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SID 5 Research Project Final Report

Department for Environment Food and Rural Affairs

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Project identification

1. Defra Project code: FO405

2. Project title:

   Greenhouse Gas Impacts of Food Retailing

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3. Contractor organisation(s):

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4. Total Defra project costs: £ 91400

5. Project: start date .... 01 December 2007

   end date .... 31 October 2008

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The main aim of the project was to investigate and quantify the greenhouse gas impacts of retail food operations and identify business and technology approaches that could offer significant potential to reduce these impacts. This project is one of a number of projects funded by Defra to consider the application of the PAS 2050 method to the food chain. FO0404 involved scenario building to test and inform the development of the BSI method for assessing GHG emissions from food. FO0405 considered the GHG impacts from food retailing and FO0406/09 addressed the GHG impacts of food preparation and consumption in the home. This report provides a summary of the results of FO0405 which was undertaken by Brunel University and was carried out in 3 phases. The objective of Phase 1 was to test the PAS 2050 method for allocating GHG emissions from the distribution and retail of food products whereas the objective of Phase 2 was to determine the impact of store characteristics and business practices on GHG emissions and the potential of new technologies and practices to effect significant reductions. The objective of Phase3 of the project, which was added at a later stage as an Annex, was to investigate and test the applicability of the PAS 2050 method for allocating GHG emissions to service operations.

Specific objectives for Phase 1 were to:
i) Identify and quantify as far as possible the GHG emissions from the storage of a range of food products in Regional Distribution Centres (RDCs) and their transport to supermarkets. The products considered area:

- packed fresh meat;
- ready meals
- dairy products (milk and cheese)
- frozen vegetables (peas)
- fresh fruit (apples, strawberries)
- potatoes
- bread.

ii) Consider the GHG emissions arising from the retailing of these product categories. These will include emissions from energy consumption, refrigerant leakage and food waste.
iii) Consider the applicability of PAS 2050 to the determination of GHG emissions derived from the distribution and retailing of food products.

Specific Objectives for Phase 2 were to:
i) Consider the range of store formats and retail food operations in the UK and determine their GHG emissions in terms of unit store area and product throughput.

ii) Compare and identify the merits of different store formats and merchandising approaches with respect to GHG emissions per unit throughput.
iii) Identify the most appropriate merchandising and technical approaches to deliver GHG emissions reductions.

Objectives for Phase 3 were to:
i) Produce comments and recommendations for the Steering Group to facilitate the application of PAS 2050 to service operations.
ii) Test the application of PAS 2050 on a food refrigeration service company to identify areas of difficulty and uncertainty and provide recommendations on ways that these can be overcome.

A number of retail food chains collaborated in Phases I and 2 of the project through the provision of data and information on the operation and energy consumption of their stores. These were:, Tesco, ASDA, Morrisons, Somerfield, Iceland and Budgens and their contribution is acknowledged.

The main conclusion of Phase 1 is that PAS 2050 can be used to quantify the GHG emissions from retail food operations (distribution and retail). If stores are submetered to a sufficient level of detail this can be done without significant difficulty. 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.

For temperature controlled food products the main contributing components to GHG emissions are the energy consumption of the refrigeration systems in the store and refrigerant leakage. Emissions from refrigerant leakage when using HFC (hydrofluorocarbons such as R404A) refrigerants can be substantial and depending on the leakage rate, much higher than the emissions from the energy consumption of the refrigeration equipment. This makes the use of HFCs in systems requiring high refrigerant charge unsustainable in the future. The use of natural refrigerants such as CO_2 and ammonia, or secondary refrigerants can make a significant contribution to the reduction of emissions from food distribution and retailing. For non refrigerated perishable food products, emissions from the use of plastic bags and landfilling of waste food can be a significant portion of total emissions from the distribution and retail phase of their life cycle – Anaerobic digestion as well as reduction of plastic bag use offer potential for reduction of these emissions.

For Phase 2 of the project, 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. This is mainly due to the variability in the type of refrigeration systems and space conditioning (HVAC) systems used in these stores, and the operation and maintenance practices employed. It was identified that 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.

Phase 3 of the project considered the applicability of the PAS 2050 to service operations. It was identified that even though it is clear that the PAS 2050 is also applicable to services, references to products in the specification predominate. Also, the definition of functional unit – 'CO2 per unit of service provided' is very broad and can present difficulties with some service operations. More guidance on the selection of appropriate functional units for different service operations should be useful at least at the early stages of application of the PAS 2050. Definition of the boundary can also be more difficult for the case of services than goods. For example, in many service operations, products which are distributed as part of the service could be either manufactured in-house or purchased from other suppliers and this would make the determination of the GHG emissions of the product more difficult.

A case study on the application of PAS 2050 to a refrigeration system manufacturer and service provider was considered in the project. Difficulties identified with the application of PAS 2050 to the service operations of the company were the wide variety of services that are provided from a single operation/journey and the apportionment of GHG emissions to individual operations. One of the main service operations provided by the company is the replacement of refrigerated cabinet shelving. Detailed study of this service operation revealed that most of the GHG emissions arise from transportation of the manufactured products. Transport emissions can be reduced through optimisation of the logistics of service operations.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

Aims

The main aim of the project was to investigate and quantify the greenhouse gas impacts of retail food operations and identify business and technology approaches that could offer significant potential to reduce these impacts. The project was carried out in 3 phases. The objective of Phase 1 was to test the PAS 2050 method for allocating GHG emissions from the distribution and retail of food products whereas the objective of Phase 2 was to determine the impact of store characteristics and business practices on GHG emissions and the potential of new technologies and practices to effect significant reductions. The objective of the third Phase of the project which was added at a later stage as an Annex was to investigate and test the applicability of the PAS 2050 method for allocating GHG emissions to service operations. Phase 1 and Phase 2 overlap so in these report, to avoid duplication they will be treated together.

PART A

Phase 1 Objective: To test the PAS 2050 method for allocating GHG emissions from the distribution and retail of food products

Phase 2 Objectives - Specific Objectives for Phase 2 were to:

i) **Consider the range of store formats and retail food operations in the UK and determine their GHG emissions in terms of unit store area and product throughput.**

ii) **Compare and identify the merits of different store formats and merchandising approaches with respect to GHG emissions per unit throughput.**

iii) **Identify the most appropriate merchandising and technical approaches to deliver GHG emissions reductions.**

1. Abstract

The GHG emissions from the distribution and retail of a number of products (packed fresh meat, ready meals, milk, cheese, frozen peas, frozen chips, fresh apples, potatoes, fresh strawberries and beef cottage pie) were considered and quantified with the view to testing the applicability of PAS 2050 to the distribution and retail of food products. The GHG emissions from retail food operations were considered in more detail to gain an appreciation of the impacts of retail food store size and merchandising approaches on overall GHG emissions from food retail operations and draw conclusions on the contribution that technical approaches can make in reducing energy consumption and GHG emissions.

The boundary for the study is shown in Figure 1.1. It includes emissions from: i) storage in the Regional Distribution Centre (RDC); ii) transportation from the RDC to the supermarket and, iii) retail of the product in the supermarket.

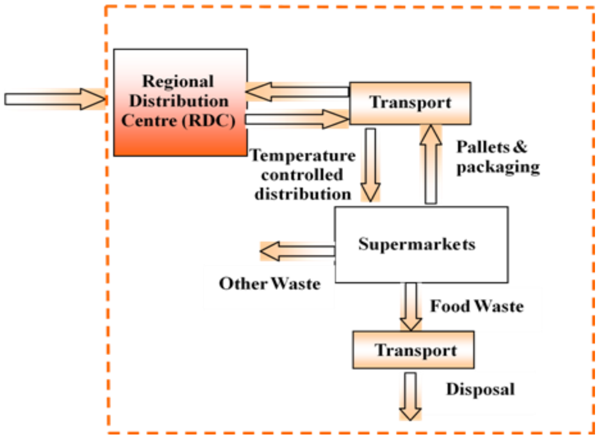

Figure 1.1: Boundary of the study

2. Energy Consumption and GHG Emissions from Food Storage in RDCs

Regional Distribution Centres play an important role in the food supply chain. They are operated continuously throughout the year and are used to balance supply of products from the manufacturer and demand from individual stores in a supermarket chain. A number of studies have been carried out to benchmark energy use by refrigerated warehouses in different parts of the world [1,2,3,4,5,6]. All of these studies are survey-based and use the Specific Energy Consumption, SEC value to represent the energy efficiency of a warehouse, SEC is defined as:

$$SEC = \frac{Annual\ Electricity\ Consumption(kWh)}{Storage\ Volume\ (m^3)}$$

Figure 2.1, shows the variation of SEC as a function of the refrigerated warehouse volume. It can be seen that the SEC can vary widely from between 20 kWh/m^3 to over 120 kWh/m^3. Factors that influence the SEC is the ambient temperature, design storage temperature and construction and method of operation of the refrigerated warehouse. In general the SEC reduces as the size of the warehouse increases.

Table 2.1 summarises the data in Figure 2.1, giving average values of specific energy consumption for different size refrigerated warehouses.

Food storage and transportation is normally done on wooden pallets which come in standard sizes. The most common pallet size is the Euro Pallet (ISO 1) which has dimensions 800 mm x 1200 mm. Goods are normally stacked to a height of around 1.6 m on a pallet so the dimensions of a standard Euro Pallet can be assumed to be 0.8 m x 1.2 m x 1.6 m, giving a volume per pallet of 1.536 m^3.

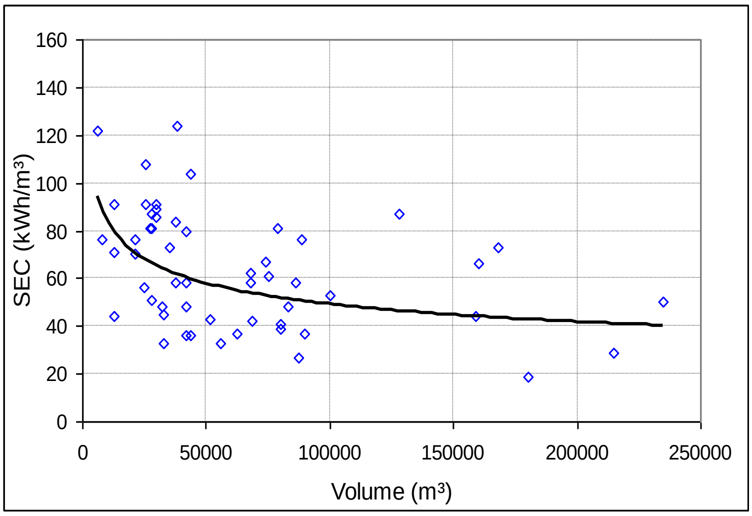

Figure 2.1: Variation of SEC as a function of refrigerated warehouse volume

Table 2.1: SEC for different volumes of refrigerated warehouses

Volume (m^3)	SEC (kWh/m^3)
Lower than 50000	74.2
50000-100000	54.2
100000-150000	48.2
150000-200000	44.7
More than 200000	42.3

If it is assumed that the products will be stored in a warehouse of volume in the range between 50000 and 100000 m^3, the specific energy consumption, from Table 2.1, will be 54.2 kWh/m^3. The energy consumption of refrigerated warehouses is primarily in the form of electricity which is used to drive vapour compression refrigeration systems. This electrical energy consumption can be converted to Greenhouse Gas (GHG) Emissions by multiplying the energy consumption by the average factor for electricity generation in the UK. This factor can be taken as 0.537 [6]. Based on this information the mass of each food type contained in a Euro Pallet can be calculated and the energy consumption and CO_2e emissions per kg of food per hour of storage can be determined as shown in Table 2.2.

Refrigeration systems employed in refrigerated warehouses and regional distribution centres normally use Ammonia as a refrigerant. Ammonia is a natural refrigerant with zero Global Warming Potential (GWP) and so direct CO_2e emissions from refrigerant leakage can be neglected. It is also worth noting that leakage rates for industrial ammonia refrigeration plant are quite low compared to the leakage rates of HFC refrigerants normally employed in commercial refrigeration systems.

3. Energy Consumption of Refrigerated Road Transport

3.1 General food transportation energy consumption and emissions

Food transport in the UK is responsible for 18444 kilotonnes of CO_2e emissions of which 45% (8300 kilotonnes) can be attributed to Heavy Goods Vehicle (HGVs) [7]. It is estimated that approximately a third of food transportation with HGVs is refrigerated but these emissions are from the truck engine alone and do not include emissions from separate engine diesel driven refrigeration units and refrigerant leakage.

Food distribution in the UK takes place through the following channels: Primary distribution from food factories to regional distribution centres (RDCs), either directly or via primary consolidation centres (PCCs), secondary distribution from RDCs to shops and tertiary distribution from wholesale depots to independent retailers. Primary distribution takes place almost always with articulated vehicles (32 to 44 tonnes). Articulated vehicles are also mainly used for secondary distribution to supermarkets and superstores. Tertiary distribution to small shops and catering outlets is mainly performed with rigid vehicles (up to 32 tonnes). Articulated vehicles over 32 tonnes, account for around 80% of the total tonne-km goods movement in the UK [8].

