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Alliance for an Energy Efficient Economy



PACKHOUSE DESIGN GUIDELINES

Design Guidelines for Energy-Efficient Packhouse Infrastructure for an Integrated Cold-Chain

September 2026



The United Nations Environment Programme (UNEP) Cool Coalition, in partnership with the Alliance for an Energy Efficient Economy (AEEE), is implementing the project "Scaling-up Investment in Clean and Efficient Cold chain in India." The project aims to accelerate the development of sustainable and integrated cold chain in India and selected states. It supports the national government and two states, namely Bihar and Haryana, in mainstreaming energy-efficient, renewable energy-powered, and low- global warming potential (GWP) refrigerant-based cold chain infrastructure and services in rural areas, with a particular focus on packhouses and reefer transport as part of an integrated cold-chain. The project contributes to the implementation of India's Cooling Action Plan and seeks to enhance rural livelihoods.

The Cool Coalition is a global multi-stakeholder network that connects a wide range of key actors from government, cities, international organizations, businesses, finance, academia, and civil society groups to facilitate knowledge exchange, advocacy and joint action towards a rapid global transition to efficient and climate-friendly cooling.

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The draft Report was submitted for approval to the Technical Committee established by BEE, chaired by the National Centre for Cold-chain Development (NCCD), comprising, Ministry of Environment, Forest & Climate Change (MoEF&CC); MIDH of Ministry of Agriculture & Farmer's Welfare (MoA&FW); National Agriculture Infra Financing Facility, Extension, AIF, Investment & Price Support under MoA&FW; Ministry of Food Processing Industry (MoFPI); Ministry of New and Renewable Energy (MNRE); Agriculture Vertical of National Institute for Transforming India (NITI) Aayog; Post-Harvest and Cold Chain Development of NABARD; National Cooperative Development Corporation (NCDC); Central institute of Post-Harvest Engineering and Technology (CIPHET); Indian Council of Agriculture & Research (ICAR); Agricultural and Processed Food Products Export Development Authority (APEDA); Confederation of Indian Industry (CII); Air-conditioning, Heating &Refrigeration Institute (AHRI); Refrigeration & Air-conditioning Manufacturers Association (RAMA); Indian Society of Heating, Refrigerating & Air Conditioning Engineers (ISHRAE); Blue Star; Carrier; Daikin; Danfoss; Emerson; Voltas; Inficold; Ecozen; New Leaf Dynamic Technologies; PLUSS Advance technologies; Covestro; Thermax Ltd.; Agri-Value Chain Service Pvt. Ltd.; Global Agri System Pvt. Ltd.; and CLASP. This Committee's comments were incorporated, and their approval of this design guideline is appreciated.

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List of Abbreviations and Symbols

Abbreviation	Full Form
%	Percent
°C	Degree Celsius
AC	Air Conditioner
ACH	Air Changes Per Hour
ACU	Air Cooling Unit
APEDA	Agricultural & Processed Food Products Export Development Authority
APFC	Agriculture Produce Marketing Committees
ASHRAE	American Society of Heating, Refrigerating, and Air- Conditioning Engineers
ASTM	American Society for Testing & Materials
BAU	Business as Usual
BOPT	Battery Operated Pallet Truck
BS	British Standard
CAGR	Compounded Annual Growth Rate
CFM	Cubic Feet Per Minute
CMH	Cubic Metre Per Hour
CO2	Carbon Dioxide
COP	Coefficient of Performance
CPCB	Central Pollution Control Board
CSCF	Cooling Seasonal Performance Factor
DBT	Dry Bulb Temperature
DC	Distribution Center
DEC	Direct Evaporative Cooling
DFI	Doubling Farmers' Income
DG	Diesel Generator
DX	Direct Expansion

Abbreviation	Full Form
ECSBC	Energy Conservation Sustainable Building Code
EEMs	Energy Efficiency Measures
EPDM	Ethylene Propylene Diene Monomer
EPS	Expanded Polystyrenes
EXV	Electronic Expansion Valves
F&V	Fruits & Vegetables
FAO	Food and Agriculture Organization
FAR	Floor Area Ratio
FDA	Food and Drug Administration
FPO	Farmer Producer Organisation
FRP	Fibre Reinforced Polymers
GHG	Greenhouse Gas
GSM	Gram Per Square Metre
GST	Goods and Service tax
GWP	Global Warming Potential
HACCP	Hazard Analysis and Critical Control Points
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HD	High Density
HFC	Hydro Fluorocarbon
HFO	Hydrofluro-Olefin
HPMP	HCFC Phaseout Management Plan
HVLS	High-Volume Low-Speed
ICAP	India Cooling Action Plan
ICAR-CIPHET	Indian Council of Agricultural Research - Central Institute of Post-Harvest Engineering and Technology

Abbreviation	Full Form
IDEC	Indirect Direct Evaporative Cooling
INR	Indian Rupee
ISHRAE	Indian Society of Heating, Refrigerating and Air- Conditioning Engineers
ISO	International Organization for Standardization
KVA	Kilovolt-Ampere
kWh	Kilowatt-Hour
l/s	Litre Per Second
LC	Least Count
LED	Light Emitting Diode
m3	Metre Cube
MoA&FW	Ministry of Agriculture & Farmers' Welfare
MoEF&CC	Ministry of Environment, Forest and Climate Change
MT	Metric Ton
NBC	National Building Code
NCCD	National Centre for Cold chain Development
NHB	National Horticulture Board
NPPO	National Plant Protection Organization
O&M	Operations and Maintenance
ODS	Ozone-Depleting Substances
P&ID	Piping & Instrumentation Diagram
PCC	Power Control Centre
PCM	Phase Change Material
PEB	Pre-Engineered Building
pH	Potential of Hydrogen
PIB	Press Information Bureau
PIR	Poly Iso-Cyanurate
PLC	Programmable Logic Control
PMS	Packing Material Store
PPC	Production Planning & Control
PPM	Parts Per Million

Abbreviation	Full Form
PQ	Produce Quality
PUF	Polyurethane Form
PV	Photovoltaic
RCC	Reinforced Cement Concrete
REGZ	Renewable Energy Generating Zone
RES	Renewable Energy System
RH	Relative Humidity
SCADA	Supervisory Control & Data Acquisition
SFAC	Small Farmer's Agri-Business Consortium
SHGC	Solar Heat Gain Coefficient
SOP	Standard Operating Procedure
SRI	Solar Reflectance Index
SS	Stainless Steel
STP	Sewage Treatment Plant
SWOT	Strengths, Weaknesses, Opportunities, And Threats
TAPPI	Technical Association of The Pulp and Paper Industry
TCT	Total Coated Thickness
TD	Temperature Difference
TDS	Total Dissolved Solids
TES	Thermal Energy Storage
TR	Ton of Refrigeration
UG	Under Ground
UNEP	United Nations Environment Programme
UP	Uttar Pradesh
VAR	Vapor Absorption Refrigeration
VCR	Vapour Compression Refrigeration
VFDs	Variable Frequency Drives
W/m^2K	Watt Per Square Metre Kelvin
WBT	Wet Bulb Temperature
WC	Water Closet
XPS	Extruded Polystyrene

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Foreword

An integrated cold chain is critical for connecting farmers to premium and export markets, safeguarding valuable produce, reducing post-harvest losses, and minimizing the greenhouse gas (GHG) emissions associated with the decomposition of produce.

The integrated packhouse serves as the vital entry point to this cold chain, functioning as the primary hub where freshly harvested produce is sorted, graded, pre-cooled, and pre-conditioned for its onward journey. Yet, despite their importance, India's packhouse infrastructure remains grossly inadequate. The India Cooling Action Plan (ICAP) projects the need for approximately 125,000 packhouses by 2037-2038, resulting in a significant increase in annual electricity consumption.

As we look to bridge this gap, we must strive to build packhouses that are energy-efficient, renewable energy-powered, and use zero-GWP/low-GWP refrigerants. By adopting the Energy Efficiency Measures (EEMs) detailed in the *Packhouse Design Guidelines*, users can achieve up to 36% reduction in both annual electricity consumption and GHG emissions compared to baseline facilities. Additionally, the use of renewable energy has the potential to further reduce electricity costs and associated emissions.

The *Packhouse Design Guidelines* developed by the United Nations Environment Programme (UNEP) Cool Coalition and the Alliance for an Energy-Efficient Economy (AEEE) serve as a comprehensive practitioner's guide covering the major aspects of planning and outfitting facility, from optimal building orientation and thermal insulation to refrigeration system sizing and efficiency. The guidelines also provide crucial guidance on integrating renewable energy options, such as solar photovoltaic (PV) and biomass-powered refrigeration.

These guidelines, which align with NCCD's *Engineering Guidelines and Minimum Systems Standards for Implementation in Cold Chain Components*, will greatly benefit packhouse design consultants and developers, Farmer Producer Organizations (FPOs), Farmer Cooperatives, agribusinesses, government departments and implementing agencies.

(Krushna Chandra Panigrahy)

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RIGHT TO INFORMATION

स्वच्छ भारत

Foreword

The United Nations Environment Programme (UNEP) and the Bureau of Energy Efficiency (BEE) are proud to present these *Design Guidelines for Energy Efficient Packhouses*, developed under the framework of UNEP Cool Coalition in collaboration with the Alliance for an Energy Efficient Economy (AEEE). This publication comes at a critical moment for India's food systems, where strengthening cold-chain infrastructure is essential for food security, rural livelihoods, and climate resilience. India is one of the world's largest producers of fruits and vegetables, yet significant post-harvest losses continue to impact farmers' incomes, food availability, and resource efficiency. Integrated packhouses at the rural level are the cornerstone of a modern cold chain. By enabling cleaning, sorting/grading, pre-cooling, staging and market linkage of fresh horticultural produce, they directly reduce food loss and emissions, thereby advancing **SDG 2: Zero Hunger** and **SDG 1: No Poverty**.

At the same time, India's agricultural systems are increasingly vulnerable to future climate shocks, including extreme heat, rising temperatures, and disruptions caused by changing weather patterns. Heat stress can rapidly compromise the quality and holding life of perishable produce, making energy-efficient and sustainable cold-chain infrastructure more important than ever. Designing packhouses that can operate efficiently under these conditions will be critical to protecting livelihoods, strengthening supply chains, and ensuring food reaches consumers safely and sustainably.

These guidelines, therefore, highlight pathways to embed **energy efficiency** and **renewable energy integration** into packhouse design. By prioritizing low-Global Warming Potential refrigerants, passive design features, and clean energy systems, we can significantly reduce greenhouse gas emissions from the cold chain sector. This aligns with India's Cooling Action Plan (ICAP) and contributes meaningfully to **SDG 13: Climate Action**. The transition to climate-friendly cooling is not just a technical imperative, it is a moral responsibility to future generations.

Beyond environmental and economic benefits, sustainable cold-chain infrastructure can generate employment opportunities and support inclusive rural development, particularly for women and youth engaged across agricultural supply chains.

This publication is more than a technical resource; it is a roadmap for building resilient, future-ready cold chains that can withstand climate challenges while advancing sustainable development. I commend the Bureau of Energy Efficiency for its leadership and encourage policymakers, industry stakeholders, practitioners, and investors to adopt and scale these guidelines across India. Together, we can build food systems that are efficient, equitable, climate-resilient, and sustainable.

,

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Message

To realize the vision of Doubling Farmers' Income (DFI), India needs to significantly reduce post-harvest losses and enable market linkages by rapidly expanding its integrated cold chain, including crucial first-mile integrated packhouses, reefer transport, and cold storage. At the same time, the India Cooling Action Plan (ICAP) calls for bridging this critical infrastructure gap sustainably to safeguard agricultural livelihoods and ensure food security without drastically increasing energy consumption and greenhouse gas emissions.

As India scales up its packhouse infrastructure, integrating energy-efficient design and renewable energy technologies will be critical for cost-effective operations and for achieving India's net-zero goals by 2070. The *Packhouse Design Guidelines* is intended to complement the National Centre for Cold-chain Development (NCCD) standards and enable the development of robust, sustainable, and energy-efficient integrated packhouses across India. The guidelines were developed using the Lean, Mean, Green and Seen approach that includes:

- **Efficient design (lean):** Optimise layout, provision for natural lighting, effective insulation and thermal barrier
- **Use energy-efficient technology (mean):** Low-energy evaporative cooling, semi-hermetic compressor, variable frequency drive, zero/low-GWP refrigerants, controls and automation
- **Integrate renewable energy (green):** Grid interactive solar PV, agri-waste/biomass/biogas absorption refrigeration system, solar thermal energy
- **Enable monitoring and tracking (seen):** Energy management system for real-time monitoring and tracking key performance parameters

We are grateful to BEE for its leadership in developing these guidelines. We hope the guidelines will enable Farmer Producer Organisations (FPOs), cold chain developers, government departments and implementing agencies to build sustainable packhouse facilities that preserve produce quality and lower operational costs while supporting the country's energy transition.



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About the document

Packhouse Design Guidelines offer comprehensive guidance for the design and development of energy-efficient integrated packhouses for horticultural produce in India. Developed as a practitioner's guide, the document is intended for a wide range of stakeholders, including cold chain design consultants, developers and investors, cold chain infrastructure owners and operators (such as Farmer Producer Organizations (FPOs), Farmer Producer Companies (FPCs), and cooperatives), as well as government bodies and implementing agencies.

The guidelines cover all major aspects of planning, constructing, and outfitting integrated packhouses—ranging from building design and layout to system specifications and renewable energy integration. Key areas include:

- Integrated Packhouse Functions: such as cleaning, grading, packing, pre-cooling, and staging cold rooms
- Building Design and Construction Good Practices
- Thermal Insulation and Building Materials
- Refrigeration System Design and Energy Optimization
- Renewable Energy Integration
- Quantification of Energy Savings from Efficiency Measures

The document also provides technical references for implementing energy-efficient interventions and highlights opportunities to enhance performance through optimal equipment selection, automation, and passive design strategies.

While this guide focuses on infrastructure and energy efficiency, it does not cover operational protocols or post-harvest management practices. For insights into energy-efficient operations, readers are encouraged to consult the World Bank's 2022 report, "Cold Chain Energy Efficiency in India: Analysis of Energy Efficiency Opportunities in Packhouses."

In addition, the guidelines align with the Government of India's notified norms for integrated packhouses, precoolers, and staging rooms as outlined in the "Engineering Guidelines & Minimum System Standards for Implementation in Cold Chain Components" published by NCCD in 2025. These standards, adopted by the Mission for Integrated Development of Horticulture (SHM and NHB) and other implementing agencies, serve as a benchmark for sanctioning need-based components—including alternative energy systems—for new as well as upgraded cold chain infrastructure.

These Packhouse Design Guidelines are intended to complement the NCCD standards and further enable the development of robust, sustainable, and energy-efficient integrated packhouses across India.

CHAPTER 01

Introduction

1

1.1 Background

India, an agricultural economy, has emerged as the world's second-largest producer of fruits and vegetables in recent years, with 355.5 million MT (including 110.2 million MT of fruits and 209.1 million MT of vegetables) of horticulture produced in 2022-23 (MoA&FW, 2024). However, the lack of an integrated cold chain (from farmgate to market) for perishable horticulture produce is leading to food losses, which in turn are leading to food security risks, economic losses, and livelihood risks. Multiple organisations, from global to national agencies have made an effort to assess post-harvest losses in multiple instances. Food and Agriculture Organisation (2019) reported 2.5 % to 15% post-harvest losses for South-east Asia (which included India), with a median value of 8%. The one done at the national level was by CIPHET in 2015, which showed a loss of 4.5% to 15.8 % in fruits and vegetables. However, another assessment done by SFAC showed losses in the range of 9% to 32%, and yet another study done by NCCD shows losses between 22% to 44 %. The DFI report took cognisance of the variance in these reports to suggest that a more comprehensive study on post-harvest food loss under a harmonised yardstick be conducted in all regions of the country.

Furthermore, the DFI Committee reviewed the unit-level information from the NSSO 70th round. After comparing the data of production with that for consumption, it estimated that post-harvest losses in the case of fruits and vegetables are 34% and 44.6%, respectively (DFI Report, Vol-II, Chapter 4 - 4.3 and DFI Report Vol-III). The below Table 1 indicates the food losses by various organisations.

This food loss perforates through every stage, from harvesting, preconditioning, packaging, and transporting to the end stage of consumption due to limited access to cold chain which introduces the proper packaging and handling systems, besides temperature-controlled environments. The food loss occurring before the produce reaches the market is effectively a loss of saleable volume and an economic burden on the food supply system. The discards occurring due to food loss decompose into GHG to further compound the problem. The problems arising from food loss can be resolved significantly by building an integrated cold chain that empowers small and marginal farmers, marketing organizations including vendors and retailers, thereby ensuring food reaches to more end-user over an expanded demand base, and hence minimising the occurrence of wasteful discards. The primary step in the integrated cold chain is a packhouse facility with precooling and associated reefer transport.

Table 1: Food loss estimations by various organisatiovns

Reported by	Post-Harvest Losses (F&V) in %
CIPHET	4.5 - 15.8
SFAC	9 - 32
NCCD	22 - 44
MoA&FW's DFI Report	34 - 44.6
FAO	2.5 to 15, with a median value of 8% (for South-east Asia)

1.1.1 Cold chain and its Components

An integrated cold chain is critical for connecting farmers to markets near and far. It allows them to safeguard valuable produce and target optimal markets for better price realization from their produce. Hence, the cold chain forms a critical link between producers and the market that helps improve livelihoods and reduces post-harvest food loss. A typical cold chain, as shown in Figure 1, consists of four key components: packhouse, cold storage (bulk and hub), reefer transport, and ripening unit. However, Ripening units are added only for certain produce (climacteric fruits) to make them fit before being dispatched for sales. They are situated at the last mile of the marketing chain but are also deployed in certain food processing industries if the fresh fruit requires to be ripened before it is processed into a food product.

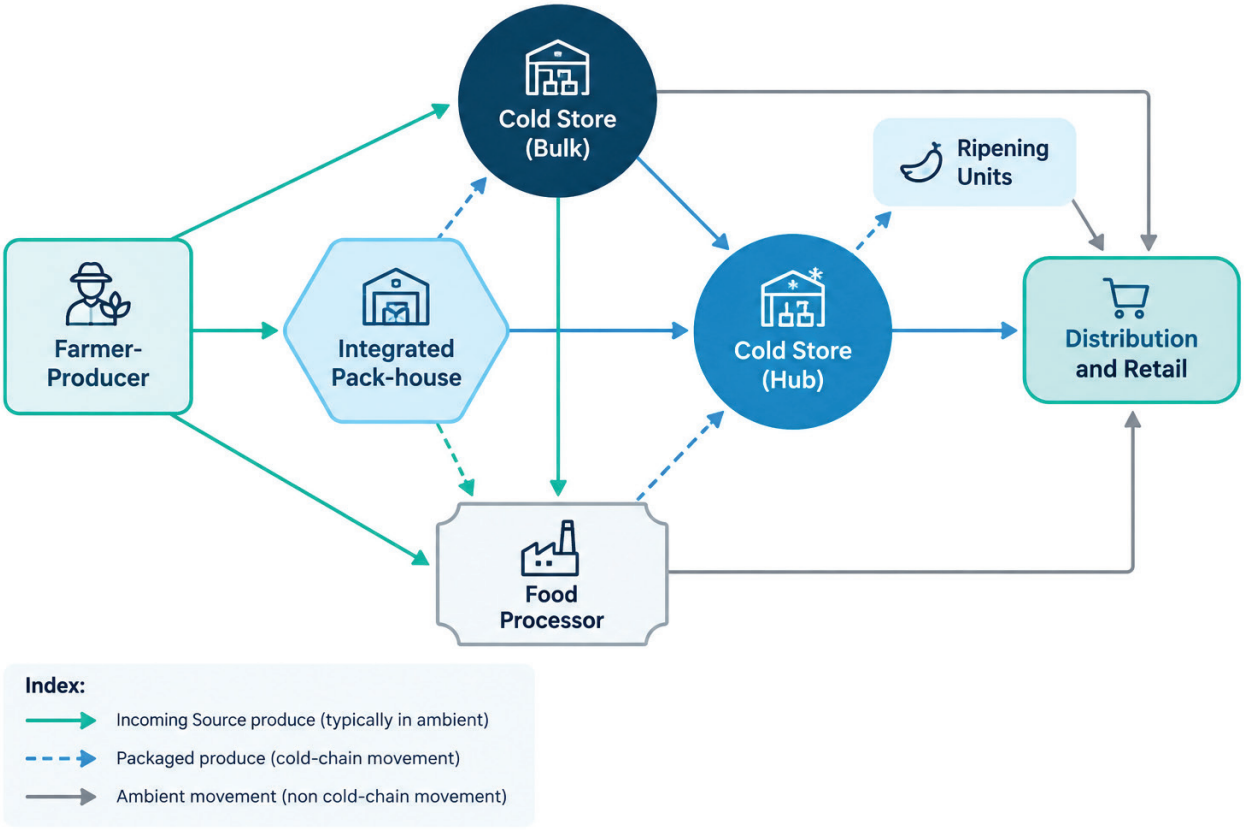


Figure 1: Typical horticultural cold chain

Source: Pawanexh Kohli (Sr. Advisor – UNEP)

The graphic above indicates the type of flow of produce from harvesting to markets, both within and without the cold chain. The green arrows indicate the movement of raw produce from farms to packhouse or a bulk cold store, or as input material to food processor. The latter is evidenced when potatoes, onions, apples are directly brought to cold stores for bulk storage, without prior precooling. Material that is culled at a packhouse can also be diverted to cottage scale food processing units and is indicated with dotted green arrow.

The blue arrows indicate refrigerated transport of produce that is packaged and precooled. This packaging is typically done in a packhouse, where the perishable produce is cleaned, sorted, graded and preconditioned for long haul transit to wholesale distributors and subsequent retail. A refrigerated distribution hub is used to cross-dock this movement for last mile distribution. A small share of precooled fruits that require ripening before markets will also travel in the cold chain to ripening chambers.

The grey arrows indicate non-refrigerated movement, as in case of processed products like canned goods, ketchup, beverages, vacuum packed products, powders, etc. The movement of fresh potatoes, onions, spices, etc. from bulk storage to processors or to markets, is also conducted in ambient conditions. It may be noted that food processor units also have captive refrigerated storage for their feedstock as well for the processed output. The dotted blue arrows indicate certain horticultural produce originating at food processing units, such as frozen peas or cut fruits, that connects the cold chain for onward distribution.

The above is illustrative of produce movement through the cold chain system however, further intervention may be required in some cases other than those shown in Fig 1.These are in the form of multiple cross-docking points, such as at ports, when modes of transport or further intermediary handling to consolidate or to break-bulk is necessitated in the supply chain.

The following section briefly discusses the major cold chain elements.

1. **Integrated Packhouse:** A packhouse that integrates a precooling facility is the entry point to the cold chain, used to aggregate and pre-condition the produce for market connectivity. Pre-conditioning refers to activities undertaken to prepare the farm produce for market connectivity, wherein the output remains farm produce and is not processed into a different food product. The term pre-conditioning is also included under the GST Law (2017) of India as a support service for agriculture, which typically includes a range of operations like sorting, grading, washing, drying, weighing, packaging, pre-cooling, and staging. Currently, India has an estimated 249 packhouses as per the data collated by the National Centre for Cold Chain Development (NCCD). The number of packhouse units is expected to increase in the coming years due to the emphasis placed on them in the Doubling Farmers' Income (DFI) initiative by the Govt of India (World Bank, 2022).

2. **Reefer Transport:** This broad term can include especially designed reefer ships, refrigerated rail units, and refrigerated trucks. However, in modern-day transportation, the unitised reefer container is prevalent and used to carry perishables on ordinary ships, rail as well as trucks. A reefer vehicle is a road vehicle with a fixed insulated body equipped with active refrigeration. Over 95% of existing reefer vehicles mainly carry frozen products, demonstrating the lack of packhouses as a source point for preconditioned horticultural produce. A commonly used reefer vehicle has a holding capacity of 10 MT and a refrigeration unit with a 2-4 kW cooling capacity that can service temperatures from −25 °C to +25 °C.

3. **Cold Store:** A typical cold store comprises of insulated and refrigerated spaces designed to store and handle perishable goods. The refrigerated spaces include warehousing chambers, handling anterooms, and others. The refrigeration system is designed to maintain the temperature and humidity parameters initiated at the packhouse (e.g., fresh produce) or after manufacturing (e.g., butter, ice cream). Based on the type of product and holding duration, NCCD has categorized cold stores into four types, i.e., Cold Store Type 1 (CS-1), Cold Store Type 1-Onion (CS-1-Onion), Cold Store Type 2 (CS-2), and Controlled Atmosphere Store Type-2-CA (CS-2-CA) (Engineering Guidelines and minimum system standards, NCCD, 2025).

4. **Ripening Unit:** Ripening unit consists of multiple chambers that are last-mile facilities in the cold chain used for the controlled and hygienic ripening of certain fresh produce. In India, these are used extensively for ripening climacteric fruits like bananas, mangoes and papayas on a commercial scale. A ripening unit usually has four chambers of around 10 MT capacity. A large facility could be in multiples of these units. A refrigeration unit is used to maintain controlled temperatures of 15-20°C with elevated humidity levels along with equipment to dose the compartments with a ripening catalyst (normally ethylene gas). Around 1,000 ripening units were present in the country, as per a study by NCCD (2015a), which served around 9% of the overall consumption.

