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D6.11
Report on Storage and Retail demonstrators

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OVERVIEW ON TASK 6.11

1. GENERAL SUMMARY

This deliverable contains five demonstrators in the retail sector. Four of these are directly for supermarkets and one for a cold storage distribution centre serving supermarkets. All of the demonstrators are focused on refrigeration and some, using heat from the refrigeration to offset natural gas used for heating. The demonstrators are listed below;

Demo 9 - Thermal energy store (TES) and Demand Side Response (DSR) in supermarkets

Demo 10 - Future retail display

Demo 11 - Thermal storage unit for refrigeration cycle

Demo 16 - Refrigerated store heat advanced recovery

Demo 19 - CO_2 pressure exchanger for retail

The benefits of these demos is either; reducing electrical demand, by increased efficiency of either the refrigeration system or equipment attached to it; shifting electrical demand to off peak times; or reclaiming heat and using this to offset natural gas use, helping to decarbonise the sector. Many of these demos have more than one of these benefits.

2. RECOMMENDATIONS

- Consider integration of supermarket store heating system with a TES to either pre-heat ventilation air or provide heat source for a heat pump.
- For supermarket based on synthetics that are not imminently to be replaced, consider retrofitting water-cooled condensers in place of the existing air-cooled condensers together with thermal energy stores as a means of increasing efficiency of existing plant and delivering a source of recoverable heat within and around stores.
- Recommend all new cold store refrigerant plant is heat recovery ready, either with water cooled heat exchangers or the means to cost effectively fit them at a later date. This is efficiently feasible with CO_2 as the refrigerant.
- For new cold store installations, on site heat demands should be evaluated and met from rejected heat from the refrigeration system.
- Further investigation of heat recovery from cold store evaporative condensers should be undertaken.
- In the UK in particular, the ratio of electricity to gas prices is so high that it is difficult to justify decarbonising schemes. Action is required at Government level to reduce this ratio.
- Academia and industry should continue to work together to investigate further improvements and thereby accelerate the phase out of HFC systems.
- New installations should only apply natural working fluids, to help the asset owners investing in clean technology, enabling them to report sustainability and saving operational expenses.

3. DESCRIPTION OF THE SECTOR

Published data for overall emissions for each section of a whole food chain were relatively scarce when this project started. However, WP1 has now evaluated these emissions. The WP1 top-down model shows 16% of food sector emissions (both scope 1 and scope 2) are from retail and wholesale trade and 1.0% from storage and logistics.

As part of eco-design and labelling studies (EC, 2025) the EC estimated that the 14 million commercial refrigerators (appliances with direct sales function) in the EU had a total energy consumption of ~53 TWh in 2020.

Refrigeration is often the largest energy load in a supermarket. The energy consumption of supermarkets depends on business practices, store format, product mix, shopping activity and the equipment used for in-store food preparation, preservation, and display. Foster et al (2018) showed a mean annual specific energy consumption of 566 $kWh.m^{-2}$ based on electrical energy consumption and sales floor area for 565 retail (supermarket) stores from one retailer in the UK in 2015. They also stated that annual electrical energy consumption can vary widely from around 407 $kWh.m^{-2}$ in hypermarkets to 1700 $kWh.m^{-2}$ in convenience stores from other studies. In this study the refrigeration systems accounted for 33% of the total electricity used, however, this is likely much higher for convenience stores.

Gas is normally used for space heating, domestic hot water and in some cases for cooking and baking. In the UK study described earlier, gas made up 25% of the total energy consumption, with grid electricity the other 75%.

Foster et al (2024) stated that "It is clear that all commercial cabinet types use more energy than the Eco-design study projection timescale." Large energy savings could easily be achieved by banning open fronted supermarket cabinets and/or removing the lowest 3 label classes and would bring these model types in line with current projections, but only if it happened immediately.

The retail roadmap from WP2 questioned how the retail food sector can decarbonise and rapidly reach net zero. They came up with 6 recommendations.

- Transition to natural refrigerants
- Add doors to open fronted cabinets
- Purchase the most energy efficient equipment
- Assess benefits of technologies according to specific location and operation
- Don't wait, early interventions will reduce cumulative carbon emissions.
- Use renewable energy, especially on-site solar PV in sunnier climates

The earlier H2020 MultiPACK Project demonstrated by field installation that an integrated CO_2 system, adopting SOTA components and lay-out, was able to save around 30% specific annual consumption (345.5 [$kWh.m^{-2}.year^{-1}$) or, considering only the shopping area, 434.4 ($kWh.m^{-2}.year^{-1}$) with respect to the average Italian energy consumption, bringing together the benefit of using all-in-one natural solution for refrigeration, air conditioning, heating and domestic hot water production.

The key technologies adopted were closed cabinets, overfed evaporators, increased evaporation temperatures, parallel compression, two-phase ejectors for vapour pre-compression and liquid recirculation, thus supporting the need for fast interventions towards long-term natural based solutions as assessed by WP2 Retail roadmap.

4. DESCRIPTION OF THE TECHNICAL SOLUTIONS

The overall characteristics of all the demonstrators are shown in Table 1. All of demonstrators were refrigeration based and mostly on the refrigeration system, however, a couple were specifically on the refrigerated display cases. All but one of the demonstrators was for supermarket facilities, however one was for a cold store facility serving supermarkets (distribution centre).

Four of the demos aimed to increase energy efficiency, either by reducing the load on the refrigeration system by better design of display cabinets, or a more efficient refrigeration system. Two of the demos investigated the use of condenser heat to offset other heating fuels, such as natural gas. Two of the demos investigated the use of demand side response to operate the refrigeration system outside of peak times.

Table 1. Characteristics of the demonstrators.

Demo	Facility	Equipment	Improved efficiency	Using condenser heat	DSR
9	Supermarket	Refrigeration system	☑		☑
10	Supermarket	Refrigerated display cabinet	☑		
11	Supermarket	Refrigeration system and Refrigerated display cabinet	☑	☑	☑
16	Cold store	Refrigeration system		☑	
19	Supermarket	Refrigeration system	☑		

4.1. Definition of KPIs and benchmarks

Energy efficiency index (EEI) - The main KPI for retail display cabinets which is used for energy labelling.

Coefficient of performance (COP) – Measurement of the effectiveness of a refrigeration cycle. It is the ratio of the amount of heat pumped to the amount of energy required to do so.

PRESENTATION OF DEMONSTRATORS

5. DEMO 9 -TES AND DSR IN SUPERMARKETS

5.1 Description

Demand Side Response (DSR) is the ability of electricity users to modify their usage patterns to better suit the grid supply profile. The CO_2 intensity of the grid tends to rise at peak demand periods as gas powered plants are turned on to supply the extra demand. In the UK, supermarkets are incentivised to reduce demand at peak periods. Currently this is done by turning off display case cooling. Obviously as the cases warm up, they must be turned on again, so this intervention has a limited duration. DSR periods vary between regions, but are between 18:00 and 20:00, lasting up to 45 minutes. The aim of this demo was to optimise DSR at a concept store in the UK. Not all European countries have implemented DSR to manage electricity demand, however, French grid operator RTE has developed sophisticated demand flexibility tools, with large industrial consumers, including supermarkets and The Netherlands is also exploring local flexibility in the distribution network, which could include supermarkets participating in demand response programs.

The duration of the DSR is limited by the thermal capacity of the food in the display cabinets. This demo investigates a Thermal Energy Store (TES) which adds to the thermal mass of the food, thus increasing the potential duration of the DSR. The system will cool water overnight and use the cooled water at peak times to reduce the system condensing temperatures, increasing system efficiency.

The demonstration evaluates the practicality of the solution for retrofit. Retrofit will accelerate reductions to CO_2 emissions as it can be applied to existing equipment which will not be replaced for many years.

5.2 Application methodology and assessment

Refrigeration packs in many supermarkets were evaluated to find a site with sufficient instrumentation in place and equipment suitable for retrofit.

A heat store and dry cooler have been manufactured in a shipping container and have now been installed at the selected site. The configuration is shown in Figure 1. Photos of the installation are shown in Figure 2 and Figure 3. When the valve to the secondary condenser is opened, some of the heat rejected by the refrigeration system will be transferred to the heat store. This reduces the amount of heat to be rejected by the existing condensers which means they can operate at a lower temperature which will reduce the amount of electricity required to provide the required cooling. The heat store can be cooled overnight using colder ambient temperatures which will maximise the secondary condenser capacity during hotter periods of the day.

The trial installation only involves a single refrigeration pack. Multiple packs could be connected to a suitably sized heat store reducing costs per pack. The heat store could also be used as the source for a heat pump to provide space heating to stores displacing existing gas heating.

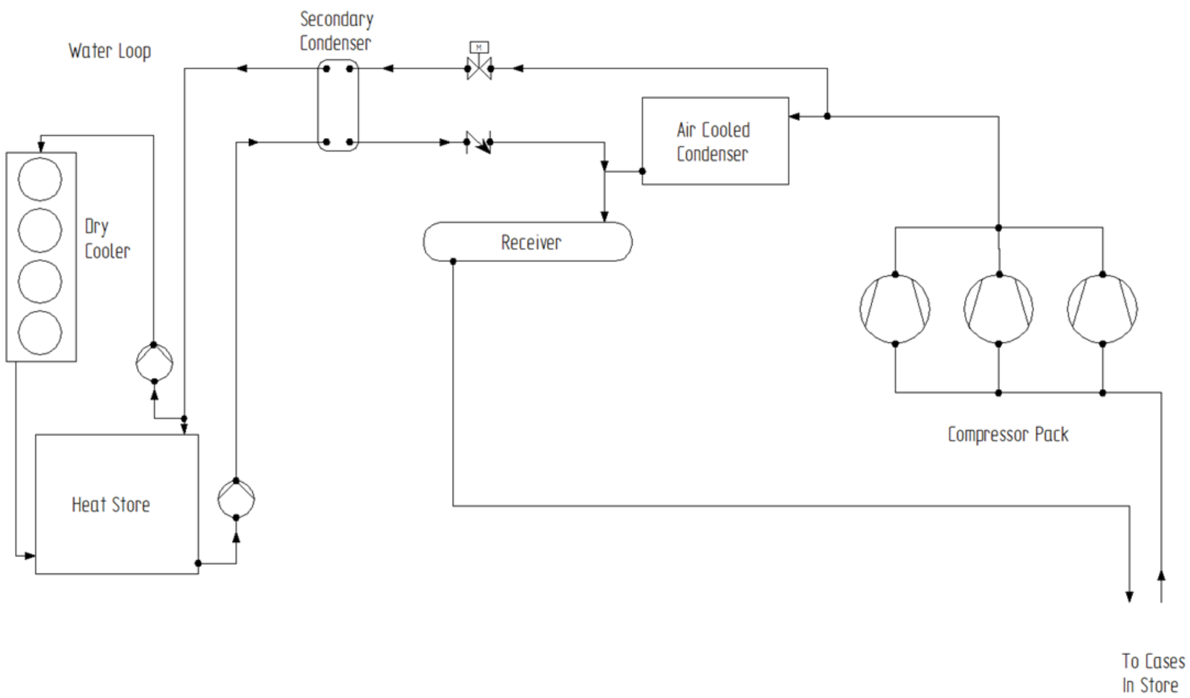

Figure 1. Integration of secondary condenser, heat store, and dry cooler into an existing supermarket condensing unit.

