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Cold Storage in India for Small Farmers - Current Status and Challenges

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ABSTRACT

India ranks 2nd in fruits and vegetable production in the world. It produces more than 100 x 10^6 metric tonne (MT) of fruits and 200 x 10^6 MT of vegetables. Despite high levels of food production, India ranks only 101th out of 116 countries on the 2021 Global Hunger Index. Since fruits & vegetables are perishable, their magnitude of loss is estimated at 35% to 40% in India resulting in a financial loss of 1,160.1 x 10^9 INR (15.2 x 10^9 USD). The deterioration in the quality of produce after harvest is the result of physical, biochemical, physiological, and biological processes. The rates of which are influenced primarily by product temperature and relative humidity (rh) in the vicinity, which can be controlled by using cold storage (CS) technologies. The current cost of grid-powered micro cold stores is in the range of 2.5 x 10^5 INR/TR (3,227.3 USD/TR), which is very high and not affordable for small farmers.

The manuscript presents a review of the commercial CS available in India, its technologies, cost, and problems associated with its uses, particularly from a marginalized farmer's point of view. The renewable energy-based micro CSs installations, their advantages, and disadvantages are also discussed. Possible solutions for addressing the challenges in the CS sector are also addressed. The manuscript also discusses the various Government of India schemes for promoting CS in India.

1. INTRODUCTION

Fruits and vegetables are essential food items to provide a balanced and healthy diet to people. The horticulture production in India is approx. 334.6 x 10^6 MT in the year 2020-21, which is an increase of 4.4% than production in 2019-20. According to the Government of India (GoI), the production of fruits and vegetables is found to be 102.5 x 10^6 MT and 200.4 x 10^6 MT respectively (Ministry of Agriculture & Farmers' Welfare, 2022). Despite high levels of food production, hunger, and malnourishment level is not going to reduce as set by 2030 in the country, and the world (Agarwal et al., 2021; India - Global Hunger Index, 2021). The estimated post-harvest loss was found to be to the tune of 9.3 x 10^{11} INR (1.2 x 10^{10} USD) at the average annual prices of 2014 in India for 45 selected crops (Jha et al., 2016), which is 250% higher than the Ministry of Agriculture and Farmer Welfare (MoA&FW) budget in the fiscal year 2014.

The reasons for such high post-harvest losses are poor harvesting techniques, defects during sorting, improper storage, traditional ripening practices, inappropriate and lack of processing units, poor transportation or delivery channels, overproduction, fragmented supply chain, lack of cold chain, and extreme weather conditions (Agarwal et al., 2021). The quality of harvested fruits and vegetables is determined by their growth conditions as well as physiological and biochemical changes that occur after harvest. After harvest, fruit and vegetable cells are still alive and continue to respirate. Fruit maturity is likely to have an impact on post-harvest quality and storage life. The quality of the fruits is good if they are harvested at the correct stage of development. Early and late harvesting cause low quality and uneven ripening, resulting in an exceptionally short shelf life(Planning Commission Government of India, 2003).

In a tropical country like India, one of the most important issues is the storage of fresh horticulture produce after harvest. Vegetables and fruit have a short shelf life and are prone to spoilage due to their high moisture content. Furthermore, they are living organisms that continue to transpire, breathe, and mature even after harvest. Fresh

horticulture product metabolism continues after harvest, and the speed of deterioration increases as ripening, aging, and adverse environmental variables increase. As a result, conserving these foods in their natural state necessitates limiting chemical, biochemical, and physiological modifications. (Basediya et al., 2013).
These changes can be slowed down to a minimum by regulating the temperature and humidity around the produce after the harvest using CS. The storage conditions and storage time for various products are listed in the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Handbook on Refrigeration (ASHRAE, 2006). In India, the CS market is currently highly scattered and disorganized, with most facilities being put up on an ad hoc basis by renters in the food, FMCG, and healthcare industries, or by their suppliers. As of 2020, India has only 8,186 CS with a capacity of 374.25 x 10^6 MT available in the country for storing perishable horticultural produce, with 75% of them suited only for keeping single commodities, primarily potatoes. (Ministry of Agriculture & Farmers Welfare, 2020). A study on cold-chain infrastructure in India (All India cold-chain Infrastructure Capacity AICIC-2015) implemented by National Bank for Agriculture and Rural Development (NABARD) consultancy service (NABCONS) assessed the need for an extra 350 x 10^6 MT capacity of CS for fruits and vegetable storage in the year 2015. As the production of fruits and vegetables increased from 281 x 10^6 MT in the year 2015 to 334 x 10^6 MT in 2021 (Ministry of Agriculture & Farmers' Welfare, 2018), the requirements for CS would have increased by the same percentage approx. 19%.

