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Advanced R744 solution for supermarkets, hotel chillers and maritime applications in India

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ABSTRACT

R744 integrated systems can meet oscillating heating and cooling demands efficiently and become a game changer in countries such as India. The present work aims to develop and present R744 system designs and disseminate the knowledge under the framework of the INDEE+ project in India, with the focus on three vital sectors: supermarkets, hotels, and seafood industries. Ejector-supported R744 systems are observed to be an ideal solution to increase the R744 system efficiency at high ambient temperature operations as in tropical regions. The strategy is also to evaluate the system operations to deal with an individually proposed R744 system performances to fulfil the thermal load handling demand on both heating and cooling side. Furthermore, students, vendors and end-users are planned to train by utilizing the upcoming demonstration sites with R744 technology. Support is being provided to communicate and finalize the R744 system design specification for the various system configurations. Each development aspect will be evaluated critically to make the proposed R744 technology demo units a success and to become flagship developments supporting India to transfer towards clean cooling and heating technologies.

Keywords: CO2, Ejector, Booster Configuration, Evaporative Cooling.

1. INTRODUCTION

Refrigeration technology is a key part of modern society, and essential for many aspects of our daily lives. It is estimated that refrigeration accounts for about 15% of the electricity use worldwide (Coulomb, 2008), covering processing plants, air-conditioning (AC), domestic refrigeration and other heat pumping applications. Space cooling is the fastest-growing energy demand in buildings today and has tripled from 1990 to 2016 (IEA, 2018). The expected growth in the global AC market is fuelled by increasing income levels in emerging economies like India, and space cooling contributes up to 45% of the peak electricity demand in these warm climates according to predictions of the IEA (IEA, 2018). As a measure to counter the rising concern of climate change and the direct emission of high global warming potential (GWP) refrigerants into the atmosphere, the Kigali Amendment to the Montreal Protocol was put into action in 2019 (Heath, 2017), currently ratified by 130 states. As alternative working fluids to the high GWP HFC refrigerants currently being affected by the F-gas phase-down process, alternative HFCs with a shorter atmospheric lifetime were introduced as the fourth-generation refrigerants. These new synthetic fluids have no ODP and by definition a very low GWP due to a fast decomposition in the atmosphere. However, there are rising concerns about the decomposition products from certain HFCs, including Trifluoroacetic acid (TFA), perfluoroalkyl and

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polyfluoroalkyl substances (PFAS) (Hafner & Ciconkov, 2021). Scientists, vendors, and other stakeholders in the HVAC&R sector should therefore focus on developing energy-efficient and safe systems based on future-proof natural refrigerants in the entire application range of these systems.

Transcritical R744 booster refrigeration systems have become the preferred choice for supermarket refrigeration in mild to cold climates over the last ten years, and are progressively expanding to warm climates with the introduction of modifications and technological advancements to improve performance and especially the efficiency at high-ambient temperature conditions (Gullo et al., 2018). The introduction of ejector technology for expansion work recovery has been one of the key technological advancements for R744 refrigeration systems, such as the multi-ejector concept (Hafner et al., 2014). The ejector-supported R744 booster refrigeration system has even been demonstrated in warm and humid conditions found in India (Singh et al., 2020). Further efficiency improvements of up to 40 % could be achieved in warm climates (46 °C) over a conventional ejector-supported R744 booster system by employing an evaporative gas cooler and an internal heat exchanger (Singh et al., 2021). Apart from supermarkets refrigeration systems, transcritical R744 systems are a suitable match for producing hot water due to the temperature glide during the heat rejection process (Nekså et al., 1998). Further improvement in the system COP can be achieved by utilizing the evaporator to produce chilled water for air-conditioning or process cooling purposes. A combined R744 heat pump and chiller system has been installed in a hotel in Norway to provide domestic hot water, space heating and air-conditioning (Smitt et al., 2020), demonstrating the feasibility of R744 technology also for retrofit projects in buildings.

