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COLD CHAIN TECHNOLOGY BRIEF

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WALK-IN COLD ROOMS IN ARTICLE 5 COUNTRIES

SUMMARY

Walk-in cold rooms are small refrigerated storage units, typically used for chilled rather than frozen goods. They are manually loaded with horticultural products and other perishable foods. These units already play an important role in connecting producers in several Article 5 countries to international export markets for high-value items such as flowers and herbs.

With 31% of the global population relying on rural and traditional food systems — especially in Africa and Asia — small walk-in cold rooms are likely to be just as essential for delivering nutritious perishable foods as large-scale cold storage facilities. Although walk-in cold rooms are currently unaffordable for most smallholder farmers, they are a feasible solution for communities, large agricultural enterprises, and export-oriented operations. Their benefits are greatest when they are integrated into a cold chain that connects producers with consumer markets.

This brief presents an overview of existing WICR technologies, refrigerants and foam blowing agents used, along with their environmental impact. The key challenges for WICRs relate to affordability and ensuring sound and sustainable business models. Issues related to access to equipment and skills in Article 5 countries are also addressed in this brief. Recommendations are included to support the development of sustainable cold chains through coordinated policies, capacity building and financial support.

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INTRODUCTION AND SCOPE

Walk-in cold rooms (WICRs) are cooled and insulated structures, sometimes equipped with humidity control, designed to extend the shelf life of perishable food products after harvest or slaughter. Cooling perishable foods after harvest or slaughter is the most effective way to slow the growth of harmful bacteria, enhance food safety, preserve quality and nutritional value, and reduce water loss. Cooling enables the safe transport of perishable food over long distances by minimising food safety risks. As small, manually loaded storage units that are accessible by walking in rather than driving in, small WICRs can play a vital role in strengthening food security for vulnerable communities in Article 5 countries.

This brief focuses on commercially available small WICRs, typically ranging from 5 to 80 cubic metres in volume, although some units may reach up to twice that size. These cold rooms are used to store fresh horticultural and agricultural produce, meat, fish, and dairy products, and are commonly located near farms, rural aggregation centres, communities, or markets. It is important to note that this brief does not cover WICRs designed for vaccine or medical applications.

The important role of small WICRs in the cold chain

Globally, the lack of cold chains results in the loss of 526 million tonnes of food production or 12% (IIR, 2021), and losses are higher in low- and middle-income economies. In Kenya for instance, approximately 40% of food is lost annually due to inadequate storage and supply chain inefficiencies (Sustainable Energy for All (SEforALL), 2024).

With 31% of the global population relying upon "rural and traditional" food systems (Barrett et al., 2022), mostly in Africa and Asia, small WICRs are as crucial to the supply of perishable foods as large scale cold storage.

WICR technologies tailored for remote areas provide timely cooling at an early stage in the post-harvest value chain, typically near farms or markets. These technologies serve for short-term storage of perishable foods, transient storage for retail, and, in rare cases, longer-term storage and ripening. Their use reduces nutritional losses, increases income generation from food sales and contributes to improving food security. This helps to raise standards of living and improve well-being in rural and remote communities.

Figure 1 | **SelfChill solar cold room in Tanzania.** (© SelfChill)

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OVERVIEW OF WICR TYPES, TECHNOLOGIES AND REFRIGERANTS

2.1 Types of WICRs

The most commonly used WICR options are containerised, ready-to-use solutions. This is largely due to limited local availability of components, shortages of skilled labour, and the need for consistent quality control. These ready-to-use solutions fall into four main types, as shown in ➔ Figure 2.

All units must be installed on a properly prepared, stable surface – such as a firm floor, base, or plinth – and must undergo commissioning procedures to verify correct operation prior to use.

1. **Pre-assembled cold rooms** are fully manufactured units delivered to the installation site as complete systems, requiring no on-site assembly. These units are designed for rapid deployment and minimal installation effort.
2. **Prefabricated cold room kits**, often referred to as flat-packed systems, include all necessary components for on-site assembly. They typically consist of insulated sandwich panels with mechanical interlocking joints and a pre-configured refrigeration unit, allowing for efficient construction and commissioning.
3. **Refrigerated ISO containers**, including reefers, railway cars, highway vans, and marine containers, offer robust and reliable cooling solutions. These units are mobile, provided that crane access is available, and may be either self-powered (e.g. equipped with an onboard diesel generator) or connected to the electrical grid. Standard ISO shipping containers can also be retrofitted into cold rooms by integrating insulation and refrigeration systems. Challenges such as heavy door mechanisms, structural modifications, humidity control, and drainage management can be addressed through established engineering practices.
4. **Custom-built or locally constructed cold rooms** are occasionally utilised in low-resource settings, particularly in Article 5 countries. These systems may incorporate locally sourced materials and conventional refrigeration technologies. In cases where cooling demand is low and storage temperatures exceed 10 °C, modified air-conditioning units may be a viable solution.

