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Energy Usage in the Industrial Refrigeration Sector:Food, Drink, Chemical and Pharmaceutical Refrigeration

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Why you should attend

1. To hear an overview of current energy usage and emissions levels in the food, drink, chemical, and pharmaceutical sectors.
2. To gain insights into the technologies currently used and how these sectors are leveraging innovative equipment.
3. To get a deeper understanding of the effectiveness of existing efficiency measures and maintenance practices.

Abstract

The UK industrial refrigeration sector has a few challenges to overcome in order to meet its net zero target by 2050. A project funded by the UK Department for Energy Security and Net Zero (DESNZ) is analysing the opportunities to reduce carbon emissions in from refrigeration equipment. The Transport, Industrial and Commercial Refrigeration (TICR) project includes reviewing the UK refrigeration carbon emissions from refrigeration equipment and to produce a roadmap for carbon emissions mitigation. This paper focuses on the findings from the site surveys and details how currently innovations are used in the sector, the quality of maintenance and the opportunities to reduce energy consumption.

Keywords: Refrigeration, TICR, Food, Drink, Chemical, Pharmaceutical, Industrial, Net Zero, Carbon Emissions, Energy Efficiency.

1. Introduction

The UK was the first major economy to approve legislation to deliver net zero emissions by 2050 [1]. This commitment requires a full understanding of emissions from all sectors and the development of policy to support the industry to reach the net zero target.

Refrigeration enables the provision of food and pharmaceuticals, ensuring that they keep their quality and safety from source to destination. Over 60% of food in the UK relies on the cold chain, emphasizing the critical role refrigeration plays in ensuring the availability and safety of food supply [2]. Refrigeration is well established in the UK in all parts of the cold chain, however emissions are not well understood due to limited available data, particularly in the food and drink and chemicals and pharmaceuticals manufacturing sectors.

The UK government wants to understand the opportunities and policies changes required to reduce the carbon emissions in the refrigeration sector to meet its overall target of Net Zero. This led to the Transport Industrial and Commercial Refrigeration (TICR) project, a consortium funded by the Department for Energy Security and Net Zero (DESNZ) to understand refrigeration related energy usage and emissions and develop roadmaps for their mitigation at different levels, considering potential technological innovations and existing best practices.

Food and drinks are a vital part of the UK economy and are the largest manufacturing sectors in the UK, comprising of 17% of the total turnover of all UK manufacturing activity in 2021 [3]. The UK hosts some of the largest food and drink manufacturing sites in Europe such as Arla Aylesbury (diary), Kraft Heinz Wigan (canned food), and Coca-Cola Enterprise Wakefield (soft drinks). UK food and drink manufacturers employ 468,000 people, which represents 23% of total manufacturing employment in the UK [5]. Thermal processes account for most of the energy use in the sector and the refrigeration energy in this sector is used to extract heat from products to chill/ freeze or blast chill/freeze them. Once heat is extracted from the food, the refrigeration system energy is much less as there is only a requirement to maintain the food at the correct temperature.

The estimated scope 1 (direct from refrigerant leakage) and 2 (indirect from energy consumption) emissions from food and drink (F&D) manufacturing in the UK are 392 and 606 ktCO_2e per year respectively. The overall refrigeration energy use from F&D manufacturing is 2.85 TWh per year. The scope 1 emissions were estimated from the HFC Outlook model, a stock-based model developed by Gluckman Consulting [6]. Scope 2 emissions were estimated based on self-reported emissions and energy use for sites or groups of sites in the Climate Change Agreements (CCA). The total electricity used for refrigeration was estimated by applying a factor of 9.1% to the total energy use, this factor is reported by ECUK, 2022 and is based on the Digest of UK Energy Statistics [7].

The Chemical and Pharmaceuticals (C&P) sectors represented 10.9% of the UK manufacturing turnover in 2021 [3]. The UK hosts some of the largest C&P manufacturing sites in Europe such as P&G London (detergents), Billingham manufacturing plant (fertilisers), and Astra Zeneca's Macclesfield site which employs 1,800 people. UK chemicals and pharmaceuticals manufacturers employ 149,000 people, this represents about 6.5% of total manufacturing employment [3]. As the C&P sector is composed of many different sub-segments there exists a complex ecosystem of refrigeration technologies and refrigerants to match the different use cases. The key drivers influencing technology and refrigeration choice are size of the facility, the type of cooling required, the techno-economic performance of refrigeration technologies and refrigerants. C&P processes will require different types of cooling. The primary types are pre-cooling of air in processes, condensation of vapours, and process refrigeration in the manufacture of different chemicals. For chemicals, control of temperature is a key factor in reaching high efficiency in chemical transformation and manufacturing processes. Pharmaceuticals have strict conditions for operating temperatures during manufacture to ensure maximum yield of safety of product.