Figure 2. Container with dry cooler mounted on top and heat store with pumps inside.

Figure 3. Secondary condenser mounted next to pack.

Data from the pack running before modification has been used to estimate potential savings. Initially the plan was to operate the heat store at times of DSR and this showed a 20% increase in energy savings during the DSR period. Using a numerical model allowed simulation of the system running continuously and showed larger overall savings of up to 20% of pack energy use while retaining a 15% increase in savings during the DSR period.

Analysis of store data has shown that the DSR intervention saves energy as well as moving demand away from the high CO_2 intensity period. Two mechanisms have been identified. First as the display cases are, on average, at a higher temperature but still within the acceptable range, the evaporating temperature and hence the COP will be higher during the cooling period. Second as there will be a consistent and higher cooling demand for a period after the DSR intervention it has been found that the system uses less electricity under these conditions. Further work is underway to investigate the effect of oscillating loads on refrigeration system performance.

5.3 Results

The system was commissioned in June 2025. The last 12 months data were used to estimate expected electricity use based on external ambient, to create a benchmark. The test days (28th June to 10th July) showed a 20% reduction in electricity use compared to the prediction; the data is shown in Figure 4. This would represent a saving of 16,000 kWh per annum or 2,800 kg CO_2e (based on UK government conversion factor for 2025).

In addition to the savings, all the display cases on this demo pack operated continuously through exceptionally hot conditions while other packs on site had display cases turned off to maintain operation. This plant was notorious for going into auto load shedding in warmer periods above 28^{o}C and since the install of the thermal store it has not done this including the exceptionally warm weekends in late June/early July we saw. This while 2 other packs on site did go into load shedding and 4 cases had to be automatically switched off as the head pressure breached 21 bar.

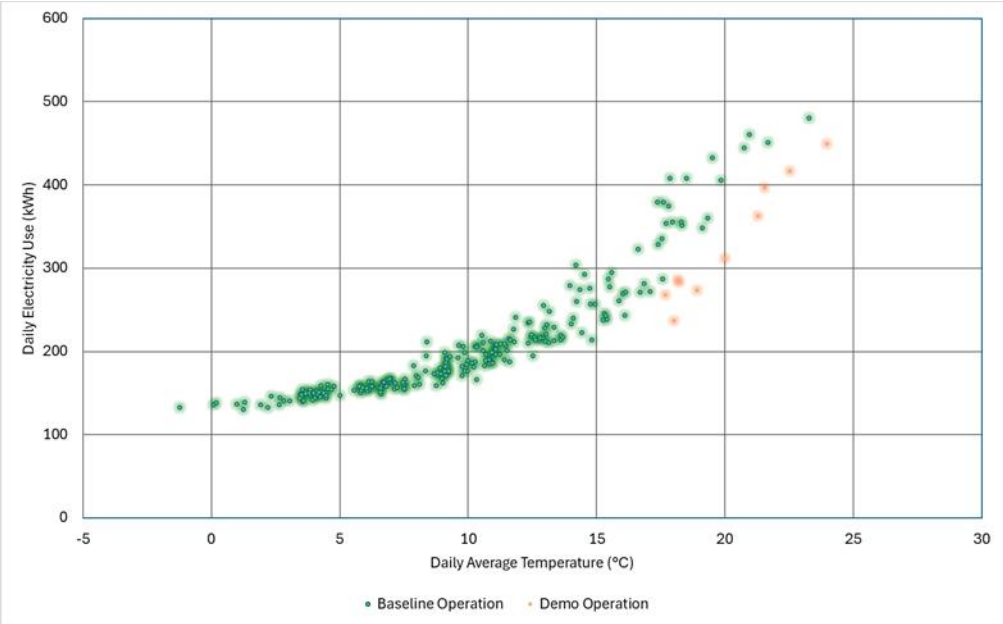

Figure 4. Operation of the test pack with and without the heat store.

5.4 Impacts

The impacts are;

- Reduced energy consumption. Expected savings of 20% of pack energy, however, more data required, as this was only measured during a 1-week summer period.
- Reduced load shedding required. In this example load shedding was eliminated in ambient temperatures, where it would be expected and other plant was load-shedding.

5.5 Business potential

The use of a parallel condenser in an existing pack has been shown to deliver significant savings in summer operation conditions. More work is required to evaluate realistic installation costs.

There is further potential in using the heat rejected by the condenser as the heat source for heat pumps to deliver space heating within store. This would offer an increased COP over air source heat pumps. At present many UK Supermarkets use gas to provide space heating, so significant carbon savings are available.

In the UK, many Supermarkets are extending the life of existing HFC systems. The water-cooled condenser could be increased in capacity to entirely replace the air-cooled condensers. This could offer both improved performance and reduced cost to replace end of life air cooled condensers.

6. DEMO 10 -FUTURE RETAIL DISPLAY

6.1 Description

The work in this demonstrator is focusing on optimising an advanced display cabinet based on best available technologies (BAT). These technologies include doors, short air curtains, proximity sensors and reflective packaging.

Chilled refrigerated display cabinets with open fronts rely on a fan-driven air curtain. This technology enables easy access for customers, while forming a barrier to the exchange of air. The aim of using the front air curtain is to minimise entrainment of the warm “moist” room air and protect the temperature of the products that are located at the front of the shelves. The air curtain is not perfect and causes entrainment into the chilled area mainly through turbulent mixing (Figure 5). As the length of the air curtain increases, so does its temperature and its ability to keep product cold at the bottom of the cabinet. A longer air curtain requires a higher flow rate to reduce this problem, increasing turbulent mixing. Short air curtains for open, vertical refrigerated display cabinets have been reported to provide between 25 and 36% reduction in total energy consumption, respectively, compared to a display cabinet with a conventional curtain (Hammond et al., 2016 and Pitchers et al., 2018).

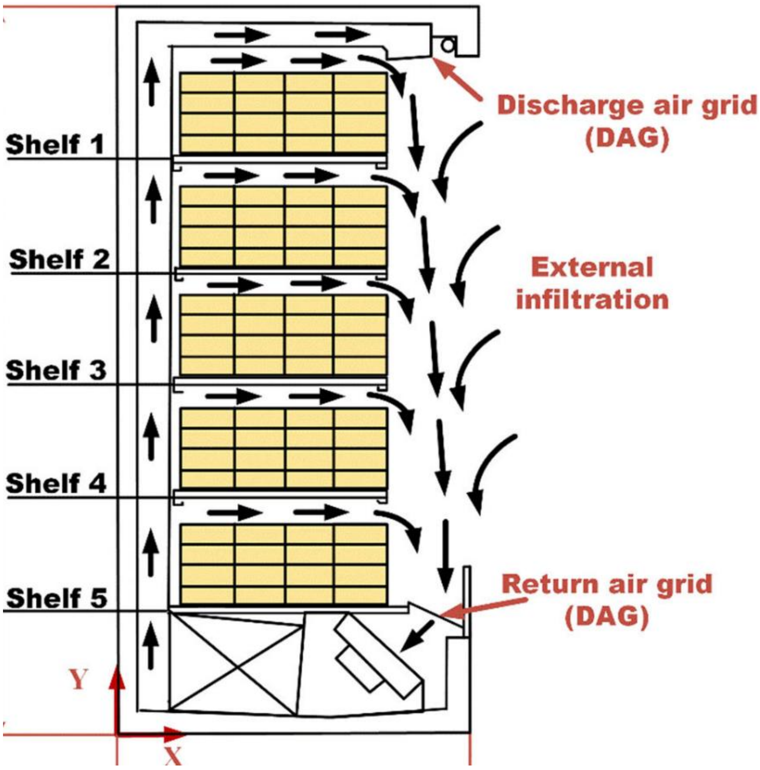

Figure 5. Vertical section of a typical open fronted refrigerated display cabinet from Yuan, et al. (2021) license under CC BY.

An additional activity is finally included to develop a methodology for measuring cabinet performances when the evaporator is overfed (not superheating the refrigerant inside the evaporator coils).

It has been widely demonstrated in the literature (Minetto and Fornasieri, 2011; Minetto et al., 2014; Tosato et al., 2020) that evaporator overfeeding in display cases can dramatically reduce energy consumption: it allows for proper use of the entire heat transfer area, thus eliminating the negative impact of refrigerant and/or air maldistribution and eliminates the boundary on maximum low evaporating temperature imposed by the need for maintain superheating. Evaporation temperature can be therefore increased with assessed benefit in COP for MT systems which can be as high as ~15% (Minetto et al., 2014).

However, the standard for performance measurements of display cases (EN ISO 23953-2: 2023) does not include the possibility of having overfed evaporators. This prevents manufacturers adopting this methodology to correctly declare the cabinet energy consumption values and does not reward their commitment toward emission reduction. A methodology is then needed to allow measuring the Total Energy Consumption (TEC) of a remote display cabinet when its evaporator is not superheated.

6.2 Application methodology and assessment

Short air curtain display cabinet

A cabinet was adapted to incorporate short air curtain technology. This involved shelves which incorporated vaned ducting to allow cold air to exit the shelves, forming sequential air curtains, and air to be returned to the evaporator to be re-cooled. To do this required the cabinet to be split into different sections along its length such that air could be delivered to the air curtains and returned to the evaporator (Figure 6).

This technology has been used for open fronted cabinets, however, there was still a considered potential for reducing energy consumption on cabinets with doors. Therefore, this cabinet had high efficiency doors fitted. Proximity sensors during door opening were simulated and reflective packages were tested. All tests were to the ISO/EN23593 test standard, which is used for Ecodesign energy labelling. The cabinet used CO_2 (R744) refrigerant (GWP=1) reducing GHG emissions from refrigerant leakage. The evaporator was fitted with variable speed fans to allow the ideal air flow to be achieved. This cabinet was optimised at the LSBU facilities to provide the best possible results in both open and doored configuration and for different temperature specifications.