While various cold chain components are present in India, fully integrated cold chain operations - where each component works in coordination - are still underdeveloped. Too often, cold store is considered synonymous with the entire cold chain and regarded as the starting point in a cold chain. However, data shows that most food losses related to Fruits and Vegetables (F&V) occur during post-harvest handling between the farm gate and markets and are attributed to improper packaging and transportation activities. As such, modern packhouses near production centres are critical for minimizing losses, reducing emissions, and improving farmer incomes. Once produce is damaged during initial handling, no amount of cold storage can restore its quality.

India's packhouse infrastructure remains grossly inadequate. In 2019, only about 500 packhouses were reported, far below the 70,000 units (Table 2) estimated by NCCD in 2015 (based on 15 MT throughput units). While some reported packhouses may have higher capacity, government data lacks clarity on actual throughput. The ICAP projects a need for 55,000 packhouses by 2027-28 and 1,25,000 by 2037-38, highlighting a significant investment gap.

Moreover, packhouses must be complemented by expanded reefer transport capacity to enable a truly integrated cold chain. This presents a key opportunity for early, sustainable investment in both infrastructure components to meet India's growing horticulture needs (World Bank, 2022).



Table 2: Cold chain infrastructure - Status & Gap

Type of Infrastructure	Infrastructure Requirement	Infrastructure Created (2014)	All India Gap	Shortfall % share
Integrated Packhouse	70,080 nos.	249 nos.	69,831 nos.	**99.6**
Reefer Transport	61,826 nos.	<10,000 nos.	52,826 nos.	**85**
Cold Store (Bulk)	34,164,411 MT	31,823,700 MT	3,276,962 MT	**10**
Cold Store (Hub)	9,36,251 MT			
Ripening Units	9,131 nos.	812 nos.	8,319 nos.	**91**

Infrastructure: in numbers refers predefined unit size; in MT denotes metric tonnes

Source: Study, NCCD 2015

The packhouse is an energy-intensive element of the cold chain with an annual electricity consumption of approx. 1 TWh in 2022-23. Meanwhile, the annual electricity consumption is expected to increase to approx. 5.2 TWh in 2037-38 (MoEF&CC, 2019a). Packhouse energy consumption depends on several factors: design, equipment and refrigerant selection, operation, and maintenance. This guide focuses only on the design aspects of building energy-efficient packhouses in India.

CHAPTER 02

About Integrated Packhouse

2

An integrated packhouse (illustrated in Figure 2) is used to precondition produce for transiting in the cold chain to markets. It functions to receive the freshly harvested produce from farms, cull the unusable produce, grade and sort the produce for target markets, clean and package the produce, and finally pre-cool the packaged produce for onward transport to the next stage in the supply chain (with flow of produce indicated in Figure 3).

The packhouse has facilities for receiving and weighing the incoming produce with manual or automatic handling lines, including sorting, washing/cleaning, drying, grading, packing, and palletization. The packaged produce is then moved to pre-cooling chambers, which are used to rapidly lower the produce's temperature. The pre-cooled produce is then transferred for short-term storage to a staging cold room, thereby vacating the pre-cooling chamber for the next incoming lot. In the staging cold room, the pre-cooled produce is maintained at its pre-defined storage temperature until it is dispatched to its onward destination through reefer transport. Packhouse operations do not end until the final dispatch to market.

Essentially, a packhouse prepares the freshly harvested produce for its onward journey in the cold chain to markets that hitherto were beyond its inherent range. A packhouse facility is necessary for exports with demonstratable benefits such as ensuring compliance with international food safety and quality standards, extended shelf life, reducing losses during transit, etc . The increasing use of such packhouse facilities for supply to domestic markets, especially when connecting across subcontinental distances, is expected to positively impact food loss reduction, food safety, food traceability, nutritional availability, accountability, transparency and overall food system efficiency.



Figure 2: Sorting, Grading and Packing area in a packhouse (first picture) & Staging/pre-cooling room in a packhouse (second picture)

Post-harvest handling commences with manual handling to receive and move the produce into working halls where grading, sorting, and packing of F&V is carried out by semi-skilled workers on Stainless Steel (SS) tables (NCCD). Depending on the volume, type, and shape of F&V being handled, automated or semi-automated lines can also be used for the sorting, cleaning, grading, and packaging activities. The use of rollers, including motorized conveyor lines, is common to facilitate the movement of the produce. Where amenable, sized-based sorting can also be automated, such as in the case of apples, tomatoes, oranges, etc.

Optical or acoustic sensors can also be used to sort the produce by colour or firmness. However, human intervention is commonly required, especially in packhouses handling irregularly shaped produce and leafy vegetables and where the local workforce is more effectively deployed. As such, packhouses are also hubs of local employment and logistical activities.

Packhouse is located close to farms and would in fact be a source of gainful employment for local women and unemployed youth in rural areas. Women workers are commonly employed for sorting and grading incoming fresh horticulture produce, and rural youth can be trained to serve as reefer transport operators and in ancillary services. Additionally, the packhouse, as a community hub, can provide facilities such as a creche for workers during working hours, short-term domestic food storage units, vaccine and medicine storage, etc., wherever any surplus cooling can be utilised as a resource to satisfy other community requirements and amenities.

Nearly all horticulture production, mainly comprising large volumes of perishable fruits and vegetables (F&V), requires initial handling in a packhouse. Whereas the produce types can be highly perishable (e.g., mushrooms, cherries, grapes, spinach, etc.) or hardier (apples, carrots, cauliflower, etc.), each type benefits from packhouse operations that safeguard their marketable value while expanding their market reach.

Packhouses can be equipped to handle a range of F&V, each of which may require a unique kind of treatment before pre-cooling, staging, and dispatch to the intended destination. The produce flow (Figure 3) in a packhouse is designed to efficiently manage energy and resources. As an example, it would be inefficient to pre-cool produce that is packaged for near-farm markets and not intended for far-away destinations.



Figure 3: Typical produce flow in a packhouse

2.1 Cleaning, Sorting, Grading and Packing

Sorting and grading can be done manually or using semi-automated / automated equipment. The type of equipment used for sorting and grading varies based on the produce handled. Manual sorting lines involve skilled workers meticulously inspecting each produce based on factors such as size, colour, and quality. Automatic sorting lines are ideal for high-volume crops like apples, oranges, mangoes, pomegranates, and lemons, where standardized characteristics allow for efficient sorting using technology such as sensors and conveyor belts. The sorting grading unit (referred to as 2 in Figure 13) would have a feeding line, conveyors on which the products are carried enables people standing alongside to visually inspect and sort the produce by quality, and a sizer which would be capable of grading by the size of the produce. Additionally, where required, a cleaning line is attached for washing, brushing, etc. Automated systems ensure rapid processing, maintaining consistency in quality while relying on technological precision and productivity.

The packhouse activity depends on the produce type and the market. Some leafy vegetables may not benefit from storage but are immediately dispatched to the market while still fresh. Vegetables may need to undergo culling to remove insect infestation or mechanical damage before they are sorted, graded, packed, and precooled for dispatch. With shorter distances to the market, precooling may not be necessary. Some examples of grading and sorting equipment for leafy vegetables (Figure 4), root vegetables (Figure 6), bananas (Figure 5), and mangoes (Figure 7) are described below[1].

Leafy vegetable lines:

- **Conveyor with multi-desk (single-layer) –** Initial sorting of the leafy vegetable is done through visual inspection, minimizing cross-contamination.



- **Vegetable Cutter** – Cuts the vegetables precisely for uniformity and consistency in size.
- **Elevator**- Vertically transport the produce, ensuring a continuous flow and minimizing manual handling. It also helps in optimizing the space occupied by the sorting grading line.
- **Vegetable Washing Machine (with ozone and worm-removing drum)** – It helps clean, sanitize, and remove contaminants and pathogens while ensuring the visual appeal and marketability of the leafy vegetables.
- **Vibration dewatering machine** – It helps remove excess water from the vegetables, preventing spoilage and ensuring a streamlined post-washing process.
- **Dryer (by blowers)** – Dryers remove residual moisture from the vegetables, preventing bacterial growth and enhancing shelf life.

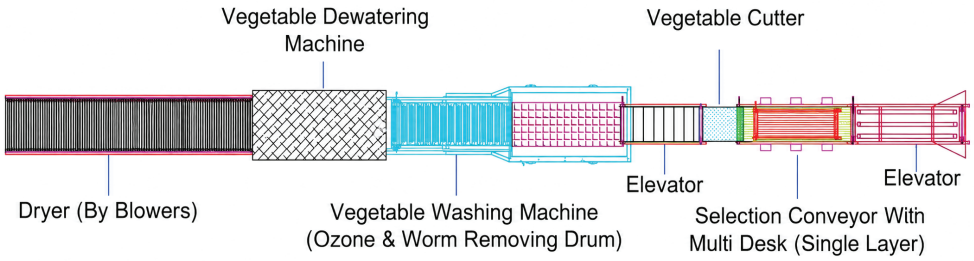


Figure 4: Layout of leafy vegetable line

Source: Pawanexh Kohli (Sr. Advisor – UNEP)

[1]*These layouts are not to be considered as the mandatory rule and are essentially given for general understanding*

Banana sorting and grading line:

The process of cleaning, washing, and drying bananas is important as it removes undesirable materials like dirt, mud, latex microorganisms, and stains and removes the chances of any fungal contamination. Multiple washing may be done with fresh water and some disinfectant. Banana is a very delicate fruit, vulnerable to damage easily, and requires minimum handling to protect its surface from any scratch, which is evident after a few hours a day or after ripening.

- **Feeding conveyor/washer** – The feeding conveyor for bananas is normally a water trough where the flowing water facilitates the movement of the produce for the next process, simultaneously conducting initial cleaning to remove dirt and contaminants.
- **Washer 1 (typically with fungicide)** – Washer 1 sanitizes and removes contaminants from bananas, ensuring food safety and quality.
- **Washer 2** – Washer 2 rinses the fruit, contributing to overall hygiene.
- **Air Dryer** – It removes the excess moisture from the bananas, preventing microbial growth and enhancing the shelf life of the fruits.

Packing conveyor – The packing conveyor ensures a smooth transition from washing and drying to packaging, reducing the handling time and maintaining the quality of the bananas.

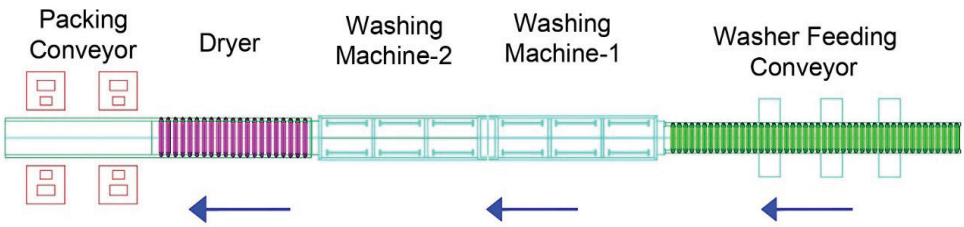


Figure 5: Layout of banana line

Root vegetable sorting and grading line:

The specific crop handling lines may be customized as per the crop requirement, the target market and buyer requirements. In the case of root vegetables, extra effort may be needed to carefully wash the crop to remove the soil and mud from the skin.

- **Elevator**- Vertically transport the produce, ensuring a continuous flow and minimising manual handling. It also helps in optimizing the space occupied by the sorting grading line.
- **Vegetable Washing Brushing Machine** – Removes dirt, debris, and contamination, enhancing the appearance and quality of the vegetable.
- **Selection Conveyor with multi-desk (single layer)** – Sorting the root vegetable through visual inspection, hence minimizing the cross-contamination
- **Elevator** - Vertically transport the produce, ensuring a continuous flow from sorting to process further and minimising manual handling.
- **Top and bottom spray washing machine for vegetables** - Cleans and rinse the root vegetables through top and bottom water spray to improve the quality and marketability of the vegetables.
- **Vegetable dewatering machine** - It helps remove excess water from the vegetables, preventing spoilage and ensuring a streamlined post-washing process.

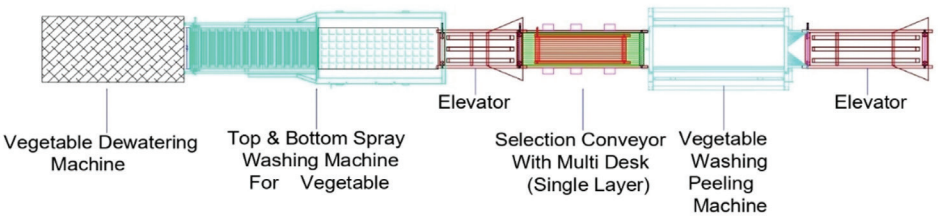


Figure 6: Layout of root vegetable line

Mango sorting and grading line:

The handling of mango at the packhouse facility must be well-regulated and controlled. Hot water treatment removes the latex, microorganisms, and any chance of fungal contamination (anthracnose).

- **Feeding/Selection Conveyor** – The feeding/Selection conveyor helps in initial inspection and ensures the mangoes' consistent spacing and movement.
- **Water Washing** – Sanitizes and removes contaminants from mangoes, ensuring food safety and quality.
- **Hot Water Treatment** – Hot water treatment of mangoes helps eliminate pathogens, controls pests, and sterilizes the surface of the mangoes to control their quality. It also helps in modulating the ripening process by regulating the activity of enzymes.
- **Brushing/Sponging –** Cleans the surface of the mangoes and provides a polishing effect to enhance the visual appearance.
- **Hot Air-Drying Section** – Remove excess moisture from the surface of the mangoes to prevent microbial growth and extend the shelf life of the produce.
- **Waxing (if required)** – It helps protect the surface of the mangoes by retaining the natural moisture generated and hence protecting it from spoilage.
- **Electronic Grading System** – It helps precisely categorise the mangoes based on the pre-defined criteria.

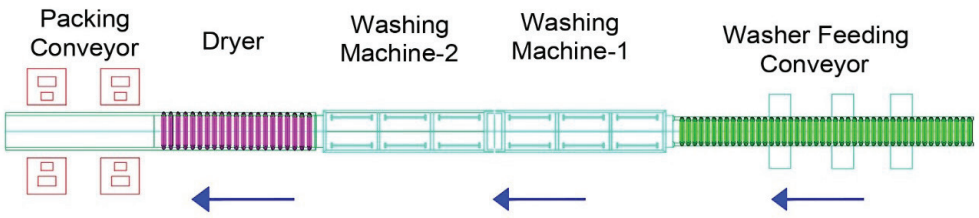


Figure 7: Typical layout of mango line

Packaging: One of the main functions of a packhouse is to prepare and package the produce for safe handling so that it can withstand the journey to its market destination in the best possible condition. The kind, size, material, and weight of the packing must all be done in accordance with the importer's and domestic purchasers' specifications. Food-grade plastic is utilized for crates, while treated cardboard sheets are used to make corrugated boxes. It is crucial to prepare the pallets after the packaging. The crates and boxes should have vents to maintain breathability and allow air to flow through the enclosed produce, as indicated in Figure 8. The size and spacing of the air vents are designed to suit the respiration rates of the produce types being handled.



Ventilated Crates and CFB boxes





Typical pallets with vented boxes

Figure 8: Type of crates and boxes used

2.2 Pre-cooling Function

Pre-cooling (referred to as 3 in Figure 13) is the most energy-intensive function in a packhouse. This is the first stage, where the packaged produce is subjected to cooling, and its core temperature is pulled down to a predetermined handling temperature. This helps the produce to increase its marketable life and drastically reduces the subsequent cooling demand (cooling required in staging and transportation). Therefore, pre-cooling not only leads to an intended extension of the saleable life of the produce but also makes the remaining period in the cold chain more energy efficient. Some key considerations are listed here:

- Most F&V intended for cold stores should be pre-cooled in a packhouse as soon as possible after harvest to remove field heat and reduce the rates of respiration, deterioration, water loss, ripening, and decay before they are placed into storage. For this purpose, pre-cooling technologies are designed for a rapid pull-down of temperatures while maintaining high humidity. The rapid pull down to storing temperatures is done by maximizing the heat exchange from the surface of the package. Towards this, a high flow of the cooling medium (chilled air) is maintained around and through the packages holding the produce.

- Highly perishable F&V such as berries, cherries, lychees, melons, stone fruits, sapotas, grapes, mandarins, okra, tomatoes, capsicum and chilli peppers, brinjal, cucumbers, green beans, peas, spinach, and other leafy vegetables should undergo rapid pre-cooling. For this reason, constructing an integrated packhouse in first-mile or near-farm locations or at the village level is highly desirable and will greatly decrease postharvest losses. Some fruits and vegetables, such as mangoes, papaya, guava, green bananas, pomegranates, radishes, cabbage, cauliflower, and carrots, are comparatively hardier, and these can be transported from the field to more centralized packhouses for pre-cooling before entering into storage or onward. As a benchmark, a packhouse should be available within a radius of 2 to 6 hours after harvest.

- The field heat of produce is inherent to each produce type and is related to its respiration rates. In addition, the produce can get warmer if exposed to additional heat sources such as sunlight or warm ambient. The combination of filed heat and external heat defines the incoming heat load from the produce. Cooling demand can be reduced by reducing such exposure to external heat and can be achieved by the following:
  - Harvesting in the early morning or cooler part of the day
  - Limiting solar incidence on harvested produce while en-route to packhouse (covered transport or shaded area)
  - Undertaking sorting, grading and packing activities in a partially cooled environment (evaporative cooling in sorting/grading hall)

- The pre-cooling set-point temperature is specific to each produce and dictated by its chill injury temperature. Pre-cooling should not expose F&V to temperatures below their chilling point, which may cause damage, besides being a waste of energy. Though the temperature at which a produce physically freezes may be sub-zero, the temperature at which chilling injury occurs is typically higher. It is imperative that the supply air temperature for all produce must never fall below this predetermined "set point" temperature. For example, if a tomato is to be pre-cooled to 10°C, the pre-cooler should not supply air at less than 10°C. Tomatoes coming in contact with air that is less than 10 °C would suffer chill injury and will eventually be rejected at point of sale. Since that supply air temperature cannot fall below a set point, therefore, the desired faster rate of heat exchange can only be ensured by way of providing a much higher air flow in the precoolers. For this reason, precoolers have very high flow rate fans to enforce rapid heat exchange at the fixed temperature.

- Produce such as apples, pears and citrus fruits, which are harvested in temperate conditions, can undergo room cooling in the cold store as harvested at temperatures already close to storing temperature. In such cases, the cold store itself is designed with extra cooling capacity to allow for a quick initial pull down of core temperatures, after which the system uses less cooling capacity to maintain the same. Such pre-cooling in cold stores is used when the produce is amenable to long-term storage and undergoes packaging operations after to this storing period. A few other vegetables like potatoes, onions, red chillies, and garlic need to undergo primary curing and are not amenable to rapid pre-cooling. These are directly placed into the cold store after curing, where a gradual pull down to their recommended storage temperature is undertaken.

2.2.1 Pre-cooling Methods

Each fruit and vegetable should be pre-cooled to the recommended temperature using appropriate methods. There are different methods of pre-cooling for F&V produce, as depicted in the flowchart provided in Figure 9.

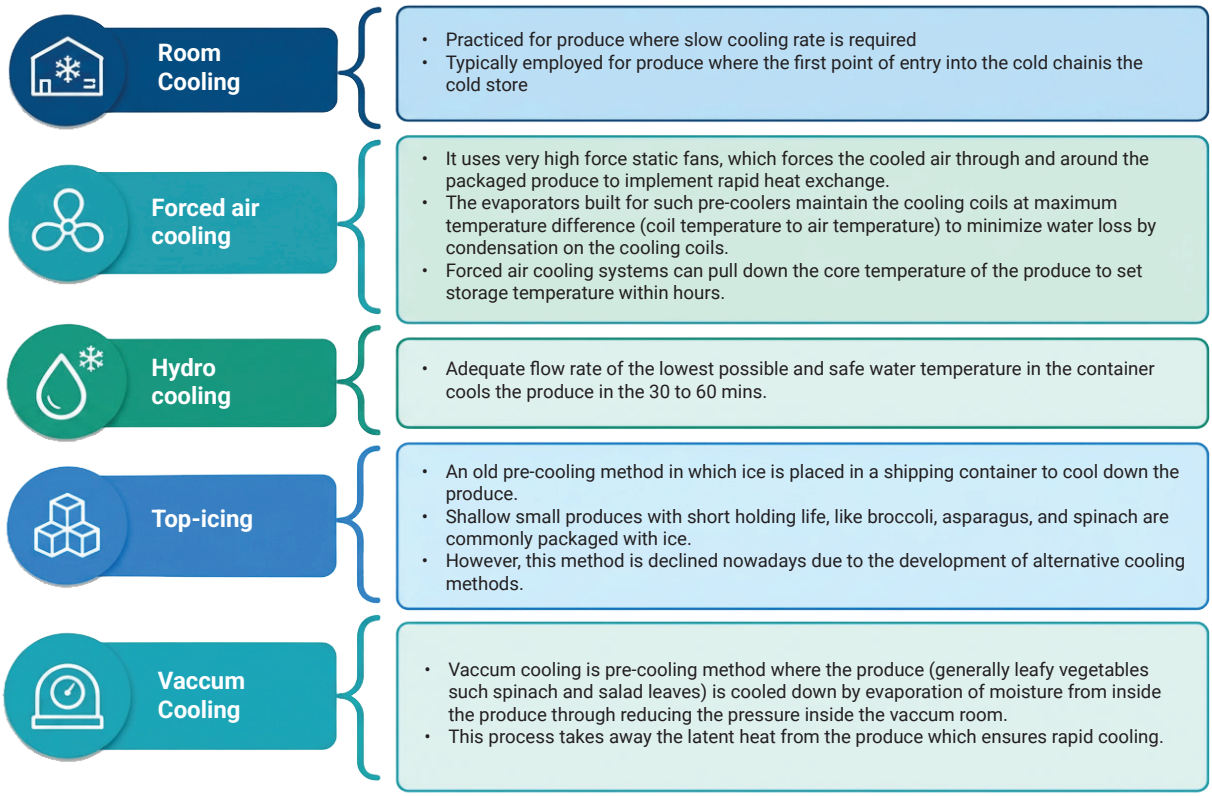


Figure 9: Methods of pre-cooling (NCCD 2015, Guidelines & minimum System Standards)

The forced-air pre-cooling method is widely adopted and typically involves a floor-mounted vertical pre-cooling unit with essential components such as a water pump, direct expansion refrigeration system, and a fan section at the front. Direct expansion refrigeration system mainly consists of a compressor, condenser, expansion device, and large coil evaporators designed to provide a larger surface area for maintaining temperature. High-flow rate fans enhance the heat exchange rate. The choice between direct expansion or secondary loop cooling depends on specific requirements, with secondary loop cooling more prevalent in cold stores where maintaining very high humidity for extended periods is necessary. The sealed and looped air cycle within the pre-cooling chamber ensures controlled and efficient discharge of cooled and humidified air, maintaining the desired static pressure for optimal pre-cooling conditions.

Figure 10 shows a photograph of the floor-mounted pre-cooling unit inside the pre-cooling chamber.



Figure 10: Floor mounted forced air-pre-cooling unit

Vacuum pre-coolers have also been prevalent in hilly areas of south India, specifically for lettuce leaves being produced for multinational food outlets. Recommended cooling methods for some of the fruits and vegetables are listed in Table 3.

Table 3: Recommended pre-cooling methods for selected fruits and vegetables (FAO, 2012)

Commodity	Room cooling	Forced air cooling	Hydro-cooling	Vacuum cooling	Package/top icing
Banana	★	★			
Grapes		★			
Guava		★			
Jackfruit		★			
Mango		★			
Papaya		★			
Pineapple		★			
Strawberry		★			
Cauliflower		★		★	
Asparagus			★		
Broccoli		★			★
Bitter gourd	★	★			
Cabbage		★		★	
Corn, sweet			★	★	★
Lettuce		★		★	
Okra	★	★			
Onion, green			★		★

2.2.2 Stacking for Pre-cooling

The pallet stacking arrangement is such that the air from the cooling unit is forced to flow through the air vents in the cartons ensuring the cold supply air comes into contact with each individual produce and then sucked by the unit through fans for recirculation. Pallet are typically stacked in opposing columns, leaving an open column in front of the pre-cooling fan. To prevent short-cycling of the supply air, the top of the empty column is covered. In doing so, the cold supply air is forced to flow through each box in each column of pallets and the warmer return air is again recirculated after passing through the evaporator. The stacking arrangement ensures that the moving air not only contacts the container surfaces but also infiltrate the boxes, containing the produce for adequate & rapid cooling. With this process, other respiratory outputs of the produce, such as CO_2 and ethylene, are also extracted instead of building up and enveloping each piece. Once pre-cooling is completed, such gaseous output reduces to a minimum, and thereafter, the normal airflow in a cold room suffices. Properly sized vents have to be provided on the boxes/crates to ensure proper vent alignment and obtain proper airflow and cooling rate. The pallets are normally 1 to 1.2 m wide and approx. 1.5 to 2.0 m high. The general arrangement of stacking is shown in Figure 11.