The estimated scope 1 and 2 emissions from C&P manufacturing in the UK are 350 and 186 ktCO_2e per year respectively. The overall refrigeration energy consumption from C&P is 0.88 TWh per year. Again, scope 1 emissions estimation comes from the HFC Outlook model and scope 2 emissions come from the self-reported emissions and energy use in the CCA. The total electricity used for refrigeration was estimated by applying a factor of 5.4% to the total energy use, the factor reported by ECUK [8].

To gain insight and identify opportunities to reduce carbon emissions across the F&D and C&P sectors, twenty site surveys were carried out by Star Technical Solutions. The surveys focused on the refrigeration systems. The owner/ management of the facilities asked for their information to remain confidential within the project team, hence within this paper no names of sites are provided. This paper focuses on the site survey findings and defines clear actions to improve the energy efficiency and reduce emissions from refrigeration systems.

2. Sites Surveyed

The focus of the refrigeration site surveys was to understand sites carbon emissions, potential opportunities to reduce their carbon emissions and provide the raw data for benchmarking and insights for the project roadmaps.

The industrial refrigeration sector equipment can have a longevity of > 30 years with the oldest system dated 1959. One site had three ammonia and seventy-seven HFC type refrigeration systems.

These industrial sites processing equipment was split into four sector cohorts: food, drink, chemical and pharmaceutical. The refrigeration requirements of industrial refrigeration facilities are dependent on the layout and the processes within the facility. Within the four industrial refrigeration cohorts, the range of differing cooling requirements from the unique processes limits a simple benchmarking to floor area or product throughput. All the facilities had unique production requirements on the sites. Some chemical manufacturing facilities that produce edible oils and carbon dioxide as a final product may also be designated as a food, drink, or pharmaceutical product. The sites have been designated into the sector determined by the owners of the site.

The technologies used for compressors, condensers, expansion valves and controls for the refrigeration systems do not vary between the sectors and wider industry. The types of evaporators vary depending on their purpose and are often specific for votators, plate freezers, condensers and fin and tube heat exchangers for cooling air.

The refrigerant used by the refrigeration systems include Ammonia (R717), Carbon Dioxide (R744), Propane (R290) and Hydrofluorocarbons (HFC's). The HFCs include R134a, R404A, R407A, R410A, R417A, R422D, R449A and R453A. Table 1 provides the detail of the purpose of processing facility visited, industrial sector, type of cooling equipment and refrigerants used. Figure 1 provides the general location of these facilities.

Table 1: Visited Sites - Types of Facilities

Site	Type of Processing Facility	Sector	Cooling Equipment	Refrigeration Systems
1	Micro-Brewery	Drink	Beer Cooling	R717 Chiller cooling glycol
2	Industrial Butchery	Food	Air conditioning and blast freezing	DX (Direct expansion) R404A, R449A & R134a

