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Refrigeration and the Road to Net Zero: Water-cooled Refrigeration

Oaksmere Design and the John Lewis Partnership

Oaksmere Design is a multidisciplinary engineering services and contracting business based in Ipswich that specialises in supporting the food retail industry. Oaksmere manages a range of energy and capital maintenance projects but has a particular strength in refrigeration engineering. The following article focuses specifically on Oaksmere's design and project management input to Waitrose's water-cooled refrigeration rollout.

Waitrose is part of the employee-owned John Lewis Partnership, which is the largest employee-owned business in the UK with over 80,000 employees known as Partners. Waitrose has over 331 shops across the UK and Channel Islands, including 59 convenience stores and 27 Welcome Break locations. The supermarkets are served by a network of distribution centres and two head offices in Bracknell and London Victoria. Waitrose also operates an online delivery service with an associated ecommerce store pick operation fulfilling online orders[1].

In 2020/21 the John Lewis Partnership consumed 799,208,795 kWh[2] of electricity and gas. The highest area of energy consumption across the estate are refrigeration, HVAC, and lighting. In 2020, 97% of electricity consumption across the Partnership's physical estate was from REGO certified renewable sources and is working with landlords to convert the remaining 3%.

Project background

The John Lewis Partnership brought forward its ambition to be net zero carbon across its entire operations by 15 years to 2035[3]. To help with this commitment emissions associated with refrigeration - which contribute to operational C02e emissions through high energy consumption and the use of high global warming potential (GWP) refrigerant gases - are being tackled.

Globally the Carbon Trust estimates that the food cold chain is responsible for 1% of GHG emissions and that the UK food cold chain is responsible for 2-4% of GHG emissions in the UK[4]. Due to a rising population and increasing food demand, the Economist Intelligence Unit predicts a 2.8% annual growth

1 John Lewis and Partners *Our Business* https://www.johnlewispartnership.co.uk/about.html
2 John Lewis Partnership PLC 2021 Annual Report and Accounts www.johnlewispartnership.co.uk/annualreport
3 www.johnlewispartnership.co.uk/media/press/y2020/waitrose-and-john-lewis-set-out-bold-plans-to-reach-more-customers.html
4 The Carbon Trust. Net zero cold chains for food | Carbon Trust

rate for commercial refrigeration between 2018 - 2030[5]. Therefore, solutions to tackle GHG emissions from refrigeration play a key role in meeting private, national, and international emissions targets.

Since the John Lewis Partnership purchases 97% of electricity through a renewable energy contract this greatly reduces the carbon emissions associated with electricity consumption. The move to water-cooled refrigeration is primarily to eliminate the use of high GWP refrigerant gases. Water-cooled refrigeration systems can dramatically reduce the entrained volume of refrigerant gas in the system, by helping to move away from centralised direct expansion systems that require large volumes of refrigerant gas. When water-cooled refrigeration systems are designed to incorporate self-contained refrigerated cabinets operating with low GWP refrigerant gases the benefit is amplified. In this respect, the partnership states that R290 and R1270, which have GWP ratings of 3 and 2 respectively, must be used where possible in place of gases with higher GWP.

Cascade and transcritical CO2 (R744) refrigeration systems were also considered due to the low GWP rating of 'natural refrigerants' (R744 has a GWP of 1). There are, however, drawbacks associated with cascade and transcritical C02 refrigeration systems. For example, R744 systems have extremely high operating and standstill pressures, which can be hazardous if pipework is damaged. In some places system pressures can be up to 120 bar, compared to just 2 or 3 bar found in a water-chilled loop. Cascade and transcritical systems introduce greater complexity in design, build and maintenance and R744 systems require two stage compression on frozen food applications due to high discharge temperatures.

To summarise, water-cooled refrigeration systems can reduce the entrained volume of gas and the average GWP of gas entrained in the system by replacing the type of refrigerant gas. While CO2 systems also operate with low GWP gases, systems are more complex and potentially hazardous. This article focuses on a recent replacement scheme to help illustrate some of the challenges and benefits associated with the wider project.

Water-cooled refrigeration: Through the generations

The latest specification currently on the estate is known as 3rd generation water-cooled refrigeration. The main benefits of reduced energy consumption and reduced refrigerant charge are due to waste heat from the refrigeration cycle being rejected to a water chilled loop, which is connected to cabinets and coldroom equipment housing self-contained refrigeration loops, rather than to roof mounted condensers. There is no mechanical cooling required on the water chilled loop, which operates at between 40^{0}C and 46^{0}C, only dry air coolers for heat rejection which negates the need for central compressor packs. The systems are estimated to achieve main meter electricity savings in the region of 20%.