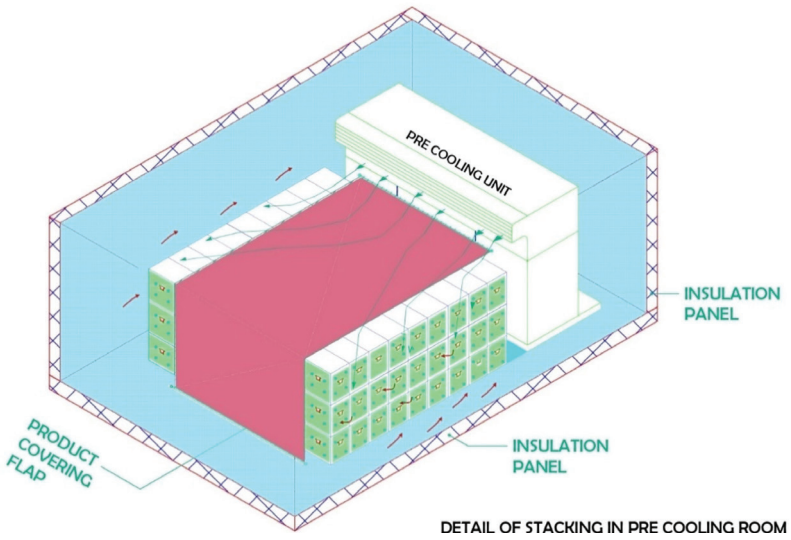


Figure 11: Illustrative diagram for pre-cooling chamber with floor-mounted unit and product stacking

Usually, pre-cooling should continue until the produce reaches its set storage temperature. However, the commercially acceptable practice is to pull down until the return air temperature is within 7/8th of the supply air temperature (set point). At this stage, the produce temperature is about 1 to 2 °C from its set point, the respiratory heat of the produce is greatly lowered, and it is amenable for ordinary cold room storage (the difference in produce temperature and set storage temperature can be handled by normal refrigeration). Therefore, both return air and supply air temperatures are monitored. The former keeps dropping as precooling progresses and the latter is maintained at the set point. If return air temperature quickly becomes equal to supply air temperature, it indicates that air flow has short cycled and stacking must be corrected. Unlike with frozen goods, the return air must always be higher than the supply air temperature. Generally, in the case of forced air pre-cooling, the time taken in pre-cooling is about 4 to 6 hours for most of the produce. In the case of vacuum pre-coolers, they are much faster, and in the case of room cooling, the period can be 12 to 36 hours. Pre-coolers operate for sequential loads, and therefore, a pre-cooling chamber designed to pre-cool 5 MT of produce every 4 hours will supply 15 MT of produce to the cold store every 12 to 15 hours. For example, in the case of pre-cooling of 5 MT mango/pomegranate, the temperature is brought down from ambient to 10 °C - 13 °C in approximately 5 hours, where the airflow rate from the unit would be 67 to 100 CMH (Cubic meter per hour). The only way to increase the speed of pre-cooling is by increasing the flow of air around the produce so that surface heat is extracted by the flowing air at a faster rate. However, beyond a certain rate, the heat exchange will not increase incrementally.

2.3 Staging Cold Room

The staging cold room (referred to as 4 in Figure 13) is an insulated, refrigerated chamber and is mainly meant to store the produce up to the time that the reefer containers or vehicles are available for dispatch to the destination. It also serves as temporary storage while allowing the pre-cooler to be utilized for the next batch of produce. The capacity or size of the staging cold room is designed to handle the output from the pre-coolers for the estimated waiting time or pending transport. For example, suppose the packhouse has only one pre-cooler that outputs 5 MT every 4 hours and is expected to operate for only 12 hours each day. In that case, the attached cold room should be, at a minimum, able to store and maintain 15 MT of package produce in case of daily dispatch. If the dispatch to market is planned every two days (and not daily), then the cold room should be sized to hold 30 MT. These cold rooms should be designed to hold fresh produce for more than 36 hours and should incorporate vents to allow minimal air replenishment.



If the packhouse is handling different produce simultaneously, which also needs to be segregated – for temperature or cross-contamination – then the staging cold rooms need to be designed accordingly. An example of this case is where a packhouse is handling both bananas and tomatoes. One needs to be stored at 13°C and the other at 8°C; one is an ethylene producer, and the other is sensitive to ethylene. In such a case, the staging cold rooms must be separate and have different temperatures.

General information about commonly handled fruits and vegetables is provided in Table 4.

Table 4: Storage condition for fruits and vegetables

SN.	Common name	Storage temp (˚C)	Relative Humidity %	Ethylene production	Ethylene sensitivity	Estimated holding life
1	Apple -not chilling	-1.1	90-95	Very High>100µL/kg-hr	High	
2	Apple -chilling sensitive	4	90-95	Very High>100µL/kg-hr	High	3-6 months
3	Banana	13-15	90-95	moderate 1.0-10.0µL/kg-hr	High	1-4 weeks
4	Cherries, sweet citrus-grapefruit	(-) 1 to 0	90-95			2-3 weeks
5	Citrus -dry areas	14-15	85-90	very low <0.1µL/kg-hr at 20 °C	Moderate	6-8 weeks
6	Lemon	10-13	85-90			1-6 months
7	Lime	09-10	85-90			6-8 weeks
8	Orange- dry areas	3 - 9	85-90	very low <0.1µL/kg-hr at 20 °C	Moderate	3-8 weeks
9	Orange- humid areas	0-2	85-90	very low <0.1µL/kg-hr at 20 °C	Moderate	8-12 weeks
10	Tangerine Mandarin	4 to 7	90-95	very low <0.1µL/kg-hr at 20 °C	Moderate	2-4 weeks
11	Grape	-0.5	90-95	very low <0.1µL/kg-hr at 20 °C	Low	2-8 weeks
12	Grape-American	-1.5	90-95	very low <0.1µL/kg-hr at 20 °C	Low	2-8 weeks
13	Guava	5 - 10	90	Low 0.1-1.0µL/kg-hr	Moderate	2-3weeks
14	Lychee, Litchi	1 - 2	90-95	Moderate 1.0-10.0µL/kg-hr	Moderate	3-5 weeks
15	Mango	13	85-90	moderate 1.0-10.0µL/kg-hr	Moderate	2-3weeks
16	Melon-Cantaloupes and other netted melons	2 to 5	95	High 10-100 µL/kg-hr	Moderate	2-3weeks
17	Melon-Crenshaw	7 - 10	85-90	moderate 1.0-10.0µL/kg-hr	High	2-3weeks
18	Melon-Honeydew, orange flesh	5 - 10	85-90	moderate 1.0-10.0µL/kg-hr	High	3-4 weeks

SN.	Common name	Storage temp (°C)	Relative Humidity %	Ethylene production	Ethylene sensitivity	Estimated holding life
19	Melon-Persian	7 - 10	45-50	moderate 1.0-10.0µL/kg-hr	High	2-3 weeks
20	Melon-Watermelon	10-15	90	very low <0.1µL/kg-hr at 20 °C	High	2-3 weeks
21	Papaya	7 - 13	85-90	moderate 1.0-10.0µL/kg-hr	Moderate	1-3 weeks
22	Pear-American	- 1.5 to 0.5	90-95	High 10-100 µL/kg-hr	High	2-7 months
24	Pineapple	7 -13	85-90	Low 0.1-1.0µL/kg-hr	Low	2-4 weeks
25	Plums and Prunes	-0.5 to 0	90-95	Low 0.1-1.0µL/kg-hr	Low	2-5 weeks
26	Pomegranate	(-)0.5 to 0	90-95			2-3 months
27	Sapotes-Caimoto; star apple	3	90			3 weeks
28	Sapotes-Canistel;Eggfruit	13-15	85-90			3 weeks
29	Sapotes-black	13-15	85-90			2-3 weeks
30	Sapotes-white	20	85-90			2-3 weeks
31	Sapotes- Mamey	13-15	90-95	High (10-100µL/kg-hr)	High	2-3 weeks
32	Beans - Snap; wax; green	4 to 7	95	Low 0.1-1.0µL/kg-hr	Moderate	7-10 days
33	Beans-Lima	5 to 6	95	Low 0.1-1.0µL/kg-hr	Moderate	5-7 days
34	cabbage-Common early crop	0	98-100	very low <0.1µL/kg-hr at 20 °C	High	3-6 week
35	Cabbage-Late crop	0	95-100	very low <0.1µL/kg-hr at 20 °C	High	5-6 months
36	Carrot-topped	0	98-100	very low <0.1µL/kg-hr at 20 °C	High	6-8 months
37	Carrots-Bunched immature	0	98-100	very low <0.1µL/kg-hr at 20 °C	High	10-14 days
38	Cauliflower	0	95-98	very low <0.1µL/kg-hr at 20 °C	High	3-4 weeks
39	Corn-Sweet; baby	0	95-98	very low <0.1µL/kg-hr at 20 °C	Low	5-8 days
40	Cucumber	10 to 12	85-90	Low 0.1-1.0µL/kg-hr	High	10-14 days
41	Daikon; Oriental radish	0-1	95-100	Low 0.1-1.0µL/kg-hr	Low	4 months
42	Garlic	0	65-70	very low <0.1µL/kg-hr at 20 °C	Low	6-7 months
43	Ginger	13	65	very low <0.1µL/kg-hr at 20 °C	Low	6 months

SN.	Common name	Storage temp (°C)	Relative Humidity %	Ethylene production	Ethylene sensitivity	Estimated holding life
44	Leafy Greens-Cool season	0	95-100	very low <0.1µL/kg-hr at 20 °C	High	10-14 days
45	Leafy Greens-warm season	7 to 10	95-100	very low <0.1µL/kg-hr at 20 °C	High	5-7 days
46	Mushrooms	0	90	very low <0.1µL/kg-hr at 20 °C	Moderate	7-14 days
47	Mustard greens	0	90-95	very low <0.1µL/kg-hr at 20 °C	High	7-14 days
48	Okra	7 - 10	90-95	Low	Moderate	7-10 days
49	Onions - Mature bulbs; Dry	0	65-70	very low <0.1µL/kg-hr at 20 °C	Low	1-8 months
50	Onions-Green	0	95-100	Low 0.1-1.0µL/kg-hr	High	3 weeks
51	Peas in pods: Snow, Snap & sugar peas	0	90-98	very low <0.1µL/kg-hr at 20 °C	Moderate	1-2 weeks
52	Peppers-Bell;Paprika	7 to 10	95-98	Low 0.1-1.0µL/kg-hr	Low	2-3 weeks
53	peppers-Hot Chiles	5 to 10	85-95	Low 0.1-1.0µL/kg-hr	Moderate	2-3 weeks
54	Pointed Gourd	8 to 15	85-90	Low 0.1-1.0µL/kg-hr	Low	4-6 weeks
54	Potato-Early crop	10 to 15	90-95	very low <0.1µL/kg-hr at 20 °C	Moderate	10-14 days
55	Potato-Late crop	4 to 12	95-98	very low <0.1µL/kg-hr at 20 °C	Moderate	5-10 months
56	Pumpkin	12 to 15	50-70	Low 0.1-1.0µL/kg-hr	Moderate	2-3 months
57	Radish	0	95-100	very low <0.1µL/kg-hr at 20 °C	Low	1-2 months
58	Spinach	0	95-100	very low <0.1µL/kg-hr at 20 °C	High	10-14 days
59	Tomato - Mature green	10 to 13	90-95	very low <0.1µL/kg-hr at 20 °C	High	1-3 weeks
60	Tomato - Firm-ripe	8 to 10	85-90	High 10-100µL/kg-hr	Low	< 2 weeks

Source: Handbook—Refrigeration, ASHRAE (2018). American Society of Heating, Refrigerating and Air-Conditioning Engineers. Inc. ISBN, 978-1.



CHAPTER 03

Building Design and Construction

3

The packhouse design is primarily driven by the produce being handled and the buyers' requirements. However, this design and construction guideline can help optimize the flow of produce and people within the packhouse. Improved design can reduce the resultant temperature variation across various sections in a packhouse, thereby minimizing deterioration of the produce and saving energy. The construction of the packhouse starts with the selection of an appropriate site. This section will discuss the key aspects to be considered for the site selection and planning for the development of the packhouse.

3.1 Site Selection and Planning

Site selection and planning for a packhouse are crucial and can significantly impact the functionality, efficiency, and overall operation. Several aspects, such as,

- Proximity to farm gate
- Proximity to key markets and distribution channels
- Plot size (sufficient to include all the necessary facilities)
- Provision for expansion
- Access to critical infrastructure like roads, transportation system
- Availability of reliable utilities such as water and uninterrupted power supply
- Compliance with regulations such as local zoning laws, environmental regulations, and other legal requirements
- Consideration for employing renewable energy for power generation
- Availability of skilled, semi-skilled and unskilled workforce
- Risk mitigation such as flooding, natural disasters and other environmental hazards

3.2 Landscaping

Landscaping is an essential component that extends beyond mere aesthetics, and its critical role lies in enhancing operational efficiency and ensuring the smooth flow of vehicles. Strategic placement of shade-providing trees addresses the need for relief from the heat. The landscaping approach accommodates various vehicle types, including those for transporting the produce, waste disposal, and machinery, emphasizing functionality and visual appeal. The goal is to cultivate an environment that seamlessly integrates with the diverse facets of packhouse operations, aiming for more than just a picturesque landscape.

- **Accessibility and Flow:** Define pathways for smooth movement of personnel, equipment, and farm produce. Prioritize accessibility in loading areas for efficient goods transportation. Consider diverse vehicle needs, from smaller produce vehicles like pick-ups to larger dispatch vehicles. Integrate electric vehicle charging provisions for sustainability.
- **Waste Management:** Implement designated waste disposal and recycling areas, promoting sustainability and cleanliness. Consider composting options for organic waste generated within the packhouse.
- **Drainage System:** Provide suitable slopes to ensure a proper drainage system.
- **Greenery and Aesthetics:** Incorporate native plants like Neem and Hibiscus that thrive in local conditions, contributing to local biodiversity and promoting a visually appealing and sustainable landscape. Integrate trees strategically to build shading, create a local micro-climate, and provide additional benefits.

- **Shading Areas:** Integrate shade-providing trees strategically around break areas and entry points to counter the heat.
- **Safety and Security:** Maintain clear sightlines by avoiding overgrown vegetation that could pose security risks. Install adequate lighting to ensure a safe and secure environment during the day and night. Consider site/facility planning elements such as measuring fencing dimensions, identifying locations for security features, and planning for adequate lighting to enhance security.
- **Water Conservation:** Opting for native plants and efficient irrigation systems to conserve water, especially in arid regions. Incorporate rainwater harvesting methods to supplement water needs during the monsoon season.
- **Pest control:** Design landscaping elements that minimize the potential to minimize pest-related concerns, such as integrating plants with natural insect-repelling properties to minimize pest-related concerns.
- **Maintenance Plan:** Develop a comprehensive plan that considers seasonal variations and specific challenges the climate poses.

3.3 Design of the Built Structure

A packhouse building is normally a single-floor structure with a 4 to 5m height. Efforts should be made to design the shape to minimize the building's external surface area to volume ratio to reduce external heat gains. Detailed discussion on orientation, ground coverage, floor area ratio, passive design features, and thermal and visual comfort is mentioned below:

3.3.1 Orientation

Generally, a rectangular building is preferred to have its orientation in the North direction (for areas in the Northern Hemisphere) to minimise wall areas exposed to direct solar radiance. The dispatch operations will typically be after the morning hours, and an easterly location is preferred to avoid exposure to the harsh afternoon sun. In most cases, wind direction also runs east-west, so a north-facing building works well in reducing the air infiltration load on the building. The roof can be a galvanized iron sheet roof or a Reinforced Cement Concrete (RCC) slab. Reflective paint of white colour is recommended over the sheet roof and RCC slab to reduce solar heat gains. The internal ceiling over the packing hall should have insulated panels with Polyurethane Foam (PUF) or Polyisocyanurate (PIR) insulation. A passive turbo vent is also recommended to ventilate the attic space to reduce heat transmission to the lower spaces.

3.3.2 Ground Coverage

Generally, a building size of 1000 m^2 would be required for a fruit /vegetable packhouse of 15 to 20 MT/day handling capacity. A minimum plot area of 2500 m^2 would be required, with ground coverage of about 40% plinth area.

3.3.3 Floor Area Ratio (FAR)

Floor Area Ratio is the ratio of the total built-up area to the total plot area on which the packhouse will be created. The packhouses are single-floor structures; however, it is recommended to have admin offices, spare parts room, canteen, etc. on the upper floor. It helps create a thermal buffer from the top and frees the ground area for future expansion.

3.3.4 Passive Design Features

Optimal building orientation plays a pivotal role in minimizing solar heat gains. Most walls in the temperature-controlled areas are well-insulated and don't have windows, to avoid heat exchange between the outside environment and temperature-controlled areas. However, windows are essential for ventilation in spaces like the sorting, grading, and packing areas, and careful consideration is given to select proper glazing material for windows to avoid heat from outside during the day. Additionally, incorporating daylight harvesting practices in these specific zones promotes energy efficiency and diminishes the need for artificial lighting, aligning with sustainable design principles.

3.3.5 Measures to Enhance Thermal and Visual Comfort

The major human activity in a packhouse takes place in the packing hall, where the F&V handling, grading, and packing activities are carried out. It is a common practice to provide evaporative cooling units with adequate exhaust systems to create reasonably comfortable conditions. The recommended temperature range is 25 to 30 degrees C during hot and dry summers. In other seasons, only ventilation is required, like in monsoon season, when ambient relative humidity is high and internal RH is usually around 70%. In other spaces like plant rooms, toilets, changing rooms, etc., ventilation is provided with exhaust fans.

Lighting is an important aspect of the packing hall & has to be provided as per recommended levels (IS-3646, Part 1, Table 1 6665) (BIS, 1992). However, packhouse

developers recommend 600 lux levels for sorting, grading, and packaging units, while 300 lux levels are recommended for the pre-cooling, staging cold room, ante-rooms, and cold dock.

3.4 Building / Facility Layout

This section provides an overview of the functionality expected from each defined facility in a packhouse so that the readers can understand why a given facility is designed as it is. There could always be different approaches to designing a facility. However, this document provides broad guidance for such a facility. It is not meant to be a 'standard' but a 'guide' providing reference to the basics of the functioning and the requirements for designing a packhouse.

The packhouse building comprises three major sections, indicated in Figure 12. The central portion has the packing hall, demarcated passages, receiving and dispatch docks, and the pre-cooling/staging cold rooms, which are refrigerated. It is surrounded by the plant room, electrical and genset rooms on one side, toilets, changing rooms, packing material storage, and labs on the other. This arrangement helps to avoid direct sunlight exposure and provides a thermal buffer to the working hall. Windows need to be provided only in external spaces (rooms). The maximum ratio can be 40% window to wall ratio, thus allowing good natural light. A separate waste removal exit is recommended to remove trimmings and discarded produce from a designated dump area.

Figure 12 is illustrative of an integrated packhouse and Figure 13 shows a sample banana packhouse layout with a unidirectional flow despite not being in a straight line. The intent of having a unidirectional flow is to avoid cross-contamination. For example, once produce has been washed and graded/sorted, it should not have any connection with the incoming produce and should move further in the process without coming in contact with the previous stages of the same produce.

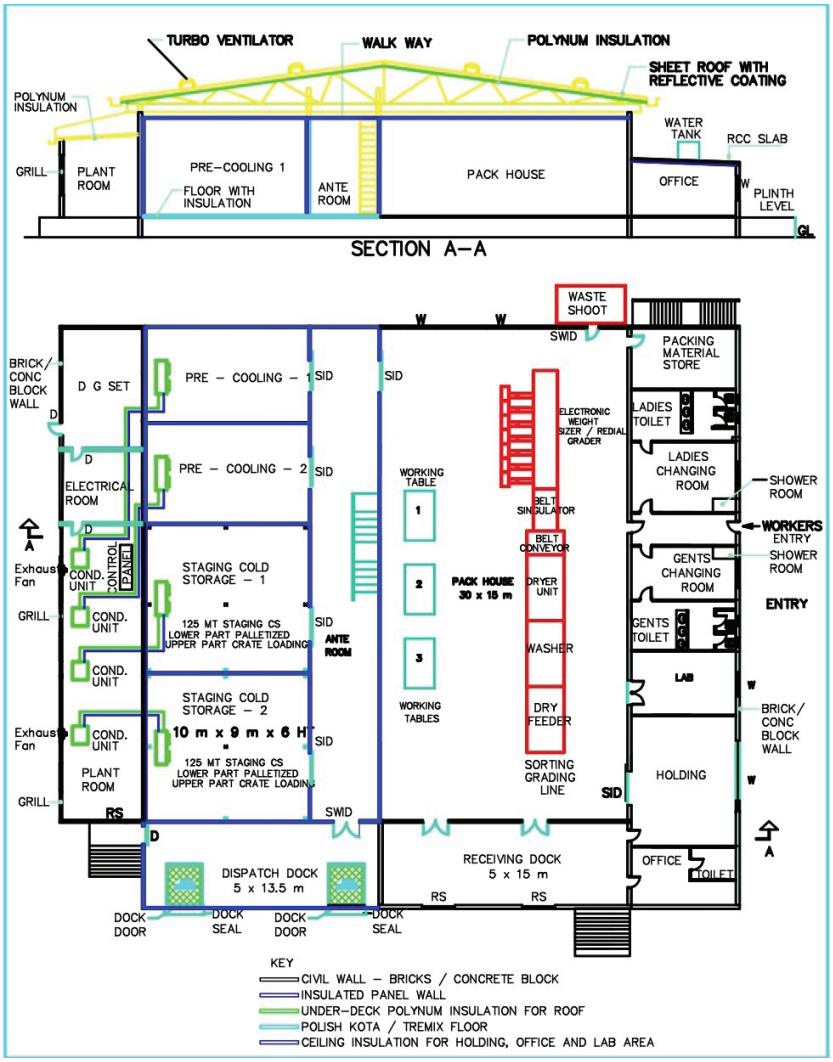


Figure 12: Illustrative layout of an integrated packhouse

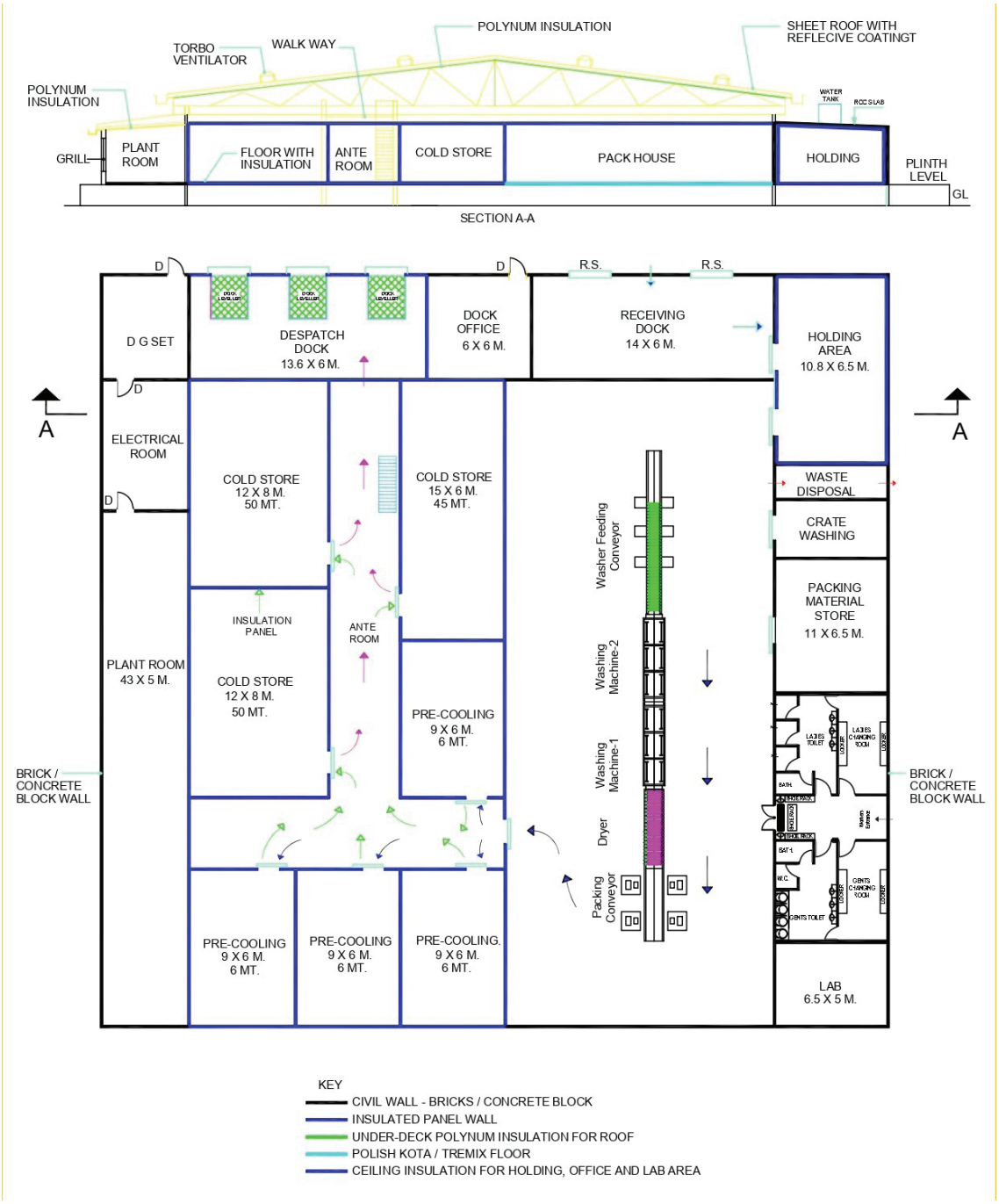


Figure 13: Illustrative layout of a banana packhouse

The recommended layout shows the East-West direction, and the cool areas are mostly covered by utility spaces on the south and north sides of doors, which have been added as per standard practice. Further detailing of the packhouse elements should be produce-specific and is not covered in this guideline.

3.5 Additional Components

Additional components include areas required to support the effective functioning of a packhouse, such as toilets, changing rooms, and receiving platform, briefly described in this section.