3	Chicken kill and process	Food	Chilling	Pumped R717 & DX R404A
4	Chicken kill and process	Food	Chilling & blast freezing	DX R422D, R453A, R134A & R404A
5	Sandwich & Chilled meals	Food	Air conditioning, blast chilling and freezing	Flooded R717 with DX R404A, R449A, R134A & R744
6	Brewery	Drink	Beer cooled by glycol	Centralised R717 Chiller for glycol cooling
7	Frozen sausages	Food	Spiral freezers & freezers	Pumped Ammonia
8	Fish cutting and freezing	Food	Spirals freezers / plate freezer/ air conditioning	Pumped Ammonia
9	Potato cooling and processing	Food	Air blast chilling and chilling	R290 Chiller & DX R407A
10	Ice-cream	Food	Votators/ ice-cream makers/ blast freezers & freezers	Pumped R717
11	Cake/ Sausage rolls	Food	Chill and Freezer rooms	DX R134a, R407A & R404A
12	Sanitiser fluid	Chem	Fluid cooled by glycol	R410A Chiller cooling glycol
13	Over counters pills	Pharma	Product cooling and air condition AHU's and splits	R717, R407A and R410A chillers and DX R410 & R417A splits
14	Refining oil (from crops))	Chemical	Oil /R717 Votators and air conditioning	DX R717 and DX R404A
15	Specialised pills	Pharma	Dry Freezing (-55°C)	DX R404A & R449A
16	Make to order chemical	Chemical	Chemicals cooled by glycol	DX R422D, R407C & R417A for cooling glycol
17	Pigments	Chemical	Cool and Condense Titanium Tetrachloride	R717 / Titanium Tetrachloride Chillers
18	Condensing CO2	Chemical	Ammonia Condensing Carbon Dioxide	Flooded R717
19	Medicine	Pharma	Air conditioning & Blast chill	R134a chillers & DX R134a and R23
20	Medicine	Pharma	Air conditioning & blast freezer	R134a chillers, DX R134a & Transcritical R744

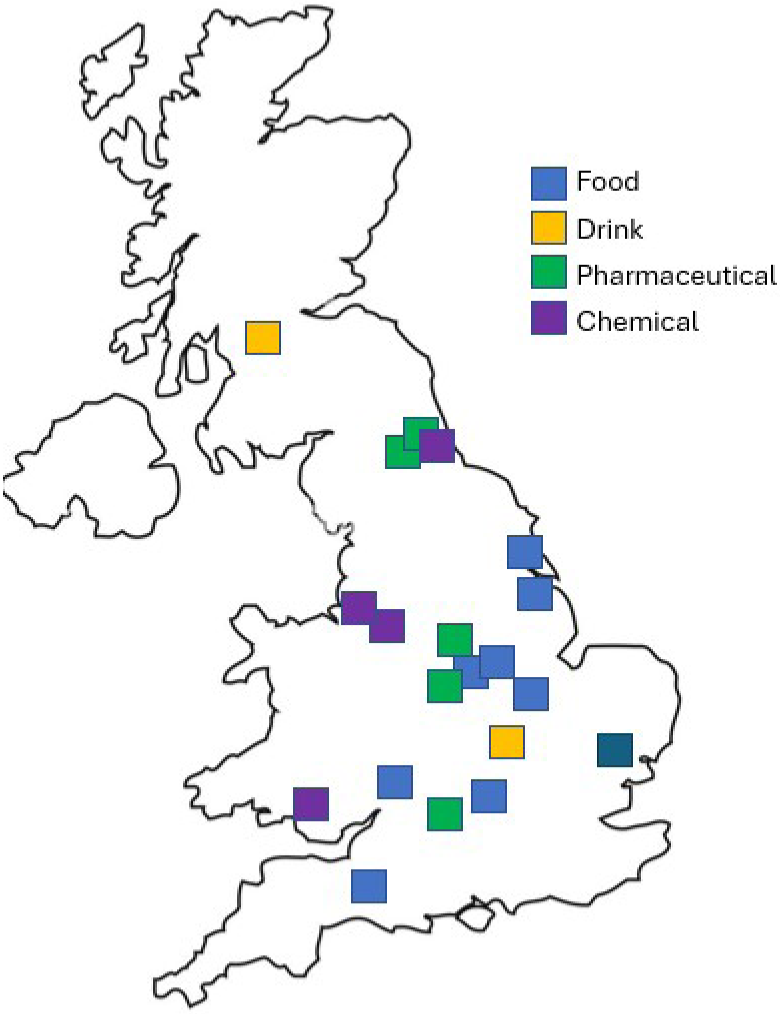

Figure 1: General Locations of Sites Visited

3. Energy Usage and Measurement

Only 18 facilities had total electric usage on site available. Site 12 did not provide incoming electrical consumption and site 3 could only provide the power used by the main incomer but did not meter the power used by the main refrigeration system that is connected to a diesel generator. The electrical consumption provided was calculated based on diesel used.

Only five out of the twenty sites (1, 5, 6, 13 & 18) had full sub-metering to their refrigeration systems. On site 14, sub-metering was only on some of the refrigeration systems. Whilst the five sites out of the twenty had sub-metering data that only measured the cumulative electrical usage, they did not use the data as part of the refrigeration maintenance regime.