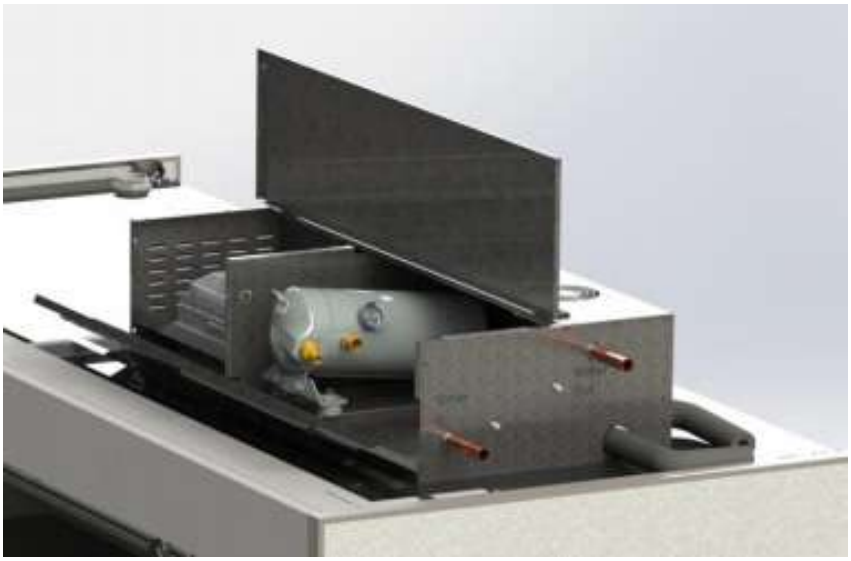

Fig. 1 - Cabinet 'top box'

Since the water chilled loop is piped to the 'self-contained' refrigerated cabinets and coldroom equipment, less pipework is needed for refrigerant and therefore less refrigerant gas. Basically, creating water-cooled integralised systems. The system also operates with natural refrigerant with very low GWP values. Figure 1 provides an illustrative example of the self-contained refrigeration unit, colloquially known as a 'top box',

5 The Economist. The cooling imperative - forecasting the size of future cooling demand (2019) http://www.eiu.com/graphics/marketing/pdf/TheCoolingImperative2019.pdf

which sits on top of each cabinet. While the 3rd generation represents the current specification, it is worth reviewing previous generations to understand the journey of innovation.

The first generation of water-cooled refrigeration chilled the water and glycol mix to between 18 and 24^{0}C, which was achieved via hydrocarbon water chillers providing progressive 'free cooling' below 18^{0}C. Ultimately this meant central refrigeration plant was required for the water chilled loop. Like generations 2 and 3, the system utilised cold aisle air retrieval and waste heat recovery to increase secondary benefits to store heating and cooling. The average annual energy savings, when comparing against a standard direct expansion system, were estimated in the region of £35,000. First generation water-cooled systems also displaced R404A with a significantly reduced volume of natural refrigerant, helping to achieve large GHG emissions reductions.

The second generation of water-cooled refrigeration chilled the water and glycol mix to two separate temperatures through a complex set of pipework. HT cabinets were served by a temperature between -6 and 0^{0}C and LT cabinets were served by a temperature between 6 and 12^{0}C. A key difference between generations 1 and 2 was that HT cabinets did not have their own condensing units, rather they used the water glycol mix directly in the coil of the cabinet to provide the required cooling duty (secondary refrigeration). Natural refrigerants were also used in generation 2 water chiller plant, so there was also a large benefit for GHG emissions. Energy usage requirements were, however, greater due to lower cooling requirement. Furthermore, the system was more complex to build and maintain.

The main benefits of 3rd generation water-cooled refrigeration, when compared to 1st and 2nd generation, is there is no need to chill the water-cooled loop. Furthermore, 3rd generation systems are less complex than generation 2.

Project brief

At Waitrose Norwich, all existing shopfloor LT and HT refrigerated cabinets were replaced with 3rd generation water cooled cabinets and several smaller air-cooled integral cabinets, each of which were entrained with R1270. The seven existing cold rooms were replaced with four cold rooms that occupied a similar footprint. Cold rooms incorporated into wider water-cooled systems had previously been fitted with self-contained air-cooled or water-cooled units, that were housed directly on top of the cold rooms. At the time, system design was transitioning to incorporate a new self-contained refrigeration unit also capable of rejecting heat to a water-chilled loop. Since the new system was still in trial, the cold rooms were fitted with direct expansion HFC evaporators entrained with R448A.

Figure 2 – Roof mounted dry-air coolers

Figure 3 – Internal pump station for the water chilled loop

Since the 3rd generation water-cooled cabinets have a condensing unit on each cabinet rejecting heat to a water-cooled loop, the roof mounted condensers were rendered redundant. The same was true for the central compressor packs given that each self-contained cabinet also houses its own compressor within the 'top box' providing cooling for the cabinet. Instead, centralised pumps were required to circulate the chilled water and glycol mix. Finally, given that the function of the water chilled loop is to act as a medium for heat rejection, with all water-cooled fixtures condensing at a suitably high enough temperature, waste heat removal is possible by use of simple roof mounted dry-air coolers.