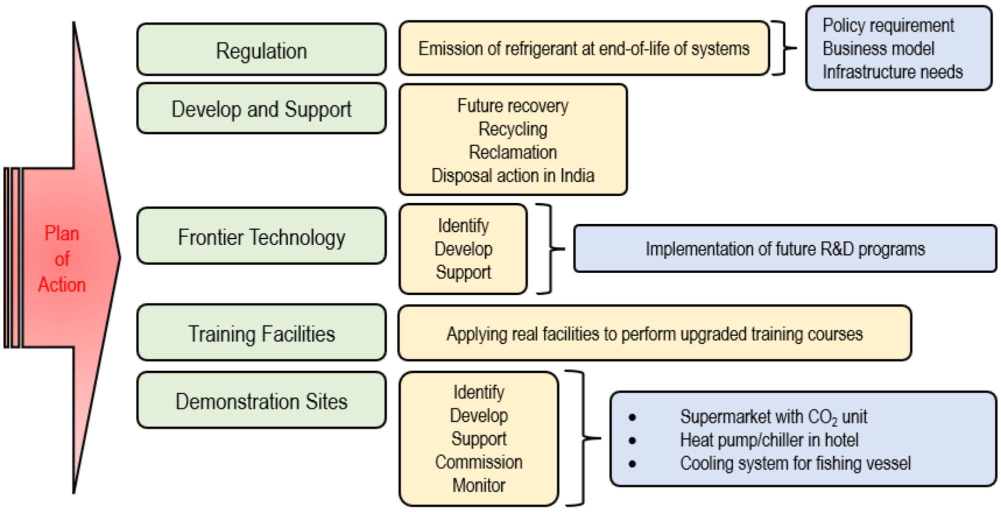

Figure 1: Major elements of the INDEE+ project.

Future Refrigeration India: INDEE+ is an umbrella project covering several dedicated projects supporting the Indian refrigeration and Air Conditioning sector in the transition towards more environmentally friendly technology to achieve the goals of the Kigali Amendment of the Montreal Protocol, ratified by the Indian government in September 2021[1]. One part of the project will investigate measures to reduce current high direct emissions of refrigerants at the end-of-life of the systems, by developing and supporting future recovery, recycling, reclamation, and disposal actions in India. In addition, frontier technologies will be described to identify, develop, and support the implementation of future R&D programs in the refrigeration and Air Conditioning sector in the country. Under this framework, three application areas are determined to install the various demonstration sites (four in total) in India at different geographical locations, among which integrated refrigeration and heat pumping units are realized for a commercial refrigeration system in a supermarket, a heat pump/chiller unit in a hotel and a compact R744/R717 cascade configuration is proposed for a blast freezer applied in a fish process plant of the maritime sector. Moreover, the existing facilities at the universities involved in the project will be applied to perform education and training courses to increase

[1] https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=_en

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the number of experts in the field also outside the academic arena. Figure 1 highlights the major elements of the project. The overall aim is to assure that environmentally friendly cooling technology is accessible, affordable, and self-reliant in the Indian market.

2. FUTURE REFRIGERATION INDIA: INDEE+ OBJECTIVES

The various objectives of the present study targeted under the framework of INDEE+ are as follows:

- INDEE+ will coordinate various actions such as design, deliver training programs, and transfer knowledge to the various stakeholders.
- Extensive support will be given to develop R&D programs, manufacture in India, implement demonstration sites in real environments, and utilize the new facilities and the existing ones at educational institutes for training the field engineers.
- Knowledge on basic R744 refrigeration systems, including troubleshooting and maintenance of these systems will be provided.
- Regarding technology transfer, the key equipment for the demonstration units will, if possible, come from Indian suppliers and manufacturers.

3. INDEE+ DEMO SITE APPLICATIONS AND LOCATIONS

To cover the broad spectre of the HVAC&R sector in India, three major areas were defined, which in which the scope is currently vast and tends to increase in the nearer future, therefore, supermarkets, hotels and the maritime sector were identified as suitable application areas for demonstration of the technology. In this section, the details, and locations of the proposed demonstration sites for all three sectors are presented.

3.1. Supermarket: Metro Cash and Carry

METRO is a leading international specialist in wholesale and food retail which operates in more than 30 countries and employs more than 97,000 people worldwide. METRO targets to reduce the use of HFC refrigerants[2] and is a suitable candidate to demonstrate clean cooling technology with natural refrigerants in supermarket applications for the Indian market. METRO Cash & Carry is the wholesale division of METRO India located in Bangalore, India. The requirements for cooling inside the shop are standard medium temperature (MT) at 2°C and low temperature (LT) at -22 °C.

