ENERGY CONSUMPTION AND CONSERVATION IN FOOD RETAILING

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Abstract

The total annual CO_2 emissions associated with the energy consumption of the major retail food outlets in the UK amount to around 4.0 $MtCO_2$. The energy consumption and emissions from supermarkets varies widely and can depend on many factors such as the type and size of the store, business and merchandising practices and refrigeration and environmental control systems used. This paper provides energy consumption data of a sample of 2570 retail food stores from a number of major retail food chains in the UK. The sample covers all major store categories from convenience stores to hypermarkets and includes approximately 30% of the total number of stores in the UK having a net sales area more than 280 m^2. The data show a wide variability of energy intensity even within stores of the same retail chain. A power law can be used to describe the variation of the average electrical energy intensity of the stores in the sample with sales area. If the electrical intensity of the stores above the average is reduced to the average by energy conservation measures, annual energy savings of the order of 10% or 840 GWh can be achieved representing 355,000 tonnes annual reduction in CO_2 emissions. The paper also discusses the major energy consuming processes in retail food stores and identifies opportunities for energy savings.

1 Introduction

Retail food outlets in the UK are responsible for around 3% of total electrical energy consumption and 1% of total GHG emissions. They are characterised by their average sales area and are normally classified as:

- Hypermarkets - 5000 m^2 to over 10,000 m^2 sales area
- Superstores - 1400 m^2 to 5000 m^2
- Supermarkets (mid-range stores) - 280 m^2 to 1400 m^2
- Convenience stores including forecourts – less than 280 m^2.

It is estimated that currently in the UK there are around 6578 supermarkets and superstores of more than 280 m^2 sales area of which just over 2000 are one stop shops of more than 1400 m^2 sales area [Defra, 2006]. Around 1700 of these stores are operated by the four largest supermarket chains, Tesco, ASDA, Sainsbury's and Morrisons. Tesco currently has a commanding market share of around 30.6 %, followed by ASDA at 16.3%, Sainsbury's at 16.0% and Morrisons at 11.3 %. The remainder 25.8% are shared by smaller chains such as Somerfield (now owned by Co-op), Waitrose, Iceland, Co-ops and other multiple chains and independents.

The IGD estimates that around £88 billion (or nearly 75 per cent) of sales occurred in stores larger than 280 square metres – that is, stores classified by the Competition Commission as either one-stop shops or mid-sized stores. The remainder £32 billion of sales takes place through more than 50,000 convenience stores. Of these sales 80% is for grocery items and the remainder for non-food products [Defra, 2006].

The energy consumption of supermarkets will depend on business practices, store format, product mix, shopping activity and the equipment used for in-store food preparation, preservation and display. The electrical energy consumption can vary widely from around 700 kWh/m^2 sales area in hypermarkets to over 2000 kWh/m^2 sales area in convenience stores. The refrigeration systems account for between 30% and 60% of the electricity used, whereas lighting accounts for between 15% and 25%. HVAC equipment and other utilities such as bakery accounting for the remainder. Gas is normally used for space heating, domestic hot water and in some cases for cooking and baking and will vary from 0 kWh/m^2 in small stores such as petrol filling stations where gas is not used, to over 250 kWh/m^2 in hypermarkets. In some stores the gas energy consumption can be as high as 800 kWh/m^2.

Retail food stores have significant impacts on the environment. These are indirect emissions through the large amounts of energy consumption but also direct emissions through refrigerant leakage. Although significant progress has been made in recent years to reduce direct emissions through better system design and leakage sensing, the direct emissions are still significant, as much as 40% of indirect emissions, due to the higher global warming potential of refrigerants employed to replace CFCs and HCFCs.

This paper details the major energy consuming processes in retail food stores and their environmental impacts. Data from monitoring programmes carried out by the authors and information available in the open literature have been used to establish the energy consumption of retail food operations. The paper also outlines current and possible future options for the reduction of energy consumption and emissions.

2 Energy Consumption of UK Supermarkets

The energy consumption in supermarkets is normally specified in kWh/m^2 sales area and can be defined as the energy intensity of the supermarket. The energy intensity can be used to compare supermarkets that merchandise similar quantities of ambient and refrigerated food products and food and non-food products. Convenience stores will mainly store core grocery products. Supermarkets and superstores will also merchandise some non grocery products and hypermarkets will devote a significant portion of their sales area to non grocery products. There is no universally accepted definition that characterises energy consumption in terms of product mix.

To characterise the energy consumption of UK supermarkets, a large sample of retail food stores that represents 50% of stores of the main supermarket chains was considered. The data covers close to 50% of stores of the main supermarket chains and it can be safely assumed that the sample is representative of the four main store categories.

Figure 1 shows the annual electrical energy consumption of 640 convenience stores of sales area between 80 m^2 and 280 m^2. The range varies from around 700 kWh/m^2 to 2900 kWh/m^2. The wide variability which applies to all the retail food chains considered in the study is mainly due to the business practices employed and equipment used.

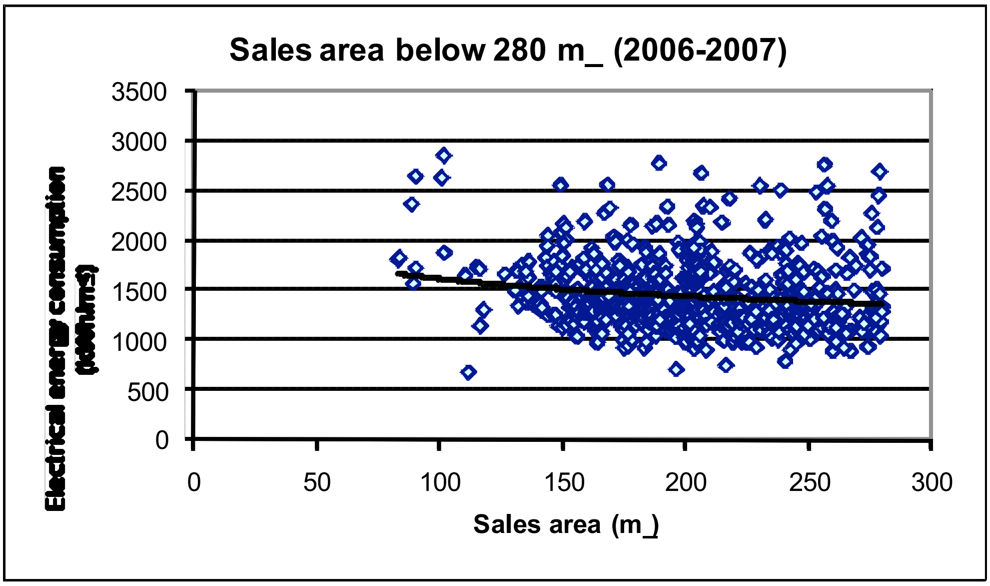

Figure 1. Electrical energy consumption of convenience stores of sales area between 80 m^2 and 280 m^2

The average electrical energy consumption for the sample of 640 stores is 1540 kWh/m^2 and the standrad deviation 446 kWh/m^2. Figure 1 also shows that the everage electrical consumption reduces with increasing sales area from around 1700 kWh/m^2 for a sales area of 80 m^2 to around

1320 kWh/m^2 for a sales area of 280 m^2. Within the sample, the average eletrical energy consumption of the stores using self contained 'integral' refrigeration equipment was approximatly 300 kWh/m^2 higher than the stores using predominantly centrally located 'remote' refrigeration equipment. The standard deviation of these stores was also slightly higher than the remainder of the stores in the sample. Another factor that has an importnt influence on the electrical energy consumption of convenience stores is the balance between temperature controlled (refrigerated) and ambient products and the balance between frozen and chilled food products.

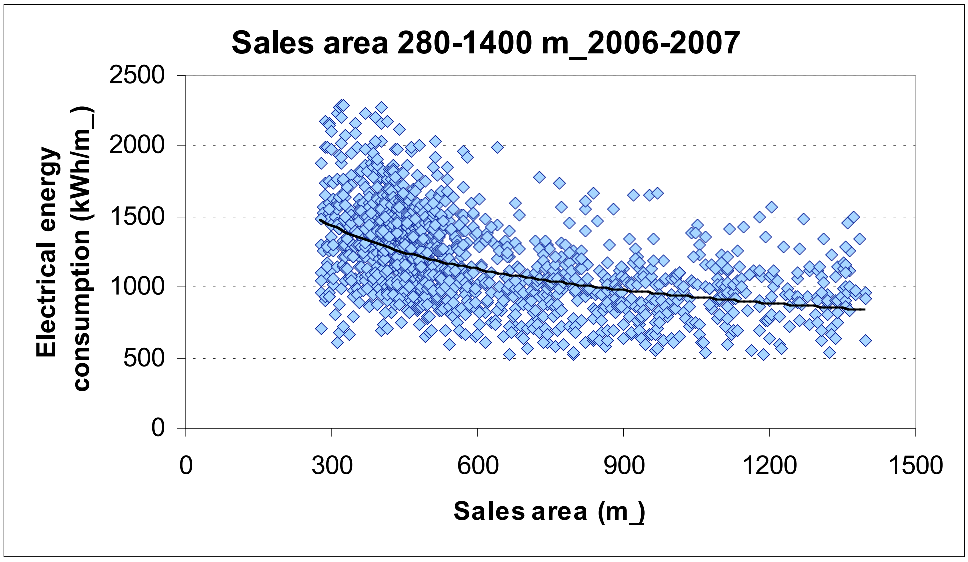

Figure 2. Electrical energy consumption of supermarkets of sales area between 280 m^2 and 1400 m^2

Figure 2 shows the electrical energy consumption of 1360 stores of sales area between 280 m^2 and 1400 m^2. The average energy consumption of these stores varies between 1500 kWh/m^2 down to 850 kWh/m^2 as the sales area increases from 280 m^2 to 1400 m^2. For the same sales area range, the range in the electrical energy consumption data also reduces significantly, from around 1600 kWh/m^2 down to 1000 kWh/m^2. The reduction in the average electrical energy intensity for all stores in the sample is 1000 kWh/m^2 and the standard deviation 220 kWh/m^2.