Part of site 13 had a pro-active refrigeration optimisation system (assessing against a digital twin) with the sub-components of the refrigeration systems metered.

It is recommend that when sub-metering systems are installed on sites, they should also include data manipulation systems where power usage can be reviewed on a daily, monthly, and annual basis. The systems should also be comparing against power usage from the previous year. To ensure that the sites' refrigeration systems are always running efficiently, a pro-active refrigeration optimisation system based on a digital twin should be installed that informs the users when the refrigeration system is operating outside of its optimised condition.

4. Refrigeration Technologies Used

When reviewing the refrigeration equipment installed on the sites, the technologies used were typically the latest technology for the age of the equipment.

Refrigeration package unit manufacturers' condensing units and compressor packs had the latest efficient compressors and used variable speed drives and control hardware. Evaporative condensers are still being installed, although it has been demonstrated by industry [9] that refrigeration systems with air cooled condensers have a similar annual electrical power consumption than refrigeration systems with evaporative condensers. Evaporative condenser heat rejection reduces for the same temperature difference in lower wet bulb condition.

In these industrial sectors where there is process cooling, the owner typically buys the processing cooling equipment with the evaporator built in. The refrigeration contractor supplies the rest of the refrigeration system that includes the compressors, condensers, vessels and connect a valve station to the process equipment evaporators.

The industry typical evaporating temperature for votators, plate freezers, ice-cream makers and low temperature spiral freezers is -38°C when product is cooled to >-20°C. The result is the saturated suction pressure at the compressor is -40°C. The same equipment could be supplied with a design evaporating temperature of -35°C, however the equipment would typical have approximately 10% more capex with having more surface. This would have the effect of increasing the saturated suction pressure from -40°C to -37°C. For refrigeration systems using ammonia, a compressor selection programme indicates a 11.6% reduced compressor power consumption when increasing the saturated suction pressure from -40°C to -37°C.

Industry purchase specification for new processing equipment with evaporators should be changed from the typical -38°C to -35°C to reduce energy consumption and it is estimated that it would have a return in capital of <1 year.

The control system technology used for refrigeration systems has not changed in 30 years. Whilst new control systems are on the market, their algorithms have not changed significantly. Control systems are often provided by electrical companies that do not have a deep understanding of how to control a refrigeration system to maximise efficiently.

5. Refrigeration Systems Operating Efficiency

During the site visits, the operating parameters of the refrigeration systems were recorded. Where there were two or more systems, we used the average saturated condensing pressure and higher/average saturated suction operating condition for the refrigeration systems.

5.1 Condensers

Fourteen sites had air cooled condensers, five with evaporative condensers, three sites with shell and tube condensers with two connected to cooling towers and one cooled by river water. Two sites had both air-cooled condensers and water-cooled condensers.

Table 2 gives the operating log for the condensers during the site visit. This includes the condenser type, ambient temperature, condensing temperature, achievable condensing temperature and the electrical power reduction opportunity available for the compressor during survey. The achievable condensing temperature is the lowest condensing temperature for the cooling capacity to achieve the lowest power consumption from the refrigeration system.

Table 2: Refrigeration System Operating Logs for Condensers

Site	Type of Condensers	Ambient temperature in °C	Actual Condensing Temperature in °C	Achievable Condensing Temperature in °C	Compressors Power Reduction in %
1	Air cooled	13.4	20.3	20.3	0
2	Air cooled	10.0	30.0	24.0	17
3	Air cooled	4.0	29.0	18.0	30
4	Air cooled	8.0	28.0	22.0	17
5	Air cooled	11.0	29.4 28	25 20	12 22
6	Evaporative	12.5	21.6	21.6	0
7	Evaporative	13.5	23.0	23.0	0
8	Evaporative	8.0	25.5	21.0	12
9	Air cooled	19.6	50.1	34.0	42
10	Evaporative	21.5	26.1	26.1	0
11	Air cooled	16.0	34.0	32.0	6
12	Air cooled	10.0	36.0	24.0	33
13	Air cooled	5.0	22.0	22.0	0
14	Air cooled	5.0	22.0	22.0	36
15	Air cooled Cooling Tower	20.0	44.6 27.6	34.0 27.6	24 0
16	Cooling Tower	10.0	29.8	22.0	21
17	Air cooled	22.0	32.9	32.9	0
18	River Water	4.0	35.5	20.00	35
19	Air cooled	12.0	50.0	26.0	50
20	Air cooled	14.0	23.1	23.1	0

