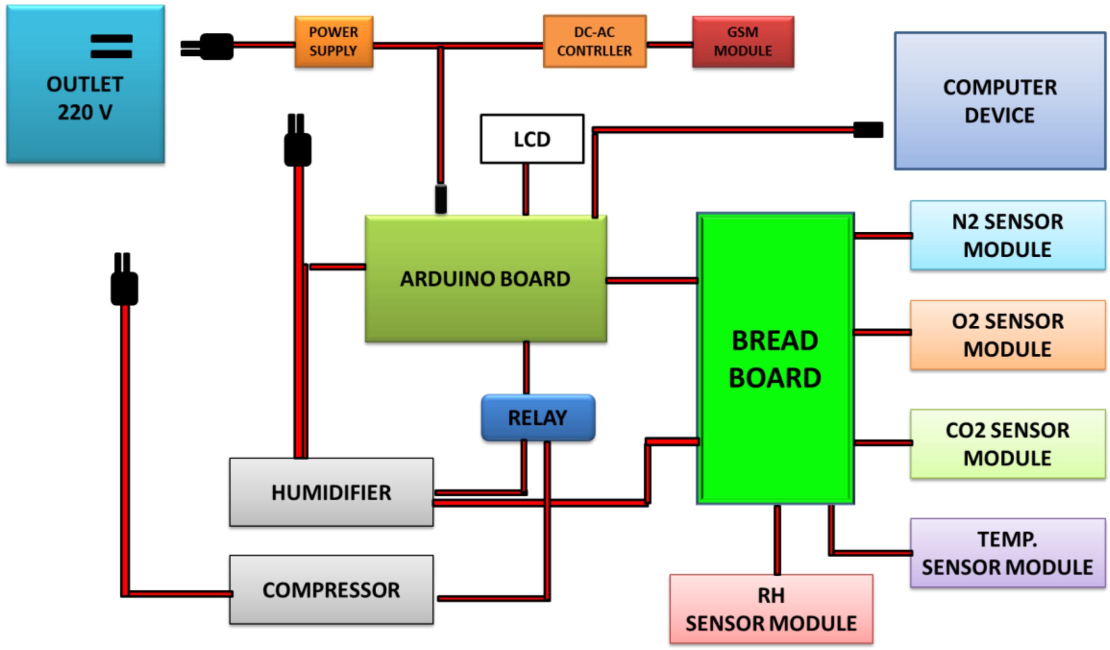


Figure 1 Arduino system framework

**2.4 Major components of the storage facility**

The main components of the facility are the compressor, condenser, capillary tube, and evaporator as the main components. The arduino system includes temperature and RH, $O_2$, $CO_2$, $N_2$ sensors, a humidifier, arduino uno board, a relay switch, a power supply, a DC-AC converter, a GSM module, a network simcard, jumper wires, and LCD monitor shown in Figure 2.

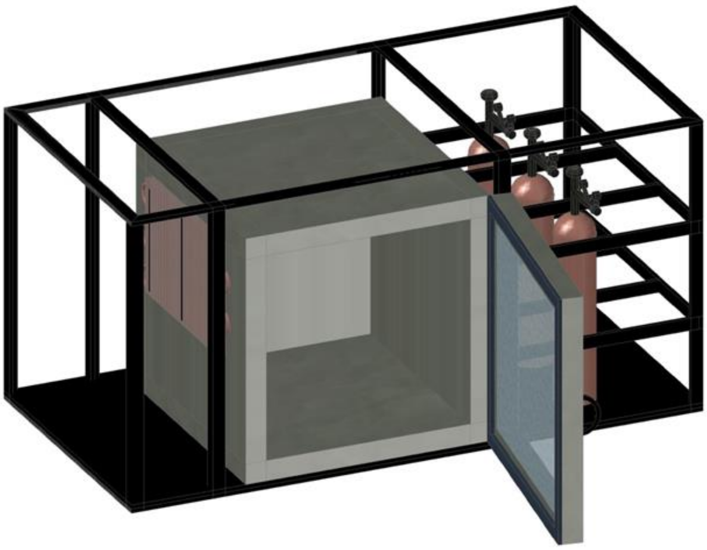

Figure 2 Design of semi-automatic controlled atmosphere storage facility for calamansi