The electrical energy consumption of 420 stores with sales area in the range 1400 m^2 to 5000 m^2 is shown in Figure 3. Again it can be seen that the range in the electrical energy consumption reduces from around 1000 kWh/m^2 to 600 kWh/m^2 as the sales area increases from 1400 m^2 to 5000 m^2. The average electrical energy consumption in this sample only reduces slightly with sales area. The average of all stores in the sample is 920 kWh/m^2 and the standard deviation 140 kWh/m^2

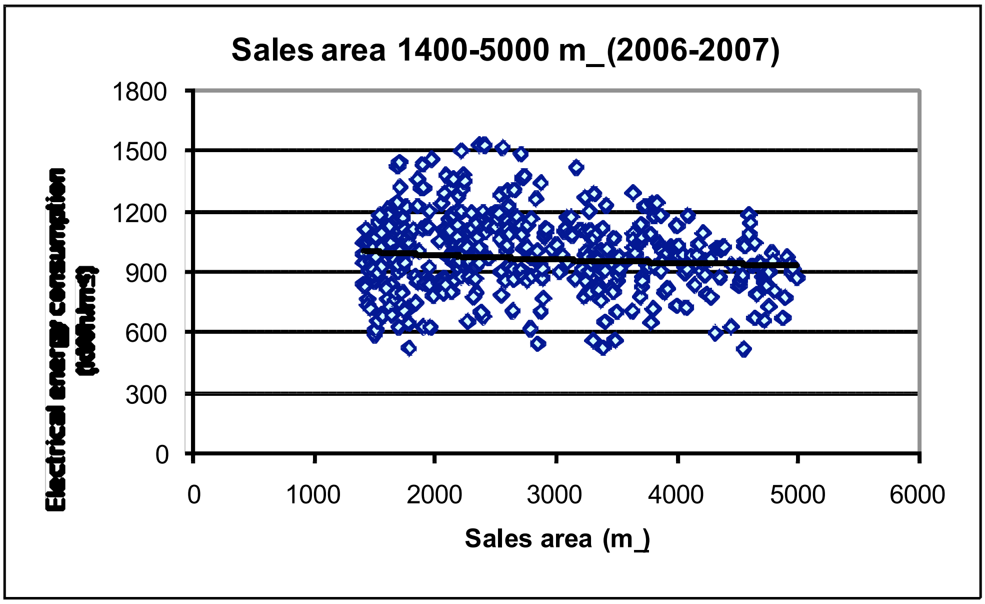

Figure 3. Electrical energy intensity of supermarkets of sales area between 1400 m^2 and 5000 m^2

Figure 4 shows the electrical energy consumption of 150 stores with sales area in the range 5000 to 10000 m^2. The range of the electrical energy consumption data reduces from aroun 600 kWh/m^2 to 220 kWh/m^2 as the sales area increases from 5000 to 10000 m^2. For the same sales area range, the average electrical energy consumption reduces from around 870 to around 660 kWh/m^2. The average electrical energy consumption in this range is 770 kWh/m^2 and the standard deviation 120 kWh/m^2.

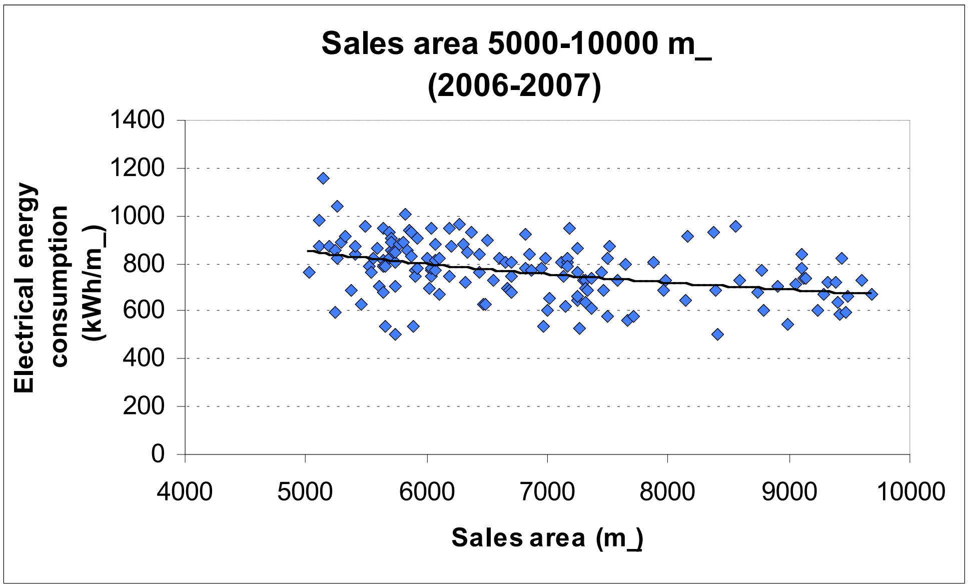

Figure 4. Electrical energy intensity of supermarkets of sales area between 5000 m^2 and 10000 m^2

Figure 5 shows the electrical energy intensity of all 2570 stores considered in the study. The variation of the average electrical energy intensity with sales area is shown by the solid curve on the graph and can be described by the following equation.

$$W_e = 3600\, x A_s^{-0.18}$$

Where:

W_e = Electrical energy consumption per unit sales area (kWh/m^2)

A_s = Sales area (m^2)

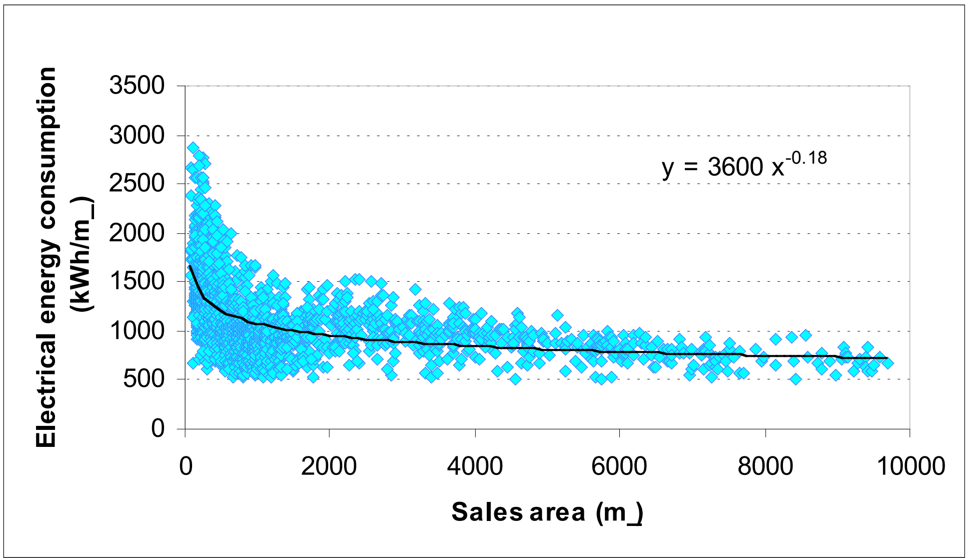

Figure 5. Variation of electrical energy intensity of 2570 UK retail food stores with sales area from 80 m^2 to 10,000 m^2

It can be seen that for convenience stores and supermarkets up to a sales area of around 1400m^2 the electrical energy intensity drops exponentially. This is due to the shift from a food dominant to non food dominant sales operation and a reduction in the refrigeration energy consumption per unit sales floor area. Above 2000 m^2 sales area, the drop in electrical energy intensity with increasing sales area becomes very small as the impact of refrigeration on the total energy consumption reduces and that of artificial lighting becomes more significant.

For the smaller size food dominant stores, the wide variation in electrical energy intensity between stores indicates that significant energy savings per unit floor sales area can be achieved if the energy consumption, particularly that due to refrigeration is reduced to the average of the sample of each store category. If the electrical energy intensity of the stores whose intensity is above average is reduced to the average by retrofit measures annual energy savings of the order of 10% (310 GWh) can be achieved.

Table 1 shows estimates of electrical and gas consumption data and corresponding greenhouse gas emissions from the retail food operations of the major retail food chains in the UK. The data refer to the retail food stores alone and does not include Regional Distribution Centres (RDC) and transport energy consumption. The estimates are based on actual data for the 2570 stores considered in this study and energy data published by the major chains. The CO_2 emissions are indirect emissions from energy consumption alone and do not include emissions from refrigerant leakage.

Table 1. Annual energy consumption and greenhouse gas emissions of major UK retail food chains

	Supermarket Electrical Energy Consumption (GWh)	Gas Energy Consumption (GWh)	CO_2 Emissions Electrical Power (tonnes)	CO_2 Emissions Gas (tonnes)	Total CO_2 Emissions (tonnes)
Major UK retail food chains	8385	2477	3538470	470630	4009100 **(4.01 $MtCO_2$)**

3 Energy used by individual cabinets

There has been little reported work on comparative performance of cabinet under similar tests conditions where performance can be directly compared. Schemes such as Eurovent and the UK ECA (Enhanced Capital Allowance) scheme compare performance data from cabinets under test conditions (currently EN23953) but there is little data on performance of individual cabinets in supermarkets. Data collected by Evans, Scarcelli and Swain (2007) from laboratory tests on 208 cabinets showed large differences in the performance of cabinets. Figure 6 shows the range in performance for open fronted chillers, chilled and frozen cabinets with doors, frozen chest freezers and frozen well cabinets. Large differences were found between the energy efficiency of different cabinet types. Differences in energy consumed were also clear between similar cabinets of similar sizes. This shows that by careful selection of cabinets that large energy savings can be achieved.