3.2. Hotel

Hotels are particularly energy-intensive buildings, with high requirements for hot water, space heating and/or space cooling, depending on the location. Both the heating and cooling demands can have substantial requirements simultaneously, which makes heat pump/chiller systems very attractive in the hotel application. R744 technology is well developed to support and fulfil the above-said elements. Hot water in a hotel has various uses such as in laundry, kitchen, and bathing. Also, the air-conditioning and refrigeration are essential elements to provide human comfort standards in the hotel.

3.2.1. Holiday Inn (Chennai), example for refurbishment

Conveniently located in the heart of the IT corridor on Rajiv Gandhi IT Expressway, also known as Old Mahabalipuram Road (OMR), Holiday Inn Chennai OMR IT Expressway is easily accessible to the city and just 13 km away from the Chennai International Airport. To handle the overall load demand in the hotel, heating side and cooling side temperature requirements are 70 °C and 7 °C, respectively.

3.2.2. Antarim Resort LLP (Goa), example for new construction

At the most popular wedding and honeymoon destination in Goa, India, Antarim Resort LLP, Hotel in Candolim is going to welcome their guest from June 2022. The newly built hotel structure is going to have 66 rooms facility in phase-I and another 22 rooms in phase-II along with a facility of banquet halls for large

[2] https://politics.metroag.eu/topics/climate-and-energy/as-cold-as-ice-f-gas

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gatherings. The overall thermal energy demands in the hotel will be provided by the heat pump chiller unit, i.e. domestic hot water of 70°C and chilled water for AC purpose at around 7°C.

3.3. Marine: Bellfoods

Bell Foods Exim Private Limited is an ISO 2200-2005 Certified Company registered and incorporated in India as per the Companies Act 1956 with its head office and plant located at Thoppumpady, Ernakulum, Kerala, India. The Parent Company, M/s. Bell Foods, was founded in the year 1968 by Mr Vikraman Puthusseril and was one of the first companies, set up in Cochin (the Hub of the Indian Seafood Industry) to process seafood for export to foreign countries. The various products they are dealing with are frozen shrimps, cuttlefish, crabs, squid, grouper fish, octopus and vannamei. The company is seeking a standard 62 kW blast freezer to provide low-temperature freezing at -45°C evaporation temperature to preserve their products. Air temperature in the batch freezer should be -38°C.

4. R744 SYSTEM PROPOSAL FOR INDIAN DEMO-SITES

This section describes suggested solutions for the four demo sites in India, based on the requirements given in previous section.

4.1. Supermarket: Metro Cash and Carry (new installation)

Similar to other supermarkets in India, Metro India supermarket also has a comparable requirement of medium temperature (MT) and low temperature (LT) refrigeration. To fulfil this, an R744 booster system configuration supported by a high-pressure (HP) ejector is proposed, designed and will be developed in India. Figure 2 shows the R744 booster configuration for the supermarket Metro India. The system is designed and equipped with an air-cooled gas cooler and a possibility of heat recovery to generate hot water to utilize in the shop. Also, the possibility of an evaporative gas cooler is considered, common to two-R744 independent units. The same will be operated along with the air-cooled gas cooler to handle peak load conditions in the shop and during periods of high ambient temperature during the middle of the day. Figure 3 shows the positioning of the outdoor unit. As it is observed that the shop floor area does not permit a sufficient space to install the R744 unit at the ground floor level, therefore, a container with a self-contained R744 unit is proposed to be located on the roof of the building. The unit will contain all important components except the evaporators, which will be positioned inside the shop in the cooling rooms and display cabinets.