Table 2.2: GHG emissions from refrigerated storage in a RDC

Component	Food (kg) in 1.6 high Euro-Pallet	kg/m³	Energy consumption per kg food per hour kWh/kg-hr	GHG emissions gCO_2e/kg-hr
Packed Fresh Meat (kg)	506	329	0.000018	0.0097
Packed Fresh Meat (Pack of 0.96 kg)	488	318	0.000019	0.0102
Ready Meals (kg)	720	469	0.000013	0.0070
Ready Meals (Pack of 0.45 kg)	1600	1042	0.000006	0.0032
Diary Product Milk (kg)	320	208	-	-
Diary Product Milk (Litre)	363	236	-	-
Diary Product Milk (pint)	375	244	-	-
Dairy Product Cheese	1440	938	0.000006	0.0032
Frozen Peas	640	417	0.000015	0.0081
Frozen chips	650	423	0.000014	0.0075
Fresh Apples	875	570	0.000011	0.0059
Fresh Potatoes	1024	667	0.000009	0.0048
Fresh Strawberries	230	150	-	-
Bread	144	-	-	-
Beef Cottage Pie (pack of 0.5 kg)	595	385	0.000015	0.0081

Table 3.1 shows typical figures for refrigeration duty and fuel consumption of self contained mechanical road refrigeration equipment. The data is based on ATP test conditions at +30°C ambient temperature. Multi-drop distribution will require a higher refrigeration capacity to counteract the infiltration load during door openings.

Chilled distribution should normally require a lower refrigeration capacity than frozen food distribution due to the higher temperature difference between the refrigerated compartment and the ambient. Not much data is available for infield energy consumption of transport refrigeration equipment. Infield fuel consumption is dependent on many factors such as the type of operation and type of product transported, solar load, fuel density, control software setup e.g. continuous compressor modulation or on/off control and defrost cycle initiation and termination.

In many cases, the in-field energy consumption for chilled distribution can be higher than frozen food distribution due to the more stringent temperature control requirements, product respiration and the higher air flow rates required to maintain uniform temperature distribution in the container [9].

Table 3.1: Refrigeration duties and fuel consumption of self contained mechanical transport food refrigeration units

Body Inside Length/Inside Volume/Type	Minimum refrigeration capacity long distance transport (W)		Required refrigeration capacity, multi drop distribution (W)		Fuel consumption (litre/hr)	
	-20 °C k=0.4 W/m² K	0 °C k=0.7 W/m² K	-20 °C k=0.4 W/m² K	0 °C k=0.7 W/m² K	-20 °C k=0.4 W/m² K	0 °C k=0.7 W/m² K
6.2 m/ 33.42 m³/ Rigid Lorry	3765	3876	5630	4554	2.0	1.5
10.4 m/ 61.15 m³/ Rigid Lorry	6155	6353	9897	7920	3.0	2.5
13.4 m/78.79 m³/ Semi Trailer	7730	7986	13500	10078	4.0	3.0

The fuel consumption of various types of vehicles involved in freight transport in the UK is shown in Table 3.2. This fuel consumption excludes any energy that may be consumed by the refrigeration equipment. Two sets of data are presented. Data from the 2002 Key Performance Indicator (KPI) Survey of Transport Efficiency in the UK Food Supply Chain presented by McKinnon et. al. [8] and data from the government's Continuing Survey of Road Goods Transport [10]. It can be seen that the two sets of data are broadly in agreement. The 2002 KPI survey indicated that 85% of the articulated vehicles of gross weight greater than 38 tonnes had an average fuel consumption efficiency in the range 2.8-3.5 km/litre with the difference between the highest and lowest fuel consumption being 1.5 km/litre.

The survey also indicated that in 67% of the loaded journey legs the average load height was between 1.5 and 1.7 m, which corresponds to the average slot height in warehouse racking. The average volume and weight utilisation of the vehicles was found to be 53%.

A high fuel efficiency does not necessarily signify an efficient distribution operation because it can be offset by poor utilisation of the vehicle's capacity. A better measure of energy efficiency in food distribution is *energy intensity* which expresses fuel consumption on a pallet kilometre basis rather than vehicle kilometre basis. In the 2002 KPI survey the energy intensity of 46 fleets was found to very from 8 ml of fuel per pallet-km to 61 ml per pallet-km. The main reasons for the wide variation were considered to be the type and size of vehicle used and the nature of the distribution operation. The average energy intensity and standard deviation are given in Table 3.3.

Table 3.2: Average fuel efficiency of food HGVs

Vehicle Class	KPI 2002 Survey (km/litre)	CSRGT (2001) (km/litre)
Small rigid less than 7.5 tonnes	4.0	4.1
Medium rigid (7.5-18) tonnes	3.6	3.7 (7.5-14.0 t) 3.3 (14-17 t)
Large rigid greater than 18 tonnes	3.1	2.9 (17-25 t) 2.7 (> 25 t)
City semi-trailer	3.2	-
32 tonne articulated vehicle	3.2	3.2 (< 33 t)
38 to 44 tonne articulated vehicle	2.9	2.9 (> 32 t)

Table 3.3: Average energy intensity of different distribution operations

Distribution type	Average energy intensity	Standard deviation
	(ml fuel/pallet-km)	(ml fuel/pallet-km)
All fleets	25.4	7.4
Primary distribution (temperature controlled)	19.3	4.9
Primary distribution (ambient)	12.2	6.5
Secondary distribution	19.2	4.9
Tertiary distribution	37.3	12.3
Mixed distribution	30.1	4.4

It can be seen that tertiary distribution had the highest energy intensity and highest variability whereas primary distribution of ambient products had the lowest energy intensity and relatively low variability. A comparison of ambient and temperature controlled primary distribution indicates that the on-board refrigeration systems in the fleets considered in the survey were responsible, on average, for around 37% of the total energy consumption of temperature controlled primary distribution.

Table 3.4 shows the average fuel efficiency, payload weight and energy intensity of the different vehicles in the 2002 KPI survey. It can be seen that the energy intensity of rigid vehicles which are mainly used for mixed and tertiary distribution is much higher than that of heavy articulated vehicles which are predominantly used for primary and secondary distribution.

Table 3.5 provides data for 17 temperature controlled fleets [11]. The data did not distinguish between chilled, frozen or mixed temperature product transportation in multi-compartment vehicles or the distribution type. It can be seen however that irrespective of the type of vehicle type the average fuel consumption of the refrigeration systems in the sample varied between 15% and 25% of the engine fuel consumption.

An analysis performed by Repice and Stumpf [12] on refrigeration unit fuel consumption for hypothetical urban and long distance distribution cycles showed that on average the urban cycle will result in a 16% higher fuel consumption than the long distance cycle.

Table 3.4: Average energy efficiency and energy intensity by vehicle type

Vehicle class	Average fuel efficiency (motive only)		Average volume Load	Average payload	Average energy intensity by volume	Energy intensity by weight
	km/litre	mpg	Pallets	Tonnes	ml/pallet-km	ml/tonne-km
Medium rigid	3.87	10.94	5.78	2.25	33.0	83.8
Large rigid	2.91	8.21	8.69	7.41	31.8	37.1
City artic	3.14	8.87	11.24	6.57	21.4	36.4
32 tonne artic	3.35	9.48	14.38	10.37	19.1	26.4
38 tonne artic	2.79	7.88	17.11	11.83	18.0	26.0

Table 3.5: Motive and refrigeration fuel consumption

Vehicle class	Distance traveled and fuel consumption (motive)		Fuel efficiency (motive)	Fuel consumption of refrigeration engine	Overall vehicle fuel efficiency (motive plus refrigeration)	Percent refrigeration energy to motive energy
	km/day	Litres/day	km/litre	Litres/day	km/litre	%
Medium rigid	409	111.3	3.7	21.0	3.09	18.9
Large rigid	286	90.71	3.15	17.7	2.63	19.5
City artic	335	112.33	2.98	26.1	2.42	23.2
32 tonne artic	419	140.8	2.97	34.1	2.40	24.2
38 tonne artic	486	159.62	3.04	24.9	2.52	15.6

Table 3.6 summarises the energy intensity of ambient and temperature controlled food distribution. To construct Table 3.6 a number of assumptions were made as follows:

i) The energy consumption of refrigeration equipment for temperature controlled food distribution is 16% higher for multi-drop compared to single drop distribution.

ii) The energy intensity of chilled food product distribution will be 20% higher than ambient distribution.

iii) The energy intensity of frozen and mixed temperature food distribution will be 33% higher than that of chilled food distribution.

Table 3.6: Energy intensity of ambient and temperature controlled distribution

Vehicle class	Average fuel efficiency (motive only)	Average energy intensity (ambient)	Average energy intensity (chilled single drop)	Average energy intensity (chilled multi-drop)	Average energy intensity (frozen and multi-temperature single drop)	Average energy intensity (frozen and multi-temperature multi-drop)
	km/litre	ml/pallet-km	ml/pallet-km	ml/pallet-km	ml/pallet-km	ml/pallet-km
Medium rigid	3.6	33.0	39.6	40.7	41.8	43.2
Large rigid	3.1	31.8	38.2	39.2	40.3	41.7
City artic	3.2	21.4	25.7	26.4	27.2	28.0
32 tonne artic	3.2	19.1	22.9	23.5	24.2	25.1
38 tonne artic	2.9	18.0	21.6	22.2	22.8	23.6

The data in Table 3.6 show that the energy intensity of temperature controlled distribution will depend on the class of vehicle used, the distribution type, long distance single drop or multi-drop, and the type of product transported, chilled or frozen. It can be seen that the energy intensity of multi-drop frozen or mixed temperature food distribution could be up to 30% higher than the energy intensity of ambient food distribution.

Table 3.7 shows the environmental impacts of food transportation using an emissions factor for diesel of 2.668 kg CO_2e per litre. It can be seen that, depending on the class of vehicle used and the type of distribution, the CO_{2e} emissions can vary between 48 gCO_2e /pallet-km for ambient single drop primary and secondary distribution with large articulated vehicles (above 38 tonnes), to 115 gCO_2e/pallet-km for multi-drop temperature controlled tertiary and mixed distribution with medium rigid vehicles (7.5-18 tonnes). These emissions do not include direct emissions arising from refrigerant leakage.

Table 3.7: GHG emissions of ambient and temperature controlled distribution excluding refrigerant leakage (gCO_2e/pallet-km)

Vehicle class	Ambient	Chilled (single drop)	Chilled (multi-drop)	Frozen and multi-temperature (single drop)	Frozen and multi-temperature (multi-drop)
Medium rigid	88	106	109	112	115
Large rigid	85	102	105	108	111
City artic	56	69	70	73	75
32 tonne artic	51	61	63	65	67
38 tonne artic	48	58	59	61	63

Transport refrigeration units on small trucks and vans will have a refrigerant charge of around 2.0 kg, mid-size trucks 5 kg, and large articulated vehicles 7.5 kg [13]. These units predominantly use R404A and R410A as refrigerants. R134A is also used for chilled distribution only vehicles. It is reported that the refrigerant emissions from transport refrigeration systems are higher than those of stationary systems because they operate in a much more severe environment [9]. The operating environment involves vibration which will be dependent on road surface and a wide range of weather conditions and operating temperatures. Annual leakage figures reported are 10-37% of the refrigerant charge [13]. A study reported by Koehler et al. [14], which assumed a 10% leakage rate showed the direct emissions (refrigerant leakage) from the refrigeration system to be 21% of indirect emissions (engine fuel consumption) for R404A and 13% for R410A.

It has been reported that on average HGV vehicles travel 100,000 km per year [7]. Data for different types of vehicle [11] show a range of distances traveled per day between 300 km and 500 km. If one assumes an average distance of 400 km per day and that the vehicle runs for 260 days in a year this gives a total distance of 104,000 km per year which corroborates the figure of 100,000 km per year.

Table 3.8 shows the CO_2e emissions from refrigerant leakage for different vehicles for R404A. R404A was chosen as it has the highest GWP (Global Warming Potential) of 3860 compared to 2060 for R410A and 1300 for R134A [13] and thus will lead to the highest CO_2e emissions.

Table 3.8: GHG emissions from refrigerant leakage (gCO_2e/pallet-km)

Vehicle class	Refrigerant charge (kg)	Average Volume load (Pallets)	Annual leakage rate for R404A (percent of system charge)					
			5%	10%	15%	20%	25%	30%
Medium rigid	5.0	5.78	1.7	3.3	5.0	6.7	8.3	10
Large rigid	6.0	8.69	1.3	2.7	4.0	5.3	6.7	8.0
City artic	6.5	11.24	1.1	2.2	3.3	4.5	5.6	6.7
32 tonne artic	7.0	14.38	0.9	1.9	2.8	3.8	4.7	5.6
38 tonne artic	7.5	17.11	0.8	1.7	2.5	3.4	4.2	5.1

From the data in Tables 3.6 and 3.7, it can be determined that if a 10% annual refrigerant leakage is assumed for a large articulated vehicle and single drop chilled food distribution, CO_2e emissions from refrigerant leakage will be 17% of the emissions from the engine of the refrigeration system.

This compares reasonably well with the 21% emissions reported by Koehler et al. for R404A [14]. For a medium rigid vehicle, and single drop chilled food distribution, emissions from refrigerant leakage will be approximately 18% of the emissions from the refrigeration system engine. For multi-drop frozen and mixed temperature food distribution, emissions from 10% refrigerant leakage will be approximately 11% of the emissions from the refrigeration system for large articulated vehicles and 12% for medium rigid vehicles.