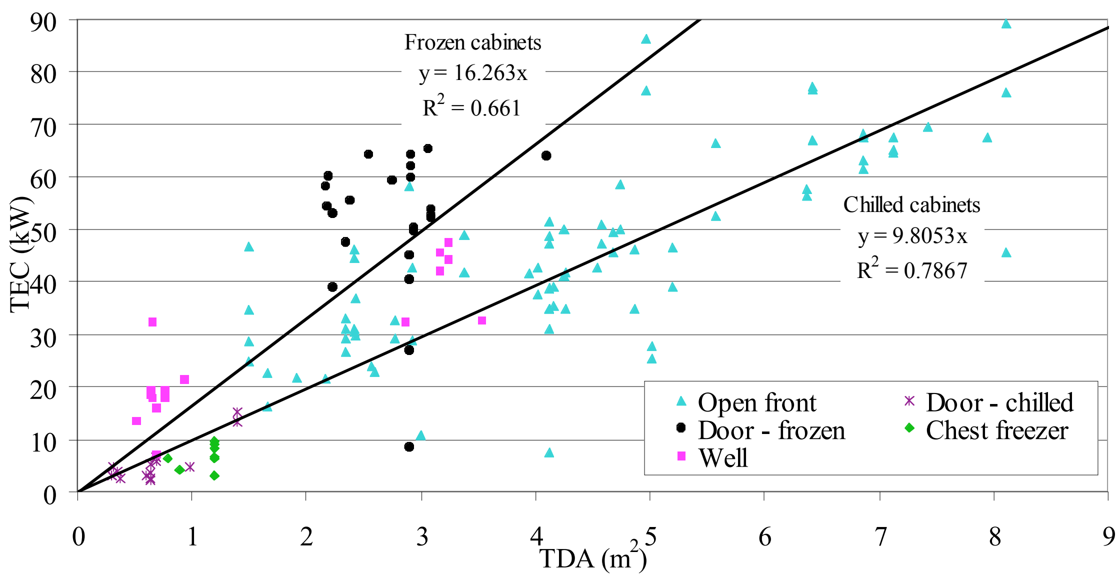

Figure 6. Relationship between total display area (TDA) and total energy consumed (TEC) for all chilled and frozen cabinets.

4 Direct energy consuming processes and state of the art

4.1 Refrigeration systems in food retailing

Refrigeration systems which include display fixtures in the sales area and systems serving the cold rooms are the major energy consuming equipment in supermarkets. Refrigerated display equipment in supermarkets and other smaller food retail outlets can be classified as `integral' where all the refrigeration components are housed within the stand alone fixture, or 'remote' where the evaporator or cooling coils within the display fixtures in the store are served by refrigeration equipment located remotely in a plant room. The main advantages of integral units are the flexibility they offer in merchandising, their relatively low cost and their relatively low refrigerant inventory and much lower potential leak rate compared to centralised systems. Their main disadvantage is the low efficiency of the compressors compared to large centralised compressors, noise and heat rejection in the store which increases cooling requirements in the summer. Although small food retail outlets invariably use `integral' refrigeration equipment, larger food retail stores predominantly use centralised equipment of much more sophisticated technology plus a small number of integrals for spot merchandising.

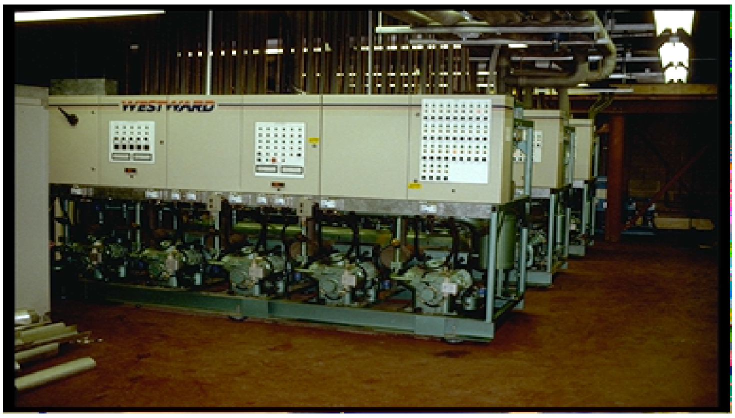

Figure 7: **Compressor Packs in Supermarket**

Centralised systems provide the flexibility of installing the compressors and condensers in a centralised plant area, usually at the back of the store or on a mezzanine floor or roof. The evaporators in the refrigerated display fixtures and cold rooms are fed with refrigerant from the central plant through distribution pipework installed under the floor or along the ceiling of the sales area. In the plant room, multiple refrigeration compressors, using common suction and discharge manifolds are mounted on bases or racks normally known as compressor 'packs' or compressor 'racks' as shown in Figure 7, which also contain all necessary piping, valves, and electrical components needed for the operation and control of the compressors. Air-cooled or evaporatively cooled condensers used in conjunction with the multiple compressor systems are installed remotely from the compressors, usually on the roof of the plant room.

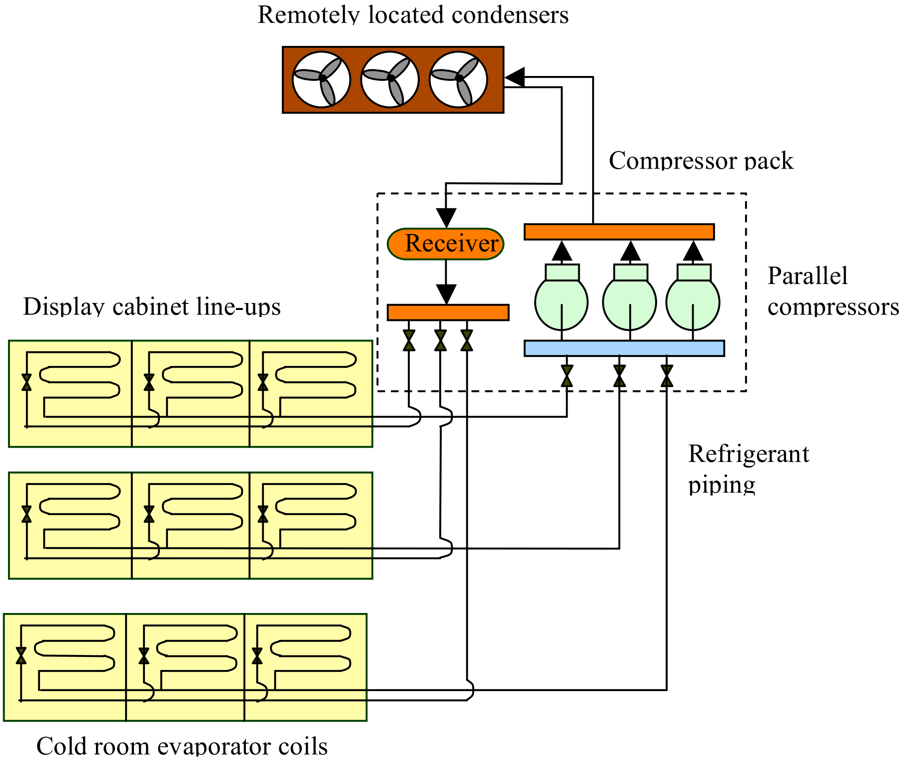

Figure 8: **Schematic diagram of a conventional direct expansion centralised refrigeration system**

A schematic diagram of the direct expansion (DX) centralised system is shown in Figure 8. Separate compressor packs are used for chilled and frozen food applications. Most large supermarkets will have at least two packs to serve the chilled food cabinets and one or two packs to serve the frozen food cabinets. A major disadvantage of the centralised DX system is the large quantity of refrigerant required, 4-5 kg/kW refrigeration capacity and the large annual leakage rates of between 10% and 30% of total refrigerant charge. One way of reducing significantly the refrigerant charge in supermarket refrigeration systems is to use a secondary or indirect system arrangement. With this arrangement, shown schematically in Figure 9, a primary system, which can be located in a plant room or the roof and can use natural refrigerants such as hydrocarbons or ammonia, cools a secondary fluid, which is circulated to the coils in the display cabinets and cold rooms. Separate refrigeration systems and brine loops are used for the medium and low temperature display cabinets and other refrigerated fixtures.

There are many secondary fluids that can be employed but none is ideal for use in both the medium and low temperature loops. For medium temperature loops the most common fluids are propylene glycol/water and for low temperature loops solutions of potassium formate/water [Tassou, 202; Van Baxter, 2003].

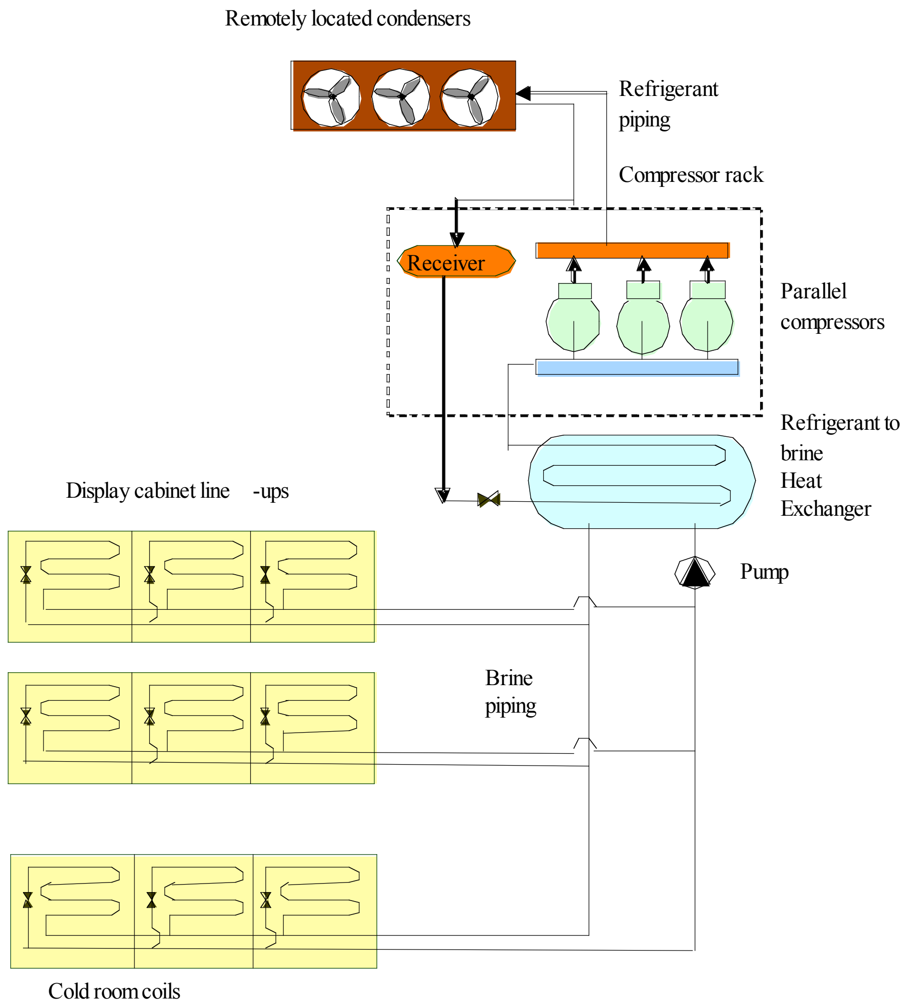

Figure 9: **Schematic diagram of a secondary refrigeration system**

Many secondary refrigeration systems have been installed in the last 15 years in Europe and North America with mixed results. In the UK, a small number of installations were made in the 1990s but a number of them suffered from problems mainly due to insufficient design knowledge, installation expertise and maintenance knowledge.

