Horticulture Cold Room Procurement Guidelines

Evaluation Guidelines for Procuring Sustainable Cold Rooms for Horticulture Applications

September 2024

Alliance for an Energy Efficient Economy (AEEE) is implementing the project "Improving Rural Livelihoods Through Energy-Efficient Cooling & Refrigeration in India". The project is envisioned as a catalyst to reduce food loss by advancing the development and implementation of energy-efficient cold chain infrastructure for agriculture, thereby supporting the Government of India's fundamental goal of doubling farmers' income. It also fosters the implementation of ICAP 2019 recommendations associated with energy-efficient refrigeration technologies by demonstrating the use of energy-efficient, renewable energy-powered, low-GWP cold chain for horticulture applications. This publication is based on the cold room evaluation framework developed and used by AEEE to select energy-efficient, renewable energy-powered, low-GWP cold room solutions that were subsequently deployed for farmer cooperatives in Bihar. This guide is specifically developed to support farmer cooperatives and agribusinesses to procure and deploy energy-efficient, clean energy-powered, and climate-friendly cold rooms for horticulture.

Prepared by: Alliance for an Energy-Efficient Economy (AEEE)

Alliance for an Energy Efficient Economy (AEEE) supports policy implementation and enables the energy efficiency market with a not-for-profit motive. AEEE promotes energy efficiency as a resource and collaborates with industry and government to transform the market for energy-efficient products and services, thereby contributing toward meeting India's goals on energy security, clean energy, and climate change.

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01 About the Document

This guide introduces an evaluation framework to streamline the deployment of sustainable cooling and refrigeration solutions, encompassing a holistic approach that includes Energy Efficiency (EE), Renewable Energy (RE), eco-friendly refrigerants, and a focus on resource sufficiency. It is designed to assist stakeholders in the agricultural and cold storage sectors, including Farmer Producer Organisations (FPOs), agribusinesses, and similar entities, as they navigate the complexities of selecting, procuring, deploying, and operating sustainable "cold storage" systems. The guide covers a broad spectrum of cold room applications: pre-coolers, staging cold rooms, ripening chambers, and short-term and long-term cold storage units. These systems cater to a diverse array of agricultural products, including fruits and vegetables (F&V), flowers, spices, pulses, etc., at different stages of the agricultural supply chain. It provides tailored guidance in alignment with the standards and directives of the National Centre for Cold-chain Development (NCCD), the Mission for Integrated Development of Horticulture (MIDH), and the National Horticulture Board (NHB). The primary objective of this guide is to empower stakeholders with the knowledge and insights required to make informed decisions that not only improve food storage and distribution but also contribute to the betterment of rural livelihoods and environmental sustainability. Its purpose is to assist these stakeholders in selecting energy-efficient, clean energy-powered, and climate-friendly solutions, thereby simplifying the process of choosing the most suitable cooling and refrigeration systems to enhance food storage, distribution, rural livelihoods, and environmental sustainability.

The Farmer Producer Organisation (FPO) / Farmer Producer Company (FPC) / cooperative / agribusiness should employ or contract an independent agriculture cold chain expert to assess their cold chain requirements, develop technical specifications for cold chain equipment, evaluate vendor proposals for equipment, and support the FPO in procuring, testing, and commissioning the cold chain equipment.

This guide is specifically developed to support the FPO in procuring and deploying energy-efficient, clean energy-powered, and climate-friendly cold rooms. This guide will help the agriculture cold chain expert develop technical specifications for energy-efficient, clean energy-powered, and climate-friendly cold rooms and storage, and evaluate vendor proposals based on criteria for energy efficiency, renewable energy and zero/low-GWP refrigerants.

Reefer transport is not within the scope of this guide.

Chapter 2: Requirements and Evaluation Process, provides a high-level overview of the procurement process.

Chapter 3: Evaluation Framework, presents the evaluation framework and guidelines for developing technical specifications for cold chain equipment and evaluating vendor proposals for the specified cold chain equipment. Additionally, a sample commissioning checklist is included as an appendix.

The annexure of this guide contains the evaluation framework template.

02 Requirements and Evaluation Process

This section provides a high-level overview of the main steps in determining the cold chain requirements, developing the technical specifications for the required solution, and evaluating the solutions provided by different vendors.

2.1 Defining "Farm to Market" Use Cases

Defining a "farm to market" use case is essential to assess which cold chain components, if any, are required to maintain produce quality and freshness from farm gate to market. Before using this guide, the Farmer Producer Organisation (FPO) / Farmer Producer Company (FPC) / cooperative / agribusiness should define their particular use case(s) depicting how the produce moves from the farm gate to the market. The use case should capture the produce type, quantity, travel distance and time, and storage period at each node in the cold chain from farm to market.

A few typical use cases are illustrated below.

Use Case 1

The FPC sells produce to the market soon after harvesting. On some days, the FPC may store surplus produce for a few days to avoid distress sales. The FPC can sell stored produce when there is more demand than supply in the market.

