

ECO – COLD STORAGES

Energy Efficiency | Automation & Digitalization

COMPENDIUM OF CLEAN TECHNOLOGIES AND USE CASES FOR RESOURCE EFFICIENCY & CLEANER PRODUCTION

Prepared by CII for Research and Innovation Circle of Hyderabad (RICH)
as part of the RAMP Telangana Greening of MSME Initiative

AUGUST 2026



Confederation of Indian Industry



Disclaimer

The compendium has been prepared for the Raising and Accelerating MSME Performance, RAMP: Greening of MSMEs initiative being implemented by Research and Innovation Circle of Hyderabad (RICH) with technical assistance and field support from the Confederation of Indian Industry (CII). The RAMP program is a program for results under the Ministry of MSME, Government of India, with support from the World Bank. In Telangana the program is being overseen by the Industries & Commerce Department, Government of Telangana, and implemented by Research and Innovation Circle of Hyderabad (RICH), to guide MSMEs in Telangana clusters towards improved resource utilisation, energy efficiency, and cleaner production practices. The information presented in this document is intended as a reference guide for MSME owners, energy managers, plant operators, and policymakers.

The technologies, performance parameters, and financial estimates provided are indicative in nature and may vary based on sitespecific conditions. MSMEs are advised to undertake detailed technical, financial, and operational feasibility assessments prior to implementation of any recommended measures. The vendor or technology provider details included in this compendium are for informational purposes only and do not constitute an endorsement or recommendation by CII, RICH, the Industries Department of Telangana, or any other stakeholders under the RAMP Programme.

The energy savings potential, benchmarks, and case references presented are derived from secondary sources and clusterlevel studies, including but not limited to studies conducted by the National Centre for Cold Chain Development (Energy transition in cold-chain infrastructure), Ministry of Environment, Forest and Climate Change (MoEF&CC) and the UNIDO Facility for Low-Carbon Technology Deployment. While every effort has been made to ensure accuracy and relevance, CII, RICH, the Industries Department of Telangana, and associated stakeholders do not assume any responsibility or liability for decisions made based on the information contained in this document or for any consequences arising thereof.



Acknowledgement

This compendium has been developed as part of the Greening of MSMEs in Telangana under RAMP Programme to conduct Resource Efficiency and Cleaner Production (RECP) Assessments and implement measures in MSMEs from Telangana state.

The Confederation of Indian Industry (CII) gratefully acknowledges the guidance, support, and contributions of the following stakeholders:

- Ministry of MSME, Government of India, for extending strategic direction and support under the RAMP Programme
- Industries & Commerce Department, Government of Telangana, for facilitating implementation and enabling ecosystem support within the State
- Research and Innovation Circle of Hyderabad (RICH), for driving innovation-led approaches to MSME ecosystem in Telangana
- The World Bank, for financial and technical support to the RAMP Programme

Local technology providers, service providers, and MSME units across Telangana, for their active participation, data input, and practical insights shared during assessments.





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Abbreviations

Abbreviation	Full Form
AHU	Air Handling Unit
APFC	Automatic Power Factor Correction
CA	Controlled Atmosphere
CAGR	Compound Annual Growth Rate
COP	Coefficient of Performance
DC	Direct Current
DG	Diesel Generator
EMS	Energy Management System
EEV	Electronic Expansion Valve
FPO	Farmer Producer Organization
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
IoT	Internet of Things
MSME	Micro, Small and Medium Enterprises
NHB	National Horticulture Board
NCCD	National Centre for Cold-chain Development
ODP	Ozone Depletion Potential
PLC	Programmable Logic Controller
PV	Photovoltaic
PCM	Phase Change Material
PUF	Polyurethane Foam
PIR	Polyisocyanurate
RECP	Resource Efficient and Cleaner Production
SCADA	Supervisory Control and Data Acquisition
TES	Thermal Energy Storage
VFD	Variable Frequency Drive
VCR	Vapour Compression Refrigeration



Units of Measurements

Unit Symbol	Description
°C	Degree Celsius
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt peak
TR	Ton of Refrigeration
LMT	Lakh Metric Tonnes
MMT	Million Metric Tonnes
kg	Kilogram
MT	Metric Tonne
%	Percentage
Rs.	Indian Rupees
m ³	Cubic meter
m ²	Square meter
hr	Hour
yrs	Years



About the Project

The Micro, Small and Medium Enterprises (MSME) sector plays a vital role in India's economic and social progress. As of July 4, 2025, MSMEs account for 30.1% of India's GDP, 35.4% of manufacturing and 45.73% of exports in the country. The Udyam Registration Portal, launched on July 1, 2020, and designed to provide a free, paperless and self-declared registration process, has recorded more than 3.80 crore MSME units. Additionally, the Udyam Assist Portal, introduced on January 11, 2023, to support informal micro enterprises and extend access to formal benefits such as Priority Sector Lending, has registered over 2.72 crore units. Together, these platforms cover around 6.5 crore MSME units across India, representing all eligible MSME category businesses, and collectively generating employment for nearly 28 crore people¹.

Despite its potential to drive entrepreneurship, economic growth and employment generation, the sector faces persistent challenges such as limited access to credit, technology and markets, infrastructure constraints, and delayed payments. The COVID-19 pandemic further exacerbated these issues, impacting liquidity, increasing non-performing assets, leading to unsold inventories, and disrupting supply chains.

To address these concerns, the Ministry of MSME, Government of India, introduced a new Central Sector Scheme called 'RAMP (Raising and Accelerating MSME Performance)', which is financially supported by the World Bank. The scheme is planned for implementation over a five-year period, starting from FY 23 till FY 27. The Cabinet approved the scheme on 30th March 2022 and the same was launched by the Hon'ble Prime Minister on 30th June 2022.

The RAMP programme is designed to have a nationwide impact, aiming to benefit all 63 million enterprises that fall under the MSME category, either directly or indirectly. However, the scheme specifically targets 5,55,000 MSMEs for measurable performance improvements. Additionally, it envisions expanding its reach to include service sector enterprises and aims to increase the participation of women-led MSMEs by approximately 70,500.

To operationalize RAMP, the central government directed all states and union territories to prepare and submit a Strategic Investment Plan (SIP) outlining their priorities and interventions under the programme. Telangana submitted its SIP identifying key objectives to strengthen the MSME ecosystem. One of the major priorities under Telangana's RAMP plan is Greening of MSMEs, which aims to:

- Promote energy efficiency, resource optimization, and cleaner production practices
- Reduce environmental impact and improve compliance
- Support MSMEs in adopting sustainable technologies and processes

The Industries Department, Govt. of Telangana, and RICH have entrusted CII to implement the "Greening of MSMEs" program in Telangana.

¹ [Press Release: Press Information Bureau, July 4, 2025](#)





About the Technology Compendium

This Technology Compendium has been developed under the Greening of MSMEs initiative of the RAMP Programme in Telangana. Its purpose is to:

- Accelerate adoption of energy and resource-efficient technologies in cold storage MSMEs.
- Serve as a reference guide for MSMEs, consultants, and stakeholders to identify practical solutions for improving energy performance and reducing environmental impact.
- Provide case studies and best practices that can be adapted to specific plant conditions.

The compendium is intended for awareness, learning, and preliminary decision-making. Implementation of suggested measures should follow detailed technical and financial assessments tailored to individual units.

Structure of the Compendium

The compendium is structured to provide MSMEs with a clear roadmap for adopting sustainable practices. It begins with an overview of the cold storage industry and Telangana's sector profile, followed by detailed descriptions of cold storages and resource consumption patterns. The document then highlights the current technology status and presents case studies showcasing opportunities for energy efficiency and cleaner production in utilities, operations, water and effluent management, and renewable energy integration. Finally, it concludes with a summary of key technologies, an implementation roadmap, and information on policy and financing support, along with references for further guidance.





Executive Summary

The cold storage sector is a critical component of India's agricultural, food processing, and pharmaceutical supply chains, contributing significantly to food preservation, reduction of post-harvest losses, and strengthening of cold chain infrastructure. Cold storage MSMEs play a vital role in this ecosystem; however, rising electricity costs, high energy consumption, ageing infrastructure, and the need for efficient and reliable operations are creating significant challenges for their competitiveness and long-term sustainability.

This compendium supports cold storage MSMEs in adopting Resource Efficient and Cleaner Production practices to improve operational efficiency, reduce operating costs, and enhance environmental performance. It highlights opportunities to optimize energy consumption, refrigeration system efficiency, water usage, and overall performance across key operations such as pre-cooling, storage, air circulation, and temperature control.

The technologies presented demonstrate that MSMEs can achieve substantial reductions in energy consumption, improve refrigeration system performance, reduce operational costs, and maintain stable storage conditions. These improvements directly contribute to improved economic performance, reduced post-harvest losses, and better compliance with emerging sustainability and efficiency requirements.

A range of interventions is covered, including energy efficiency measures in refrigeration systems, waste heat recovery, thermal energy storage, renewable energy systems, advanced control and monitoring technologies, and alternative cooling solutions. These technologies offer varying levels of investment, savings, and payback periods, enabling MSMEs to prioritize actions based on feasibility and impact.



The following table summarizes the list of technologies included in the compendium:

Table 1: List of Technologies

S. No	Technologies	Investment (Rs. Lakhs)	Annual Savings (Rs. Lakhs)	Payback (Months)
Energy Efficiency				
1	Variable frequency drive for compressor	1.25	1.5	10
2	Smart monitoring and remote management system	3 – 8	1 – 3	12 – 36
3	Electronic expansion valve	4 – 8	1.5 – 3	24 – 36
4	PLC based environmental control system	5 – 12	2 – 5	24 – 48
5	Waste heat recovery system	5 – 15	2 – 6	24 – 48
6	Floating head pressure control	6 – 10	2 – 4	24 – 36
7	Pump-Fed Ammonia Refrigeration System	6 – 10	3 – 7	18 – 24
8	PCM based cold energy storage system	15 – 35	4 – 10	36 – 48
9	Evaporative condenser with stainless steel coils	10 – 20	6 – 10	20-24
10	Thermal energy storage system	25 – 60	6 – 15	36 – 48
Water				
11	Dew point cooling system	10 – 25	4 – 10	24 – 48
Environment				
12	Low GWP natural refrigerants (ammonia or CO ₂)	10 – 30	3 – 8	24 – 48
13	Controlled atmosphere storage system	50 – 200	15 – 60	36 – 48
Renewable Energy				
14	Grid connected rooftop solar PV system	25	6.4	46
15	Biomass based adsorption refrigeration system	25 – 80	8 – 20	36 – 48
16	Solar wind hybrid power system	50	8	75

The summarized technologies indicate that a wide spectrum of opportunities exists, ranging from low-cost operational improvements with short payback periods to advanced technologies offering significant improvements in efficiency, reliability, and sustainability.

The compendium also emphasizes the importance of transitioning toward low carbon and energy efficient cold storage systems through refrigeration system optimization, integration of renewable energy, adoption of sustainable refrigerants, and implementation of advanced monitoring and control solutions. A phased implementation roadmap is provided to guide MSMEs from immediate efficiency improvements to long term modernization, automation, and sustainable cold storage operations.



01 Cold Storage Sector Overview

Cold storage refers to the controlled preservation of perishable goods at low or sub-zero temperatures to slowdown microbial growth and enzymatic activity, thereby extending product shelf life. These systems are engineered to handle large volumes with high precision, ensuring consistent temperature management and enhanced operational efficiency while reducing manual labor. Cold storage plays a critical role in modern supply chains, particularly within the food and pharmaceutical sectors, by maintaining product integrity and minimizing spoilage throughout storage and distribution.

1.1. Indian Cold Storage Sector:

India's cold storage sector is a critical infrastructure pillar of the country's agricultural, food processing, and pharmaceutical supply chains. As the world's second-largest producer of fruits and vegetables, India produces over 341 million tonnes of horticultural crops annually. However, an estimated 49.9 million metric tonnes (MMT) are lost each year due to inadequate post-harvest infrastructure, with the primary cause being the lack of temperature-controlled storage facilities at the farm-gate and across the supply chain².

1.1.1. Post-harvest Losses – Commodity-wise

The comparison of postharvest losses between 2015 and 2022 across major agricultural commodities in India reveals a mixed trend. While notable reductions are observed in commodities such as fruits, marine fisheries, and cereal-indicating improvements in storage, transportation, and partial strengthening of cold chain infrastructures, several other commodities like oilseeds, eggs, and certain livestock products continue to experience relatively high or increasing losses. This reflects uneven development in postharvest management practices and infrastructure across different value chains.

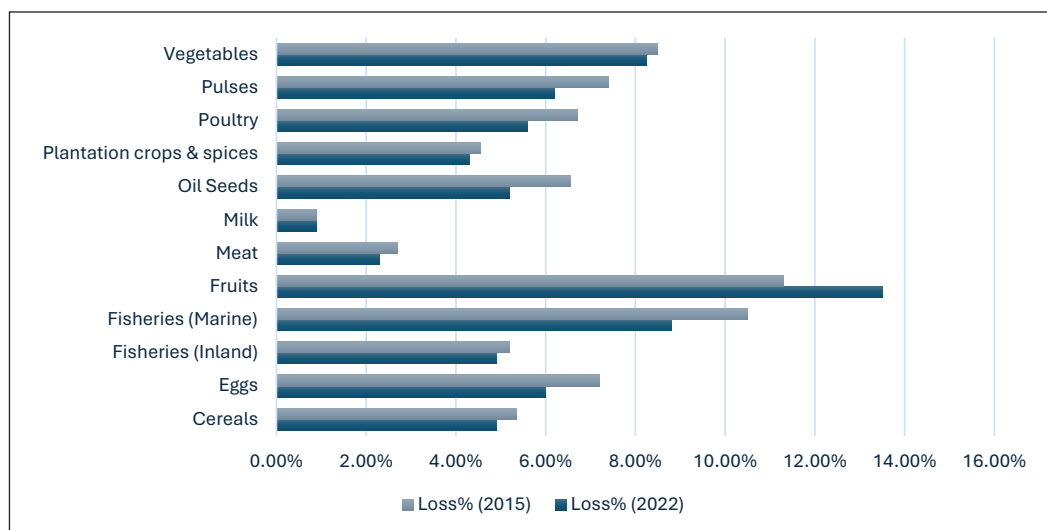


Figure 1: Post-Harvest Losses of Major Crops and Commodities - 2015 vs 2022³

- Fruits show the highest losses (13.5% in 2022) due to high perishability, handling damage, and limited cold-chain coverage.
- Milk records the lowest losses (<1%), supported by organized collection networks, chilling centers, and dairy processing infrastructure.
- Marine fisheries reduced losses significantly (from 10.5% to 8.8%), reflecting improvements in cold storage and refrigerated logistics.
- Cereals, pulses, and spices maintain lower losses because of their longer shelf life and better storage suitability.
- Lower losses are associated with stronger infrastructure and technology, including cold chains, quality monitoring systems, improved packaging, and value-addition facilities.