4.2 Environmental Impacts of Refrigeration Systems

Refrigeration systems contribute to global warming directly through the emission of refrigerants from leakage taking place gradually or through catastrophic failures, and indirectly through greenhouse gas emissions from power stations.

To account for both direct and indirect greenhouse gas emissions and compare alternative systems, the TEWI factor (Total Equivalent Warming Impact) is now increasingly being used to measure and compare the life cycle global warming impact of alternative refrigerants and system designs. The calculation of TEWI for refrigeration systems is only of relevance when comparing systems which are designed to meet the same application need. TEWI is made up of two basic components [BRA, 2004].

These are:

a) Refrigerant releases during the lifetime of the equipment, and unrecovered refrigerant losses on final scrapping of the equipment.

b) The impact of energy generation from fossil fuels to operate the equipment throughout its lifetime.

The calculation of the direct contribution involves the estimation of total refrigerant releases and subsequent conversion to an equivalent mass of CO_2. Refrigerant loss can occur due to leaks, purging and servicing, fluid recovery and catastrophic failure. Once the total refrigerant loss is known, the direct effect can be calculated by applying the appropriate GWP value for the fluid. GWP is the 100 year integrated time horizon Global Warming Potential value for the refrigerant.

The indirect effect arises from the release of carbon dioxide resulting from the generation of energy to operate the system through its lifetime. In many refrigeration applications, the indirect effect will be the major contributor to TEWI.

For refrigeration systems powered directly by electrical energy, it is necessary to calculate the electricity consumption of the system in kWh and then convert this to an equivalent CO_2 emission. The electrical energy generation power factor (kg of CO_2 emitted per kWh of electricity supplied) is dependent on the generation mix. The best available overall estimate for the UK for the period 2005 and 2010 is 0.422 CO_2/kWh [BRA, 2004]. Refrigeration system will also have other environmental impacts such as from the manufacture and disposal of the equipment and the manufacture of refrigerant but these are quite small (5% to 10% depending on the size of the equipment) compared to the environmental impacts of the use phase [Watkins, Tassou and Pathak, 2005].

4.3 Recent research and development to reduce the environmental impacts of supermarkets

International effort to reduce the environmental impacts of supermarket refrigeration systems culminated in the IEA Annex 26 project – Advanced Supermarket Refrigeration/Heat Recovery Systems. This ran between 1999 and 2003 and included collaboration between a number of public and private organisations in five different countries: USA (operating agent) Denmark, Sweden, the UK and Canada [Van Baxter, 2003]. The Annex involved analytical and experimental investigations on a number of systems and design approaches to reduce energy consumption and refrigerant usage. Systems investigated include: distributed compressor systems where small parallel compressor racks are located in close proximity to the display cabinets to reduce refrigerant inventory, indirect systems, self contained display cabinets with heat rejection to water, the use of heat pumps to recover heat rejected by the refrigeration equipment and integration of services in the store using CHP (Combined Heat and Power) systems or CCHP (Combined Cooling, Heating and Power).

The results of a TEWI analysis of the alternative systems with a range of assumptions for annual refrigerant leakage rates showed that lower TEWI was achieved for the distributed compressor system and the secondary loop system. It was also shown that for systems with low charge and low leakage rates, indirect emissions will be much higher than direct emissions.

In another demonstration project in Canada undertaken in partnership between National Resources Canada (CAMNET) and the Loblaws supermarket chain, a secondary refrigeration system with heat recovery was designed for a 9000 m^2 supermarket in Repentigny [Pajanu, Giguere and Hosatte, 2004]. The supermarket uses two refrigeration loops, with potassium formate brine in the low temperature loop at -2^oC and propylene glycol brine at -5^oC for the medium temperature loop. A third loop using ethylene glycol is used to recover heat from the condensers for space heating and hot water and heat rejection of surplus heat to the ambient. The temperature of the heat rejection loop and hence the condensing pressure of the primary refrigeration plant is controlled to optimise performance in response to the heating needs due to outdoor weather conditions. The system was expected to produce 18% energy savings in refrigeration and heating and a 73% reduction in CO_2 emissions.

In another project in the USA an advanced secondary refrigeration system was designed and installed in a Safeway store by Foster-Miller and Southern California Edison (California Edison , 2004) and its performance compared against another Safeway store employing a state of the art conventional direct expansion system. Comparison of the two systems based on modelling predicted annual savings of 6,130 kWh, or 1% for the secondary loop system over the conventional system. Monitoring results, however, indicated a 37,266 kWh/yr, or 4.9% savings. The savings achieved by the secondary loop system were attributed to energy-saving features incorporated in its design, the most important being the multiple parallel pumps and the subcooling from the warm brine defrost. The project concluded that secondary loop refrigeration systems are a viable option for supermarket refrigeration.

The use of secondary loop refrigeration systems has become quite common in Northern Europe due to strict environmental legislation. For example in Denmark from 1st January 2006 the use of HFCs is not allowed in new products [Van Baxter, 2003]. Exemptions to this are refrigeration equipment, heat pumps, air conditioning plants and dehumidifiers with a refrigerant charge of up to 10 kg. This precludes the use of direct expansion multi-compressor systems to supermarkets after January 2006. In Denmark there is also a heavy CO_2 tax on industrial gases, including HFCs, which makes their use in refrigeration systems quite expensive. Hence the significant interest in natural refrigerants.

In recent years, a number of approaches have been employed including secondary systems with hydrocarbons (propane) in the primary plant, and cascade systems with propane in the primary plant, propylene glycol in the medium temperature chilled food cabinets and CO_2 in the frozen food cabinets [Christensen and Berilsen, 2004]. Such a cascade system was installed in a Fakta chain store in Beder, Denmark. The sales area of the store is 490 m^2 and the gross floor area 720 m^2. The refrigeration load of the store was 33 kW for chilled foods and 10 kW for frozen foods. Monitoring of the store from July 2001 to February 2002 indicated that the Energy consumption of the refrigeration system in the Beder store compared to eight similar Fakta supermarkets with conventional R404A direct expansion refrigeration systems. The capital cost of the system was estimated to be 15% higher than the conventional system.

A second test store with a 190 kW chilled food load and 60 kW frozen food load and a cascade system using R404A as the high temperature refrigerant and CO_2 for both the frozen food and chilled food cabinets was shown to reduce the R404 refrigerant requirement to 120 kg, which was a tenth of that of a conventional system, and produced initial refrigerant cost savings of around £17,000 due to the high refrigerant taxes. The capital cost of the system was around 10% higher but was found to produce a 15% - 20% energy savings over a conventional R404A system.

Over the last 10 years, a number of supermarket chains in the UK have experimented with secondary systems. These systems, however, have not become common place due to uncertainties about their capital and operating costs as well as their environmental impacts compared to conventional `primary' systems. As part of IEA Annex 26 Brunel University investigated the viability of secondary systems in the UK through system simulation using an in-house developed supermarket model [Tassou, 2002]. The model was validated against data from a conventional supermarket refrigeration system as well as pumping power data from a supermarket employing a secondary system and was used to compare alternative systems for a 2400 m^2 sales floor area supermarket in Scotland. The results showed that a well engineered direct system with a leakage rate of 5% per annum using R22 as a refrigerant will have a lower capital cost, lower running cost and lower TEWI than an indirect system. A system employing refrigerant R404A and having the same energy consumption as the R22 system will have a higher TEWI, approaching the TEWI of indirect systems. In summary, results from installations and theoretical studies on indirect systems in Europe have shown that:

- They have higher energy consumption of between 10 and 30% over R404A DX systems.
- Investment costs are also between 15 and 30% higher than R404A DX systems.
- Indirect systems are more appropriate for use in medium temperature applications
- For indirect systems to become more competitive with direct systems in the UK, both their capital and running costs should be reduced from current levels.

4.4 CO_2 refrigeration systems for supermarket applications

CO_2, one of the earliest refrigerants, which was later superseded by CFCs mainly due to its high operating pressures, is now experiencing a resurgence. Most of the development work of CO_2 systems for supermarkets has taken place in Scandinavia, Germany and Italy and a number of systems are now in operation.

Most of these systems operate on the sub-critical cycle where CO_2 is used in a `cascade' arrangement with a conventional refrigeration system operating with ammonia, HCs or HFCs. Figure 10 shows a schematic of the first cascade NH_3/CO_2 system installed in the Netherlands in 2004 [van Riessen, 2004]. The systems potential energy savings, based on manufacturers' performance data, were calculated to be 13 to 18% compared to an R404A reference system. With government subsidies, the investment costs were expected to be lower than those for a R404A system. Without the subsidies, however, investment costs would be 28% higher than the R404A system. The payback period based on the annual energy savings was calculated to be 8 years.

Cascade arrangements keep the pressures in the CO_2 system relatively low. Different system arrangements can be implemented for refrigerant condensation as shown in Figure 11 (Sawalha et. al. 2005). Some of these systems, particularly in Northern Europe use natural refrigerants such as ammonia and propane for condensation of the CO_2 and heat rejection to the ambient but in the majority of installations R404A is employed with its associated global warming implications.