Ten sites out of fourteen with air cooled condensers had excessive heat exchanger fouling (Sites 2, 3, 4, 5, 9, 11, 12, 15, 19 & 20) with nine sites having elevated condensing temperatures. Maintaining clean air-cooled condensers on these nine sites would give an average electrical power reduction opportunity of 26% at the compressors during the visits based on their compressor selection software. Whilst site 20 had dirty air-cooled condensers, it did not result in increased condensing temperatures due to the refrigeration systems running at part load.

On site 15 there is a chiller with a micro channel condenser. This site is continuously cleaning the condenser as the condenser is acting like an air sieve and must be cleaned typically every two months. When selecting condensers, the fouling factor should be considered and not just design for a clean condition.

Site 5 HFC condensing units suffered from air recirculation. Some condensing units are located between buildings and others in roof voids. Whilst the condensing units in the roof void were relatively clean, they were operating with a condensing temperature of 37°C for an ambient of 11°C. (26K differential). The condensing units should be relocated.

Site 5 & 8 evaporative condenser sites had elevated condensing temperatures due to an elevated condenser fan control set points.

Site 18 river water condenser had issues with fouling on the water side of its shell and tube condenser which the site is looking to replace/ rectify. However, the minimum design operating temperature is 32°C as the refrigeration system compressor oil separator will have excessive oil carry over if the condensing temperature is reduced further. We have shown the energy saving if secondary oil separation was fitted.

5.2 Evaporators

We reviewed the opportunity to increase the operating saturated suction temperatures (pressure) at the compressors. Fifteen out of the twenty sites had process type heat exchangers for chilling / freezing product with nine sites having process evaporators built into its machinery (Sites 3, 4, 7, 8, 10, 14, 15, 17 and 18) and seven sites with secondary fluid heat exchangers (Sites 1, 6, 12, 13, 16, 19 and 20) that supplied as part of refrigeration system and four sites (Site 2, 5, 9, and 11) with fin and tube air evaporators only.

Sites 3 & 4 evaporators are supplied as part of the chicken multi-tier air chilling line with a railing system with fixed speed fan on fin and tube heat exchangers. An insulated box is built around the chilling line. Sites 7 & 8 evaporators are in an insulated box with a spiral conveyor system. The dwell time for the product depends on the air temperature in the insulated box, if the rail/ conveyer is extended for a longer dwell time at design stage the evaporating temperature can be increased.

Site 10 has votators for cooling oils and site 14 has ice-cream makers. These scrape surface heat exchangers provide direct cooling to products. The product passes through these heat exchangers rapidly. If the length of the surface heat exchangers was increased or others connected in series/ parallel, then at design stage the evaporating temperature can be increased this would reduce the compressor power consumption by approximately 11.6%.

Site 15 is for freeze drying product where the refrigeration system purpose is to protect the vacuum pumps from excessive moisture. This site is operating with an evaporating temperature of -55°C. The writer is aware of other sites with dry freezers operating at -40°C. This could be achieved by having a larger evaporator to freeze the ice. On this site, this would reduce the compressor power consumption by approximately 37%.

Site 18 was installed in 2021 for condensing carbon dioxide. The carbon dioxide is cooled by ammonia and the heat exchanger has been designed with a 5K temperature difference between carbon dioxide and ammonia. A larger carbon dioxide condenser could have been fitted originally and would reduce this temperature difference from 5K to 2K. This would give a compressor power consumption reduction of 9.2% when using compressor selection software. The extra capital cost of installing a larger carbon dioxide condenser would have had a payback period of <1 year.

The site 2 has a 7°C production chamber has an air evaporator design to operate at -6°C with and is air defrosted. The evaporators in the rooms ice-up and now have excessive fin damage resulting in reduced performance and are not able to maintain the original 6°C temperature requirement. The design evaporating temperature should have been 0°C and this issue would not have occurred.

On site 5 the glycol air cooler has excessive fouling which will result in the air coolers running longer than required.

The use of electronically controlled fans (Variable speed) on evaporators was not observed on any site surveyed.