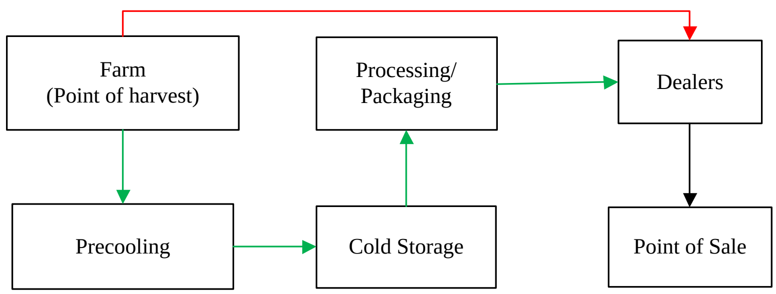

Figure 1: Fruits and Vegetables Supply Chain in India

The reasons for such low penetration of CS in India are the high initial investment, high operating **costs** due to the use of diesel generators to provide uninterrupted power, limited focus on CS needs, highly fragmented industry, uneven distribution of CS, (71% of CS supply located in only four states), lack of support infrastructure including effective transport and 24/7 power (Bala et al., 2021). Figure 1 represents India's ideal and actual supply chain of fruits and vegetables. Ideally, the produce from the farm should be precooled first, followed by storage in a cold chamber, and before going point of sale, it should be packed and transported in refrigerated vehicles. Because of the nonavailability of CS, the farmers are forced to sell their products as soon as the produce is harvested. This results in stress sales, more wastage of produce, reduction in profits, and income of the farmer, which is already very less. Food loss has a multiplier effect on other inputs such as water, electricity, and fertilizers wastage. It also increases greenhouse gas emissions.
Many studies conducted in India asserted the need for affordable CS at the village level to minimize distress sales and wastage, enable stability in the price throughout the year, improve the export of horticulture produce and increase the profits realized by farmers (Banik, 2017; Bhanot et al., 2021; Cooper et al., 2021; Nuthalapati et al., 2020; Roy & Thorat, 2008). The cost of commercial CSs is very high, vague, nonuniform, and nonstandardized in India resulting in low penetration and use by farmers. GoI developed many policies to support farmers and small entrepreneurs in setting up CS facilities due to the importance of cold chain facilities for horticulture storage. These policies are implemented through various Government agencies for a different set of end-users. There is a need to summarise the various policies of the agencies for a better understanding of the applicability and propagation of these schemes and to identify the possibilities for improving the techno-economic of CS.
The paper presents a review of the commercial small and micro CS available in India, its technologies, cost, and issues associated with its uses, particularly from a marginal farmer's point of view. It also presents renewable energy-based micro CSs installations, their advantages, and disadvantages. Techno-economics of renewable energy-based micro cold stores along with the way forward for addressing the challenges is presented. The authors have also presented the various GoI schemes for promoting CS in India.

2. COLD STORAGE TECHNOLOGIES IN INDIA

In this section, the CS based on various technologies are discussed. The section discusses vapor compression refrigeration system (VCRS), vapor sorption refrigeration system (VSRS), and evaporative cooling system (ECS) technologies based on which small and micro CS are commercially available in the Indian market and summarized in Table 1.