**2.5 Carbon dioxide ($CO_2$), oxygen ($O_2$), and nitrogen (N) tank**

The $CO_2$ generator is the source of required carbon dioxide in the storage system. A 15 lbs $CO_2$ tank made of food-grade material was purchased and installed at the side of the storage room. The 15 lbs $CO_2$ tank is fitted with a valve, regulator, and fittings that set the required discharge of gases. The 15 lbs $CO_2$ regulator has a carbon dioxide resistant hose with a 3 ft length which is connected to the injection valve that is mounted in the wall of the storage system. The $CO_2$ is released when the storage atmosphere decreases to 0-5% concentration.

On the other hand, the oxygen tank is used to supply the required oxygen within the storage system to prevent anaerobic respiration. It is maintained from 5%-10% concentration, while the nitrogen tank is used for the required nitrogen to decrease the amount of oxygen to inhibit the continuous absorption of oxygen of the calamansi which was utilized in the metabolic process of the fruit which leads to faster respiration. The principle of supplying the required concentration of oxygen and nitrogen is similar to the carbon dioxide generator.

**2.6 Humidifier**

The humidifier is used when it is found that the level of RH is not at the optimum. It was installed at the center point of the storage system for equal distribution. The humidifier is connected to the relay switch of the arduino board for the automation of the function.

**2.7 Compressor**

The compressor keeps the refrigerant moving throughout the system by discharging refrigerant into the condenser against the head pressure. The recomputed compressor size is 0.28 Hp. The reciprocating compressor is used on the system because it is one of the most widely used types of refrigerating compressors. The principle of this compressor is by reciprocating motion of the piston due to external power compresses the refrigerant inside the cylinder. It has also overload relay or thermocouple protector that is design to regulate its temperature before it was damaged because of overheating.

**2.8 Evaporator coil**

The evaporator is a coil of a tube where heat is being absorbed, thus, changing liquid refrigerant into gas refrigerant. The computed evaporator capacity was 157 Watts of heat. The shelf-type evaporator is made of an aluminum tube with a thermal conductivity of 229 W $m^{-1}$ $K^{-1}$, an internal diameter of 7 mm, an external diameter of 8 mm, and a length of 20 ft.

**2.9 Condenser coil**

The condenser transfers the absorbed heat from the cold room to the atmosphere. The condenser is made of copper tubes with a thermal conductivity of 386 W $m^{-1}$ $K^{-1}$, an inner diameter of 5.3 mm, an outside diameter of 6.35 mm, and an approximate length of 31.22 ft.

**2.10 Expansion valve**

The expansion valves control the flow of refrigerant on the system. It is installed between the condenser and the evaporator. A capillary tube is made up of small diameter tubes that is used to provide constant throttle on the refrigerant.

**2.11 Operation procedure of the semi-automatic controlled atmosphere storage system for calamansi fruit**

To start the operation, all the controls and commands are needed to be checked if they are functioning. The inside temperature was first set to 8℃ -10℃. Then 90 -120 kilograms of *calamansi* was stored inside the controlled atmosphere storage system. The commodity was placed in a crate inside the storage system and the door then, was tightly closed. The door lid fitting was ensured to the wall of the storage system, as it seals the storage room using a gasket that prevents the leakage of gasses. The required condition of the atmosphere of the calamansi storage, therefore, was set.