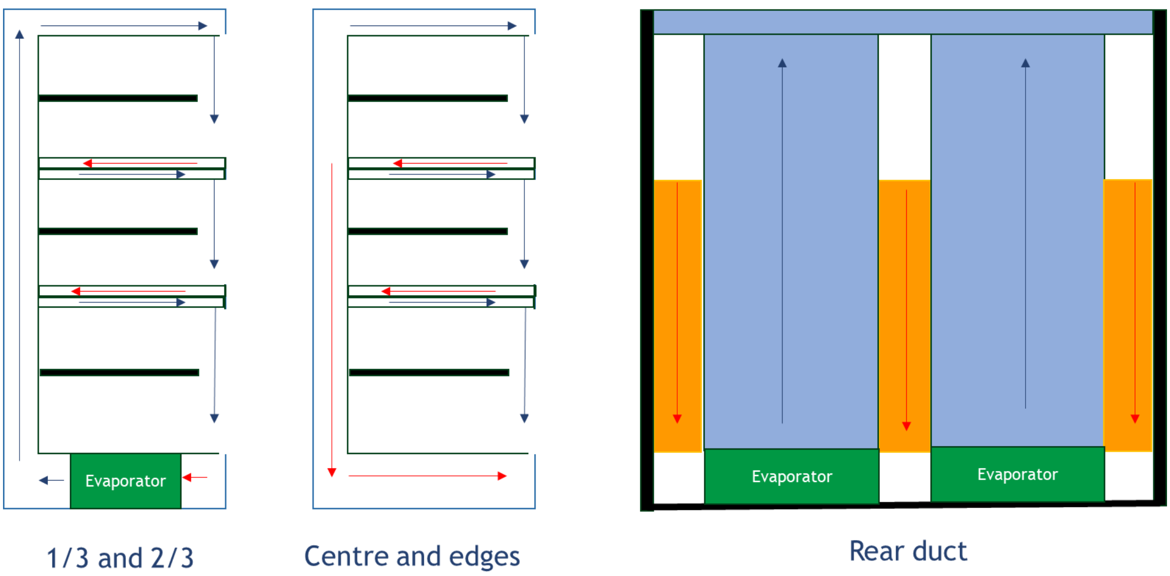

Figure 6. Short air curtain concept showing how air is discharged up the rear panels at 1/3 and 2/3 sections and returned to the evaporator in the centre and edges.

Methodology for testing cabinets with overfed evaporator

As for the measurement of TEC in a remote display cabinet under overfeeding condition, a specific test has been set up at Epta. A Low Temperature Vertical Cabinet with doors was selected, as performance improvement with freezer appliances has not been reported in the literature yet. The refrigerant is Carbon Dioxide. The system set up is presented in Figure 7.

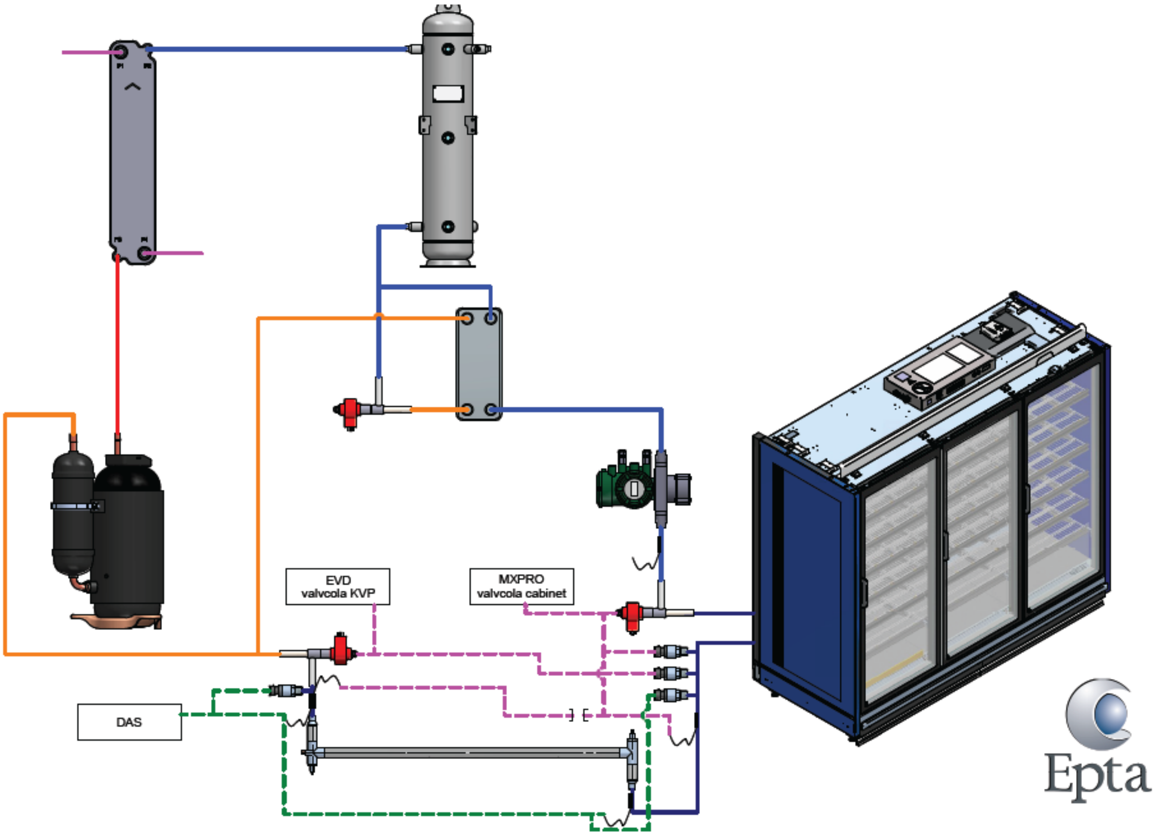

Figure 7. Experimental set-up to for testing overfed evaporator display cabinet.

The refrigerant enthalpy at the evaporator exit, which is required to evaluate the actual cooling/freezing capacity, is determined by heat balance at the heat exchanger installed at the evaporator exit (Figure 8). The heat exchanger was designed and manufactured by Epta.

Figure 8. Heat exchanger to measure enthalpy at evaporator exit.

6.3 Results

Short air curtain display cabinet

The open fronted short air curtain cabinet was able to operate at EN23953 M1/CC3 conditions. This meant that the cabinet operated with all test packs between -1 and 5°C whilst the ambient was 25°C and 60% RH. The cabinet had a range of temperature of only 5.3 K which is very low for an open fronted cabinet in CC3 conditions.

Adding double glazed, hinged doors had a great benefit to the cabinet, allowing the evaporating temperature to be increased significantly to -2.8°C limiting the need for defrosts when the cabinet was running at M0 (-1 to 4°C). At this temperature classification the temperature range was only 4.2 K. The EEI of 17.3 (Energy Class B) is class leading for a 2.5 m supermarket. Running the cabinet at the higher temperature classification of M2 (-1 to 7°C) allowed the evaporating temperature to be increased to 0°C eliminating the need for defrosts.

The major drawback is that the shelves in the cabinet are not moveable, however supermarkets do not always adjust shelves even though there is a perceived need to do so.

The benefits of reflective packaging are unlikely to outweigh the costs and carbon associated with the packing, for chilled product. However, there is significantly more benefit for freezer cabinets.

The benefits of sensors to turn lights off when customers are not present obviously depends on the level of customer footfall. In tests where a typical usage was applied the results demonstrated small but significant energy savings. For a technology that requires minimal costs to apply this is worthwhile.

Methodology for testing overfed evaporators

Methodology for testing overfed evaporators is under finalisation.

6.4 Impacts

Short air curtain display cabinet

One of the major benefits of the short air curtain technology is that that product is maintained at a low chilled temperature (<4°C) within a very tight temperature band (4.2 K). This reduces food waste and provides less variability in product shelf life as all products are stored at a low temperature without freezing.

In addition, the technology enables the cabinet to be very energy efficient with, possibly, the lowest EEI (EEI of 18.3, Energy Class B) of a 2.5 m vertical chilled display cabinet sold in Europe. According to EC (2025) vertical display cabinets used more than 30 TWh of energy in 2020. The most popular energy class for commercial refrigerator on the European Product Registry for Energy labelling (EPREL) in June 2025 was a D. A mid-range B class display cabinet uses 65% less energy than a mid-range D class. Therefore, using a very crude calculation, applying best available technologies could potentially save the EU 19.5 TWh of energy accounting for 4.4 $MtCO_2e$.

The high evaporating temperature (-2.8°C) at M0 and 0°C at M2, reduce the possibility of icing and need for defrost which is a major cause of failure in refrigerated display cabinets.

Although the short air curtain technology has been shown to increase energy efficiency, the technology does not allow shelves to be moved and the TDA of the cabinet is smaller than equivalent cabinets.

The benefits of reflective packaging are unlikely to outweigh the costs and carbon associated with the packing, for chilled product. However, there is significantly more benefit for freezer cabinets.

The benefits of sensors to turn light off when the customer is not merchandising have limited benefits with high efficiency LED lights, however, the savings are not insignificant.

Methodology for testing overfed evaporators

The possibility of testing evaporators under overfeeding conditions will give visibility to manufacturers already producing and installing this kind of technology and will encourage the remaining ones to adopts this methodology, thus leading to already documented energy and operational benefits.

6.5 Business potential

Short air curtain display cabinet

The owner of the IP is not willing to share any information on this.

Methodology for testing overfed evaporators

Being Commercial Refrigerators subject to Regulation (EU) 2019/2024, Regulation (EU) 2019/2018 and reported in the EPREL list, the establishment of a methodology for testing and declaring energy values according to overfeeding methodology can represent a relevant commercial advantage.

7. DEMO 11 -THERMAL STORAGE UNIT FOR REFRIGERATION CYCLE

Demo 11 combines two distinct technologies for thermal energy storage in refrigeration systems: an integrated unit known as “Thermosiphon Thermal Accumulator (TTA)”, and a centralised unit referred to as "Centralised Cold Thermal Energy Storage (CTES)".

7.1 Description

Thermosiphon Thermal Accumulator (TTA)

A novel approach combining a latent heat accumulator and a thermosiphon was investigated for cold storage in refrigeration systems. The TTA is designed to substitute the refrigeration cycle during both planned power outages - as part of demand-side management (DSM) strategies to reduce energy consumption and support the integration of intermittent renewable energy sources - and unplanned power outages, in the event of sudden compressor failure, in order to extend product shelf life. A laboratory-scale prototype, reaching Technology Readiness Level (TRL) 7, was developed at the FRISE Laboratory (INRAE, France) (see Figure 9).

Figure 9. TTA laboratory prototype at the FRISE facility (INRAE, France).