² [ET_in_cold_chain_sector_in_India_v8_3bfe3b8148.pdf](#)

³ [\(PDF\) Cold storage warehouse dynamics in India: Growth trends, regional disparities and Infrastructure gaps \(2014-2023\)](#)



1.1.2. Infrastructure Metrics, Structural Challenges and Market Growth

India's cold storage infrastructure comprises bulk single-commodity stores, multi-commodity cold stores, ripening chambers, dry commodity cold stores, controlled atmosphere (CA) stores, pharmaceutical cold rooms, and blast freezer facilities. While the sector has expanded steadily over the past decade, structural imbalances persist. Approximately 75% of the installed cold storage capacity is dedicated to potato storage, primarily concentrated in Uttar Pradesh and West Bengal, resulting in limited availability of specialized storage facilities for horticulture, fisheries, dairy, pharmaceutical, and other temperature-sensitive products³.

Table 2: India Cold Storage - Key Infrastructure

Parameter	Current Status (June 2025)
Cold storage units	8,815 units (as of 30 June 2025) ¹
Total installed capacity	402.18 lakh MT ⁴
CAGR – units (2014–2023)	2.13%
CAGR – capacity (2014–2023)	2.26%
Projected cold storage capacity (2031) ²	436.5 lakh MT
Packhouse count (2024 est.) ²	~1,312 integrated packhouses
Reefer vehicles (2024 est.) ²	~19,388 vehicles
Share of infrastructure > 20 years old ²	~70% of bulk cold storage

Table 3: India Cold storage - Market Metrics⁴

Parameter	Current Status (June 2025)
Cold storage market size (2025)	USD 6.54 Billion
Projected market size (2035)	USD 23.06 Billion
Cold storage CAGR (2025–2035)	~12.1%

Growth is driven by rising demand for perishable food, pharmaceuticals, and organized retail supply chains.

1.1.3. Regional Classification and Growth Trends

India is geographically divided into five regions with distinct agricultural characteristics. The Central region (led by Uttar Pradesh) dominates in both units and capacity, reflecting the dominance of potato cold storage. The West region (Maharashtra, Gujarat) shows the fastest-growing capacity CAGR at 7.10%, driven by grapes, onion, and multi-commodity facilities.

Table 4: Region-wise Cold Storage Distribution & Growth (2014–2023)³

Region	Mean Units (2014–23)	Capacity (Mean MT)	CAGR – Units	CAGR – Capacity	Key States
Central	2,786	16,323,748	1.54%	1.24%	Uttar Pradesh (leads), MP, CG, Uttarakhand
East	1,034	8,376,895	1.07%	0.64%	WB, Odisha, Bihar; older infrastructure
West	1,472	4,225,091	4.59%	7.10%	Maharashtra, Gujarat; fastest-growing capacity
North	1,415	4,049,909	2.88%	3.83%	Punjab, Haryana, Rajasthan
South	1,113	2,875,959	2.88%	4.37%	AP, Karnataka, TN, Kerala

As of May 2024, the top 10 states account for approximately 90% of India's total cold storage capacity and 82% of total units.

⁴ India Cold Storage Market Size & Share | Industry Report 2035

**Table 5: Top 10 States - Cold Storage Capacity (as of May 2024)²**

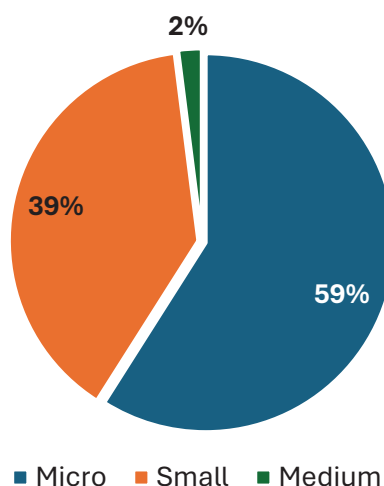
Rank	State	No. of Facilities	Total Capacity (Lakh MT)	Notes
1	Uttar Pradesh	2,481	151.00	Largest; dominated by potato bulk storage
2	West Bengal	517	59.50	Old infrastructure; avg age >30 years
3	Gujarat	1,023	40.40	Semi-modern; mid-new age profile
4	Punjab	770	26.00	Wheat, potato, horticulture
5	Andhra Pradesh & Telangana	471	19.10	Chilli, fruits, horticulture clusters
6	Bihar	315	14.80	Potato; significant post-harvest loss
7	Madhya Pradesh	315	13.60	Soyabean, potato, horticulture
8	Maharashtra	655	11.70	Grapes, onion; highest packhouse count (~70% of India)
9	Haryana	380	8.70	Dairy, vegetables
10	Karnataka	261	8.50	Grapes, mango, spices

Note: The state-wise cold storage figures presented above are based on the number of physical cold storage facilities and installed capacity reported by NCCD. These figures are not directly comparable with MSME enterprise counts from Udyam, iPASS, or other government databases, which capture registered business entities engaged in cold-chain/cold-storage activities and may include different categories of enterprises.

1.2. Telangana Cold Storage Sector

1.2.1. Enterprise Landscape

Based on secondary research, Telangana has approximately 500 cold storage MSMEs, of which 59% are Micro enterprises, 39% are small enterprises, and 2% are medium enterprises.

**Figure 2: Telangana - MSME Cold storages Enterprise Type**

1.2.2. Key Commodity Clusters

Telangana's strong agricultural and livestock sectors generate significant demand for commodity-specific cold storage infrastructure. Adequate cold chain facilities are essential to reduce post-harvest losses, maintain product quality, support exports, and improve farmer incomes. The table below identifies key commodities, major production districts, and the corresponding cold storage requirements across the state.

**Table 6: Telangana - Key Commodity Clusters with Cold Storage Relevance**

Commodity	District(s)	Cold Storage Relevance & Need
Mango	Mahbubnagar, Nalgonda, Ranga Reddy	Highly perishable; 4–8 day shelf life without cold chain; requires pre-cooling + CA storage for export
Tomato & Vegetables	Karimnagar, Warangal, Khammam	Surplus producing region; high post-harvest loss without cold storage; farm-gate solar cold rooms needed
Red Chilli (Mirchi)	Khammam, Bhadrachalam, Warangal	Dry cold storage (8–12°C); major domestic and export commodity;
Turmeric & Spices	Nizamabad, Karimnagar, Jagtial	State ranks 1st in turmeric nationally; dry cold storage + MA chambers for export quality
Dairy & Milk	State-wide (Operation Vijaya)	80% national dairy cold storage gap; critical for dairy cooperative supply chains
Poultry & Meat	Hyderabad, Ranga Reddy, Medchal	Frozen storage (–18°C to –25°C); fastest-growing segment; essential for food safety compliance



02 Cold Storage – Technology & Process

Cold storage facilities vary in complexity, ranging from conventional commodity storage to advanced refrigerated infrastructure requiring precise temperature, humidity, and atmosphere control.

The diagram below illustrates the complete cold chain network, highlighting the flow of goods from packhouses and processors through bulk and hub cold storage facilities, and finally to ripening chambers and retail outlets.

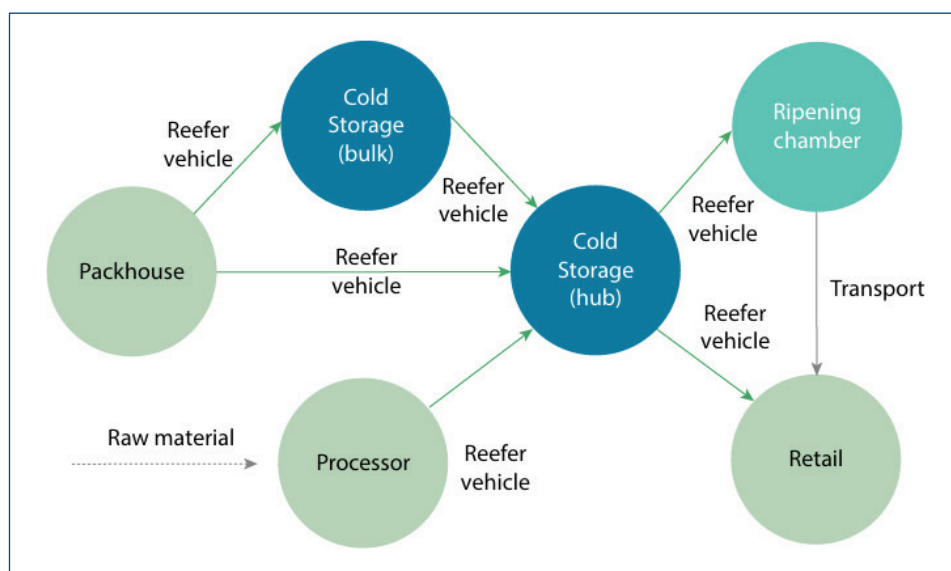


Figure 3: Flow of produce in a typical cold chain⁵

2.1. Type of Cold Storage Facilities:

Cold storage encompasses a spectrum of facility types, each designed for specific commodities, temperature requirements, and end uses. The type of facility determines the refrigeration system design, insulation specification, gas management requirements, and operational protocols.

Table 7: Types of Cold Storage Facilities and Supporting Cold-chain Components^{2,3}

Type / Classification	Temperature Range	Key Applications	Key Infrastructure & Technology Features
Bulk Single-Commodity (CS Type 1)	0°C to +4°C	Potato (75% of India's cold storage capacity), onion	VCR-based refrigeration; insulated storage chambers; ammonia or HFC refrigerant systems
Hub Multi-Commodity (CS Type 2)	-1°C to +15°C (multi-zone)	Fruits, vegetables, dairy, frozen, pharma	Multi-zone refrigeration systems; blast freezing facilities (where required); insulated chambers
Ripening Chamber (Type 3)	14°C to 18°C	Banana, mango, avocado, papaya	Ethylene-based ripening system; temperature and humidity-controlled chambers
Dry Commodity (CS Type 4)	8°C to 12°C	Chilli, spices, dry fruits, raisins, lentils	Temperature and humidity-controlled storage with compact refrigeration systems

⁵ [WB-BEE-AEEE-cold-chain-energy-efficiency-in-india.pdf](#)



Type / Classification	Temperature Range	Key Applications	Key Infrastructure & Technology Features
Specialized Cold storage Facilities			
Controlled Atmosphere (CA) Store	0°C to +5°C; O ₂ 1–3%, CO ₂ 1–5%	Apple, grape, mango, pear, kiwi	Atmosphere control (O ₂ /CO ₂), refrigeration, humidity management, gas-tight chambers
Pharmaceutical Cold Room	+2°C to +8°C (±0.5°C)	Vaccines, biologics, reagents, kits	Precision refrigeration, continuous monitoring and validated data logging
Blast Freezer / Deep Freeze	–18°C to –40°C	Meat, seafood, ice cream, export frozen	High-capacity refrigeration systems and heavy-duty insulation
Supporting Cold-chain Components			
Integrated Packhouse (with pre-cool)	Pre-cool: 0°C to +10°C; staging rooms	Fresh horticulture (export and domestic)	Pre-cooling, sorting, grading and packing facilities
Farm-gate Solar Cold Room	0°C to +10°C	Fresh produce at FPO/ micro-storage (5–30 MT)	Solar-powered refrigeration with battery/ thermal backup

Among the cold storage categories presented above, multi-commodity cold storages, controlled atmosphere (CA) stores, blast freezers/deep freezers, pharmaceutical cold rooms, and integrated packhouses are the most energy-intensive due to their continuous refrigeration requirements, precise temperature and humidity control, air circulation systems, and product-specific environmental management.

Accordingly, this technology compendium primarily focuses on technologies applicable to these energy-intensive cold storage segments, particularly multi-commodity cold storages, CA storage facilities, blast freezing operations, pharmaceutical cold rooms, and packhouse-linked refrigeration systems. The proposed interventions target key improvement areas including refrigeration system efficiency, renewable energy integration, thermal energy storage, advanced monitoring and automation, low-GWP refrigerants, waste heat recovery, and intelligent environmental control systems.

2.2. Cold Storage Operational Process:

Cold storages in Telangana are predominantly used for the storage of agricultural commodities such as dry red chilli, turmeric, seed spices, seeds, fruits, and vegetables. A significant proportion of the state's cold storage capacity serves the red chilli and turmeric-producing regions, where temperature and humidity-controlled storage helps preserve product quality, reduce post-harvest losses, and facilitate year-round marketing.

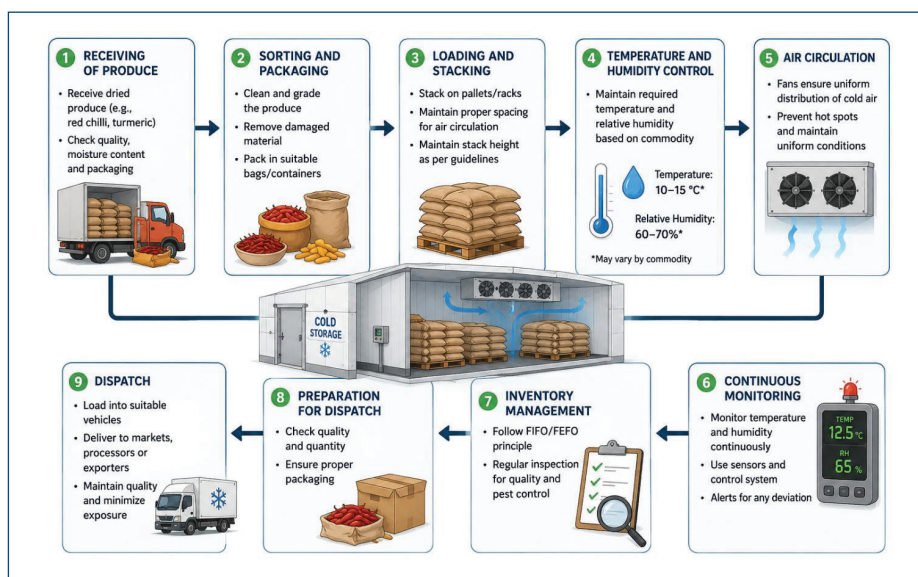


Figure 4: Cold storage - Operational Process Flow

**Receiving of Produce:**

The agricultural produce is received at the cold storage facility after harvesting, drying (where applicable), and preliminary handling. The incoming produce is inspected for quantity, quality, moisture content, and packaging condition to ensure its suitability for storage.

Sorting, Grading, and Packaging:

The produce is cleaned (where required), sorted, graded, and packed in appropriate bags, cartons, or palletized units. Damaged, contaminated, or substandard material is segregated to maintain the quality of the stored produce.

Loading and Stacking:

The packaged produce is systematically loaded and stacked on pallets or racks while maintaining adequate spacing between stacks and walls to facilitate proper air circulation and safe material handling. Stacking practices are followed as per recommended storage guidelines to prevent product damage.

Temperature and Humidity Control:

The storage chamber is maintained at the required temperature and relative humidity based on the specific commodity. Maintaining optimum environmental conditions minimizes quality deterioration, reduces pest activity, and preserves the product's colour, aroma, texture, and market value throughout the storage period.

Air Circulation:

Cold air is uniformly circulated throughout the storage chamber using evaporator fans to maintain consistent temperature distribution, eliminate hot spots, and ensure uniform cooling of the stored commodities.