Figure 2 | **The main four types of WICRs used in Article 5 countries: pre-assembled (A), prefabricated / assembled on site (B), reefers and converted ISO containers (C), and custom-made / self-built cold rooms (D).** (Efficiency for Access and IIR, 2023)

2.2 Temperature ranges

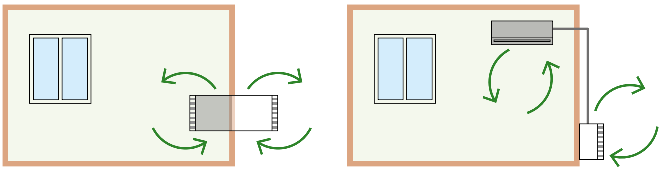
Almost all WICRs in low- and middle-income economies are for chilled food products between 0 °C and +18 °C; freezer stores are very rare, although sometimes used for meat and fish. The achieved storage temperature is important because:

- Cooling typically extends the shelf life of perishable foods by a factor of two to three for every 10 °C decrease below the ambient temperature[i].
- Food products deteriorate if stored at a temperature that is either too warm or too cold. The target temperature for each product is the lowest possible value that does not adversely affect quality.

Lower temperatures require more energy: for each degree Celsius decrease, energy consumption increases by approximately 1% to 3%, resulting in higher power demand and operating costs. Humidity management – using humidifiers or manual wetting – may be justified to reduce produce weight loss and prevent wilting and similar drying-related quality issues.

2.3 Cooling technologies used

In many Article 5 countries, mechanical refrigeration typically relies on electrically driven vapour compression technology, combined with conventional insulated sandwich-panel construction. For WICRs, the cooling units are most often monobloc systems – compact units installed through the wall – or split systems. Nearly all of these units operate using direct expansion (DX) of refrigerant, as shown in ➔ Figure 3. This approach follows established good practice for reliability, accessibility, and relatively simple maintenance, using equipment and skills that are available in most regions, though still limited in many Article 5 countries.



Figue 3 | **Through-the-wall packaged unit or monobloc unit (left) and split-type unit (right).** (Efficiency for Access and IIR, 2023)

Thermal energy storage (**TES**) offers a cost-effective solution for managing power interruptions and periods of peak electricity pricing, while also reducing the required peak cooling capacity and the associated costs of the refrigeration system. Thermal storage can be as simple as water containers stacked inside the WICR, or ceiling-mounted panels containing a phase change material (PCM) or an ice bank. Some systems use stacks of thermal packs within cooling ducts, between which air is blown to charge and discharge the storage.

"Passive assist" solutions, such as shading and evaporative cooling, are low-cost and recommended measures that can reduce the temperature of food products by 5 °C to 15 °C below ambient before mechanical cooling is applied (Defraeye et al., 2025). Hybrid evaporative coolers blow air through wet porous material to reduce its temperature and increase its humidity, then direct the cooled humid air around food products.

2.4 Current refrigerants, foam blowing agents and potential alternatives

Refrigerant and foam blowing agent selection is an important consideration in terms of environmental impact, safety and efficiency. The decision represents a compromise based on many criteria, which vary depending on the application. Geographical factors also play a role, due to the availability of replacement refrigerant and the local expertise required to safely operate and maintain refrigeration systems.

2.4.1 Current refrigerants and low-GWP alternatives

Commercially available walk-in cold room units have historically used R-404A, a high global warming potential (GWP) HFC blend. Other HFCs used include R-134a, R-410A, R-125, R-22 and R-32 (Efficiency for Access and IIR, 2023). R-404A saw a tenfold price increase in the EU within a year of HFC quota implementation and is also facing growing restrictions in Article 5 countries.