2.1 Vapor Compression Refrigeration System

Most of India's small and micro CS are based on VCRS technology and are ideal for small applications because they are reasonably simple and require little maintenance. The refrigeration unit (RU) contains two heat exchangers (condenser and evaporator), a compressor, and an expansion valve. Most of the small CS in India use R-22, R-407F, and R-404A refrigerants. The operating temperature with R-407F is above 0ºC, and with R404A it is below 0ºC. R-22 has to be phased out in the new system by 2023 and completely phased out by 2030 and other refrigerants used in CS in India are also having higher GWP will be phased out from 2028.(MoEF&CC, 2017) The cost of CS based on VCRS is 1.75×10^5 to 4×10^5 INR /TR (2,292 to 5,240 USD/TR) or 1×10^5 to 3×10^5 INR/ MT (1,310 to 3,930 USD/MT). The biggest problem with VCRS-based CS is their high initial cost and very high operating cost. Low reliability of grid supply necessitates the use of backup generator sets, which increases the initial cost, and due to the high cost of diesel, the cost per unit of generated power is 3 to 4 times higher than grid power. The cost of producing power from the gen-set is 25 to 30 INR/kWh (0.33 to 0.39 USD/kWh). The refrigerant being used are also having a high global warming potential (GWP). Although 35% to 50% Government subsidy is available for CS installations, its high operating cost is a big hindrance to its penetration in India. Realizing this, many manufacturers have come up with solar energy-based CS. Thermal storage (TS) based solar CS is also developed and commercially available in India to make CS grid-free without using costly batteries. GoI has also drafted policies and recommendations to support the small capacity solar CS with TS and discussed in section 3.

2.2 Vapor Sorption Refrigeration System

The VSRS system is extensively presented and studied (Fan et al., 2007). VAbM uses a liquid-gas working pair, i.e. a working fluid that is a mixture of a refrigerant and an absorbent. Whereas in VAdM, solid-gas pair is used. There are few manufacturers of CS with sorption technology in India and most of them are making in big TR capacity with very high initial cost and not affordable to farmers. The small and micro CS based on sorption technology is even fewer in India, some of them are listed in Table 1. The cost of CS based on VSRS is 2.9×10^5 to 4.7×10^5 INR/TR (3,800 to 6,157 USD/TR). The cost of the VSRS system is more compared to VCRS.

2.3 Evaporative Cooling System

India is a tropical country for most of the part. ECS is extensively used in rural India for horticulture produce storage because of the minimum initial and operating costs. Using ECS, the temperature of the ambient around the product can be reduced by 5ºC to 20ºC below the environment temperature. Authors found few standard commercial CS based on ECS technology in India claiming certain performance parameters. Sabji cooler (Rukart, 2022) is one innovation, claiming 3 to 6 days shelf life improvement of horticulture produce using 15 to 20 L of water and no electricity. SunFridge CS is based on hybrid VCRS and ECS technology, during the daytime VCRS and ECS, both systems are operated and used to cool the CS. During the night only ECS is operated and CS is cooled. The details of the SunFridge are summarized in Table 1. Out of all the commercial small CS reviewed, hybrid CS is the lowest cost, casting 3.3×10^5 INR/TR (4,323 USD/TR) for refrigeration unit (RU), 5 kW PV array, CR and TS. The problem with the ECS-based CS is, the inability to maintain the temperature in the range of 0ºC to 5ºC. Even the hybrid CS with VCM and ECS technology can maintain the temperature in the range of 8ºC to 14ºC.

Table 1: Commercial Micro Cold Stores in India
(All of the information shown below is based on open literature and is merely intended to be indicative)

Sr #	OEM	Technology	t_{cs} °C	Storage	Size	Unit	PV kWp	Cost 10^5 INR	Cost INR/TR INR/MT	Remark Cost includes	Ref.
1	A	VCM+ECS	8 to 14	Thermal _SE	1.5 2 27	TR MT m^3	5	5	3.3×10^5 2.5×10^5	CR + RU + TS + PV	(Chopra et al., 2021)
2	B	VCM_DX_ R404A	4	Thermal _LH_200 MJ	3.6 5	TR MT	7	14.6	2.8×10^5 2.9×10^5	CR + RU + TS + PV	(Inficold, 2021)
3	C	VCM_ R407F	4 to 10	Thermal _LH_20 h	1.5 to 2.7 5	TR MT	5	6	4×10^5	RU + TS	(ecozen, 2019)
4	D	VCM_R404 A	2 to 20	With and without TS	2 3 to 5	TR MT	5	3.5	1.75×10^5 1×10^5	RU	(ICE Make, 2021)
5	E	VCM_R407 F	0 to 2	Thermal, Grid, and/or DG set	4 to 5 34	MT m^3	3.6	-	-	-	(Singh sons Refrigeration, 2021)
6	F	VCM_ R407F	5 to 8	Thermal, Grid, and/or DG set	2 5 27	TR MT m^3	4	8 to 12	3.5 to 4×10^5	CR + RU + TS + PV	(Bharat Refrigerations, 2021)
7	G	VCM_R22 &R404A	0 to 10	-	3	TR	-	-	-	RU	(Polfrost, 2021)
8	H	VAdM_Water-Silica Gel	10 to 15	-	2.84	TR	-	10	3.5×10^5	VAM	(Bry-Air, 2017)
9	I	VAdM_NH_3 -Carbon	0	-	3	TR	-	14	4.7×10^5	VAM+CR	(New Leaf, 2021)
10	J	VAdM	7 to 12	-	5	TR	-	14.5	2.9×10^5	VAM	(Technodyne, 2021)