3.5.1 Receiving Platform

The receiving platform's purpose is for marshalling the incoming (harvested horticulture produces) produce, where it undergoes initial weighing and verification. The receiving platform handles the produce directly from farmers in non-standardised lots, possibly even in gunny bags and baskets. The produce typically arrives in small lots and is then carted into the main hall of the packhouse for the next set of activities. This is an ongoing process in which bins and plastic crates are used until the sorting grading lines. These crates are then emptied and reverted to the marshalling platform. The produce is usually fresh and resilient to harsh handling, but with each passing hour, it deteriorates. This phase comes under the golden hour; hence, the receiving platform must be designed to handle the types of produce received efficiently. It should be large enough to allow congestion-free movement and handle multiple incoming loads quickly. The following aspects should be considered while designing the receiving platform:

- **Type and height of the vehicles bringing the produce:** Vehicles carrying incoming produce may be of varied sizes and heights. Most of the time, the produce from the farm level is brought in small vehicles like pickup vehicles, three-wheeler tempos, etc. For a standard facility, the plinth height is 1200 mm. However, most of these vehicles are between 650 and 1000 mm tall. A height of 900 mm should be appropriate for an incoming area. This can also be done by increasing the ground level just outside the incoming dock by about 300 mm so that the effective plinth level continues to be at 1200 mm, which is the standard requirement and matches the height of regular trucks.
- **Covered receiving platform:** A receiving platform should be protected from rain and direct sunlight. Special care should be taken so that the canopy of the platform is extended to 900 mm (or more, if possible) beyond the plinth line. There should ideally be a water gutter in case the packhouse is expected to be operational in the rainy season. While doing so, the maximum height of the vehicles coming in needs to be considered. Normally, a clear height of about 4.5 m meets most requirements.
- **Receiving platform levelling:** To ensure the least damage at the receiving platform during unloading, platform levelling is recommended if there is a difference between the vehicle height and the receiving platform. Platform levelling can be done by adding interim devices like mild steel plates. It is generally implemented when a unitised load is handled, such as a fixed truckload sent from a large farm. However, in most cases, incoming lots are generally not unitised and off-loaded by hand from motorcycles, tempos, vans, etc.
- **Holding space** – Holding space is an enclosed area meant for short-term storage. However, it is not recommended as it can become a bottleneck for the produce flow. Instead, the receiving platform should have multiple doors into the working hall, and the produce should be stored outside and moved in constantly to feed the sorting tables/lines.

3.5.2 Packaging Material Store (PMS)

The packaging material store is a designated area to store the packing material, such as baskets, crates, etc., and should be ventilated. It does not need to be cooled under normal circumstances. Sometimes, the incoming air is filtered by a 10-micron pre-filter for the supply side. The PMS should have a separate entry from the outside of the building to have the packing material delivered to the PMS directly without interfering with the working of the packhouse. Hence, the PMS would also have two doors: one outside for produce entry and one towards the grading/sorting hall. The entry towards the grading and sorting hall can often be a small opening, and the packing material can be sent out through the opening onto a conveyor for further utilization in the area.

3.5.3 Ante-room

The Ante-room (shown in Figure 14) is another much-misunderstood concept in a packhouse and is observed to be avoided to save space. However, an ante-room is crucial for a packhouse for effective energy saving. Ante-room prevents large breaches in temperature when cooled produce is moving from one cold space to another and especially when waiting for loading onto transport. The temperature range for an ante-room varies between 15°C to 20°C (which helps to buffer the refrigerated produce from ambient temperature).





Figure 14: Photo of an ante-room

3.5.4 Dispatch Dock

Dispatch dock is an essential component connected to the ante-room, allowing safe loading/unloading of cold produce to/from refrigerated vehicles. Dispatch Dock has three main parts:

- **Dock Door:** An insulated door that opens only after a truck or container is docked in position and ready for operations to load the goods easily. The door may have a motorized operation for the vertical lift of the shutter.
- **Dock Shelter:** The dock shelter has retractable flaps or inflatable booms that form an air seal against the body of the truck or container. The purpose is to avoid losing cold air (energy) from inside the truck, which is pre-cooled before commencing the loading operation.
- **Dock Leveller:** The dock leveller is a load-bearing ramp with hydraulic or pneumatic operation for adjusting the ramp height to suit the container floor level. Integrated safety controls are provided on the door leveller with an emergency off switch, restart, and press and hold actuation.



3.5.5 Toilets and Changing Rooms

A packhouse should have separate toilets and changing rooms for males, females, and others. The toilet size depends on how many people are expected to use the facility and can be determined per local factory norms. With more female workers in the packhouse, the number of Water Closets (WCs) can be suitably increased. The labour laws of the respective state or territory may also be considered while considering the number of WCs and toilets. It is suggested to provide shower rooms in the toilets. Additional provisions like ramps can be made along with staircases for people with disabilities. The changing rooms should have lockers for the workers to change into working dresses and keep their belongings in the lockers. Some certification norms require that toilets be placed away from the main processing building and only hand washing facilities be provided along with changing rooms.

3.5.6 Crates Washing and Storage

Packhouses use plastic crates to store/transport the produce. The crates are typically segregated into those that rotate between the farm and packhouse and those used between the marshalling platform and working hall. This practice is as per Hazard Analysis Critical Control Point (HACCP) conventions and to minimise the risk of disease and contamination. Using manual loading, crates are ordinarily stacked to a height of about 2.1 to 2.2m. As such, the crates need to have the strength to be able to have multiple stacks. A facility (indicated in Figure 15) for washing the crates is necessary for a packhouse, and segregated space for storing the crates is also advisable. Washing should be done as per HACCP norms (FDA, 1997) of each packhouse at regular intervals so that produce leftovers, such as juices, flies, pests, dirt, etc., do not become breeding grounds for bacteria and mould.

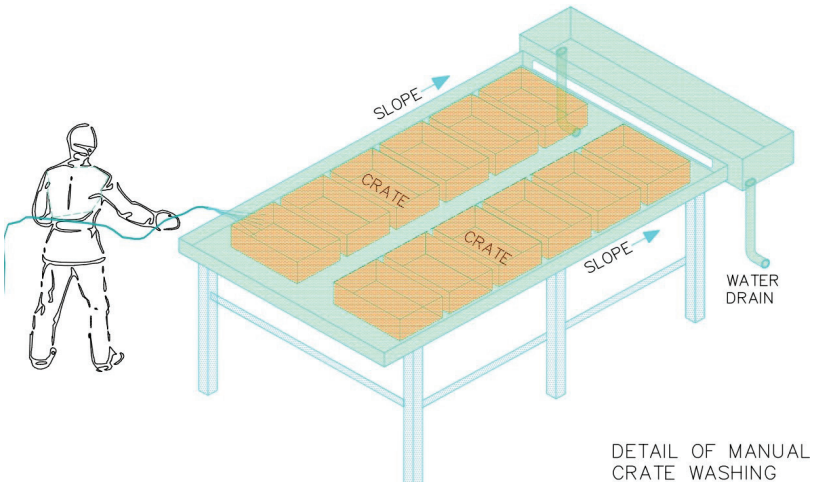


Figure 15: Manual crates washing in a packhouse

3.5.7 Office and Canteen

Office space in the packhouse is necessary for tracking incoming and outgoing produce, keeping updated on stock held at any given time, and planning the use of the facility considering the expected produce & demand.

The workers will use Canteen for dining and should maintain a certain hygiene level. The canteen or dining area should be a clean and dry space with proper tables and chairs for eating food and tea/snacks, depending on the time of the day, and a designated space for washing hands with access to clean drinking water.

3.5.8 Waste Disposable Area

A packhouse generates a lot of culled material, colloquially called a dump. Waste generated from the grading/sorting activity should be disposed of properly. On average, it may be in the range of 3 to 5% of the produce. Such material can be used for biogas generation for possible water heating or generating electricity for small loads, cattle fodder, mulching, or other uses, promoting a circular economy.

To avoid cross-contamination issues, a separate area for waste disposal should be built, distanced from the main packhouse building. Dump collected in the waste disposal area should be regularly evacuated to avoid infestation of flies, mosquitoes, etc. A packhouse should also have a separate access path for dump pickup vehicles.

3.5.9 Internal roads, Parking, Electronic weigh bridge, Main gate, Security cabin

While designing a packhouse, elements such as internal roads, parking, electronic weighbridge, main gate, and security cabin should be considered for an efficient and safe working place for people within a packhouse.

- Internal roads for the movement of vehicles for loading, unloading and emergency.
- Parking for trucks, containers, cars, and bikes.
- The main gate and security cabin should be sufficiently sized for day and night service with proper outdoor lighting including emergency lighting.

3.5.10 Underground water storage, Water treatment and water supply, Drainage system, and Fire pump room

Water storage would depend on the quantity of produce handled, the number of crates and type of refrigeration used, and the fire-fighting and husbandry requirements. Based on the requirement, a storage size should be considered. Normally, if the daily requirement is around 5000 liters, then a storage tank of about 10 days capacity is recommended, which would mean around 50,000 liters. Overhead tanks should be installed to maintain water pressure through gravity to feed the service lines. These can be topped up during daylight hours using solar-powered pumps, which will make the facility more energy efficient.

Depending upon local regulations and CPCB norms, a water treatment plant and effluent treatment plant is recommended.

Scupper drains are normally provided in the cold room to drain excess water, including after periodic cleaning (i.e., mopping). Depending on the facility's location, a septic tank or sewage treatment plant may be necessary. If the local authorities provide a sewage drain, the sewage may be connected to the given line. However, a septic tank or an STP is suggested if that is not available.

3.6 Machinery and Equipment Space

The section discusses the placement and clearances required for various types of essential equipment and machinery to be employed in a packhouse for effective and safe functioning.

3.6.1 Refrigeration Plant

The layout of the refrigeration plant should be properly designed to ensure the efficiency of the operation. The design of the refrigeration plant will majorly depend on the refrigerant selected for the refrigeration system operation. The design space of the refrigeration plant will vary for the ammonia-based refrigeration system and HFC/HFO/HC-based system. Further, water-cooled or air-cooled systems would have different plant room designs. The normal requirements to be taken care of when designing a refrigeration plant are as follows:

- Located close to or adjoining cooling space to minimize piping lengths to indoor units and minimize transmission losses
- Incorporate refrigerant recovery units to prevent the release of refrigerant into the atmosphere during maintenance cycles.
- Adequate clearance space between the walls and any equipment to allow space for movement and additional clearance on any side that needs servicing.
- Adequate ventilation from at least three sides (if not on all four sides) for airflow so that the air cannot get blocked and lead to short cycling. Free or forced air flow movement in any plant room is very important, and a well-maintained plant room will always have adequate ventilation. Suitable overhand for protection from wind gusts in the rainy season.
- If a condensing unit is air-cooled, it is recommended to have adiabatic type air coolers for the same (for dry and hot climatic conditions). Thus, a forced air cooling is used when the ambient temperature increases, around 30 °C. Further, for air-cooled condensers, there should ideally be an obstruction-free clear space in front of the condensing unit to allow the hot air from the condensing unit to flow into the atmosphere and not circulate back to the coil. If it does that, the compressor will work at higher condensing pressure, eventually leading to higher power consumption and lower system efficiency.

3.6.2 Electrical Panel Distribution Space

The electrical panel room should be a ventilated facility with a separate lockable door and a separate entry following the CEA guidelines and National Electrical Code. It is important to keep track of the electrical panel requirements when designing the electrical room. Electrical panels should have enough space for clearance around them to open and service the panels. The free space normally depends on the door size but should be at least 1.2 m clear in front of the panel. If panels face each other, the clear space should be adjusted to ensure both doors are open and there is still space for human movement. Maintaining clearance/service space behind the panels is also suggested. All electrical installations should be properly earthed as per IS 3043 or NBC/NEC.

3.6.3 Electrical Substation

A regular substation area includes a liquid filled distribution transformer (location for which depends on the plot size and the main power supply source), breaker, metering kiosk, cable from the substation to the main Power Control Centre (PCC to be run underground), main PCC, and auto transformer switch (Bureau of Indian Standards, 2011). The main PCC and auto transformer switch from the listed items can be placed in the electrical room (Bureau of Indian Standards, 2018). Substation should be suitably illuminated with lighting level specified in Table 1 of IS 3646 Part 1.

3.6.4 DG set

It is recommended that a packhouse has a diesel generator set, which will run the refrigeration and other equipment when electricity is disrupted. Take care to provide a proper foundation for installing the DG set. DG set size should be designed to:

- cater to the higher starting current of the compressor motor with generally 20 % higher KVA capacity.
- cater to the starting current of the large compressor, as and when a refrigeration system operates. It is the compressor that starts last; hence, the starting current of the large compressor motor will typically be the last to come on[2].
- suit other independent running equipment like grading, sorting lines, heaters, etc.

It is suggested to provide a proper foundation for installing the DG set. The DG has an acoustic enclosure and should be given clearance space for maintenance and easy access and it should comply with the CPCB regulation for air and noise pollution.

Selection of suitable rating of DG set should be decided based on the total connected load, starting and running power needs.

3.6.5 Allied Equipment

Several allied equipments (listed below) are required within a packhouse catering to the specific requirements of the produce line(s). Some of the allied equipment that comes into the picture are:

- **Boiler / hot water generator with steam piping** – Packaged boiler/hot water generators are used to provide steam/hot water for a few applications, such as hot water treatments of fruits and vegetables and crate washing. In the case when the packhouse is located near the processing unit, then steam generated from the boiler can be utilized to operate the Vapour Absorption Refrigeration System (detailed in Chapter 5).
- **Air compressor with piping** – Compressed air in a packhouse is majorly used to operate pneumatic conveying systems, sealing, and packaging machines.
- **Box Strapping Machine** – Its primary purpose is to securely bind and strap packages, ensuring that the produce remains intact and stable in the packaged box.
- **Hand pallet trucks/Electric pallet trucks** – Pallet trucks are used to load and unload packaged produce from pallets and transport it within the packhouse.
- **Battery Operated Pallet Truck (BOPT)** – BOPT is an electrically powered pallet truck that helps in the precise, controlled, and efficient movement of pallet trucks within the packhouse.

Most equipment used in the packhouse requires space, and the designated space and clearance/servicing requirements for each piece of equipment need to be considered while planning their place in the packhouse. These need to be discussed with the respective manufacturer, and this space needs to be allocated for BOPTs that require space that provides ventilation for battery charging stations.

3.6.6 Laboratory Equipment

Most packhouses may not need a dedicated lab, and it is an additional or optional room for a domestic packhouse. However, if the quality analysis is required in a packhouse, a laboratory can be set up where the produces are tested for various parameters like defects, hardness, etc., and the decision on whether the produce is acceptable or not is taken based on the test results. A generic equipment list for a laboratory is provided in Table 5. All test equipment and measuring instruments should be calibrated from an accredited calibration lab to ensure that the test results are accurate and free form error.

[2]The DG set can be ideally selected for the full working capacity of packhouse facilities. However, if it is selected only for essential loads during power outages, it could be about 60% of the full working load.

Table 5: List of laboratory equipment

Sr. No	Equipment
1.	**Digital Vernier Caliper –** It precisely measures the dimensions of the produce, ensuring accuracy in sizing and quality control of produce.
2.	**Weighing balance -** Used for accurate weighing of produce,
3.	**Weighing balance 0.001 to 200 gm. (Regular Quality) -** Used for precise weighing of smaller quantities of produce
4.	**Digital pH meter –** Measures the acidity or alkalinity in fruits and vegetables.
5.	**TSS meter (Refractometer) ranges from 0 to 32°.** It measures the sugar content in fruits and vegetables to assess the total soluble solids.
6.	**Rubber cork -** Used for airtight sealing of containers stored with sauces, jams, etc. It is mostly used in the processing industry.
7.	**Digital hand-held TDS meter 0-3000 –** Measures total dissolved solids in the water to check the quality of the water used for packhouse operation.
8.	**Digital multi-system Thermometer (pen type) (-)50 to 300°C –** Used to check the temperature of the stored produce.
9.	**Binocular research microscope -** Used for detailed quality assessment and disease detection.
10.	**Differential Colour Charts to Check the Colour of the Fruit -** Used for assessment of harvest maturity of fruits and vegetables
11.	**A penetrometer is used to measure pulp pressure.** It is used to monitor the ripeness stage and to check the consistency of the inner fruit.

3.6.7 Clearance Around Equipment

Most equipment requires the following clearances to be kept around them:

- For the movement of workers and material
- For servicing of the equipment as and when required
- For maintenance of equipment like painting, touch up, etc.

Generally, clearance space is expected to be around 2m on all sides of any equipment or as the manufacturer recommends. If two lines are next to each other, then this space may be optimized to 2.5m. Clearance should also be kept above the equipment for maintenance, as any item may need to be removed from the top after installation. Clearance norms depend on the specific unit type and cannot be generalized.

3.6.8 Safety and Firefighting System

The electrical room and plant should not use a water-based firefighting system; instead, a CO_2 or dry powder-based system should be installed. The facility should incorporate suitable fire-detecting sensors and appropriate portable extinguishers and sand buckets with stands per local guidelines/norms. Most refrigeration plants are kept open to air, and dry powder extinguishers are commonly used.

CHAPTER 04

BUILDING ENVELOPE AND CONSTRUCTION MATERIAL

4

A packhouse's building envelope and construction materials play a crucial role in shaping the facility's sustainability, energy efficiency, and overall functionality. Energy efficiency considerations can be incorporated at the design and planning stage, for example, in decisions related to orientation, natural lighting, proper insulation, well-designed air sealing, efficient fenestration and shading of walls and roof, that can contribute to low heat ingress and stable temperatures inside the packhouse. Skylights, energy-efficient windows, and the strategic placement of vents can reduce the reliance on artificial lighting and mechanical ventilation, decreasing energy demand. These first principle-based building design considerations reduce the facility's cooling load, enhance thermal and visual comfort for packhouse operators and workers, and could have positive implications for overall productivity. Selecting appropriate building materials for roofing and walling can minimize solar heat gains from the high-temperature difference between outdoor and indoor practices. Table 6 below describe the features to be considered while designing the packhouse building. Table 7 provides low-GWP foam insulation specifications (Bureau of Indian Standards, 2002).

- Building size to accommodate various facilities required in the packhouse.
- Building structure to be earthquake-proof.
- Building structure: Pre-Engineered Building (PEB) structure with 150 GSM Galvalume metal sheets roofing with a reflective coating.
- Cold block construction with anteroom, pre-cooling chamber, staging cold stores, cold dispatch dock – in insulated panel for walls & ceiling floor insulation to be done with low-GWP foam slabs.
- The packhouse false ceiling should have low-GWP foam insulated panels.



Table 6: Material specification for a packhouse and cold storage

Description	Specification
Structure	The packhouse structure with the required facilities should be housed in a steel structure or PEB structure with sheet metal roofing at an appropriate height.
Foundation	The civil works for the foundation will depend on the soil strata at the site. If the soil has the low bearing capacity, the structure must be in concrete piles. With good soil-bearing capacity, the same should be designed in open foundations.
	The plinth work shall consist of plinth and tie beams for the walls and other required supports.
Plinth height	For easy loading and unloading operations, the ideal height should be 1.20 M to 1.35 m.
Flooring	The general flooring should be constructed on well-compacted earth, rubble soling, or granular sub-base and finished with the appropriate thickness of grade slab in the packing hall. The floor should be finished in polished Kota flooring/Tre mix flooring with proper drain points for easy cleaning.
	The floorings in the cold rooms should have proper insulation fixed over the base concrete, and the insulation should be covered with P.C.C/trimix with light reinforcement. The final finish can be in EPOXY coating of a minimum of 2 mm thick to take the movement of the pallet trucks.
Walls	The wall above the plinth can be in concrete block or fly ash bricks, finished in double coat plaster from outside, and painted in a light colour. The external walls can have sliding windows with aluminium frames up to 40% window-to-wall ratio. The overall heat transfer factor should be up to 0.58 W/m^2K.
Emergency doors	To be provided as per the fire norms
Pre-engineered building	For the packhouse, the minimum height is 4 to 4.5 m. For the cold room, the height should be as per the stacking system.
Roof slope	1 in 20
Bay spacing	Bay spacing should have maximum wide operational areas.
Frame	Rigid frame
End frame	Rigid frame with no future expansion.
Purlins & girts	Pre-galvanized
Bracing on roof and wall	Diagonal rod bracing
Roof panel	Standing seam - 0.55mm TCT bare galvalume AZ150, 345 MPa steel.
Thermal insulation	All roofing and cladding (excluding FRP sheeting area) should be treated with Polynum of 8 mm thick/ equivalent low-GWP foam insulation.
Fasteners	Mechanically galvanized Hex-washer head self-drilling fasteners with integral EPDM seals.
Accessories	Flashing, trims, eave gutters, and downspouts (matching the colour scheme) Roof access ladders with landings. All staircases are as per requirement.
Daylight panel	2.0mm thick polycarbonate sheet for daylight panel - 3% of roof area
Canopy	Canopy projection as per requirement.
Gutters	Matching the colour scheme.
Paint finish	All primary and secondary members should be supplied with one factory-applied epoxy primer coat. Painting should include 2 coats of epoxy paint over a coat of epoxy primer. (blast cleaning SA-215/ epoxy primer – 140-micron average/ PU dove grey paint finish – 80-micron average.
Ridge ventilator	(Throat – 600 mm) and turbo ventilators as per practice.

Description	Specification
Rolling shutter	Sectional doors should be a part of the pre-engineered building (fixing of rolling shutters will be done by the civil contractor).
Design loads	- (LIVE/ WIND) as per the location.
Dead load	0.15 kN/m^2 The structure, i.e. the main frame and the purlins, should be designed to take the load of the firefighting system, including the sprinklers, if required, as per local fire norms.
Live load	0.60 kN/ m^2
Solar panels load	To be considered at about 20 kg/m^2.
Wind speed	47m/sec (as per IS 875 Part-III, 1987)
Seismic zone (Z)	IV (0.16) (as per IS 1893) 2002 subject to location
Deflections	
Main frame	L/180
Vertical	EH/100
Lateral	L/180

Table 7: Low-GWP foam insulation specification

Property	Units	Location	Value
Nominal thickness	8 mm	Underneath roof sheeting	
Emissivity (ASTM C 1371)			0.05
Reflectivity (ASTM C 1371)			0.95
Heat resistance (R)-under roof	m^2 °C /W		3.06
Noise reduction coefficient (ASTM E-384)	%		55%
Sound transmission class (ISO 171-1)	dB		-6
Tensile strength @peak (ASTM C-1136)	g/cm-width	MD	2650
		TD	2750
Elongation @peak (ASTM C-1136)	%	MD	18.7
		TD	18
Tear strength (ASTM D-1938)	N	MD	12.5
		TD	13.5
Puncture resistance (TAPPI T 803)	Joule		4
Surface flame spread ** (BS 476: Part 7)			Class 1
Water vapor transmission (ASTM E-96)	g/ft^2hr		0.018 (method A)
Fungal resistance test (ASTM C 1338)			No fungal growth
Corrosion resistance (internal test)	Conc.HCl		High resistance *
Yield (nominal)	g/m^2		320
Standard roll size	m x m		1.20 x 40
Standard roll weight (gross)	Kg		±15.4

4.1 Thermal Insulation for Temperature-controlled Area

Temperature-controlled areas include the pre-cooling chamber, staging cold stores, ante room, holding room, and dispatched dock. The whole construction involves insulated sandwich panels for walls and ceilings as well as underfloor insulation (see Chapter on insulation in Guidelines & Minimum System Standards). The current practice uses low-GWP foam panels with camlocks or continuously formed panels (MoEF&CC, 2022), including in floor insulation slabs. The insulated doors should be sliding type with panel insulation, and SS latches and hinges. The recommended heat transfer coefficients as given in IS: 661:2000 on thermal insulation of cold storage and the thickness of the insulation material for roofs, walls, floors, and ceilings are mentioned in Table 8 and Table 9, respectively. However, in actual practice in projects it is recommended that the external peripheral walls of the temperature-controlled areas have a PUF/PIR insulation thickness of 120mm or 150 mm as the incremental cost is quickly recovered through energy savings.

Table 8: Overall heat transmission coefficient for refrigerated chambers

Operational temp. range (°C)	Max. U Value (W/m² K)			
	Exposed walls	Intermediate walls/ ceilings	Roofs	Floors
(-) 4 to 2	0.27	0.58	0.24	0.29
2 to 10	0.35	0.93	0.29	0.47
10 to 16	0.47	0.93	0.29	0.64

Table 9: Properties and recommended minimum thickness for storage temperature −4 to +2-degree °C

Type of insulation material	Properties		Wall U value =0.23 (W/m² K)	Ceiling/Roof U value =0.16 (W/m² K)	Floor U value =0.28 (W/ m² K)
	Density kg/m³	K (at 10 °C) W/mK	Thickness mm	Thickness mm	Thickness mm
EPS	15	0.036	150	225	125
PUF/PIR	38	0.023	100	150	100
XPS	30-35	0.025	100	150	100
Phenolic foam	50	0.026	125	175	100

In addition to the thermal insulation for the refrigerated section, insulation is also provided with ceiling panels on the packing hall and ceiling under the truss roof. Indian Standard (IS 661) recommends an overall heat transfer coefficient for temperatures of 16 °C and above to determine the thickness of the panel. Thus, a 20 °C to 27 °C temperature range can be considered for the packing hall, as it is always better to assume a higher range for insulation design. Floor insulation is only necessary in the pre-cooling and staging cold room. The standard practice is to select low-GWP PUF slab as the insulation material. The polythene sheet will be fixed with a vapour barrier at the bottom and a tar felt cover before the PCC / tremix floor finish.