Table 3.9 combines the data in Tables 3.7 and 3.8 to show the total greenhouse gas emissions for both ambient and temperature controlled distribution.

Table 3.9: GHG emissions of ambient and temperature controlled distribution including 10% refrigerant leakage rate for R404A (gCO_2e/pallet-km)

Vehicle class	Ambient	Chilled (single drop)	Chilled (multi-drop)	Frozen and multi-temperature (single drop)	Frozen and multi-temperature (multi-drop)
Medium rigid	88	109	112	115	118
Large rigid	85	105	108	111	114
City artic	56	71	72	75	78
32 tonne artic	51	63	65	67	69
38 tonne artic	48	60	61	63	65

The data in Table 3.9 can be used to determine CO_2e emissions arising from ambient and temperature controlled food distribution.

3.2 GHG Emissions from the Transportation of selected food products

3.2.1 Milk

Milk can be delivered to the retail outlet directly or through the retailer's RDC. In either case, however, milk is distributed in milk roll containers or roll cages which are rolled directly into roll-in refrigerated cabinets with the milk merchandised directly from the roll containers. The roll containers are designed to handle both cartons and polybottles. The standard unit of measurement for milk in the UK still remains the pint and the vast majority of milk is merchandised in 1.0 pint (1.136 litres) and 2.0 pint (2.272 litres) poly bottles.

Milk roll containers are available in different sizes but a common size is 660 mm long, 420 mm wide and approximately 1300 mm high as shown in Figure 3.1 Two of these roll containers will occupy approximately the same space as a Euro Pallet on a transport vehicle. If a 4 pint poly bottle is used then this roll container will carry 80 poly bottles (320 pints of milk or 363 litres, or 375 kg). A europallet will be equivalent to 640 pints or 726 litres or 750 kg of milk. If it is assumed that the milk is distributed by a medium rigid vehicle, for multi-drop distribution the GHG emissions will on average be 0.15 g CO_2e /kg-km or 0.154 g CO_2e /litre-km or 0.175 g CO_2e /pint-km. If the milk is distributed by a 38 tonne articulated vehicle the GHG emissions will on average be 0.081 g CO_2e /kg-km or 0.084 g CO_2e /litre-km or 0.095 g CO_2e /pint-km.

Figure 3. Milk roll container

3.2.2 Cheese

Cheese is distributed in cardboard boxes. A box of cheddar cheese of dimensions (360 mm x 340 x 250 mm) for example, would contain 30 pieces of cheese (170 mm x 120 mm x 50 mm), Figure 3.2. Each piece will weigh approximately 0.96 kg, and the total box will weigh approximately 28.8 kg. A Europallet will accommodate approximately 36 boxes of total weight of 1045 kg of cheese.

3.2.3 Bread

Inside the store, the bread is distributed in trays of approximate dimensions 600 mm x 530 mm x 185 mm. The trays can be stacked 12 high, but a normal transport height would be approximately 1.6 m (9 trays), Figure 3.3.

Each tray contains 10 loaves of bread of 800 g weight. Two stacks of trays (9 high each) will occupy a volume in the transport vehicle equivalent to 1.0 Europallet. The total weight of bread in the europallet will be approximately 144 kg and the weight of the plastic trays will be 29 kg (1.6 kg each).

Milk Cheese

Figure 3.2: Merchandising milk and cheese in a retail food store

Figure 3.3: Bread merchandising

3.2.4 Fresh meat, ready meals and cottage beef pie

Fresh meat, ready meals and cottage pie are merchandised in individual packs in the form shown in Figure 3.4. The food is distributed to retail food outlets in cardboard boxes which will contain a number of food packs. The size of each pack will vary depending on the type of food and quantity in each package. Ready meals in packages of 120 mm x 160 mm x 50 mm can have a weight of approximately 0.5 kg whereas fresh packed meat in a package of 300 mm x 150 mm x 70 mm can have a weight of around 1.0 kg and the beef cottage pie in packages of 185mm x 155mm x 45mm and weight of 0.5 kg. Based on the above assumptions, a europallet 1.6 m high will approximately carry between 500 kg and 750 kg of fresh packed meat or ready meals or beef cottage pie

3.2.5 Frozen chips and peas

Frozen chips and peas are delivered to retail food outlets in boxes of different sizes and weights depending on the sizes of the plastic bags used for each item. A cardboard box of frozen chips 380 mm x 280 mm x 210 mm will have a weight of 10 kg whereas a box of frozen peas, 380 mm x 280 mm x 180 mm cm will have a weight of 8 kg. A Europallet 1.6 m high will carry 640 kg (64 boxes) of frozen chips and 72 boxes or 576 kg of frozen peas respectively.

Ready meals Fresh meat Beef cottage pie

Figure 3.4: Merchandising of ready meals, fresh meat and beef cottage pie

3.2.6 Strawberries

Strawberries are sold in small transparent plastic containers. A typical size, 160 mm x 170 mm x 50 mm will weight approximately 0.45 kg. The small containers are transported in crates of approximate dimensions of 590 mm x 390 mm x 130 mm shown in Figure 3.5. Each crate carries 12 boxes of strawberries of total weight of 5.4 kg. A europallet will accommodate approximately 24 crates of strawberries of total weight of 130 kg.

3.2.7 Apples and potatoes

A number of different approaches are used for the merchandising of apples and potatoes. One such approach is the use of plastic crates of dimensions 600 mm x 400 mm x 190 mm where bagged or loose apples or potatoes are displayed, Figure 3.6. The weight of the crates will vary depending on the size of the bags and the size of the apples or potatoes. Crate weights will vary from 10 kg to 30 kg. Potatoes will also have a higher weight than apples. If on average the weight of the crates is assumed to be 20 kg for potatoes and 15 kg for apples, and a europallet 1.6 m high can accommodate 32 crates, a crate of apples will weigh 480 kg and a crate of potatoes 640 kg.

Figure 3.5: Merchandisin of strawberries

Figure 3.6: Merchandising of apples and potatoes

3.2.8 Summary of products and GHG emissions during transportation

Table 3.9 shows a summary of possible weights of products in one Europallet. The widths of products in a europallet will vary depending on the density of the product and the type of packaging used. Damage sensitive products such as bread and strawberries which are lightly packed will have the lighter weight in the order of 140 kg per europallet. Higher density and more densely packed products will have weights ranging between 500 kg and 1000 kg per europallet.

Table 3.9: Product weights in a euro-pallet

Food product	Weight (kg) of product in a euro-pallet (1.2 x 0.8 x 1.6 m high)
Packed fresh meat	500-750
Ready Meals	500-750
Milk	750
Cheese	1045
Frozen peas	576
Frozen chips	640
Apples	480
Potatoes	640
Fresh strawberries	130
Bread	144
Beef cottage pie	500-750

An estimate of the greenhouse gas emissions from the transportation of these products to the retail food outlets is given in Table 3.10. In the calculations a return journey of 190 km was assumed with a single delivery drop and with the vehicle being empty on the return journey. Distance of return journeys will vary widely depending on the relative location of the supermarket and RDC. An average estimated journey distance for the UK is 190 km [56]. The fuel consumption of an empty truck will be approximately 30% lower than that of a loaded truck [55] and the refrigeration system will be switched off during the return journey. Emissions during the return journey will therefore be almost 50% lower than emissions during the outbound journey.

Table 3.10: GHG Emissions from food transport

Food Product	Transport emission factor outbound journey (Refrigerated truck, including 10% refrigerant leakage)		Transport emission factor return journey (Empty vehicle and refrigeration system off)	
	Medium rigid vehicle Multi-drop distribution $gCO_2e/kg\text{-}km$	38 tonne articulated vehicle $gCO_2e/kg\text{-}km$	Medium rigid vehicle $gCO_2e/kg\text{-}km$	38 tonne articulated vehicle $gCO_2e/kg\text{-}km$
Packed Fresh Meat²	0.22-0.15	0.12-0.08	0.12-0.08	0.07-0.045
Ready Meals²	0.22-0.15	0.12-0.08	0.12-0.08	0.07-0.045
Milk ²	0.15	0.08	0.08	0.04
Cheese²	0.11	0.06	0.06	0.03
Frozen Peas³	0.20	0.11	0.11	0.06
Frozen chips³	0.18	0.10	0.09	0.05
Apples²	0.23	0.13	0.13	0.07
Potatoes²	0.18	0.10	0.10	0.05
Fresh Strawberries²	0.86	0.47	0.47	0.26
Bread¹	0.61	0.42	0.43	0.23
Beef cottage pie²	0.22-0.15	0.12-0.08	0.12-0.08	0.07-0.045

¹ Ambient ² Chilled ³ Frozen

A reduction factor of **30%**, was used to calculate the transport emission factor for vehicle engine during the return journey (transport vehicle is empty) [55].

4. Retail Food Operations

All supermarkets merchandise their foodstuff in a similar manner. Virtually all food sold is bar coded and scanned at the sales tills, where a running total of the products sold is tallied. Each product and sub-product e.g. the retailers own name product or a retail label product is allocated a facing - a space on the retail display computed to provide a reasonable duration of products to be displayed between re-merchandising periods which is daily or more frequently at peak trading times. A stock of food is held at the back of the store where trigger levels dictate that shelves need to be replenished as the till scans total up sales and establish a stock level has been reached. The system calculates the back stock and calculations are made for the system to place an order on the Regional Distribution Centre (RDC) for the store to have its back stock replenished. The individual orders are totalled and collated at a depot in order to schedule a delivery where the stock is computed to provide replenishment to a number of stores or in certain instances to an individual store by a suitable vehicle either refrigerated ambient or a hybrid vehicle. The system calculates the schedule of loading and optimises the vehicle routing making sure it departs full and returns with waste returns.

The RDCs run a just in time process for short life perishable products e.g. vegetables and fruit, dairy products, meat etc. Small levels of stock may be held for longer life products such as frozen food. The optimum level of stock is normally determined from predictive software that modifies the demand data against various criteria such as weather local demand trends, seasonal demands, promotions etc.

As the lorry is empty used pallets from previous deliveries are multi-stacked and loaded for return to the suppliers via the RDC. Surplus plastic and cardboard derived from the stores is packed and returned via the delivery vehicle. It has been common practice to reduce volume of both plastic and cardboard by compression baling and strapping with nylon string ties on the cardboard bales and into plastic tie bags for the compressed plastic. Tesco at Clacton are returning the waste not baled and in loose caged containers. At the RDC's a Resource Recovery Unit RRU bales the cardboard and plastic into high density bales, which are bound, with wire ties. In the common process at this time the plastic is collected at a UK port and in turn shipped abroad for hand sorting and reprocessing into downgraded plastic products, China is a common destination. The cardboard price fluctuates and depending on the price is either burnt or sent to various locations for reprocessing.

4.1 GHG Emissions from retail food operations

GHG Emissions from food retailing in the shop arise from the following operations and waste streams:

i) Energy Consumption and indirect emissions:

In UK supermarkets, more than 70% of the energy consumed is electricity of which between 30% and 60% is used to drive the refrigeration equipment in the store. The remainder is used for lighting, HVAC (heating ventilation and air conditioning) baking and other ancillary services.

Retail food stores will also use gas for space and domestic hot water heating, and sometimes for baking.

ii) Direct emissions from refrigerants

Refrigeration systems in supermarkets contain substantial amounts of refrigerant. Some refrigerants are potent greenhouse gases and their impact is characterised by their Global Warming Potential. Although significant progress has been made in recent years to reduce refrigerant leakage and direct GHG emissions through better system design and leakage sensing, the direct emissions are still significant, as much as 30% of indirect emissions, due to the higher global warming potential of refrigerants employed to replace CFCs and HCFCs.

iii) Food waste

Food waste from retail food operations is estimated at 1.6 m tons per annum (WRAP, 2007) [15]. The vast majority of this waste is disposed to landfill.

iv) Other Waste

Used pallets from previous deliveries are multi-stacked and loaded to the distribution vehicles for return to the suppliers via the RDC. Surplus plastic and cardboard derived from the stores is packed and returned via the delivery vehicle. It has been common practice to reduce volume of both plastic and cardboard by compression baling at the store. There are cases, however, where the waste is returned in loose caged containers. At the RDC's a Resource Recovery Unit RRU bales the cardboard and plastic into high density bales, which are bound, with wire ties.

It is common process at this time for the plastic to be collected at a UK port and in turn shipped abroad for hand sorting and reprocessing into downgraded plastic products. China is a common destination. The cardboard price fluctuates and depending on the price it is either burnt or sent to various locations for reprocessing.