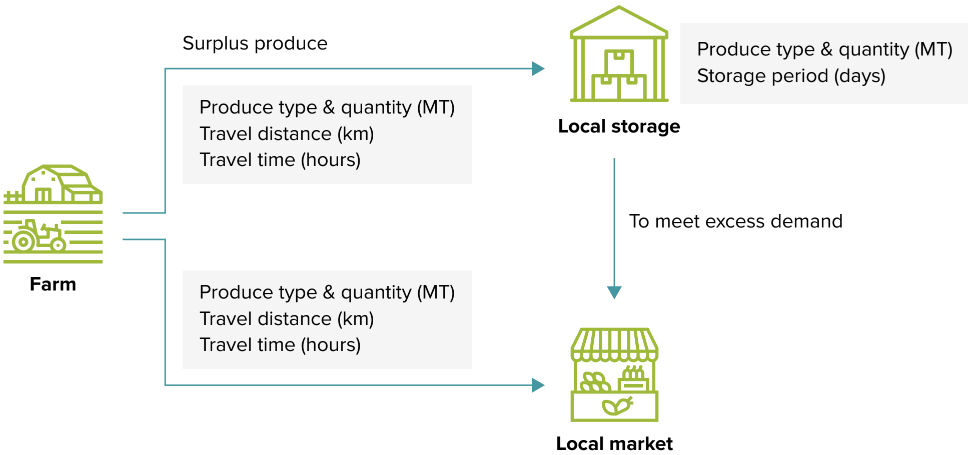

Figure 1: Use case 1

Use case 2

The FPC sells produce to a supermarket chain and transports it to the supermarket's distribution centre. The FPC operates the packhouse and transportation to the distribution centre. The supermarket chain operates its distribution centre, retail network and associated logistics. Alternatively, the FPC may have its own farm-to-retail business, in which case the FPC operates the packhouse, distribution centre, retail outlets and associated logistics.

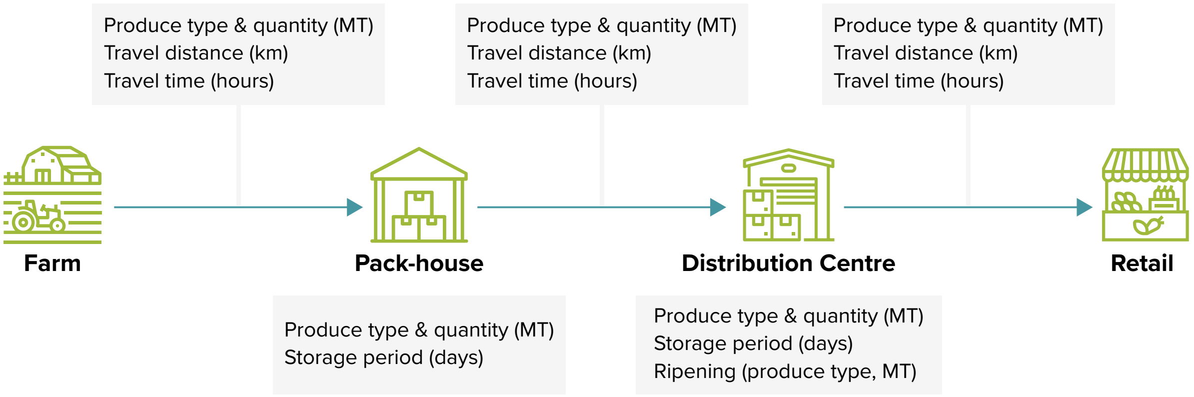

Figure 2: Use case 2

Use case 3

The FPC prepares produce for long-term storage. The FPC or a wholesaler may operate the long-term storage facility.

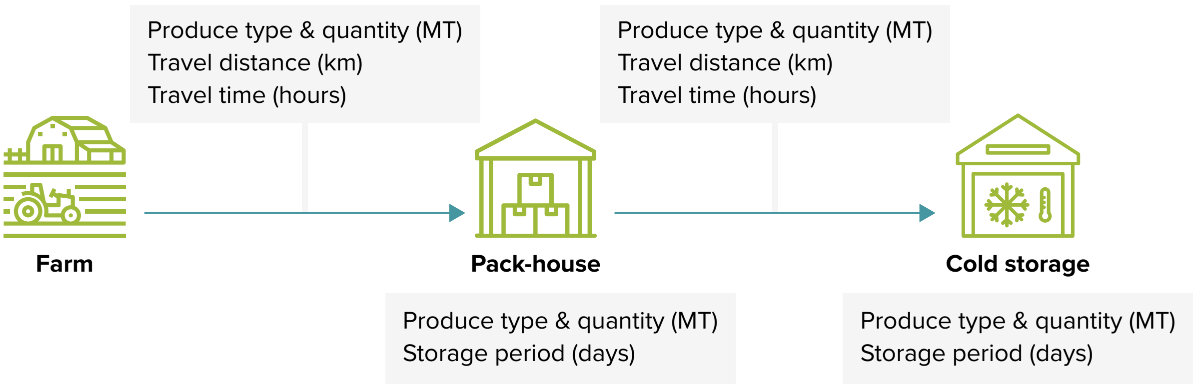

Figure 3: Use case 3

Use case 4

The FPC produce is intended for export.