Continuous Monitoring and Control:

Temperature, relative humidity, and other critical operating parameters are continuously monitored using sensors and automated control systems. Regular monitoring enables timely corrective actions to maintain the desired storage conditions.

Inventory Management:

Stored commodities are managed using established inventory management practices such as First In First Out (FIFO) or First Expiry First Out (FEFO), as applicable. Periodic inspections are conducted to assess product quality and identify any signs of spoilage, moisture ingress, or pest infestation.

Dispatch of Stored Produce:

Prior to dispatch, the stored commodities undergo quality and quantity verification. The produce is then carefully loaded onto suitable transport vehicles for delivery to markets, processing units, or export facilities while minimizing exposure to ambient conditions to preserve product quality.

2.2.1. Pre-cooling (A critical but frequently skipped stage)

Pre-cooling is one of the most energy-critical and commonly neglected stages in India's cold chain. Field assessments by NCCD (2025) indicate that most farm-gate and hub facilities lack dedicated pre-cooling infrastructure. As a result, warm produce is often loaded directly into cold storage, leading to thermal shock, elevated respiration rates, compressor overload, and accelerated deterioration of existing stock.

Although pre-cooling is not a part of cold storage operations, it significantly influences cold storage performance and energy consumption.





03 Energy, Water and Waste Management

3.1. Energy Consumption Profile

Cold storage facilities are among the most electricity-intensive operations in the agri-logistics and food supply chain sectors. The sector's energy profile is fundamentally different from other agri-processing industries: cold storage is an almost entirely electrical operation. There is no significant use of steam, thermic oil, coal, or gas in routine cold storage operations.

Where thermal energy is used, it typically accounts for only 2–5% of total energy consumption and is mainly required for auxiliary applications such as hot water generation for cleaning and sanitation, space/floor heating, and other facility-specific heating needs.

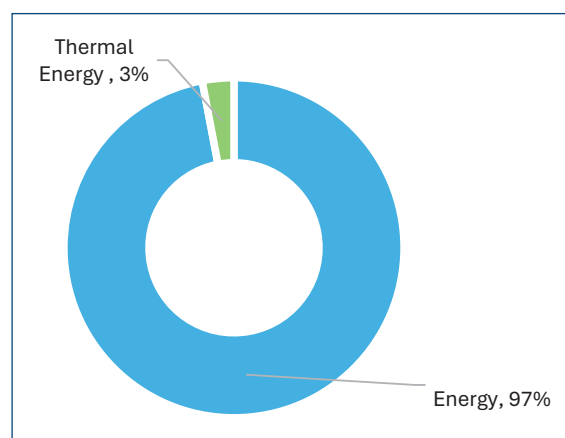


Figure 5: Cold storage - Energy share

Electricity from the grid is the primary energy source for most cold storage facilities. Renewable energy systems, particularly rooftop solar PV, are increasingly being adopted to reduce operating costs and improve sustainability. Diesel Generator (DG) sets are typically used as standby power sources during grid outages to ensure uninterrupted refrigeration and prevent product losses.

3.1.1. Section-wise Energy Consumption

A typical distribution of energy consumption across major systems is presented in the table below.

Table 8: Section-wise energy consumption

Section	Equipment / Function	Typical Energy Share %	Description
Refrigeration System	Compressors, condensers, evaporators, expansion valves	70-85%	Primary energy consumer responsible for maintaining storage temperature and preserving product quality.
Air Circulation & Ventilation	Evaporator fans, ventilation fans	8-12%	Ensures uniform temperature distribution and airflow throughout the storage chambers.
Lighting	Internal and external lighting systems	2-5%	Provides illumination for storage, inspection, and operational activities.
Auxiliary Systems	Pumps, control systems, SCADA/ IoT monitoring, battery chargers, office loads	3-8%	Supports refrigeration operations, monitoring, automation, and facility management.
Defrosting & Hot Water Systems	Hot gas defrost systems, electric defrost heaters, water heaters	1-3%	Used for evaporator defrosting and limited cleaning/sanitation requirements where applicable.



The refrigeration system is the dominant energy consumer in cold storage facilities, accounting for the majority of energy consumption.

3.2. Water Management

Water consumption in cold storage facilities is relatively lower than in processing industries; however, it plays an important role in system efficiency and maintenance. Water is primarily used in evaporative condensers, cooling towers, cleaning operations, and occasionally in humidification systems.

Efficient water management practices such as automated control systems, proper bleed-off management, and reuse systems can significantly reduce water consumption and improve system efficiency.

Key sources of water inefficiency include:

- Excessive water usage in evaporative condensers due to lack of flow control and monitoring
- Poor cooling tower management leading to high blowdown losses
- Lack of water recirculation and reuse systems
- Leakages in water distribution pipelines
- Discharge of relatively clean cooling water without reuse

3.3. Waste and Refrigerant Management

The primary solid waste generated includes packaging materials such as cartons, plastic crates, wooden pallets, stretch films, and damaged insulation materials. In addition, spoiled or deteriorated produce resulting from improper storage conditions, temperature fluctuations, extended storage periods, or handling damage can contribute significantly to waste generation and economic losses. Wastewater generation is generally limited to cleaning activities and cooling system operations. However, improper disposal can still impact local water systems.

Refrigerant management is one of the most critical environmental aspects in cold storage systems. Leakage of refrigerants, particularly high Global Warming Potential (GWP) refrigerants, contributes significantly to greenhouse gas emissions. Poor maintenance practices and ageing systems increase the risk of leakage and inefficiency.



04 Resource Efficiency and Cleaner Production Measures

4.1. Energy Efficiency

4.1.1. Variable Frequency Drive (VFD) for the Compressor:

Background & Problem:

In conventional cold storage facilities, refrigeration compressors often operate at a constant speed regardless of the actual cooling demand. During periods of partial load operation, the cooling requirement may be significantly lower than the compressor's rated capacity. In such situations, capacity control is typically achieved through compressor unloading, slide valve control, or start-stop operation, which can result in energy losses and reduced system efficiency.

Technology Intervention: Installation of VFD for compressor

It is proposed to install a Variable Frequency Drive (VFD) on the refrigeration compressor motor to enable variable-speed operation based on cooling demand.

The VFD continuously adjusts compressor motor speed based on refrigeration load requirements, thereby reducing energy consumption during part-load operation.

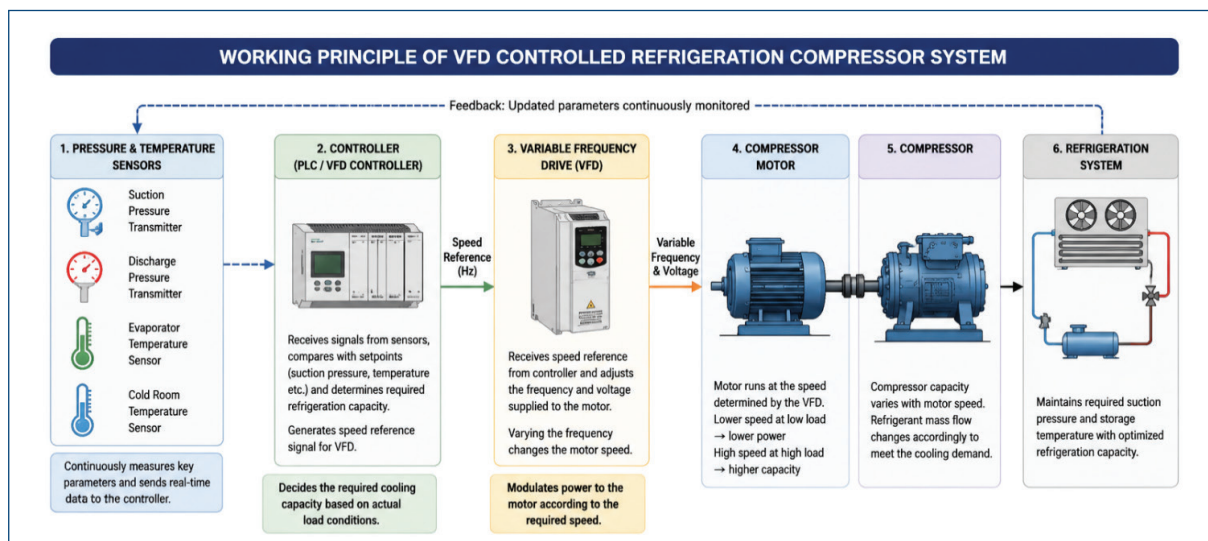


Figure 6: Variable Frequency Drive - Working Principle

Working Principle:

Pressure and Temperature Sensors: The refrigeration system continuously monitors key operating parameters such as suction pressure, discharge pressure, evaporator temperature, and cold room temperature. These parameters provide real-time information on the refrigeration load and system operating conditions.

Controller (PLC/VFD Controller): The controller receives signals from the sensors and compares the measured values with predefined setpoints. Based on the cooling demand, the controller determines the required refrigeration capacity and generates a control signal for the VFD.

Variable Frequency Drive (VFD): The VFD receives the control signal from the controller and adjusts the frequency and voltage supplied to the compressor motor. By varying the motor speed, the VFD enables the compressor capacity to match the actual refrigeration load.

Compressor Motor: The compressor motor operates at a speed determined by the VFD. During periods of low cooling demand, the motor speed is reduced, resulting in lower power consumption. During periods of high cooling demand, the motor speed increases to provide the required refrigeration capacity.



Compressor: As the compressor speed changes, the refrigerant mass flow rate through the refrigeration system is adjusted accordingly. This allows the system to maintain the required suction pressure and storage temperature without relying heavily on compressor unloading, slide valve operation, or frequent start-stop cycles.

Cost-Benefit analysis:

Estimated Investment: 1.25 lakhs

Estimated Annual Savings: 1.5 lakhs

Payback: 10 months

Benefits:

- ✓ Reduces compressor energy consumption by matching refrigeration capacity with actual cooling demand.
- ✓ Improves part-load operating efficiency and overall refrigeration system performance.
- ✓ Achieves energy savings typically ranging from 15–35% of compressor energy consumption.
- ✓ Minimizes compressor unloading losses and frequent start-stop operation.
- ✓ Can be integrated with PLC, SCADA, and energy monitoring systems for advanced refrigeration control.

4.1.2. Smart Cold Storage Monitoring & Remote Management System

Background & Problem:

Cold storage facilities require continuous monitoring of critical parameters such as temperature, humidity, air quality, and equipment performance to maintain product quality and prevent spoilage.

Conventional monitoring systems are limited because:

- They rely on manual inspections or basic indicators
- Lack real-time tracking and remote accessibility
- Fail to provide early warning for system deviations or faults

Technology Intervention: Smart IoT-Based Monitoring System & Remote Management System

Smart monitoring systems based on Internet of Things (IoT) technology enable continuous tracking of critical cold storage parameters such as temperature, humidity, air quality, and equipment performance. These systems integrate multiple sensors, communication networks, and cloud-based platforms to provide real-time data visibility, remote access, and intelligent alerts.

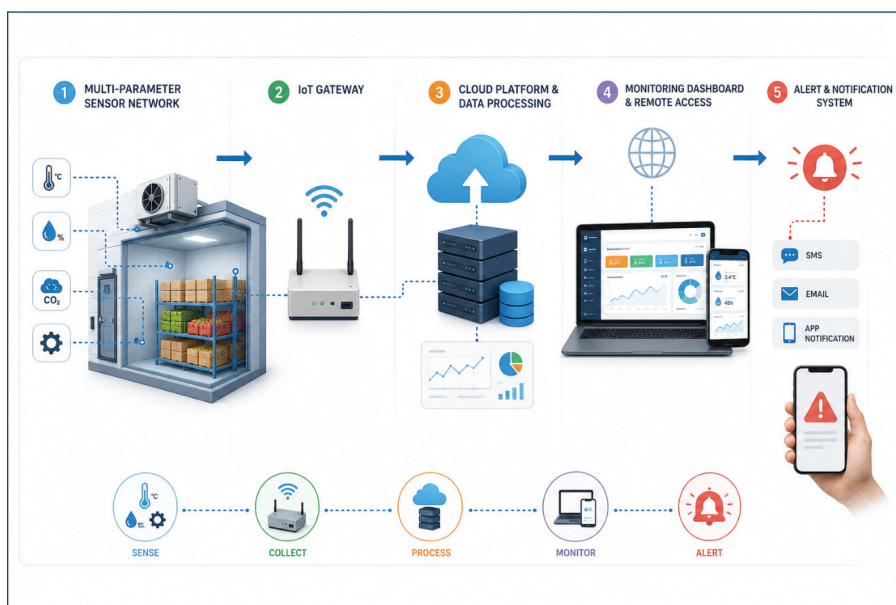


Figure 7: Smart IoT-Based Monitoring System & Remote Management System



Working principle:

Multi-Parameter Sensor Network:

- A network of sensors is installed across the cold storage to measure parameters such as temperature, humidity, gas concentration, and equipment conditions.
- These sensors continuously capture real-time data at defined intervals from different zones.
- This ensures accurate and comprehensive monitoring of both storage environment and system performance.

Data Acquisition & IoT Gateway:

- Sensor outputs are transmitted to an IoT gateway through wired or wireless communication protocols.
- The gateway aggregates and converts sensor signals into digital data suitable for transmission.
- It acts as an interface between field devices and cloud-based platforms.

Cloud Platform & Data Processing:

- The collected data is transmitted to a cloud server, where it is stored and processed.
- Advanced analytics are performed to identify trends, deviations, and inefficiencies.
- Historical data analysis supports performance evaluation and predictive maintenance.

Monitoring Dashboard & Remote Access:

- The processed data is displayed on user-friendly dashboards accessible through mobile or web applications.
- Operators can monitor real-time conditions, historical trends, and system status remotely.
- This enables centralized management of cold storage operations from any location.

Alert & Notification System:

- When monitored parameters deviate from predefined setpoints, the system automatically generates alerts.
- Notifications are sent via SMS, email, or application interfaces for immediate action.
- This helps prevent product loss and equipment damage due to delayed response.

Cost-Benefit Analysis:

Estimated Investment: 3–8 lakhs

Estimated Annual Savings: 1–3 lakhs

Payback: 12–36 months

Benefits:

- ✓ Real-time monitoring of storage and equipment parameters
- ✓ Remote access and centralized control
- ✓ Early fault detection and preventive maintenance
- ✓ Reduction in product losses and spoilage
- ✓ Improved operational efficiency and energy use
- ✓ Data-driven decision making

4.1.3. Electronic Expansion Valve in Refrigeration System

Background & Problem:

Cold storage refrigeration systems operate under highly variable load conditions due to fluctuations in product load, door openings, ambient temperature, and operating schedules.



Conventional expansion devices such as thermostatic expansion valves (TXV) or capillary tubes have limitations:

- Slow response to load variations
- Inaccurate refrigerant flow control
- Higher superheat fluctuations
- Reduced evaporator efficiency
- Increased compressor energy consumption

Technology Intervention: Electronic expansion valve in refrigeration system

It is proposed to replace conventional expansion devices with an Electronic Expansion Valve (EEV) integrated with a control system.