The TTA demonstrator uses a paraffin mixture as a phase change material (PCM: RT-4 from Rubitherm) and a commercial closed vertical refrigerated display cabinet (OFFLIP 2 Eco DV; 200 × 134.5 × 70.5 cm) as the vapour compression system (Figure 9) Positioned outside the cabinet, at the upper rear section, the TTA does not occupy the space intended for refrigerated products, and there are no limitations on the quantity of PCM that can be used. Furthermore, the system operates without a secondary refrigerant, thereby increasing thermodynamic efficiency and eliminating the cost of installing an additional refrigerant loop.

During the charging phase, thermal energy is stored in the TTA while the refrigeration system continues to operate without any negative impact on its cooling performance (Figure 10). In the discharging phase (i.e. without electricity), cold is transferred back to the evaporator through the thermosiphon effect. The charging and discharging processes are independent of the evaporator technology used, making the TTA adaptable to any vapour compression cycle system. Both the display cabinet and the TTA are fitted with calibrated T-type thermocouples to monitor air and product temperatures, along with a power meter to record energy consumption (Figure 11). The cabinet was loaded with methylcellulose packages (20 × 10 × 5 cm) to simulate food products. Compressor shutdowns lasting 1.5 hours were carried out to simulate DSM events and assess the TTA's response.

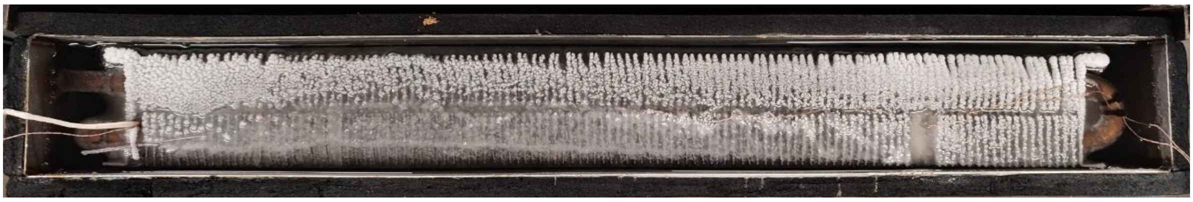

Figure 10. TTA during the charging phase.

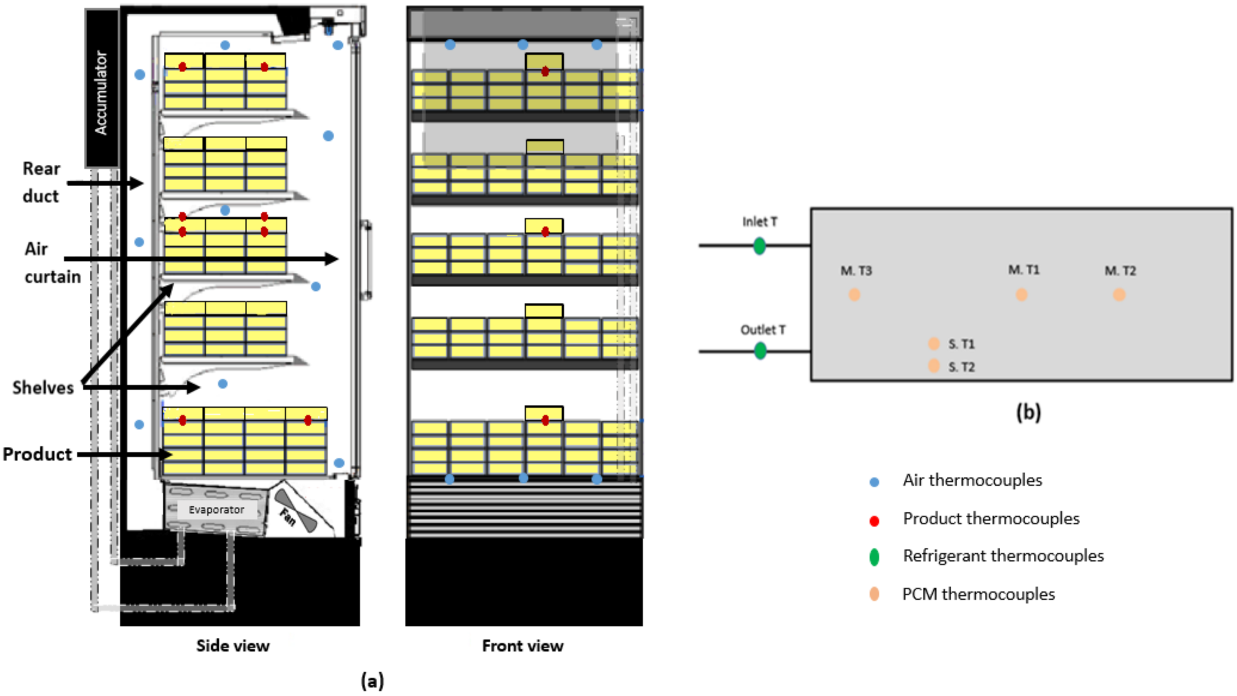

Figure 11. Temperature measurements of air and product (a); PCM and refrigerant (b).

Centralised Cold Thermal Energy Storage (CTES)

A centralized cold thermal energy storage (CTES) system in a supermarket is installed in a REMA1000 shop near Oslo, Norway. This demo-site was not initially planned in the beginning of ENOUGH; however, it is presented here as it can provide valuable insights into implementing thermal storage for load shifting and food security in a centralised system, thereby enhancing the project impact and potential for exploitation and complementing what already demonstrated in D11.

Such centralized CTES technology, which enables cooling of food in supermarket display cabinets by using stored cold in a CTES system, has not yet been demonstrated, however it retains a potential. In 2024, a first step was taken with a CTES demonstrator integrated with an CO_2 refrigeration system in a REMA1000 supermarket as part of a national research project. The CTES unit is used to store cooling provided by the refrigeration pack of the supermarket during the night to be actively used for cooling the interior of the entire supermarket during the day. The charging capacity toward CETS can be flexible and adjusted, to enable the centralised refrigeration system able to operate efficiently, i.e. avoiding part load operation. The plan was to adapt this CTES system in operation for serving the refrigeration demand in selected display cabinets in the supermarket (currently at TRL 7).

Figure 12 shows the upper part of the pillow plate type CTES unit, where water is entirely flooding the space between the pillow plates, where CO_2 is evaporated and ice is building up on the pillow plate surfaces during charging. During discharging, CO_2 condensing inside the pillow plates and the ice is melting.

Figure 12. Top view of the CTES unit in the workshop, not charged with water. (Photo: Cartesian.no).

As mentioned above and shown in Figure 13, the existing R744 refrigeration pack and the CTES unit provides independent cooling (AC) for the supermarket via an evaporator (DX) inside the Air handling unit (AHU), which is the centralized air handling system for the entire supermarket.

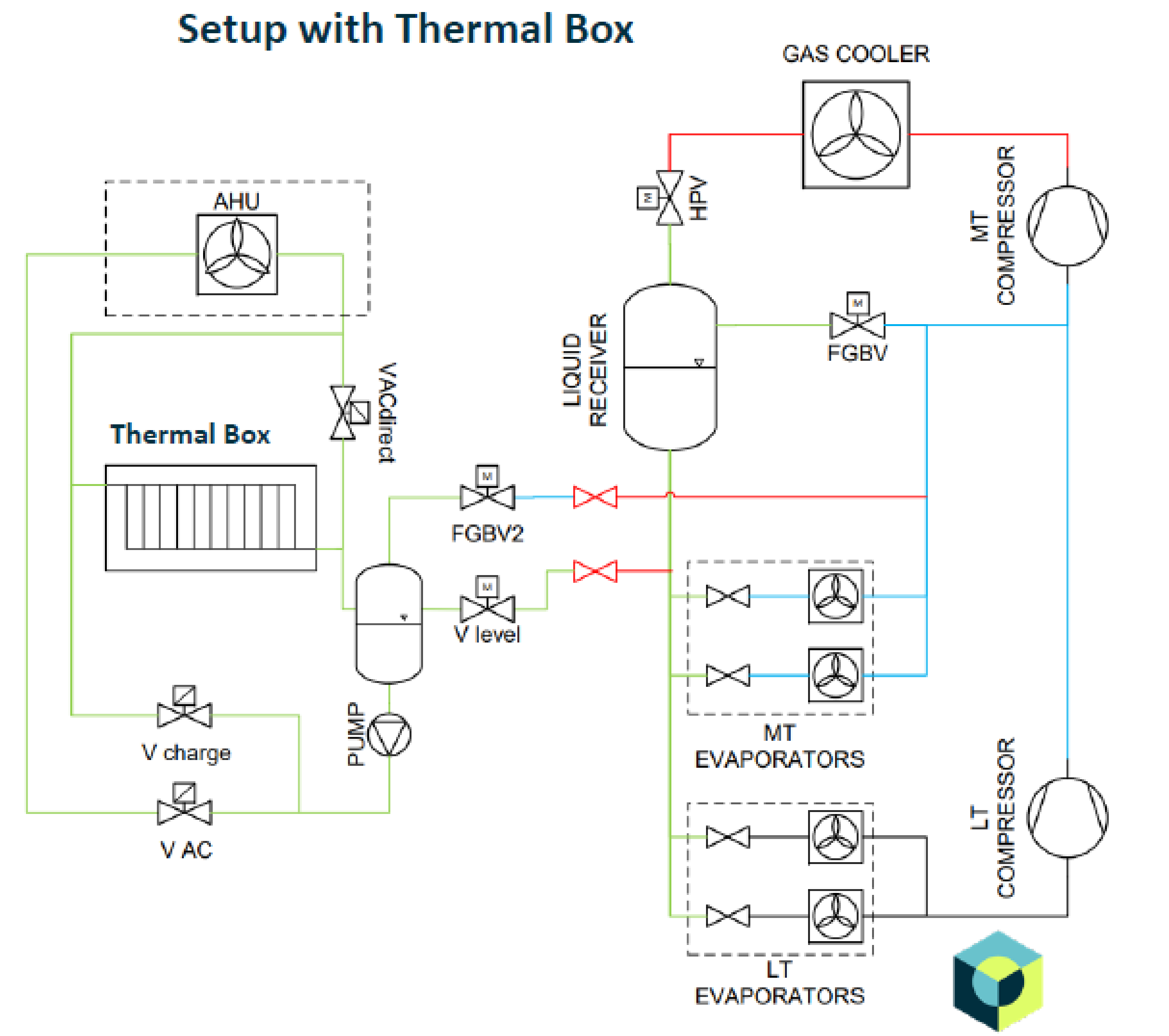

Figure 13. Simplified P&ID of the CO_2 booster system with the integrated CTES (thermal box) circuit, providing AC via the air handling unit (AHU). (ref: Cartesian.no).

Figure 14 indicates the location of the thermal storage device outside the building, side by side of the existing gas cooler. The CTES receiver and pump is located in the machine room, next to the refrigeration pack.