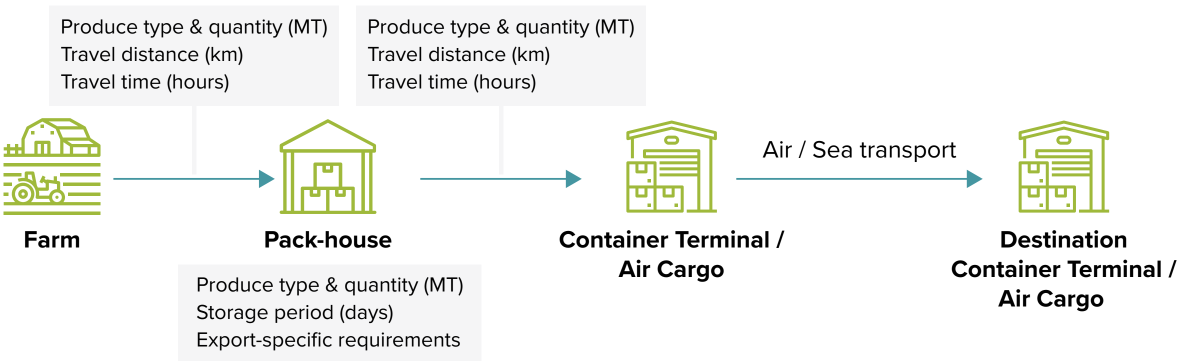

Figure 4: Use case 4

The use cases illustrated in Figures 1 to 4 do not comprise an exhaustive list of use cases. The FPO/FPC/cooperative/agribusiness should develop all use cases relevant to their marketing and business needs. For example, an FPC could have one use case for selling vegetables in domestic supermarket chains and another for exporting mangoes. Likewise, a single type of produce, such as potatoes, may have two use cases, i.e., one for sale to the local market and one for long-term storage. Use cases can help determine which cold chain components, such as pre-cooler, staging cold room, long-term cold storage, ripening chamber, reefer transport, etc., are required to meet the marketing and business requirements of the FPO/FPC/cooperative/agribusiness.

2.2 Detailed Project Report

If the FPO/FPC/cooperative/agribusiness intends to apply for a loan or financial assistance for its cold chain project, the financial institution or agency may request a detailed project report (DPR). A detailed project report typically includes a brief description of the project; the project's technical, economic and financial feasibility; a business plan; a technical assessment of the cold chain equipment; a financial assessment including capital expenditure and operational expenditure; risk assessment; project implementation plan; staffing; environmental and government regulations; and other specific information requested by the financial institution or agency.

In order to estimate the economic feasibility of the cold room intervention, the FPO/FPC/cooperative/agribusiness, with assistance from an agriculture cold chain expert, should bring a clear understanding of the length of each storage cycle (e.g., 2 days, 10 days, 6 months, etc.), the number of storage cycles per year, as well as the expected revenue gain at the end of each storage cycle (e.g., Rs 2/kg price increase, Rs 10/kg price increase, etc.; or a 20% reduction in spoilage on produce valued at Rs 100/kg leading to Rs 20/kg gain, etc.). As part of the economic assessment, the payback period for the required capital expenditure should be calculated based on the estimated net revenues per year after considering operational and maintenance costs, including energy expenses.

If the revenue gain in a cycle is less than the operating cost, there is a genuine risk that the solution may be under-utilised as users may not perceive sufficient benefits to justify incurring these operating costs. Furthermore, if the solution is intended for rental purposes, the rental fee should cover the operating costs; failure to do so may still lead to underutilisation.

2.3 Request for Proposal (RFP) Preparation

The Request for Proposal (RFP) preparation marks the crucial initial steps in procuring cold chain solutions tailored to specific requirements. After outlining the specific use case necessitating cold chain storage solutions, this phase is structured to perform due diligence to evaluate technical and financial aspects, and establish a comprehensive framework for soliciting proposals. The key steps are outlined below:

1. Define the cold chain solutions per the identified use case (such as pre-cooling, cold room, etc.), including produce throughput details.
2. Define the respective weightage for technical and financial evaluation scores (suggested weights are specified in an MS-Excel-based Evaluation Framework included as an Annexure to this guide).
3. Define the technical specifications such as design intent, envelope design, refrigeration system design, renewable energy integration, remote monitoring and energy/environmental management controls, supply, installation, testing, and commissioning (SITC), operations and maintenance (O&M), etc., which will be the basis of the technical evaluation. "Chapter 3. Evaluation Framework" provides the detailed criteria to include in the technical specifications.
4. The technical specification should include the minimum mandatory performance levels wherever available, along with reference standards. Requirements such as heat load calculations for system sizing can also be specified.
5. Allocate the technical evaluation weightage within the requisite specifications (suggested weights are specified in an MS-Excel-based Evaluation Framework included as an Annexure to this guide).
6. Define the scoring criteria for the technical evaluation of each criterion (specification).
7. Define the financial evaluation criteria, such as upfront capital expenditures (CAPEX) and operational expenditures (OPEX). The OPEX includes energy costs, i.e., electricity or other fuels such as biomass and O&M expenditures associated with the cold room.

8. Allocate the financial evaluation weightage within the requisite criteria (suggested weights are specified in an MS-Excel-based Evaluation Framework included as an Annexure to this guide).

9. Define the scoring criteria for (financial) evaluation of each criterion.

10. #1-5 and #7-8 can be part of the request for proposal (RFP) sent to select vendors or for open bidding.

11. Specify payment terms and conditions and other requirements, such as annual reports and audited balance sheets or turnover statements, in the RFP.

12. Some technical or financial evaluation criteria can be made mandatory, leading to vendor disqualification in case of non-compliance. These details may or may not be part of the RFP.

13. Request contact details of existing customers of the interested vendors for reference check of the proposed solutions. This can also be made part of the technical criteria.

2.4 Proposal Evaluation

The proposal evaluation stage constitutes the subsequent phase, where received techno-commercial proposals undergo meticulous scrutiny against the defined RFP criteria. The key steps are outlined below:

1. Do the technical and financial criteria scoring based on the information provided in the techno-commercial proposals submitted by interested vendors.

2. Perform reference checks on shortlisted vendors to gather feedback from existing customers.

3. Select the final vendor based on the highest score on the combined technical and financial evaluation and satisfactory reference checks.

03 Evaluation Framework

All specifications must be clearly outlined individually for the desired infrastructure components, whether they are cold room(s) or pre-cooling room(s). An MS-Excel-based Evaluation Framework is included as an Annexure to this guide for reference and assistance in the evaluation process.