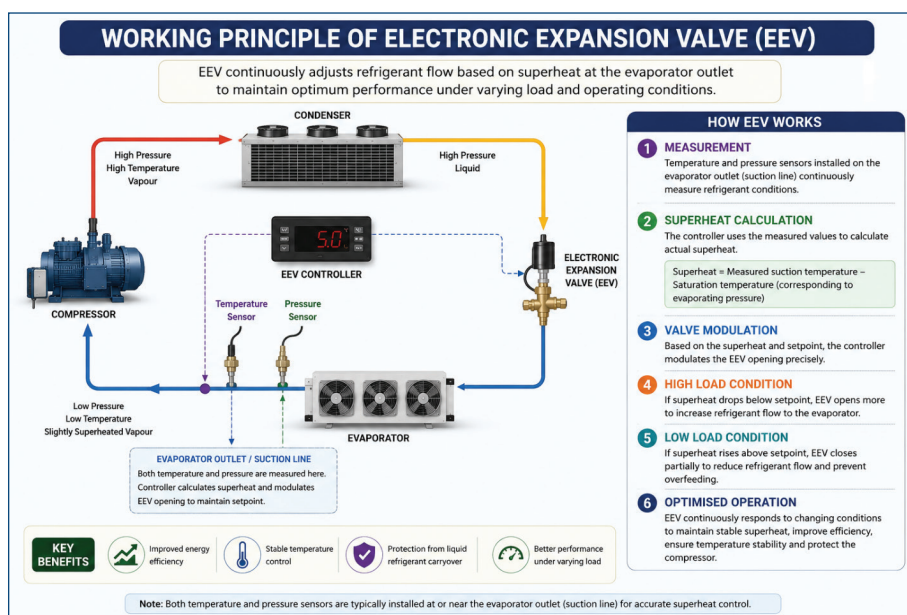


Figure 8: Electronic Expansion Valve – Working Principle

Working Principle:

- Temperature and pressure sensors installed at the evaporator outlet (suction line) continuously monitor the refrigerant conditions leaving the evaporator.
- The Electronic Expansion Valve (EEV) controller receives the temperature and pressure signals and calculates the actual refrigerant superheat at the evaporator outlet.
- Based on the calculated superheat, the controller continuously modulates the opening position of the EEV to maintain a predetermined superheat setpoint.
- During periods of high cooling demand, the EEV increases its opening to allow a greater flow of refrigerant into the evaporator, ensuring adequate cooling capacity.
- During low-load conditions, the EEV reduces refrigerant flow to prevent overfeeding of the evaporator and maintain stable system operation.
- By continuously adjusting refrigerant flow in response to changing operating conditions, the EEV ensures optimum evaporator utilization and efficient heat transfer.

Cost-Benefit Analysis:

Estimated Investment: 4-8 lakhs

Estimated Annual Savings: 1.5-3 lakhs

Payback: 24-36 months



Benefits:

- ✓ Provides precise refrigerant flow control under varying operating conditions.
- ✓ Maintains optimum evaporator superheat and improves refrigeration system efficiency.
- ✓ Improves evaporator utilization and cooling performance.
- ✓ Reduces compressor energy consumption through better system optimization.
- ✓ Minimizes risk of liquid refrigerant carryover and compressor damage.
- ✓ Supports advanced refrigeration control strategies such as floating suction pressure and smart refrigeration management.

4.1.4. Advanced Environmental Control System (PLC-Based) for Cold Storage

Background & Problem:

Maintaining uniform and precise environmental conditions inside cold storage is critical for product preservation. However, conventional control systems face challenges such as:

- Uneven temperature and humidity distribution
- Poor response to load variations
- Inefficient airflow management
- Limited control precision

These issues lead to:

- Localized spoilage of stored products
- Energy inefficiencies
- Increased compressor and equipment load

Technology Intervention: PLC-Based Environmental Control System

Advanced environmental control systems use PLC-based automation with intelligent control logic (PID/Fuzzy) to maintain precise temperature, humidity, and airflow conditions in cold storage facilities. These systems continuously process real-time sensor data and dynamically adjust operating parameters to ensure uniform storage conditions and optimized refrigeration performance.

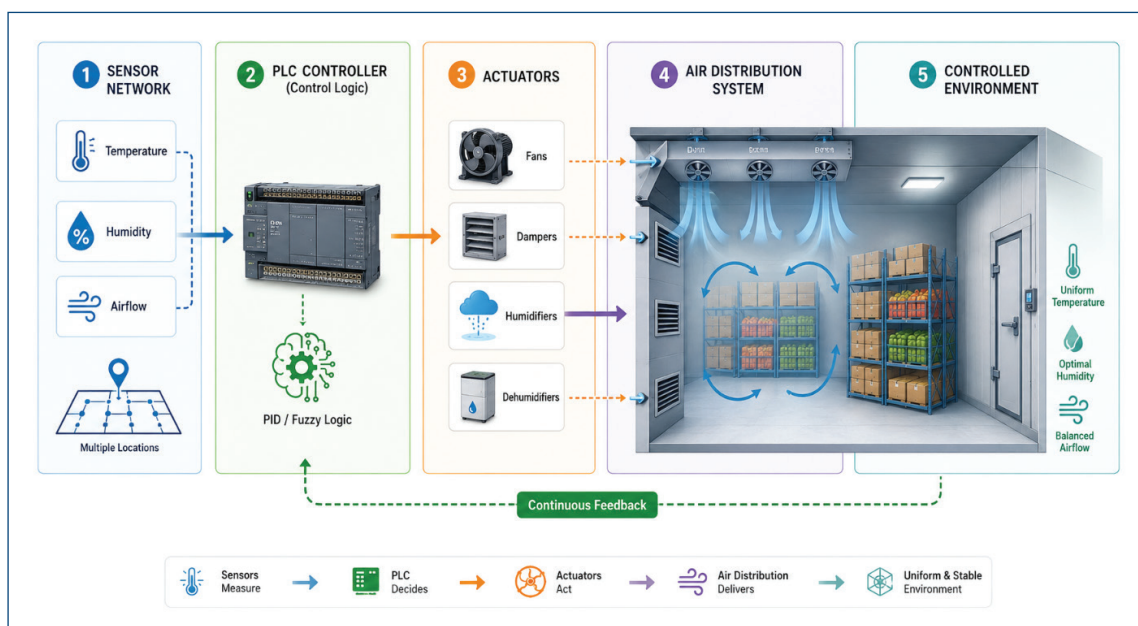


Figure 9: PLC-Based Environmental Control System



Working principle:

Sensor Network (Temperature, Humidity & Airflow):

- Sensors installed at multiple locations measure real-time environmental conditions such as temperature, relative humidity, and airflow distribution.
- These inputs provide continuous feedback on storage conditions and identify any deviations or non-uniformity.

PLC Controller with Control Logic:

- The PLC receives sensor inputs and compares them with predefined setpoints.
- Using control algorithms (PID/Fuzzy logic), it determines the required corrective actions to maintain desired conditions.
- Ensures fast and accurate response to load and environmental variations.

Actuators (Fans, Dampers, Humidifiers/Dehumidifiers):

- Based on PLC output signals, actuators are automatically controlled to regulate cooling, airflow, and moisture levels.
- Fan speed, air circulation, and humidity control devices are adjusted to maintain uniform conditions.

Air Distribution System:

- Controlled airflow ensures uniform temperature and humidity across the entire storage area.
- Eliminates hot/cold spots and uneven moisture distribution within the cold room

Cost-Benefit Analysis:

Estimated Investment: 5–12 lakhs

Estimated Annual Savings: 2–5 lakhs

Payback: 24–48 months

Benefits:

- ✓ Energy efficiency improvement through optimized control of compressors, fans, humidification system and airflow
- ✓ Reduced product spoilage and material losses due to uniform temperature and humidity distribution
- ✓ Lower emissions (indirect) by minimizing excess energy consumption
- ✓ Enhanced operational efficiency with automated control and reduced manual intervention

4.1.5. Waste Heat Recovery System from Refrigeration Plant

Background & Problem

Cold storage refrigeration systems continuously reject a large amount of heat through condensers during the refrigeration process. In most conventional cold storage facilities, this waste heat is dissipated into the atmosphere without any beneficial use. At the same time, many facilities require hot water for equipment cleaning, crate washing, floor sanitation, maintenance activities, and other utility purposes, which are typically met using electric heaters or diesel/LPG-fired systems.

Technology Intervention: Heat Recovery System from Refrigeration Plant

A heat recovery system utilizes the waste heat available in the hot refrigerant discharged from refrigeration compressors before it reaches the condenser. A refrigerant-to-water heat exchanger (desuperheater) transfers this heat to water, producing hot water that can be used for cleaning, sanitation, and other utility applications within the facility.

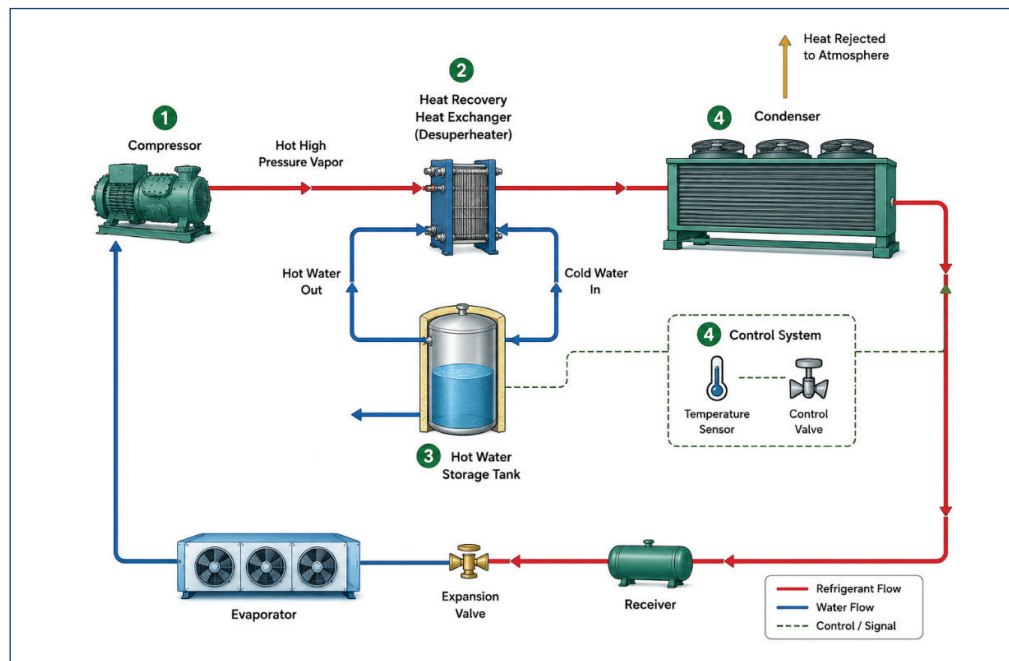


Figure 10: Waste heat recovery

Working Principle:

Compressor: The refrigeration compressor compresses low-pressure refrigerant vapour into a high-pressure, high-temperature gas. In a conventional system, this heat is rejected to the atmosphere through the condenser.

Heat Recovery Heat Exchanger: A refrigerant-to-water heat exchanger (desuperheater) is installed in the compressor discharge line before the condenser. As the hot refrigerant flows through the heat exchanger, a portion of its heat is transferred to circulating water, producing hot water without affecting the refrigeration process.

Hot Water Storage Tank: The heated water is stored in an insulated tank and supplied for equipment cleaning, crate washing, floor sanitation, and other utility applications within the cold storage facility.

Condenser and Control System: The refrigerant then enters the condenser, where the remaining heat is rejected before continuing through the normal refrigeration cycle. Temperature sensors and control valves regulate the heat recovery process. When hot water demand is low, excess heat is automatically rejected through the condenser.

Cost-Benefit Analysis:

Estimated Investment: 5–15 lakhs

Estimated Annual Savings: 2–6 lakhs

Payback: 24–48 months

Note: Actual investment depends on refrigeration capacity, hot water demand, and system configuration.

Benefits

- ✓ Reduces electricity or fuel consumption for hot water generation.
- ✓ Improves overall energy efficiency of the refrigeration system.
- ✓ Reduce operating costs and indirect greenhouse gas emissions.
- ✓ Provides hot water for cleaning, sanitation, and maintenance activities.

4.1.6. Floating Head Pressure Control

Background & Problem:

Cold storage facilities consume significant electrical energy for refrigeration systems, where compressors operate continuously to maintain required storage temperatures. In conventional systems, condensing (head) pressure is maintained at a fixed high value irrespective of ambient conditions.



This results in:

- High compressor energy consumption
- Inefficient operation during cooler climatic conditions
- Increased electricity costs
- Unnecessary stress on refrigeration equipment

Since cold storage facilities operate year-round and experience varying ambient temperatures, maintaining a constant high head pressure leads to avoidable energy losses and reduced system efficiency.

Technology Intervention: Floating head pressure control:

It is proposed to implement a floating head pressure control strategy in the refrigeration system by automatically adjusting the condenser pressure setpoint based on ambient temperature conditions.

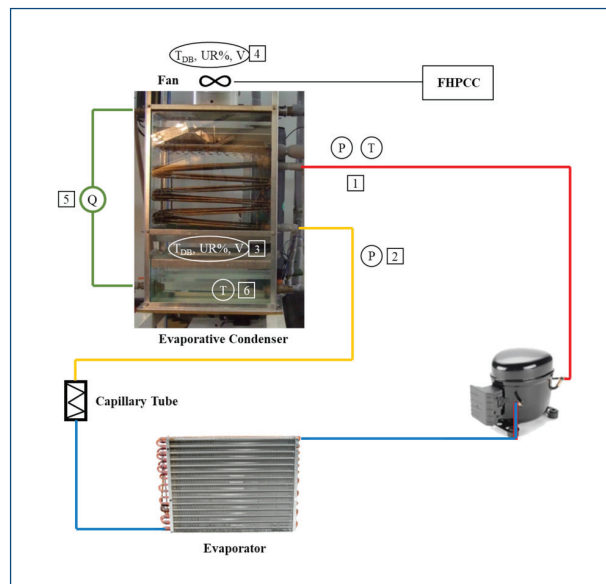


Figure 11: Floating head pressure control⁶

Working Principle:

- The refrigeration system is equipped with multiple sensors installed at critical points of the evaporative condenser and refrigerant circuit to continuously monitor system parameters such as condensation pressure, refrigerant temperature, air temperature, humidity, air flow velocity, and water flow rate.
- Key measurement points include:
 - o Point 1: Condensation pressure and refrigerant temperature at condenser inlet
 - o Point 2: Refrigerant pressure at condenser outlet
 - o Points 3 & 4: Air properties at inlet and outlet of the condenser (dry bulb temperature, relative humidity, and air velocity)
 - o Point 5: Water flow rate in the evaporative condenser
 - o Point 6: Sump water temperature
- All sensor data are directly connected to a PLC-based control system, which continuously records and stores data at predefined intervals for real-time monitoring and analysis.
- Based on these real-time inputs, the PLC determines the optimum condensing pressure required for efficient system operation under prevailing ambient and load conditions.
- The system dynamically adjusts the condenser performance by:
 - o Modulating fan speed (airflow rate)
 - o Regulating water circulation in the evaporative condenser

⁶ *Implementation of a Floating Head Pressure Condensation Control to Reduce Electrical Energy Consumption in an Industrial Refrigeration System*



- During lower ambient temperature or favorable heat rejection conditions:
 - o The PLC reduces the condensing pressure (floating head condition)
 - o Compressor discharge pressure decreases
 - o Compression ratio reduces, leading to lower power consumption
- During higher ambient temperatures: The system maintains adequate condensing pressure to ensure proper heat rejection and refrigerant condensation

Cost-Benefit Analysis:

Estimated Investment: 6-10 lakhs

Estimated Annual Savings: 2-4 lakhs

Payback: 24-36 months

Benefits:

- ✓ Reduces compressor power consumption significantly (energy savings up to 15–25%)
- ✓ Improves overall refrigeration system efficiency (higher COP)
- ✓ Reduce operating and electricity costs
- ✓ Minimizes wear and tear on compressors and equipment

4.1.7. Pump-Fed Ammonia Refrigeration System

Background & Problem

Many industrial cold storage facilities operate with gravity-fed ammonia refrigeration systems, where liquid ammonia reaches the evaporators primarily through gravity. During varying cooling loads, this arrangement may result in inadequate refrigerant circulation, reduced evaporator performance, and inefficient utilization of the refrigeration system. Consequently, compressors operate for longer durations to meet the required cooling demand, leading to higher electricity consumption and increased operating costs.