All redundant compressors were decommissioned and removed in accordance with a suitable phasing plan to ensure existing packs were unaffected by light loading. The new water-cooled plant was brought online in a coordinated effort between the electrical, mechanical and refrigeration contractors and Waitrose merchandising. Four new direct expansion condensing units were located on the roof condenser platform to serve the cold room evaporators, two for the HT plant and 2 for the LT plant. The fluid medium for the water-cooled loop was water with 15% MonoPropylene glycol. All reclaimed R404A/R407A was removed and sent for re-manufacturing and banking. All control panels were replaced, and the frozen food, meat and dairy chillers were fitted with a trapped man & gas leak detection system.

Operational feasibility

Waitrose stores usually remain open for the duration of a replacement scheme and in most cases, stores are operational 24 hours a day, although not trading, and 7 days a week as night teams work to replenish stock. In the last year there has also been a rapid expansion of the store pick ecommerce operation, which increases foot traffic overnight as online orders are fulfilled by in-store picking teams. To minimise disruption to online orders, the Waitrose Norwich ecommerce operation was temporarily relocated to a nearby store. Furthermore, planning for the project had to be carried out during Covid restrictions, which introduced new ways of working.

Site access presented a challenge for the removal of existing cabinets and delivery of new cabinets, due to door heights and locations. For instance, the front doors lead to a busy main road which has limited parking and is on a slight incline, while the warehouse shutters are obstructed by a loading dock leveller. The fire escape doors, which lead from a ramp directly to the sales floor, provided the best access but they are neither wide nor tall enough.

The solution was to remove a set of handrails next to the door, build a temporary platform and temporarily increase the height of the door. The new layout of the cabinets also presented a challenge in that drainage had to be relocated from a gravity fed system at the location of the existing cabinets to a vacuum fed system located in the warehouse.

A crane was required to remove the existing direct expansion condenser units from a roof mounted steel support structure and install the new dry air-coolers. Fortunately, there was sufficient space on the roof to build a new steel structure, alongside the existing structure, to house the new condensing unit required for the coldrooms.

To minimise disruption to customers, sound deadening material was placed on the roof to prevent vibrations through the supporting steels and into the store. The existing compressors were removed from an internal plant room by cutting up the equipment and removing piece by piece, making room for pumps required for the water-cooled refrigeration loop. Installation of the new pipework was completed in the four weeks leading up to the installation of the new cabinets and cold rooms.

Project evaluation

Prior to the water-cooled refrigeration project at Waitrose Norwich, there was approximately 700kgs of R448A (GWP 1390) entrained in the system. The water-cooled refrigeration project reduced the entrained volume to 64kgs of R448A across the cold rooms, 52.1kgs of R1270 (GWP 2) across the main cabinets and 3.35kgs of mixed hydrocarbons (with a GWP of less than 4) in the air-cooled integral cabinets.

Based on recent recorded refrigerant leak rates, water-cooled refrigeration at Waitrose Norwich is forecast to save 36 tonnes of CO2e annually from direct emissions. Across all sites completed in 2020 there is an estimated annual saving of 2336 tonnes of CO2e. In 2021 the projected figure increases to 3125 tonnes of CO2e.

The projected estimated energy saving at Waitrose Norwich, based on like for like savings between January and March, is 1,039 MWh, which represents a like for like main meter saving of 24.5%. The reduction in energy consumption is mainly attributable to the removal of centralised refrigeration plant.

There is also an energy reduction benefit in replacing fixed-speed compressors with inverter-driven compressors, which is a benefit specifically associated with the evolution from 1st to 3rd generation water cooled refrigeration. The energy reductions are partly offset by an increase in consumption at the cabinets, however the result is still an overall reduction. Aside from a 24.5% cost reduction, the reduction in energy consumption also translates to a 24.5% reduction in carbon emissions related to energy production, transmission, and distribution.

Future plans

Leveraging innovation in refrigeration design has led to massive reductions in energy consumption and GHG emissions from refrigeration. As we continually strive to meet the challenge of net zero, innovative refrigeration technology must remain at the forefront of system design. The challenges faced at Waitrose Norwich in converting the entire system to water-cooled refrigeration illustrates both the scale of the challenge and the scale of achievement when we face issues head-on. While 3rd Generation water-cooled refrigeration represents a step on the journey to net zero in refrigeration. The next step on the road to further improvements are to utilise A2L gases in the coldroom plant.

Continuous improvement to system design has also led to the adoption of new self-contained units, which provide an improved solution for cold rooms. The self-contained units reject heat to the water-cooled loop in the same manner as the current system, but they have an improved lifespan. The new units have been incorporated into the standard specification from 2020 and they will be incorporated into future systems. To date nearly 200 Waitrose shops across the estate have undergone a water-cooled refrigeration replacement. In line with the John Lewis Partnership's net zero 2035 ambitions, the aim is to replace all existing direct expansion refrigeration systems with water-cooled refrigeration by 2030.

Author's profile:

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