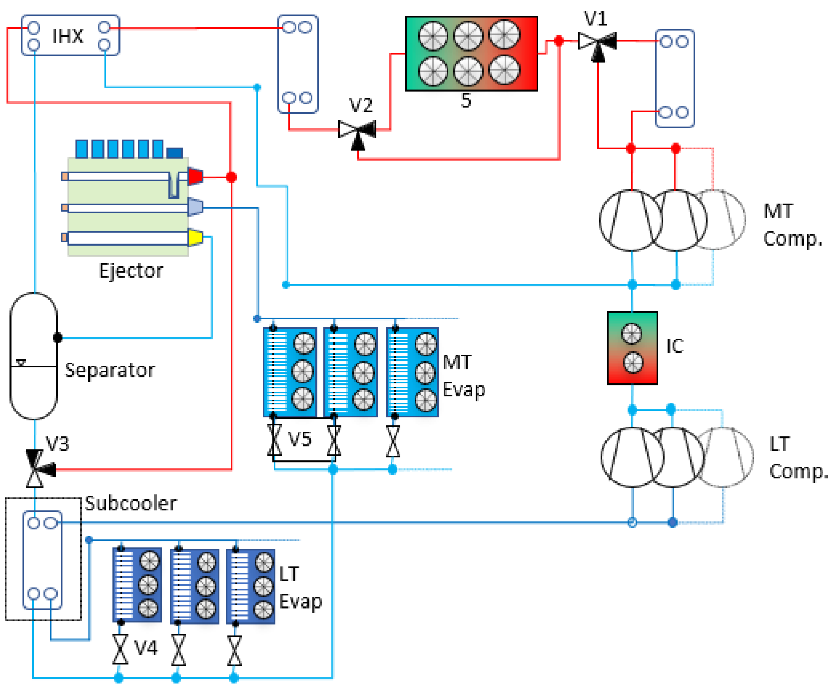

Figure 2: R744 Booster Configuration for Supermarket Metro India

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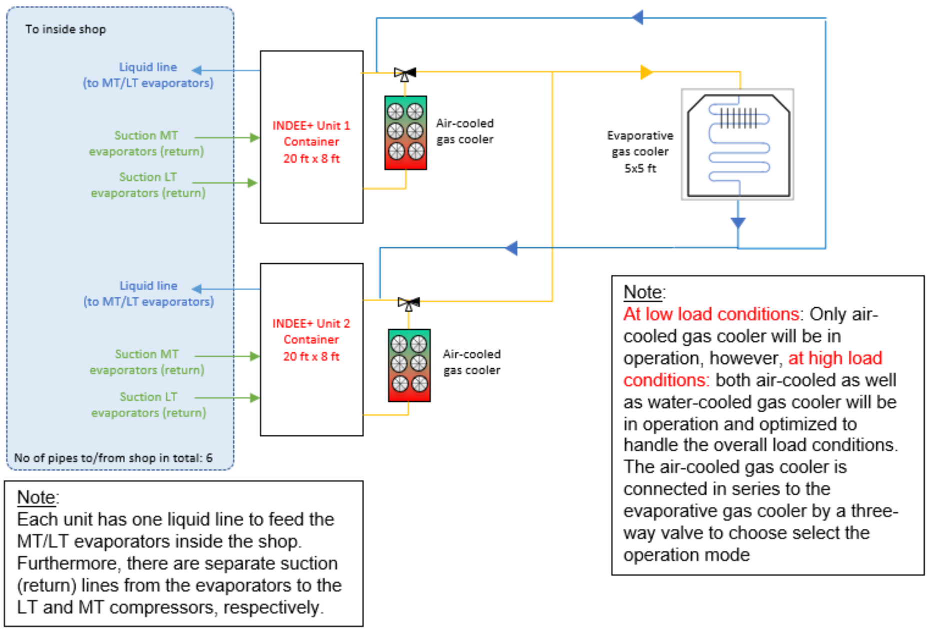

Figure 3: Robustness and compact positioning of the outdoor unit

To offer a complete HFC/HFO free cooling solution to the Metro India supermarket, a propane-based chiller and R744 direct expansion unit are recommended to handle the overall Air-Conditioning load inside the shop.