Technology Intervention: Pump-Fed Ammonia Refrigeration System

A pump-fed ammonia refrigeration system replaces gravity-based refrigerant circulation with a dedicated ammonia recirculation pump. The system continuously supplies liquid ammonia from the low-pressure receiver to the evaporators at the required flow rate.

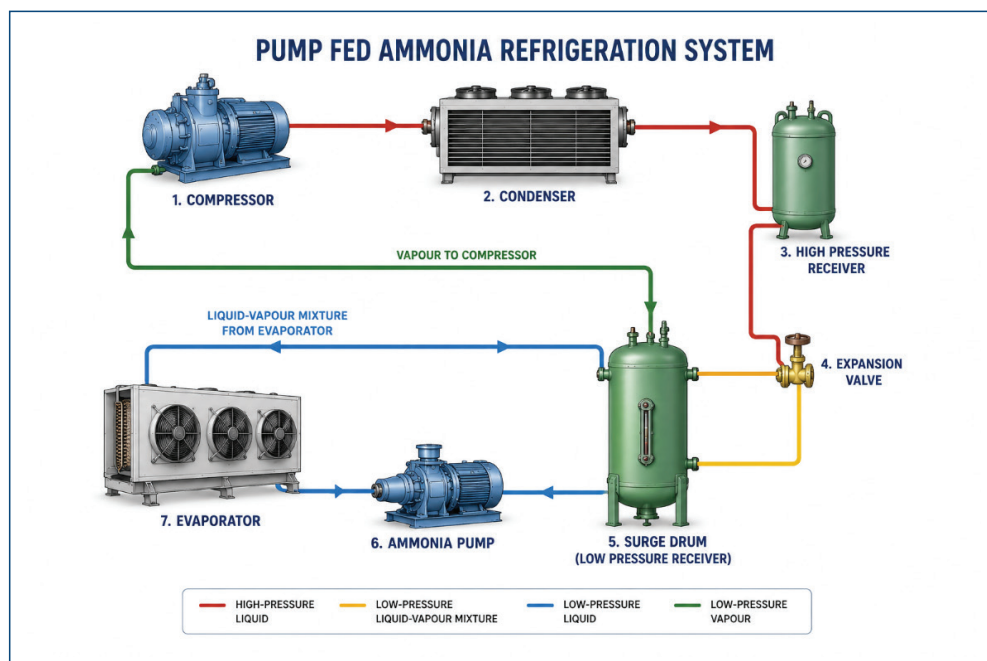


Figure 12: Pump-Fed Ammonia Refrigeration System



Working Principle:

Compressor

- Draw low-pressure ammonia vapor from the liquid separator.
- Compresses it into high-pressure, high-temperature vapor.

Condenser

- Hot ammonia vapor enters the condenser.
- Heat is removed, and the vapor condenses into high-pressure liquid.

Receiver

- Store the high-pressure liquid ammonia from the condenser.
- Provides a steady liquid supply to the system.

Expansion Valve

- High-pressure liquid passes through the expansion valve.
- Pressure drops suddenly, creating a cold liquid-vapor mixture.

Liquid Separator (Surge Drum)

- Separates flash vapor from liquid ammonia.
- Vapor goes to the compressor suction.
- Liquid collects at the bottom for recirculation.

Pump

- Pumps liquid ammonia from the separator to the evaporators.
- Ensures sufficient liquid supply to keep the evaporators flooded.

Evaporator

- Liquid ammonia absorbs heat from the space/product being cooled.
- Part of the liquid evaporates, producing refrigeration.

Return to Separator

- The liquid-vapor mixture returns from the evaporator to the separator.
- Liquid settles, and vapor rises.

Cost-Benefit Analysis:

Estimated Investment: 6–10 lakhs

Estimated Annual Savings: 3–7 lakhs

Payback: 18–24 months

Benefits:

- ✓ Ensures continuous and reliable liquid ammonia circulation to the evaporator.
- ✓ Improves refrigeration efficiency and cooling capacity.
- ✓ Reduces compressor operating hours and electricity consumption.
- ✓ Maintains stable system performance under varying cooling loads.
- ✓ Reduces indirect greenhouse gas emissions through lower energy consumption

4.1.8. PCM-Based Cold Energy Storage System for Cold Storage

Background & Problem:

Maintaining stable storage temperatures is critical for preserving the quality and shelf life of perishable commodities in cold storage facilities. In conventional cold storage, refrigeration systems must continuously compensate for heat ingress



caused by door openings, product loading and unloading activities, ambient heat transfer, and power interruptions. These factors can lead to temperature fluctuations within the storage chamber and increased compressor cycling.

Frequent compressor operation not only increases electricity consumption but also causes mechanical wear and reduces equipment life.

Technology Intervention: PCM – Based cold energy storage system for cold storage

Phase Change Material (PCM)-based thermal energy storage systems provide an effective solution by storing cooling energy and releasing it when required, thereby improving temperature stability and reducing fluctuations in refrigeration load.

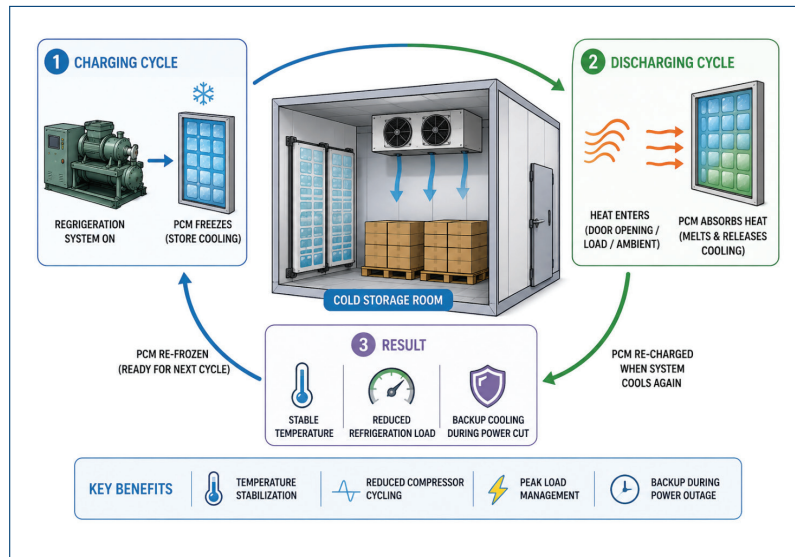


Figure 13: PCM-Based Cold Energy Storage System for Cold storage

Working Principle:

PCM Thermal Energy Storage: PCM modules are installed inside the cold storage chamber and selected to have a phase change temperature close to the desired storage temperature.

Charging Cycle (Cooling Energy Storage): During normal refrigeration operation, the refrigeration system removes heat from the PCM, causing it to freeze or solidify. In this process, cooling energy is stored in the PCM as latent heat.

Temperature Stabilization: When heat enters the cold storage chamber through door openings, product handling activities, or heat transfer from the surroundings, the PCM absorbs a portion of this heat while gradually melting. This helps maintain a more stable chamber temperature and reduces temperature fluctuations.

Refrigeration Load Reduction: By absorbing part of the incoming heat load, the PCM reduces the instantaneous cooling demand on the refrigeration system and minimizes compressor cycling.

Backup Cooling Function: During short-duration power outages or refrigeration interruptions, the PCM continues to absorb heat while melting, thereby maintaining storage temperatures for a longer duration and protecting stored products.

Cost-Benefit Analysis:

Estimated Investment: 15-35 lakhs

Estimated Annual Savings: 4-10 lakhs

Payback: 36-48 months

Benefits:

- ✓ Improves temperature stability within the cold storage chamber.
- ✓ Reduces refrigeration load fluctuations and compressor cycling.
- ✓ Provides thermal backup during short-duration power interruptions.
- ✓ Can be retrofitted into existing cold storage facilities.



4.1.9. Replacement of Atmospheric Condenser with Evaporative Condenser and Stainless-steel Coils

Background & Problem:

Cold storage refrigeration systems commonly use air-cooled (atmospheric) condensers, which reject heat directly to the surrounding air. These systems face several limitations:

- Reduced heat rejection efficiency, especially during high ambient temperatures
- High condensing pressure leading to increased compressor power consumption
- Large condenser size and higher fan energy usage
- Susceptibility of conventional condenser coils (e.g., copper/aluminum) to corrosion, scaling, and fouling in harsh operating environments

As a result, the system operates at higher compression ratios, reducing efficiency and increasing operating costs. There is also a need for durable and corrosion-resistant materials to ensure long-term reliability in cold storage facilities.

Technology Intervention: Evaporative Condenser

It is proposed to replace the existing atmospheric condenser with an evaporative condenser system equipped with stainless-steel coils.

Working Principle:

- In an evaporative condenser, heat rejection occurs through a combination of evaporation and convection, significantly improving heat transfer efficiency.
- Refrigerant vapor from the compressor enters the stainless-steel condenser coil, where it releases heat and begins to condense.
- Simultaneously:
 - Water is sprayed over the coil surface
 - Air is drawn across the wetted coils using fans
- A portion of the sprayed water evaporates, removing latent heat from the refrigerant. This process allows the system to operate at a condensing temperature close to the wet-bulb temperature, which is significantly lower than dry-bulb temperature (used in air-cooled systems).

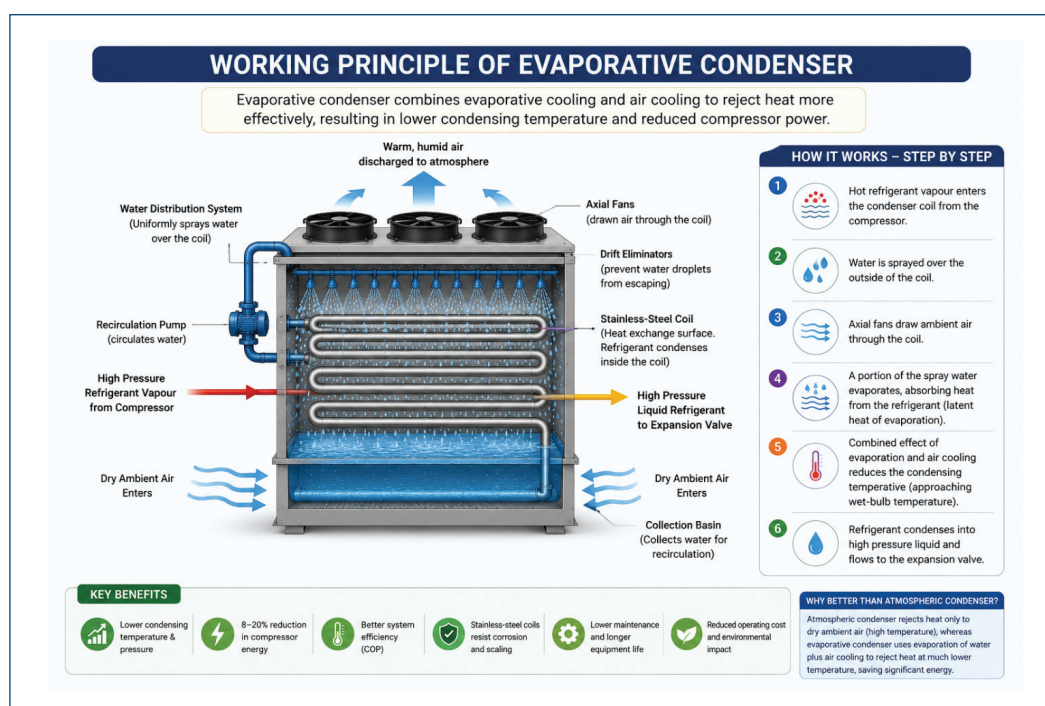


Figure 14: Evaporative Condenser



Applicability: Applicable to cold storage facilities using air-cooled condensers where replacement with an evaporative condenser is technically feasible. Suitability depends on the refrigeration system design, refrigerant type, water availability, and space constraints.

Cost-Benefit Analysis:

Estimated Investment: 10-20 lakhs

Estimated Annual Savings: 6-10 lakhs

Payback: 20-24 months

Benefits:

- ✓ Lower condensing temperature leading to reduced compressor power consumption
- ✓ Improved overall system efficiency and higher COP
- ✓ Reduced operating and electricity costs
- ✓ Compact design compared to air-cooled condensers
- ✓ Stainless-steel coils provide superior corrosion resistance and durability

4.9.10. Integration of Thermal Energy Storage (TES) System with Cold Storage Refrigeration Plant

Background & Problem:

Cold storage facilities experience variations in cooling demand due to fluctuations in ambient conditions, product loading patterns, door openings, and operational activities. To meet peak cooling requirements, refrigeration systems are typically designed for maximum load conditions, resulting in higher compressor capacities, increased peak electricity demand, and elevated operating costs. This increases electricity consumption, peak demand charges, and mechanical stress on refrigeration equipment.

Technology intervention: Integration of Thermal Energy Storage System

Thermal Energy Storage (TES) systems provide an opportunity to store cooling energy during periods of lower demand and utilize the stored cooling during peak load conditions, thereby reducing compressor loading and improving overall plant operation.