Sainsbury's in its Clapham store installed the first CO2 system for supermarket applications in the UK in early 2005. It is based on the sub-critical cascade arrangement with an R404A system acting as the cascade cooler. No results have as yet been reported for the system but the designers and installers expect energy savings in the region of 14% and neutral capital cost over conventional systems (Maunder, 2006).

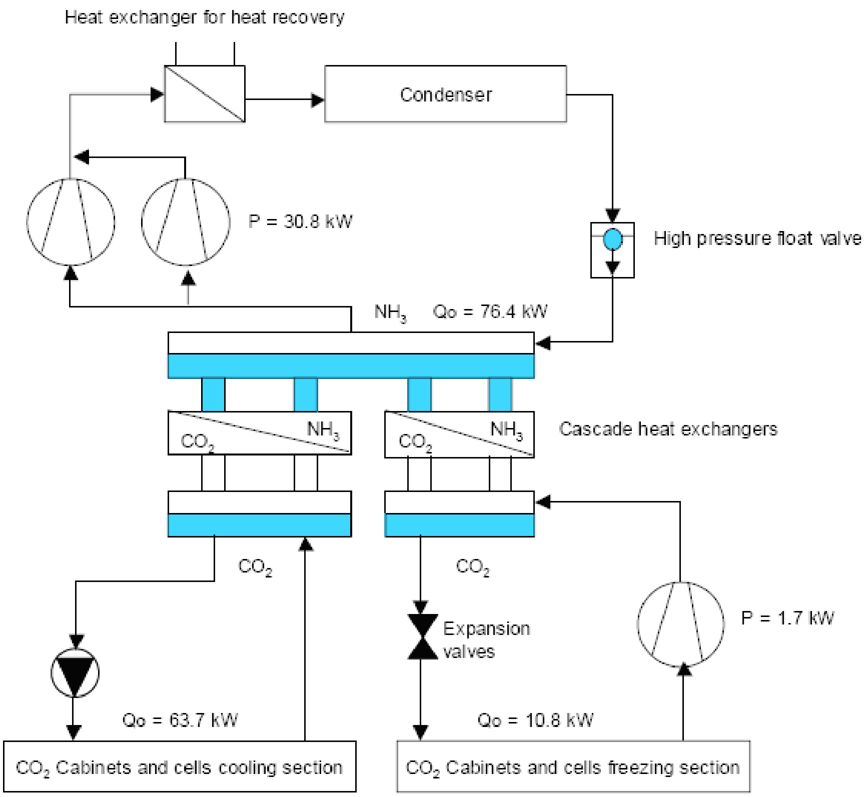

Figure 10: **Schematic Diagram of the 1st Cascade NH_3/CO_2 system in the Netherlands [van Riessen, 2004]**

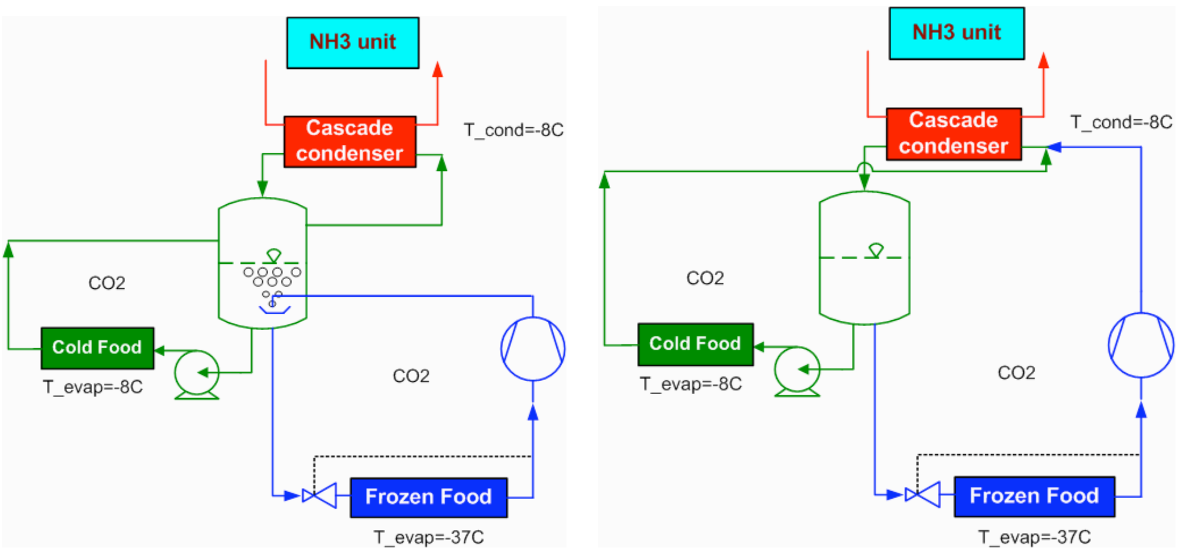

Figure 11: **Schematic diagram of NH_3/CO_2 cascade system with CO_2 at the medium temperature level [Sawalha, Rogstam and Nilsson, 2005]**

An installation of two systems, one subcritical and the other transcritical at a Tesco Extra store in Swansea followed this installation. The subcritical system, which uses propane and CO2 in cascade, is used to serve frozen food glass door cabinets and the transcritical system chilled food cabinets [Epta Group, 2006]. In 2007 more system installations were implemented by Tesco, Marks & Spencers and Morrisons.

One disadvantage of the subcritical cascade systems is the use of two refrigerants in the system, one for refrigeration (CO_2) and the other for heat rejection (HFCs , ammonia, or hydrocarbons). CO_2 trascritical systems enable the use of a single refrigerant, for both the low and medium temperature refrigeration requirements in the store. This should simplify system installation but the high pressures involved in the system, 100 bar or above, impose specific design, control and safety challenges. Linde installed a cascade system with CO_2 used for the medium temperature refrigeration requirements in the store in a large supermarket in Wettingen, Switzerland [Haaf, Heinbokel and Gernemman, 2005].

The system consists of three separate circuits, two for medium temperature and one for the low temperature requirements of the supermarket. The performance of the system was expected to be better than R404A, and have lower power consumption per unit cooling capacity, at ambient temperatures below 14°C and worse at ambient temperature above 28°C. The performance of the CO_2 medium temperature system can be improved at high ambient temperature through the use of evaporative cooling. The capital cost of the system was found to be higher than the capital cost of R404A systems due to the higher cost of the major components which were prototype developments. As such, the cost of the system is likely to reduce through wider application and mass production of components.

Various other possible system arrangements exist for transcritial CO_2 refrigeration systems. Such systems are at an early development and significantly more research and development work is required to optimise their performance and assess their application in supermarket refrigeration systems.

4.5 Summary of performance of CO_2 systems

In summary, CO_2 refrigeration systems for supermarket applications are still in the early stages of development. Results to date indicate that their performance for low temperature food refrigeration applications in a cascade arrangement where the CO_2 system operates in the subcritical range is superior to R404A direct expansion systems. Operation of CO_2 systems in the transcritical range has been found to be less efficient compared to R404A systems, particularly for heat rejection at high ambient temperatures. The cost of CO_2 systems has been found to be between 10% and 30% higher than the cost of R404A systems due to the much higher pressures and specialist components and controls required for these systems.

The higher temperatures available for heat rejection in the gas cooler of CO_2 systems provides opportunities for heat recovery and the use of the heat for heating or desiccant cooling.

4.6 Opportunities for energy savings in supermarket refrigeration

4.6.1 CO_2 systems

Many countries in the EU have recognised that the use of natural refrigerants in supermarket refrigeration systems is unavoidable. In the UK the interest in natural refrigerants is increasing and the momentum that is gathering with major supermarket chains may expedite the introduction of natural refrigerants. At present, the most promising candidate is CO_2 which can be used as a single refrigerant in a trascritical system or in a cascade arrangement with another natural refrigerant for heat rejection. Application of CO_2 for supermarket refrigeration is relatively new with only a few installations around the world.

For CO_2 to become widely accepted in supermarket applications considerable research and development effort is required on all aspects of system design, component development and system design optimisation, control and effective maintenance systems. Component development includes evaporator coils, gas cooler, compressors, particularly for transcritical operation, and expansion valves. Other issues include compressor lubrication and oil management in the system, and impact of oil on heat transfer.

The performance of CO_2 systems can be improved if operation of the system remains in the subcritical region for the majority of the time. This will require heat rejection at low temperature, for example to the ground or to ground water. Operation of CO_2 in the transcritical region provides opportunities for heat recovery and use of the heat for heating or for regeneration of the desiccant in desiccant air conditioning systems.

4.6.2 Conventional Centralised Refrigeration Systems

In conventional multi-compressor refrigeration systems in supermarkets compressors account for around 60% of the total energy used for refrigeration and 30% of the total electrical energy consumption of the store. In recent years the trend has been towards the use of scroll compressors due to their lighter weight and ease of replacement by maintenance engineers in the event of failure. Although the efficiency of scroll compressors has increased in recent years they are still less efficient than well engineered reciprocating semi-hermetic compressors particularly during operation at high pressure ratios.

Irrespective of the type of compressor employed, energy savings can be achieved:

- Through better matching of the compressor capacity to the load by on-off cycling or variable speed control.
- The minimisation of the pressure differential across the compressors through condensing (head) and evaporating (suction) pressure control. Head pressure control is now well established with the condenser pressure allowed to float in response to the variation in the ambient temperature. Head pressure control limits opportunities for heat recovery from desupeheating the compressor discharge gas however, and the relative economic and environmental benefits of the two strategies should be re-examined. A way to benefit from heat recovery and low head pressure may be to employ heat rejection to water and use ground cooling instead of air cooling and a heat pump to upgrade the reject heat for heating and hot water purposes as discussed in Section 3. Suction pressure control is not widely applied as yet, due to greater control complexity and the requirement to maintain product temperature in all refrigerated cabinets whilst adjusting the suction pressure.