4.2 Construction Features

As per site condition, the foundation is walled with fly ash bricks, sand cement plaster, and light-coloured paint on the outer side. The inner side would have a plaster-covered unit with glazed tiles up to 2.4 m, minimum height. Insulation is not provided on the walls of the sorting grading hall, which is surrounded by service rooms, and the pre-cooling and cold storage are on the other side, as they are usually insulated walls. However, some windows are provided on the side external wall unit where the exhaust fan units are usually provided. Maximum “U” factors and SHGC factors

for vertical fenestration can be adopted from ECSBC 2024, provided for ECBC+ & ECBC super buildings as tabulated in Table 10. Maximum "U" factors for the external opaque wall for composite, hot & dry, and warm & humid climates as per ECSBC are given in Table 11. The maximum "U" factor for the fenestration assembly with an aluminium frame shall be as follows:

Table 10: Maximum U-factor for fenestration assembly as per ECSBC 2024

ECBC Type	ECSBC	ECSBC +	ECSBC super
Max 'U' factor ($W/m^2 K$)	2.2	1.8	1.8
Max SHGC	0.25	0.2	0.25

Table 11: Max 'U' factor for opaque walls as per ECSBC 2024

ACU building types	Composite	Hot & dry	Warm & humid	Temperate
Max 'U' factor ($W/m^2 K$)	2.2	1.8		1.8



CHAPTER 05

Equipment and System Design

5

Pre-cooling (one of the most critical packhouse functions) and staging cold rooms are the two most energy-intensive systems in a packhouse, where the refrigeration system plays an important role in maintaining the required temperature. Refrigeration systems and associated auxiliary components consume a significant portion of total energy; thus, refrigeration system design and equipment should follow some guidelines to make them efficiently serve the purpose. The selection of refrigeration systems and components, correct sizing depending on the refrigeration demand, sizing of pre-cooling and staging cold rooms, along with the required door sealing to prevent air infiltration and air changes for ventilation, is essential. This should also include suggested measures for the design of energy management controls and automation systems. Furthermore, several strategies can be implemented to enhance the efficiency of the refrigeration system and promote energy conservation. This section discusses heat load calculations, refrigeration technologies, and types of refrigerants employed for efficient packhouse operation.

5.1 Refrigeration System Sizing (Heat Load Calculation Reference) and Selection Criteria

Suitable equipment selection and design are critical factors to ensure the operational efficiency of a packhouse. Further, refrigeration systems for pre-cooling and staging cold room applications can be designed and selected to maintain the appropriate level of cooling while managing adverse environmental impacts from energy use and refrigerant choice.

The following considerations are essential for system design:

- Determine the heat load based on the calculations of the total amount of heat gain or loss within a space, which involves factors like area, insulation, volume of farm produce to be stored, occupancy, and any other possible internal/external heat sources.
- Utilizing typical heat load sheets for pre-cooling, staging cold room, and ante-room calculations.
- Incorporating factors considered for regional climatic conditions within the heat load sheets.
- Adapting air circulation rates based on the specific produce, with typical rates provided as reference.
- Suggesting pre-cooling time per batch rather than mandating it.
- Ensuring compliance with recent regulations by updating refrigerant choices, including low-GWP and natural refrigerants (NHB, 2010)

5.1.1 Refrigeration Load Calculations (Indian Society of Heating, Refrigerating and Air Conditioning Engineers [ISHRAE] 2015a)

The load calculation is generally made for 24 hours and covers the following:

1. Transmission load (Heat gain through walls, roof, and flooring)
2. Load due to workers
3. Air change load/infiltration
4. Electrical lighting and motor load
5. Produce load (comprising of load due to the difference in product loading temperature and storage temperature, and respiration load, as the product continues to breathe during storage for a considerable period)

The method of calculating the various loads is as follows:

Transmission load (Q_t): The transmission heat gain through walls, roofs, and floors can be determined by the following formula:

$$Q_t = \frac{A \times U \times \Delta T \times 24}{1000} \quad \text{eq. (1)}$$

Here, Q_t=Transmission heat gain in kWh

A=Area of wall in m^2

U=Overall heat transfer coefficient in $W/m^2 K$

ΔT=Temperature difference between outside air and refrigerated space in °C

Typical U values are provided in Table 10 and Table 11 according to different conditions and insulating materials. The temperature difference shall be between the outside and inside design temperature plus the effect of solar gain on walls and roofs. Typical values of solar gains on wall and roof heat transmission (in °C) are tabulated in Table 12. The insulation thickness for walls, ceilings, and floors shall be selected as given in Table 7 and Table 7.

Table 12: Effect of solar gains on walls and roof heat transmission (in °C)

Walls	East	South	West	Roof
Medium colour	3	2	3	8
Light colour	2	1	2	5

Load due to workers (Q_w): The people working in the cold stores dissipate heat at a rate depending on the temperature of the room but, usually, for a short period during the day, the typical amount of heat generated by a person can be taken as given in Table 13:

Table 13: Typical amount of heat generated by a person

Temperature in °C	Watts/person
5	240
0	270

Thus, the heat generated can be calculated (in kWh) as (ISHRAE 2015b):

Q_w=No.of workers×No.of hrs per day of their work×heat generated per person

eq. (2)

Air Change for Various Room Volume (Q_a): The fresh air enters the cold store due to the door openings and/or through controlled ventilation (when storing fresh produce for longer than 48 hours). Depending on the number of door openings, the average air changes per day can be considered as indicated in Table 14:

Table 14: Average air changes per day at corresponding room volume

Room volume (m3)	Average air changes/ 24 hrs at 0 °C room temp.
10	32
100	9
500	2.7
1000	2.5
2000	1.7

The air changes can be increased by 100 % in case of heavy usage causing frequent door openings. If strip curtains are provided on cold room doors, the air changes can be reduced by around 70 %. In the case of precoolers, air changes are not considered because of the nature of operations – the batch load enters at one time and exits after precooling is completed, and there are no intermittent door openings.

The air change load (kWh) can be calculated using the following formula.

Q_a=Air quantity kg/day×(H_1- H_2)

eq. (3)

Where, H_1 = enthalpy of air at ambient condition in kJ/kg,

H_2= enthalpy of air at inside temperature in kJ/kg

Electrical lighting and motor load (Q_l + Q_m): The irrandiance vary between 2.5 W/m^2 to 10 W/m^2 in packhouse areas, depending on the type of operation of the store. The fan motors generate the heat as per the energy inputs to the motors. Thus, the cooling load (in kWh) can be calculated as follows:

For lighting (Q_l)

$$Q_l = \frac{\text{No of lights} \times \text{watts/lamp} \times \text{no.of hrs/day}}{1000} \quad \text{eq. (4)}$$

Evaporator fan motors (Q_m): The following equation can be used for the heat generated by various fan motors. For motors of small electrical capacity from 0.25 to 0.37 kW, about 1.43 kW of heat generated per kW of motor capacity can be considered, whereas, for the larger electrical capacity motors used in precoolers, heat generated per kW of motor capacity can be considered about 1.14 kW. In general, the fan motors used in the evaporators unit of a cold room have lower power rating compared to the fan motors used in precoolers.

Q_m=Total kW×Heat generated per kW capacity of motor×-No.of hrs day

eq. (5)

Produce load (Qp): The produce load in this case can be calculated as follows:

Q_p=m×C×(T_p-T_f)

eq. (6)

Where Q_p=Heat generated due to product in kWh

m=Mass of product in kg

C=Specific heat of product in kWh/kg.K

T_p=Initial product temperature

T_f=Final product temperature

Specific heat is a measure of the energy required to change the temperature of a produce by one degree. Therefore, the specific heat of produce can be used to calculate the heat load imposed on the refrigeration equipment by the cooling of the produce. Typical values of specific heat for some fresh fruits and vegetables are given in Table 15.

Table 15: Typical values of specific heat for some unfrozen fruits and vegetables

Produce	Specific heat (kWh/kg.K)* 10^{-3}	Produce	Specific heat (kWh/kg.K)*10^{-3}
Apples (average of many cultivars)	1.05	Mushrooms	1.11
Apricots	0.79	Lettuce	1.13
Banana (green)	0.99	Onions	1.09
Cherries (sweet)	1.06	Okra	1.10
Grapes	1.03	Peas	1.04
Oranges	1.05	Potatoes	1.02
Pineapple	1.06	Spinach	1.12
Mangoes	1.03	Tomatoes (ripening)	1.12

Source: Handbook—Refrigeration, ASHRAE (2018). American Society of Heating, Refrigerating and Air-Conditioning Engineers. Inc. ISBN, 978-1.

Respiration heat generated by produce depends on temperature, time from harvest, ripening condition, variety of produce, etc., and needs to be added to estimate the overall heat load. The respiration heat rate values are very small compared to the other heat loads and, thus, can be ignored for practical purposes.

$$Q_r = m \times \text{Respiration heat rate per kg} \quad \text{eq. (7)}$$

For instance, some of the typical values of respiration heat rates at various temperatures are provided in Table 16.

Table 16: Typical values of respiration heat rate for some fresh fruits and vegetables at various temperatures

Commodity	Respiration Heat Rate (W/kg) *10^{-3}				
	0 °C	5 °C	10 °C	15 °C	20 °C
Apples (Average of many cultivars)	6.8-12.1	15.0-21.3	-	40.3-91.7	50.0-103.8
Apricots	15.5-17.0	18.9-26.7	33.0-55.8	63.0-101.8	87.3-155.2
Banana (Green)	-	-	-	59.7-130.9	87.3-155.2
Cherries (sweet)	12.1-16.0	28.1-41.7	-	74.2-133.4	83.4-94.6
Grapes	8.2	16.0	-	47.0	97.0
Oranges	9.2	18.9	36.4	62.1	89.2
Pineapple	-	-	16.5	38.3	71.8
Mangoes	-	-	-	133.4	222.6-449.1
Lettuce	68.4	86.6	116.9	186.7	297.8
Onions	6.8-9.2	10.7-19.9	-	14.7-28.1	-
Mushrooms	83.4-129.5	210.5	-	-	782.2-938.9
Okra	-	-	259.0	432.6	774.5
Nuts	2.4	4.8	9.7	9.7	14.5
Mint	23.8-44.5	89.0	225.6-270.1	311.6-403.6	762.7-940.8
Peas	90.2-138.7	163.4-226.4	-	530.1-600.4	728.4-1072.2
Potatoes	-	17.5-20.4	19.7-29.6	19.7-34.6	19.7-47.0
Radishes	43.2-51.4	56.7-62.1	91.7-109.1	207.6-230.8	368.1-404.5
Spinach	43.4-63.5	81.0-95.5	173.6-222.6	-	549.0-641.6
Tomatoes (Ripening)	-	-	-	79.1	120.3

Source: Handbook—Refrigeration, ASHRAE (2014). American Society of Heating, Refrigerating and Air-Conditioning Engineers. Inc. ISBN, 978-1.

Note: Generally, the produce cooling is assumed to be achieved within 24 hours for room cooling & within batch hours for forced air pre-cooling chambers. However, if faster cooling is required, the produce load can be calculated separately on an hourly basis and added to the total load reduced to an hourly basis.

Box 1: Example of Refrigeration Loads Calculation for Pre-Cooling Chamber

The pre-cooling chamber load calculation for operating in batch process for varying time period between 4-6 hours can be calculated using transmission load, electrical lighting and motor load, and produce load.

Pre-cooling Chamber Dimensions: 9m x 6m x 3.5m height
Insulation thickness: Wall: 100 mm PIR / PUF, Ceiling: 100 mm PIR / PUF, Floor: 100 mm XPS / PUF
It is presumed that two walls are exposed to outside & remaining two are inner partition walls
Produce: Daily 6000 kg grapes coming at 30°C
Outside design conditions: 40 °C DBT, 25 °C WBT
Inside Design conditions: 2 °C± 1 °C, 95 %RH
Anteroom temperature: 12 °C±1 °C
Cooling Range: 30 °C to 2° C
Batch time: 5 hours – with zero door openings

1 Calculation of Transmission Load (Q_e): refer eq. (1)

Partition Walls:	(52.5(m²)×0.58×10(°C)×5(hrs))/1000=1.52 kWh (assuming adjoining room at 12°C – practically front wall faces ante-room and adjoining wall is of cold room or other precooler.)
Exposed walls:	(52.5(m²)×0.27×40(°C)×5(hrs))/1000=2.83 kWh
Ceiling:	(54(m²)×0.24×43(°C)×5(hrs))/1000=2.79 kWh (assuming exposed roof of precooler)
Floor:	(54(m²)×0.29×35(°C)×5(hrs))/1000=2.74 kWh (assuming floor is at 37 °C)

Total Transmission Load (Q_t) = 9.88 kWh

*A solar gain effect of 2°C for walls and 5°C for exposed roof has been considered and added to the normal temperature difference. The floor temperature difference is reduced by 3°C. (can be much lower as built on 3 feet raised plinth besides insulation)

2 Heating load from electrical equipment ($Q_l + Q_m$)

Lighting:	Q_l = (54 m² x2.5 W)/1000 x 1 hrs = 0.135kWh..... from eq. (4) (lighting is kept off in a precooler when batch pre-cooling is happening)
Motor:	Q_m = 3nos. x 2.2 x 1.14 x5hrs = 37.62 kWh..... from eq. (5) (motors are normally placed outside, except for main precooler fans)

Total Electrical Load ($Q_l + Q_m$) = 37.75 kWh

3 Produce Load (Q_p): refer eq. (6) and (7)

Q_p	Q_p = 6000 kg/batch x 10^{-3} kWh/kgK x (30-2) K= 168 kWh
Q_r	Q_r = 6000 kg/batch x 100 x 10^{-3} (W/kg) x 5 (hrs) = 3.0 kWh (assuming apples as produce)

Total Produce Heat Load (Q_p)+ (Q_r) =171.0 kWh

Thus, total load Q= Q_t + Q_l + Q_m + Q_p + Q_r= **218.63 kWh**
An additional 10% safety factor = 21.9 kWh; the total load will be **240.5 kWh.**
The total estimated refrigeration capacity required for pre-cooling for a batch time of 5 hours is: **Q_p**

Total refrigeration capacity = 240.5 kWh/5hrs = 48.1 kW (approx. 14 tons of refrigeration)

Safety factor: A safety factor of 10 % has been considered on the refrigeration load to obtain the total refrigeration load calculated. A safety factor is considered for redundancy, excessive heat loads due to changing weather conditions, ageing, and covering a wider variety of produce categories.

Box 2: Example of refrigeration load estimate for a staging cold room

Chamber Dimensions: 10m x 5m x 4m height

Insulation thickness: Walls: 100 mm, Ceiling: 100 mm (PIR / PUF) and Floor: 100 mm (XPS / PUF)

Outside design conditions: 40°C DBT, 25°C WBT

Design conditions inside staging cold room: 2 °C +/- 1°C, 95% RH

Ante-room temperature: 12°C +/- 1°C, 95% RH

Produce: Daily 12500 kg/24hrs coming at 4°C (Pre-cooled)

Consider 2 men working for 4 hrs.

Consider 2 walls exposed & 2 walls as partition walls

Consider 2°C rise in pre-cooled produce temperature during handling, loading etc.

1 Transmission Load (Q_e) — from *eq. (1)*

a)	**Exposed Walls**	(60(m^2) x 0.27 x 40(°C) x 24(*hrs*))/1000 = 15.52 kWh
b)	**Partition Walls**	(60(m^2) x 0.58 x 10(°C) x 24(*hrs*))/1000 = 8.35 kWh
c)	**Ceiling**	(50(m^2) x 0.24 x 45(°C) x 24(*hrs*))/1000 = 12.96 kWh
d)	**Floor**	(50(m^2) x 0.29 x 37(°C) x 24(*hrs*))/1000 = 12.88 kWh

Total Transmission load (Q_w) = 49.71 kWh

*A solar gain effect of 2°C for walls and 5°C for exposed roof has been considered and added to the normal temperature difference. The floor temperature difference is reduced by 3°C.

2 Workmen Load (Q_w) — from *eq. (2)*

Q_w = 2 x 4 hrs x 270/1000 = 2.16 kWh

3 Air Change Load (Q_a) — from *eq. (3)*

Q_a =200 m^3 x 7.5 (air changes/day) x 1.10 (density in kg/m3) x (79.3-13.11) (enthalpy diff. in kJ/kg) / 3600 = 30.3 kWh

4 Electrical Load ($Q_l + Q_m$)

Lighting:	Q_l = (12 (W) x 6(*nos*) x 8(*hrs*))/1000 = 0.6 kWh	*from eq. (4)*
Motor:	Q_m = 2.25 (kW) x 1.14 x 24 (*hrs*) = 61.56 kWh	*from eq. (5)*

Total Electrical Load ($Q_l + Q_m$) = 62.16 kWh

5 Produce Load (Q_p)

$Q_p = 12500 \left(\frac{kg}{day}\right) \times 1.1{,}2 \times 10^{-3}$ (kWh/kgK) x 2K = 25 kWh — *from eq. (6)*

Q_r = 12500 kg/batch x 15 x10^{-3} (W/kg) x 5 (*hrs*) = 0.94 kWh — *from eq. (7)*

Total Produce Load ($Q_p + Q_r$) = 25.94 kWh

Thus, total load Q= $Q_t + Q_w + Q_a + Q_l + Q_m + Q_p + Q_r$ = **170.27 kWh**

Total load Considering Safety factor of 15% = **195.8 kWh**

The **total estimated load** based on 18 hrs of operation per day the refrigeration **capacity** will be **=10.8kW (approx. 3 tons of refrigeration)**

Refrigeration Load for Ante-room & Dispatch area: For the total combined area of the ante-room and dispatch area, 100 m^2, the refrigeration load may be taken around 10 to 12 kW. This is an average thumb rule and may vary based on multiple factors. The heat load calculation is essentially similar to that of other cold areas, as given above.



5.2 Refrigeration System Design and Selection Criteria

In order to meet the required conditions of temperature and humidity in cold-chains, a variety of cooling technologies are possible, such as vapour compression refrigeration (VCR), adsorption/absorption refrigeration, sorption-compression refrigeration, ejector refrigeration, evaporative cooling, magnetic refrigeration, etc., as discussed in India Cooling Action Plan (MoEF&CC, 2019 and MoEF&CC, 2021). These technologies differ in terms of their performance, the form of energy required, the refrigerant used, capital and operational expenses, etc. VCR systems have dominated the refrigeration industry owing to their operability in a wide range of conditions, technological maturity, availability, ease of deployment, etc. Refrigeration system design is critical for enabling energy-efficient performance for packhouses. Additionally, performance, type of refrigerants and the operation of the refrigeration unit play an important role in reducing energy consumption.

Vapour Compression Refrigeration (VCR) - VCR uses mechanical energy as the driving force for refrigeration to accomplish the removal of heat through evaporation of refrigerant at low pressure and condensation of refrigerant at high pressure. The compression refrigeration cycle consists of circulating a liquid refrigerant through four stages of a closed system. As the refrigerant changes state, heat is absorbed and expelled by the system, lowering the temperature of the conditioned space.

The piping and instrumentation diagram (P&ID) of a simple single-stage vapour compression refrigeration system used for pre-cooling or cold rooms / ante-rooms is described in Figure 16. The vapour compression refrigeration system comprises four key components: the compressor, condenser, expansion valve, and evaporator. The cycle begins as the compressor draws low-pressure refrigerant vapour from the evaporator, compressing it to raise both pressure and temperature. The high-pressure vapour then moves to the condenser, where it releases heat to the surroundings, causing it to condense into a high-pressure liquid. This liquid passes through the expansion valve, experiencing a sudden pressure and temperature drop, transforming it into a low-pressure mixture of liquid and vapour. The low-pressure mixture enters the evaporator, absorbing heat from the surroundings and evaporating back into a vapour. This continuous cycle enables the system to cool a space by transferring heat from the refrigerated area to the surroundings. The compressor then repeats the process by drawing in the low-pressure vapour, completing the refrigeration cycle.

Vapor Absorption Refrigeration (VAR) - Absorption cooling is a cooling technology that employs a liquid solution called an absorbent to absorb a vapour, typically water-absorbing ammonia, to create a cooling effect. Unlike compression-based cooling systems that rely on mechanical work, absorption cooling relies on thermal energy, making it a sustainable and efficient cooling method. Hence, these systems are also called heat-operated or thermal energy-driven systems. The method of creating the pressure difference and circulating the refrigerant is the primary difference between the two cycles. Absorption cooling systems have gained prominence for their ability to operate quietly and with minimal environmental impact, making them suitable for various cooling requirements while reducing electricity consumption.

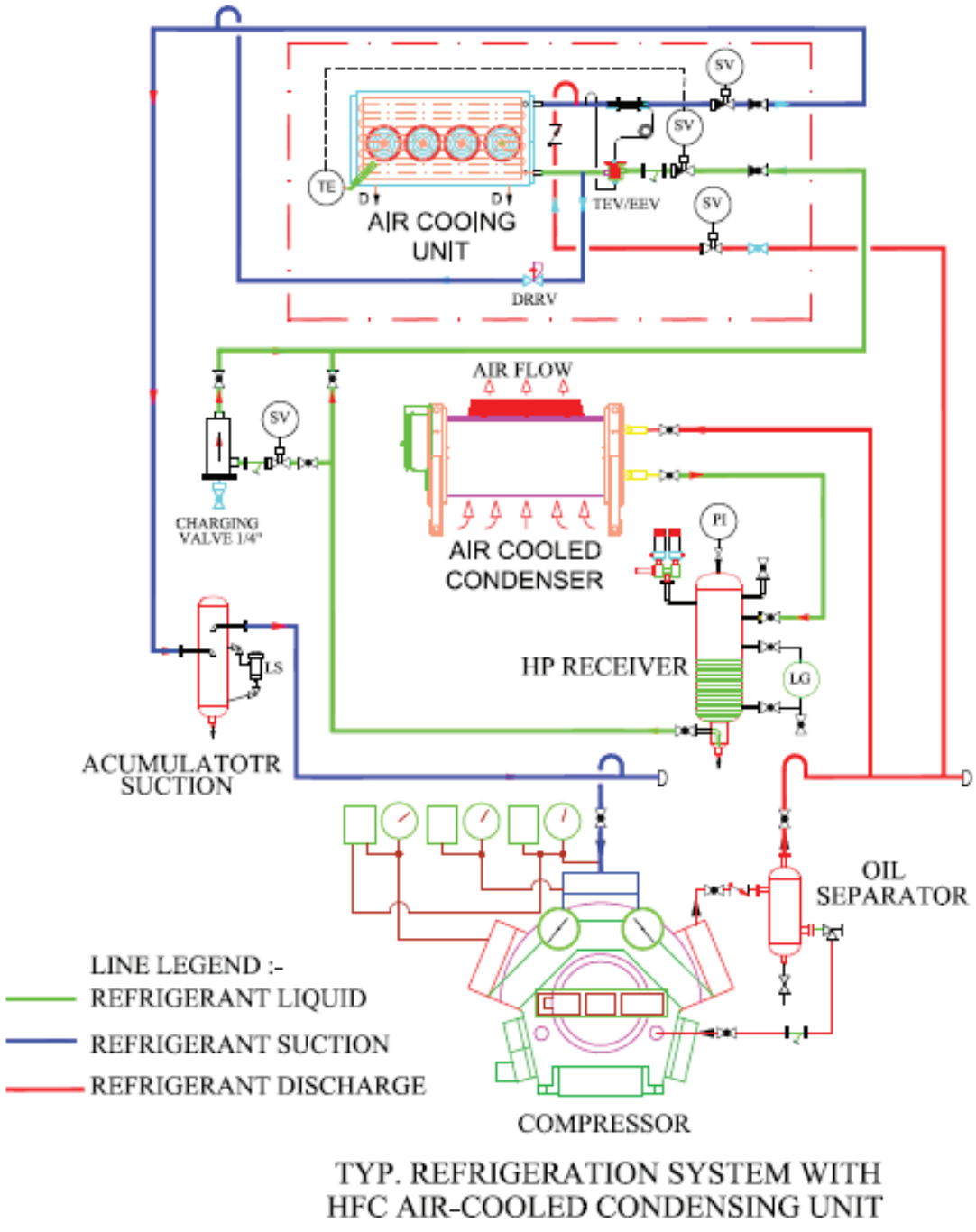


Figure 16: Typical P&ID for Refrigeration Systems

5.2.1 Refrigeration System- Coefficient of Performance (COP)

The coefficient of Performance (COP) of a system is defined as the ratio of the refrigerating effect generated (cooling capacity) to energy consumed by the system and is measured by the following equation:

$$\text{COP} = \frac{\text{Cooling capacity in kW}}{\text{Power consumption by refrigeration system in kW}} \qquad \text{eq. (7)}$$

Refrigerating effect/cooling capacity = Total cooling effect generated for all the cold facilities in operation.

As there is season-wise variation in temperature, the amount of cooling and consequently, the amount of energy required to operate the refrigeration system will also vary from season to season. Considering the diverse climatic conditions of India, estimating the refrigeration system performance using the Cooling Seasonal Performance Factor (CSPF) is more appropriate.

CSPF is the ratio of the total amount of heat that the equipment can remove from the indoor air when operated for cooling in active mode to the total amount of energy consumed by the equipment during the same period.

$$\text{CSPF} = \frac{\text{Cooling total seasonal load in kWh}}{\text{Cooling seasonal energy consumption in kWh}} \quad \text{eq. (8)}$$

In India, where there are five distinct climatic zones, the estimation of CSPF is conducted for a representative location from each climatic zone. The estimation follows ISO 16358-1 and utilizes the reference outdoor temperature bin distribution for an accurate assessment.

