Impact of a Warming Climate on UK Food Retail Refrigeration Systems: Recommendations for Industry

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Background

In 2010, Sainsbury's established a partnership with Imperial College London with the goal of pursuing research that results in reducing carbon footprint from retail activities and thus mitigates the future impacts of climate change. Research has been carried out on a range of multi-disciplinary topics and due to its success the partnership now enters its 10th year.

By being one of the largest food retailers in the UK, Sainsbury's possess a large complex supply chain of food producers, logistics, and shops to optimise. The Partnership is constantly reviewing technologies and innovative approaches to enhance business operations. Sainsbury's is committed to reaching NET ZERO operational carbon emissions by 2040 and collaboration with Imperial College is key to reach important milestones.

Executive Summary

Climate change is now an inevitable reality, with only the extent of temperature increase still uncertain. Efforts to minimise the warming of our planet must continue, and rapidly expand, though now in conjunction with proactive measures to adapt to a changing climate, across all sectors of the economy. This report seeks to understand the challenges facing cold-chain food supply, with a focus on UK supermarket retailers, though the recommendations will apply to the wider UK refrigeration industry.

At the current rate of warming, the hot 2018 summer experienced in the UK is likely to become the norm by 2050, making refrigeration system performance from this period an invaluable benchmark of their ability to cope with a warming climate. July 2018 is a particular focus due to substantially elevated temperatures. This report summarises an in-depth analysis undertaken with a major UK supermarket retailer to understand the key learnings and ultimately develop a comprehensive strategy moving forward. The analysis undertaken included individual store case-studies, a wider scale statistical analysis, discussions with stakeholders and literature review to provide a clear picture of the actions required to ensure sustainability of refrigeration systems up to 2050 and beyond.

A key metric for quantifying the impact on the systems in summer 2018 is the energy penalty incurred, defined as the increase in 2018 refrigeration energy consumption relative to the 2016/17 baseline. This was calculated for a sample subset of 30-stores, spread across the UK, before being extrapolated to a 600-store template estate. The energy penalty *for July alone*, with average temperatures elevated by 2.67ºC relative to 2016/17, was 5.1% - 11.2% of energy consumption. This can also be translated into additional carbon emissions of 616 – 1,353 tCO_2e, which is likely to be of increasing importance given the UK's legally binding net-zero emissions target for 2050 (Climate Change and Energy, 2019). As a general rule, a 2ºC increase on today's average summer temperatures will increase the estate's refrigeration energy consumption by 6.1% or 7,835 MWh across June-August. Interestingly, no correlation was found between system age and the energy penalty, implying site-specific factors tend to drive the response to elevated temperatures.

Refrigeration system alarm data was also analysed and revealed that during July 2018, a threshold temperature was crossed after which systems began struggling estate-wide. This indicates systems were pushed beyond their designed capabilities and underlines the importance of investigating new system-design innovations.

Technological solutions to increased summer temperatures include both short-term measures to keep existing systems operating effectively, and long-term strategies for new-system design. Industry has been forced by regulation to move away from traditional hydrofluorocarbon (HFC) refrigerants, which are potent greenhouse gases, towards 'natural' refrigerants, primarily CO_2. New systems are therefore restricted exclusively to CO_2, in line with widespread industry adoption. Findings from this study indicate negligible performance difference between HFC and CO_2 refrigerants. Previous research also indicated no financial case for installing new HFC systems, largely due to the EU F-gas regulations. Managerial and behavioural factors were also found to be crucial and are a further focus. This study finds that there is no one solution applicable to all refrigeration systems, and the determination of which recommendations are most relevant should be made on a site-by-site basis. Finally, a section with recommendations to policy makers is included, highlighting crucial areas requiring government intervention – specifically the need for legislation to make doors on refrigeration cabinets a legal requirement, or to incentivise innovation that achieves equivalent energy-saving outcome through other approaches.

Introduction

In 2018, the UK experienced its joint hottest summer on record, with a 15.8°C mean temperature, rising to a record 17.2°C for England. July had particularly elevated temperatures of 2.2°C above the 1981-2010 average, especially in central and southern locations (Met Office, 2018a). At current rates of warming, an equivalent hot summer will become the UK norm by 2050 (Met Office, 2018b). This is of concern to the UK cold-chain food supply industry, with refrigeration accounting for half of supermarket-store energy consumption (Carbon Trust, 2011).