Although HFC-based systems remain readily available, virtually all WICR suppliers now provide equipment using low to ultra-low GWP alternatives, such as hydrocarbon refrigerants (R-290 or R-600a) (Efficiency for Access and IIR, 2023), which are also accessible in Article 5 countries. For instance, many major manufacturers of monobloc cooling units offer models running on approximately 150 g of R-290 (propane), which technicians can install following a few hours of training.

Given the availability of environmentally safer alternatives, the use of refrigerants with high GWP and non-zero ozone depletion potential (ODP) is not recommended for walk-in cold rooms within the size range discussed in this brief, particularly given the phase-down of R-22 as an alternative in Article 5 countries.

2.4.2 Current foam blowing agents and low-GWP alternatives

Some blowing agents currently used still contain ODS and have medium to high GWP, such as the R-141b (GWP_{100} 860; ODP 0.11). The insulation foam of a small 14 m^3 walk-in cold room can contain just over 6 kg of R-141b. In case of leakage, this

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[i] This is referred to as the Q10 Quotient by UN FAO, see *Costs and Benefits of Clean Energy Technologies in the Milk, Vegetable and Rice Value Chains*, FAO, July 2018, p. 136.
Available from http://www.fao.org/3/I8017EN/i8017en.pdf.

could cause direct global warming equivalent to around 5.4 tonnes of CO_2, along with ozone depletion impacts (Efficiency for Access and IIR, 2023).

Many foam producers have already converted or will convert soon to ultra-low to zero GWP alternatives such as cyclopentane (C5H10), a common alternative with a GWP of 11, pentane, isopentane, water-blown or liquid CO_2. Some newer-generation insulation panels use HFOs like R-1234ze, which have ultra-low GWP but may have potentially harmful impacts from chemical decomposition. Upon atmospheric degradation, HFOs can form trifluoroacetic acid (TFA), a highly persistent and water-soluble compound. Widely recognised as a perfluorinated substance (PFAS), TFA has been increasingly detected in surface waters and precipitation globally (European FluoroCarbons Technical Committee, n.d.). While the UNEP Environmental Effects Assessment Panel (EEAP) notes that current environmental concentrations of TFA are below thresholds of concern for human and ecological health (UNEP, 2024), its persistence and potential for accumulation in localised areas remain subjects of ongoing scientific and regulatory scrutiny. Additionally, the flammability and toxicity profiles of certain HFOs raise safety considerations.

Ordinary expanded polystyrene sheets are often selected as a lower cost alternative to prefabricated structural insulated panels. Natural materials such as straw bales, wool, or rice husks can be used but they rarely match the thermal and structural performance of prefabricated panels and therefore must be thicker to achieve the same insulation effect. Furthermore, they tend to degrade more rapidly than synthetic options, and if good practices are not followed, they may risk insect or mould infestation.

2.4.3 Availability of alternative refrigerants

Most WICRs use hermetically sealed monobloc cooling systems, which do not require any refrigerant top-up, so local availability of replacement refrigerant is generally not an issue. If a heat exchanger is punctured, the unit must be repaired or replaced. WICRs at the upper end of the volume range or those with pre-cooling capacity may use split systems charged with refrigerant on site during installation. Opting for hydrocarbon refrigerants depends on local availability of the refrigerant and entails additional safety and design considerations. Two hydrocarbon refrigerants are possible for WICRs: R-600a whose availability is growing in Article 5 countries as the global transition from R-134a to R-600a in household refrigerators is nearing completion (UNEP, 2023; UNEP, 2025), although cost remains an issue in many countries; R-290 is less widely available, mainly in countries with commercial refrigerators and room air conditioners using R-290. A pilot plant for the production of high-purity R-600a and R-290 refrigerants was set up in Nigeria in 2015, with a capacity of 400 tonnes per year (IIR, 2025).

2.4.4 Safety issues and skilled technicians

Many Article 5 countries lack the local safety regulations and access to technical skills that influence refrigerant selection. HFC refrigerants present few safety risks, other than asphyxiation if released into confined spaces. Hydrocarbon refrigerants on the other hand are highly flammable. Their use is therefore subject to design restrictions and adherence to specific technical standards, along with proper training to ensure safe handling.

2.4.5 Possible restrictions on shipping

Possible restrictions on shipping equipment with flammable refrigerants must be considered. Monobloc WICR systems contain only around 150 g of R-290 and shipping rules are similar to those for household refrigerators using R-600a. Road, rail, and sea transport generally pose no problem, although local interpretation of regulation may vary. Air shipment may be challenging for natural and many low-GWP refrigerants, as the refrigerant may need to be removed prior to flight and recharged upon arrival in the destination country. This is particularly true for equipment containing more than 100 g of flammable refrigerant.