3.1 Design Intent

3.1.1 Produce incoming temperature

This is the temperature at which the produce enters the cold room or the pre-cooling room. It depends upon the produce procurement source, i.e., either 1) field or collection centre (CC) or 2) wholesale market (mandi). If the produce is procured directly from the field, through a CC, then the produce incoming temperature depends upon the time of harvesting. During the night or early morning, the produce temperature is lower than in the daytime. The incoming temperature of the produce may further depend upon the handling and transportation practices from harvest till the produce reaches the cold room or pre-cooling room. If the produce is procured from a mandi, then the incoming temperature depends upon the storage infrastructure at the mandi and handling after procurement till the produce reaches the cold room or the pre-cooling room. This is an important input in the heat load calculation analysis for the refrigeration system design and sizing.

3.1.2 Design temperature (produce outgoing)

This is the desired temperature condition for the produce to be either maintained in the cold room or to be cooled down to in the pre-cooling room. This is an important input in the heat load calculation analysis for the refrigeration system design and sizing. Careful consideration must be given to determining this parameter, adhering to sufficiency principles. The optimal temperature must strike a balance, avoiding extremes of being excessively cold or too warm.

In the absence of research data for Indian conditions, it is recommended to adopt commodity storage conditions as prescribed by the WFLO Commodity Storage Manual[1].

3.1.3 Design relative humidity (produce outgoing)

This is the desired relative humidity (RH) condition for the produce to be either maintained in the cold room or to be achieved in the pre-cooling room. It is an important input in the heat load calculation analysis for the refrigeration system design and sizing. As with the design temperature, careful attention must also be given to establishing the design relative humidity, ensuring adherence to sufficiency principles.

The RH level required in cold storage rooms is determined by the specific storage needs of the produce being stored. For fresh fruits and vegetables such as grapes, kiwi, carrots, and cabbage, the recommended RH level can range from 95% to 98%,

1 World Food Logistics Organization (WFLO) Commodity Storage Manual.

whereas for onions and garlic, it should be lower, typically ranging from 65% to 75%. In the absence of research data for Indian conditions, it is recommended to adopt commodity storage conditions as prescribed by the WFLO Commodity Storage Manual.

3.1.4 Lighting condition

Some horticultural produce is sensitive to light and can change colour when exposed to light. For example, some fruits and vegetables may turn brown or lose their vibrant colour when exposed to light. This can reduce the visual appeal of the produce and make it less desirable to consumers.

It is advisable to store perishable fruits and vegetables in dark conditions.

3.2 Envelope Design

3.2.1 Layout of the pre-cooling and staging cold rooms

The layout includes drawings showing the plan, elevation, and sectional views of the desired infrastructure components, with measurements. This is an important input for planning the overall infrastructure and ensuring alignment with other facilities such as in the case of a distribution centre.

3.2.2 Internal stacking layout of crates and pallets

Drawings showing the plan and sectional view of the internal stacking of crates and pallets inside the desired infrastructure components, with measurements, should be prepared. This will help ensure two things: 1) the cold room or pack-house dimensions are optimised for the designed produce handling capacity, and 2) sufficient space for air movement around the crates to ensure effective and uniform cooling across the cold room or pre-cooling room.

The crates, pallets, boxes, and bins should be stacked to allow the moving air to come into contact with all surfaces for adequate and swift cooling. Well-ventilated boxes and crates with vent alignment can be beneficial as they accelerate the cooling rate by allowing the air to flow uniformly. It is advisable to stack the storage pallets to create air channels that are four to six inches wide to direct air movement. Additionally, there should be enough space between the produce and the walls to allow the refrigerated air to absorb the heat of conduction through the walls. Poor air distribution may occur in improperly stacked rooms, leading to a decrease in the cooling rate. Therefore, it is recommended to design multi-commodity cold storage chambers/facilities for storage of PVC crates, bins, and ventilated cardboard boxes stacked in pallet frames. For commodities that do not require rapid cooling, such as onions, garlic, and potatoes, jute/nylon net bags stacked in pallet frames can be used.

3.2.3 Internal floor area (ft^2)

The internal floor area should be calculated from the measurements on the layout.

3.2.4 Internal volume per MT (ft^3/MT)

The internal volume should be calculated from the measurements on the layout.

As per NCCD guidelines[2], 3.4 m^3 (cubic meter) or 120 ft^3 (cubic feet) of temperature-controlled storage space shall be considered equivalent to 1 MT (metric tonne) of storage capacity, irrespective of the produce carried. In the case of ripening chambers, 11 m^3 (cubic meter) shall be considered equivalent to 1 MT (metric tonne) of storage capacity. However, the internal volume per MT of produce for the pre-cooling room is not clear in this guideline.

3.2.5 Type, thickness, density and fire rating of thermal insulation for walls, roof, and floor

Thermal insulation reduces the amount of heat that can pass through the walls, ceiling, and floor of the cold room. This is achieved by using materials with low thermal conductivity, such as polyurethane foam (PUF), polyisocyanurate (PIR), expanded polystyrene (EPS), or mineral wool, to create a barrier between the inside and

2 National Centre for Cold-chain Development (NCCD): Guidelines & minimum system standards for implementation in cold-chain components

outside of the room. The thickness and density of the insulation material are carefully selected based on the desired temperature range and the given ambient conditions. The higher the thickness and density, the better the thermal performance of the insulation, resulting in reduced energy demand for the refrigeration system to maintain the desired temperatures within the cold room. It is also important to acknowledge that certain insulation materials may pose a fire hazard if they lack fire-rated properties. Fire-rated insulation materials are specifically engineered to resist flame spread and combustion, thereby lowering the risk of fire hazards. Additionally, they provide occupants with extra time to evacuate safely in the event of a fire, enhancing overall safety precautions.