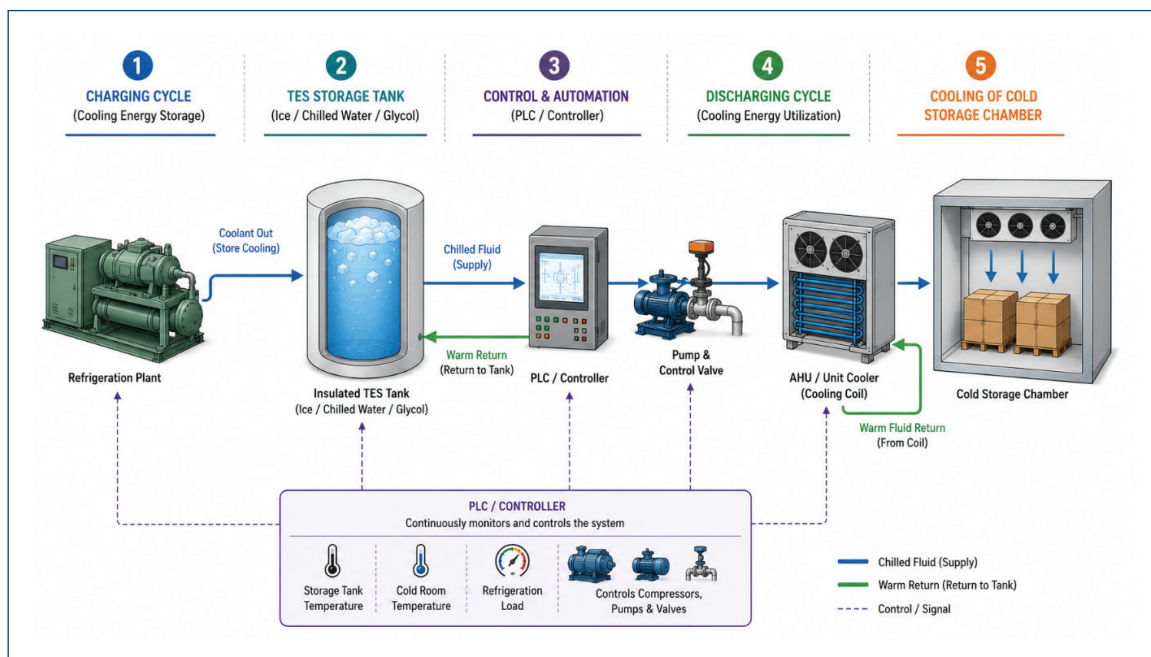


Figure 15: Thermal Energy Storage System



Working principle:

Thermal Energy Storage Medium: The TES system stores cooling energy in the form of ice, chilled water, or chilled glycol within a well-insulated storage tank integrated with the refrigeration system.

Charging Cycle (Cooling Energy Storage): During periods of low cooling demand or off-peak electricity hours, the refrigeration plant removes heat from the storage medium and stores cooling energy by producing ice, chilled water, or chilled glycol.

Control and Automation System: A PLC or refrigeration controller continuously monitors storage tank temperature, cold room temperature, and refrigeration load, and automatically manages the charging and discharging cycles by controlling compressors, pumps, and valves.

Discharging Cycle (Cooling Energy Utilization): During periods of high cooling demand, chilled water or glycol from the storage tank is circulated through cooling coils installed in air handling units (AHUs), unit coolers, or heat exchangers serving the cold storage chambers. In ice storage systems, the melting ice cools the circulating fluid, which is subsequently supplied to the cooling coils.

Cooling of Cold Storage Chamber: Fans within the AHU or unit cooler circulate room air over the cooling coils. Heat from the cold storage chamber is transferred to the chilled fluid, resulting in cooling of the storage space. The warmed fluid is then returned to the storage tank for re-cooling.

Cost-Benefit analysis:

Estimated Investment: 25-60 lakhs

Estimated Annual Savings: 6-15 lakhs

Payback: 36-48 months

Benefits:

- ✓ Lowers peak electricity demand and associated demand charges.
- ✓ Reduces compressor operating hours and cycling frequency.
- ✓ Improves system reliability during short-duration power interruptions.
- ✓ Extends the service life of refrigeration equipment by reducing mechanical stress.

4.2. Water

4.2.1. Low-Energy Dew Point Cooling System for Cold Storage

Background & Problem:

Cold storage systems are usually designed using vapour compression refrigeration, which depends heavily on compressors and continuous electricity supply. This leads to:

- High energy consumption
- Increased operating costs
- Dependence on grid power or diesel backup
- Higher environmental impact due to energy use and refrigerants

However, for many agricultural products such as fruits and vegetables, storage does not require very low temperatures. Instead, maintaining moderate temperatures (15–20°C) is sufficient to preserve quality and extend shelf life.



Technology Intervention: Dew Point Cooling-Based Cold Storage System

The dew point cooling system is an energy-efficient cooling technology that works based on evaporation of water and indirect heat transfer, instead of using a refrigeration cycle.

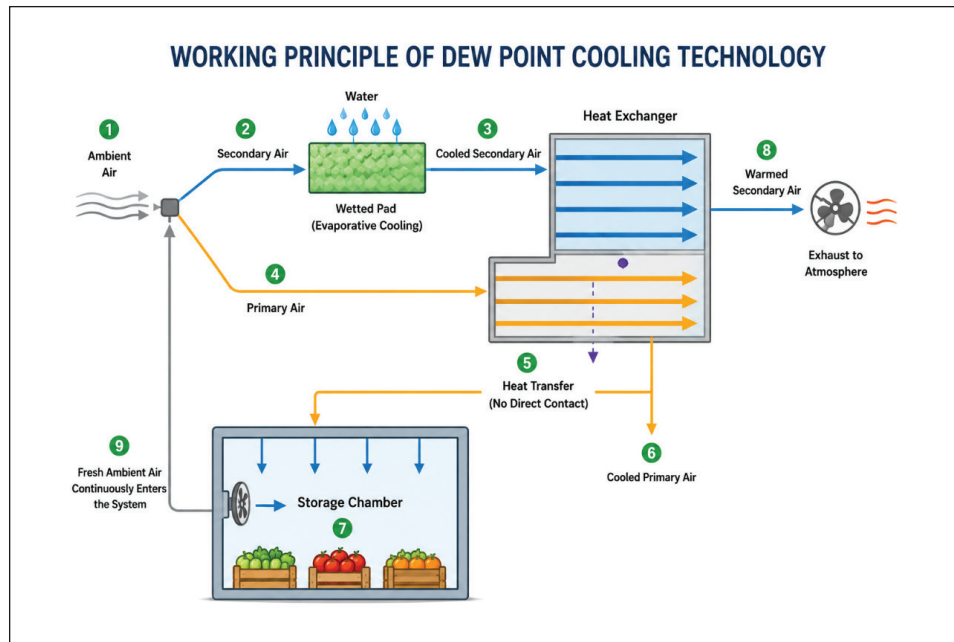


Figure 16: Dew point cooling

Working principle:

- Ambient air is divided into two separate air streams: primary air and secondary air.
- The secondary air passes through wetted pads or surfaces, where water evaporates and absorbs heat, thereby reducing the air temperature.
- The cooled secondary air flows through a heat exchanger.
- Simultaneously, the primary air passes through separate dry channels within the heat exchanger.
- Heat is transferred from the warmer primary air to the cooler secondary air through the heat exchanger without direct contact.
- The primary and secondary air streams remain completely separated and do not mix during the process.
- The cooled primary air is supplied to the storage chamber, where it absorbs heat from the stored produce, lowering the chamber temperature.
- The warmed secondary air is exhausting to the atmosphere.
- Fresh ambient air continuously enters the system, ensuring uninterrupted cooling operation.

Cost-Benefit Analysis:

Estimated Investment: 10-25 lakhs

Estimated Annual Savings: 4-10 lakhs

Payback: 24-48 Months

Benefits:

- ✓ Reduces electricity consumption by 66–71% compared to conventional refrigeration systems
- ✓ Lower operating and maintenance costs
- ✓ Avoids use of high-GWP refrigerants and significantly reduces carbon footprint
- ✓ Provides suitable cooling (20°C) for fruits and vegetables, reducing post-harvest losses



4.3. Environment

4.3.1. Adoption of Low-GWP Natural Refrigerants (Ammonia/CO₂) in Cold Storage Refrigeration Systems

Background & Problem:

Refrigerants are the primary working fluids in refrigeration systems and play a critical role in maintaining the required storage conditions in cold storage facilities. Historically, several refrigeration systems have utilized synthetic refrigerants with high Global Warming Potential (GWP), which contribute significantly to greenhouse gas emissions in the event of refrigerant leakage.

With the phasedown of high-GWP refrigerants under international climate commitments and increasing emphasis on sustainable refrigeration technologies, there is a growing need to transition towards refrigerants with lower environmental impact. Low-GWP refrigerants, particularly natural refrigerants such as ammonia (R717) and carbon dioxide (R744), offer environmentally sustainable alternatives while maintaining the required refrigeration performance for cold storage applications.

Technology Intervention: Adoption of Low-GWP Refrigerants

It is proposed to replace high-GWP refrigerants with low-GWP refrigerants suitable for cold storage applications, subject to technical feasibility and safety considerations.

Typical refrigerant options include:

- Ammonia (R717)
- Carbon Dioxide (R744)
- Hydrocarbon Refrigerants (R290, R1270) where applicable
- Low-GWP HFO blends

Working principle:

Low-GWP Refrigerant: The refrigerant circulates through the refrigeration system and transfers heat from the cold storage chamber to the external environment.

Evaporator: The refrigerant absorbs heat from the storage chamber and evaporates at low pressure, thereby maintaining the required storage temperature.

Compressor: The refrigerant vapour is compressed to a higher pressure and temperature to facilitate heat rejection.

Condenser: The refrigerant rejects heat to the surrounding environment and condenses into a high-pressure liquid.

Expansion Device: The liquid refrigerant undergoes pressure reduction before entering the evaporator, completing the refrigeration cycle.

Cost-Benefit analysis:

Estimated Investment: 10-30 lakhs

Estimated Annual Savings: 3-8 lakhs

Payback: 24-48 months

Benefits:

- ✓ Environment-friendly with low or zero GWP and ODP
- ✓ Compliance with future refrigerant regulations
- ✓ Improved energy efficiency and reduced operating costs
- ✓ Better thermodynamic performance (especially ammonia & CO₂)
- ✓ Reduced carbon footprint of cold storage operations
- ✓ Long-term sustainability and reliability



4.3.2. Controlled Atmosphere (CA) Storage System

Background & Problem

Conventional cold storage preserves agricultural produce primarily by maintaining low temperatures. However, many fruits and vegetables continue to respire even under refrigerated conditions, leading to gradual quality deterioration, moisture loss, ripening, and reduced storage life. For high-value horticultural commodities such as apples, pears, kiwifruit, grapes, and pomegranates, conventional refrigeration alone is often insufficient for long-term storage. This results in:

- Reduced shelf life
- Higher post-harvest losses
- Quality deterioration during storage
- Reduced market value
- Increased food wastage

Technology Intervention: Controlled Atmosphere (CA) Storage System

Controlled Atmosphere (CA) storage is an advanced cold storage technology that maintains precise concentrations of oxygen (O_2), carbon dioxide (CO_2), temperature, and relative humidity inside a gas-tight cold room. By reducing oxygen concentration and controlling carbon dioxide levels, the respiration rate of stored produce is significantly slowed, thereby extending storage life while preserving freshness and quality.

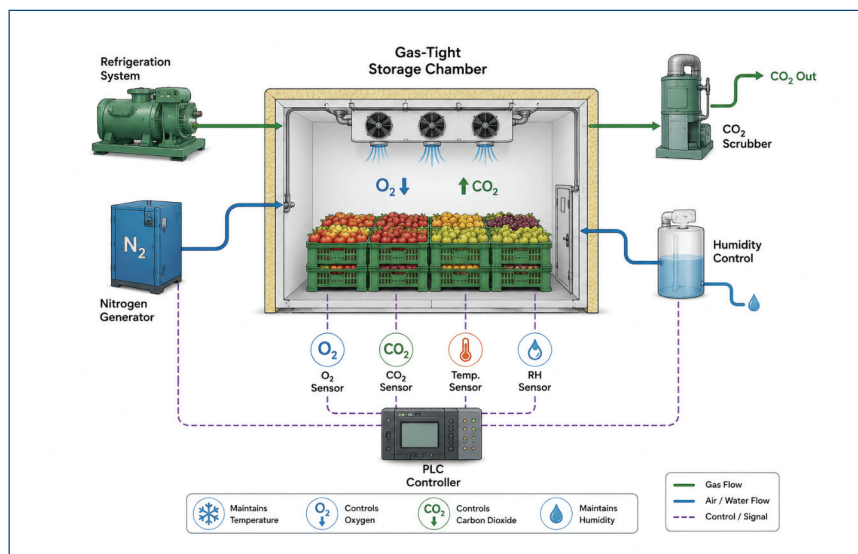


Figure 17: Controlled atmosphere storage system

Working Principle:

Gas-Tight Storage Chamber: Fresh produce is stored inside a gas-tight insulated chamber that minimizes air leakage and enables precise control of the internal atmosphere.

Refrigeration System: The refrigeration system lowers the storage temperature to the desired level, slowing the respiration rate and preserving product quality.

Nitrogen Generation and CO_2 Control: A nitrogen generator reduces the oxygen concentration inside the chamber, while a CO_2 scrubber removes excess carbon dioxide produced during respiration. This creates the optimum atmosphere for long-term storage.

Humidity Control System: Humidity control equipment maintains the required relative humidity to minimize moisture loss and prevent condensation.

Sensors and PLC Controller: Oxygen, carbon dioxide, temperature, and humidity sensors continuously monitor the storage conditions. A PLC compares the measured values with predefined setpoints and automatically controls the refrigeration system, nitrogen generator, CO_2 scrubber, and humidity control equipment to maintain optimum storage conditions.



Cost-Benefit Analysis:

Estimated Investment: 50–200 lakhs

Estimated Annual Savings: 15–60 lakhs

Payback: 36–48 months

Note: Actual investment depends on refrigeration capacity, hot water demand, and system configuration.

Benefits:

- ✓ Extends the storage life of high-value fruits and vegetables by reducing respiration and delaying ripening.
- ✓ Reduces post-harvest losses and food wastage.
- ✓ Maintains product freshness, firmness, colour, and market quality.
- ✓ Enhances resource efficiency by minimizing product losses throughout the supply chain.

4.4. Renewable Energy

4.4.1. Grid-connected Rooftop Solar PV System

Background & Problem:

Cold storage facilities consume substantial amounts of electricity for refrigeration, air circulation, lighting, pumps, and auxiliary systems required to maintain controlled storage conditions. Rising electricity tariffs significantly increase operating costs, while reliance on grid power contributes to indirect carbon emissions. Since most cold storage facilities have large unobstructed roof areas, rooftop solar PV systems offer an effective opportunity to reduce electricity costs, enhance energy security, and support sustainable cold chain operations.

Technology intervention – Installation of 50 kWp Rooftop Solar PV System:

It is proposed to install a 50 kWp Rooftop Solar PV System at the cold storage facility.

The proposed system will consist of:

- Solar PV modules,
- Grid-connected inverter,
- Module mounting structures,
- AC/DC distribution panels,
- Protection and monitoring systems,
- Net metering arrangement.