Other waste includes waste water, cooking oils and ice disposal, shopping bags and other food packaging. A schematic diagram of flows and waste is given in Figure 4.1

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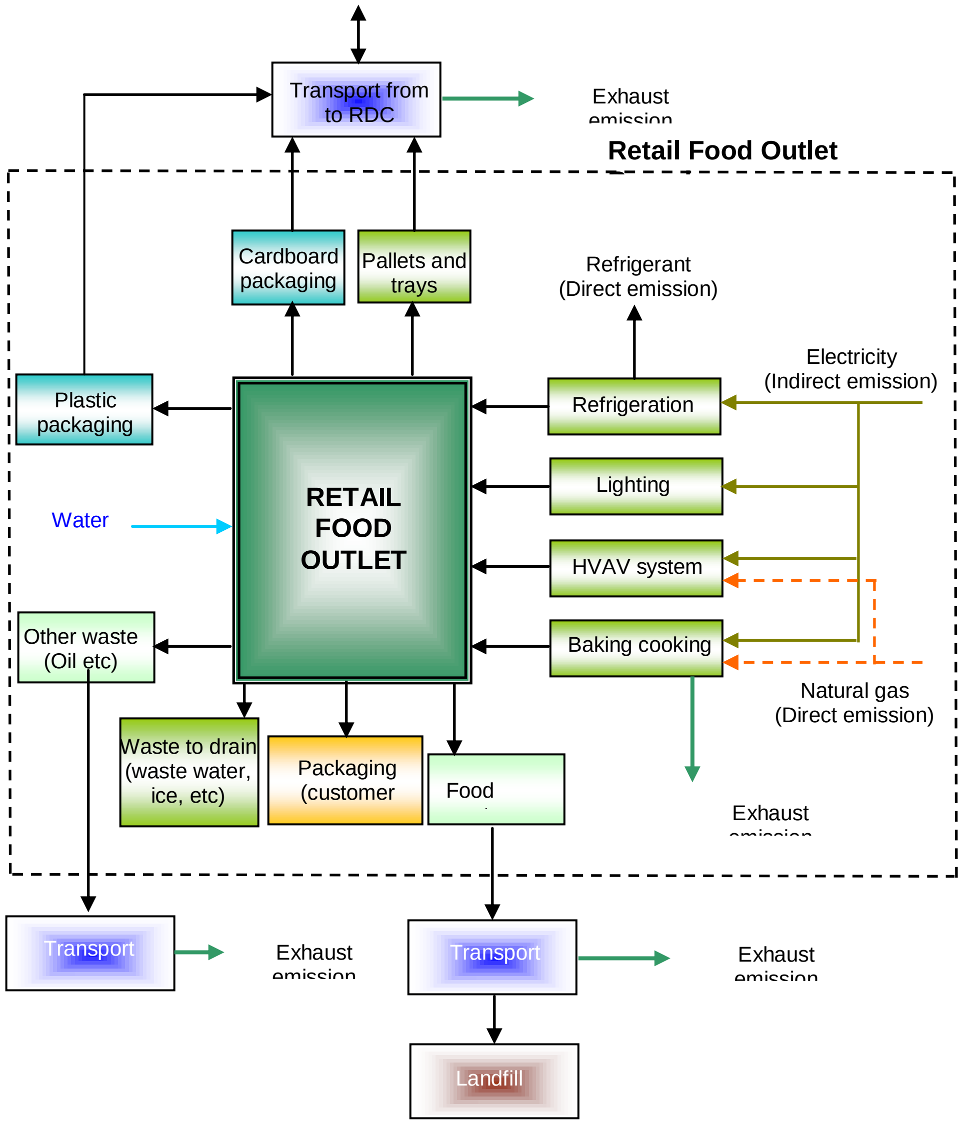

RDC – Regional Distribution Centre
HVAC – Heating Ventilation and Air Conditioning

Figure 4.1: Schematic diagram of flows and waste within the retail food outlet boundary

4.2 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. Even though convenience stores will normally mainly store core grocery products, supermarkets and superstores in the majority of cases 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 4.2 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 which is a factor of four. 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.

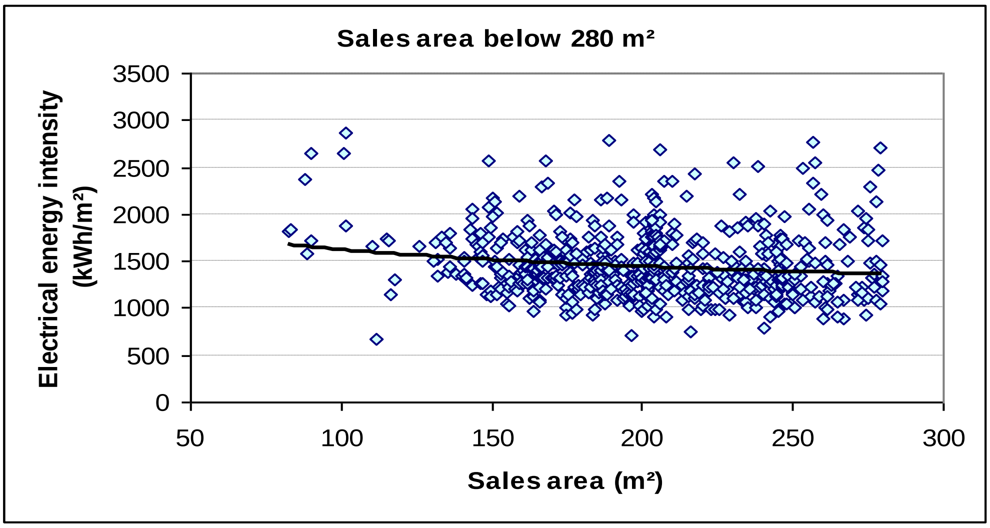

Figure 4.2: Electrical energy intensity of convenience stores of sales area between 80 m^2 and 280 m^2

The average electrical energy intensity for the sample of 640 stores is 1540 kWh/m^2 and the standrad deviation 446 kWh/m^2. Figure 4.2 also shows that the everage electrical energy intensity 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 intenisty 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 intensity of convenience stores is the balance between temperature controlled (refrigerated) and ambient products and the balance between frozen and chilled food products.

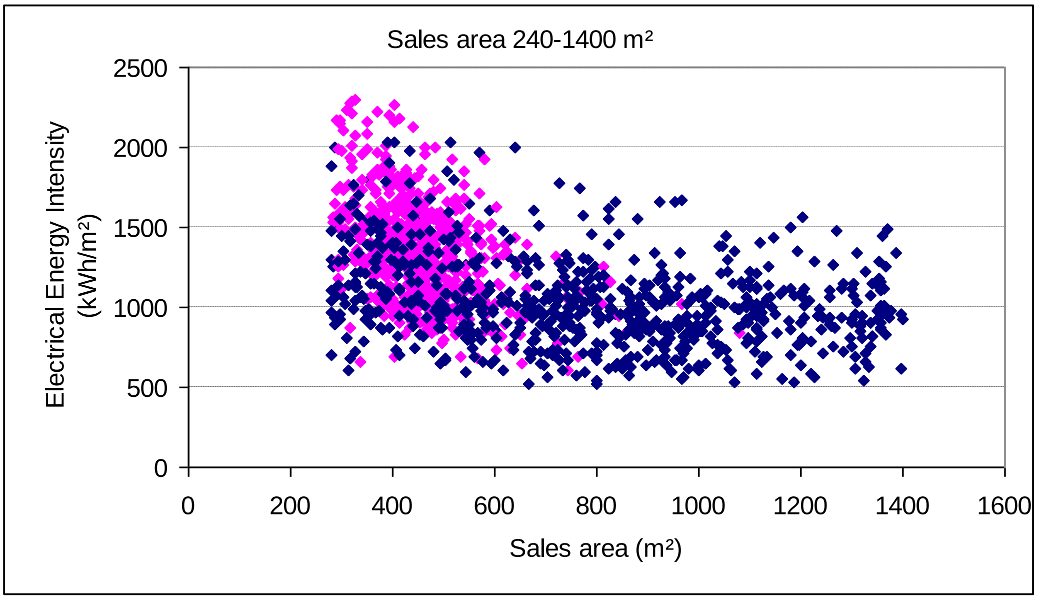

Figure 4.3: Electrical energy intensity of supermarkets of sales area between 280 m^2 and 1400 m^2

Figure 4.3 shows the electrical energy intensity of 1360 stores of sales area between 280 m^2 and 1400 m^2. The average electrical energy intensity 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 intensity 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. Stores shown in ping are stores that use `integral' (self contained) refrigeration equipment as opposed to remote systems in which the compressors and condensers are located remotely from the evaporator coils in the display cabinets. It can be seen that the electrical energy intensity of stores with integral systems is on average higher than that of similar size stores with remote refrigeration equipment but also that stores with integral refrigeration systems can also have lower electrical energy intensities than stores with remote equipment if the integral equipment are properly maintained and their impact on the air conditioning load is minimised.

The electrical energy intensity of 420 stores with sales area in the range 1400 m^2 to 5000 m^2 is shown in Figure 4.4. Again it can be seen that the range in the electrical energy intensity 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 intensity 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.

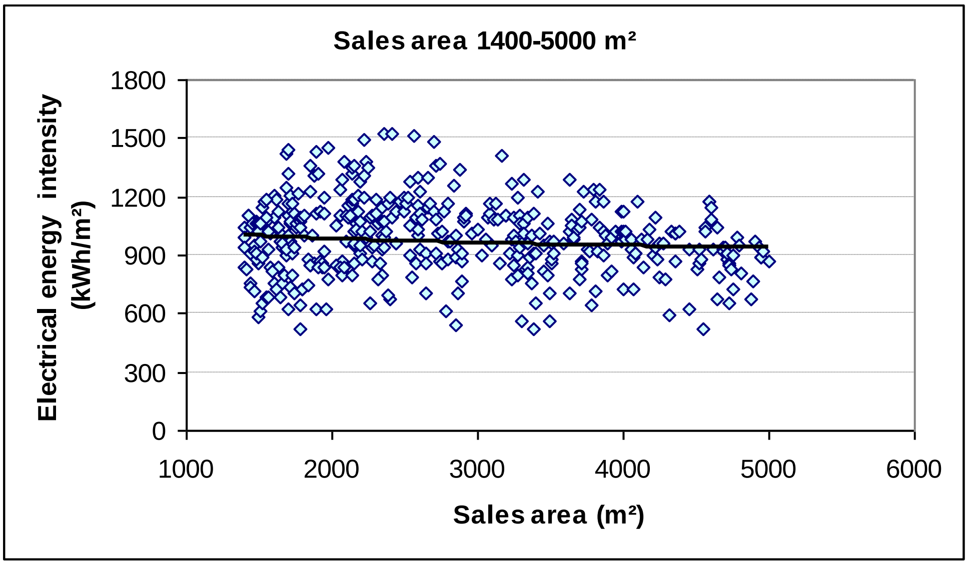

Figure 4.4: Electrical energy intensity of supermarkets of sales area between 1400 m^2 and 5000 m^2

Figure 4.5 shows the electrical energy intensity of 150 stores with sales area in the range 5000 to 10000 m^2. The range of the electrical energy intensity 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 intensity 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 4.6 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 = Saleas area (m^2)

It can be seen that for convenience stores and supermarkets up to a sales area of around 1400 m^2 the electrical energy intensity drops exponentially. This is due to the shift from food dominant to non food dominant sales operations 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.

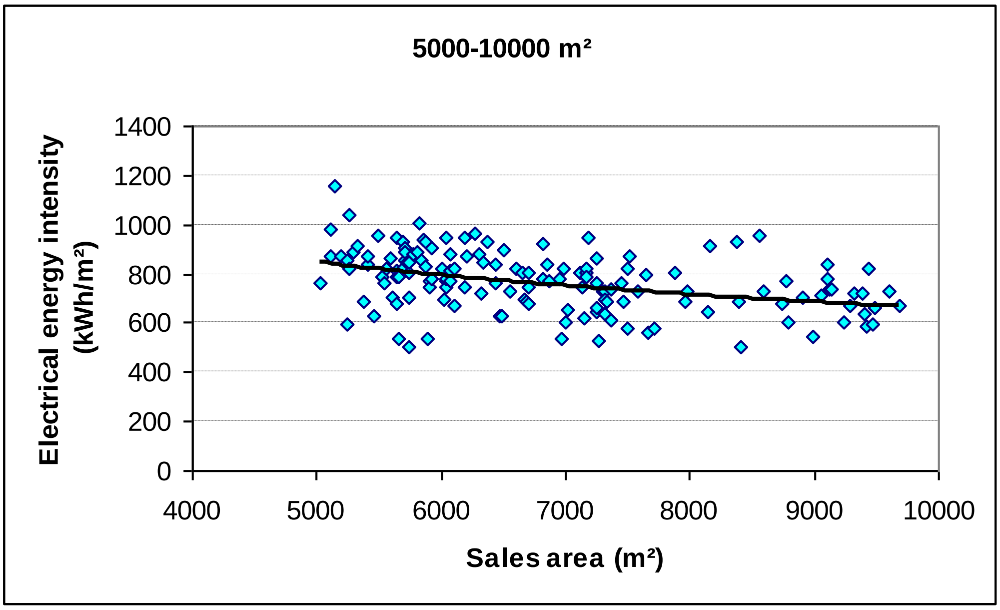

Figure 4.5: Electrical energy intensity of supermarkets of sales area between 5000 m^2 and 10000 m^2

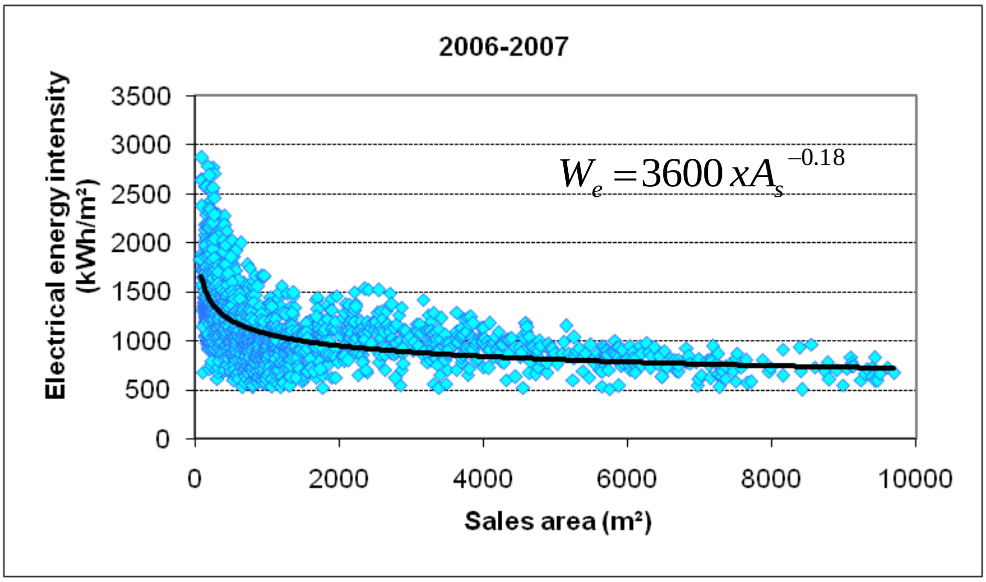

Figure 4.6: Variation of electrical energy intensity of 2570 UK retail food stores with sales area from 80 m^2 to 10,000 m^2

Table 4.1 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 do not include Regional Distribution Centre (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. The emissions in Table 4.1 represent approximately 85% of the food sales in the UK but also include the sale of some non food items.