Referring to the sample refrigeration demand in the packhouse (Section 5.1.1), the estimated CSPF is given in Table 17.

Table 17: Cooling Seasonal Performance Factor for different climatic zone

Climatic zone	Representative location	Cooling Seasonal performance factor (CSPF)
Composite	Delhi	2.77
Hot and Dry	Jodhpur	2.78
Temperate	Bengaluru	3.35
Warm and Humid	Kolkata	2.94
Cold	Tezpur	3.21

5.2.2 Variable Speed Operation

In a small to medium packhouse, most equipment is compact (i.e., unitary machines), including condensing units, air cooling units, piping, and valves for one chamber. However, in large packhouses, there can be multiple chambers and many varied cooling requirements. In every designing instance, equipment loads are chosen based on extreme conditions, as the setup must function at maximum capacity under such conditions. However, in the majority of cases, the plant operates under part-load conditions. These conditions can be varying due to several factors, including:

- Difference in produce temperature coming in (due to climatic factors)
- Difference in the volume or quantity of the farm produce
- Diurnal and seasonal changes in ambient conditions
- Lower amount of produce available for the given batch or load

Variable speed operation for motors, compressors, fans, and, in some cases, ACUs is considered due to the inherent needs of higher capacity system design but lower actual operating conditions. Variable speed operation ensures that the system will run on optimum performance and will not consume excessive power during its part-load operation. Hence, variable frequency drives (VFDs) are recommended for cold room compressors and, in some cases, fans as well. Sometimes, it may also be a good idea to have variable frequency operation for pre-cooling compressors, especially if very low produce is expected to be available for pre-cooling.

5.2.3 Thermal Energy Storage

Thermal energy storage (TES) serves as a technical solution for industrial cooling loads that peak at two or more times higher than the daily 24-hour average load, efficiently addressing heat source-demand mismatches in refrigeration and cooling applications. TES encompasses three storage methods: sensible, latent, and thermo-chemical, with latent storage using Phase Change Materials (PCMs) proving particularly effective due to reduced storage volume compared to sensible heat storage. PCMs, available in various categories such as organic, inorganic, and eutectic materials, ideally possess high latent heat and thermal conductivity within a practical temperature range.

TES plays a crucial role in optimizing refrigeration systems, by maximizing efficiency, minimizing energy consumption, improving seasonal performance factors, and facilitating peak shaving to reduce strain on the electrical grid. TES also enables renewable energy integration, charging strategically during sunlight hours and discharging stored thermal energy during low sunlight or grid power absence to ensure continuous cooling in cold rooms. Additionally,

the system allows compressors to operate at full capacity, avoiding part load operation by storing extra cooling and thereby reducing total operational time and power consumption. TES can further shift cooling production to off-peak periods, reducing electricity costs and supporting renewable energy integration, making it an ideal solution for cooling in packhouse applications.

The system incorporates a chilled water/brine tank either with ice accumulation coils or with modules (balls) filled with PCM or eutectic fluid. The TES tank and associated ice/PCM bank coil or chilling system for freezing modules are designed to take care of the peak load cooling requirement as needed, e.g. during pre-cooling operation hours. TES offers the following benefits:

- Cooling storage is available for a few hours in case of sudden power failure.
- A low electricity tariff offered by electric supply companies during certain hours may be beneficial.
- It allows continuous cooling in the absence of power, is very useful in off-grid renewable energy-powered packhouses and allows demand flexibility.
- Full-load compressor operation results in higher efficiency.
- Salient features of PCMs are as follows:
- Stores large energy in the form of latent heat, also called thermal batteries
- Release/absorbs heat at a constant temperature
- Release/absorption process is repeatable over a substantial number of cycles.

One typical type of thermal battery that can be used inside smaller cold rooms is containers with evaporator coils inside them and phase change material on the outside of the coil but inside the battery. The coil inside the battery comes in direct contact with the PCM and enables efficient freezing. The freezing normally takes place in layers and continues till the full volume is frozen. During the discharge cycle, the PCM closer to the outer surface melts first, thereby providing cooling in the cold room space.

However, the integration of TES into existing systems presents challenges, such as the need for sophisticated control mechanisms to manage the charging and discharging cycles seamlessly. Another challenge involves the optimization of system efficiency, requiring careful consideration of the interplay between TES and other refrigeration elements to achieve a harmonized and reliable operation. Despite these challenges, the strategic integration of TES stands as a transformative approach to enhance sustainability and resilience in horticulture packhouses.

Geothermal heat exchanger: Another option for cooling in a cost-effective manner is the utilization of ground source cooling through a closed-loop circulation of groundwater, known as geothermal heat exchange. This geothermal technology leverages the Earth's cooling, making it highly effective even during scorching summers, as the Earth, just a few feet below the surface, maintains a consistent annual average temperature for the location. Geothermal cooling operates by circulating a temperature-conducting fluid through an underground network of pipes. This process allows the fluid to absorb the heat generated within the packhouse and release it into the Earth at a lower temperature. The cooled underground water can help dissipate heat build-up within the workspace, providing a comfortable environment for operations.

The cold fluid returning from the geothermal heat exchanger serves a dual purpose. It can directly cool the workspace or be used to enhance the efficiency of the refrigeration system by cooling the condenser. This can be achieved by circulating the cool water through an embedded ceiling system, utilizing either solar-powered or low-powered pumps for circulation. The water itself is not consumed; instead, it returns to the underground well or utilizes the Earth as a heat sink, making this an environmentally friendly and cost-effective cooling solution.

5.2.4 Refrigerant Selection

Vapour compression refrigeration (VCR) systems mainly use halocarbons as refrigerants, such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) and their blends. HCFCs are ozone-depleting substances (ODS) and can have a global warming potential (GWP). HFCs do not contribute to ozone depletion; however, they can have significant GWP, contributing to direct emissions to the atmosphere. Other refrigerants such as hydrofluoroolefins (HFOs), hydrocarbons (HCs), and inorganic compounds such as ammonia (NH_3) (R717) and carbon dioxide (CO_2) (R744) are other common refrigerants used in VCRs (MoEF&CC, 2021).

India, as a signatory to the Montreal Protocol, enacted the Ozone Depleting Substances (Regulation and Control) Rules, 2000, under the Environmental Protection Act of 1986 (MoEF&CC, 2022). Through proactive policies, India has successfully phased out ozone-depleting substances (ODSs), including hydrofluorocarbons (HCFCs), meeting all phase-out targets as per the Montreal Protocol schedule. HCFC phaseout management plan (HPMP) stage-III, endorsed in the 91st Executive Committee, will operate from 2023 to 2030, with the goal of eliminating all HCFCs,

including R22. The phase-out of HCFCs in manufacturing new equipment must be completed by December 31st, 2024, with a complete phase-out set for January 1st, 2030, for all controlled applications, with a service tail of 2.5% of the baseline (HPMP-III, 2023). This action not only accelerates the phase-out of HCFCs but also reduces the inventory of refrigeration and air conditioning equipment, promoting the retirement of obsolete technology. According to HPMP-III, the use of R22 in manufacturing new equipment/products will be prohibited from January 1, 2025 (HPMP-III, 2023).

With the goal of exerting control over and gradually reducing the production and utilization of hydrofluorocarbons (HFCs), India, on September 27, 2021, ratified the Kigali Amendment to the Montreal Protocol and committed to adhering to the prescribed timeline for Article 5, Group 2 countries. The primary objective of this amendment is to curtail HFC production and usage by 85% by the late 2040s. This phasedown process presents substantial benefits for India, enabling it to transition to superior alternatives in the future. India's HFC phasedown timeline sets a baseline formula of the average of HFC production and consumption in the years 2024-2026 plus 65% of their HCFC baseline, with a freeze of production and consumption at baseline levels occurring by January 1 2028. The phasedown will occur in four stages, commencing in 2032, with reductions of 10% in 2032, 20% in 2037, 30% in 2042, and reaching a cumulative 85% reduction by 2047, as illustrated in Figure 17. To ensure compliance with the Kigali Amendment, amendments to the existing legislative framework, the Ozone Depleting Substances (Regulation and Control) Rules of 2000, are currently in development and are expected to be finalized by mid-2024 (PIB, 2019).

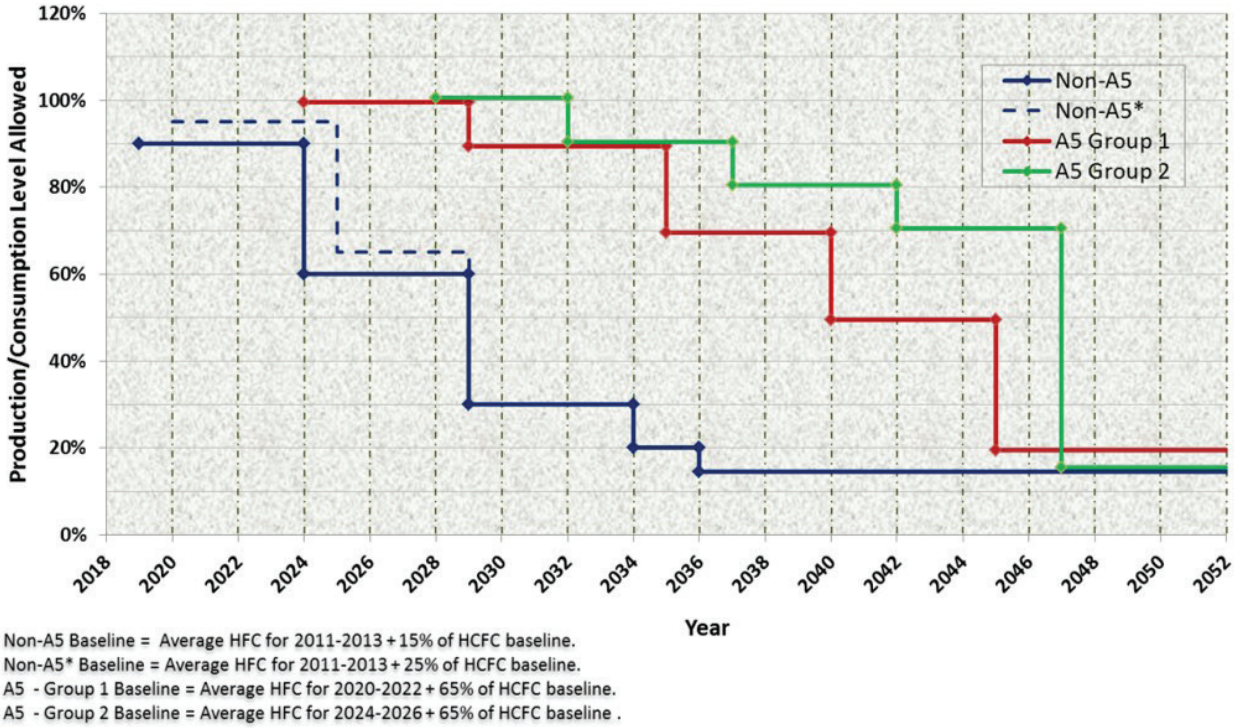


Figure 17: HFCs consumption/production reduction schedule

Source: UNEP, 2016

The selection of refrigerants in refrigeration systems is contingent upon the intended cooling temperatures, refrigerant thermophysical properties, and ambient conditions, as it affect the system performance. Cold storage mainly uses R717, R22, and R404A; refrigeration systems in packhouses and ripening chambers use refrigerants such as R22, R134a, R404A, R407C, and R407F. A reference list of refrigerants suitable for packhouse/ pre-cooling rooms with some replacement options, their GWP, and safety group properties are provided in Table 18 and Table 19. This list can be used as a reference when choosing replacement refrigerants for phased-out HCFC and HFC refrigerants.

It is important to highlight that most refrigerants in the Table 18: are for new equipment and may not be direct drop-in replacements for retrofit applications; the compatibility of these refrigerants needs to be assessed for any retrofit and potential system modifications with replacement refrigerants. Be aware that many HFC refrigerants, like R404A, R134a, R407A, R407C, R407F, R422A, etc., will be

phased down in the coming years due to their high GWP and will become scarcer and more expensive due to phase-down measures; consider transitioning to energy-efficient equipment using environmentally friendly refrigerants such as R717, R744, etc.

The information provided is based on multiple sources and is not an exhaustive listing. Instead, it serves as a guide to help understand refrigerants scheduled to be phased down and their potential alternative.

Table 18: Refrigerant Selection

Refrigerant	Type	Safety class (ISO 817/ASHRAE Std. 34)	GWP
R134a	HFC	A1	1430
R404A	HFC blend	A1	3920
R407A	HFC blend	A1	2110
R407C	HFC blend	A1	1770
R407F	HFC blend	A1	1825
R426A	HFC blend	A1	1508
R442A	HFC	A1	1888
R448A	HFC/HFO blend	A1	1273
R449A	HFO	A1	1282
R450A	HFC/HFO blend	A1	547
R453A	HFC	A1	1765
R454A	HFO	A2L	239
R454C	HFO	A2L	148
R455A	HFC/HFO blend	A2L	146
R464A	HFC/HFO blend	A1	1288
R507	HFC blend	A1	3985
R513A	HFO	A1	573
R290	HC	A3	3
R717	Natural	B2L	0
R744	Natural	A1	1

Table 19: Refrigerant Safety Classification

Higher flammability	A3	B3
Flammable	A2	B2
Lower flammability	A2L	B2L
No flame propagation	A1	B1
	Lower toxicity	Higher toxicity

Source: ASHRAE standard 34

Apart from the HFC & HFOs, hydrocarbon refrigerants with a minimal GWP, such as R290, are suitable for packhouse application. However, due to the high flammability of R290, it can only be used for only smaller capacities. A most promising alternative is to use Ammonia (R717), which is a natural refrigerant with nearly zero GWP but an ISO classification of B2L, the best thermal efficiency among various refrigerants, but toxic by nature and can burn only under certain concentrations. As the low charge system becomes popular, & smaller sizes with air-cooled

condensers have been developed, ammonia systems can become a good solution for packhouses in pre-cooling & staging cold stores. However, with proper design & testing, these plants have been working on thousands of Cold chain projects.

The latest developments in the field include an absorption/ adsorption technology-based unit that works on ammonia refrigerant. The unit works on thermal energy from agro waste, biogas or other combinations of heat sources. This would open a new scope for the refrigeration unit for packhouse sector. Absorption systems also work on thermal energy but are normally available for larger capacities and, hence, not used for packhouses (MoEF&CC, 2021).

5.2.5 Evaporative Cooling for Packing Hall

Evaporative air-cooling technology works on the principle of latent heat of evaporation, in which the water gets evaporated and provides a cooling effect to the air. Evaporative air cooling is most efficient in areas with hot and dry weather.

Evaporative cooling is highly efficient in hot and dry climatic conditions and is thus most desirable for packhouses in such climatic conditions. Figure 18 below shows a packhouse with evaporative cooling with round ducting and collars pointing downwards (inclined). The tropical and subtropical parts of India and the surrounding regions, e.g., Maharashtra, Rajasthan, and Gujarat, have a similar climate, leaving aside the coastal zones. Evaporative cooling has the following advantages:

- Evaporative cooling uses water as the medium of cooling and hence is significantly lower in terms of initial cost as well as operating cost than air conditioning.
- Evaporative cooling increases the relative humidity of the air as it cools it down, which is also a well-desired requirement when we are considering fresh produce, which, anyway, requires higher humidity levels.
- Energy and cost savings for cooling
- Environment-friendly as no mechanical refrigeration is required.

Limitations of evaporative cooling:

- Water supply is needed.
- Performance is highly dependent on environmental conditions.
- An exhaust system is required for effective performance.

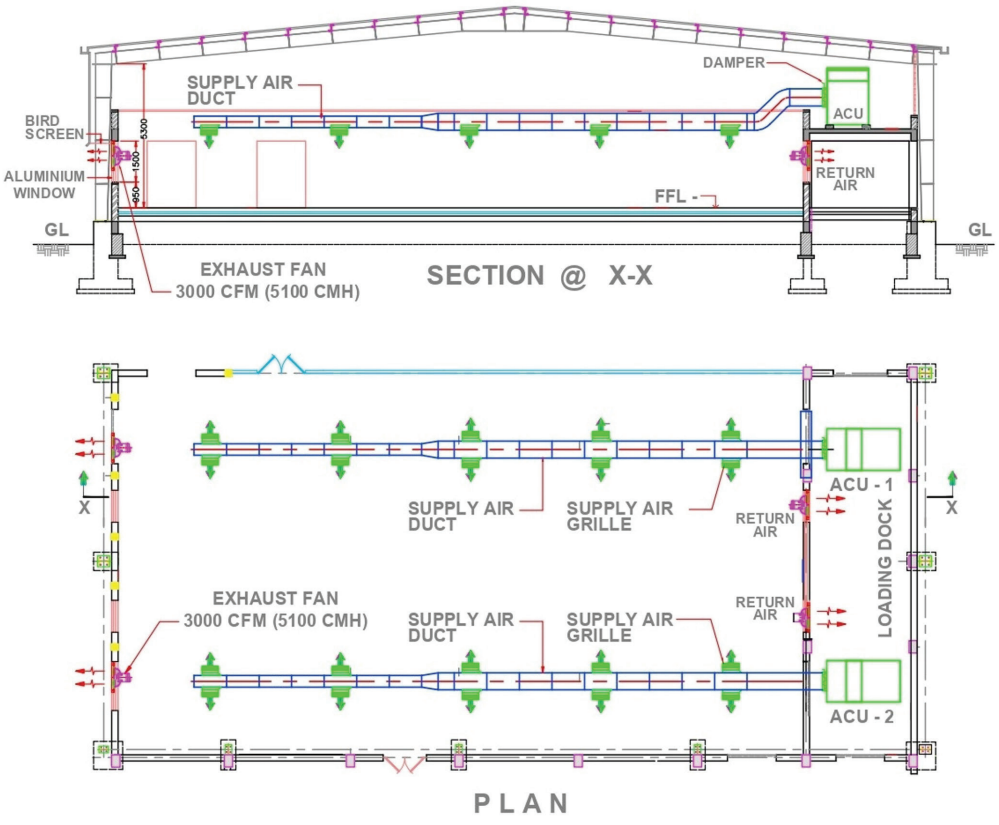


Figure 18: Plan and section showing air-cooling units and distribution for the packing hall.

Conditions that are achieved in a packhouse which is evaporatively cooled mainly depend on the wet bulb temperature (WBT) of the given area at that point in time. The lower the WBT, which indicates either cool air, low humidity, or a combination of the two, deliver more cool air. The thermal performance of the evaporative cooler is thus affected by the entering WBT; the entering air DBT has an insignificant effect on thermal performance.

The approach is the most important indicator of evaporative cooler performance. The approach is the temperature difference between the cold air leaving the cooler and the ambient WBT. If a cooler produces 25°C air when the ambient WBT is 22°C, then the cooling tower approach is 3°C. Normally, most evaporative coolers are able to reach up to 3°C above the wet bulb temperature of that area. There are also two-stage evaporative coolers which can attain temperatures even closer to the ambient wet bulb temperature.

5.2.5.1 Indirect-Direct evaporative cooling:

It is also known as two-stage cooling. In the first stage, the heat exchanger is used to cool the air so that water and air do not mix with each other, and the air is cooled without adding moisture. In stage 2 water-soaked pads are used to cool the air. So, in this stage, air picks up moisture due to evaporation. It delivers the air with 70-80 % R.H.

In a large number of packhouses, it is normal in summer to experience lower productivity levels among workers. Owners can mitigate the high costs of conventional air conditioning by installing an evaporative cooler, which is due to the benefits stated above. The "Air Change" method is a practical way to increase the size of the evaporative cooling system. For packing hall cooling, ACH can generally be in the range of 20 to 30 ACH depending on what kind of occupancy and level of activity is present in the packhouse.

Forced air exhaust is an essential requirement when it comes to evaporative cooling, as this scheme works well only when the air that is brought into the working space goes out as well. If the air does not find a proper path for going out, then the relative humidity can go higher and cause an undesired effect in the given zone. Normally, around 75% to 80% of the air which is put into the zone should be exhausted out of the area so that the conditions can be properly maintained. The IDEC is more assured cooling compared to direct evaporative cooling and has lower energy demand than refrigeration. A few limitations of the evaporative cooling are:

1. Cooling effect depends on the supply of air condition
2. It can be used only in hot and dry climate areas.
3. Effectiveness is reduced in a dusty environment.

5.3 Auxiliary Systems Design and Equipment Selection

- Other than the refrigeration system, a few other components are used to maintain the required condition in the packhouse. This section discusses some allied equipment that is normally required for packhouses. The auxiliary system includes humidifiers, turbo ventilators, defrosting, controls, automation, and air circulation fans.

5.3.1 Humidifiers:

In addition to maintaining the correct temperature inside the cold room for all kinds of fruit and vegetables to increase shelf life, it is equally important that the relative humidity levels inside the cold room are correctly maintained. It is necessary to control the relative humidity between 85% and 95% in the cold rooms as per commodity. A humidification system or humidifier is installed to maintain the required relative humidity levels. Humidifiers are categorized into two primary types, each differing in their approach to adding energy for converting water from liquid to gas during the humidification process, resulting in distinct air temperature outcomes. The capacities of industrial humidifiers are generally measured based on litre per hour of operation. Humidifiers are typically not used in precoolers; instead, modern precooler units are designed with large-area evaporator coils to minimise condensate losses. However, they are used in cold stores that expect to retain produce for an extended duration.

Isothermal Type Units: Isothermal units, commonly referred to as steam humidifiers, rely on external energy sources to generate steam vapour. All the energy required for steam production is added by the humidifier unit prior to entering the airstream. As a consequence, isothermal humidification leads to a nearly constant air temperature. A typical steam humidifier is presented in Figure 19.

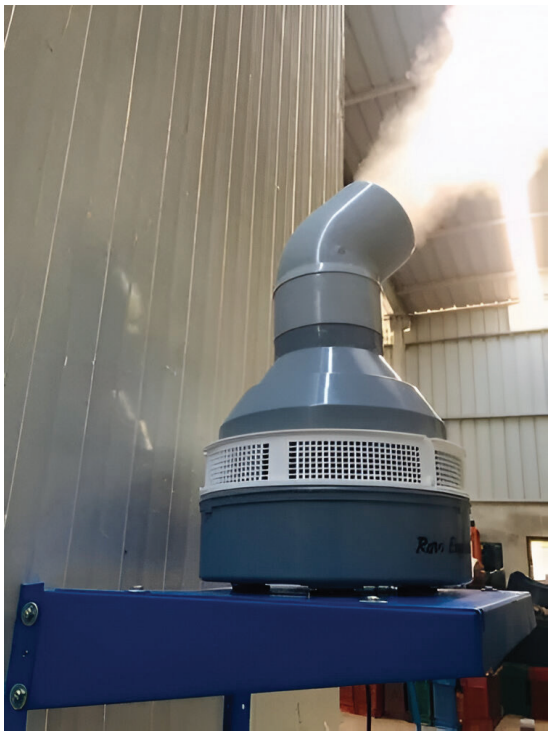


Figure 19: Steam Humidifier

Adiabatic Type Units: Adiabatic humidifiers, such as atomizers or evaporative systems, introduce energy for the transformation of water from liquid to gas directly through the airstream. This approach One popular subtype of adiabatic humidifiers is the ultrasonic humidifier, frequently utilized in cold room applications. These devices employ a piezoelectric transducer submerged in demineralized water. The transducer converts a high-frequency electrical signal into a corresponding mechanical oscillation. This oscillation creates a momentary vacuum during the negative phase, prompting the water to vaporize at low pressure. Simultaneously, the positive oscillation generates a high compression wave, propelling the water particles from the surface into the airstream, where they are rapidly absorbed. Ultrasonic humidifiers offer benefits such as low power consumption, the addition of water vapours in the airstream without additional heat gain, low vapour particle size, etc. Figure 20 shows a typical ultrasonic humidifier.



Figure 20: Ultrasonic Humidifier

Humidifiers are used in pre-cooling chambers when the air-cooling units have limitations in maintaining RH above 92%. In such cases, external humidifiers are provided to maintain higher RH above 95 – 96%. The humidifiers are selected to provide additional humidification with the airflow from the air-cooling units based on the room volume, airflow, and required increase in humidity.

5.3.2 Air Circulation Fans

High-volume, low-speed (HVLS) fans can be considered in packhouses for air circulation, especially if the ceiling height available is 4 m or more. When ceiling height is high, the HVLS fans are quite effective in providing a good current of air flow and increasing the airflow of an evaporative cooling scheme if present. It must be considered that ceiling-mounted fans may cause a reduction in light levels, especially where higher lux levels are expected and installed/ located accordingly. Luminaire selection can be for high bay or low bay depending on the ceiling height and interference.

HVLS fan selection has to be done on a case-to-case basis and should be done in consultation with the fan manufacturer, who would have specific selections for the given case based on the requirement, height available, temperature of the packing hall, etc. These high-volume, low-speed fans are used for large areas needing uniform distribution of air in the occupied space. These are not used for packing foods where evaporative cooling is provided normally with overhead round ducting. A typical HVLS fan selection is given below for reference.

Commercial applications:

- Aluminium blades – 3 nos.
- 3050 mm diameter
- Airflow = 1,54,000 m^3/hr
- Motor = 0.75 kW
- 350 – 460 Volts
- 1.7 Amp
- 50-60 Hz A.C. supply
- Coverage - around 1000 m^2
- Airspeed = 2 m/s max, variable speed

5.3.3 Turbo Ventilators

Turbo Ventilator is a self-driven ventilation system that is powered by wind energy. They are completely self-driven and don't require any energy source like electricity. Turbo ventilators expel hot and stale air from the attic space to the outside through the roof. Turbo ventilators help to keep the temperature of attic space (space between the insulated panel false ceiling and top roof) lower, thus reducing the heat load.