The IS 661 (2000) standard[3] specifies minimum insulation thickness for various insulation materials based on recommended U-values for -4 to +2 °C cold storage.

3.2.6 Blowing agent used in PUF panel manufacturing

High ozone-depleting potential (ODP) and global warming potential (GWP), chloro-fluoro carbon (CFC) gases are sometimes used as blowing agents in the manufacturing of PUF panels. It is important to ensure that the manufacturing process of PUF panels does not deploy ozone-depleting or high GWP blowing agents. Consequently, adopting climate-friendly manufacturing practices for PUF panels becomes an essential consideration alongside evaluating their thermal properties.

3.2.7 Vapour barrier in wall and roof panels

The PUF panels are sandwiched in pre-painted galvanised iron (PPGI) sheets which act as a vapour barrier to stop the ingress of moisture into the PUF panels from both sides. Moisture is detrimental to the life and thermal performance of the PUF panels. Therefore, selecting the appropriate thickness of the PPGI sheets, with appropriate levels of galvanisation, is crucial as they not only serve as a moisture barrier but also provide structural support to the PUF panels.

3.2.8 Air-tight doors (with stainless steel handles and hinges) and pressure relief valves

Air-tight doors are important to ensure the thermal intactness of the cold rooms or pre-cooling rooms. Any leakage from the doors may increase the heat loads on the refrigeration system and adversely impact their energy performance. The door frame, gasket, and hinges must all be constructed and installed properly to ensure the door closes tightly and remains sealed when not in use. Stainless steel (SS) handles and hinges are recommended for the long life of the door fittings.

Pressure relief valves are critical safety features found in cold room doors. These valves are designed to release excess pressure from inside the cold room when it reaches a specific level, preventing damage to the door and injury to individuals nearby. Excess pressure can result from factors such as temperature fluctuations, changes in air volume, or door opening and closing. Pressure relief valves also help to maintain the efficiency of the cold room by preventing the refrigeration system from working harder than necessary, which can lead to increased energy consumption and higher operating costs.

3.2.9 Strip curtain or air curtain

Strip curtains and air curtains are two types of energy-efficient barriers commonly used in cold room or pre-cooling room doorways to minimise air transfer and maintain a consistent temperature inside the cold room.

A strip curtain is a flexible barrier made of strips of PVC material that hang from a header mounted above the doorway. The strips overlap each other and create a barrier that allows people and equipment to move through the doorway while minimising air transfer. They are also relatively easy to install and maintain.

An air curtain is another type of energy-efficient barrier that uses a high-velocity stream of air to create a barrier between the inside and outside of the cold room. The air curtain is mounted above the doorway and blows a stream of air downward, creating a barrier that prevents warm air from entering the cold room while allowing people and equipment to move through the doorway.

3 IS 661 (2000): Thermal Insulation of Cold Storage - Code of Practice [CHD 27: Thermal Insulation]

Both strip curtains and air curtains are effective at maintaining temperature control, reducing energy costs, and protecting against insects, dust, and other contaminants.

3.3 Refrigeration System Design

3.3.1 Heat load calculations

Calculating the heat load of a cold room or pre-cooling room is the first step in designing an effective and energy-efficient refrigeration system. An undersized cooling system may fail to provide the required cooling, potentially damaging the stored produce. Conversely, an oversized system wastes upfront capital costs and operational energy, operating inefficiently and incurring higher energy expenses. Achieving the right system size is essential for efficient and effective cooling. The heat load calculation involves determining the amount of heat that must be removed from the cold room to maintain the desired temperature and humidity levels. Several factors must be taken into consideration when calculating the heat load of a cold room or pre-cooling room, including the ambient conditions (temperature and humidity), the room's size, the insulation properties of the wall/roof/floor, the size of the door, the frequency and time period of door openings, the produce load (quantity and type of produce stored), and the internal loads, such as lighting.

After considering all of these factors, the heat load can be calculated using a formula that accounts for the specific heat capacity of the produce, the temperature difference between the interior and exterior of the cold room, and the rate of heat transfer through the walls, roof, and floor of the room. Subsequently, the outcomes of the heat load calculation can be used to determine the appropriate refrigeration system for the cold room, including the capacity and size of the outdoor refrigeration unit and the type and quantity of indoor evaporators.

It is recommended to follow ASHRAE Fundamentals[4] and Refrigeration[5] handbooks for heat load calculation procedures. For ambient conditions, 0.4% annual design conditions of the location as per ASHRAE/ ISHRAE data is recommended. Refrigeration capacities should be calculated at various operating conditions, and necessary arrangements for capacity control should be included in the selected equipment.

3.3.2 Refrigeration system details

The type of refrigeration/cooling system, type and number of compressors, condensers, and evaporators (air handling units) should be selected based on the application. Vapour compression, absorption, adsorption, evaporative cooling, indirect direct evaporative cooling (IDEC), among others, can be considered. In terms of indoor units, for cold rooms required to maintain the produce conditions, ceiling-suspended or wall-mounted evaporators are typically used. The generally used design incorporates a Direct Expansion (DX) cooling coil in case of Hydro-chloro-fluoro-carbon (HCFC) / Hydro-fluoro-carbon (HFC) refrigerants or flooded ammonia cooling. The air handling units for pre-cooling are specially designed units for a faster rate of cooling with high RH in the range of 96-98%. For such pre-cooling applications, a floor-mounted evaporator unit with a recirculating water sprinkler is the typically used indoor unit. The floor-mounted evaporator unit consists of a fan, cooling coil, water sump and water pump.