Table 4.1: Annual energy consumption and greenhouse gas emissions (energy only) of major UK retail food chains

	Supermarket Electrical Energy Consumption (GWh)	Gas Energy Consumption (GWh)	CO_2e Emissions Electrical Power (tonnes)	CO_2e Emissions Gas (tonnes)	Total CO_2e Emissions (tonnes)
Major UK retail food chains	8385	2477	4502745	470630	4973375 **(~5.0 Mt CO_2e)**

4.3 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 TWEI 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 [16].

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_2e. 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_2e emitted per kWh of electricity supplied) is dependent on the generation mix. The best available overall estimate for the UK for 2008 was 0.537 CO_2e /kWh [6]. 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 [17].

4.4 Greenhouse Gas Emissions from food display in refrigerated display cabinets

Food in retail food stores is merchandised from different types of refrigerated display cabinet. These cabinets can be classified as integral or remote based on whether the refrigeration system is integral to the cabinet or is positioned remotely from the cabinet. In large retail food stores the majority of the cabinets will be of the remote type whereas in convenience stores the cabinets will invariably be of the integral type (Appendix A).

Display cabinets are also classified with respect to the temperature they are designed to maintain the product during display. This classification is illustrated in Table 4.2 [18].

Table 4.2: Display Cabinet Temperature Classes

Class	Highest temperature (°C)	Lowest Temperature (°C)	Lowest Temperature equal to or lower than (°C)
L1	-15	-	-18
L2	-12	-	-18
L3	-12	-	-15
M0*	+4	-1	-
M1	+5	-1	-
M2	+7	-1	-
H1	+10	+1	-
H2	+10	-1	-
***All class per ISO 23953-2: 2005, except M0 which is based upon recommendation**			

The performance of display cabinets is characterised by the ratio of the total energy consumption (TEC) which includes the refrigeration equipment and all other electrical consuming equipment in the cabinet (lighting, evaporator fans, electrical defrost circuit etc) to the total display area of the cabinet (TDA), calculated as per ISO23953-2 [18].

Table 4.3 shows average energy consumption of a range of refrigerated display cabinets, the average quantity of products displayed in the cabinet at a given point in time (taken from cabinets of three different supermarket chains) and the resulting average GHG emissions per hour of kg of product displayed ($gCO_2e/kg.hr$). The average energy consumption of the different families of display cabinets was determined from data in the open literature and test data in the laboratory.

The refrigerant charge in a supermarket refrigeration system will depend on the type of refrigeration system employed (primary or secondary system) the type of refrigerant used and the design and efficiency of the system.

For remote refrigeration systems using HFC/HCFC refrigerants van Baxter [19] gave an estimate for refrigerant charge as 4.15 kg/kW load. The Market Transformation programme provided range estimates of refrigerant charge for different types of refrigeration system. These estimates for different central supermarket refrigeration systems (Direct System) and different refrigerants are summarised in Table 4.4 [19]. For HCFC/HFC refrigerants that are most commonly used in supermarket refrigeration systems the refrigerant charge is in the range 2-5 kg/kW refrigeration. As a first approximation one can assume an average charge of 3.5 kg/kW (Refrigeration Capacity) and annual refrigerant leakage rate of 15%.

The energy consumption of refrigeration systems in supermarkets for the display of specific food products is given in Table 4.3. If it is assumed that the refrigeration system will employ R404A as refrigerant with Global Warming Potential (GWP) of 3860 [13], the GHG emissions from refrigerant leakage can be calculated as shown in Table 4.5. Comparing emissions from refrigeration system energy consumption (Table 4.3) and refrigerant leakage, (Table 4.5), it can be seen that refrigerant leakage can be responsible for almost the same CO_2e emissions as energy consumption in display cabinets.

Table 4.3: GHG Emissions as a result of retailing different types of food product in refrigerated food display cabinets

Food product	Display Cabinet Family*	Average Energy Consumption (kWh/m²-day)	Energy Consumption (kWh/m²-h)	Equivalent quantity in 1 m² TDA (kg)	Energy Consumption kWh/kg-h	Average GHG emissions gCO_2e /kg-h
Packed Fresh Meat	RVC2	13.4	0.56	36.0	0.0155	8.32
Ready Meals	RVC2	13.4	0.56	36 Packs 23.0 kg	0.0243 (0.0155 per pack)	13.05 (8.32 per pack)
Milk	RVC3	13.8	0.58	196.0 L	0.0029 per L	1.56 per L
Cheese	RVC2	13.4	0.56	53.0	0.0105	5.64
Frozen Peas	RHF4	13.0	0.54	80.0	0.0067	3.6
	IHF5	17.8	0.74	95.0	0.0077	4.13
	IYF3	32.3	1.34	72.0	0.0186	10
Frozen Potatoes (Finger chips)	RHF4	13.0	0.54	87.0	0.0062	3.33
Apples & Potatoes	No Cooling in store	-	-	-	-	-
Strawberries	RVC2	13.4	0.56	25.8	0.021	11.23
Bread	No Cooling	-	-	-	-	-
Beef Cottage Pie	RVC2	13.4	0.56	53	0.01	5.37
Carbon emission factor of 0.537 (kg CO_2e /kWh) was considered [6] Designation of refrigerated display cabinets is detailed in Appendix A						

Table 4.4: Typical refrigerant charge in central supermarket refrigeration systems

Sector/equipment		Specific refrigerant charge by refrigerant type (kg/kW)				References
		HC	HFC/HCFC	R717	R744	
Central Supermarket (Direct System)	Value	0.15- 0.35	2.0-5.0	0.09-0.21	1.0-2.5	[20]
	Average	0.25	3.5	0.15	1.75	
Central Supermarket (Indirect System)	Value	-	1.0 - 2.0	-	-	[21]
	Average	-	1.5	-	-	

Table 4.5: GHG emissions from refrigerant leakage (Direct refrigeration system)

Food product	Cabinet Load (kW/kg)	Refrigerant (kg) required per kg food kg (refrigerant)/ kg(food)	15% Annual Refrigerant Leakage kg (refrigerant)/ kg(food)	$kgCO_2e$/ kg.yr	Hourly gCO_2e/ kg-hr
Packed Fresh Meat	0.038	0.135	0.02	78.5	8.9
Ready Meals	0.038 per pack 0.06 per kg	0.135 per pack 0.212 per kg	0.02 per pack 0.03 per kg	78.5 per pack 123.1 per kg	8.9 per Pack 14.0 per kg
Diary Product Milk	0.0072 per L	0.025 per L	0.0038 per L	14.7 per L	1.67 per L
Dairy Product Cheese	0.026	0.09	0.013	53.1	6.0
Frozen Vegetables Peas	RHF4 0.0087	0.03	0.0045	17.6	2.0
	IHF5 0.01	0.035	0.005	20.2	2.3
	IYF3 0.024	0.084	0.012	49.0	5.6
Frozen Potato (Finger chips)	0.008	0.028	0.0042	16.3	1.8
Fresh Fruit Apples	-	-	-	-	-
Fresh Fruit Strawberries	0.052	0.183	0.027	106.3	12.1
Bread	-	-	-	-	-
Beef Cottage Pie	0.025	0.0875	0.0131	50.6	5.8
It was assumed that, the COP of LT Cabinets 1.3 and the COP of the MT cabinets 2.5 [52]					

4.5 GHG emission from walk-in coolers and freezers

The vast majority of supermarkets will have store rooms for temporary storage of refrigerated products. The low temperature storage rooms are normally referred to as walk-in freezers, and the medium temperature rooms as walk-in coolers. The size of these rooms is dependent on the size of the supermarket and product trading volume.

Even though a number of supermarkets use the same refrigeration systems to serve both the refrigerated display cabinets and cold rooms, the preferred solution in modern supermarkets is to use separate systems for the display cabinets and cold rooms. Energy consumption of cold room refrigeration systems will depend on the type of system used and the method of operation of the cold room. Figures reported in the literature vary widely as can be seen in Table 4.6. For the calculations in this report energy consumption figures of 0.12 kWh/m^2-h and 0.3 kWh/m^2-h have been assumed for walk in coolers and walk-in freezers respectively.

Table 4.6: Energy consumption of walk-in coolers and freezers per unit floor area

Reference		Walk-in coolers	Walk-in freezers	Reference		Walk-in coolers	Walk-in freezers
[52] (central- system)	kWh/h	25.2	29.9	[52] (self contained-system)	kWh/y	42306	15555
	m^2	278.8	92.9		m^2	22	7.5
	kWh/m^2-h	0.09	0.32		kWh/m^2-h	0.32	0.33
[53] (self contained-system)	kWh/h	1.85	2.44	[22] (central - system)	kWh/day	116	215
	m^2	15	15		m^2	72	26
	kWh/m^2.h	0.123	0.16		kWh/m^2-h	0.067	0.34

The product inside the walk-in coolers can be stacked in different ways such as on shelves, roll cages or just on the floor, as shown in Figure 4.7.

Figure 4.7: The product load patterns inside the walk-in coolers and freezers

To allow for product loading and unloading, sufficient free space is allowed for the operation of fork-lift trucks (in large cold rooms) and roll cages. Roll cages such as those shown in Figure 3.1 can be used for milk but larger roll cages can be used for other chilled and frozen food products. This free space has been assumed to be approximately 40% of the floor area. The ceiling height of the walk in cold rooms can also vary as well as the stacking height. The volume of product held in cold rooms can therefore vary widely and for the application of PAS 2050, a reasonable assessment should be made for each individual cold room and product.

For the calculations in this report, if products apart from those in roll cages, are assumed to be stacked to 2.4 m high, and each milk roll cage is assumed to occupy 0.27 m² of floor area, the weight of products held in the walk-in coolers and corresponding energy consumption and emissions can be determined as shown in Table 4.7. For refrigerant leakage, the same assumptions have been made as those for the refrigeration systems of the display cabinets (section 4.4)

Table 4.7. GHG emissions from walk-in coolers and freezers

Components	kg_{food}/euro-pallet	$Kg/m^2_{(walk-in)}$	kWh/ kg-h including 40% free walk-in floor area	Energy consumption emission gCO_2e/kg-h	Kg_{ref}/kg_{food} (15% annual leakage)	Refrigerant leakage emission gCO_2e /kg-yr	Refrigerant leakage emission gCO_2e /kg-h	Total emissions (power consumption + refrigerant leakage) gCO_2e /kg-h
Packed fresh meat	500	781.3	0.00026	0.14	0.0003	1298.6	0.15	0.29
Ready Meals	500	781.3	0.00026	0.14	0.0003	1298.6	0.15	0.29
Milk (pint)	320	1185.2	0.00017	0.09	0.0002	856.0	0.10	0.19
Milk (litre)	363	1344.4	0.00015	0.08	0.0002	754.6	0.09	0.17
Milk (kg)	375	1388.9	0.00014	0.08	0.0002	730.5	0.08	0.16
Cheese	1045	1632.8	0.00012	0.07	0.0002	621.4	0.07	0.14
Frozen peas*	576	900.0	0.00056	0.30	0.0004	1465.5	0.17	0.47
Frozen chips*	640	1000.0	0.0005	0.27	0.0003	1318.9	0.15	0.42
Apples	480	0	0	0	0	0	0	0
Potatoes	640	0	0	0	0	0	0	0
Fresh strawberries	130	203.1	0.00098	0.53	0.0013	4994.8	0.57	1.10
Bread	144	0	0	0	0	0	0	0
Beef cottage pie	500	781.3	0.00026	0.14	0.0003	1298.6	0.15	0.29

The COP of the HT and LT refrigeration systems was assumed as 2.5 and 1.3 respectively, [52].
GHG emission factor for electricity = 0.537 $kgCO_2e$/kWh was considered, [6].
3.5 kg refrigerant per kW refrigeration capacity [20]
* Low temperature walk-in (freezer)

4.6 Greenhouse Gas Emissions from lighting in the retail sales area

For a typical supermarket the total annual store electrical energy use is of the order 800-1000 kWh/m² sales area and lighting energy can account for up to 25 % of the total [23] giving a lighting load of approximately 225 kWh/m^2-yr. In a supermarket food products are usually displayed on shelves or refrigerated cabinets (approximately 80 cm deep) which are arranged facing each other along aisles. The width of the aisles can vary between 2.0 and 4.0 m depending on the size of the supermarket. In the analysis in this report an aisle width of 3.0 m was assumed and the energy consumed by lighting of the aisles and the checkout area was apportioned to the products on the shelves as indicated in Table 4.8.