The storage system for calamansi makes the operation convenient and time-saving for it is powered by the arduino system. Once the storage atmosphere of the *calamansi* is reached the maximum or minimum condition was attained, the machine automatically send SMS to the operator to give notifications on what the storage is needing. As an example, when the sensor detects that there is an insufficient amount of carbon dioxide the operator will receive an SMS from the system to provide the required supply of $CO_2$. This operation was achieved by setting the regulator valve on the desired pressure of gas to be discharged. Then, the operator has to turn the gas valve clockwise to release gas, the gas is delivered by the $CO_2$-resistant hose that is connected to the injection valve mounted on the storage wall. The same approach was used with other gasses.

However, when the sensor detects that there is a low level of relative humidity the machine also sends a SMS to the operator but there is no need to operate it manually. The humidifier's other wire terminal is directly connected to the plug of the 220-V outlet while the other one is connected to the relay switch module. If the system meets the minimum programmed condition for relative humidity reading, it automatically turns on the humidifier thru relay switch module until it reaches a certain reading of RH and then, switches off.

On the other hand, the process of cooling in the storage room of the system was switched on. The low-pressure liquid refrigerant will flow into the evaporator and will absorb heat from the *calamansi* fruits stored. The heat being absorbed by the refrigerant will make it into a vapor state. Then, the refrigerant will be driven by the compressor around the cycle. The compressor will compress the low temperature while the low-pressure vapor that leaves from the evaporator will be converted into high-temperature and pressure vapor. The vapor will flow to the condenser, then, the refrigerant will be condensed, thus giving off heat at high temperatures in the environment. Next, the high-pressured liquid refrigerant will move to the capillary tube, thus lowering its pressure and temperature after it leaves the capillary tube. This low-pressure liquid refrigerant will move to the evaporator where the entire cycle will be repeated.

**2.12 Testing procedure**

The operating temperature and relative humidity in the storage system were monitored using DHT11 module temperature and RH sensor. The temperature must be maintained at 8 ℃ -10 ℃ only. On the other hand, the concentration of $CO_2$, $O_2$, and $N_2$ was measured using $CO_2$, $O_2$, and $N_2$ gas sensors. The measurement was performed in different segments of the storage system to ensure the equal concentration of gasses and the level of RH and temperature was measured shown in Figure 3 and Figure 4. The measurement was based on seven days' trials to attain the accuracy of measurements. While, in the normal storage room, the operating temperature and relative humidity were measured using RH490 Hygro-Thermometer. The measurement was conducted in different areas of the storage room.

Figure 3 Measuring the temperature of the different surfaces of CA storage facility

Figure 4 Measuring the temperature of the different surfaces in the normal storage room

### 2.13 Data analysis

The difference in amount of rotten fruit between the designed semi-automatic controlled atmosphere storage facility and the normal storage room was determined using an independent two-sample T-test

## 3 Results and discussion

The recorded temperature of both the CA storage and normal storage room for seven days' observation is shown in Figure 5. The average temperature under CA storage dropped to 8.64℃ while on the normal storage room, the temperature ranges from 27.88℃. After 7 days of observation, the operating temperature of the normal storage room fluctuated between 27℃ -29℃ pattern. While the operating temperature under CA storage was 8℃ -10℃, the desired storage temperature for *calamansi.*