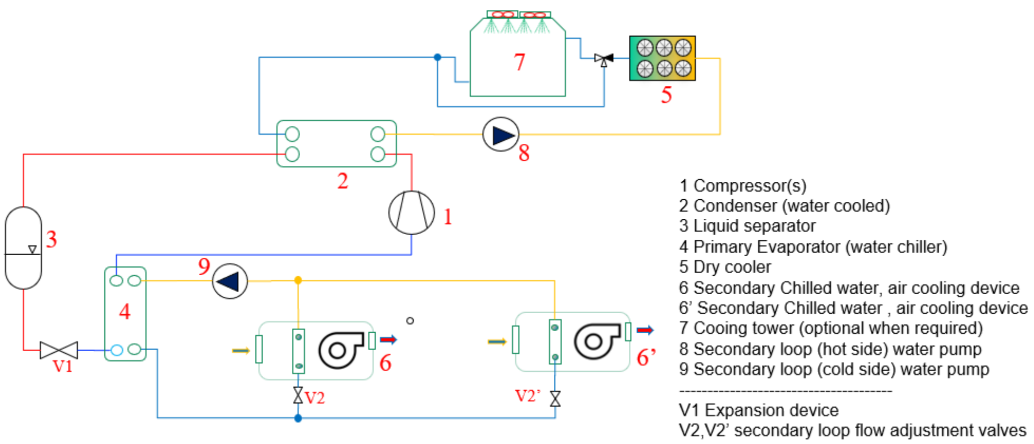

Figure 4: Proposed solution for chiller using hydrocarbon refrigerant in a supermarket.

Figure 4 shows the proposed solution for chiller using hydrocarbon refrigerant in a supermarket. In this system configuration, two independent secondary loops are offered to manage both hot and cold side thermal load, and a cooling tower to enhance the heat dissipation to promote a higher system efficiency. Table 1 shows the preliminary calculations for propane-based chiller solution in supermarket application. To produce the temperature bins, real-time ambient conditions are used. The overall COP (ideal and real) is computed on the basis of an hourly operation for both DBT and WBT.

Table 1: Preliminary calculations for propane-based chiller solution in supermarket application

	Temperature bins [°C]	10	15	20	25	30	35		
Hourly Weather Information	*DBT Operation Time [hrs]*	0	462	3192	3674	1226	206		
	WBT Operation Time [hrs]	55	2247	5897	561	0	0	DBT	WBT
COP	*COP ideal*	11.728	8.579	6.678	5.401	4.480	3.779	5.867	7.116
	COP	7.649	6.497	5.510	4.699	4.035	3.488	4.968	5.725

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Figure 5 shows the proposal for direct expansion R744 unit for AC application in a supermarket. In this robust and a simple configuration, direct R744 is offered to circulate through the gas-cooler (air cooled) and evaporators to minimise the overall losses of adopting secondary loops. Table 2 shows the preliminary calculations for a R744 system for AC application in a supermarket. The overall COP (ideal and real) is computed on the basis of hourly operation based on DBT and WBT.

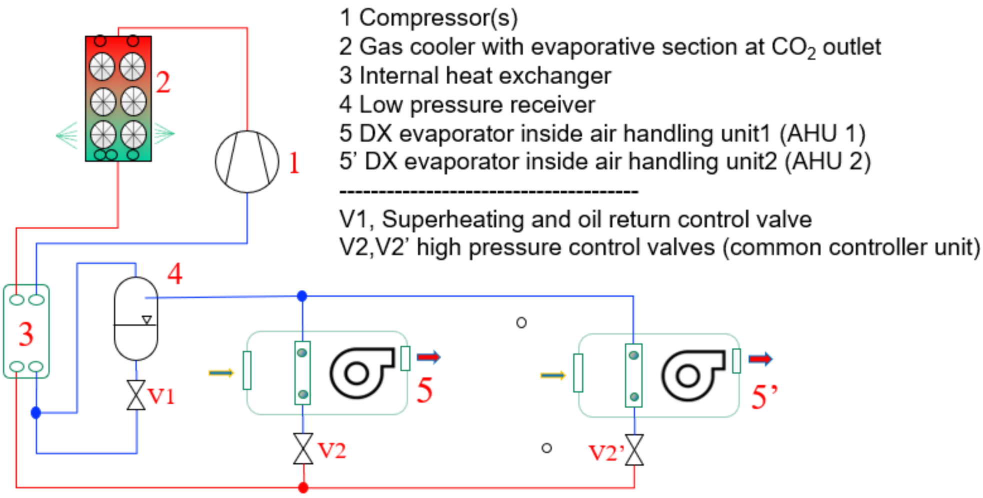

Figure 5: Proposal for direct expansion R744 unit for AC application in a supermarket

Table 2: Preliminary calculation for a direct expansion R744 system for AC application in a supermarket.