Import tariffs represent another significant hurdle, especially in African countries, where tariffs on refrigeration equipment range from 20% to 111% (U-3ARC, 2025), as illustrated in ➔ Figure 4. According to Efficiency for Access, import duties and taxes account for up to a third of the cost of domestic refrigerators/freezers and compressor refrigerator parts (Efficiency for Access, 2020).

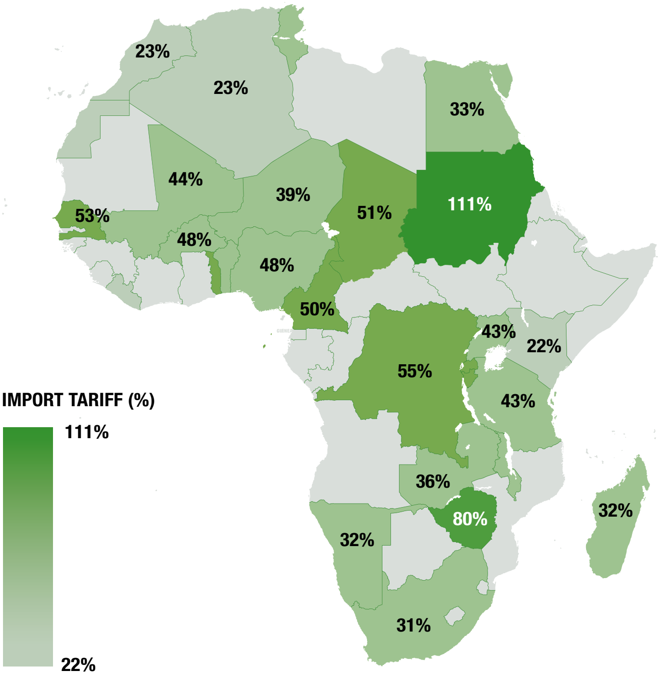

Figure 4 | Import tariffs on refrigeration equipment in Africa, based on data from (U-3ARC, 2025).

2.5 Life-cycle climate impacts of WICRs

In many low- and middle-income countries, the electricity consumption of grid-powered walk-in cold rooms contributes more significantly to global warming than refrigerant emissions. This underscores the importance of implementing energy efficiency measures. Exceptions may exist in regions with low grid carbon intensity, although such cases remain relatively uncommon.

A 2023 study by Efficiency for Access examined the life-cycle GHG emissions[ii] of a 20m^3 solar-powered WICR using a hydrocarbon refrigerant, covering direct and embodied emissions as well as raw material production through to disposal. The broad conclusions were that embodied GHG emissions from manufacturing of equipment account for over four-fifths of the total life-cycle impact, while the use phase represents less than 2% thanks to solar power. The highest emissions were related to manufacturing of lead acid batteries, followed by photovoltaic (PV) panels, the manufacturing of the cold room structure, and the release of blowing agents at end of life[iii]. Impact summary charts are shown in ➔ Figure 5.

In many countries, access to facilities for the recovery of refrigerants and foaming agents remains limited. This makes design choices particularly important to ensure environmental responsibility and long-term sustainability.

➔ Figure 6 compares the impacts of three refrigerants commonly used in WICRs of this size and type. Selecting a hydrocarbon refrigerant over an HFC (as used in the studied WICR) results in a 99% reduction in GHG emissions. Incorporating thermal energy storage enables smaller electrical batteries and further reduces environmental impacts in this case.

2.6 Power sources for WICRs

Most commercial WICRs require a grid power connection to operate, although voltage stabilisers and surge protectors are recommended to prevent damage from the widespread prevalence of voltage fluctuations. A backup power source is usually essential, whether supplied by the grid, generators, or distributed renewable sources such as solar photovoltaic. A growing market exists for solar-powered, mini-grid, and other distributed power systems in areas with unreliable grid or no grid connection.

[ii] “Embodied emissions” means carbon related to energy and material input to processes in the upstream manufacture of components, raw material extraction, processing and transportation, etc.

[iii] The cold room studied used R-290 as the refrigerant and polyurethane insulated panels with a foam blowing agent consisting of 90% pentane and 10% HFC. A blowing agent with lower GWP could be chosen to reduce environmental impact.