Table 4.8: Lighting energy consumption per m² of sales area for a typical supermarket

Lighting load kWh/m²-yr	Lighting Load kWh/m²-h	Area of aisle just in front of the shelves	Area of check-out	Total area equivalent to 1 m² of floor area occupied by cabinets or shelves (including aisle and check-out)	Total lighting load for 1m² of the floor area including aisle and check-out
225	0.025	1.87 m²	1.13 m²	4 m²	0.1 kW/m².hr

The mass of food product displayed in 1.0 m^2 floor area was determined from measurements in retail food stores. This and the resulting emissions are displayed in Table 4.9.

Table 4.9: GHG emissions from lighting in the sales area of the supermarket

Component	Weight of product (kg) per m² sales area	Lighting Load per kg of food product kWh/kg-hr	GHG Emissions from Lighting g CO_2e/kg-hr
Packed Fresh Meat (kg)	91.2	0.0011	0.59
Packed Fresh Meat (Pack of 0.96 kg)	95	0.0011	0.57
Ready Meals (kg)	57.6	0.0017	0.93
Ready Meals (Pack of 0.45 kg)	128	0.0008	0.42
Diary Product Milk (kg)	339	0.0003	0.16
Diary Product Milk (Litre)	328	0.0003	0.16
Diary Product Milk (pint)	576	0.0002	0.09
Dairy Product Cheese	378	0.0003	0.14
Frozen Peas	180	0.0006	0.30
Frozen chips	216	0.0005	0.25
Fresh Apples	216	0.0005	0.25
Fresh Potato	182.5	0.0005	0.29
Fresh Strawberries	172.8	0.0006	0.31
Bread	144	0.0007	0.37
Beef Cottage Pie	100	0.0010	0.54

4.7 Greenhouse Gas Emissions from HVAC in the retail sales area

From data collected from supermarkets used in this study as well as data published in the literature it can be reasonably assumed that, on average, the gas energy consumption for space conditioning of a supermarket will be around 200 kWh/m² of sale area. Another 80 kWh/m² of sales area, on average, will be required for ventilation [23]. Using emissions factors of 0.2 kgCO_2e/kWh for gas and 0.537 kgCO_2e/kWh for electricity [6], the total annual CO_2e emission from HVAC will be around 81.0 kgCO_2e/m² of sales area. Considering the equivalent area of 1 m² cabinet footprint to 4 m² total sales area (as per lighting see Table 4.8), the total emission will be 324 kgCO_2e/m^2 sales area.

Table 4.10 shows the CO_2e emissions from HVAC from the food products considered in this study.

Table 4.10: GHG emission from HVAC in the sales area of the supermarket

Component	Mass (kg) equivalent to 1.0 m² of sales area	GHG Emissions from HVAC $gCO_2e/kg\text{-}hr$
Packed Fresh Meat (kg)	91.2	0.40
Packed Fresh Meat (Pack of 0.96 kg)	95	0.40
Ready Meals (kg)	57.6	0.64
Ready Meals (Pack of 0.45 kg)	128	0.29
Diary Product Milk (kg)	339	0.12
Diary Product Milk (Litre)	328	0.12
Diary Product Milk (pint)	576	0.07
Dairy Product Cheese	378	0.11
Frozen Peas	180	0.23
Frozen chips	216	0.19
Fresh Apples	216	0.19
Fresh Potato	182.5	0.22
Fresh Strawberries	172.8	0.24
Bread	144	0.28
Beef Cottage Pie	100	0.41

4.8 Greenhouse Gas emissions from plastic shopping bags

Assuming a 10g LDPE plastic bag is used to carry the food products, the equivalent CO_2e emission from manufacturing and transportation of the plastic bag to the supermarket will be in the region of 37.63 gCO_2e [25]. The maximum load that an average plastic bag can support is around 4.5 kg [26]. Assuming plastic bags are filled to the maximum carrying load the corresponding emission from the use of plastic bags to carry different food products are given in Table 4.11.

Table 4.11: GHG emissions from plastic shopping bags

Component	Maximum load (kg) per plastic bag of 10 g	GHG emissions of plastic bags gCO_2e/kg
Packed Fresh Meat	4.5	8.3
Ready Meals	4.5	8.3
Diary Product Milk (Litre)	4 litre	9.4 per litre
Dairy Product Cheese	4.5	8.3
Frozen Peas	4.5	8.3
Frozen chips	4.5	8.3
Fresh Apples	4.5	8.3
Fresh Potato	4.5	8.3
Fresh Strawberries	2 (size limit)	20
Bread	2.4 (size limit)	15.6
Beef Cottage Pie (pack of 0.5 kg)	4 (size limit)	18.8

4.9 Greenhouse Gas Emissions from baking

The energy required to bake 1 kg of bread depends on a number of factors such as the specific heat of the dough, the temperature of the dough entering the oven, the moisture evaporation rate, and oven temperatures, fuel type etc. Values of energy of between 0.096-0.16 kWh have been quoted in the literature [27]. If an average value of 0.128 kWh/kg is considered and an emission factor of 0.537 kg CO_2e/ kWh is used for electricity and 0.2 kg CO_2e / kWh for gas [6], then baking 1 kg of bread in an electric oven will emit 68 g CO_2e /kg_{bread} and a gas oven 24.3 gCO_2e /kg_{bread}.

4.10 Greenhouse Gas emissions from food, packaging and other waste

GHG emissions from food, packaging and other waste are dependent on the waste management options available. If the food waste is landfilled without any composting or anaerobic digestion the net GHG emissions will be in the region of 400 kgCO_{2e}/tonne waste. If the gas generated from landfilling is recovered and flared, the net GHG emissions will be in the region of 90 kgCO_{2e}/tonne [28, 29]. If on the other hand the food waste is either composted or used in anaerobic digestion process to generated power, there will be CO_{2e} emissions savings of the order of 50 kgCO_{2e}/tonne [28].

The food industry produces large amounts of food waste, and food retailing alone in the UK is estimated to produce 1.6 million tonnes per year [54]. Unfortunately it has not been possible to obtain data for waste rates of specific food products as waste from food retail outlets is normally reported in tonnes per £million of sales. Relevant personnel of a number of retail chains indicated food wastage rates of perishable food products to be in the region between 1% and 5%. Of course, this will depend on the type of product and supermarket. In this report a wastage rate of 2.0% has been assumed for illustrative purposes.

Table 4.12 shows the CO_2e emissions from food waste for different waste management options. If it is assumed that the solid waste is transported by a trailer “net weight 32 tonne” and the return distance travelled is 150 miles CO_2e emissions for transportation will be around 90 kgCO_2e/tonne [30,24,31].

Emissions from packaging waste will depend on the waste management option available. It has been reported that recycling 1 tonne of recovered soft plastic “wrapping” and paper & cardboard will save 1586 kgCO_2e and 496 kgCO_2e respectively, giving emissions savings per kg of 1.6 kgCO_2e/kg and 0.5 kgCO_2e/kg [32]. Table 4.13 gives information on CO_2e emissions from other supermarket waste

Table 4.12: GHG emissions from food waste

Component	Food waste %	GHG emission of food waste including transportation gCO_2e/kg (food supplied to supermarket)			
		Landfill without recovery	Landfill with LFG recovery and flaring	Composting	Combustion
Mixed food waste	2.0%	9.8	3.6	0.8	0.8
LFG Landfill gas flaring					

Table 4.13: GHG emissions from other waste in the supermarket

Waste component	Release emission factor
Waste water	Water - only power consumption for pumping and treatment of domestic wastewater were considered for the emission calculations. Electrical energy required to pump 1 m³ of water is 0.085 kWh/m³ [33] Electrical energy consumption required to treat 1.0 m³ of domestic wastewater is 0.416 kWh/m³ [34] Total energy required to pump and treat 1m³ of water will be 0.501 kWh/m³ and the equivalent emission is 0.269 kgCO_2e/m³
Used cooking oil	The GHG emission factor for collection and transportation of used cooking oil will depend on the vehicle type and will range between 0.11-0.21 gCO_2e/kg-mile. The GHG emission factor from the direct combustion of used cooking oil will depend on the oxygen supply and the combustion temperature and is reported to be in the range between 1.29-2.7 kgCO_2e/kg. If the waste cooking oil is used to produce biofuel, the emission factor will be in the range between 0.479-0.71 kgCO_2e per kg biofuel produced [35].

5. Impact of Merchandising Practices on GHG Emissions

Having established the GHG emissions of the food products considered per kg mass per hour of their life cycle, the total emissions during the transportation and retail stage of their cycle if the residence times in the RDC, the supermarket cold-rooms and the refrigerated display cabinet shelves are known. As an example, average residence times from three different supermarket chains were used to determine average residence times for the products considered in this study. These residence times are shown in Table 5.1.

Table 5.1: Residence times of food products in RDC and supermarket

Food Product	Food in Refrigerated Warehouse (h)	Food in Store (h)	Food in Store	
			Display cabinet (h)	Walk-in coolers or freezers (h)
Packed Fresh Meat	12	48	24	24
Ready Meals (chilled)	12	48	38	10
Milk	-	24	12	12
Cheese	12	72	48	24
Frozen Peas	158	120	96	24
Frozen Potatoes (Finger chips)	158	120	96	24
Fresh Apples	24	48	-	-
Fresh potatoes	24	72	-	-
Strawberries	-	36	36	-
Bread	-	24	-	-
Beef cottage pie (chilled)	12	48	38	10

Using the data in Tables 3.10, 4.3, 4.5, 4.7, 4.10, 4.11, 4.12, and 5.1 the GHG emissions from each product were determined and are shown in Table 5.2. It can be seen that the highest emissions arise from the energy consumption of the refrigerated display cabinets and refrigerant leakage. For the 15% annual leakage rate and R404A refrigerant assumed in this study, the GHG emissions from refrigerant leakage are slightly higher than the GHG emissions from the electrical energy consumption of the chilled food display cabinets and slightly lower that the emissions from the electrical energy consumption of the frozen food cabinets. Some supermarkets will have lower leakage rates than 15% but many more will have much higher leakage rates, 30% or more.

It can also be seen from Table 5.2 that the products that are packed and displayed more densely in the refrigerated display cabinets lead to lower GHG emissions. The same applies for products that have lower residence times in the display cabinet.

The results for a selection of products are presented pictorially and discussed below. Figure 5.1 shows the results for fresh packed meat. It can be seen that 87% of the emissions arise from refrigerant leakage and energy consumption of the refrigerated display cabinets. The other emission sources are quite small in comparison with plastic bags accounting for around 2%, food waste to landfill 2% and transport from RDC to supermarket 3%. Emissions due to refrigeration energy consumption and refrigerant leakage in the supermarket cold room is around 1%.