4.7 Refrigerated Display Cabinets

The cooling load of refrigerated cabinets determines the load on the refrigeration compressors. The load on the cabinets at steady state conditions is mainly due to heat transfer between the fabric of the cabinet and the ambient air (conduction and convection), radiation from the surrounding surfaces to the products in the cabinet, internal gains from fans and lights and infiltration. Infiltration arises from air exchanges between the cabinet and the surrounding environment. Typical contributions of the various heat transfer elements to the load of an open front multi-deck chilled food refrigerated cabinet are shown in Figure 12 [Datta et al, 2005]. These contributions will vary with the cabinet type, the cabinet design and the operating and control conditions. For example the contribution of infiltration will be much higher for open multi-deck display cabinets compared to frozen food well or frozen glass door reach-in cabinets.

4.7.1 Infiltration

Ways of reducing the infiltration load for open multi-deck cabinets are:

- To improve significantly the performance of the air curtain that is used to reduce ambient air infiltration into the cabinet.

- The use of night blinds during periods when the store is closed.

Significant research has been carried out to improve the performance of air curtains in recent years. This included both experimental studies and modelling using Computatoinal Fluid Dynamics [Stribling, Tassou and Marriott, 1997; Smale, Moureh and Cortella, 2006; Foster, Madge and Evans, 2005]. The majority of these studies have been carried out on specific cabinets and the results have not been generalised, even though some generic principles have been established. A major study funded by the US Department of Energy had the aims of developing an understanding of the infiltration phenomenon, identifying the key variables affecting infiltration and developing a design tool to predict infiltration in display cabinets [Faramazi, 2007].

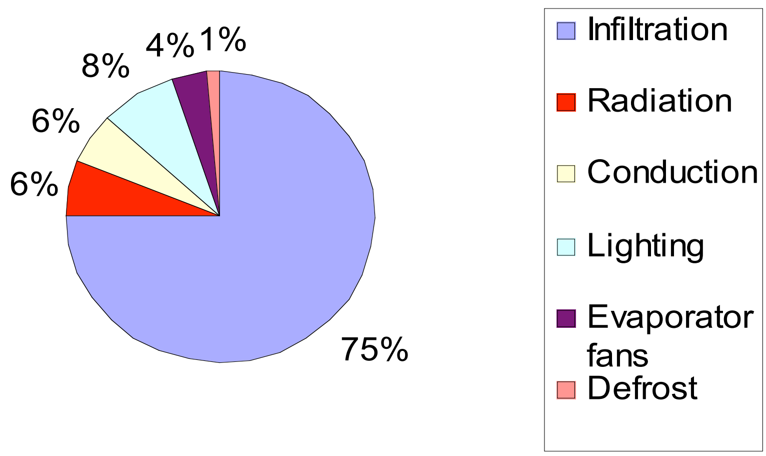

Figure 12: **Contributions to the load of a vertical multi-deck open front chilled food display cabinet [Datta, Watkins, Tassou, Hadawey and Maki, 2005]**

The results to date indicate that an 18% reduction of infiltration rate can be achieved with the following parameters: opening height to discharge air curtain width ratio of 16; a linear velocity variation across the discharge air curtain width, Reynolds number at air curtain of 4500, aligned discharge and return air grille with no back panel flow, and throw angle of zero degrees. These results are still to be validated on a prototype cabinet and do not incorporate other important display cabinet design parameters.

The energy savings achieved through the use of night blinds will be a function of the ambient temperature, the quality of the blind and its fitting on the cabinet and the on-off operational cycle of the blind. The use of night blinds has been found to generate energy savings of up to 20% but their use has been mainly concentrated on stand alone cabinets in smaller food retail outlets [Datta et al, 2005]. Night blinds cannot be used on cabinets employed in 24 hour trading stores and are also not popular with larger stores as they are considered to interfere with cabinet loading during the night.

Cabinet loading also has a major impact on infiltration into open fronted cabinets. When cabinets are tested the loading is consistent and generally fills the cabinet shelves. In reality shelves are often partially filled. This allows more air to infiltrate into the cabinets. Therefore fully loading shelves is likely to improve efficiency of cabinets and any means to ensure shelves remain fully stacked would have energy efficiency benefits.

4.7.2 Glass doors

A simple option to reduce infiltration is to place doors on open fronted cabinets. Although in the past supermarkets have considered doors would have a negative impact on sales they are now beginning to trial this technology. One issue is the potential for water to condense on the doors and the need for anti sweat heaters that would add to the energy demand. Therefore most doors have highly insulated glass doors with low emissivity coatings. Savings of 35-50% can be achieved depending on the cabinet type and the efficiency of the cabinet prior to fitting doors.

4.7.3 Fans

The use of more efficient fans (aerodynamic blades on axial flow fans) and more efficient fan motors such as ECM (Electronically Commutated Motors) can reduce fan heat loads. ECMs have been shown to produce a 67% energy savings over conventional shaded pole motors [Karas, Zabrowski and Fisher, 2006]. ECMs are more expensive than conventional motors and the use of tangential fans in the place of axial fans can reduce the number of fans required. A problem with tangential fans is that they are more difficult to clean in comparison to axial flow fans.

4.7.4 Lighting

Internal loads from lighting can be reduced through the use of more efficient lighting fixtures and electronic ballasts, for example T5 instead of T8, T10 or T12 fluorescent tubes. A number of supermarkets are now trialling linear strip LED lighting fixtures for frozen food display cabinets, which are expected to produce up to 66% energy savings over conventional fluorescent lighting fixtures [GE Consumer Industrial, 2006].

4.7.5 Evaporator design

Efficiency improvements can also be achieved through the use of more efficient evaporator coils. An efficient coil will lead to an increase in the evaporating temperature and pressure and will lead to a reduction in the compressor power consumption [Bullard and Chandrasekharan, 20049]. The need to maintain a certain evaporator coil air off temperature to satisfy the cooling needs of the displayed products imposes a limit on the maximum possible evaporation temperature. This limits the efficiency gains that can be achieved through the heat transfer enhancement of evaporator coil performance. Other important issues to be considered are pressure drop on the coil that increases the fan power, and frosting and defrosting losses. Depending on the coil design and environmental conditions it is possible to defrost the coils of chilled food display cabinets using off-cycle defrost. With this defrost method the refrigerant supply to the evaporator is switched off and defrost is achieved by circulating cabinet air through the coil. The temperature of this air increases with infiltration of ambient air from the surroundings and melts the ice accumulated on the coil.

4.7.6 Suction-liquid heat exchange

Exchange between the suction and liquid lines is common in domestic refrigerators but less so in retail cabinets. Suction-liquid heat exchange has several advantages:

- Increased system performance.
- Subcools liquid refrigerant and prevents flash gas formation at inlets to expansion device.
- Enables all refrigerant to be evaporated before returning to the compressor.

However, the suction-liquid heat exchanger does increase the temperature of the refrigerant and reduce the pressure of the refrigerant entering the compressor causing a decrease in the refrigerant density and compressor volumetric efficiency. Therefore it is not an energy efficient option for all refrigerants.

4.7.7 Anti sweat heaters (ASH)

ASH control is quite common in supermarkets. The control system ensures that the heater is used only when needed and is controlled by the dew point of the supermarket air. Once a certain dew point is exceeded the heaters are switched on. ASH controls save energy by reducing the amount of time the heater runs and by also reducing the heat added to the cabinet from the heaters that the refrigeration system needs to extract. Savings of up to 7% are suggested.

4.7.8 Compressor efficiency

Variable-speed-drive (VSD) compressors have potential to reduce energy used by integral cabinets. Energy savings associated with variable speed are due to lower mass flow rate that reduce condensing pressure making energy consumption of the compressor lower. Generally a VSD compressor is not as efficient as a comparable load/unload compressor as the variable-frequency drive increases power draw by 2 to 4%. At 100% speed the constant speed compressor is more efficient than the VSD.

A VSD compressor can achieve a 20 to 30 % energy savings in comparison to a fixed speed compressor. Generally, if a constant-speed compressor operates above 80% of its capacity, it will be more efficient; whereas if it operates below 80% of its capacity the VSD compressor is likely to be more efficient (Figure 13).

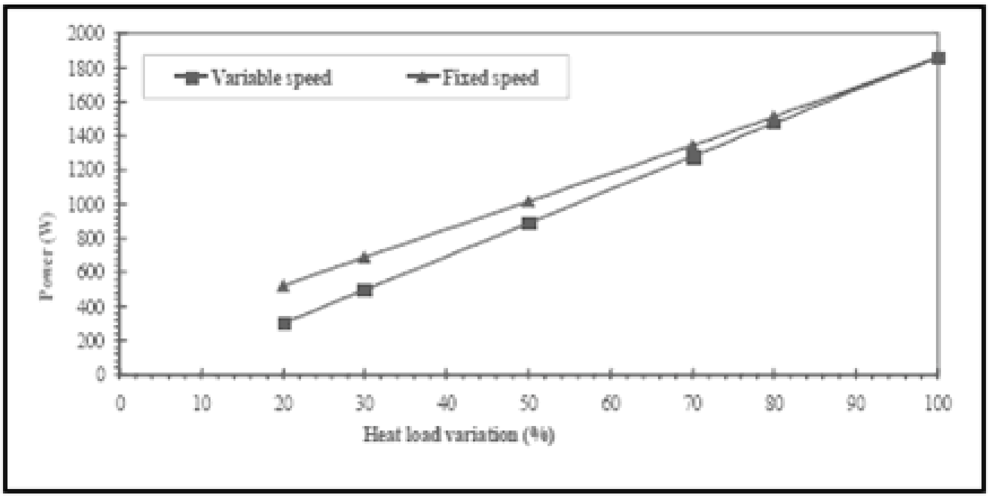

Figure 13. Energy savings by using a VSD compressor [Lot 12]

4.7.9 Expansion valve

Generally TEV (thermostatic Expansion Valves) are used on larger retail display cabinets. Occasionally EEV (electronic Expansion Valves) are used. Most smaller cabinets have capillary expansion.

EEVs are claimed to enable better superheat control and therefore achieve more efficient usage of the evaporator. This only correct if the TEV is not correctly set. EEV are also claimed to reduce the minimum pressure drop required to allow proper operation of a standard TEV thereby allowing condenser pressure to float. Although EEVs have been shown in some instances to reduce energy consumption the savings are low when compared to optimised TEVs.