Figure 18: Rooftop solar PV system

**Working Principle:**

- Solar photovoltaic modules convert incident solar radiation directly into direct current (DC) electricity through the photovoltaic effect.
- The DC power generated by the PV modules is collected through DC cabling and routed to a grid-connected inverter.
- The inverter converts the DC power into alternating current (AC) power synchronized with the plant's electrical system and utility grid parameters.
- The generated AC power is supplied directly to the plant loads, offsetting a portion of the electricity that would otherwise be drawn from the grid.
- During periods when solar generation exceeds the plant's instantaneous demand, surplus electricity is exported to the utility grid through a net metering arrangement.
- When solar generation is insufficient, such as during nighttime or low solar irradiance conditions, the required power is automatically imported from the grid to ensure uninterrupted plant operation.
- The monitoring and protection systems continuously supervise system performance, energy generation, voltage levels, and safety parameters to ensure reliable and efficient operation.

Cost-Benefit Analysis:

Estimated Investment: 25 lakhs

Estimated Annual Savings: 6.4 lakhs

Payback: 46 months

Benefits:

- ✓ Reduces grid electricity consumption and operating cost.
- ✓ Utilizes renewable solar energy for industrial operations.
- ✓ Reduces carbon emissions and supports sustainability initiatives.
- ✓ Improves energy security by reducing dependence on grid power

4.4.2. Solar–wind Hybrid Power System for Cold Storage**Background & Problem:**

Cold storage facilities require a continuous and reliable electricity supply to maintain the desired storage temperature and preserve product quality. In many rural and agricultural regions, frequent power interruptions, voltage fluctuations, and rising electricity costs increase operating expenses and affect refrigeration reliability. Although rooftop solar photovoltaic (PV) systems can reduce grid dependence during daytime, they cannot generate electricity at night or during periods of low solar irradiance.

These challenges lead to:

- High dependence on grid electricity and diesel generators.
- Increased operating costs.
- Higher greenhouse gas emissions.
- Risk of temperature fluctuations during power interruptions.

Technology Intervention: Solar–Wind Hybrid Power System

The solar–wind hybrid power system is an integrated renewable energy solution that combines solar photovoltaic (PV) panels and wind turbines to generate electricity. By leveraging two complementary energy sources, the system ensures more stable and reliable power generation compared to standalone renewable systems.

- Solar energy is available during daytime
- Wind energy is often available during night or non-sunny periods



Working Principle:

Solar PV Panels:

- Solar photovoltaic (PV) panels convert sunlight into direct current (DC) electricity during daytime.
- The generated power is utilized to meet the electrical load of the cold storage facility.

Wind Turbine and Generator:

- The wind turbine converts wind energy into mechanical energy, which drives a generator to produce electricity.
- Wind power supplements solar generation and can produce electricity during cloudy weather and nighttime when sufficient wind is available.

Hybrid Charge Controller with MPPT:

- The electricity generated from the solar PV panels and wind turbine is regulated through a hybrid charge controller with Maximum Power Point Tracking (MPPT).
- The controller optimizes power generation from both renewable sources and manages the power flow.

Battery Storage and Grid Integration:

- The generated electricity is supplied to the cold storage loads, while surplus energy is stored in the battery bank (if provided) or exported to the utility grid.
- During periods of low renewable energy generation, the battery or grid supplies the additional power required for uninterrupted operation.

Power Supply to Cold Storage:

- A hybrid inverter converts DC electricity into AC electricity and supplies power to compressors, condensers, evaporator fans, pumps, lighting, and other electrical equipment.
- This reduces dependence on conventional grid electricity and improves the reliability of cold storage operations.

Cost-Benefit Analysis:

Estimated Investment: 50 lakhs

Estimated Annual Savings: 8 lakhs

Payback: 75 Months

Note: For 50 kWp (Solar-wind combined)

Benefits:

- Reduces dependence on grid electricity and diesel generators.
- Lowers electricity costs through renewable energy generation.
- Improves energy reliability in areas with unstable grid supply.
- Reduces greenhouse gas emissions and supports cleaner production.

4.4.3. Biomass-Powered Vapour Adsorption Refrigeration System for Cold Storage

Background & Problem:

Cold storage facilities predominantly rely on electrically driven vapour compression refrigeration systems. These systems consume substantial electrical energy for compressor operation, leading to:

- High operating costs due to rising electricity tariffs
- Increased dependence on grid power or diesel generators in rural/off-grid areas
- Higher indirect carbon emissions
- Limited feasibility of cold storage facilities in remote agricultural zones with unreliable electricity supply



Technology Intervention: Biomass-Based Vapour Adsorption Refrigeration System

The biomass-powered vapour adsorption refrigeration system (GreenCHILL) is an alternative cooling technology that uses thermal energy instead of mechanical compression to produce refrigeration. It operates on an adsorption refrigeration cycle, where heat generated from biomass combustion is used to drive the cooling process.

Working principle:

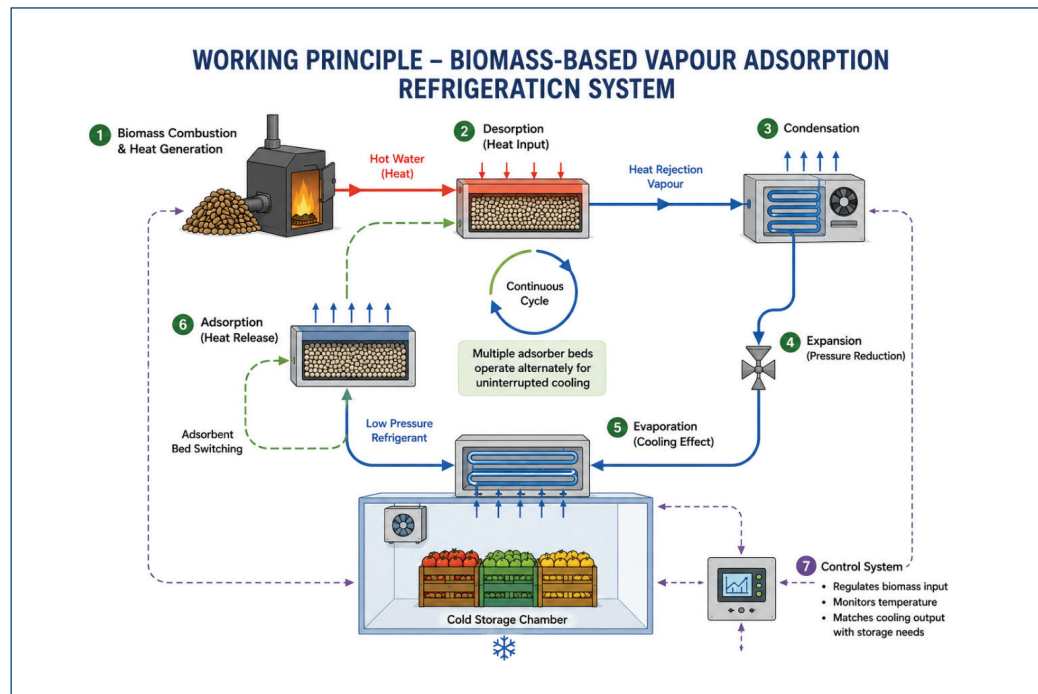


Figure 19: Biomass-Powered Vapour Adsorption Refrigeration System for Cold Storage

Biomass Combustion and Heat Generation:

- Biomass such as agricultural waste or briquettes is combusted to generate thermal energy in the form of hot water.

Adsorption Cycle:

- The system operates on adsorption-desorption principles.
- Heat from biomass drives the desorption process, releasing refrigerant vapour from the adsorbent material.

Condensation Process:

- The refrigerant vapour is condensed by rejecting heat to the surrounding environment.

Expansion and Cooling:

- The condensed refrigerant undergoes pressure reduction and enters the evaporator at low pressure.
- It absorbs heat from the cold storage chamber, producing the cooling effect.

Adsorption Phase:

- The refrigerant vapour is re-adsorbed by the adsorbent material, completing the cycle.

Continuous Operation:

- Multiple adsorber beds operate alternately to ensure uninterrupted cooling.

Control System:

- Automated controls regulate biomass input, system temperature, and cooling output to match storage requirements.

**Cost-Benefit Analysis:**

Estimated Investment: 25-80 lakhs

Estimated Annual Savings: 8-20 lakhs

Payback: 36-48 months

Note: Actual investment depends on refrigeration capacity, hot water demand, and system configuration.

Benefits:

- ✓ Significant reduction in electrical energy consumption
- ✓ Suitable for off-grid and rural cold storage facilities
- ✓ Utilizes low-cost, locally available biomass fuel
- ✓ Reduces dependence on diesel generators and grid electricity
- ✓ Lower carbon emissions due to renewable energy use
- ✓ Enhances energy security in areas with unreliable power supply



05 Additional Measures

Additional Resource Efficiency and Cleaner Production measures are broadly classified into the following three categories based on investment requirement, implementation complexity, and level of analysis needed:

Low Cost - Easy to implement options:

Minimal or nil investment measures that can be implemented quickly with short payback periods. These include operational improvements and minor modifications aimed at achieving immediate efficiency gains.

Medium Investment - Options requiring further information and detailed analysis:

Medium investment interventions that involve the adoption of advanced process technologies require in-depth technical analysis, performance assessment, and financial feasibility studies.

High Investment - Options for consideration at a later stage (Resource Dependent):

Capital-intensive measures require major changes and long-term planning. Suitable for future expansion or phased implementation.

5.1. Low Investment

Table 9: Low investment RECP measures

S. No	RECP Opportunities	Description
1	Automatic Door Closing / Door Interlock System	Automatically closes cold room doors and prevents simultaneous opening, reducing cold air loss and minimizing heat ingress into storage areas.
2	Air Curtains / PVC Strip Curtains	Creates a barrier at door openings to reduce warm air infiltration during loading and unloading, helping maintain stable cold room temperature.
3	Demand-Controlled Ventilation	Adjusts ventilation based on actual air quality or occupancy requirements, reducing unnecessary fan operation and energy consumption.
4	Automatic Refrigerant Leak Detection System	Continuously monitors refrigerant levels and detects leaks early, improving system safety, efficiency, and reducing environmental impact.
5	Automatic Power Factor Correction (APFC) System	Maintains optimal power factor by minimizing reactive power losses, thereby improving electrical efficiency and avoiding utility penalties.
6	Replacement of Low-Speed Compressors with High-Speed Screw Compressors	Higher rotational speed and improved rotor design provide greater refrigeration capacity with lower specific power consumption.



5.2. Medium Investment

Table 10: Medium investment RECP measures

S. No	RECP Opportunities	Description
1	High-speed insulated cold room doors	Rapid opening and closing insulated doors minimize exposure time during loading and unloading, significantly reducing heat ingress and refrigeration load.
2	EC (Electronically Commutated) fans for evaporators	Energy-efficient fans with integrated motor control that optimize air flow and reduce electricity consumption compared to conventional AC fans.
3	VFD for evaporator fans	Adjusts fan speed based on cooling demand, reducing unnecessary energy consumption and improving overall refrigeration system efficiency.
4	Replacement of conventional motors with IE3/IE4 energy efficient motors	High-efficiency motors reduce electrical losses and improve performance of compressors, pumps, and fans, leading to lower energy consumption.
5	Automatic defrost optimization system	Optimizes defrost cycles based on actual frost formation rather than fixed schedules, reducing energy use and maintaining evaporator efficiency.
6	High efficiency LED lighting with controls	Replaces conventional lighting with low-energy LED systems integrated with occupancy or timer controls to reduce electricity consumption and heat load.

5.3. High Investment

Table 11: High investment RECP measures

S. No	RECP Opportunities	Description
1	Replacement of existing insulation with PUF or PIR panels	Upgrading insulation reduces heat ingress into cold rooms, significantly lowering refrigeration load and improving temperature stability.
2	Dock shelters and dock levelers	Sealed loading interfaces minimize air infiltration during loading and unloading, reducing thermal losses and improving energy efficiency.
3	Replacement of reciprocating compressors with screw compressors	High-capacity screw compressors provide better efficiency under varying load conditions, reduce energy consumption, and improve system reliability.
4	Automated storage and retrieval system (ASRS)	Automated material handling system that optimizes storage space, reduces door opening frequency, and improves operational efficiency and inventory management.



06 Financial Mechanism & Support Schemes

The adoption of Resource Efficiency and Cleaner Production (RECP) technologies in cold storage facilities often requires substantial investment in refrigeration systems, renewable energy, automation, insulation, and energy-efficient equipment. To encourage modernization of the cold chain sector, the Government of India, Government of Telangana, and financial institutions provide financial assistance through capital subsidies, interest subvention, credit guarantees, and concessional financing. Cold storage operators can leverage these schemes to reduce investment costs and accelerate the implementation of sustainable technologies.

6.1. Financial Support Schemes for Cold Storage Sector

Table 12: Financial Support Schemes for Cold Storage Sector

Scheme	Implementing Agency	Type of Support	Suitable For
PM Kisan SAMPADA Yojana (PMKSY)	Ministry of Food Processing Industries (MoFPI)	Capital assistance	New cold storage, integrated cold chain projects, modernization
Agriculture Infrastructure Fund (AIF)	Ministry of Agriculture & Farmers Welfare	Interest subvention and credit guarantee	Cold storage, warehouses, pack houses, post-harvest infrastructure
PM Formalisation of Micro Food Processing Enterprises (PMFME)	Ministry of Food Processing Industries	Credit-linked subsidy	Food processing units incorporating cold storage facilities
Prime Minister's Employment Generation Programme (PMEGP)	KVIC	Margin money assistance	New MSMEs and cold storage entrepreneurs
Credit Guarantee Fund Trust for Micro and Small Enterprises (CGTMSE)	Ministry of MSME & SIDBI	Collateral-free credit guarantee	MSMEs requiring bank finance for technology upgradation
MSME Sustainable (ZED)	Ministry of MSME	Financial assistance for certification and sustainable practices	MSMEs adopting cleaner production technologies
MSE-GIFT	Ministry of MSME	Interest subvention for eligible green technologies	Energy-efficient refrigeration and RECP technologies

6.2. Telangana State Support Schemes

Table 13: Telangana State Incentive Schemes for Cold Storage Facilities

Scheme	Key Support
Telangana Logistics Policy	Incentives for warehouses and cold storage infrastructure, including capital and interest support for eligible projects.
T-IDEA	Capital investment subsidy, reimbursement of stamp duty and registration charges, interest subsidy, and other incentives for eligible MSMEs.
T-PRIDE	Enhanced financial assistance for SC/ST entrepreneurs establishing industrial units.
TG-iPASS	Single-window approval system for obtaining statutory clearances and approvals.



6.3. Green Financing Opportunities

Apart from Government schemes, several financial institutions provide dedicated financing for energy-efficient and low-carbon technologies.

- **SIDBI Green Finance** – Financing for renewable energy, energy-efficient refrigeration systems, and cleaner production technologies.
- **Commercial Bank Green Loans** – Several public and private sector banks provide loans for solar PV systems, energy-efficient refrigeration equipment, and cold chain modernization.
- **NABARD Infrastructure Financing** – Financial assistance for agricultural infrastructure, including cold storage facilities and integrated value chains.