3.3.3 Humidification system

To preserve the freshness and quality of perishable produce in pre-cooling or staging cold rooms, it is necessary to maintain a specific humidity level that prevents moisture loss, weight loss, and decreased freshness. This required humidity level can be maintained with the help of humidification systems, which prevent moisture loss and ensure that the produce remains fresh.

To achieve higher humidity levels of 85-90%, it is recommended to maintain a low delta T in the cooling coil. However, during loading periods or if the humidity level exceeds 90%, a separate humidification system is highly advised. Various methods can be used, but it is preferable to use a water mist with a particle size of 2-10 microns that is uniformly distributed throughout the chamber to prevent the product from getting wet.

4 2021 ASHRAE Handbook- Fundamentals

5 2022 ASHRAE Handbook- Refrigeration

3.3.4 Cooling capacity

The heat load calculations determine the capacity of the refrigeration system for the cold room or pre-cooling room.

3.3.5 Refrigeration system efficiency at different operating conditions

The efficiency of a vapour compression refrigeration system is heavily influenced by the type of compressor used. The efficiency typically represented in coefficient of performance (COP) terms is the ratio of cooling capacity and power input. The COP should be specified for different operating conditions and not just the design conditions. The COP should be specified for different combinations of evaporating and condensing temperatures.

3.3.6 Variable speed operation principle

Typically, refrigeration systems achieve optimal efficiency when operating at maximum capacity. However, in reality, refrigeration systems operate under varying load conditions and ambient temperatures. Variable frequency drives (VFDs) can aid in efficient operation even during partial load conditions by regulating the speed of compressors and fans. This approach can lead to significant energy savings and noise reduction by matching the actual cooling requirements. Moreover, VFDs can enhance the lifespan of compressors and fans by decreasing the stress on the system. By commencing the compressor at a lower speed, VFDs can prevent damage from sudden power surges and mitigate the risk of mechanical failure. Electronically Commutated (EC) fans are additionally suggested as an energy-efficient option.

3.3.7 Refrigerant type

The environmental impact of refrigeration systems is closely linked to the choice of refrigerant. To minimise this impact, it is recommended to select refrigerants with zero ozone depletion potential (ODP), low or no global warming potential (GWP), and good thermal performance. While natural refrigerants such as Ammonia have zero ODP and GWP, their use must comply with national and international safety regulations due to toxicity concerns.

Ammonia is often recommended as a top refrigerant choice due to its environmental friendliness and energy efficiency. However, its toxic nature necessitates careful handling, as outlined in safety protocols, including IS 4544 (2000)[6].

3.3.8 Air circulation

Adequate air circulation in a cold room or pre-cooling room is important for maintaining uniform temperature and humidity levels throughout the room. Proper air circulation helps distribute cold air evenly and prevents the formation of hot spots, which can cause uneven cooling and potentially spoil the produce. This is typically achieved by using strategically placed evaporator units that circulate cold air throughout the room. The velocity and direction of the airflow can be adjusted to meet the specific requirements of the room and the produce being stored. This is expressed in available air volume (cubic meter per hour (CMH)) per metric tonne (MT) of produce.

3.3.9 Pre-cooling (pull-down) time per batch

Several factors can influence the pre-cooling (pull-down) time per batch, including the size of the batch, the produce incoming temperature, the desired storage temperature, and the efficiency of the pre-cooling system. Typically, pre-cooling times can vary from a few hours to overnight, depending on the specific situation. It is also important to note that the pre-cooling time per batch sets the limit for the maximum number of batches that can be pre-cooled per day, thus determining the overall pre-cooler handling capacity.

3.3.10 Thermal energy storage

Thermal energy storage (TES) in cold rooms refers to the process of storing excess refrigeration capacity during off-peak periods and using it during on-peak periods to reduce energy consumption and costs. In the case of off-grid solar power systems, the TES could be charged during the daytime and released during the nighttime. This is achieved by using thermal storage systems such as ice banks, chilled water storage tanks, or phase change materials (PCMs). By using TES, cold storage facilities can reduce their peak energy demand, decrease energy costs, and operate more efficiently.

6 IS 4544 (2000): Ammonia - Code of Safety [CHD 8: Occupational Safety, Health and Chemical Hazards]

3.3.11 Total overall connected load

This refers to the overall connected load on the grid for determining the electricity connected load and, thus, the fixed demand charges.

3.4 Renewable Energy Integration

3.4.1 Solar photovoltaic integration

The size and configuration of a solar photovoltaic (PV) system depends on the intended use and can be categorised as either off-grid or grid interactive. Off-grid systems usually incorporate battery energy storage, while grid-interactive systems can be further classified as gross-metered or net-metered.

3.4.2 Biomass

Biomass refers to organic matter, such as wood, crop residues, or animal waste, that can be burned to produce heat or electricity. Biomass can be used to power absorption/adsorption technology-based cooling systems. This is a sustainable and cost-effective approach as it is a renewable energy source and can often be locally sourced. However, the availability, quality, and type of biomass fuel, as well as the efficiency and emissions of the combustion or gasification process, must be carefully considered.