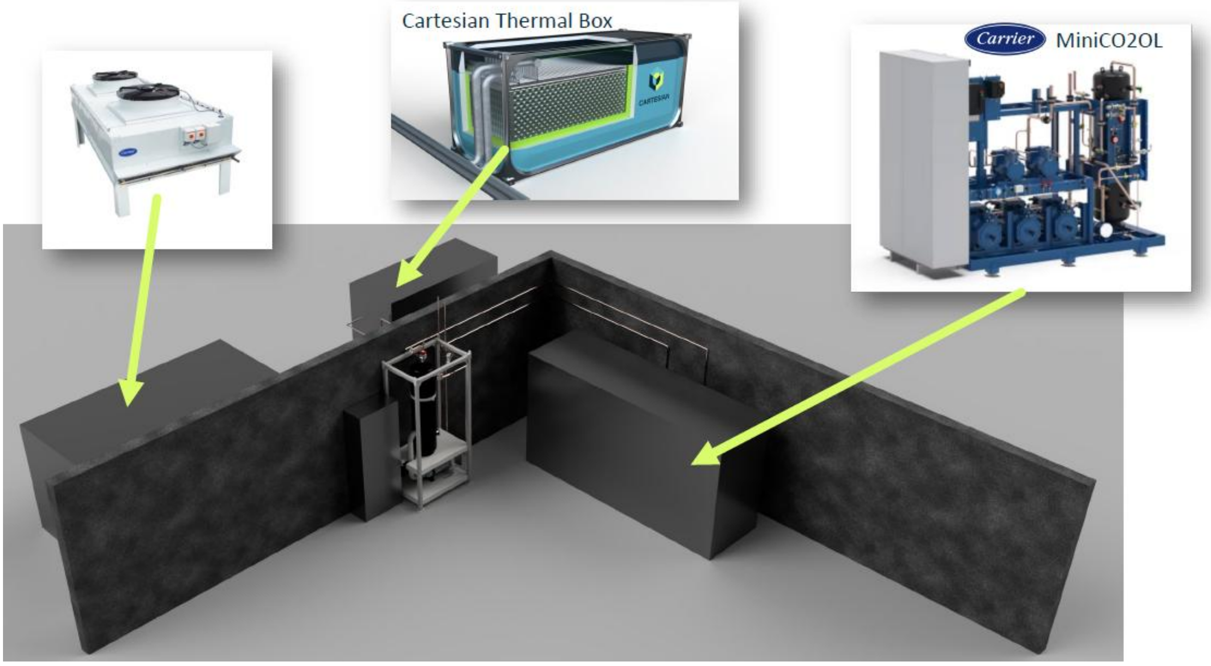

Figure 14. Location (inside and outside) of the major CO_2 booster and CTES components. (ref: Cartesian.no).

Figure 15 shows the simplified layout of the supermarket, indicating the new refrigeration lines (in red on top of the figure) required from the CTES unit towards and back from the display cabinets.

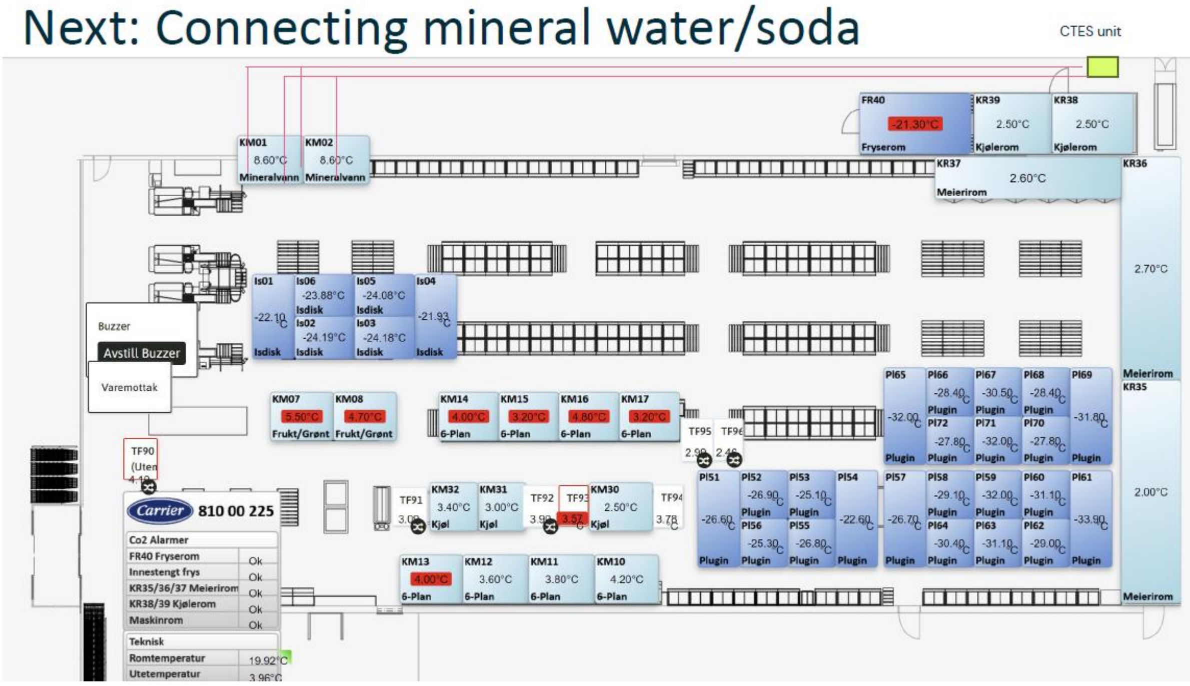

Figure 15. Proposed connection of food cabinets KM01 and KM02 into the loop of the CTES circuit. (ref: Cartesian.no).

Figure 16 illustrates the connections, requiring four on/off valves to enable a possibility to switch between normal or CTES operation of the two display cabinets with a nominal capacity of 3.75 kW each.

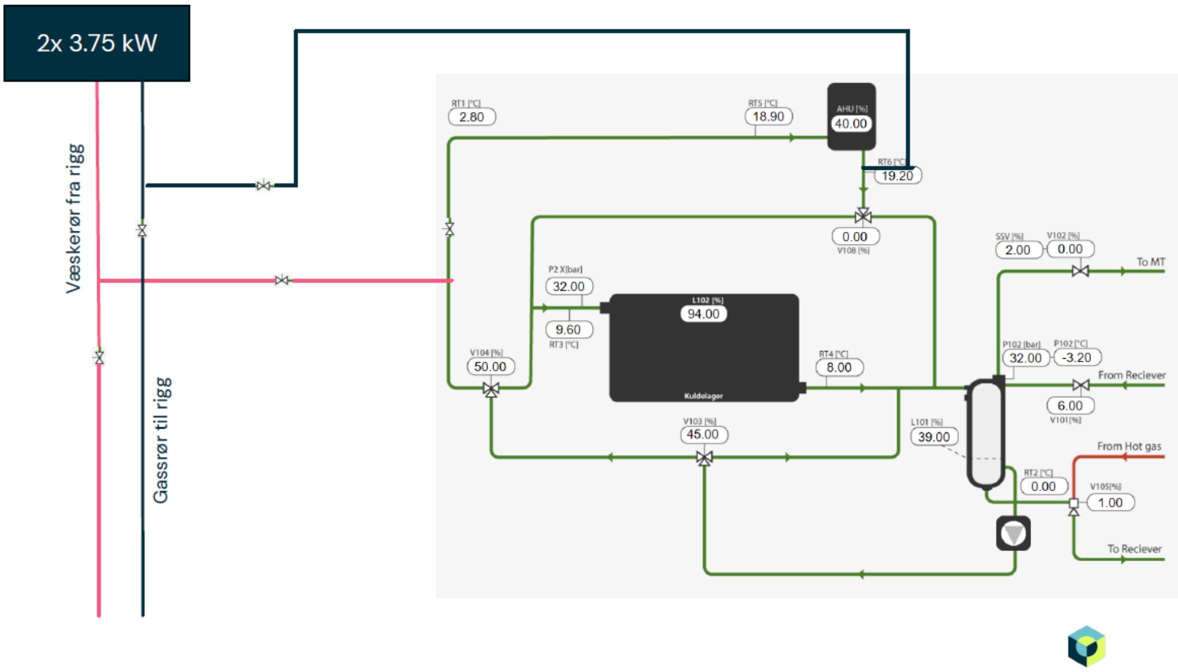

Figure 16. Proposed connection (CO_2 pipes: red and black) towards and back from the food cabinets KM01 and KM02 with an expected cooling demand of 2x 3.75 kW. (ref: Cartesian.no).

7.2 Application methodology and assessment

Thermosiphon Thermal Accumulator (TTA)

Developed for easy integration into any device using a vapour compression cycle as part of a refrigeration system, including display cabinets (e.g. in supermarkets or convenience stores), professional catering equipment as well as household refrigerators and freezers.

The system has been fully designed and is protected under Patent No. WO 2020/201116 A1.

Centralised Cold Thermal Energy Storage (CTES)

Developed for supermarkets.

Designed in detail and received a quote from vendor.

7.3 Results

Thermosiphon Thermal Accumulator (TTA)

The reliability and energy performance of the TTA were tested under a range of operating conditions, including variations in ambient and thermostat temperatures, product loads, door-opening scenarios, types of PCMs, and single/multiple DSM events within a day. The results demonstrated that the TTA consistently delivered cold energy to the cabinet across all scenarios, maintaining product temperatures within regulatory limits. Figure 17 illustrates the evolution of air temperature in an empty cabinet during a compressor shutdown, with and without the TTA. Figure 18 presents the evolution of product temperature during a compressor shutdown, with and without the TTA operating this time a fully loaded cabinet (90% of the storage volume occupied).

Under all tested conditions, DSM experiments did not result in higher daily energy consumption compared to standard operation. In fact, energy use decreased by up to 7% in some cases, corresponding to about 15 g of CO_2 saved per day, based on an emission factor of 63 g CO_2/kWh (RTE-

France, January 2025 projection). This reduction is due to an increase in evaporation pressure and temperature, which results in fewer compressor restarts and a lower compressor duty cycle.