	Temperature bins [°C]	10	15	20	25	30	35		
Hourly Weather Information	*DBT Operation Time [hrs]*	0	462	3192	3674	1226	206		
	WBT Operation Time [hrs]	55	2247	5897	561	0	0	DBT	WBT
COP	*COP ideal*	16.771	10.582	7.461	5.563	4.011	3.588	6.255	8.198
	COP	10.492	7.388	5.485	4.207	3.093	2.786	4.651	5.922

From the preliminary calculations it is evident that even though the R744 unit needs to be operated at high pressure due to high ambient temperature conditions in the tropical region, it could successfully outperform the overall efficiency of the propane-based units for a similar operational and load handling conditions.

4.2. Hotel: Holiday Inn (retrofit installation)

The renovation of the domestic hot water (DHW) heating system at the Chennai (India) based Holiday Inn fits well to be a demo site for the INDEE+ activities. The daily DHW demands "for both hotel rooms and kitchen" reach 38 m^3 at 45˚ C, while the existing heating system consists of a diesel operated boiler requiring about 85 liter of fuel daily.

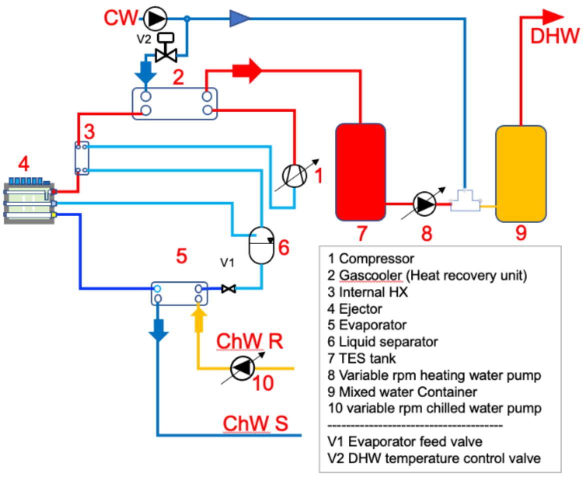

Figure 6: R744 Heat Pump/Chiller for the Hotel Holiday Inn

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Accordingly, the CO_2 heat pump/chiller of 50kW heating capacity and an integrated thermal storage tank TES is considered a very energy efficient solution. Not only because it provides for the daily DHW demands but also it provides for a by-product of a cooling capacity reaching 37kW. The proposed CO_2 heat pump/chiller-TES system illustrated in Figure 6 is not a deep renovation solution, meaning that some of the existing system components such TES tank [7] container [9] and the DHW supply piping system had to be kept.

The dominating operational mode of the CO_2 heat pump/chiller unit is heating, where the daily heating energy supply reaches 700kWh with a gas cooler entering/leaving water condition of 30/70°C. The unit ON/OFF status is decided by a supervisory controller that monitors the water level in tank [7]. During the discharging phase and when the water level is equal to or lower than 40% from the maximum filling level, the heat pump/chiller is switched ON until it reaches 100% of its filling level. The TES and control system guarantee a smooth peak demand shifting and avoiding short cycling of the unit. Meanwhile, the bonus cooling energy reaches 518 kWh/day supplied to the main hotel chilled water circuit, with entering/ leaving water temperatures of 12/6.5°C. This simple configuration could reach high COP values of 6.7 since both heating and cooling are needed as it is always the case for hotel buildings.

4.3. Hotel: Antarim Resort LLP (new installation)

To provide and cover simultaneous heating and cooling demand in the hotel, the R744 system of 120 kW cooling capacity (each evaporator of 60 kW) is designed and proposed to produce 70-75 °C hot water and 6 °C cold water (see figure 7). The water temperature could be further relaxed by mixing valve placements according to the various requirements on the premises. The unit is designed with the channel of a hot water storage tanks facility to manage and optimize the load oscillating demand, however, the chilled water to fulfil the cooling purpose will be produced according to the load demand. The ejector supported R744 system will have two gas-cooler in series to produce the hot water at two temperature levels (70 °C and 45 °C). The design is also configured with two evaporators, being evaporator 1 gravity-driven and evaporator 2 ejector-driven.