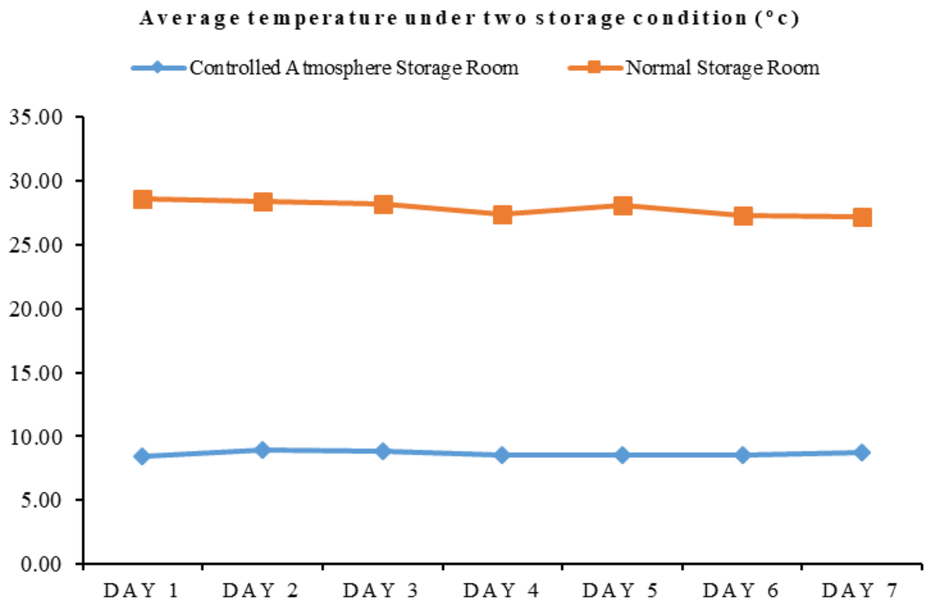


Figure 5 Observed temperature in CA storage room and normal storage room

The relative humidity was monitored and controlled by the use of DHT11 Module humidity sensor. While on the normal storage room the EXTECH 445703 Hygro-Thermometer was used. Figure 6, illustrates the average level of relative humidity and gas concentrations between the controlled atmosphere storage room and the normal storage room. The data was obtained in seven days' observation.


(a) CA storage room (b) normal storage room

Figure 6 Humidity level and gas concentration in CA storage room and normal storage room

It shows in the graph that the normal storage has higher level of humidity than the controlled atmosphere storage. It was observed that the humidifier cannot satisfy the desired RH for *calamansi* because the concentration of $CO_2$ greatly affects the changes in relative humidity (Singh and Malarvili, 2020).

Thus, the effect of low relative humidity to the *calamansi* was observed as shown in Figure 7. After seven days' trial, the commodity under CA storage shows shriveling causes of high water loss because of lower relative humidity. While the *calamansi* normal storage shows rotting of the commodity due to high activity of decaying microorganism because of the uncontrolled environment. Thus must really be maintained in order not to lessen weight of the commodity inside the develop storage system that is why humidifier used must be changed.


Figure 7 Condition of calamansi after 7-days in (a) CA Storage and (b) normal room storage

The level of $CO_2$, $O_2$, and $N_2$ gases is illustrated in Figure 8. The graph shows that the nitrogen is ranging from 90-140 ppm which is 80%-90% of the average concentration, while carbon dioxide is average of 0-14 ppm which is 1%-6% and oxygen is ranging from 7%-12% thus, the system can provide appropriate atmosphere for the storage of calamansi to retard senescence and lower the rate of respiration.