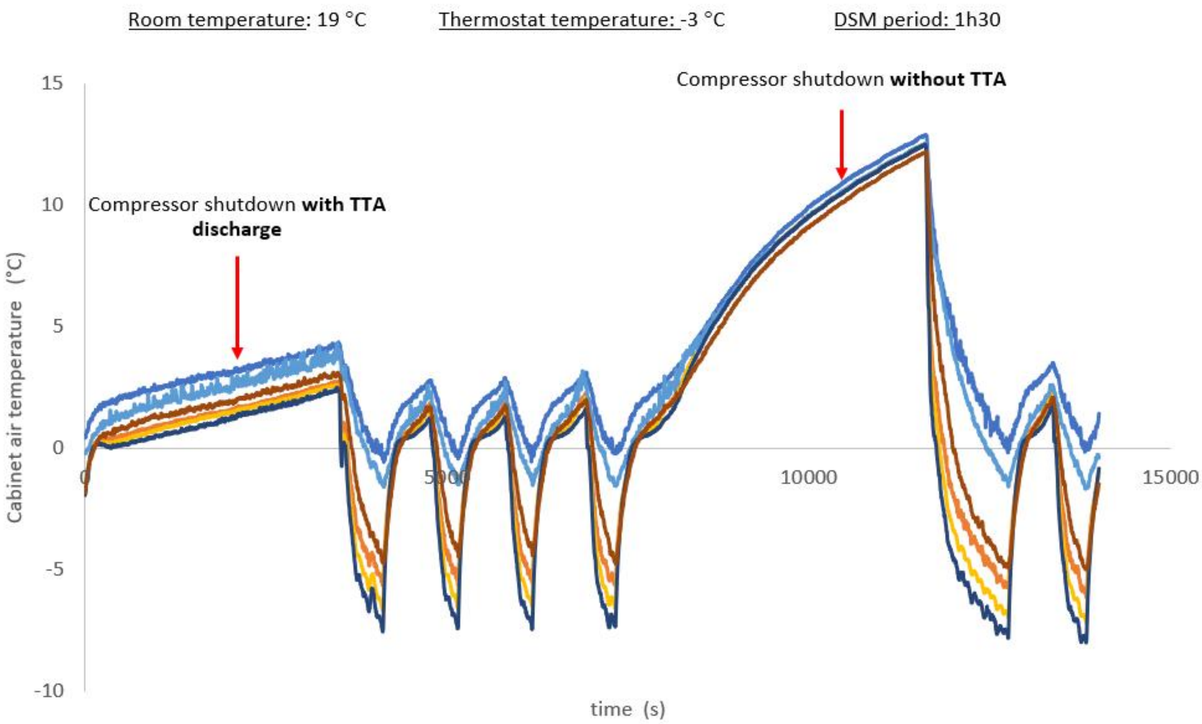

Figure 17. Evolution of air temperature during two compressor shutdowns, with and without TTA.

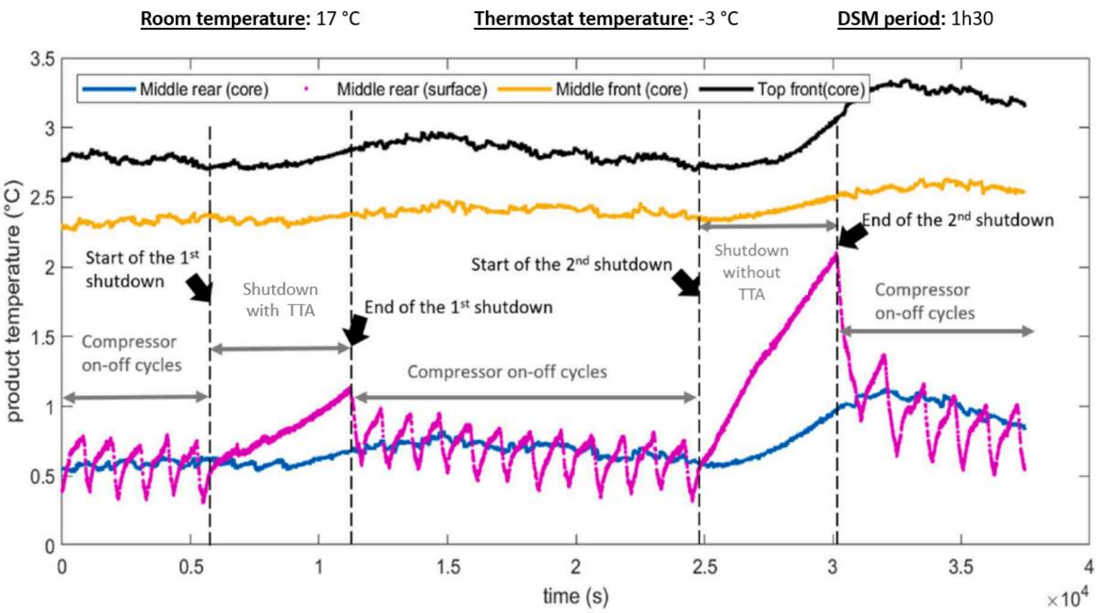

Figure 18: Evolution of product temperature during two compressor shutdowns, with and without TTA.

To enhance charging/discharging efficiency - a key performance factor - the TTA design was optimised using COMSOL Multiphysics software. The numerical study focused on two optimisation criteria: the solid fraction of PCM after one hour (i.e. the proportion of frozen PCM) and the PCM ratio in the accumulator (i.e. the proportion of PCM relative to the total volume of the accumulator). This optimisation aimed to maximise heat transfer between the refrigerant and the PCM. As a result, the PCM solid fraction after one hour increased from 76.6% to 100%, and the PCM ratio from 76.2% to 80.4% (Figure 19). These optimisations provide a solid foundation for developing a better integrated TTA system with enhanced charging and discharging performance.

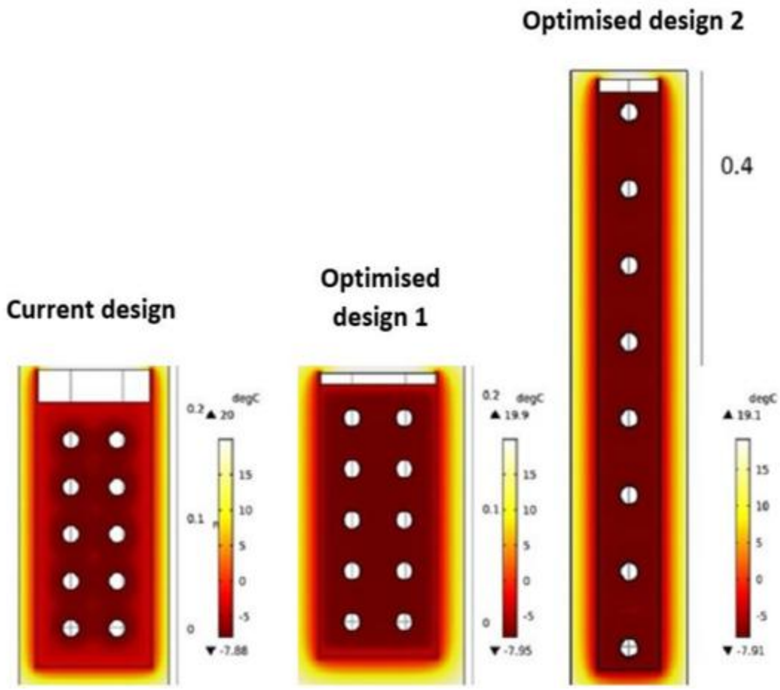

Figure 19: Comparison of accumulator geometries: temperature profile at 3600 seconds.

Centralised Cold Thermal Energy Storage (CTES)

Based on gained experience with AC system, potential benefits of the centralized demonstration of a Cold Thermal Energy Storage device, applying water as the phase change material, supporting the cooling of food and providing AC with CO_2 as the working fluid are as follows:

This technology can demonstrate significant load shifts from the refrigeration unit. This has an impact on the future design of such refrigeration systems, as the maximum cooling capacity will be provided by a combination of the full load operation of the refrigeration system and by unloading the CTES unit at the same time. Therefore, if the maximum required capacity is equal to current systems, less capacity needs to be installed and the footprint inside the machine room might be reduced (when the storage device is placed outside the machine room). The total CAPEX is reduced as less compressors are required.

By adding several cabinets of the supermarket to the CTES, food safety in case of a power outage can be secured, reducing the food waste challenge after power cuts lasting many hours. This can be managed without operating the large capacity refrigeration pack as only the low energy demanding CO_2 circulation pump and the fans inside the cabinets need to be operated by the emergency electric battery pack.

Despite the detailed design and effort during the final year of ENOUGH, no results can be reported, but the manufacturer of the unit is able to supply these CTES system across Europe to any potential customer.

7.4 Impacts

Thermosiphon Thermal Accumulator (TTA)

- Significant reduction in energy consumption (up to 7%).
- Its flexibility enables users to manage their energy consumption more effectively. For example, by scheduling TTA charging during off-peak hours when electricity is cheaper and discharging during peak demand periods, it helps lower energy costs.
- Can help users adapt to the intermittency of renewable energy by allowing them to switch between the refrigeration system and the TTA in case of compressor shutdown, thereby promoting greater use of these sustainable solutions.

Centralised Cold Thermal Energy Storage (CTES)

- Food securing device, in case of power cuts, cooling can be provided inside the CTES connected cabinets.
- Smaller refrigeration capacities installed in the centralized refrigeration pack and simpler capacity control as cooling demand can be adapted by more, or less charging of the CTES.

7.5 Business potential

Thermosiphon Thermal Accumulator (TTA)

The TTA technology is highly versatile and can be integrated to any vapour compression cycle system, whether in existing equipment or new devices. Furthermore, the technology is well known to the EPTA Group following collaboration efforts during the project.

Centralised Cold Thermal Energy Storage (CTES)

The technology is commercially available, and the solution can be specifically designed and customized.

8. DEMO 16 – REFRIGERATED STORE HEAT ADVANCED RECOVERY

8.1 Description

Cold stores (chilled and frozen) generate significant quantities of waste heat as a by-product of the operation of refrigeration plants. Currently the heat generated is rarely reclaimed and used (the exception is underfloor heating in frozen cold stores). Significantly more heat reclaim is possible. A UK assessment of cold stores with greater than 250 kW waste heat output (total of 193) estimated that 404 MW of heat was available. Approximately 74% of the heat was estimated to have been rejected at temperatures between 21 and 27°C, and up to 26% at 60 to 90°C (Davies et al., 2023).

Cold stores generally have requirements on site for heating for offices, roof voids above the store, dehumidification systems, hot water, heating of some higher temperature rooms at some point during the year (e.g. banana ripening) and processes such as tray washing. These heat demands are never connected to a waste heat source (condensers, oil coolers, waste heat from dehumidifiers) and so are supplied by gas or electricity. Approximately 40% of the energy required by a cold store is used for non-refrigerated purposes of which at least half is related to heating.

Cold stores are generally located on industrial estates where there is a need for space and process heating. Potentially the waste heat could contribute to a heat network providing resources to the local area.