3.5 Monitoring and Controls

3.5.1 Remote monitoring and energy/environmental management controls

To effectively monitor and track important metrics, the remote monitoring system must be configured to store key parameters both locally and on the cloud. These parameters, which should be timestamped every one or two minutes, may include:

- **i.** Indoor temperature and RH for each room
- **ii.** Ambient temperature and RH
- **iii.** Power parameters (voltage, current, power factor, and kilowatts) for each machine
- **iv.** Energy parameters (kilowatt-hours) for each machine
- **v.** Daily energy consumption (in kilowatt-hours) or energy consumption between any two specified date-time periods for each machine
- **vi.** TES charge level for each machine; Temperature and level of thermal energy storage medium (ice/water/PCM/others) inside the TES tank
- **vii.** If solar PV is used, then Solar PV power parameters (voltage, current, power factor, and kilowatts) and energy parameters (kilowatt-hours). Daily energy generation, consumption, and grid export or energy generation, consumption, and export between any two specified date-time periods should be available.
- **viii.** Power parameters (voltage, current, and kilowatts) of the battery bank, if applicable
- **ix.** Compressor low-pressure and high-pressure monitoring for refrigerant leaks or other system malfunctions for each machine
- **x.** Ethylene levels in each room.

It is important to note that these parameters should be customised based on the specific requirements of the project. By storing and monitoring these key parameters, the remote monitoring system can effectively track the performance of the system and identify any potential issues or inefficiencies.

3.6 Supply, Installation, Testing, and Commissioning (SITC)

3.6.1 SITC timeline

The timeline for Supply, installation, testing, and commissioning (SITC) encompasses the entire project lifecycle, beginning with the supply of necessary materials and concluding with the testing and commissioning of the installed system.

It is advisable to install, test, and commission the plant in accordance with either IS 660[7] or ASHRAE Std. 15[8].

3.6.2 Commissioning checklist

Commissioning is the final stage of a project and involves a range of activities to ensure the proper operation of the equipment and system to meet the project requirements. To facilitate this stage, a commissioning checklist tailored to the specific needs of the project should be developed. The checklist should include activities such as fine-tuning the system to optimise performance, training end-users on safe and effective operation, conducting final acceptance testing to ensure project requirements are met, and documenting the commissioning process in detail.

A sample commissioning checklist prepared for a solar cold room with a thermal energy storage system is provided as Appendix 1.

3.7 Operations and Maintenance (O&M)

3.7.1 Warranty (manufacturing defects and workmanship)

The exact terms of a warranty can vary depending on the product and the manufacturer or seller. Some warranties may cover both manufacturing defects and workmanship issues, while others may only cover one or the other. In some cases, the warranty may be limited to certain parts of the product or may require the user to follow specific maintenance and usage instructions to qualify for the warranty.

3.7.2 Training of the local operations team and O&M manual

Training the local operations team and creating an operation and maintenance (O&M) manual is crucial for successful project implementation. The local team must be trained to operate and maintain the system or equipment efficiently. The O&M manual should include an introduction to the system, major components of the system (including schematics and sectional views) with their description, operating limits (indoor and outdoor temperatures) of the system, description of the electrical and control panels, temperature controller settings, detailed operational instructions for different modes, troubleshooting procedures, guidelines on maintenance schedules, and safety precautions. With proper training and a comprehensive O&M manual, the local team can ensure smooth operation, reduce downtime, and avoid equipment failure or maintenance issues.

3.7.3 After-sales services

After-sales services refer to the support and services provided by a manufacturer or vendor to customers after the sale of a product or service. This includes services such as technical support, maintenance, repairs, and warranty support.

7 IS 660: Safety code for mechanical refrigeration.

8 ANSI/ASHRAE Standard 15-2009 Safety Standard for Refrigeration Systems.

Appendix-1: Sample commissioning checklist for a solar cold room with a thermal energy storage system

S. No.	Checklist	Values	Remarks	Photographic evidence (Yes/No)	Nameplate details (Yes/No)
1. Cold room- Internal dimensions and other details					
1.01	PUF panel room width, feet				
1.02	PUF panel room length, feet				
1.03	PUF panel room height, feet				
1.04	PUF panel room internal volume, cubic feet				
1.05	PUF thickness of walls/roof/floor, mm				
1.06	Vapour barrier in Wall and Roof panels				
1.07	Number of doors				
1.08	PUF thickness of door, mm				
1.09	Strip curtains installed on doors, (Yes/No)				
1.10	Number of chambers				
1.11	Cold room roofing				
1.12	Waterproofing type for walls and roofs				
1.13	Air tightness of doors				
2. Solar PV system					
2.01	Solar panel make				
2.02	Solar panel model number				
2.03	Solar panel type (monocrystalline or polycrystalline)				
2.04	Solar panel capacity (per panel), kWp				
2.05	Number of solar panels				
2.06	Total solar capacity, kWp (Number of solar panels x solar panel capacity)				
2.07	Solar structure pillar size and type (For example, 75 mm x 32 mm x 3 mm C channel)				
2.08	Solar structure rafter size and type (For example, 40 mm x 40 mm x 3 mm L channel)				
2.09	Solar structure purlin size and type (For example, 42 mm x 42 mm x 2 mm C strut)				
2.10	Solar structure tilt, degrees				

S. No.	Checklist	Values	Remarks	Photographic evidence (Yes/No)	Nameplate details (Yes/No)
3. Electrical battery system					
3.01	Battery make				
3.02	Battery model				
3.03	Individual battery voltage, V				
3.04	Individual battery ampere-hour rating, Ah				
3.05	Number of batteries				
3.06	Total battery bank capacity, VAh				
3.07	Battery discharge rating, % (C20 5% or C10 10%)				
3.08	Battery discharge capability, VA (Total battery capacity x battery discharge rating)				
4. Compressor and refrigerant line					
4.01	Compressor make				
4.02	Compressor model				
4.03	Number of compressors				
4.04	Refrigerant				
4.05	Compressor cooling capacity and power input (Refer compressor datasheet at different indoor and outdoor conditions)				
4.06	Pressure and vacuum testing of the refrigerant line				
5. Thermal energy storage system					
5.01	Phase change material (PCM) type				
5.02	Phase change material quantity, kg (in case of water as PCM type, can be estimated by calculating the volume of water and density				
5.03	Thermal energy storage capacity, MJ (in case of water as PCM type, can be estimated by calculating the quantity of water and latent heat of 333 kg/kJ)				
6. Evaporator					
6.01	Evaporator fan make				
6.02	Evaporator fan model				
6.03	Evaporator fan flow, CFM				
6.04	Evaporator fan input voltage, V				
6.05	Evaporator fan input power, Watts				