The number of turbo ventilators to be installed on the roof depends on the air exchange rate considered. While manufacturers have different claims as per their produces, one can safely consider a 600 mm diameter turbo ventilator is expected to have an air discharge capacity in the range of 1000 to 2600 CFM. These rates change depending on outside air movement, the height of the unit above the lower false ceiling, and whether air removal space is kept between the false ceiling and the roofing.

An important consideration when using turbo ventilators: An important consideration in turbo ventilators is the air entry into the attic space, which will allow the air to get sucked into the turbo. If the attic space is completely sealed, then air will not enter the attic space and will not make the turbo ventilators effective.

5.3.4 Defrosting

Defrosting in refrigeration systems plays a vital role in maintaining the efficiency of cold rooms or packhouses operating at low temperatures. It is essential to prevent the accumulation of frost and ice on evaporator coils and other components, as excessive frost build-up can reduce the system's cooling capacity and increase energy consumption. There are several methods for defrosting, including electric resistance heaters, hot gas defrosts, and off-cycle defrosting. Each method varies in terms of energy consumption and effectiveness. To make defrosting more energy-efficient, some strategies include implementing adaptive control systems that defrost only when necessary, utilizing low-temperature defrosting techniques, and optimizing the insulation and sealing of cold room doors to minimize heat exchange. These energy-efficient practices not only reduce operational costs but also enhance the overall sustainability of the refrigeration system. For temperatures over 3°C, air defrosting is a common practice and for lower temperatures, the choices are a) water defrosting, b) hot gas defrosting, and c) electric defrosting. In the horticulture packhouses cold rooms, the minimum temperature remains above 0°C and thus, air defrosting is recommended. It may be noted that frost on evaporator coils occurs when the set point for the produce is close to 0°C and the coil temperature is below freezing temperature. In cases of other produce - such as mangoes, bananas, tomatoes, etc. – where the coil temperature is much above freezing temperatures, frost buildup is not a concern.

5.3.5 Control and Automation

The integration of control and automation systems within packhouses and refrigeration systems is of paramount importance. These systems not only ensure the precise regulation of temperature and humidity but also contribute significantly to the efficient operation of the entire setup. By continuously monitoring and adjusting environmental conditions, control and automation systems help to maintain product quality and safety, reduce energy consumption, and extend the lifespan of equipment. Furthermore, they offer real-time data analysis and remote access, enabling swift responses to variations or emergencies. The ability to optimize cooling cycles, implement energy-saving strategies, and provide predictive maintenance through these systems results in cost savings, reduced environmental impact, and enhanced reliability in cold storage and refrigeration systems. In an era where sustainability and resource efficiency are top priorities, control and automation systems are indispensable tools for the modern cold storage industry. Programmable Logic Controller (PLC) and automation can be done to the extent that is possible in the promoter's budget. It can go up to any level, and now it has come to the stage where all parameters of a given system can actually be seen on a mobile phone through a dedicated app for the same. The packhouse equipment, viz. process lines, cold rooms, ripening chambers, pre-cooling room, etc., works on dedicated PLC for auto operations.

For any system to be connected through PLC and automation done based on the same, the following must be taken care of:

- Sensors of the gauges like pressure gauges and temperature gauges need to be compatible with PLC linking
- If a display screen is to be included in the system and the system is to be viewed on display, then a SCADA (Supervisory Control and Data Acquisition) system is to be considered for this to be enabled.
- These systems will normally be designed especially for the given plant, though some manufacturers have come up with small dedicated PLCs for small units.

5.3.6 Lighting Selection and Electrical Considerations in a Packhouse

Lighting in the packhouse is critically important for workers to accomplish tasks efficiently and safely. Proper light levels prevent eye strain, which allows working comfortably for longer periods of time. While intensity of light is important for reducing eye strain, colour should also be considered. The recommended lighting level in the packhouse, as per the IS 3646 part 1, is in the range of 350 – 750 Lux. Bureau of Indian Standards (1992)

LED light fittings are used to light the packhouse. Various types of light fittings are available in the market. The number and layout of light fittings are decided on based on the size/ area of the packhouse. Generally, proper fittings are provided above the workplace. Light fittings shall be of LED type 20-30Watts, IP65 protection, suitable for 230V A.C. supply. Different types of lighting fixtures can be used depending on location, application. These are planner, troffer, batten, high/low bay for interior lighting and flood light and street light luminaire for outdoor.

These lamps shall be powered from the distribution board in the cold room area with necessary isolation switches. These lamps can also be powered by an alternate source of energy, which is normally used for other lights in cold room areas. The standard wire size used for lamps is 1.5/2.5 mm^2 copper wire. Various equipment is required for different types of process lines. Some of these are inspection belt conveyors, rope graders, brush washers, waxing machines, cold rooms, pre-cooling systems, etc. All such equipment is powered by a 3-phase/1-phase electrical supply from the control panel.

The control panel is generally made of SS304 sheet as per IS 6911 and contains suitable starters, on/off switches, indicating lamps, emergency stop push buttons, and relays. It also contains a controller to operate the line in auto mode. Typical electrical equipment used in the packhouse are as follows:

- Distribution Transformer
- D.G. Set
- HT/LT panels
- APFC panel
- LT/HT cabling & earthing
- Indoor and outdoor lighting
- Emergency lighting & alarm in cold rooms, pre-cooling chambers, ripening chambers
- Lighting arrestor
- Electrical work for refrigeration and ripening / pre-cooling system.

CHAPTER 06

Energy Efficiency Measures (EEMs) and Energy Saving Potential

6

Energy efficiency interventions can be introduced during (i) building design (improving thermal performance) and (ii) equipment and system design (optimising refrigeration and cooling system performance). The interventions are recommended based on a previous study conducted by AEEE, commissioned by BEE and supported by the World Bank, where a comprehensive assessment of site visit observations, technical features of the proposed measure, and energy saving potential (estimated based on the consultants' research and feedback from design consultants and manufacturers) were estimated.

6.1 Scope of integrating Energy Efficiency measures in Packhouse building and design

Energy efficiency interventions at the packhouse building design level are applicable for existing and upcoming (new) packhouses for various types of produce and include interventions focusing on building design, materials, and different design strategies to reduce heat gain.

1.	Natural lighting to reduce lighting load, proper orientation, and shading for minimizing solar heat gains
Proposed measure	• The orientation of the building should be such that the longer facades face North-South and the short facades face East-West. • Native trees could be planted along the south-facing walls, maintaining an appropriate distance. Building designers could use measures to integrate natural lighting to reduce artificial lighting load through clerestory windows and transparent polycarbonate roofing patches. (Central Public Works Department, 2013). Natural lighting will further boost the productivity of the packhouse staff. For daylighting Part 8 section 1 and IS 2440 can be referred. (Bureau of Indian Standards, 1989)
Energy saving potential	• Indicative energy saving potential can be 1-2% of total energy consumed. • The reduction in cooling demand is around 1%.

2.	Wall and Roof insulation
Proposed measure	• Insulation of the roof with adequate insulation (a few examples of insulation include PUF, mineral wool, and rock wool) will reduce heat gain inside the building by reducing the conductive heat transfer from the wall and roof. For insulation, IS 12432 part 2 and IS 12436 can be referred. (Bureau of Indian Standards, 1999)
Energy saving potential	• The energy saving potential is 1-2% of the total energy consumed in a packhouse (Koelet 1992a).

3.	Provision for natural ventilation- ceiling-mounted turbo ventilators
Proposed measure	• Providing windows for cross ventilation and turbo-ventilators on the roof will ensure adequate ventilation (5 to 8 air changes per hour) and help remove built-up heat in the sorting/grading or packing areas, thereby removing the accumulated built-up loads due to air stagnation. Additionally, natural ventilation will positively impact the health and productivity of the packhouse staff. Bureau of Indian Standards (2016)

4.	Optimized size and insulation of pre-cooling and cold rooms
Proposed measure	• Optimum sizing of the pre-cooling and cold room as per the throughput requirement. • Improvement in the quality of the construction of the doors by using gaskets (neoprene), hinges and latches made of industrial-grade stainless steel material. • Strip curtains and airtight doors can be a complementary solution for cooling loss prevention.
Energy saving potential	• The saving potential in overall energy consumed in cooling is around 2% (GCCA, 2010).

5.	Pre-cooling and staging cold room insulation with optimum thermal performance
Proposed measure	• Consider the thickness mentioned in the earlier chapter, and no less.Standards (2016)
Energy saving potential	• Reduction of around 3-5% (Koelet 1992b) of total refrigeration (cooling) energy consumption.

6.2 Prioritization of Energy Efficiency measures in Packhouse building design

The prioritised list of energy efficiency measures under the packhouse building design category is compiled in Table 20 below. The prioritisation is based upon the cost-effectiveness of the suggested measures reflected by the simple payback calculations.



Table 20: Prioritized set of EEMs: Packhouse building design

S. No.	Energy Efficiency Measure	Prioritization remarks
1.	Natural lighting to reduce lighting load, proper orientation and shading for minimizing solar heat gains	Minimal cost measure. Applicable for all types of upcoming (new) packhouses
2.	Optimized size of pre-cooling and cold rooms	Low-cost measure. Applicable for all types of existing and new packhouses.
3.	Provision for natural ventilation- ceiling-mounted turbo ventilators	Low-cost measure. Applicable for all types of upcoming new packhouses having no active air conditioning in the sorting/grading or packing areas.
4.	Airtight doors for pre-cooling and cold rooms	**Low-cost measure.** Applicable for all types of existing and new packhouses without active air conditioning in the sorting/grading or packing areas.
5.	Pre-cooling and staging cold room insulation with optimum thermal performance	**Medium cost measure.** Applicable for all types of new packhouses and existing packhouses, where feasible.
6.	Wall and roof Insulation	**Medium cost measure.** Applicable for large upcoming (new) packhouses with high refrigeration loads and operating hours, such as apple and grape.
7.	Fast roll-up doors to prevent hot/moist air infiltration.	**High-cost measure.** Applicable for export-oriented grape packhouses and large facilities operating in the peak-summer season, such as mango
8.	Air curtains to prevent hot/moist air infiltration	**Medium-cost measure** Applicable for all types of new and existing packhouses operating in peak-summer seasons.

6.3 Energy Efficiency Interventions for Equipment and System Design

Energy efficiency interventions at equipment and system design are generally applicable for existing and upcoming (new) packhouses for various types of produce and include interventions focussing on – low-energy cooling systems, efficient equipment and refrigerants, efficient lighting, adequate metering and monitoring, controls, and automation. BEE has established standards and labeling (S&L) for 34 equipments, comprising 11 mandatory and 16 voluntary labelling categories. These S&L-labelled equipment can be adopted in packhouses to enhance energy efficiency. Some examples of equipment applicable in packhouses include LED lamps, motors, pumps, refrigerant compressor, solar PV module, solar inverter, DG sets, office equipment, ceiling fans, and office air conditioners.

1.	Low-energy evaporative cooling system for temperature control in the packing hall
Proposed measure	• Installing a low-energy evaporative cooling system for the packing hall area, utilizing the cooling and moisture effect of water evaporation, can effectively provide favourable post-harvest environmental conditions required for fruits and vegetables. Evaporative cooling is more suitable for the hot & dry and composite climatic conditions prevalent in major horticulture production zones in India growing bananas, mangoes, grapes, kinnows, etc.
Energy saving potential	• The energy-saving potential of evaporative cooling over an air-conditioned space can be up to 40-50% (*Acedo et al. 2016*).

2.	Selection of energy-efficient equipment for pre-cooling and cold room operation
Proposed measure	• System configuration and compressor type: Semi-hermetic reciprocating or scroll compressors in a rack system offer the best energy performance for pre-cooling and staging cold room refrigeration applications. The compressor rack system works more efficiently than independent one-to-one compressors to meet the varying refrigeration demand. • Heat rejection: Contingent upon the availability of water (with TDS levels < 1000 PPM and PH < 8% PH), water-cooled heat rejection system or evaporatively cooled (adiabatic) condensers are proposed.
Energy saving potential	• System configuration and compressor type: Semi-hermetic reciprocating or scroll compressors in a rack system can reduce energy consumption by 15-20% over the one-to-one system (Bitzer Software 2019)[3]. • Heat rejection: Water-cooled/evaporative condenser can reduce energy consumption by 20% over the air-cooled system.

3.	Sub-metering individual energy loads, including pre-cooling, staging cold rooms, process machinery, etc.
Proposed measure	• Sub-metering for pre-cooling, staging cold rooms, sorting and grading machinery, lighting loads, and other miscellaneous loads are recommended.
Energy saving potential	• No direct energy saving; however, it will help track the energy performance of individual loads and flag inefficiencies and unexpected performance deviations, if any, during operation. These meters can help the facility operator identify any abnormal energy use performance deviations, preventing further energy waste that can be remedied relatively quickly by corrective measures.

4.	Electronic expansion and subcooling
Proposed measure	• EEVs are proposed for all DX systems as they dynamically allow the quantity of subcooled liquid refrigerant required for the evaporator based on superheat measurement.
Energy saving potential	• The installation of EEV and subcooling arrangements can reduce the energy consumption of refrigeration loads by 20 to 25%, depending on the condensing system and refrigerant type (Carel, 2008).

5.	Energy Management Systems (with control and automation) to effectively manage refrigeration plant and indoor environmental parameters
Proposed measure	• Programmable Logic Controller (PLC) based refrigerated plant operation will enable real-time monitoring of the refrigerated plant and help optimize the cooling demand in the pre-cooler and cold room.
Energy saving potential	• The accurate setting of plant operation parameters, including the right suction and discharge pressure, can improve the overall system efficiency by 8 to 10% (Thompson, 2010).

[3]*Based on manufacturer's software such as Bitzer Compressor Selection software and Star Coolers and Condensers software (Tested as per Eurovent Certification standards).*

Adopting monitoring, control mechanisms, and automation in data capturing will be useful as the cold chain sector has a long way to go. The key to transforming this aspect is to localize the technologies to suit the scale of the industry and create flexibility in the system to accommodate and modify the elements of complex supply chains on a need b asis.

6.4 Prioritization of Energy Efficiency Measures for Equipment and System Design

The prioritized list of EEMs under the packhouse equipment and system design is compiled in Table 21.

Table 21: Prioritized set of EEMs: Equipment and System Design

S. No.	Energy Efficiency Measure	Prioritization remarks
1.	Sub-metering individual energy loads, including pre-cooling, staging cold rooms, process machinery, etc.	Low-cost measure. Applicable for all types of upcoming packhouses and existing packhouses having dedicated electrical feeders for different end-use categories
2.	Low-energy evaporative cooling system for temperature control in the packing hall	Low-cost measure. Applicable for all types of existing and upcoming (new) packhouses located in the hot & dry and composite climatic zones of India
3.	Electronic expansion and subcooling	Low-cost measure. Applicable for all types of existing and upcoming (new) packhouses
4.	Energy Management Systems (with control and automation) to effectively manage refrigeration plant and indoor environmental parameters	Medium-cost measure. Applicable for all types of existing and upcoming (new) packhouses
5.	Selection of energy-efficient equipment- Semi-hermetic reciprocating or scroll compressors in a rack system	Medium-cost measure. Applicable for all types of upcoming (new) packhouses.
6.	Selection of energy-efficient equipment- Water-cooled/evaporative condenser	Medium-cost measure. Applicable for all upcoming (new) packhouses contingent upon water availability.
7.	Refrigerant selection meeting environmental and thermal performance requirements	High-cost measures, sometimes, due to safety measures needed if the refrigerant is flammable or toxic, with respect to energy savings and safety but recommended for better environmental performance. Applicable for all upcoming (new) packhouses.

6.5 Energy Efficiency Interventions for Operation and Maintenance Processes

The current focus of the packhouse guidelines is design. However, operation and maintenance are equally important to enhance the energy efficiency of the packhouse. Therefore, this section briefly describes the suggested energy efficiency interventions for the operation and maintenance of the packhouses, which are detailed in World Bank (2022) for reference.

1. For operational efficiency, ensure optimum capacity utilization of precoolers with full batch loads when precooling incoming fresh produce and avoid half loads to maximize energy efficiency. Precool the produce closer to its setpoint for subsequently storing in staging cold room to maintain the temperature while it awaits loading in reefer transport. Further, if a load has commenced

precooling, it should not be exposed to fresh hot produce in between. For example, if you are forced to start precooling 2 tons of produce, and then another 3 tons is available. Do not introduce the additional load into ongoing load as it will expose the earlier load to high risk.

2. Development of packhouse operation manual: Produce-wise packhouse operation manuals should be developed for categorising tropical / subtropical /temperate produce grown seasonally or round the year in local as well as Hindi and English languages, which can ensure better execution of the desired packhouse protocols. Amongst other operational aspects, the manual should describe packaging and palletisation protocols as well. Proper packaging in boxes/ cartons with adequate holes and palletisation along airflow direction is required for attaining uniform cooling in the pre-cooling and cold room operations.

3. Operational procedures and protocols for produce, specific packhouse functions such as sorting, grading, and packaging and palletisation could be adopted from the Food and Agriculture Organization (FAO) guidelines and further adapted for Indian conditions. The operational guidelines can also recommend operations practices and specific produce flow requirements, for efficient conduct of packhouse functions by minimising movement of people and produce and reducing the produce's high temperature exposure time.

4. Guidelines for Periodic Maintenance Schedule (PMS): In order to ensure energy efficient operation of all energy systems, it is proposed first to develop a rigorous periodic maintenance schedule. The PMS should cover equipment/system-wise check-points, frequency, and maintenance procedures, including-

- Daily checks on refrigeration plant operating parameters, compressor motor current consumption, oil level, refrigerant level, pre-cooling and cold room temperature & RH, air inlet and outlet, temperature of the coil. For all measuring instruments or device, it is necessary to calibrate then once a year or even earlier depending upon their criticality in the operation.
- Monthly inspection checks covering operating of expansion valves, filters, cleanliness of the condenser, water quality, oil quality, defrost lines, vibration and noise levels, door gasket condition, integrity of insulation, etc.
- Periodic inspection of product process flow adopted in the packing hall, water drainage, and door opening in receiving and delivery areas.
- Protocols on good practice for refrigerant handling and recharge to ensure energy efficient operation and avoid leakages.
- Protocols for refrigerant reclamation, disposal or incineration at the end of life of refrigeration systems.
- Secondly, the proposed PMS should be enforced through appropriate government guidelines and regulations.

5. Training of packhouse operators and technicians: In order to plug the need for skilled packhouse operators and technicians, a training program should be developed focused on packhouse operation, including refrigeration plants for pre-cooling and staging cold rooms. Energy management system certification as per ISO 50001 can be referred for its execution. (International Organization for Standardization)

6.6 Energy Saving Potential

With an increased demand for stored goods and preservation of fruits and vegetables in the country, energy use in the cold chain industry is growing tremendously. Storage space cooling, typically through the refrigeration system, contributes increasingly to energy demand. The development of packhouse facilities in India has been growing steadily over the past few years, and there is no doubt that its demand and the energy needed will continue to grow for decades to come.

Table 22 shows an estimated annual electricity consumption and GHG emission through a typical packhouse. The baseline scenario highlights the estimated annual electricity consumption and GHG emission from a packhouse developed without integrating EEMs, while the intervention scenario provides estimation after integrating EEMs.

Table 22: Electricity consumption and GHG emission per installation

Baseline Scenario	Estimated annual electricity consumption for a sample packhouse	1,25,000 kWh/year
	Estimated GHG emission	1,00,000 $kgCO_2e$
Intervention Scenario	Estimated annual electricity consumption for a sample packhouse integrated with EEMs	80,000 kWh/year
	Estimated GHG emission	65,000 $kgCO_2e$
Percentage reduction in electricity consumption by a sample packhouse after integrating EEMs		36%
Percentage reduction in GHG emissions		36%

Based on the per-installation estimation, a quantitative analysis is performed to estimate the impact of energy efficiency intervention on total electricity consumption and carbon emission till 2030 under two scenarios, taking 2017 as the base scenario:

Business as Usual (BAU) Scenario: This scenario assumes the continuation of the market trends and energy usage patterns through packhouses in India till 2037.

Aggressive Scenario: In comparison to BAU, this scenario assumes if the packhouse development is initiated based on all the recommendations provided through the guidelines, a significant amount of energy and emission footprints can be avoided during the same timeline. Table 23 shows the comparative analysis of the savings potential in two scenarios.

Table 23: Savings estimation under different scenarios

	Unit	Base Year	Business as Usual Scenario (Cumulative up to year*)			Aggressive Scenario (Cumulative up to year*)		
		2017	2025	2030	2037	2025	2030	2037
Annual requirement of packhouse as per ICAP 2019 (MoEFCC, 2019b)	No.		5,441	6,007	6,900	5,441	6,007	6,900
Required stock of packhouse infrastructure in India as per ICAP 2019	No.	500	33,739	62,619	1,08,171	33,739	62,619	1,08,171
Electricity Consumption								
Annual electricity consumption through the required packhouses	TWh		0.69	0.76	0.87	0.44	0.49	0.56
Saving w.r.t BAU	TWh					0.25	0.27	0.31
Saving w.r.t BAU	%					36%	36%	36%
Consumption through stock	TWh	0.06	4.26	7.91	13.66	2.73	5.08	8.77
Saving w.r.t BAU	TWh					1.53	2.83	4.89
Saving w.r.t BAU	%					36%	36%	36%
Carbon Emission								
Carbon Emission	tCO2e	0.04	3.02	5.61	9.70	1.94	3.60	6.23
Saving w.r.t BAU	tCO2e					1.08	2.01	3.47
Saving w.r.t BAU	%					36%	36%	36%



The above analysis indicates that there is a cumulative electricity savings of approx. 2.83 TWh and 4.89 TWh by 2030 and 2037, respectively, in the aggressive scenario compared to BAU. Aggressive scenario has a reduction of carbon emission of approx. 2.01 million tCO2e and 3.47 million tCO2e by 2030 and 2037, respectively, as compared to BAU.

Further analysis was conducted to identify the energy saving potential in a packhouse by implementing efficient packhouse design and efficient equipment and machine design (mentioned in above sections) up to year 2037. Potential savings by implementing efficient building design will be approx. 2.92 TWh by 2037, while through efficient equipment and machinery design, the electricity saving potential will be approximately 1.97 TWh by 2037.

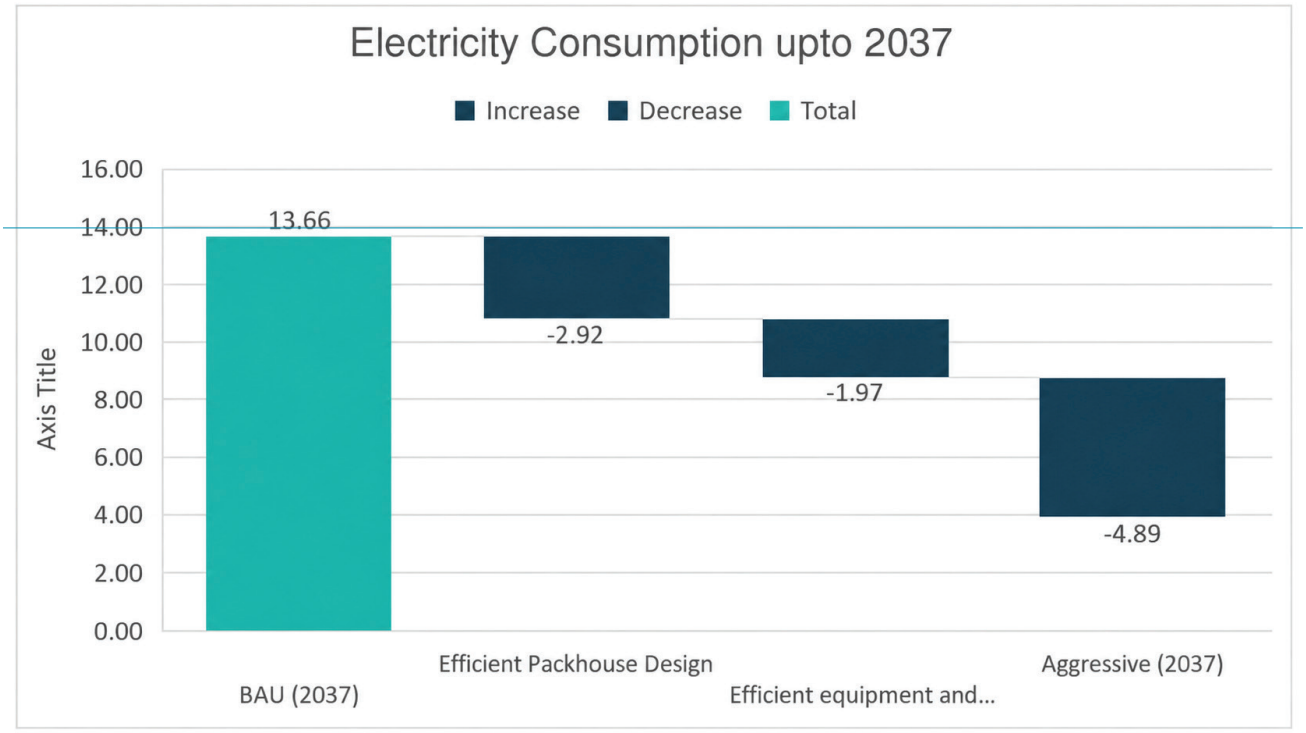


Figure 21: Electricity saving potential (up to 2037)

The cumulative electricity saving up to the year 2037 (described in Table 21) of approx. 4.89 TWh is equivalent to approx. 34 lakh households transitioned to off-grid for a year, and one coal-based power plant shut down for a year (Abraham 2023).