5.3 Compressor Packs

Twelve out of the twenty sites have at least one compressor with a variable speed drive. Eight sites (Sites 2, 4, 6, 7, 9, 12, 15 & 16) did not have any compressor variable speed drives fitted. These sites would benefit from fitting inverters to control the compressor speed to reduce power consumption.

The compressor control system on seven sites with secondary fluids (Sites 1, 6, 12, 13, 16, 19 and 20) is based on the secondary outlet temperature setpoint which keeps the suction pressure elevate and the remaining sites compressors which have do no cool secondary fluid are controlled based on common suction pressure setpoint.

Smaller newer equipment and older equipment lack gauges or functioning digital displays (HMIs) to allow non-evasive maintenance of the refrigeration systems. Operating conditions like suction and discharge pressure or condenser fan run speed were not available for refrigeration systems on ten sites (Sites 1, 3, 5, 8, 9, 13, 14, 15, 16, and 19).

5.4 Heat Recovery

Only Site 18 had heat recovery used to provide heat outside of the refrigeration system. The heat recovery was used to vapourise carbon dioxide for another part of the process. This was part of its original installation and is bespoke to this application. The survey did not investigate where heat could be used in other part of the process.

6. F-gas Logs

Sixteen of the sites used F-gases. Six sites provided F-gas logs and a further two sites F-gas logs were only partially filled in. Eight sites had no F-gas logs.

Of the eight sites that had F-gas logs, two sites claimed to have no refrigerant losses in the last 12 months (Sites 1 and 16). Sites 2, 13, 19 and 20 had refrigerant losses of 11.1%, 4.3%, 15.2% and 8.1% of their total refrigerant quantity.

Since there were only six sites with F-gas logs, we do not believe using only this small sample would be a good basis for estimating the overall Scope 1 carbon emissions for the industrial refrigeration sector.

7. General Maintenance

It was evident from the survey data gathered that sites with multiple refrigeration systems (Sites 4, 5 , 9 ,13 ,15 ,16 ,19 & 20) were not maintained as effectively that those with fewer refrigeration systems. The higher the number of refrigeration systems, the less well they were maintained and optimised.

For the industrial sector, it is recommended that a centralised plant is installed where possible and preferably with a secondary fluid like glycol for chilled areas.

8. Use of Renewables

There were only two sites generating renewable electricity. Sites 1 and 9 had photovoltaic panels and generated 1.2 % and 8.6% of the total site electricity consumption respectively.

9. Energy Saving Opportunity Scheme (ESOS) Reporting

ESOS reporting is required for business that have over 250 employees or have an annual turnover in excess of £44 million, with the ESOS Phase 3 qualification date of 5th July 2024. Organisations that qualify for ESOS must conduct ESOS assessments every 4 years. These assessments are audits of the energy used by their buildings, industrial processes and transport. The ESOS audit aims to identify measures to allow businesses to save energy, carbon and costs. It requires the identification of total energy consumption, areas of significant energy consumption (at least 95% of total energy consumption), calculation of energy intensity ratios and include site audits.

For some sites there ESOS surveys had been carried out, but the survey report had not been completed as the deadline was approaching when the refrigeration surveys were carried out. Site 10 ESOS report was dated 2015 and site 15 report was dated 2024. The ESOS reports did not focus on energy saving opportunities for the refrigeration systems.

10. Site Management and Expertise

No site had in house refrigeration expertise. The sites were dependant on the expertise of their maintenance providers to ensure the refrigeration systems operated efficiently.

11. Consolidated data on energy and emissions

The data for the twenty sites surveyed has been analysed and consolidated in Table 3 (3 pages).

Where data was unavailable and we were able to make accurate estimates based on site feedback, we have highlighted our estimates in purple in the tables. Where we did not have enough information to make estimates, we have indicated these as unknowns. This is particularly relevant where the refrigeration systems electrical usage was only a small part of the sites overall electrical usage.

For the 20 surveyed sites we have only been able to provide the refrigeration Scope 1 emissions for thirteen sites, Scope 2 emissions for fifteen sites and the Scope 1 and 2 emissions for eight sites.

ESOS reporting is required for business that have over 250 employees or have an annual turnover in excess of £44 million. If less, there is no requirement to report. For some sites they had an ESOS survey carried out, but the report had not been completed.