Increased electricity consumption under elevated ambient temperatures will inevitably increase carbon emissions, as grid carbon neutrality is not expected before 2050 (National Grid, July 2018). Rising ambient temperatures will therefore counteract other initiatives aimed at improving environmental sustainability as cooling-related electricity demand increases. The UK's new net-zero carbon target is expected to further increase emphasis on environmental sustainability via punitive legislation, not just relying on corporate social responsibility schemes (Climate Change and Energy, 2019).

A further pressing concern under prolonged high ambient temperatures is systems failing to provide adequate cooling for safe perishables storage. If an asset encounters a significant fault or is unable to maintain the set-point temperature, stock must be removed from cabinets resulting in labour costs and inhibited sales performance. Refrigeration systems must therefore be robust enough to withstand the summer 2018 temperatures into the future.

The cold-chain food supply industry is in the process of transitioning towards low carbon refrigerants following legislation aimed at curbing the greenhouse gas (GHG) emissions associated with refrigerant leakage. Previously UK retailers relied on hydrofluorocarbon (HFC) refrigerants, which are powerful GHGs. The Kigali Amendment to the UN Montreal Protocol ratified a removal timeline for all HFC refrigerants and the subsequent EU regulations impose strict phase-down deadlines, focusing on the most potent GHGs. Industry has responded by transitioning to low carbon, 'natural' refrigerants with R-744 (CO_2) clearly the optimal choice (Gullo, Hafner, & Banasiak, 2018).

Analysing the impacts of summer 2018 is crucial for developing short and long-term strategies to ensure the continued sustainability of refrigeration systems. Understanding the learnings will enable early identification of existing system vulnerabilities under higher ambient temperatures, and inform a proactive approach to pursuing potential solutions.

Methods

To identify the impact of the warm 2018 summer on refrigeration system performance, a multi-level analysis was carried out using both qualitative and quantitative methods. The study was conducted interacting extensively with key stakeholders within the UK supermarket industry including a UK supermarket retailer's refrigeration specialist, lead engineer, capital operations manager and sustainability manager along with maintenance, estate management and system design contractors. This should ensure consideration of a wide range of perspectives. Design contractors were particularly helpful in developing the long-term technological recommendations presented. Energy data from a retailer's estate was made available and site visits were used to gain an in-depth understanding of store-specific factors that influenced energy consumption over the summer of 2018, compared to a 2016/17 baseline.

Case Studies

Three individual store case studies were carried out, investigating system performance in summer 2018 relative to a 2016/17 baseline. A further backdated average was not used for the baseline to minimise the likelihood of system updates having taken place, altering performance. Analysis of the relationship between refrigeration energy consumption and ambient temperature revealed the extent to which factors other than temperature were driving performance. Conversations with contracted refrigeration managers for the stores, along with site visits, then allowed identification of these factors. Finally, calculation of energy penalties, defined as the increase in 2018 refrigeration energy consumption relative to the 2016/17 baseline, provided a basis for comparison between the stores.

Statistical Analysis

A wider scale statistical analysis of refrigeration energy-consumption data, and its relationship with ambient temperature, was then undertaken to build on the case-study learnings. A 30-store subset was generated based upon availability of both complete refrigeration consumption data and complete temperature data, from weather stations within a 5km radius of stores. This subset was then analysed to understand estate-wide performance in summer 2018, focusing on July with a 2.67ºC average temperature elevation in 2018, relative to the 2016/17 baseline. Of particular interest are stores demonstrating improved performance, despite the warmer temperatures, and what actions were taken to generate the improvement. These actions informed the recommendations given below.

Recommendations

Based on the energy data analysis and discussions with key stakeholders, we set out a series of technological, behavioural, managerial and policy recommendations to help mitigate the negative effects of higher summer temperatures on refrigeration system management.

Technological

Short-term

When existing systems are struggling under high ambient temperatures, short-term, cost-effective solutions are required to minimise disruption to both retailers and consumers. These will also avoid expensive replacement of systems that are well within nameplate life expectancies. Condensers (HFC refrigeration systems) and gas coolers (R-744 refrigeration systems), from where heat is rejected, are the primary components impacted under high ambient temperatures. The heat removal rate drops as temperatures rise, making compressors work harder to compensate, both increasing energy consumption and potentially leading to system failure. Technologies available to help struggling systems are detailed below.