S. No.	Checklist	Values	Remarks	Photographic evidence (Yes/No)	Nameplate details (Yes/No)
6.06	Evaporator fan type (Brushless or carbon brush)				
6.07	Total number of evaporators in the entire cold storage				
6.08	Total evaporator flow, CFM				
7. Condenser					
7.01	Condenser fan make				
7.02	Condenser fan model				
7.03	Condenser fan flow, CFM				
7.04	Condenser fan input voltage, V				
7.05	Condenser fan input power, Watts				
7.06	Condenser fan type (Brushless or carbon brush)				
7.07	Total number of condensers in the entire cold storage				
7.08	Total condenser flow, CFM				
8. Auxiliary electrical loads connected to battery					
8.01	Number of LED lights x LED wattage, W				
8.02	Number of evaporator fan x evaporator fan wattage, W				
8.03	Number of pumps x pump wattage, W				
8.04	Number of condenser fans x condenser fan wattage, W (if connected on batteries)				
8.05	Total auxiliary load connected to batteries, W (LED + Fans + Pumps)				
9. Safety protection (Yes/No)					
9.01	Lightening arrestor				
9.02	Earthing				
9.03	Solar Direct Current (DC) surge protection fuse				
9.04	Low pressure switch on compressor				
9.05	High pressure switch on compressor				
9.06	Receiver tank				
9.07	Sight glass				
9.08	Suction accumulator				
9.09	Suction to discharge heat exchanger				

S. No.	Checklist	Values	Remarks	Photographic evidence (Yes/No)	Nameplate details (Yes/No)
10. Cold room cooling performance verification					
10.01	The refrigeration system should be able to maintain the cold storage temperature and relative humidity as per the pre-determined design intent, with no loading and full or partially loaded conditions for at least 2 days of monitoring post commissioning of the rest of the systems.				
11. Remote monitoring system					
11.01	The operating parameters, including temperature, humidity, cooling backup capacity, grid electricity consumption, and refrigeration system energy performance, should be accessible in real-time through tabular and graphical formats on a cloud-based online portal. The data must be available with a specified time lag for monitoring purposes, and there should be an option to download historical data in CSV format. The monitoring frequency should be set at 2 to 5 minutes.				
12. O&M manual and training on-site					
12.01	Provide a copy of O&M manual of the entire system including the refrigeration system (both condensing and evaporating units), thermal energy storage system, remote monitoring and control system, and solar PV system (to be discussed with Nitin). Provide training of operators after installation of the systems				
13. Others					
13.01	Physical verification of quality of material against delivery defects: Check for assembly defects, surface defects such as scratches, rust, colour fade and material defects such as crack, dent, etc.				
13.02	All components, systems, sub-systems, meters, sub-meters, circuit breakers, controllers, panels, switches, LED indicators, etc., should be properly tagged				

04

Annexure- MS-Excel-based Evaluation Framework for Deploying Energy-efficient, Climate-friendly Cold Rooms

S. No.	Evaluation Framework	
1	Technical Criteria	**Design Intent**
1.01		Produce incoming temperature
1.02		Design temperature (produce outgoing)
1.03		Design relative humidity (produce outgoing)
1.04		Lighting Condition
2		**Envelope Design**
2.01		Layout of the pre-cooling and staging cold rooms
2.02		Internal stacking layout of crates and pallets
2.03		Internal floor area (sq. ft.)
2.04		Internal volume per MT (cuft/MT)
2.05		Type, thickness, density and fire rating of thermal insulation for walls, roof,
2.06		Blowing agent used in PUF panel manufacturing
2.07		Vapour barrier in wall and roof panels
2.08		Air tight doors (with S.S. handles and hinges) and pressure relief valves
2.09		Strip curtain or air curtain
3		**Refrigeration System Design**
3.01		Heat load calculations
3.02		Refrigeration system details
3.03		Humidification system
3.04		Cooling capacity
3.05		Refrigeration system efficiency at different operating conditions
3.06		Variable speed operation principle
3.07		Refrigerant type
3.08		Air circulation
3.09		Pre-cooling (pull-down) time per batch
3.10		Thermal energy storage
3.11		Total overall connected load
4		**Renewable Energy Integration**
4.01		Solar photovoltaic integration
4.02		Biomass
5		**Monitoring and Controls**
5.01		Remote monitoring and energy/environmental management controls
6		**Supply, Installation, Testing, and Commissioning (SITC)**
6.01		SITC timeline
6.02		Commissioning checklist
7		**Operations and Maintenance (O&M)**
7.01		Warranty (manufacturing defects and workmanship)
7.02		Training of the local operations team and O&M manual
7.03		After-sales services
		Sub-Total
8	Financial Criteria	**CAPEX**
8.01		Upfront capital investment
9		**OPEX**
9.01		Electricity or other fuels expenditure
9.02		Operations and Maintenance (O&M) expenditures
		Sub-Total
		Total

Figure 5: Illustrative image of the MS-Excel-based Evaluation Framework for Deploying Energy-efficient, Climate-friendly Cold Rooms

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