3. GOI POLICIES AND RECOMMENDATIONS FOR COLD STORES

3.1 Cold Storage Policies in India

Cold-chain logistics is a development priority, and it is seen as a component of the second green revolution. It is an end-to-end logistics bridge that ensures continuous custody of the value harvested at farm-gate all the way to end consumers The Indian government along with state governments is encouraging the development of cold-chain technologies through the Mission on Integrated Development of Horticulture (MIDH), National Horticulture Board (NHB), National Bank of Agriculture and Rural Development (NABARD) by providing the capital investment subsidy scheme for construction or expansion or modernization of CS.

Credit Linked Back-ended Subsidy Scheme (CLBSS) is a subsidy policy for the construction or expansion or modernization of CS, providing 35% to 40% of the capital cost of the project limited to 30 x 10^5 INR (39,302 USD) for general areas and 50% of the capital cost of project limited to 37.5 x 10^5 INR (49,127 USD) for the Northeast region, Hilly states, and Scheduled areas (like Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Andaman & Nicobar, and Lakshadweep) in India. The summary of various subsidy schemes provided to farmers and small entrepreneurs for CS installation per MT is given below in Table 2.

NABARD is a national bank and acts as a credit for all agriculture activities to support technology upgradations for Micro and Small Enterprises in India. It gives 12% to 15% of the capital cost with a cap of 15 x 10^5 INR (19,651 USD) under CLCSS. NHB follows the CLBSS for setting up CS of capacity above 5000 MT and up to 10,000 MT, and for the CS capacity below 5,000 MT is assisted by National Horticulture Mission (NHM). MIDH follows the same norms as followed by NHB for setting up a CS. In addition, they assist 15 x 10^5 INR (19,651 USD)/unit (5 MTs), or 50% of the total cost for solar CS. They also provide 25.0 x 10^5 INR (32,751 USD)/ unit with a batch capacity of 6 MT for setting up a pre-cooling unit. Ministry of New and Renewable Energy (MNRE) follows the same norms as MIDH for solar CS. Development of Agriculture Cooperation (DAC) follows the NHM norms with a little change in subsidy amount. They provide 2,000 INR/MT lower than NHM. Agricultural and Processed Food Products Export Development Authority (APEDA) provides financial aid for the establishment of CS facilities, up to 40% of the total capital cost with a ceiling of 25 x 10^5 INR (32,751 USD). For subsidy calculations of the CR size, 3.4 m^3 (120 ft^3) is considered equivalent to 1 MT storage capacity (NPCS, 2016).

Overall through various agencies and policies, GoI is providing financial assistance for conventional CS in the range of 5,000 to 8,000 INR/MT (65 to 104 USD/MT) with a ceiling of 35% to 50% of the total capital cost. Additional subsidies are also provided for setting up precooling, controlled atmosphere (CA) CS in the range of 10,000 to 32,000 INR (131 to 419 USD). For solar-powered CS, the applicable subsidies of 3 x 10^5 INR/MT (3,930 USD/MT) are provided. Authors feel that a single-window subsidy system combining different agencies and uniform guidelines will result in better utilization of funds. This will also minimize the confusion among all the stakeholders

Table 2: Cold Store Policies in India

Sr #	Agency	Item	Cost Norms	Pattern Assistance	Reference
1	NABARD	Technology Upgradation	12% to 15% of capital cost	CLCSS	(MSME Govt of India, 2015)
2	NHM	Type 1: Single temp zone with a large chamber (>250 MT)	Up to 35% of total capital cost	CLBSS	(National Horticulture Board, 2021)
			8,000 INR/MT, (max 5,000 MT)		
		Type 2: Multiple temp zone, >6 chamber <250 MT	10,000 INR/MT, (max 5,000 MT)		
		CS Units Type 2 with add on technology for CA	Additional 10,000 INR/MT		
3	NHB	Type 1: Single temp zone in the large CR (>250 MT)	Up to 35% of total capital cost	CLBSS	(National Horticultur
			8,000 INR/MT, (5,000-10,000 MT)		