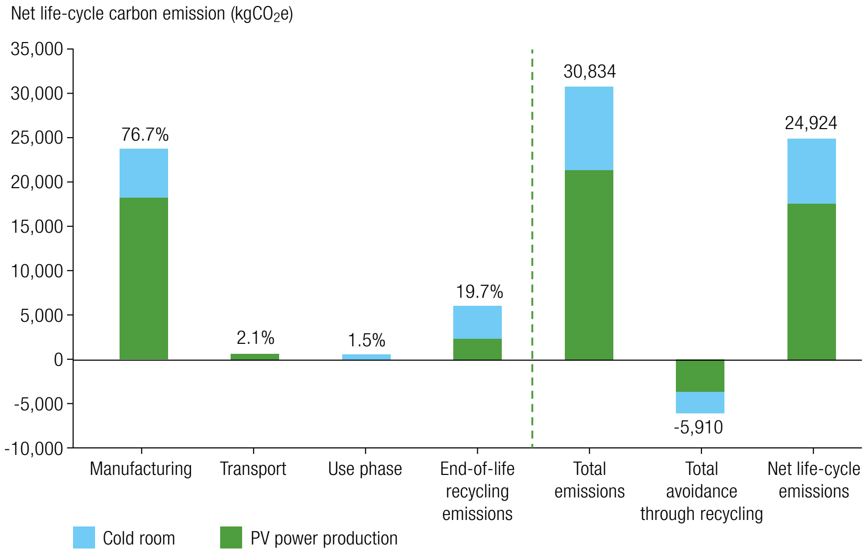

Figure 5 | **Emission summary for a 20 m^3 solar photovoltaic powered cold room (Efficiency for Access, 2023a).**

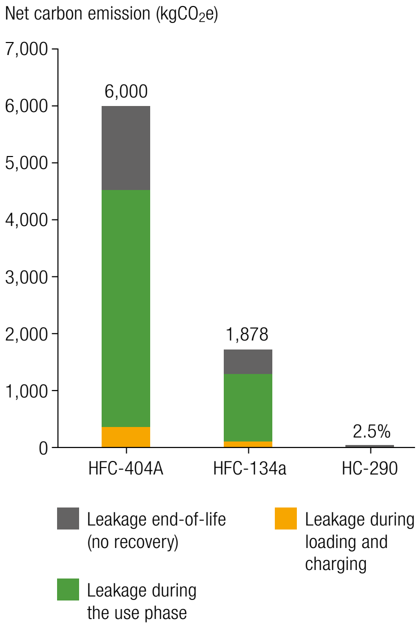

Figure 6 | **Emission summary for various refrigerants that could be used with cold rooms of this size and type (Efficiency for Access, 2023a).**

TECHNICAL TRENDS AND DEVELOPMENTS

3

3.1 Status of the WICR market

Walk-in cold rooms and equipment designed for unreliable, or off-grid electricity supply are still in the early stages of development, but they are now receiving growing attention from governments, NGOs, and donors. There are at least 25 active solar cold room suppliers across many parts of the world. Affording a WICR of any type is currently non-viable for smallholder farmers in Africa on a fully commercial basis but is feasible for communities, large farm businesses and for export situations (Efficiency for Access, 2021).

Some indicators of market status:

- **Across Africa**, more than one hundred solar-powered cold rooms are already in operation, with Nigeria and Kenya alone accounting for dozens of installations[iv].
- Agriculture contributes to one quarter of Nigeria's GDP and employs over a third of the country's workforce. Yet, government support for cold chain infrastructure is minimal and primarily focuses on imports and exports (Efficiency for Access, 2023b).
- Despite being at the forefront of cold chain development efforts in Africa (Open Capital, 2023), Kenya has complete agricultural cold chains in place only for a limited number of high value export crops (Efficiency for Access, 2023c).
- **India** has the highest cold storage capacity of any middle-income country (The Carbon Trust, 2020), with over 1,400 solar-powered WICR units operational as of February 2025 (Ministry of New and Renewable Energy, Government of India, 2025). Despite India's 98% electrification rate, solar-powered and solar-assisted WICRs are actively promoted in rural areas where grid reliability remains a challenge. This push reflects a strategic government initiative to strengthen the agri-food sector and cold chain infrastructure, launched in 2014 through the Mission for Integrated Development of Horticulture (MIDH). Today, it is supported by the National Centre for Cold Chain Development (NCCD), which plays a key role in publishing national standards and guidelines (Ministry of Agriculture and Farmers' Welfare, Government of India, 2025).