Almost all commercial refrigerators operate using ‘dry’ expansion where the entire refrigerant is boiled before it leaves the evaporator. This is not the case with large industrial systems that are often fully flooded. This has the effect of allowing boiling heat transfer over the entire surface of the evaporator and increasing the efficiency of heat transfer. The exception to this is an overfeed system developed by Evans, Hammond and Gigiel (2008) based on a low pressure receiver. In the system multiple evaporators were overfed draining to a common low pressure receiver.

A bubble expansion device has been developed that allows evaporators in small refrigeration systems to operate fully flooded. The expansion of refrigerant is controlled by a valve whose position is controlled by the liquid level in the condenser. The device allows the liquid in the condenser together with a small amount of gas to leave the condenser. The gas (which must be low) ‘slip streams’ the liquid and acts as a signal to the expansion valve. The device incorporates an ejector to improve fluid recirculation in the evaporator loop, a tiny drum to separate flash gas and a unit to return oil to the compressor, heated by sub cooling of the liquid from the condenser. All these functions are integrated into a compact unit.

4.7.10 Defrosting

The evaporator coils of frozen food cabinets cannot be defrosted by off cycle defrost alone and electric defrost is employed in the majority of cases. Experience has shown that the defrost frequency may be excessive for the majority of operating conditions and this penalises system performance. Defrost energy savings can be achieved using defrost on demand [Tassou, Datta and Marriott, 2001; JTL Systems, 2005].

Usually defrosts are scheduled at pre set times (every 6 or 8 hours would be typical) and this can result in unnecessary defrosts and excess energy use and increase in product temperatures. The defrost is most usually terminated on a temperature or time setting, whichever occurs first. It is generally good practice to terminate on temperature to ensure all the ice has melted. During a defrost the ‘useful’ energy is used to melt the ice on the evaporator. As the ice build up on an evaporator is rarely even over the whole surface and the defrost heaters do not heat the evaporator block uniformly areas of the evaporator are ‘over defrosted’ and this excess heat needs to be removed once the refrigeration system begins operating. This obviously adds heat to the cabinet after every defrost that needs to be removed by the refrigeration system. The cost of a defrost therefore consists of an overhead and an amount of energy to melt the ice. In work with frozen retail display cabinets the overhead was found to be around 85% of the energy used (Lawrence and Evans, 2008). Defrosting the evaporator only when necessary can therefore save considerable amounts of energy.

Various systems for defrost on demand have been proposed (artificial intelligence techniques, neural networks, air pressure differential, temperature difference between air and evaporator surface, fan power sensing, comparing the heat transfer rate on the air and refrigerant side of the evaporator and measuring ice thickness). Most of these methods have been proposed for retail display cabinets but have not gained widespread acceptance due to the complexity of sensing methods, reliability and cost. Methods such as ice thickness measurement have been used in the past in cold rooms but such systems have not been widely applied in retail.

Recently work has shown that thin, electrically-conductive films applied to surfaces and heated with milliseconds-long pulses of electricity can make ice melt from surfaces. Called thin-film, pulse electro-thermal de-icers (PETD) they create a thin layer of melted water on a surface that melts ice efficiently (http://engineering.dartmouth.edu/thayer/research/ice-engg.html). If this technology can be economically applied to evaporators it has potential for low energy and efficient defrosting of evaporators.

4.7.11 Insulation

The heat load across the insulation of retail cabinets varies and is higher in frozen cabinets than open fronted chillers (Figure 14). In frozen cabinets the heat load across the incitation can be as high as 17% of the total heat load and therefore improved insulation solutions are an effective way to improve efficiency.

With typical mid-panel thermal conductivities as low as one-fifth of those of conventional expanded polyurethane (PU), Vacuum insulated panels (VIPs) can offer significantly improved insulation performance (Wu, Sung and Chu, 1999). Depending upon application, this can translate to enhanced energy efficiency, improved temperature control or reduced insulation thickness.

Certain limitations on performance of the panels has so far restricted their uptake to niche applications (Brown, Swain and Evans, 2007). These include edge effects where heat is conducted through the metalized foil outer components especially at the corners and the integrity of the panels. However, is these could be overcome VIPs have huge potential to save energy in smaller domestic and commercial appliances.

Insulation performance can also be improved by decreasing the foams thermal resistance. This can be achieved by the formation of smaller cells within the foam insulation structure and better cell-size consistency.

Most insulation foam is now blown using cyclopentane instead of HFCs. Isopentane, CO_2, and water have also been suggested but the thermal conductivity of these blowing agents is higher than that of HFCs and therefore will not achieve reductions in energy consumption (but will reduce environmental impacts such as GWP).

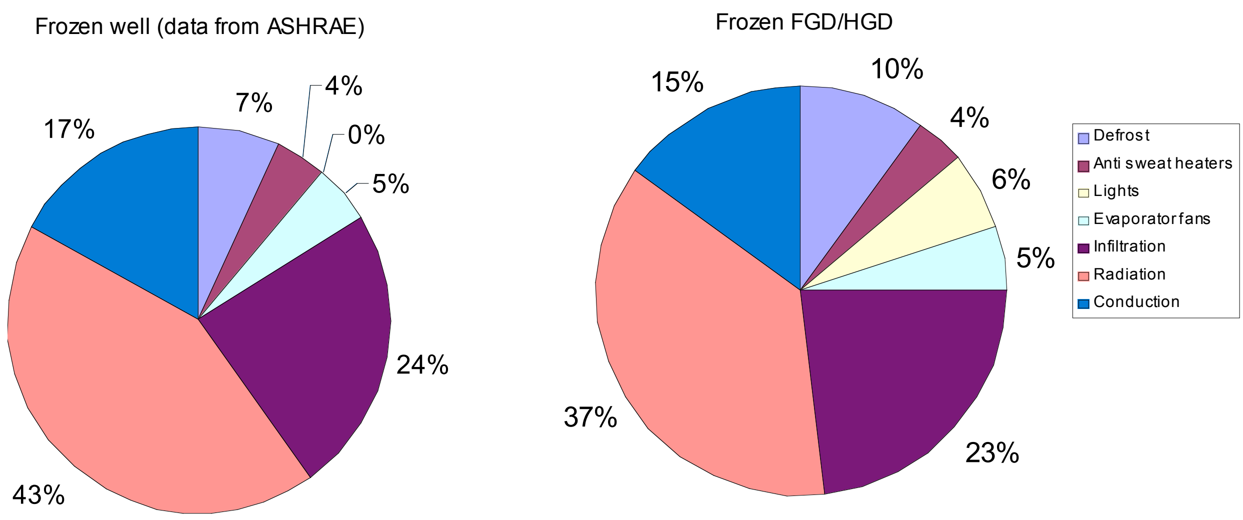

Figure 14. Heat loads on frozen well and half/full glass door cabinets.

4.7.12 Radiant heat

Radiant heat load can be a significant in frozen retail cabinets (Figure 14). Methods to reduce the radiant load have been suggested but rarely implemented in supermarkets. Hawkins, Pearson and Raynor (1973) investigated the use of low emissivity materials to lower temperatures and temperature gradients within products. They examined protective materials used in three ways related respectively to (i) the product producer (reflecting packaging), (ii) the cabinet supplier (reflecting night blinds) and the shop keeper (reflecting ceilings and canopies). Using reflective mirrors it was found that product temperatures could be reduced by 5°C. The study did not investigate energy savings as the only aim was to reduce product temperatures. However, increasing the evaporating temperature of a frozen supermarket pack by 5°C would achieve significant energy savings.

4.7.13 Spot cooling

In most supermarket cabinets temperatures of product vary according to the position within the cabinet. In chilled cabinets centre product temperature often vary between -1 and 7°C. In frozen cabinets centre product temperatures vary between -15 and -30°C. Reducing the maximum temperature of the food has the potential to reduce the overall range in food temperatures. This would have the effect of not only stabilising food temperature but would enable evaporating temperature to be increased with an associated energy savings.

Several methods have been proposed to reduce the range in temperatures within a cabinet. Linde have proposed a method using chute shelves [Schuster and Krieger, 2007] to create sequential air curtains. The work demonstrated that was possible to keep product temperatures within a -1 to 2°C range whilst reducing the heat extraction rate by 6%.

The use of heat pipes to cool the front of chilled multi-deck shelves was proposed by Wang et al, 2004. By inserting the heat pipe into the shelf the heat transfer between the rear and front of the shelf was enhanced.

5 Environmental control in supermarkets

5.1 HVAC Systems

Supermarkets present a unique space conditioning challenge because of the interaction between the Heating, Ventilation and Air Conditioning (HVAC) system and the refrigerated display cases. The display cases provide significant sensible cooling and increase the latent load fraction on the HVAC system. To-date in the UK, however, for traditional reasons and the way that the two industries developed over the years, the two systems are controlled completely independently.

The energy consumption of the HVAC systems in retail food stores can be between 15% and 25% of the total energy consumption depending on the system design, geographic location and controls. Although different types of systems and approaches have been tried over the last few years to improve thermal comfort and reduce energy consumption, such as underfloor heating, displacement ventilation and natural ventilation, the most common system nowadays is the all air constant volume system. This system provides ventilation, heating and cooling in the store by conditioning air in the central plant and providing this air through overhead distribution ductwork to different parts of the store. Return air ducts return the air to the air handling unit(s) where part of it is mixed with fresh and recirculated and the rest is discharge to the atmosphere. In supermarkets, however, significant infiltration takes place through the high traffic doorways and this will reduce the fresh air requirements. These doorways are normally protected using air curtains or automatic doors and in some new supermarkets a combination of a lobby area with automatic doors, leading to a second set of doors protected by air curtains. Even with these arrangements, however, infiltration will still have an impact on the HVAC load (both heating and cooling) and the fresh air requirement through the mechanical ventilation systems.