Table 5.2: GHG emissions from different stages of the food product life cycle (gCO_2e/kg)

Food Component		38 tonne articulated vehicle							Landfill without recovery	
	RDC[1]	Transport[2]	Refrig. display cabinets[3]	Walk-in cold rooms[5]	Refrig. Leakage[4]	Lighting	HVAC	Plastic bags	Food waste including transport	Total
Packed Fresh Meat	0.1	14.9	199.7	7.0	213.6	14.2	9.6	8.3	9.8	477
Ready Meals	0.1	14.9	495.9	2.9	532	35.3	24.3	8.3	9.8	1124
Milk (per litre)	0.0	11.8	18.7	2.0	20.4	1.9	1.4	9.4	9.8	76
Cheese	0.038	8.6	270.7	3.4	288	6.7	5.3	8.3	9.8	601
Frozen Peas	0.0	16.2	567.4	11.3	336	28.8	22.1	8.3	9.8	1000
Frozen Potatoes	0.0	14.3	319.7	10.1	172.8	24.0	18.2	8.3	9.8	577
Fresh Apples	0.0	19.0	0.0	0.0	0.0	12.0	9.1	8.3	9.8	58
Fresh potatoes	0.1	14.3	0.0	0.0	0.0	20.9	15.8	8.3	9.8	69
Strawberries	0.0	69.4	404.3	0.0	435.6	11.2	8.6	20.0	9.8	959
Bread	0.0	61.8	0.0	0.0	0.0	8.9	6.7	15.6	9.8	103
Beef Cottage Pie	0.1	14.9	204.1	2.9	220.4	20.5	15.6	18.8	9.8	507

[1] Regional Refrigerated Distribution Centre
[2] Truck engine plus refrigeration (Total return distance with a single drop is 190 km [56] - vehicle empty during return journey with refrigeration system off , see Table 3.10)
[3] Cabinets energy only
[4] Cabinets refrigerant leakage only
[5] Energy plus refrigerant leakage

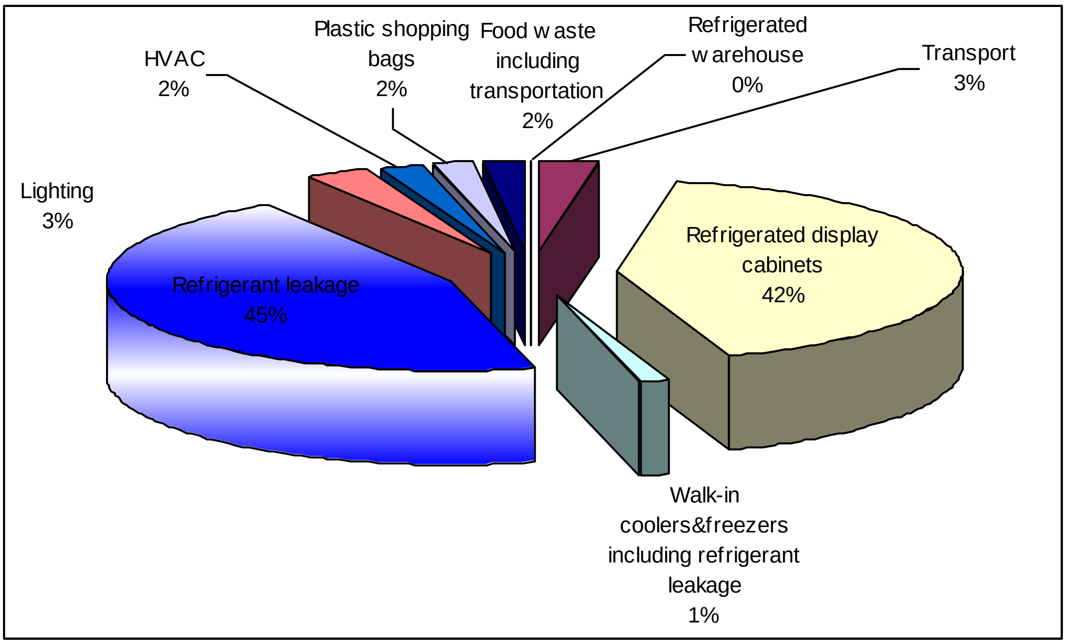

Figure 5.1: Percentage contributions to total GHG emissions for Fresh Packed Meat

Figure 5.2 shows the percentage emissions for milk. It can be seen that because the residence time of milk on the shelves of the refrigerated display cabinets is not very long, and milk is stacked very densely in the cabinet the emissions from display cabinet refrigeration energy consumption are not as pronounced as those for packed fresh meat.

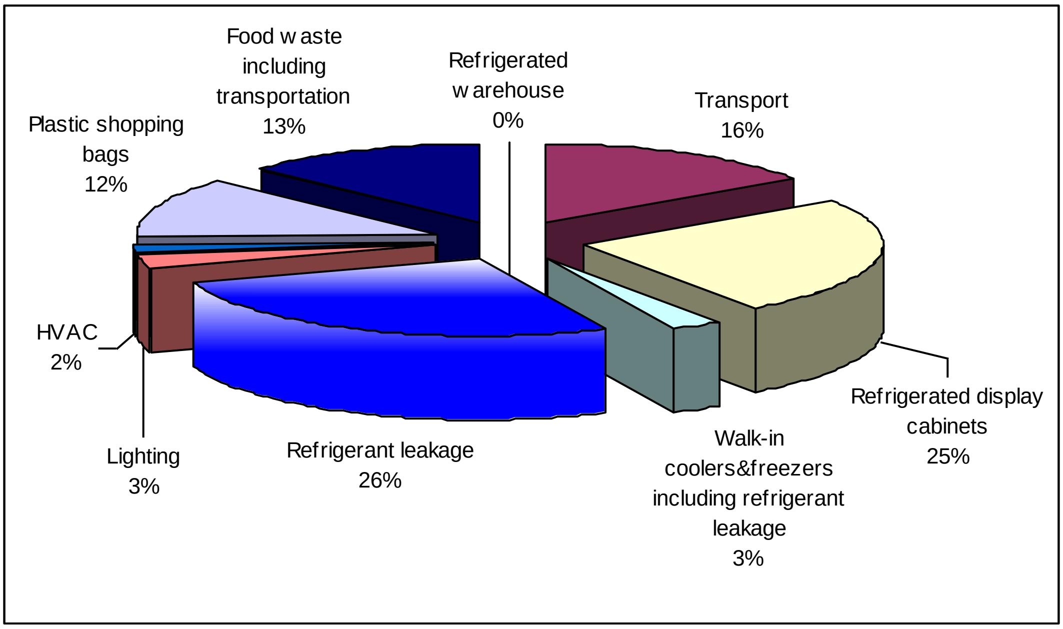

Figure 5.2: Percentage contributions to total GHG emissions for Milk

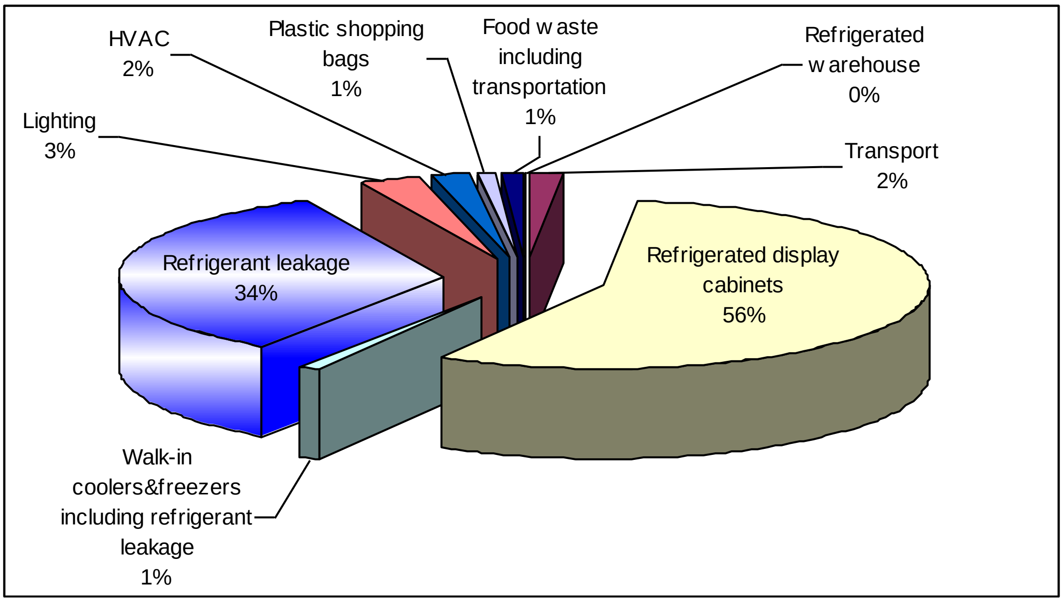

Figure 5.3: Percentage contributions to total GHG emissions for Frozen Peas

Figure 5.3 shows the percentage contributions to GHG emissions for frozen peas. It can be seen that due to the longer residence time and the higher energy consumption of frozen food display cabinets compared to chilled food cabinets, the emissions from the display cabinet energy consumption is higher than emissions from refrigerant leakage. The two account for 90% of total emissions with the remainder of the emission between 0% and 3% each.

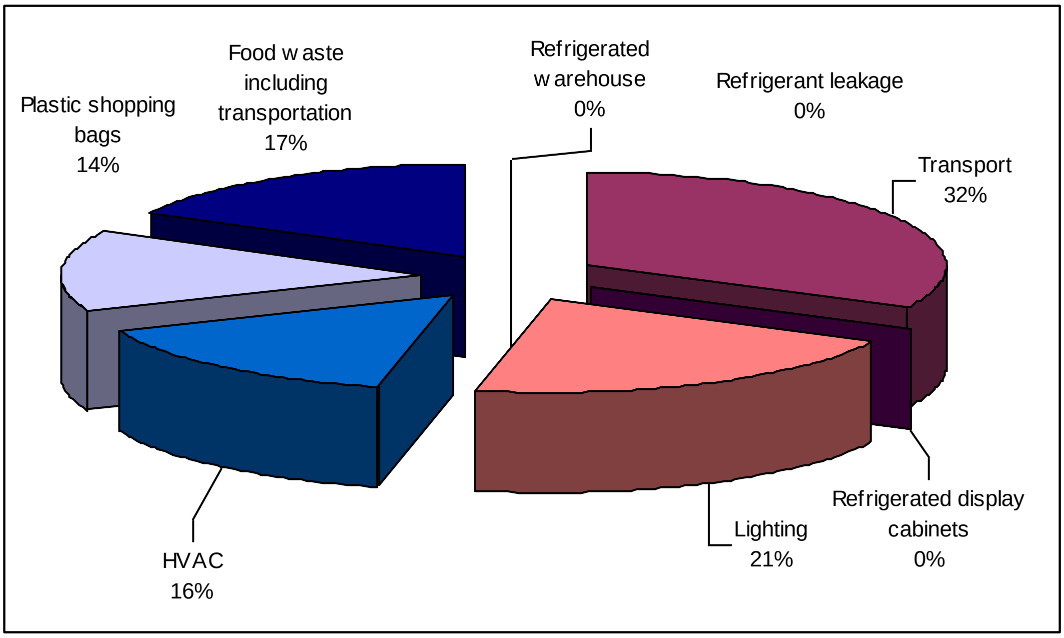

Figure 5.4: Percentage contributions to total GHG emissions for fresh Apples

Figure 5.4 shows the percentage emissions for apples which are not refrigerated. It can be seen that in this case transport and landfilling of waste (assumed to be 2% by weight) are responsible for almost 49% of total emission. Emissions from plastic bags 14%, and lighting and HVAC together representing 37% of total emissions.

5.1 Concluding remarks – Merchandising Practices

From the above it can be concluded that for most temperature controlled products energy consumption of refrigerated display cabinets and refrigerant leakage account for the vast majority, over 80%, of the emissions from the distribution and retail phase of the food product life cycle. For milk, which has a shorter residence time on the display cabinet shelves and is packed densely in the display cabinet, emissions due to transport, waste and plastic bags are also important. For fresh ambient products, which have much lower overall emissions than temperature controlled products, emissions from transport and waste to landfill become significant.

For all temperature controlled products, emissions from storage in Regional Distribution Centres and to a lesser extent cold rooms in the supermarket are quite small due to the short residence time and the large quantity of products stored per unit area or volume. It can therefore be concluded that significant reductions can be achieved by optimising distribution logistics to the store and the management of product flows in the store to minimise the time that the product is displayed on the shelves of the display cabinet. Of course, if the shelves are not fully loaded then emissions per unit product sales from the refrigerated display cabinets will increase. It is therefore important for both the display area and the number of refrigerated cabinets as well as cabinet loading frequency to be optimised in respect to the product throughput. Reduction of the range of products in each category and the number of products that are refrigerated can also help in this respect. For example, in many supermarkets fresh produce is refrigerated. The cabinets used for refrigeration of fresh produce have lower efficiencies than dairy and meat cabinets due to the requirement to store larger boxes and facilitate loading of the cabinet and display of the product. If more frequent and just in time deliveries of fresh produce are arranged so that the need of refrigeration is removed then emissions from the merchandising of fresh produce can be significantly reduced. Logistics, therefore, have a big role to play in reducing emissions from retail food stores.

From Figure 4.6 it can be seen that smaller stores in general have higher electrical energy consumption per unit sales area than larger sores. One reason for this is that smaller stores are food dominant with refrigeration accounting for most of the electrical energy consumption. Another reason is that convenience stores in a large number of cases use 'integral' refrigeration equipment which are less efficient compared to centralised remotely located equipment. Many convenience stores are also owned, or operated as franchises by operators that do not have the technical expertise in-house or the resources to manage the refrigeration systems effectively. The study has also shown that the equipment in these stores are generally older and less well maintained than equipment in stores of large supermarket chains which are refitted at more frequent intervals.

In summary, significant potential for energy savings and GHG emissions reduction exist in food retailing through the optimisation of logistics as well as the merchandising practices and refrigeration technologies employed. Optimisation should be based on the type and size of store. The replacement of HCFC and HFC refrigerants with natural refrigerants as well as the reduction of the quantities of refrigerant used can make a substantial contribution to emissions reduction.

It is very difficult to draw conclusions on which store format might be better in terms of GHG emissions due to the large variety of factors and variables, both business and technical, that can influence the emissions. Keeping everything else the same, stores with higher food sales volume will have lower emissions per unit of product sold due to the shorter residence time of the food on the shelves and store cold rooms. Convenience stores many of which will use integral refrigeration equipment which are inherently less efficient than remote equipment are in general expected to have higher electrical energy intensities and emissions due to electrical energy consumption than stores with remote refrigeration equipment. Integral equipment, however, are less prone to refrigerant leakage and hence their direct emissions will be less than the direct emissions of remote equipment if the latter are not regularly monitored and maintained to minimise leaks.