In many countries, users of grid-connected and off-grid walk-in cold rooms often target high-value export markets such as flowers, exotic fruits, herbs, and vegetables. Applying these systems to local supply chains is more economically challenging, but some providers are addressing this by offering cooling-as-a-service solutions and enabling shared access at markets and within farming communities.

3.2 Technical challenges

The essential equipment and technology are proven, though not yet economically viable nor readily accessible to many low- and middle-income countries. The technical challenges remaining are primarily:

- **Access to reliable technical specifications for walk-in cold rooms remains limited**. Available performance data is often inconsistent, lacks a clear technical foundation, and cannot be independently verified, making it difficult to assess suitability for specific uses. This creates uncertainty for investors and slows market development (Efficiency for Access, 2023d).
- **Integrating thermal energy storage**: WICR systems are increasingly incorporating TES, although its economic and practical viability varies by context. A wide range of TES options exist, from simple, low-cost solutions to more advanced systems, but monitoring charge levels remains a challenge. TES can improve energy efficiency, reliability, and throughput, particularly when walk-in cold rooms serve as flexible anchor loads for solar energy projects and business hubs. To fully realise these benefits, standardised performance testing and research support for control systems are needed.
- **Achieving scalability**: Key technical challenges include improving affordability, reliability, and repairability of walk-in cold rooms to support wider adoption and economies of scale.
- **Reducing greenhouse gas impact**: There is a need for systems that use ultra-low-GWP insulation materials and natural alternatives with minimal environmental impact.

[iv] Expert views from Efficiency for Access / World Bank suggest a significant increase since the figure of 100 for Africa which was quoted in *Solar Appliance Technology Brief: Walk-In Cold Rooms* (July 2021), Efficiency for Access.

3.3 Resources and technical support

Extensive good practice resources are freely available for postharvest care of food products, including the use of refrigeration. Many are targeted at smallholder and rural farms in low- and middle-income countries, such as via the Postharvest Education Foundation (The Postharvest Education Foundation, 2025), the Postharvest Loss Alliance for Nutrition (PLAN), the University of California Davis, and the UN FAO.

Resources and support on WICR technologies and products are being provided by some government and NGO programmes:

- Regional centres of excellence are being established in Africa by UNEP, with UK support and under the Clean Cooling Network, through the Africa Centre of Excellence for Sustainable Cooling and Cold chain (ACES). The main base is located in Rwanda, with a spoke established in Kenya (The Clean Cooling Network, 2025). Centres In India have also been developed and are being expanded.
- The National Centre for Cold chain Development (NCCD) in India promotes integrated cold chain infrastructure for perishable agriculture (Ministry of Agriculture and Farmers' Welfare, Government of India, 2025). It serves as a policy think tank and collaborative hub for technical issues.
- The Efficiency for Access coalition has developed a portfolio of market studies, good practice guides, and impact reports on WICRs and cold chain (Efficiency for Access, 2025), including its *WICR Practitioners Technical Guide*, produced jointly with the International Institute of Refrigeration (Efficiency for Access and IIR, 2023).
- The Cool Move Initiative (CMI) – a business planning and finance coordination initiative for rural cold chain networks – was launched in 2021 by a consortium including the Global Food Cold Chain Council, WWF, and Rabo Bank (Global Food Cold Chain Council, n.d.). In 2025, CMI launched a project led by Wageningen University and Research to improve the private-sector approaches to cold chain development.
- A Postharvest Assessment Method (PHAM) has been developed to evaluate the suitability of walk-in cold room applications (see Case Study: "The Postharvest Assessment Method (PHAM), Wageningen").
- Crop and farming planning apps and information platforms have been created to help farmers optimise harvest timing to market prices and produce readiness and manage stored produce, such as "Your Virtual Cold Chain Assistant" by BASE/EMPA (BASE and EMPA, n.d.).
- Several training colleges in Africa have offered courses on the design and assembly of walk-in cold rooms (Efficiency for Access and IIR, 2023), including the Sustainable Energy Resource Centre of Strathmore University in Nairobi, although demand has been variable (Strathmore University Energy Research Centre, 2025).