Table 3: Consolidated data for industrial sites surveyed

Site	No of Systems	Refrigerant	Refrigerant Quantity (kg)	GWP[14]	F- Gas Log (12 months) kg	ESOS	Imported Electricity (kWh/yr)	Site Generated Electricity (kWh/yr)	Refrigeration Electricity (kWh/yr)	Refrigeration Efficiency Improvement Opportunity %	Refrigeration Scope 1 emissions (tCO_2e)	Refrigeration Scope 2 emissions (tCO_2e)
1	1 3	R717 R407C	180 10.5	0 1774	0 0	Report Not Available	978,768	11,967 solar	86,394	0	0.0	18.3
2	2 6 3	R449A R404A R134a	252 1059 23	1397 3922 1430	99 93 0	Report Not Available	3,140,579	0	Not Known	15	503	Not Known
3	1 15 1 1	R717 R404A R449A R410A	0 125 10 12	0 3922 1397 2088	Not Available	Report Not Available	2,376,863	11,967 solar	Not Known	25	Not Known	961.2
4	9 1 3 7 2	R404A R449A R422D R453A R134a	261 65 268 900 47	0 3922 1397 2088	Not Available	Report Not Available	3,489,248	0	2,616,939	25	Not Known	554.8
5	1 3 3 2 3	R717 R404A R449A R134a R744	2000 48 79 60 350	0 3922 1397 1430 1	Not Available	Report Not Available	11,222,778	0	1,946,942	15	Not Known	412.8
6	1	R717	2000	0	Not Required	In Progress	15,636,733	0	3,396,722	50	0.0	720.1
7	3 1	R717 R407F	6000 275	1 1825	Not Available	Report Not Available	6,098,725	0	4,270,000	0	Not Known	905.2
8	3 4 8 2 3 2	R717 R410A R449A R448A R407F R422A	8000 55 104 27 70 30	0 2088 1397 1387 1825 2730	Not Available	In Progress	14,550,882 Include Site CHP	2MW CHP	12,700,000	10	Not Known	2692.4

Site	No of Systems	Refrigerant	Refrigerant Quantity (kg)	GWP[14]	F- Gas Log (12 months) kg	ESOS	Imported Electricity (kWh/yr)	Site Generated Electricity (kWh/yr)	Refrigeration Electricity (kWh/yr)	Refrigeration Efficiency Improvement Opportunity %	Refrigeration Scope 1 emissions (tCO_2e)	Refrigeration Scope 2 emissions (tCO_2e
9	2 5 1 4	R407F R404A R449A R290	44 385 78 121	1825 3922 1397 3	Not Available	Report Not Available	1,969,674	185,499 Solar	980,000	50	Not Known	207.8
10	1	R717	43,000	0	Not Required	2024 Version	23,187,723	12,606,900 CHP	14,200,000	0	0.0	3010..4
11	5 3 6	R407F R449A R134a	108 15 384	1825 1397 1430	0 0 0	Report Not Available	1,600,000	0	800,000	50	0.0	169.6
12	5	R410A	38	2088	0	Report Not Available	Not Provided	0	Not Provided	25	0.0	Unknown
13	3 8 11 2 1 47 3 5	R717 R407F R407C R404A R422D R410A R417A R134a	900 256 603 20 3 242 3 65	0 1825 1774 3922 2730 2088 2346 1430	0 39.4 0 0 0 11 0 1	In Progress	17,000,000	0	1,850,000	0	96.3	2692.4
14	2 2	R717 R404A	1758 40	0 3922	Not Available	Not Required	14,779,680	0	2,800,000	5	Not Known	593.6
15	3 21 20 7 8	R407C R449A R410A R134a R513A	105 1680 605 412 518	1774 1397 2088 1397 631	0 340 0 0 0 Site do not trust log	2015 version	27,466,878	0	21,973,502	50	Not Known	4658.4
16	8 7 2	R407F R422D R417A	18.4 116 3853	1825 1397 1430	Not Available	Not Required	8,056,050	0	Not Known	35	0.0	Not Known