- Adiabatic (Evaporative) Cooling
    - Water sprayed into air inlet stream to condenser/gas coolers. May be controlled automatically when air temperatures exceed a set-point.
    - Energy efficiency improvement of 8-12%, verified in the statistical analysis.
    - Substantial obstacles to broad uptake; water wastage, scaling/corrosion and legionella contamination. Latter mitigated through regular water circulation, but senior management should determine risk trade-off.
- Load Shedding
    - Take non-essential cabinets offline in extreme temperatures.
    - May be carried out remotely, providing cabinets are stocked according to designation.

- Set-Point Reduction
    - Increase cabinet/cold room set-points to highest safe value.
- Cabinet Doors
    - Approx. 40 % reduction in energy consumption achievable, dependent on manufacturer (Sluis, 2007).
    - Often not pursued as trials indicate reduction in sales revenue.
- Cold Room Plastic Curtains
    - Use 'strip' curtains, rather than swing-hinged, to prevent from being propped open.
        - PVC strips reported to rip – *stronger material required*.
- Predictive Alarms
    - Use flags in system data to predict system issues before alarms triggered.
    - Prevents issues arising under subsequent extreme temperatures.
- Insulate/Cover Outdoor Equipment
    - Direct sunlight can determine whether systems fail in summer.
    - Sunshades should be considered but must ensure unobstructed gas cooler airflow.

Long-Term

The focus here is on design innovations for new R-744 systems, many of which are already implemented in warmer European climates. The options detailed should promote internal investigation, with contractor collaboration, into the research, trialling and economic assessment of potential system designs.

- Oversizing Gas Coolers
    - Increases robustness to high temperatures.
    - May be an economic case dependent on system size and characteristics, as higher investment cost of oversizing can yield energy savings.
- Parallel Compression
    - Vapour refrigerant separated from the liquid and compressed in parallel, reducing compression work (Bella & Norbert, 2011).
    - 10-15% efficiency savings over standard booster systems (Danfoss, 2016).
- Ejectors
    - Recovers energy from pressure drop out of gas cooler, reducing compression work to allow smaller, cheaper compressors.
    - The warmer the climate, the greater the savings – up to 30% efficiency savings over booster systems when used alongside parallel compression (Danfoss, 2016). Estimated payback of 1-6 years, dependent on supermarket size (Environmental Investigation Agency, 2018).
    - Potential to retrofit existing transcritical booster systems.
- Gas Cooler Corrosion
    - Serious issue with R-744 systems due to higher airflow. Components <5 years old requiring replacement.
    - Increase fin spacing would reduce the likelihood of crevice corrosion – further research required.
- Heat Recovery
    - UK's net-zero 2050 climate target means waste energy will be an increasingly valuable resource.
    - Standard setup uses a heat exchanger between the refrigerant and fluid to be heated.
    - Reduces the airflow required to the gas cooler, with high flow both increasing debris fouling and exacerbating corrosion.
    - Parallel compression can allow integration with energy efficient air conditioning (Karampour & Sawalha, 2017).

    - 40-100% of supermarket heating demand could be met, with potential payback on R-744 transcritical booster system as low as 5 months (Environmental Investigation Agency, 2018) (Funder-Kristensen, 2012). UK study indicates 32% reduction in *total* supermarket energy consumption and 22% reduction in carbon emissions (Sarabia Escriva, et al., 2019).
- Heat Recovery with Seasonal Storage
    - Peak heating requirements in winter but peak heat recovery in summer.
    - Cheapest, easiest solution may be to sell excess heat for district heating systems, though heat generation will then be required in winter (ADE, 2018).
    - Phase change materials (PCMs) have potential to help address the imbalance (Mishra, Sinha, & Gupta, 2019).
    - Combine with a ground source heat pump and reject heat to the ground in summer, for later utilisation in winter. Requires access to land.
        - ***Reject heat at low temperatures beneath the ground, which negates hotter summer temperatures, the focus of this study.***
        - Water-cooled condensers used can give 20% reduction in energy consumption if ambient temperature higher than the water coolant (Efstratiadi, Acha, Shah, & Markides, 2019).
        - Some trials indicate efficiency of heat transfer to ground limits utility.