5.1.1 Opportunities for energy savings in HVAC systems

Considerable opportunities exist to reduce the energy consumption of HVAC systems in retail food stores which can also have a positive impact on the reduction of the energy consumption of the refrigeration systems. More sophisticated design and control strategies can be used to allow for free cooling when the outdoor temperature is lower than the store air set point temperature. Other strategies that can be adopted is to use demand controlled ventilation using CO_2 measurements or other control parameters such as shopping activity to control the amount of fresh and total air supplied using variable speed fans. Heat recovery systems can also be employed to utilise heat rejection from the refrigeration plant and bakery ovens for space and water heating. To facilitate heat recovery and at the same time allow the use of floating condensing pressure control, the use of heat pumps can be considered.

Air overspill from open display cabinets which leads to the `cold aisle' effect can be used to provide cooling in other parts of the store. At present Tesco, in its new stores, recover part of this air and return it to the air-handling unit for recirculation to the store in the summer. Although this can reduce the `cold aisle' effect and should theoretically lead to energy savings there may be other more effective approaches to control the local aisle environment that could lead to both energy savings and reduction of refrigeration energy consumption and emissions [Tasou and Xiang, 2007].

Other approaches for energy conservation in HVAC systems is to use variable space temperature set-points based on the outdoor temperature and better zonal control to provide low levels of humidity (moisture content) close to the refrigerated display cabinets to reduce frosting and defrosting losses and energy input to anti-sweat heaters.

5.2 Lighting

Lighting plays an extremely important role in attracting customers in the food retail industry. In supermarkets, lighting design requires different approaches in the various departments: refrigerated display cases, bakery, meat, produce, and general packaged foods. In addition, lighting of the entryway needs to be attractive to the customer and the checkout area must provide enough light to make the sales transactions easy. In general, supermarkets in the general sales area are designed for high lighting levels, around 1000 lux, as there is a belief that bright light is generally attractive to customers. Accent lighting is also provided in many cases to highlight particular products and displays.

Lighting is a major consumer of energy in supermarkets, and depending on the age of the store and lighting fixtures used, lighting can account for between 15% and 25% of total energy consumption. The majority of lighting fixtures in stores use fluorescent lighting. Older stores may use T12 fluorescent tubes but newer stores will have T8 tubes. Nearly all commercial refrigerated cabinets use linear fluorescent lamps. Although fluorescent lamps may provide superior energy efficiency in many lighting applications, their use in commercial refrigeration is not ideal. Fluorescent lamps in this application exhibit a reduced light output of up to 25% and uneven lighting on the products. These problems are a result of ineffective lamp operation at cold temperatures, and poor configuration and mounting location within the cabinets.

5.2.1 Energy Conservation in Lighting

A number of new supermarkets have been designed to maximise daylighting through:

- Light pipes mainly in the office areas.
- The store façade at design stage.
- Glazed parts of the roof introduced at the design stage.

A case study has shown that there is significant potential to reduce energy consumption in retail food stores with daylighting supplying up to 25% of lighting energy requirements. The main barriers to the wider application of daylighting, however, is the requirement to satisfy the new building regulations in terms of the overall thermal performance of the building fabric, the high cost of the first store design to incorporate daylighting and the requirement to have consistent levels of illumination on certain types of food and non food products. Integration of daylighting with artificial lighting should be able to satisfy both energy and merchandising requirements at acceptable additional capital cost but detailed research and development is required to reduce the impacts and maximise the benefits of daylighting in retail food stores.

For stores operating late at night or 24 hour stores, dual level switching for overhead lighting fixtures can be employed, allowing alternate fixtures to be turned off during low traffic hours. Further lighting energy reduction can be achieved through:

- The installation of occupancy sensors to reduce lighting in storage rooms, back-of-house offices, and other vacant or low-traffic areas.
- Upgrading to more efficient lighting technologies, including replacement of T-12 lumps with T-8 or even T-5 fixtures.
- Switching from high-pressure sodium lamps to metal halide lamps in car parks and upgrade to LED lighting for outdoor signage.

In recent years, LED lighting was improved to the level that they are now becoming competitive with fluorescent lighting in glass door freezer cabinets. LEDs have the potential to provide more uniform lighting levels in the cabinet, very long life (up to 50,000 hours) and energy savings that as yet have not been quantified in service applications. A number of retailers are currently trialling LED lighting for glass door freezer cabinets and other applications [Narendran, brons and Taylor, 2006].

5.3 Building fabric and use of renewable energy sources

New supermarket designs have to comply with the new Part L building regulations with respect to their overall insulation, air tightness and heat transmittance but also they have to incorporate renewable energy technologies to satisfy 10% of their energy requirements. The definition of renewable energy sources in this context is quite broad and incorporates a number of technologies such as solar electricity (PV), solar thermal, wind energy, heat pumps, biomass, geothermal heating and cooling, and Combined Heat and Power (CHP). Many of these technologies are currently under assessment by a number of major retailers. A number of research and development programmes are also under way. For example, Brunel University has recently completed a scoping study funded by DEFRA on the potential of solar energy in food manufacturing, distribution and retail [Tassou, 2006; Tassou, Delille and Shilliday, 2007]. Another project, again funded by DEFRA is also investigating the application of tri-generation systems in the food retail industry [Tassou, Chaer, Sugiartha amd marriott, 2006; Tassou Chaer, Sugiartha, Ge amd Marriott, 2007].

5.3.1 Emissions reduction from the application of renewable energy sources and research and development needs

With current energy prices and the absence of legislation to make mandatory a much higher percentage of CO_2 reduction in supermarkets from the use of renewables, reduction of the energy consumption of refrigeration equipment and artificial lighting are much more economically attractive to retailers than the wider application of renewable sources. However, as the potential to increase further refrigeration and lighting efficiency at reasonable cost is exhausted, further reduction of the carbon footprint of supermarkets and other food facilities could be achieved through:

1. Better integration and control of current and emerging technologies.
2. Technological developments and radical approaches to merchandising.
3. Improvement of the performance of renewable technologies and their optimum integration within the building structure, for example, application of transparent PV modules into appropriately oriented supermarket façades to replace conventional glazing. Consideration should be given to potential reduction of structural costs over conventional roof mounted PVs; impact on daylighting; integration of daylighting and artificial lighting to achieve required lighting levels at minimum running costs.
4. Evaluation and integration of renewables such as solar, wind, biomass and other low carbon technologies such as CHP, tri-generation, ground source heat pumps within the

context of overall thermal energy management and environmental control of the food facility.

5.4 Demand Side Management and System Integration

Most large retail food stores are equipped with central monitoring and control systems to primarily satisfy food hygiene regulations. These systems monitor and control the temperature in the refrigerated display cabinets within specified limits and control the centralised refrigeration systems (packs) to balance the load on the cabinets with the refrigeration capacity of the packs. The control functions performed are fairly simple and in the vast majority of cases, the data collected remain unutilised due to the unavailability of automated data mining and diagnostic systems for this application.

This data, however, provide the opportunity not only to characterize the various energy consuming processes in the supermarket but also to relate the consumption patterns to fuel pricing and tariff structures and thereby develop advanced control techniques to minimize maximum electrical demand, energy consumption and fuel costs. It may be possible to perform these tasks on-line by employing adaptive control and diagnostics through Artificial Intelligence techniques.

Energy savings can also be achieved through system integration and pinch technologies to utilise thermal energy, both heating and coolth, generated in some parts of the store, in other parts of the store that require heating or cooling. Other approaches could include on-site combined heat and power generation (CHP) or combined heating power and refrigeration (tri-generation) [Tassou, Marriott, Chaer, Sugiartha and Sugiarthar, 2007; Maidment ans Tozer, 2002].

6 Conclusions

- Investigation of the electrical energy consumption of 2570 retail food stores covering the whole range of retail food outlets from convenience stores to hypermarkets has shown that a wide range of variability exists in the electrical energy intensity of these stores even within the same store category and the same retail food chain. The variability is wider in small sales area stores, convenience stores and supermarkets, where the sales are food dominant.
- The variation of the average electrical energy intensity with sales area of all stores in the sample considered can be described with a power law. If the electrical energy intensity of the stores whose intensity is above the average is reduced to the average through energy conservation measures, 10% electrical energy savings can be achieved, representing 310 GWh per annum for the sample of stores considered or approximately 840 GWh for all the stores of the major retail food chains in the UK. This will produce approximately 355,000 tonnes of CO_2 emissions savings.
- Refrigeration is responsible for a major percentage of the electrical energy consumption of retail food stores ranging from around 25%-30% for hypermarkets to over 60% for food dominant convenience stores. Refrigeration systems are also responsible for direct emissions through refrigerant leakage so in recent years significant effort has been devoted not only to increasing efficiency but to the development of technologies that employ natural refrigerants such as CO_2.
- A number of CO_2 systems mainly of the cascade type has already been installed in the UK and. These systems are reported to be performing satisfactorily but no data or comparisons with traditional R404A systems have been published in the open literature. A small number of transcritical systems has also been installed but the retail industry in the UK is still concerned with high pressures in the sales area.
- Estimates of capital cost of CO_2 systems compared to R404A vary but are quoted to be between 10% and 30% more expensive than comparable R404A systems. The higher cost is due to the low volume of production and the specially designed components and fabrication needed particularly for transcritical systems. These costs are expected to reduce significantly with the wider adoption of CO_2 refrigeration systems.
- Other technologies, such as secondary loop refrigeration systems have also been employed to avoid the use of HCFC and HFC refrigerants. Results from installations to date are mixed but

efficiency and cost comparisons between secondary loop and R404A systems are thought to be similar to those between CO_2 and R404A systems.

- Irrespective of the type of refrigerant employed, significant energy savings can be achieved by improving the efficiency of the compressors, reducing the pressure ratio in the system, and continuously matching the refrigeration capacity to the load. The pressure ratio can be reduced by employing floating and suction pressure control or heat rejection to the ground.
- Considerable opportunities also exist from refrigeration and HVAC system integration, heat recovery and amplification using heat pumps and demand side management and system diagnostics.
- Another area that provides significant opportunities for energy savings is the design of more efficient display cabinets. Research and development areas to be addressed are the reduction of the infiltration rate, reduction of fan and lighting energy consumption, the design of more efficient evaporator coils to increase the evaporating temperature, reduce frosting rates and the implementation of defrost on demand.

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