Site	No of Systems	Refrigerant	Refrigerant Quantity (kg)	GWP[14]	F- Gas Log (12 months) kg	ESOS	Imported Electricity (kWh/yr)	Site Generated Electricity (kWh/yr)	Refrigeration Electricity (kWh/yr)	Refrigeration Efficiency Improvement Opportunity %	Refrigeration Scope 1 emissions (tCO_2e)	Refrigeration Scope 2 emissions (tCO_2e
17	2	R717	4,700	0	Not Required	Not Required	82,652,000	0	2,000,000	10	0.0	424.0
18	1	R717	2,200	0	Not Required	In Progress	8,354,000	0	1,829,000	35	0.0	387.7
19	11 1	R134a R23	2236 8.0	1430 14,800	327 2.4	Report Not Available	2,847,345	0	Not Known	30	503.1	Not Known
20	6 2	R134a R744	1170 134	1430 1	82 48	Report Not Available	1,932,761	0	Not Known	0	136.3	Not Known

Conclusions

The refrigeration requirements of industrial refrigeration facilities are dependent on the layout and the processes within the facility. Within the four industrial refrigeration cohorts; food, drink, chemical and pharmaceutical; no simple benchmarking basis could be identified using floor area (W/m^3) or product throughput (kg/kW). All the facilities had unique production requirements on the sites.

Only five sites had sub-metering of the refrigeration systems, and no site used the sub-metering as part of maintaining their refrigeration systems. A chiller on site 13 had digital twin technology used to optimise refrigeration system operation.

When owner/users buy process equipment from suppliers, the supplier provides equipment with industry typical evaporating temperatures and do not highlight the benefit of investing more to allow their refrigeration system to operate more efficiently. For freezing type application, the design evaporating temperature should be increased from the standard -38 to -35°C as that would reduce compressor consumption by 11.6%.

There were fourteen sites with air cooled condensers, ten sites had excessive fouling on their heat exchangers. If the condensers had been kept clean, the compressor electrical power consumption on average could be reduced by 26%. Elevated condenser fan set points was also identified as an issue for all types of condensers.

On one site that had an air-cooled micro-channel condenser, it was regularly clean, however it quickly became fouled as it's operating as an air sieve. It is recommended that research is carried out to determine air side coil fouling factors for different coil geometries under typical field operating conditions. Whilst gas coolers and condensers can be tested for efficiency in laboratory environments, their efficiency effectiveness reduces when in the field. Some condenser designs act like air filters and some cannot be effectively cleaned. The wider the fin geometry the longer it takes for debris to accumulate. Fitting air filters in front of will only result in the heat exchanger fan power increasing.

No sites had electronically commutated (EC) fans (variable speed) installed on evaporators or air coolers that would provide the benefit of being able to adjust the fans speed lower, reducing the fan input power and reducing the heat to be extracted from the refrigerated space on low load conditions. Sites must also ensure evaporators air coolers are cleaned to keep the fan running time to a minimum.

Eight sites did not have compressor motor inverters fitted onto their refrigeration systems and ten sites had equipment where there were no pressure gauges or functioning digital displays fitted. These refrigeration systems cannot be maintained for efficiency and are only reviewed when they fault.

It was evident from the site visits, the higher the number of refrigeration systems, the less well they were maintained. For the industrial sector, it is recommended that centralised plant is installed where possible and preferably with a secondary fluid like glycol for chilled areas.

The site owner/ management did not have in-house refrigeration expertise for managing the efficiency of their refrigeration systems.They are dependent on the refrigeration maintenance provider whose primary focus is keeping the refrigeration system operating reliable. The result is a lack of focus on energy efficiency.

A more detailed set of recommendations for end users in the manufacturing sector are being published by the TICR project in March 2025, together with a Roadmap of technologies for emissions reduction.
See www.netzerorefrigeration.uk .

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Dermot Cotter is the Managing Director of Star Technical Solutions the consultancy arm of Star Refrigeration Limited. In his secondary role as a Board Member the Cold Chain Federation, he provides advice to its members on matters related to refrigeration systems and insulated envelopes. He is currently a member of the IOR Board of Trustees, chairs the IOR Paper Committee and has been working on the Transport, Industrial and Commercial Refrigeration project (TICR), which is funded by the Department of Energy Security and Net Zero, and aims to investigate the real energy use and greenhouse gas emissions from the transport, industrial and commercial refrigeration sectors in the UK. His interests and focus include industrial and commercial equipment life cycle costs, optimisation of refrigeration systems, regulatory compliance and efficiency of low charge ammonia systems which was the focus of his PhD.

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