Behavioural

A key opportunity to improve the reliability and energy efficiency of systems is the actions and behaviours of staff on the shop floor. These steps generally do not require significant capital investment, mainly requiring staff awareness and can be the simplest, most cost-effective way to improve performance. Additionally, the fractional improvements have most impact in summer, minimising energy penalties and aiding struggling stores. Informing store managers, and staff, when 48 hr hot weather warnings are in place can ensure focus during the most crucial periods. Potential behavioural interventions include:

- Utilisation of Night Blinds
    - High night temperatures in summer mean refrigeration systems do not get significant downtime, exacerbated in urban locations with the 'heat island' effect.
    - Night blinds reduce heat ingress to lighten load on the refrigeration system.
    - Demonstrated to improve energy efficiency *but must be used by staff* (Acha, Du, & Shah, 2016).
- Ensuring Cabinets Not Overstocked
    - Overstocking cabinets can block grilles, forcing cold air into aisles and making the refrigeration plant work harder.
    - Care should be taken by staff not to block grilles.
- Using and Maintaining Cold Room Swing Doors
    - The single largest load on cold rooms is caused by warm air passing through open doors, typically 30% of total heat gain (Carbon Trust, 2011).
    - Ensure swing hinges on cold room doors are maintained and doors not propped open.
        - Staff often fail to report broken swing hinges as considered a nuisance.

Managerial

A crucial finding from the study is the importance of communication and collaboration at the system design stage. Additionally, summer maintenance programmes can have a significant impact ensuring systems are in the best possible shape to deal with the higher temperatures expected. Potential managerial improvements include:

- Refrigeration Engineer involvement in store layout
    - A simple measure, only requiring effective communication and planning across disciplines when store layout is being confirmed. Gas cooler placement is particularly crucial.
        - Direct sunlight, solar gain and appropriate ventilation can determine gas cooler performance.
        - Trees close to coolers can lead to leaves/debris clogging up the gas cooler inlet - netting is a cheap and effective solution to this problem.
        - Pollen production is of greater concern as it is not easily prevented from reaching gas coolers, and can clog inlets within hours of cleaning.
- Summer Maintenance Programme
    - Refrigeration managers and engineers should ensure the following actions are carried out prior to the summer months.
        - Cleaning gas coolers.
        - Maintaining key components.
        - Refilling refrigerant.
        - Reemphasise importance of behavioural aspects to store managers and staff.

Government policy

Stakeholder discussions demonstrated that viable and sensible solutions to engineering problems faced by the cold-chain supply industry are often overlooked due to commercial factors. Even when solutions are financially viable, unilateral adoption by companies will provide competitors with a financial advantage. Government involvement is therefore required in legislating to ensure organisations across the industry pursue these solutions. Clearly, the checks and oversight required to implement the legislation must be manageable and sustainable. Recommended policy actions include:

- Make doors on cabinets a legal requirement
    - Results in a loss in sales, so not widely pursued in UK food-retail.
    - Approx. 40% reduction in refrigeration energy consumption is achievable, dependent on the manufacturer (Sluis, 2007).
    - Such massive consumption reduction **must** warrant action whether through making doors a legal requirement or by incentivising innovation in this space to achieve equivalent energy-saving outcomes through other, as yet undiscovered, approaches.
- Make proper maintenance of cabinets' operational fabric a legal requirement
    - Cabinet dividers, honeycombs, weir screens and risers all contribute to substantially reducing energy consumption.
- Make maintaining cold room plastic curtains a legal requirement
    - Approx. 30% of total heat gain by cold room's (Carbon Trust, 2011).
    - Flimsy designs mean both swing and strip curtains break frequently.
    - Issue around whether facilities management (FM) or individual stores carry the cost.
        - Tight budgets mean never fixed – *should be an FM responsibility*.
- Make parallel compression a legal requirement for new systems
    - Investigate other system-design innovations, including ejectors.
- Encourage/subsidise refrigeration engineer apprenticeships.
    - Lack of skilled workers available to drive forward the changes required.

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The references included in this report, and detailed below, are a summary of the research being conducted in the field of improving refrigeration system performance.

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