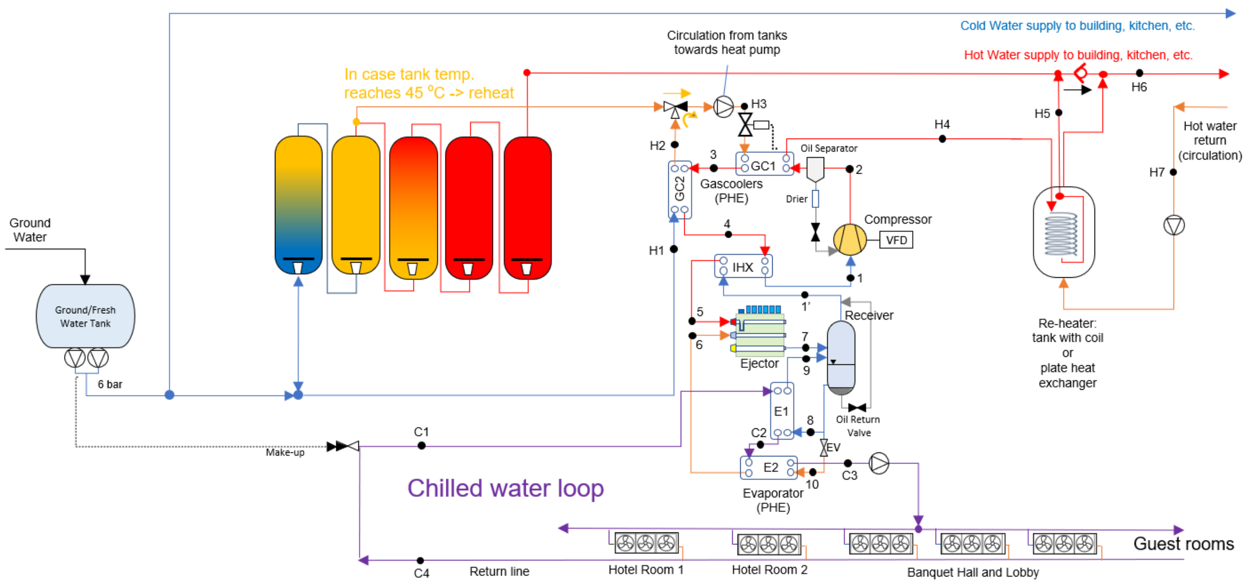

Figure 7: R744 Hot Water Chiller for Hotel in Goa

Furthermore, the hot water supply will be directed through the hot water tanks by using a non-return valve. Along with that, a reheater is proposed to pre-heat the return hot water which will be approximately 45°C. A constant temperature fresh/groundwater supply will be supplied to the unit to maintain a smooth flow. The chilled water loop will be designed through a common distributer to the various rooms and banquet halls in the hotel buildings. Water feed pumps that are independent of each section will be utilized to divert the required ratio of the hot water to maintain the required temperature. Table 1 shows the major components and operational (ideal) parameters of the R744 heat pump chiller for the hotel.

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4.4. Maritime industry: Bell foods Division (new installation)

Bell Foods (end-user) wants to maintain the traditional design and loading pattern for the new installation of the R744 unit for their cold storage. The existing dimensions of the blast freezer are 7.5 m (length), 3.9 m (width) and 3.2 m (height) with a capacity of 14 trolleys at a total of 126 kg and size 0.83 m (length), 1 m (width) and 2 m (height). The cold room will be maintained at -38 °C to store the product with a total of 62 kW cooling capacity. Figure 8 shows the proposed cascade configuration for the maritime application. Due to the absence of the heating requirement in the process plant, there is no heat reclaim proposed in the unit. So, R717/744 cascade configuration is proposed in which R717 will be integrated to disseminate the product heat. At the low-temperature stage of the proposed cascade refrigeration system, a pump-circulated R744 circuit is ensuring the supply of liquid refrigerant at -43 °C to the evaporators in the blast freezer. A layout with pump circulation and receiver ensures operation with no superheat to improve the efficiency of the proposed system.