		Type 2: Multiple temp zone, >6 chamber <250 MT	10,000 INR/MT, (5,000-10,000 MT)		e Board, 2021)
		CS Units Type 2 with add on technology for CA	Additional 10,000 INR/MT		
4	MIDH	Follows NHB Norms	Follows NHB Norms	CLBSS	(MIDH, 2020)
		Solar-powered CR	15 x 10^5 INR/units (5 MTs) or 50% of the total cost		
		Precooling Unit	25.0 x 10^5 INR/ unit with a batch capacity of 6 MT		
5	MNRE	Solar CS (4-5 MT)	15 x 10^5 INR/units (5 MTs) 50% of the total cost		(MNRE, 2021)
		Product type: Energy Efficient/Solar Powered/Hybrid (Wind+Solar)			
6	DAC	Follows NHM Norms	Max storage capacity of 5000 MT per project 6000 INR/MT	CLBSS	(Ananth, 2015)
			For CA storage 32000 INR/MT for 5000 MT		
7	APEDA	CSs	40% of the cost of the equipment with a ceiling of 25 x 10^5 INR		(APEDA, 2022)

3.2 GoI Recommendations for Cold Storage

India has a very low penetration of CS and GoI agencies had the opportunity to formulate the policies in such a way that the growth in the CS sector is sustainable and environmentally friendly at the same time economical. In this section, the various policies related to renewable energy-based CS in India are summarised and presented. MNRE's recommendation for renewable energy-based CS is given in Table 3. The manufacturers are guided in designing renewable energy-based small capacity CS in the range of 3 to 15 MT for small farmers. This will facilitate the lower operating cost of CS. The minimum specifications of thermal backup for 12 h with the required photovoltaic (PV) size for 5 MT and 10 MT capacity CS are presented in Table 4. The GoI recommends manufacturers use low GWP refrigerants in CS.

Table 3: MNRE recommendation (Ministry of New and Renewable Energy, 2021b)

	Sr #	Machinery	Product Type	Motor	Capacity
					MT
Cold Store, and Rooms	1	Solar Cold Store	Energy Efficient/ Solar Powered/Hybrid (Wind+Solar)	AC compressor	4 to 15
	2	Cold Room	Biomass powered	Very small (mainly thermal adsorption)	10 to 15
	3	Walk-in Cold Rooms	Energy Efficient/ Solar Powered/Hybrid (Wind+Solar)	2 to 5 Ton Cooling AC /DC	3 to 8

Table 4: Recommendations for Solar Cold Store with TES Backup for 5 MT and 10 MT Capacity (Ministry of New and Renewable Energy, 2021a)

Particulars	Version 1	Version 2	Version 3	Version 4	Unit
Storage capacity	5	5	10	10	MT
Min solar PV capacity	5	7	10	14	kWp

Min thermal backup	125	175	250	350	MJ
Min compressor capacity	2	2	4	4	TR
Min pre-cooling capacity only with thermal back-up	500 within 12 h	750 within 12 h	1000 within 12 h	1500 within 12 h	kg
Min internal vol of CR	750	750	1500	1500	ft^3
Insulation	100 mm PUF or 150 mm EPS or equivalent				
Refrigerant	R-407F/R-134a or any other with **Zero ODP and GWP <2000**				
Operation of compressor power circuit	Compressor power line should not be operated using batteries				
Remote monitoring	GPRS or Wi-Fi Connectivity				
Remote Parameters	CR temperature, humidity, Ambient temperature, Solar power, Grid power utilization, Compressor speed, and on-off state				
Power supply	Solar PV as well as a grid with auto-switching based availability				

4. CHALLENGES ALONG WITH POSSIBLE SOLUTIONS

The challenges identified along with possible solutions to improve the techno-economic viability of micro cold stores are summarized hereafter.

a. Operating compressors only during solar availability restricts the operating hours typically in the range of 4 to 6 h, which increases the capacity and size of the compressors and refrigeration components like evaporator, condenser, and thermal storage. A possible solution is to extend the compressor operating hours in the range of 8 to 12 h by suitably integrating with micro windmills without having to use battery backup and ensure grid-independent installation. A big advantage of extended operating hours with smaller compressor/s and associated components will reduce initial cost and improve system performance.
b. It was observed that small compressors which are needed for small cold stores are not efficient as compared to larger compressors. There is a need to identify/develop an efficient small compressor capable of handling low GWP refrigerants like R-290, R-600a, and R-32.
c. Development of low-cost IT-enabled controller to run small capacity inverter coupled compressor to run as per the available renewable power at any given time.