6.4. RECP Technologies Eligible under MSE-GIFT

The MSE Green Investment and Financing for Transformation (MSE-GIFT) scheme supports MSMEs in adopting energy-efficient and low-carbon technologies through interest subvention on eligible term loans. Several technologies relevant to cold storage facilities are included in the approved technology catalogue and can significantly improve energy efficiency, reduce operating costs, and lower greenhouse gas emissions.

Table 14: Major RECP Technologies Eligible under MSE-GIFT for Cold Storage Facilities

Eligible Technology	Application in Cold Storage
Energy-efficient refrigeration compressors	Improve refrigeration efficiency and reduce electricity consumption.
De-superheater for chiller compressors	Recovers waste heat from refrigeration systems for hot water applications.
Ice Bank Tank (IBT)	Stores cooling energy during off-peak hours to reduce peak electricity demand.
Thermal Energy Storage (TES) System	Stores chilled energy for use during peak load periods and improves system efficiency.
CO ₂ packaged chilling units	Low-GWP refrigeration solution with improved energy performance.
High-efficiency cooling towers	Enhance condenser performance and reduce compressor power consumption.
Cooling tower fan temperature controllers	Automatically regulate fan speed based on cooling demand to save energy.
Thermal insulation systems	Reduce heat gain through insulated walls, roofs, and pipelines.
High-efficiency motors	Improve efficiency of compressors, pumps, and evaporator fans.
Variable Frequency Drives (VFDs)	Optimize motor speed according to cooling demand and reduce electricity consumption.
Automatic Power Factor Correction (APFC) Systems	Improve power factor and reduce electrical losses and demand charges.

6.5. Circular Economy Support under MSE-SPICE

The MSE Scheme for Promotion and Investment in Circular Economy (MSE-SPICE) encourages existing MSMEs to adopt circular economy practices by providing a Credit Linked Capital Subsidy for eligible resource-efficient technologies. The scheme supports investments that improve energy efficiency, recover waste resources, minimize waste generation, and promote sustainable industrial operations.

For cold storage facilities, the following technologies align well with the objectives of the MSE-SPICE scheme.

**Table 15: RECP Technologies Supporting Circular Economy under MSE-SPICE**

Technology	Circular Economy Benefit
Heat recovery system from refrigeration plant	Recovers waste heat for hot water generation, reducing energy consumption.
De-superheater for refrigeration compressors	Utilizes compressor waste heat instead of rejecting it to the atmosphere.
Thermal Energy Storage (TES) System	Stores excess cooling energy for later use, improving energy utilization.
Ice Bank Tank (IBT)	Shifts cooling load to off-peak hours and minimizes energy wastage.
Vapour Absorption Refrigeration System	Utilizes waste heat or renewable thermal energy for refrigeration.
Water recycling systems for cooling towers	Reduce freshwater consumption through reuse of treated water.
Effluent treatment and water reuse systems	Enable recycling of process water for non-potable applications.

6.6. Institutions Supporting Cold Storage Development

Table 16: Key Institutions Supporting Cold Storage Development and RECP Adoption

Organization	Role
Ministry of Food Processing Industries (MoFPI)	Cold chain infrastructure schemes
Ministry of MSME	MSME development and technology support
National Centre for Cold-chain Development (NCCD)	Technical guidance and best practices
NABARD	Agricultural infrastructure financing
SIDBI	Green finance and MSME credit
Government of Telangana	State incentives and industrial promotion
District Industries Centres (DICs)	Facilitation of state and central schemes
Telangana Food Processing Society (TGFPS)	Support for food processing and cold chain projects





07 Implementation Roadmap

The implementation roadmap for Resource Efficient and Cleaner Production (RECP) in the cold storage sector is structured into four progressive phases based on priority, investment level, and technological maturity. The roadmap begins with immediate efficiency improvements in refrigeration and utilities, and gradually advances toward advanced control systems, renewable integration, and long-term modernization.

This phased approach enables cold storage facilities, particularly MSMEs, to systematically improve energy efficiency, resource utilization, operational reliability, and environmental sustainability.

7.1. Phase-wise Implementation Roadmap

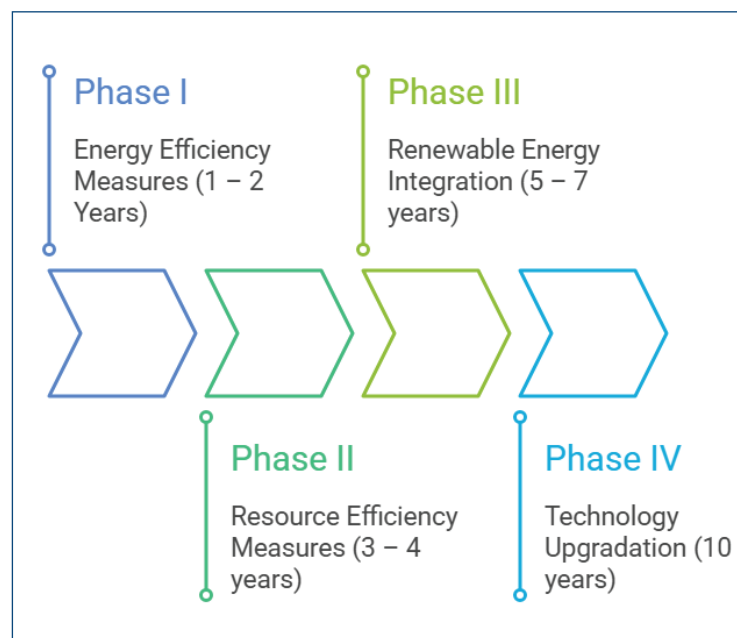


Figure 20: Implementation Roadmap

Phase I: Energy Efficiency Measures (1 – 2 Years)

MSMEs initiate their RECP journey by improving energy efficiency in existing systems and utilities. These measures are prioritized as they deliver immediate cost savings and improve process reliability with minimal disruption.

Key Measures:

- Optimization of refrigeration systems (compressors, condensers, evaporators)
- Preventive maintenance and system tuning
- Installation of energy-efficient equipment (VFDs, efficient motors, EC fans)
- Floating head pressure and compressor optimization
- Thermal insulation improvement (walls, doors, piping)
- Reduction of heat ingress (door management, air curtains, strip curtains)
- Energy monitoring and tracking systems (EMS)
- Operator training for efficient system operation



Phase II: Resource Efficiency Measures (3 – 4 years)

This phase focuses on efficient utilization of energy, air, and materials inside the cold storage facility, along with improved process control.

Key Measures:

- Implementation of smart monitoring systems (IoT-based systems)
- Advanced PLC-based control of temperature, humidity, and airflow
- Demand-controlled ventilation (DCV) for optimized air management
- Reduction of product losses through better environmental control
- Optimization of refrigerant usage and leak reduction
- Improved defrosting strategies and moisture management
- Integration of data-based performance monitoring and analysis
- Adoption of cleaner production and operational optimization practices

Phase III: Renewable Energy Integration (5 – 7 years)

This phase emphasizes the transition toward renewable and low carbon energy sources. The objective is to reduce dependence on fossil fuels and improve long term sustainability.

Key Measures:

- Rooftop solar photovoltaic (PV) systems for cold storage loads
- Hybrid systems integrating solar with grid/diesel backup
- Energy storage systems (battery storage) for load management
- Smart energy management integration with renewable sources

Phase IV: Technology Upgradation (10 years)

This phase focuses on transitioning toward advanced, automated, and sustainable cold storage systems aligned with global standards.

Key Measures:

- Adoption of advanced refrigeration technologies (CO₂, ammonia systems, green refrigerants)
- Full automation and digitalization (Industry 4.0 integration)
- Smart cold storage systems with AI/IoT-based optimization
- Advanced thermal storage and integrated energy systems
- Circular economy practices (waste heat reuse, material recovery)

7.2. Role of stakeholders

Successful implementation of Resource Efficient and Cleaner Production requires coordinated efforts from multiple stakeholders. MSMEs often face constraints related to finance, technology adoption, and technical expertise. Therefore, a strong support ecosystem is essential for effective implementation.

The Government of Telangana, through the Director of Industries and Research and Innovation Circle of Hyderabad, plays an important role in policy support, awareness generation, and capacity building. It also facilitates access to financial incentives and schemes.

Financial institutions support MSMEs by providing credit, subsidies, and green financing options for adopting RECP measures.



Technology providers and clean technology startups contribute by offering efficient technologies, process optimization solutions, and digital tools. These stakeholders collectively enable MSMEs to improve resource efficiency, reduce environmental impact, ensure regulatory compliance, and enhance long term competitiveness.

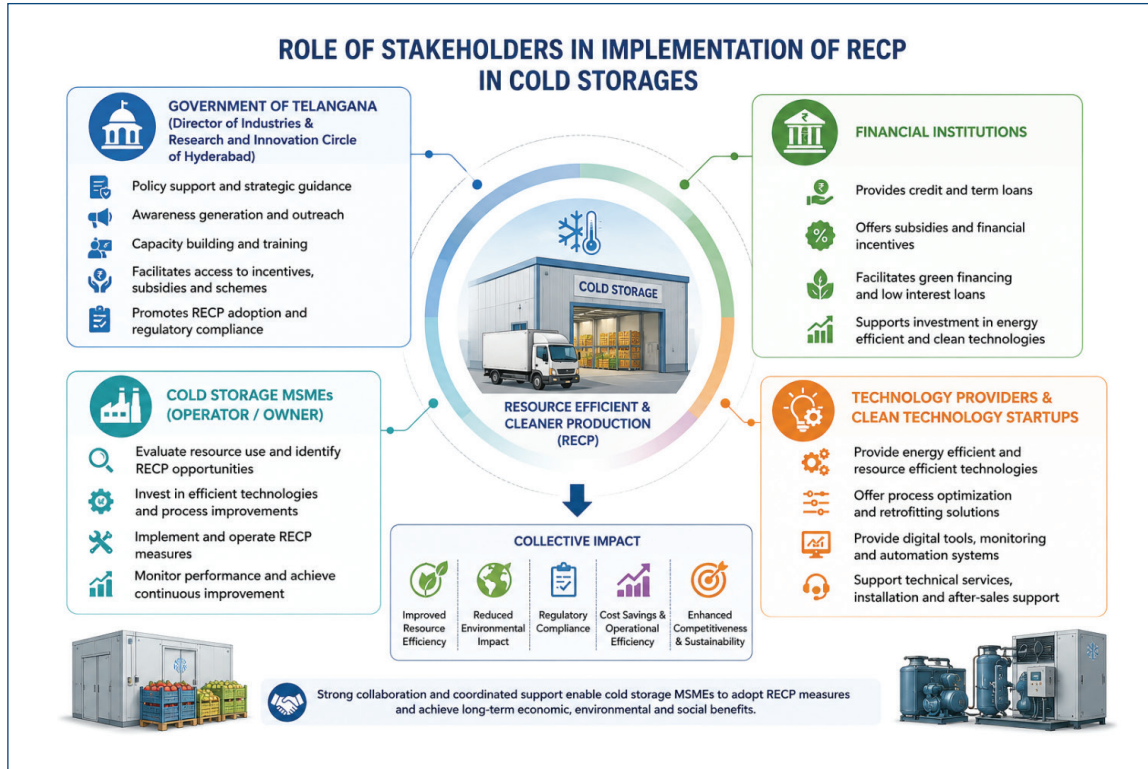


Figure 21: Role of stakeholders in Implementation Roadmap





08 Conclusion

The cold storage sector is a critical enabler of India's agricultural and food supply chains, supporting preservation of perishable commodities, enhancing food security, and improving farmer incomes. This compendium presents a comprehensive overview of the sector, including cold storage processes, energy consumption patterns, cleaner production opportunities, and implementation pathways for sustainable transformation.

The analysis highlights that, although the sector has expanded significantly, it continues to face key challenges such as high energy consumption, ageing infrastructure, inefficient refrigeration systems, and inadequate adoption of modern technologies. Refrigeration systems dominate energy usage, accounting for 70–85% of total energy consumption, making them the primary focus for efficiency improvement.

Key insights from this compendium include:

- Refrigeration systems are the most energyintensive component, and their optimization offers the highest potential for energy savings and cost reduction.
- Poor operational practices, such as lack of precooling, excessive door openings, and improper loading, significantly increase energy demand and reduce system efficiency.
- Resource Efficient and Cleaner Production (RECP) interventions can typically achieve substantial savings in energy consumption, improve system performance, and reduce operating costs with relatively short payback periods.
- Advanced technologies, including thermal energy storage systems, controlled atmosphere storage, smart monitoring systems, renewable energy integration, and alternative cooling solutions, provide significant improvements in efficiency, reliability, and environmental performance.
- With strong policy support, increasing demand for cold chain infrastructure, and growing focus on food preservation, states such as Telangana are well positioned to expand sustainable cold storage capacity, particularly in agriculturedriven clusters.

The transition toward energyefficient and sustainable cold storage systems is no longer optional. Rising electricity costs, increasing demand for reliable cold chains, environmental concerns, and the need to reduce post-harvest losses necessitate a structured and phased implementation approach across the sector.

This compendium emphasizes that a stepwise approach, starting with low-cost operational improvements, followed by system optimization and automation, and ultimately progressing toward renewable energy integration and advanced technologies, can enable MSMEs to achieve long term sustainability and competitiveness.

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Greening of MSMEs in Telangana

The Government of Telangana has taken up the “Greening of MSMEs” initiative, under the Raising and Accelerating MSME Performance (RAMP) Programme, with an intent to support MSMEs in adopting sustainable and resource-efficient industrial practices. Research and Innovation Circle of Hyderabad (RICH) is implementing the Greening of MSMEs program in Telangana with technical support and program delivery comprising awareness creation, energy audits, and handholding support being provided by CII. The initiative promotes cleaner technologies, energy and water conservation, waste reduction, and improved operational efficiency through Resource Efficient and Cleaner Production (RECP) assessments, awareness programs, and cluster-level interventions. By facilitating technical guidance and implementation support, the programme helps MSMEs reduce environmental impact, improve productivity, and enhance their competitiveness in both domestic and global markets.

Research and Innovation Circle of Hyderabad (RICH)

RICH was launched in 2017 as a first-of-its-kind initiative by the Government of Telangana. RICH was established to bridge the gap between research and real-world applications by enabling collaboration among research institutions, industry, startups, and government bodies.

RICH also serves as Hyderabad’s Science and Technology City Cluster, under a national initiative led by the Office of the Principal Scientific Adviser to the Government of India. In this capacity, RICH drives multidisciplinary projects to address complex local and national challenges.

Working at the intersection of science, technology, and entrepreneurship, RICH focuses on three critical sectors “Life Sciences”, “Food & Agriculture”, and “Sustainability”. In the Sustainability area, RICH focuses on Clean Energy Transition, Industrial Decarbonization and Circularity through strategic partnerships, pilot initiatives, and policy engagement. RICH fosters a culture of innovation that delivers scalable and transformative solutions for long-term impact.

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