WICR performance testing and quality assurance are often cited as crucial gaps to be addressed, and progress is being made:

- The Government of India has published design specification and test procedure for solar cold storage, following its *2014 Technical Standard for WICRs* document (Bureau of Indian Standards, 2018). However, the earlier standard was not widely adopted by the industry.
- An Off-Grid Cold Chain Challenge was run in 2019 and 2022 as part of the Global LEAP programme by the Efficiency for Access coalition, involving field testing of WICRs in a collaborative international competition to stimulate innovation, with prizes for technical performance (Efficiency for Access, 2022).
- The VeraSol quality assurance programme for off-grid equipment has developed a comprehensive laboratory testing methodology and standard product specification sheet for WICRs in Article 5 countries.
- Walk-in cold rooms can be tested for performance in chambers designed for refrigerated container testing, such as ATP testing stations. One such station is operational in South Africa and another is planned at the ACES centre in Kigali (UNECE, n.d.).

DEVELOPMENT PERSPECTIVES AND CHALLENGES

4

4.1 Overview

Whilst some technical issues remain to be addressed, the most demanding challenges in low- and middle-income economies relate to:

- Developing viable approaches and financing models that ensure only sound business cases for WICRs are selected – incorporating not only affordability of equipment and its operation, but also sustainable business models rooted in viable, often newly established supply chains that extend from farm gate to end users.
- Ensuring access to varied types of equipment, as well as installation, operation, and maintenance skills near to where WICRs are needed, with emphasis on supply chains and safe-handling skills for hydrocarbon refrigerants through operator training.

Walk-in cold rooms are rarely viable when integrated into existing farming and supply chain practices. This is not only due to limited familiarity with the technology, but also because traditional agricultural systems have evolved over centuries without relying on refrigeration systems. To fully benefit from cold storage, significant changes are needed in harvesting methods, timing, crop planning, and transport. Adopting such a system therefore requires a well-informed approach.

4.2 Affordability and business challenges

The purchase of a 33 m^3 WICR (equivalent to a 20-foot container), costing between USD 20,000 and USD 50,000 (Defraeye et al., 2025), is well beyond the financial means of any smallholder farmer in low- and middle-income economies. However, a business case can be made for aggregators and communities when the WICR forms part of a wider supply chain redesigned for the use of cold storage. A WICR installed as an isolated investment cannot deliver extended shelf life or improved quality in any sustainable way (Efficiency for Access, 2023d). Farmers, aggregators, transporters, wholesalers, and retailers have little control over the temperature to which produce is exposed before or after their involvement, so an isolated investment is often largely wasted (Efficiency for Access, 2021). The greatest benefits are achieved when the WICR serves as one node within a well-structured supply chain connecting suppliers and customer bases, as illustrated in the Case Study: "The Postharvest Assessment Method (PHAM), Wageningen".

WICRs generally require innovative financing, subsidies, or other incentive to cover initial capital and, in many cases, operating costs. Good examples are already established in Africa and elsewhere through rental or pay-as-you-store business models, which are helping to improve accessibility and build familiarity with WICRs (Efficiency for Access, 2023e). Import duties on components and finished products can significantly increase the cost of cold chain equipment. Targeted reductions or exemptions could therefore improve affordability and support wider adoption. Public sector investment is especially crucial where private-sector-led models may not be commercially viable to establish infrastructure and create enabling environments conducive to cold chain growth (Efficiency for Access, 2023d).

CASE STUDY THE POSTHARVEST ASSESSMENT METHOD (PHAM), WAGENINGEN (OOSTEWECHE ET AL., 2022)

For any intervention, the level of technology should match the level of market sophistication and cost benefits must be objectively assessed. Goals at the food-system level (e.g. cutting food waste) must be aligned with interests at the value-chain level (i.e. the economics). The PHAM provides a framework to assess eleven main criteria for potential cold chain investments: resource potential, benefits for chain partners, policy and legal issues, knowledge, finance, markets, technology, input supply, logistics, storage, and processing and retail. Cooling facilities of the appropriate quality and size must be built in the right location, with product-market combinations that justify the investment, ensure access to quality produce, and guarantee ongoing equipment maintenance.

4.3 Government policy and financing

To date, most WICR projects have been implemented as pilot initiatives, financed through grants, results-based financing, and other subsidies. In other cases, blended finance mechanisms have been leveraged to mitigate investor risk to investors through philanthropic and commercial lending. Equity and bank loans remain less common (Efficiency for Access and IIR, 2023).