5. CONCLUSION AND RECOMMENDATIONS

The objective of the manuscript was to review the commercial CS available in India, its technologies, cost, and problems associated with its uses, particularly from a small farmer's point of view with GoI initiatives in the promotion of CS. The conclusions drawn from the study and the authors' recommendations for addressing the challenges in the CS sector are presented below.

India is the second-largest producer of horticulture, producing 334.6 x 10^6 T in 2020-21. Despite large production, India ranked 101th out of 116 countries in GHI. The main reason for the same is attributed to 35% to 40% loss of productivity amounting to 9.3 x 10^{11} INR (1.2 x 10^{10} USD) at average annual prices of 2014. These losses can be minimized by maintaining optimum temperature and rh around produce using cold chain technologies.

In India, the CS market is currently highly scattered and disorganized, amounting to only 8,186 CS with a capacity of 374.25 x 10^6 MT as of 2020, with 75% of them suited for potatoes only. India needs an extra 416 x 10^6 MT capacity of CS for fruits and vegetable storage.

The cost of commercial CSs is very high, and nonstandardized in India, the high operating costs, and interrupted power result in low penetration and use by farmers

Most of the small CS based on VCRS in India use R-407F and R-404A refrigerants. Normally systems operating above 0ºC use R-407F and below 0ºC, R-404A is used. The cost CS based on VCRS is 1.75 x 10^5 to 4 x 10^5 INR/TR (2,292 to 5,240 USD/TR) or 1 x 10^5 to 3 x 10^5 INR/MT (1,310 to 3,930 USD/MT). The cost of CS based on VSRS is 2.9 x 10^5 to 4.7 x 10^5 INR/TR (3,800 to 6,157 USD/TR).

GoI is encouraging the development of cold-chain technologies through the MIDH, NHB, and NABARD by proving 35% to 50% of subsidy in CS. Despite proving subsidies, the penetration of CS is limited because of high operating costs.
Development should be targeted for small-size compressors capable of handling low GWP refrigerants like R-290, R-600a, and R-32.
Authors feel that a single-window subsidy system (example: solar rooftop scheme and PM solar pump scheme) combining different agencies and uniform guidelines will result in better utilization of funds. This will also minimize the confusion among all the stakeholders.
The use of solar energy with wind power and thermal storage can reduce the operating cost and improve the reliability of systems.

NOMENCLATURE

AC	alternate current
AICIC	all India cold-chain infrastructure capacity
APEDA	Agricultural and Processed Food Products Export Development Authority
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CLBSS	credit linked back-ended subsidy scheme
CLCSS	credit linked capital subsidy scheme
CR	cold room
CS	cold storage
DAC	development of agriculture cooperation
DC	direct current
DX	direct expansion
EPS	expanded polystyrene
ECS	evaporative cooling system
GPRS	general packet radio service
GoI	Government of India
GWP	global warming potential
INR	Indian national rupee
MIDH	Mission on Integrated Development of Horticulture
MNRE	Ministry of New and Renewable Energy
MoA&FW	Ministry of Agriculture and Farmer Welfare
MT	metric tonne
NABARD	National Bank for Agriculture and Rural Development
NABCONS	National Bank for Agriculture and Rural Development consultancy services
NHB	National Horticulture Board
NHM	National Horticulture Mission
NIIR	National Institute of Industrial Research
NPCS	National Institute of Industrial Research project consultancy services
ODP	ozone depletion potential
PUF	polyurethane foam
PV	photovoltaic
R-404A	zeotropic composition of R-125/R-143a/R-134a (44/52/4)
R-407F	zeotropic composition of R-134a/R-125/R-32 (40/30/30)
RH	relative humidity
RU	refrigeration unit
SE	sensible energy
TES	thermal energy storage
TR	ton of refrigeration
TS	thermal storage
USD	united states dollar
VAbM	vapor absorption machine
VAdM	vapor adsorption machine
VCM	vapor compression machine

VARS	vapor absorption refrigeration system
VCRS	vapor compression refrigeration system

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