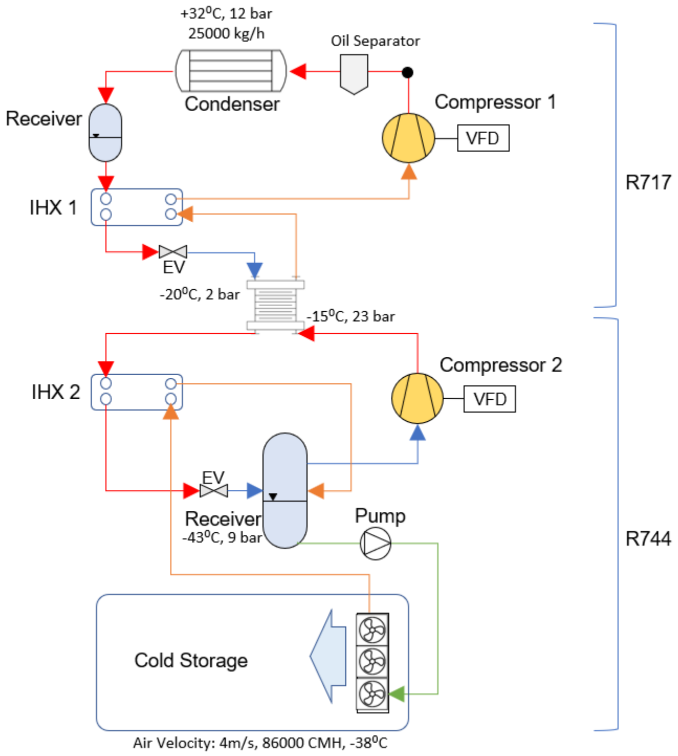

Figure 8: R744/R717 cascade configuration for maritime application.

Air velocity maintained inside an air blast freezing tunnel is important to effectively maintain the total heat transfer from the product and it highly influences the freezing time. Therefore, in the proposed configuration, the air velocity will be maintained between 4 to 6 m/s using fan coil units. Six-fan coil unit is considered for the blast freezer R744 unit. To prevent uneven air velocity distribution around the fish product trays, air guide vanes will be used to direct the blast air which will result in more uniform and effective product freezing. High-velocity air will be channelized in the middle of the blast freezer and fans will be optimized to run at their optimum capacity during the freezing process. The fan coil unit consumes 20 to 25% of the total input power to the cooling unit. It also adds heat into the system which will be reduced by efficient fan control (Widell et al. 2009). The final frozen products will be packed in cardboard boxes, each containing 10 kg of seafood. It is planned to handle two metric tons of incoming batches to be processed within a time frame of 5 hours.

5. CONCLUSIONS AND NEXT PLAN OF ACTION: INSTALLATION AND COMMISSIONING

The aim of the INDEE+ project is to facilitate the phase-in of environmentally friendly refrigeration and heating solutions to the Indian market through knowledge transfer and competence building of clean cooling

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technology among researchers, vendors, and end-users in India. With close follow-up, technical know-how and support from the technical expertise in the INDEE+ project team, the hardware for the demonstration units will be built/assembled and installed in India by local vendors. Three sectors have been identified as suitable demonstration sites for proving the performance of natural refrigerant-based cooling solutions in the Indian context: supermarket refrigeration, air-conditioning and hot water heating in hotels and refrigeration plants for maritime applications.

A close follow-up during the different phases for the realisation of the demonstration sites by the partner institutions, with their experience in R744 refrigeration technology, will enable continuous knowledge building support and technology transfer towards industrial partners in India. Focus will be given to enabling the implementation of equipment made in India, if available, or else the missing parts will be sourced on the global market coordinated by INDEE+ in close interaction with the involved industry partners responsible for the dedicated assembly and installation. The demonstration sites will be owned by the end-user, and service will be provided by the local vendor in India. The INDEE+ team gives active support during the design, tender, commissioning, and the first year of operation. INDEE+ will support the exploitation of the findings and share the know-how for various sectors in India; encouraging others to start similar developments for the phase-in of clean cooling solutions. After the commissioning of the various demonstration sites, the operation of the refrigeration/heat pump units will be monitored and reported to prove the feasibility of such solutions in the Indian context.

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