The government of India has set a leading example of a strategic national approach for cold chain related investment and business development. Under the framework of its Mission for Integrated Development of Horticulture (MIDH) and supported by the India Cooling Action Plan (Ministry of Environment, Forest & Climate Change, Government of India, 2019), the government has introduced several incentives to stimulate cold chain development. These include low-interest loans for infrastructure setup, subsidies ranging from 25% to 75% for investment in facilities, exemptions and reduced rates in excise and basic customs duty, tax deductions, and a five-year income tax holiday on profits and gains from cold chain operations. This policy has contributed to India's refrigerated warehouse cold chain development being more advanced than that of many European countries (Salin, 2020). The government is now also deploying solar photovoltaic walk-in cold rooms to serve areas with unreliable grid or no grid access.

Among African countries, Kenya stands out for its progress in developing cold chain infrastructure, primarily for the export of a small number of high-value crops and flowers. The country has also been the focus of sustained investment and NGO activity in cold chain development, with an emphasis in recent years on solar-powered photovoltaic WICRs for rural and off-grid locations. According to Kenya's 2022 National Cooling Action Plan (Ministry of Environment, Climate Change and Forestry, Kenya, et al., 2023) 80% of farmers are smallholders and approximately 30% of their produce is lost due to limited access to adequate cold chain infrastructure. However, farmers in Kenya cannot afford refrigeration solutions to reduce post-harvest losses. Measures have been identified to expand fiscal incentives for cold storage systems, raise awareness, and strengthen technology R&D, with a particular focus on innovative business and financing models.

4.4 Supply chain and access to skilled technicians

A key challenge is access to expertise and equipment in locations beyond existing cooling equipment supply chains, especially for ultra-low-GWP refrigerants. The skills deficit encompasses specifying, installing, commissioning, servicing, and repairing equipment safely.

There is a need for both trained technicians and access to spare parts and systems. In India, the government has developed a comprehensive and detailed skills and capacity-building strategy to support the country's cold chain sector as part of the National Cooling Action Plan.

Certification in safe refrigerant handling is essential to meet the need for trained technicians. Many Article 5 countries have certification programmes in place, established through HCFC phase-out management plans (HPMPs), with funding from the Multilateral Fund for the Implementation of the Montreal Protocol (MLF). For instance, in Indonesia, over 9,000 technicians were certified between 2018 and 2023 with HPMP funding along with support from national and industry stakeholders (UNDP, 2024). In Ghana, the Environmental Protection Authority, with support from GIZ, published the *Refrigeration and Air-conditioning Certification Regulations 2025* (LI 2503), which standardises the training and certification of refrigeration and air-conditioning technicians (Ghana News Agency, 2025).

CONCLUSIONS AND RECOMMENDATIONS

5

Technologies for scaling WICRs in Article 5 countries are well-established but economically viable only under the right conditions and approaches. Key challenges relate to affordability and ensuring sound business cases across supply chains from farm or market to end user. Access to equipment and skills remains challenging, and cold chains are still nascent in most Article 5 countries. While WICRs are financially non-viable for individual smallholder farmers, their use is feasible and arguably essential in the future for communities, larger farms, and aggregators. Their application in export markets is well-established and financially self-supporting when properly implemented.

HFC-based systems are readily available, and virtually all WICR suppliers can provide equipment using low- to ultra-low-GWP refrigerants. Hydrocarbon refrigerants (R-290, R-600a) are technically ideal for WICR systems, but limited supply chains and a lack of trained technicians with the skills and tools to handle flammable refrigerants safely severely constrain deployment. Some blowing agents for insulating foams used in Article 5 countries still contain ODS and have medium to high GWP, although many foam producers have now converted to ultra-low- or zero-GWP blowing agents.

The development of sustainable cold chains requires coordinated policies and programmes of raising awareness, building skills, supporting early adopters, providing financing, coaching on business plans, and ensuring equipment quality. The government of India provides a leading example in its comprehensive approach to cooling and cold chains, while Ghana sets a valuable example in skills regulation and certification. Key policy elements to develop WICRs include:

- Implementation and enforcement of food safety regulations.
- A national cooling action plan, covering both local market cooling "webs" and industrial cold chains for export.
- Focus on expanding safety skills and supply chains for natural refrigerants.
- Focus on affordability and financial mechanisms, including measures to restrict imports of subsidised produce that undermine the local business case.

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