The carbon intensity of electricity fell to a record-low 162g CO_2/kWh in 2023. This is now lower than natural gas which is 184 g of CO_2e/kWh. The wholesale cost of both electricity and gas spiked several times in 2021/22, but have now stabilised at a level which is higher than pre-crisis levels. Therefore, the benefits of heat reclaim are more financially attractive than they were pre-crisis levels. Decarbonising heat is a major initiative across all of Europe. Natural gas is used widely in the food industry and needs to be removed from the energy network to create a zero-carbon future. Heat reclaim has the potential to remove natural gas and reduce energy demands from electricity.

Removing gas and integration of waste heat has significant potential to reduce emissions from cold stores. It is estimated using data from the project partners that the emissions savings from removing gas can be between 450 and 1,350 tonnes CO_2e per year for a typical regional distribution centre (RDC). Some further savings could be achieved if the heat reclaim system also reduced the refrigeration system condensing temperature at the RDCs. This could increase the carbon emissions savings by a further 2-5%. The 9 largest UK supermarkets in the UK operate a total of 141 RDCs. If waste heat technology could be applied to all of them it would conservatively save more than 65,000 tonnes CO_2e per year.

8.2 Application methodology and assessment

The two cold storage sites that have been selected are at Avonmouth and Falkirk in the UK. These sites represent the two main types of refrigeration systems used in distribution centres, namely centralised ammonia 2-stage systems and ammonia/carbon dioxide cascade systems.

Avonmouth

The Avonmouth site is a particularly attractive prospect because it has a higher gas consumption than most sites due to the tray wash facility, which has a significant heat requirement. Two sources of heat reclaim from the ammonia refrigeration plant have been considered: de-superheating of the high stage ammonia and heat reclaim from the compressor oil coolers.

De-superheating was found to have the potential to supply useful amounts of heat at moderately high temperatures. It would not be sufficient to fully replace gas heating on the main heating assets (tray wash water heaters) but could provide partial pre-heating of the water supply. Alternatively, it could be used for low temperature hot water and/or domestic hot water heating. If these options are deemed feasible, the project plan calls for designs and costings to be produced and if cost-effective, equipment installed to demonstrate the application.

Heat from the oil coolers is already used successfully to heat the underfloor heating mat under the frozen store floor to prevent frost heave. There are indications however that temperatures in the mat are higher than required, possibly resulting in addition of unnecessary heat loads to the store. This use of reclaimed heat could readily be used for demonstration purposes.

Falkirk

Falkirk represents the other type of refrigeration system and has roof void heating as a potential application for heat recovery.

At Falkirk the possibility of reclaiming heat from the evaporative condensers was considered.

Both the refrigeration and void systems are monitored. This allowed an assessment to be made of the practicality of directly heating the void and using a heat pump to supply heat to the void.

It was found that the condensing temperature was too cold to supply heat at a sufficient temperature and that there was insufficient heat available from the superheated refrigerant. A heat pump was considered as means of using reclaimed heat.

8.3 Results

At Avonmouth, monitored data was used to estimate how much heat could be reclaimed via a desuperheater. It was found that the total heat available from desuperheating was an average of 70 kW. The tray washes had a requirement for 330 kW of heat. The tray wash was 200 m from the refrigeration plant which would make interconnection expensive and difficult to justify. The tray wash operation ceased in 2024, so no further investigation was carried out.

At Falkirk the annual void heat requirement was 910 MWh. 170 MWh of this comes from the circulating fans and the remaining 740 MWh is supplied by natural gas heating. It was found that the significant distance between the refrigeration system and the air handling unit for the roof void together with the need for a heat pump to raise the temperature of the waste heat meant that the scheme would not be viable.

Modifying the refrigeration system to extract heat using for example a water-cooled condenser was found to be impractical due to cost and risk to the operating plant. An alternative proposal has been developed using the water in the sump of the evaporative condensers as the heat source for a water-to-water heat pump. This approach would allow access to a high temperature heat source without the requirement to modify the existing refrigeration circuit, which is prohibitively expensive.

An experiment was conducted to determine whether the sump water was a useful heat source for a heat pump. The condenser fans during normal plant operation were disabled for a 5-minute period to allow heat gain in the sump water to be measured. The temperature gain by the condenser water was from 25 to 33ºC (a temperature rise of 8 K). Using the refrigeration monitoring system, the total heat rejection of the condenser was calculated for the same period. The sump water was found to retain 41% of the total heat of rejection of the compressor. This amounted to 508 kW.

It is strongly recommended that heat recovery should be considered in the design of new RDCs. Implementing a water-cooled condenser with a separate cooling tower would allow future integration with waste heat utilisation schemes. As a low-cost measure, specifying valved connections for heat recovery heat exchangers within an otherwise standard refrigeration system would be a minimal cost option which could provide the flexibility for later integration with heat recovery systems. At a minimum a comprehensive review of all heat demands on a site should be undertaken prior to finalising the specification of the refrigeration system, ensuring that opportunities for energy efficiency and sustainability are not overlooked.

8.4 Impacts

Designing RDCs with heat recovery in mind is a cost-effective way to decarbonise the sector.

Specifying the refrigeration system with valved connections for heat recovery heat exchangers, allows flexibility in adding heat recovery in the future.

For existing systems, water in the sump of the evaporative condensers provides a plentiful quantity of heat which is relatively cheap to recover.

8.5 Business potential

Avonmouth

The energy centre where the refrigeration plant is located is 200 m from the offices. There is a total of 72.3 kW of heat available from the desuperheater to pre heat domestic hot water or for LTHW heating.

The budget price for supply, installation and commissioning of the de superheater, buffer tank, pumps and 400 m of pipework would be £165,000. This does not include any heat exchangers to the domestic hot water or LTHW.

The gas cost at Asda is 8.3p/kWh. If the average of 72.3 kW of available heat from the desuperheater can be fully utilised all year round to replace domestic hot water or LTHW heating, which is presently heated by gas, then the saving on gas is £54,531 (not accounting for pumping power costs). The ROI is, therefore 3 years.

Falkirk

Using the condenser water as a heat source for a heat pump to meet all space heating demand would need to provide a heat output of 340 kW.

The budget price for the supply, installation and commissioning of heat pump, 10 m^3 buffer tank, 500 m pipework and pumps is £450,000 nett. This does not include any heat exchangers in the air handling units.

The annual heat requirement of air preheating is 880,000 kWh and void heating is 360,000 kWh - a total of 1,240,000 kWh. The cost to heat with gas is £102,920 (based on 8.3p/kWh). Power consumed by the heat pump motor is 70.2 kW for 400 kW of heating which is a CoP of 5.7. Pumping power has not been included.

The electrical energy used by the heat pump to produce 1,240,000 kWh of heat is 217,544 kWh. Electricity cost at Asda Falkirk is 26p/kWh, therefore total heat pump electrical cost is £56,561 nett. Nett saving is £46,359. ROI is 9.7 years.

9. DEMO 19 – CO_2 PRESSURE EXCHANGER FOR RETAIL

9.1 Description

A pressure exchanger (PX) has been proposed in recent years as a device able to recover expansion work and improve the performance of a vapour compression refrigeration system.

The proposed sector of application is **all retail application of refrigeration with natural refrigerant R744**, so any kind of food or beverage refrigeration equipment with the following general objective to bring the TRL level to 8 starting from level 6.

Pressure exchangers are commonly used in desalinisation plants with water as the working fluid. One first challenge is to realise a PX capable to operate with CO_2 within the envelope of pressure, temperature and mass flow rates of typical retail refrigeration plants. Compared to the desalination open circuit, the main challenge in the application of pressure exchangers in closed circuits is the need to overcome the pressure losses that inevitably occur within the system. A positive pressure gradient is always needed between HPin and HPout, and between LPin and LPout (see component layout in Figure 20), to guarantee the correct flow direction.

Proposed cycle layout

A novel cycle architecture is proposed as depicted below, guaranteeing correct cycle operation on one side while reducing complexity on the other.

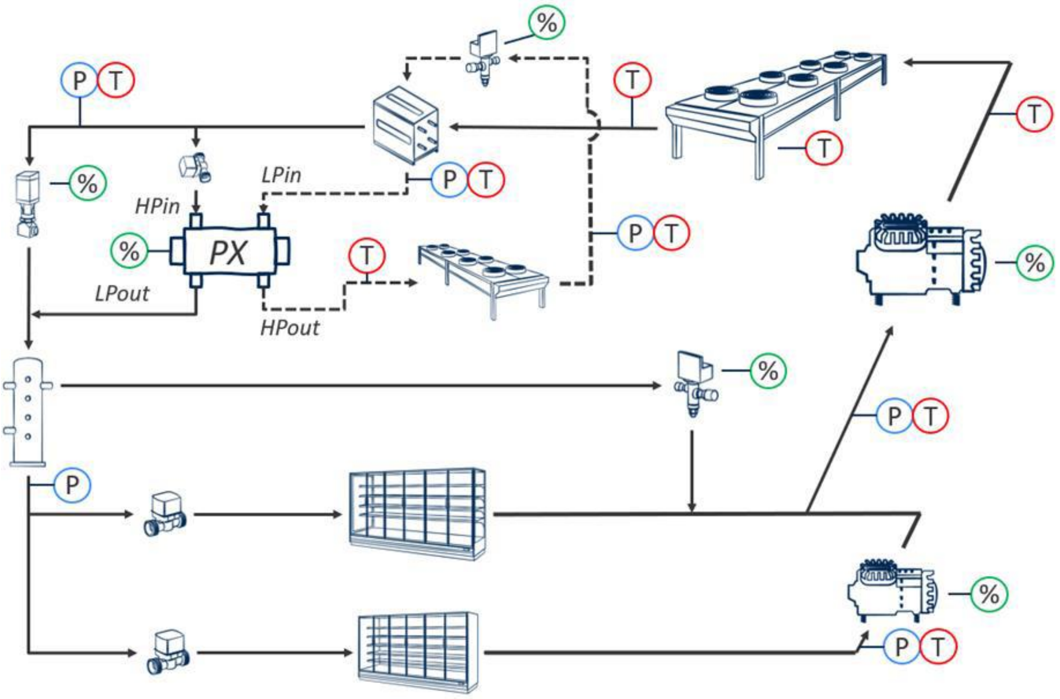

Figure 20. XTE system concept and main component layout.

The PX system has been implemented in a standard transcritical CO_2 pack connected to a refrigeration system serving a 10,000 m^2 hypermarket in Hungary, with a total installed cooling capacity of 40 kW at low temperature (LT / -33°C) and 140 kW at medium temperature (MT / -8°C) level, with a design gas cooler outlet temperature of 42°C. The refrigeration pack is connected to more than 130 refrigerated cabinets, with mainly closed chilled, frozen vertical and semi-vertical cabinets, in addition to some serve-over cabinets.

The equipment is entirely controlled by standard parametric controllers, including the PX module. The PX module is connected to the gas cooler return line via a three-way motorized valve, so that it can be excluded from the rest of the system if needed.