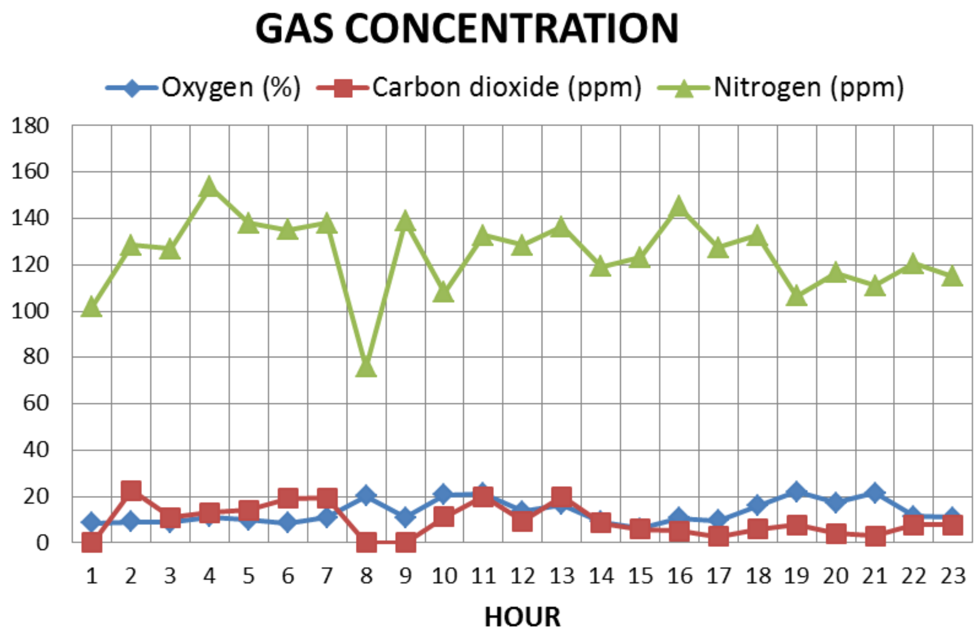


Figure 8 Actual gas concentration in the controlled atmosphere storage room

The amount of weight loss is shown Table 1. High percentage of weight loss was observed in normal storage room after removing the rotten fruits this is due to the presence of molds, pathogens and decay-causing microorganisms which was accelerated/tripled due to high temperature.

An independent two-sample T-test was used to compared the performance of the developed semi-automatic controlled atmosphere storage and normal storage room under ambient conditions. Table 2 illustrates that there is highly significant difference between the storage facility in terms of the amount of rotten fruit within the seven (7) days observation, where $t$ = 4.24 is greater than the *p-value* at 99.9% confidence level and a degrees of freedom $df$ = 6. This indicate the developed semi-automatic controlled atmosphere storage facility is more effective in maintaining the fresh state of the commodity.

**Table 1 Percentage of weight loss under controlled atmosphere storage and normal storage room**

| | CA STORAGE | NORMAL STORAGE |
|---|---|---|
| Initial Weight (g) | 9468 | 9468 |
| Final weight after removing the rotted fruit (g) | 8236 | 6022 |
| Weight of rotted fruits | 1232 | 3446 |
| Percent of Rotten Fruit (%) | 13.01 | 36.39 |

**Table 2 Difference in the amount of rotten fruit in both storage facilities**

| Observation | Normal room storage | CA Storage facility | (X – Y) | $(X – Y)^2$ | t | *p* |
|---|---|---|---|---|---|---|
| Day 1 | 255.16 | 30.94 | 224.22 | 50724.61 | 4.24** | 2.447<br>3.707 |
| Day 2 | 280.54 | 50.35 | 230.19 | 52987.43 | | |
| Day 3 | 320.2 | 109.15 | 210.64 | 44369.21 | | |
| Day 4 | 324.3 | 110.15 | 214.15 | 45860.22 | | |
| Day 5 | 430.54 | 220.25 | 210.29 | 44221.88 | | |
| Day 6 | 580.35 | 250.35 | 330.00 | 108900.00 | | |
| Day 7 | 1254.75 | 350.25 | 904.50 | 818120.25 | | |
| p<0.01** | | | | | | |

## 4 Conclusion

Based on the test, observations and data gathered, conclusions were drawn by the researchers. The use of arduino system is accurate and convenient in controlling the storage temperature, relative humidity and storage atmosphere on its optimum level. It is effective also in monitoring of $CO_2$, $O_2$, and $N_2$ level, its automatic SMS notification can minimize time and labor requirement since the operator can monitor and identify the required storage requirements without inspecting or seeing the machine. The developed facility has the capacity to lengthen the shelf-life of commodity with only 13.01% of rotten or shriveled fruit.

## 5 Recommendations

The semi-automatic controlled atmosphere storage facility is an effective method of lengthening the shelf life of the calamansi. However, the valve of the tanks should be relayed to the arduino system for automatic operation using shutoff gas valve which is an electrically operated gas valve that automatically open and close depends on demand signal and the evaporative humidifier should be used and it should be placed outside the storage room. But the vapor can be supplied using suction valve inside the cold storage room to increase humidity level.

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