CHAPTER 07

Renewable Energy Integration

7

Renewable energy integration in the packhouse plays a major role where grid power is unreliable and it can also help reduce overall energy costs. One of the primary advantages is the potential to make these facilities off-grid, reducing dependence on fossil fuels and conventional power grids. Employing renewable energy enhances energy resilience and significantly decreases greenhouse gas emissions associated with electricity generation. Solar PV panels, for example, harness the sun's power, providing a clean and consistent energy source that can be stored in batteries for use during cloudy periods or at night. Packhouses and cold rooms can achieve energy independence by combining renewable energy generation with advanced energy storage solutions, simultaneously reducing their carbon footprint and operational costs. This section discusses a few renewable energy options that can be integrated with the packhouse to satisfy the required demand:

- Solar PV-powered refrigeration systems and packhouses
- Solar thermal energy-powered vapour absorption refrigeration system
- Agri-waste/Biogas/Biomass powered vapour absorption refrigeration system
- Geothermal heat exchanger

Solar PV-powered refrigeration system and packhouses: Solar PV is the most logical form of renewable energy, which can be integrated with the packhouse and connected to the grid. Solar energy could be used as the packhouse's primary energy source, while grid energy could be the backup. Excess energy generated through solar PV can be supplied to the grid or stored in the TES system for later use. The packhouse operation needs electrical energy to run the F&V handling line, pre-cooling and staging cold room, cold dock cooling, process hall cooling, lighting, and other small loads. Due to the low-temperature operation, the energy consumption is higher than a commercial building of a similar size, and the energy cost is a sizable part of the total operational cost. Solar PV installation will reduce energy costs and grid emissions by providing renewable energy.

The parameters mentioned below will determine the solar PV capacity:

- **Space availability:** The availability of the required non-shaded area for installing solar PV is one of the major parameters as it determines the capacity of the solar PV that can be deployed and the overall energy output. Typically, the area required for rooftop solar PV installation is about 9.5 m²/kWp, with the high-efficiency panels available in the market with BEE star label.



- **Maximum capacity limitation for behind-the-meter grid-connected renewable plants:** For customers with captive power requirements, there is a threshold on the maximum solar capacity for grid-connected plants as stipulated by the state's power distribution company/electricity department/ electricity regulatory commission. This will apply to packhouses as well. The maximum capacity threshold varies by state, with most states having a restriction capped at the connected load of the customer.
- **Annual electricity requirement:** Solar capacity installation also depends on the annual electricity requirement for the facility's operation.

An example of calculating solar capacity for a sample packhouse is mentioned in Table 24. The average estimated connected load and average estimated power consumption are obtained from the previous section. The daily average solar insolation (or full sun hours) for the solar capacity estimation is 5 kWh/m^2/day. Considering all the major types of losses, a conservative factor of 80% is considered for DC to AC electricity generation.

Table 24: Solar capacity for a typical packhouse

Average estimated connected load	60 kW
Average estimated annual electricity requirement	1,25,000 kWh
Total estimated solar capacity required to meet 100% of the electricity requirement	77 kWp
Average estimated non-shaded rooftop area required to meet 100% of the electricity requirement	770 Sq.m

Various methods of modelling the electricity sourcing for the packhouse range from the grid to diesel to solar. Figure 22 below depicts the transition from business-as-usual using grid electricity and diesel generators as back-up to using solar PV and battery storage, leading to a sustainable packhouse. As the consumer moves from the baseline scenario (left to right in the figure) to using solar PV as the primary energy source, there will be a reduction in energy cost, grid reliability, improved energy resilience, operational risk reduction, and carbon footprint.

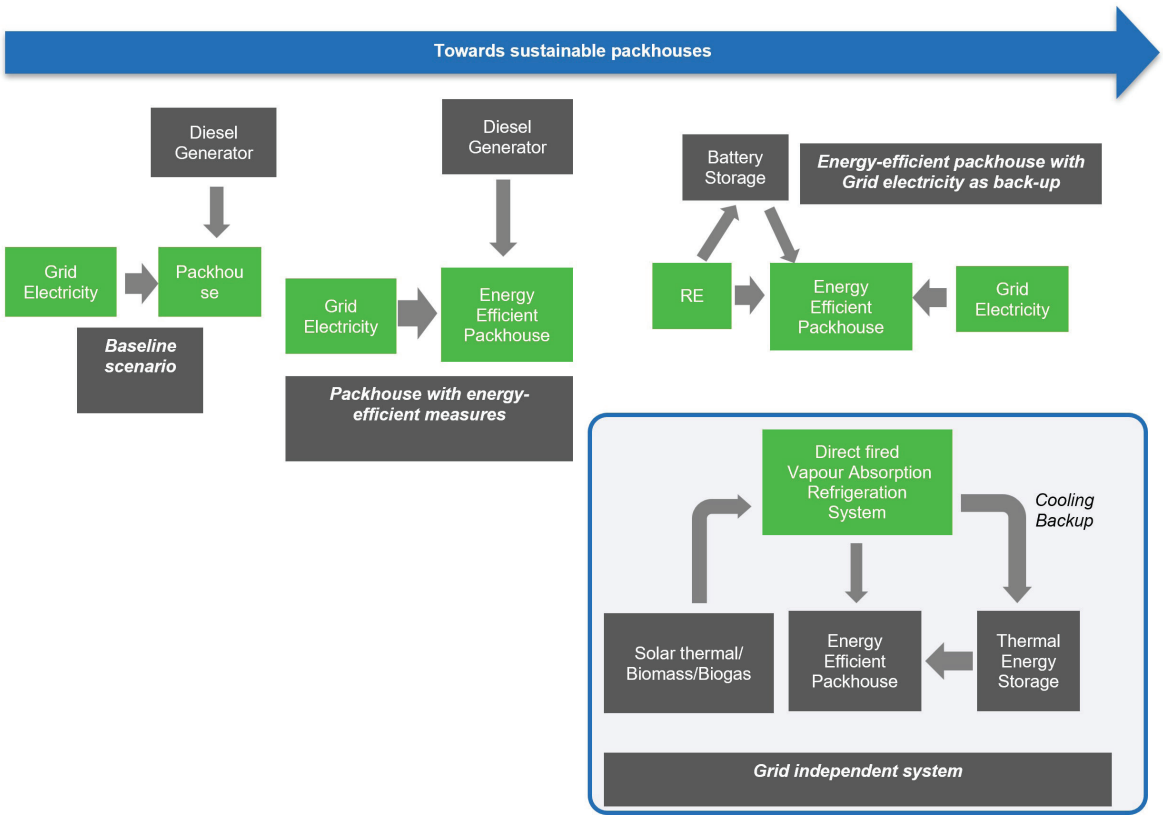


Figure 22: Step-wise transition towards sustainable packhouse development

Solar PV can also function as a grid-interactive system, feeding the grid with the electricity produced. In this scenario, installing batteries might not be necessary; instead, the amount of energy provided to the grid is measured using a meter. A safety system is required to separate the system from the grid when necessary. To offset the facility's energy costs, this operational model enables the facility to have a secondary source of income. Solar PV system consists of the following components:

- Solar PV modules: Converts sunlight into electricity using semiconductor materials

Battery Energy Storage System: Provide backup power, stabilize the grid, and store excess renewable energy Solar Inverter: Converts the DC electricity generated by solar panels into AC electricity and also enables the integration of solar power into the electrical grid

There are further options like wind energy, harnessing water energy, etc., but they are not viable. Some sample cases of solar PV systems used for cold stores and a packhouse are given in Table 25 below.

Table 25: Practical application of renewable energy for cold-chain

Renewal Tech Type	Location	Cost Estimate	Advantage/Disadvantage
Solar PV for small cold-stores with Thermal Energy storage (TES) as a cooling back-up	Agro farms owned by small farmers/ farmer groups	Approx. INR 15 Lakhs for 20 MT storage	Small cold room connected with solar PV and grid for energy source. Electrical battery as a backup for auxiliary loads and TES as a cooling backup.
Solar PV for packhouse & cold-store 300 kWp, capacity 20 MT, pre-cooling + cold-store 700 MT for staging + other uses	Baramati, Maharashtra	Approx. INR 1cr, 40 Lakhs	Project under completion The system provides only about 50% of demand with a Net-metering facility required.
Agro waste / Thermal energy-based Adsorption units for cold-stores 20 MT Capacity Units for multiple uses, e.g., storing banana or mango ripening and for chillies. Fuel used: mustard husk, wheat husk-based food, etc.	Bigbasket, Hoskote, Bengaluru used for packhouse pre-cooling cold-stores and ripening KhetKisan, FPO, Fatehpur, UP	Approx. INR 15.0 Lakhs for 20 MT units	Sustainable technology followed with ammonia as the refrigerant Continuous supply of agro-waste / biogas required.

Note: Based on consultations with prominent technology providers

Solar thermal energy powered vapour absorption refrigeration system: Solar thermal energy generates hot water or steam, which can be used to run absorption/ adsorption systems for pre-cooling and staging cold stores. However, these units are available only in small capacities of around 15 kW. The required heat can be supplemented by integrating solar thermal heat with biomass-powered heat.

Agri-waste/Biogas/Biomass powered vapour adsorption/ absorption refrigeration system: These energy sources can be used to operate the packhouse's vapour absorption/ adsorption refrigeration units. Refrigerants can be salt based such as with Li-Br combination suitable for up to 4°C temperature or use ammonia water mixture (NH_3-H_2O). This system requires heat energy as input, which can be in the form of:

- Steam generated by boilers or the waste steam available from nearby sources.
- Heat is generated in a direct-fired vapour absorption unit. These units are suitable for small as well as larger capacity requirements and commonly used in milk chillers as well as for cold rooms in India.

In addition to the environmental benefits, renewable energy integration in packhouses and cold rooms offers long-term economic advantages. Although the initial capital cost of installing or integrating a renewable energy system can be comparatively higher, over time, the initial investment in renewable energy infrastructure pays off through energy savings, reduced operating costs, and a competitive edge in a market increasingly driven by sustainability. By transitioning

to a renewable-powered system, businesses demonstrate their commitment to a low-carbon future, showcasing their dedication to environmental stewardship and resource efficiency. In essence, renewable energy integration is a powerful strategy for achieving low carbon emission targets while securing a sustainable and competitive position in the marketplace. Table 26 presents the SWOT analysis for the identified technologies.

Table 26: SWOT analysis of major RE technologies suitable for packhouses

RE Type	Strengths	Weakness	Opportunities	Threats
Solar PV Energy (Elavarasan et al. 2020	• Fully commercialized technology and extremely modular • Low O&M cost • Zero fuel utilization • GHG reduction potential compared to fossil fuel power • Minimum unit cost price • Location preferable: Pan India, except areas with low irradiance (coastal and north-east India)	• Fully commercial • Experience intermittency and idleness • Low energy efficiency • High upfront cost • Space constraints • Geographic limitations	• Technological advancements • Energy storage solutions can mitigate the intermittency issue • Decentralised/microgrids reducing strain on central grid • Huge potential • Energy security • Increased focus from Government • Highly subsidized technology	• Changing policy uncertainties • High energy storage costs • Heavy dependence on imported solar cell • Supply chain dependencies
Thermal Energy (Pochitonow et al. 2010)	• A direct heating source can power heat-driven refrigeration systems based on adsorption/ absorption. • Low operating cost • Well-developed and commercialized technology • Wide market offers in terms of technology and financing • It could be combined with another RES technology like biomass and solar PV	• Space constraints • Diurnal and seasonal variability • Experience intermittency and idleness • Space constraints • Limited geographic suitability	• Good potential in pan India, except areas with low irradiance (coastal and north-east India) • Integration with the VAR refrigeration system could save significant energy. • Can support hybrid system • Supported by a subsidy scheme for cold-chains	• Changing policy uncertainties • Supply chain disruption • Complex system and maintenance challenges when integrated with VAR
Biomass/ Biogas Energy (Kretschmer, W. 2014; Ministry of New and Renewable Energy 2022; Rawat, S. 2019; Singh, P. 2023.	• Generally available at all geographies in many forms like agri and forest residues, municipal waste • Carbon neutral, huge GHG reduction potential compared to fossil fuel • High capacity factor • Cost competitive with fossil fuels • Steady supply, continuous source of energy • High energy efficiency, particularly if its gasification technology • It can directly supply heat to the VAR system	• Low return on investment • Lack of adequately skilled and technical workforce • Lack of infrastructure for implementation • Lack of end-user awareness • Comparatively higher O&M cost • Lack of resource availability, seasonally and regionally dependent	• Integration with solar thermal or waste energy from gasifiers to power VAR • Shortening Demand supply gap • Government initiatives	• Variability in biomass fuel supply • Competing technologies • Inadequate infrastructure • Severe lack of low-cost financing • Dependency on biomass availability

RE Type	Strengths	Weakness	Opportunities	Threats
Geothermal Cooling (Romanov 2022)	• Steady and reliable source • Small environmental impact • Low operating cost • Predictable performance • Long lifespan • Applicability to different climate and hydrogeological conditions • Reduced environmental impact • Flexible capacity installation	• Location dependency • High upfront costs • Complex installation • Resource depletion and saturation • Lack of regulation and incentives • Lack of knowledge and awareness • Lower energy efficiency and performance leading to surface instability	• A hybrid system can be integrated with other RE sources • Technological advancements • Availability scale is very flexible • Discovery of thermal water resources for profitable use	• Maintenance complexity • Upfront investment cost and risk before the payback period • The utilization depends on the demand at the site.
Waste heat utilization (Kordana 2017)	• Improved overall energy efficiency • Operational cost saving • Generally available at food processing plants • Possibility to use waste heat with negligible expenses • Lower environmental emission • Profitable in the long run • Compliance benefits	• High infrastructure and retrofitting costs • Dependence on the source, location and technical conditions • High upfront cost • Required skilled technician for operation • Complex engineering design of heat exchanger network	• Technological advancements • Waste minimization • Developments of new designs for heat exchangers • Introducing relevant regulations and subsidies • Decreased use of fuel inputs	• Maintenance complexity • Regulatory hurdles Contamination or scaling of surface in heat exchangers • Lack of capacity for expansion

Table 27 below provides a high-level assessment of renewable energy sources. Solar PV is commercially and financially the most attractive option among the energy sources mentioned below. Biomass with a competitive Levelized Cost of Electricity (LCOE) and unintermittent generation potential are attractive options, provided that an adequate type and quantity of feedstock at an affordable rate is available. Solar thermal energy can be seen as a potential option for cooling applications through VAR systems.

Table 27: Technology assessment of various renewable energy technologies

Technology	Solar PV	Biomass	Solar Thermal
LCOE Range	INR 2.8-3.5/kWh	INR 4.5-21.75/kWh	INR 13.65-32.25/kWh
Commercial Availability	1 kWp and onwards	10 kW – and onwards	6 kW and onwards
Technology Readiness (TRA)	Fully Commercialized	Fully Commercialized	Partially Commercialized
Resource	Solar Irradiance (No minimum value)	Dry feedstock	Solar Irradiance (Minimum 350 W/m^2)
Area required	10 m^2 for 1 kWp	NA	16 m^2 aperture area & 35 m^2 shadow free are for 6 kW
Intermittency	Hourly	NA	Hourly

Source: Zaman, A., and Agarwal, G. (2023). Assessment of Energy-Efficient and Clean Energy Technology in the Cold chainSector. Energise, 2023

References

Abraham, A., Gangahar, M. (2023). Decoding numbers, inspiring action: Using equivalence to bridge the gap between jargon and meaningful energy communication. Alliance for an Energy Efficient Economy

Acedo AL Jr., Rahman MA., Buntong B., Gautam DM. (2016). Vegetable Postharvest Training Manual. World Vegetable Center. https://avrdc.org/download/publications/from_the_field/postharvest/vegetable-pht-training-manual-english.pdf

Bitzer Software (2019). https://www.bitzer.de/websoftware/Default.aspx?cid=

Bureau of Indian Standards (1973). Indian Standard Code of Practice for Industrial Lighting. https://law.resource.org/pub/in/bis/S05/is.6665.1972.pdf

Bureau of Indian Standards (1989), Guide for Daylighting of Buildings (Second Revision), https://ia800300.us.archive.org/5/items/gov.in.is.2440.1975/is.2440.1975.pdf

Bureau of Indian Standards (1992), Code of Practice for Interior Illumination, https://law.resource.org/pub/in/bis/S05/is.3646.1.1992.pdf

Bureau of Indian Standards (1999), Application Of Spray Insulation - Code Of Part 2 Calcium Silicate, https://law.resource.org/pub/in/bis/S02/is.12432.2.1999.pdf#:~:text=This%20Indian%20Standard%20(Part%202)%20was%20adopted,been%20approved%20by%20the%20Chemical%20Division%20Council.&text=This%20standard%20(Part%202)%20prescribes%20codes%20of,surfaces%20operating%20at%20temperatures%20up%20to%208OOOC.

Bureau of Indian Standards (2002), Application of Spray Applied Insulation - Code of Practice, https://law.resource.org/pub/in/bis/S02/is.12432.3.2002.pdf

Bureau of Indian Standards (2011), National Electrical Code 2011, https://law.resource.org/pub/in/bis/S05/is.sp.30.2011.pdf

Bureau of Indian Standards (2016), Guide for Using National Building Code of India, https://www.bis.gov.in/wp-content/uploads/2022/08/Booklet-Guide-for-Using-NBC-2016.pdf

Bureau of Indian Standards (2018), Code of Practice for Earthing (Second Revision), https://elinkearthing.com/home/wp-content/uploads/2022/06/IS-3043-2018.pdf

Carel (2008). Integrated solution for control and energy savings in commercial refrigeration. https://www.carel.com/documents/10191/0/+302240481/f2579142-154a-4084-8e90-4ca80142fdbf?version=1.0

Central Public Works Department (2013), General Specifications for Electrical Works, https://www.dgll.nic.in/sites/default/files/2023-06/CPWD%20%E0%A4%95%E0%A5%87%20General%20Specifications%20for%20Electrical%20Works%20%28Part-1%20Internal%29%202013_compressed.pdf

Elavarasan, R. M., Afridhis, S., Vijayaraghavan, R. R., Subramaniam, U., & Nurunnabi, M. (2020). SWOT analysis: A framework for comprehensive evaluation of drivers and barriers for renewable energy development in significant countries. Energy Reports, 6, 1838-1864. https://www.researchgate.net/publication/343049514_SWOT_analysis_A_framework_for_comprehensive_evaluation_of_drivers_and_barriers_for_renewable_energy_development_in_significant_countries

Food and Agriculture Organization, (2012). Good practice in the design, management and operation of a fresh produce packing-house. ISBN 978-92-5-107194-6.

Food and Agriculture Organization, (2019). 2019 State of Food and Agriculture: Moving forward on food Loss and waste reduction.

Food & Drug Administration (1997). HACCP Principles & Application Guidelines. https://www.fda.gov/food/hazard-analysis-critical-control-point-haccp/haccp-principles-application-guidelines#:~:text=Seven%20basic%20principles%20are%20employed,and%20record%2Dkeeping%20and%20documentation

GCCA. 2010. Presentation on Cold Storage Doors by Dr. Andy Pearson, UK

HCFC phase-out management plan (HPMP) stage-III, Ozone Cell, MoEF&CC, Govt of India. https://ozonecell.nic.in/wp-content/uploads/2023/09/2-HPMP-Stage-III.pdf

Indian Society of Heating, Refrigerating and Air Conditioning Engineers (2015a). Refrigeration Handbook-2015. https://shop.ishrae.in/product/details/e-book-refrigeration-handbook-/47

Indian Society of Heating, Refrigerating and Air Conditioning Engineers (2015b). Refrigeration Handbook-2015. https://shop.ishrae.in/product/details/e-book-refrigeration-handbook-/47

International Organization for Standardization, ISO 50001 Energy management, https://www.iso.org/iso-50001-energy-management.html#:~:text=ISO%2050001%20is%20based%20on,Management%20system%20standards

Bureau of Indian Standards (2000). Indian Standard Code of Practice for Thermal Insulation of Cold Storage. https://law.resource.org/pub/in/bis/S02/is.661.2000.pdf

Koelet, P.C. (1992a). Industrial Refrigeration Principles, Design and Applications. https://www.standardsmedia.com/Industrial-Refrigeration--Principles-Design-and-Applications-1660-book.html

Koelet, P.C. (1992b). Industrial Refrigeration Principles, Design and Applications. https://www.standardsmedia.com/Industrial-Refrigeration--Principles-Design-and-Applications-1660-book.html

Kordana, S. (2017). SWOT analysis of wastewater heat recovery systems application. In E3S web of conferences (Vol. 17, p. 00042). EDP Sciences. https://www.researchgate.net/publication/317134538_SWOT_analysis_of_wastewater_heat_recovery_systems_application

Kretschmer, W., Bischoff, S., Hanebaeck, G., & Muller, H. (2014). SWOT analysis and biomass competition analysis for SUPRABIO biorefineries. IUS Institute for Environmental Studies. https://www.ifeu.de/fileadmin/uploads/IUS_2014_SWOT-and-biomass-competition-analyses-of-SUPRABIO-biorefineries_2014-08-31.pdf

Ministry of Agriculture & Farmers Welfare (2021). Agricultural Statistics at a Glance 2021. https://eands.dacnet.nic.in/PDF/Agricultural%20Statistics%20at%20a%20Glance%20-%202021%20(English%20version).pdf

Ministry of Agriculture & Farmers Welfare (2024). Area and Production of Horticulture crops for 2022-23 (Final Estimates). https://agriwelfare.gov.in/en/StatHortEst

Ministry of Environment, Forest & Climate Change Government of India (2019). India Cooling Action Plan (ICAP). https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf

Ministry of Environment, Forest & Climate Change Government of India (2021). Study on cold chain sector in India for promoting non-ODS and low-GWP refrigerants. https://ozonecell.nic.in/wp-content/uploads/2021/09/Cold-Chain-Sector-Report.pdf

Ministry of Environment, Forest & Climate Change Government of India (2022). Reduction in GHG emissions through ODS phase-out under the Montreal protocol implementation in India. https://ozonecell.nic.in/wp-content/uploads/2022/09/4-GHG-Report.pdf

Ministry of New and Renewable Energy (2022). Guidelines for implementation of Biomass Programme "Scheme to Support Promotion of Manufacturing of Briquettes & Pellets and Biomass (Non-Bagasse) Based Cogeneration in Industries in the Country" for the period of FY 2021-22 to 2025-26. https://mnre.gov.in/bio-mass/

NABCONS (2022). Study to determine post-harvest losses of agri produces in India.

National Centre for Cold chain Development (2015a). All India Cold chain Infrastructure Capacity Assessment of Status & Gap. https://nccd.gov.in/PDF/CCSG_Final%20Report_Web.pdf

National Centre for Cold chain Development (2025). Engineering Guidelines & Minimum System Standards For Implementation In Cold Chain Components. https://www.nccd.gov.in/PDF/2024-25/ENGINEERING%20GUIDELINES-%20Revised%20Final%20Edition_04.02.2025-2025.pdf

National Centre for Cold chain Development (2015b). Guidelines and minimum system standards for implementation in cold chaincomponents. https://www.nhb.gov.in/pdf/NCCDGuidelines2014-15.pdf

National Horticulture Board (2010). Postharvest handling of fruits and vegetables Intended for Cold Storage. https://nhb.gov.in/documents/storage-manual.pdf

National Horticulture Board (2010). Report of Technical Standards Committee on Technical Standards and Protocol for the Cold Chain in India. Control Atmosphere Cold Stores (Technical Standards Number NHB-CS-Type 03-2010). https://nhb.gov.in/documents/cs3.doc

Pochitonow, Z., Szymusik, B., Boruń, A., Dzwonnik-Zatora, A., Fijałkowska, I., Pacak, A., Ciszek, A., 2010. A SWOT Analysis for Renewable Energy Sources and Energy Efficiency in the Administrative District of Gorlice. European Regional Development Fund, Central Europe Programme. http://www.visnova.energie-zentrum.com/pdf/swot_analysis_-_gorlice_district.pdf.

Romanov, D., and Leiss, B. (2022). Geothermal energy at different depths for district heating and cooling of existing and future building stock. Renewable and Sustainable Energy Reviews, 167, 112727. https://www.sciencedirect.com/science/article/pii/S1364032122006165

Singh, P. (2023). Biomass-powered storage demonstrates benefits for Maharashtra farmers. https://www.iamrenew.com/sustainability/biomass-powered-storage-demonstrates-benefits-for-maharashtra-farmers/

Singh, P. (2023). Biomass-powered storage demonstrates benefits for Maharashtra farmers. https://www.teriin.org/blog/biomass-solar-combination-cold-storage-farm-produce

Thompson, J. F., Mejia, D. C., Singh, R. (2010). Energy Use of Commercial Forced-Air Coolers for Fruit. University of California, Agriculture and Natural Resources. https://ucanr.edu/datastoreFiles/234-1907.pdf

World Bank, Bureau of Energy Efficiency, Energy Sector Management Assistance Program, Alliance for Energy Efficient Economy (2022). Cold Chain Energy Efficiency in India: Analysis of Energy Efficiency Opportunities in Packhouses. https://aeee.in/wp-content/uploads/2022/03/WB-BEE-AEEE-cold-chain-energy-efficiency-in-india.pdf

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