All the sensors and controllers are connected to a data network acting as an acquisition system. The relevant variables for the data post processing are collected with standard NTC temperature probes, 4-20mA pressure probes, and recorded with a sampling time of 30 s. A use phase with changes in operation was monitored to record operational data for summer winter and midseason to verify the behaviour of the plant.

9.2 Results

Being a real installation, energy consumption is related to the main parameters of the working plant. These major parameters are the temperature at the gas cooler exit, the evaporating temperature of both the LT and MT stages and the ratio of the LT versus MT load. Hence, to allow a fair comparison, more than 120,000 sampling points from the overall dataset have been filtered according to the following criteria: $Te_{vap,MT}$ is filtered from -13°C to -11°C, $T_{evap,LT}$ is filtered from -34.5°C to -33.5°C, and Q_{LT}/Q_{MT} is filtered from 0.45 to 0.55.

In term of efficiency, the COP of the enhanced PX system, when compared to standard trans-critical architecture, shows an average improvement ranging from 8.0 to 15.1%.

The installation, showed efficiency gain of up to 15% on average compared to standard booster systems, with ambient temperatures higher than 20°C, and allowing a reliable and more efficient operation up to 45°C.

Additionally, we also found an increase of cooling capacity for a given compressor set, thanks to the higher cycle efficiency. This effect is particularly interesting for retrofitting existing installations where, due to increasing ambient temperatures, the installed equipment is not sufficient to cover summer peaks.

A detailed analysis of results and description of methods will be found in a paper that will be presented at the 1st IIR International Conference on Refrigeration Adapting to Rising Temperatures in August 2025 (Trabucchi et al., 2025).

9.3 Impacts

The proposed innovation aimed to increase the efficiency of R744 refrigeration plant. The demo showed an average improvement ranging from 8.0 to +15.1%.

The main impact of this technology is making natural refrigerant solutions more efficient in general and particularly at higher ambient temperature (30 °C to 40 °C). For a given required cooling capacity, the PX allows to decrease the size of the refrigerating pack. Alternatively, the same effect could also be used to increase the capacity of an existing plant.

9.4 Business potential

The business potential is linked with the costs of the equipment which is mainly dominated by the PX device. The potential today is already good, and the rise of volume production can bring some further cost saving that consequently will increase it. The business potential is also increased by the possibility to create equipment for retrofit, applicability is then larger and not limited to new installations only.

GENERAL CONCLUSIONS

10. GENERAL KPIS/IMPACT

Using the TES in Demo 9 allows 20% energy savings, this would represent a saving of 16,000 kWh per annum or 2,800 kg CO_2e (based on UK government conversion factor for 2025), as well as moving demand away from the high CO_2 intensity period leading to DSR.

The refrigerated retail display cabinet of Demo 10 demonstrated an EEI of 17.3 (Energy Class B). This is class leading for a 2.5 m supermarket cabinet.

An implementation of CTES enables to secure foodstuff during power outage periods, while operating the refrigeration system via battery power without compressors. The installed cooling capacity can also be reduced, as the maximum cooling capacity can be provided simultaneously from the compressor rack and the charged CTES in high demand situations.

Recovering heat from the desuperheater of an RDC to pre heat domestic hot water for LTHW heating can provide 72.3 kW of heat to replace domestic hot water or LTHW heating, which is presently heated by gas, giving an ROI of 3 years.

Using the condenser water from an evaporative condenser as a heat source for a heat pump for an RDC to meet all space heating demand gives an ROI of 9.7 years. This includes installation and commissioning of heat pump, buffer tank, 500 m pipework and pumps, but does not include any heat exchangers in the air handling units.

The enhanced PX system of Demo 19, showed an average improvement in COP ranging from 8.0 to 15.1% better than standard trans-critical architecture.

11. DISSEMINATION AND COMMUNICATION

Information from Demo 9 and Demo 16 is being used within the UK Research and Innovation (UKRI) funded project “Zero-Emission Cold-Chain (ZECC)”. The aim of which is to publish 3 papers on; heat reclaim from supermarkets; heat reclaim from cold stores and compressor control in supermarkets.

Demo 19 Publication:

Trabucchi, S., Farkas, D., Tarjan, G., Nemeth, L., Szabo, T., Orlandi, M., Mazzola, D. CO2 pressure exchanger technology in commercial refrigeration: a new case study towards technological maturity. DOI:10.18462/iir.adaptation.2024.1163.

12. GENERAL FUTURE OUTLOOK

These demos have provided insight into the potential to decarbonize the food supply chain, using natural refrigerants, improving thermodynamics, use of heat storage, increasing efficiency of plants and heat recovery wherever possible.

These demos have shown that there is still opportunity to improve efficiency of supermarket refrigeration, whether this be at the consumer end (retail display cabinets) or the refrigeration system end. However, all new refrigeration systems for supermarket must apply natural working fluids, to enable the owners to report sustainability and enable specific power savings compared to outdated technologies. Deployment of harmful chemical fluids, such as fluorinated gasses must be avoided, as natural refrigerants represent a real, energy efficient and clean solution.

Natural gas or other fossil flues are still being used at supermarket and cold storage facilities across Europe to provide heat, whilst condenser heat is being wasted. Whilst the technical hurdles of using this heat are relatively easy to overcome, the economics (price of gas to electricity ratio), is still a hurdle in making it happen. Although retrofitting heat reclaim systems is possible, costs of cutting into refrigeration systems can be prohibitive, especially ammonia cold stores. Planning for potential heat reclaim and building it into new systems, reduces costs dramatically.

As electrical grids become more reliant on renewable energy which do not provide energy 24/7, large consumers, such as cold store and supermarkets will require DSR, to keep energy costs low. The opportunities of operating refrigeration systems at outside of peak times and storing the energy tends tie up with lower ambient temperatures (night-time), providing a welcome efficiency boost as well as cheaper energy.

13. REFERENCES

EC, 2024. Commercial Refrigerators - Energy labelling and ecodesign requirements apply to this product. European Commission Available at: https://energy-efficient-products.ec.europa.eu/product-list/commercial-refrigerators_en (Accessed: 11 July 2025).

Davies, G., Lagoeiro, H., Turnell, H., Wegner, M., Foster, A., Evans, J., Revesz, A., Leiper, A., Smyth, K., Hamilton, J. and Cooke, H., 2023. Evaluation of low temperature waste heat as a low carbon heat resource in the UK. *Applied Thermal Engineering*, *235*, p.121283.

EC, 2025. Commercial Refrigerators: Energy labelling and ecodesign requirements apply to this product. European Commission.

EN ISO 23953-2: 2023 “Refrigerated display cabinets — Part 2: Classification, requirements and test”

EPREL - European Product Registry for Energy Labelling – Commercial Refrigerators https://eprel.ec.europa.eu/screen/product/refrigeratingappliancesdirectsalesfunction. Foster, A., Evans, J. and Maidment, G.G., 2018, April. Benchmarking of supermarket energy consumption. In *5th International Institute of Refrigeration Conference on Sustainability and the Cold Chain*. IIR.

Foster, A. and Evans, J., 2024. Commercial, professional and domestic refrigeration equipment efficiency in the UK: current and future trends. In *8th IIR International Conference on Sustainability and the Cold Chain*.

H2020 MultiPACK, Demonstration of the next generation standardised integrated cooling and heating packages for commercial and public buildings based on environment-friendly carbon dioxide vapour compression cycles. Pr. No. 723137. D4.7 Technical Report on verified supermarket packs. https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5e2aec621&appId=PPGMS

Hammond, E., Marques, C. and Ketteringham, L.P., 2016. Application of short air curtains in retail display refrigerators. *Refrigeration Science and Technology*, *2016*, pp.49-56.

Minetto, S., Fornasieri, E., 2011. An innovative system for feeding once-through evaporators in flooded conditions. Appl. Therm. Eng. 31, 370-375.

Minetto, S., Brignoli, R., Zilio, C., Marinetti, S.,2014. Experimental analysis of a new method for overfeeding multiple evaporators in refrigeration systems. International Journal of Refrigeration -38, 1-9.

Pitchers S, Marques C, Rees R, Cooper R, Hammond E. Performance comparison between shorter and conventional air curtains in retail display refrigerators. Refrigeration Science and Technology. 2018 Apr 6;2018:215-24.

Selvnes, Håkon; Alvarez Pardinas, Angel; Hafner, Armin; Cold thermal energy storage for air conditioning in a supermarket CO_2 booster refrigeration system , proceedings of the 10th IIR Conference on Ammonia and CO_2 Refrigeration Technologies., 10.18462/iir.nh3-co2.2023.0021 and here

Tommasini, Davide; Selvnes, Håkon; Hafner, Armin, Integrating Cold Thermal Energy Storage for Air Conditioning Demand in a CO2 Refrigeration System at a Supermarket. Energies. 2024, 17 (23), 5923-5940, or here.

Tosato, G., Minetto, S., Hafner, A., Rossetti, A., Marinetti, S., Girotto, S., 2020, Field assessment of the performance of a state-of-the-art CO2 integrated system for supermarket with distributed HVAC terminals in the shopping area. In *6th IIR Conference on Sustainability and the Cold Chain* Nantes, France August 26-28, DOI: 0.18462/iir.iccc.2020.292847.

Trabucchi, S., Farkas, D., Tarjan, G., Nemeth, L., Szabo, T., Orlandi, M., Mazzola, D. CO2 pressure exchanger technology in commercial refrigeration: a new case study towards technological maturity. DOI:10.18462/iir.adaptation.2024.1163.

Weerawardhana, Neshan: Cold Thermal Energy Storage for Supermarket Application, Master Thesis NTNU 2024, download. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/3159411/no.ntnu%3ainspera%3a178462746%3a122009973.pdf?sequence=1&isAllowed=y

Yedmel, Maria Aurely, R. Hunlede, Stéphanie O. L. Lacour, Graciela Alvarez, Anthony Delahaye, et Denis Leducq. « A Novel Approach to Integrate Cold Energy Storage in a Vapour Compression Cycle. » International Institute of Refrigeration (IIR), 2023. https://doi.org/10.18462/iir.icr.2023.0467.

Yedmel, Maria Aurely, Ella Gbehe, et Denis Leducq. « Numerical optimisation of a cold energy storage accumulator for thermosiphon application in vapour compression refrigeration systems », 13. Tokyo, Japan, 2024. https://doi.org/10.18462/iir.iccc2024.1048.

Yuan, P., Zeng, Q., Lei, Z., Wu, Y., Lu, Y. and Hu, C., 2021. Experimental and numerical study of heat transfer and flow characteristics with different placement of the multi-deck display cabinet in supermarket. Open Physics, Vol. 19 (Issue 1), pp. 256-265. https://doi.org/10.1515/phys-2021-0023