To gain a better inside of the impact of store format and store location on GHG emissions it will be necessary to control the number of variables involved in the study. This will be difficult but not impossible to do. For the results to be statistically significant, it will require large sample sizes for each store format. Alternatively the exercise can be done through detailed simulations using supermarket energy and environmental impact models in combinations with shopping transport models.

5.2 Concluding remarks – Application of the PA2050 specification to the food distribution and retail phase of product life cycle

The PAS 2050 method requires that GHG emissions should include 'all sources of emissions anticipated to make a material contribution (more than 1%) to the life cycle GHG emissions of the functional unit' and 'at least 95% of the anticipated life cycle GHG emissions of the functional unit'.

For the temperature controlled products considered in this study, GHG emissions from a number of operations for the distribution and retail phase of the product are very small, below 1%. The percentage GHG emissions of these operations will be even lower if GHG emissions from the whole life cycle of the product are considered. It is therefore possible that for simplicity the emissions from some operations can be either neglected, for example storage in regional distribution centres or grouped together, for example, emissions from all storage operations (at RDC and supermarket).

The same can be said for lighting and HVAC as well as other emission sources and the decision whether to include these emissions individually or group them together can be made by the individuals applying the specification. The level of detail with which PAS 2050 can be applied will depend on the level of instrumentation and primary data available.

Regional Distribution Centre - For the RDCs overall electricity and gas consumption data, normally on a monthly basis, as well as individual product volume flow or product residence times should be available for the calculation or GHG emissions. With half hourly metering that a number of RDCs are now installing it will be possible to refine further the calculations to include seasonal variations in GHG emissions. This may not be very important for the PAS 2050 as the RDC emissions are very small compared to the other emissions in the product life cycle but it will be useful if one wishes to consider a detailed carbon footprinting of a specific product.

Transport – GFG emissions from transport will depend on the type of transportation vehicle used, distribution logistics and distance travelled, vehicle loading and the way that the vehicle is loaded and unloaded. The vast majority of refrigeration systems used in transport refrigeration are either driven by the main vehicle diesel engine or by an auxiliary diesel engine. Calculation of GHG emissions from transportation can therefore easily be done using primary data for fuel used and quantity of product transported.

Retail – Currently, all retail food outlets have data for their energy usage, electricity and gas, on a monthly basis from utility bills. A proportion of supermarkets, namely those of the large food retail chains are also sub-metered to a certain level but unfortunately in the majority of cases data from this sub-metering is unreliable because sub-meters are not regularly checked and calibrated. Sub-metering, where it exists, mainly covers the refrigeration plant, lighting, HVAC and bakery.

Detailed sub-metering, provided it is reliable, can facilitate significantly the determination of GHG emissions from retail operations. The level at which this is currently done by some of the large retail chains, installing between 10 and 14 sub-meters for electricity, will to a large extent provide most of the information required. There are many cases, however, where one operation impacts on the emissions of other operations. For example, refrigeration of display cabinets impacts on the heating energy requirement and emissions from HVAC in the store due to the cold air overspill from the cabinets. Lighting and baking will also impact on HVAC, this time increasing the cooling requirements of the store in the summer and reducing the heating requirements in winter. Although if one was considering a detailed energy analysis it would be interesting and important to consider the effects of the interactions of the different operations on energy consumption, for the case of the application of the PAS 2050 this is not necessary because first of all the emissions from some of the operations are very small and secondly the impact of some of the emissions that are not included in one operation will be captured by their effect on another operation.

Applying PAS 2050 to temperature controlled products in the store can be done by apportioning the emissions from the refrigeration equipment, for frozen and chilled products, to the product throughput and the percentage of display cabinet volume occupied by the specific product. In effect, the product throughput divided by the volume of display cabinet occupied by the product gives the residence time of the product on the shelves and this is the measure used to calculate the emissions of temperature controlled products in refrigerated cabinets in this report in the absence of sales data of specific products from individual stores. These data, even though available, are considered to be commercially very sensitive by the retailers.

6. Impact of Technologies on Energy Savings and Emissions Reduction

6.1 Opportunities for energy savings in supermarket refrigeration

6.1.1 CO_2 and natural refrigerant refrigeration technologies

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 transcritical system or in a cascade arrangement with another natural refrigerant for heat rejection.

For CO_2 to become widely accepted in supermarket applications more 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.

6.1.2 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 need further investigation, particularly with the introduction of transcritical CO_2 systems.
- The use of Liquid Pressure Amplification (LPA) technology offers opportunities for greater reduction in head pressure than is currently possible with conventional head pressure control systems. LPA can overcome the effects of pressure drop and liquid flashing in long liquid lines and this may be beneficial in supermarket applications.
- 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. 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.

6.2 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 between the products in the cabinet and the surrounding surfaces, 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 is shown in Figure 6.1 [37]. 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.

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,
- and the use if night blinds during periods when the store is closed.
- Significant research has been carried out to improve the performance air curtains in recent years. This included both experimental studies and modelling using Computatoinal Fluid Dynamics [38,39,40]. 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.
- The energy savings 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 [37]. 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.
- Another way of significantly reducing the infiltration load of vertical chilled multi-deck cabinets is to introduce glass doors. This approach, even though has been found to reduce the cabinet refrigeration load by up to 40%, is not preferred by the merchandisers of retail food chains as it has been found to impact negatively on sales.

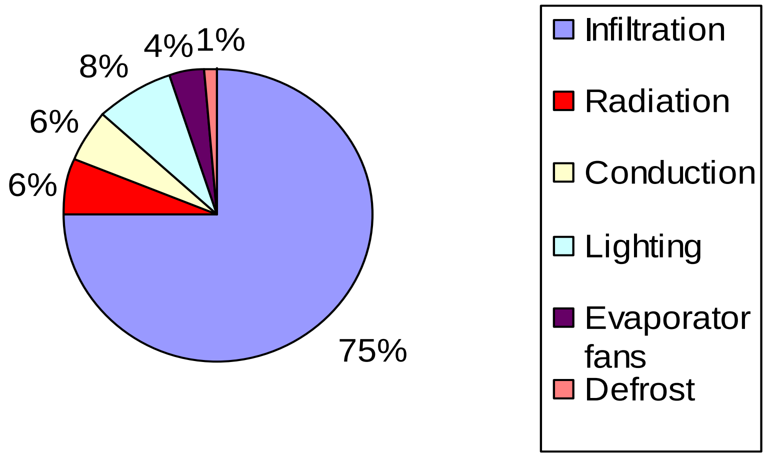

Figure 6.1 Contributions to the load of a vertical multi-deck open front chilled food display cabinet [12]

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The internal loads of cabinets from fan gains which are proportional to the energy consumed by the fan can be reduced by using more efficient fans (aerodynamic blades on axial flow fans) and more efficient fan motors such as ECM (Electronically Commutated Motors). ECMs have been shown to produce 67% energy savings over conventional shaded pole motors [41]. 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 re more difficult to clean in comparison to axial flow fans.

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 [42].

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 [43]. 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 and 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.

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. Defrost of frozen food cabinets is normally effected at between six and 12 hourly intervals, depending on the refrigerated fixture. 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 [44,45].

6.3 Space environmental control in supermarkets

6.3.1 HVAC Systems

Supermarkets present a unique space conditioning challenge because of the interaction between the 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 (heating, ventilation and cooling) in retail food stores can be between 15% and 25% 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.

6.3.2 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 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 [46].

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.

6.4 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.

6.4.1 Energy Conservation in Lighting

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

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

Analysis using a case study in a recently energy efficient Tesco store employing design features for the utilisation of solar energy in the form of daylighting has shown that there is significant potential to reduce energy consumption in retail food stores through the use of daylighting, 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, there has been considerable developments in LED lighting 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 [47].

6.5 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, 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 [46]. Another project, again funded by DEFRA is also investigating the application of tri-generation systems in the food retail industry [48,49].

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

With current energy prices and 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 wider application of renewable source. 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:

i) better integration and control of current and emerging technologies;

ii) technological developments and radical approaches to merchandising;

iii) 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.

iv) 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.

6.6 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) [51,53].

6.7 Operation and maintenance

Experience from the retail food partners that participated in the project has shown that the operation of retail food premises in terms of management practices and maintenance policies and procedures will influence the energy consumption by at least ±10%.

A common practice with major food retailers in the UK is to subcontract the maintenance operations. In large retail food stores key plant in the store, particularly the centralised refrigeration equipment are monitored remotely by data management bureaus. Data logged are normally the temperature of the refrigerated display cabinets in the store. The main purpose is to ensure that food storage and display complies with food hygiene regulations. In the event that a particular temperature falls outside the set control limits, an alarm triggers a visit by the maintenance contractor to identify and remedy the problem. The refrigeration monitoring systems are normally an integral component of the refrigeration system controls which control the operation of the refrigeration plant to maintain the required temperature in the refrigerated storage and display equipment.

Major progress in more effective maintenance can be achieved through effective insentivisation of maintenance contractors and store managers to ensure that energy consumption and emissions are minimised. A major difficulty in devising and implementing such schemes is the accurate determination of the impact of proactive measures taken by the contractor and/or store managers on reducing energy consumption and emissions whilst maintaining or improving other operational efficiencies and sales. This is because energy consumption and emissions can be affected by a large number of parameters such as weather conditions, trading patterns, volumes of sales etc.

Research and development is required to develop methodologies and models by which the energy consumption and emissions of retail food store can be determined accurately based on historical data of weather conditions sales volumes etc. This will facilitate the setting of targets and incentives for contractors and store managers to reduce emissions.

PART B

Objective: Investigate the Application of the PAS 2050 method to the service sector.

1. Abstract

The main objective of this part of the project was to investigate and test the applicability of the PAS 2050 method to service operations. The work was carried out in two phases. The main objective of Phase 1 of the project was to provide comments and recommendations for the Steering Group to improve and facilitate the application of PAS 2050 to service operations. This was done and the comments were considered in the preparation of the final version of the PAS 2050. The main objective of Phase 2 was to test the application of the PAS 2050 METHOD methodology to a refrigeration service company. This was done through a case study and this section provides a report on the work undertaken for the case study.

2. Case Study

A food refrigeration service company was chosen for the case study. The company is engaged in the remanufacture of old refrigerated display cabinets, the manufacture of new refrigerated display cabinets and the provision of services to the food retail industry. These services include the provision of shelving, remodelling and updating of food store refrigeration equipment, and replacement of faulty components which can be either sourced from the manufacturer/supplier or manufactured in the company's manufacturing facility.

The company operates a separate service section in the company that shares office space and manufacturing facilities with the rest of the company. The service operations carried out are also very wide, presenting challenges in the application of the PAS 2050 both in terms of specification of system boundary and identification of the functional unit and reporting unit for each service. For example, the system boundary could be different for a service operation which includes components manufactured by the company to operations that include components sourced from a separate supplier.

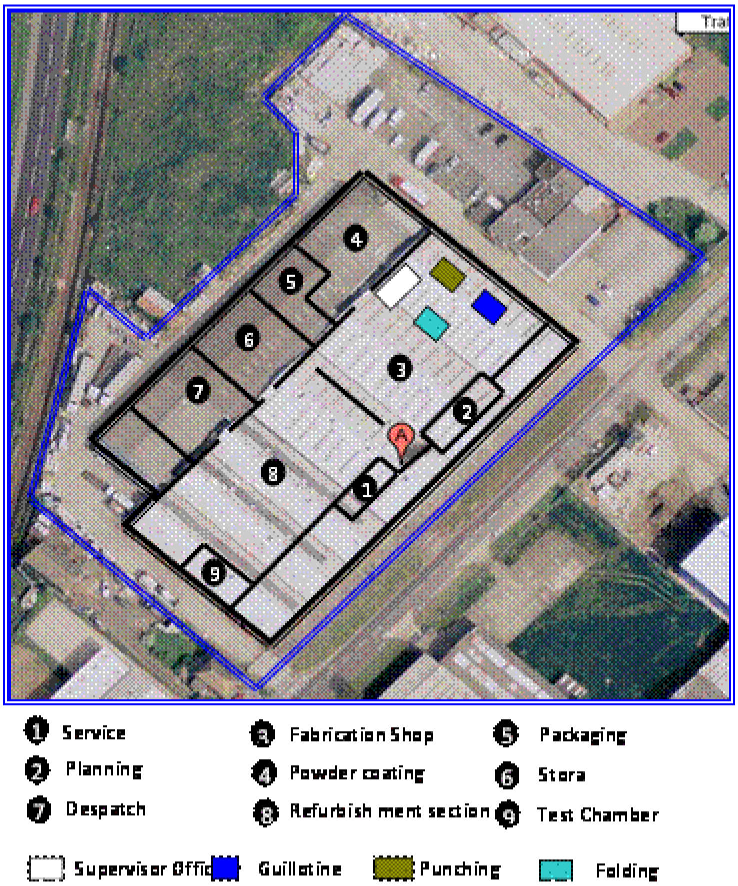


Figure 1: Company Site

For the case study, the supply of in-house manufactured refrigerated display cabinet shelves to supermarkets was considered.

2. Life Cycle Process Map

Figure 2 shows the cycle process map for the manufacture and supply of a display cabinet shelf which includes processes and material flows.

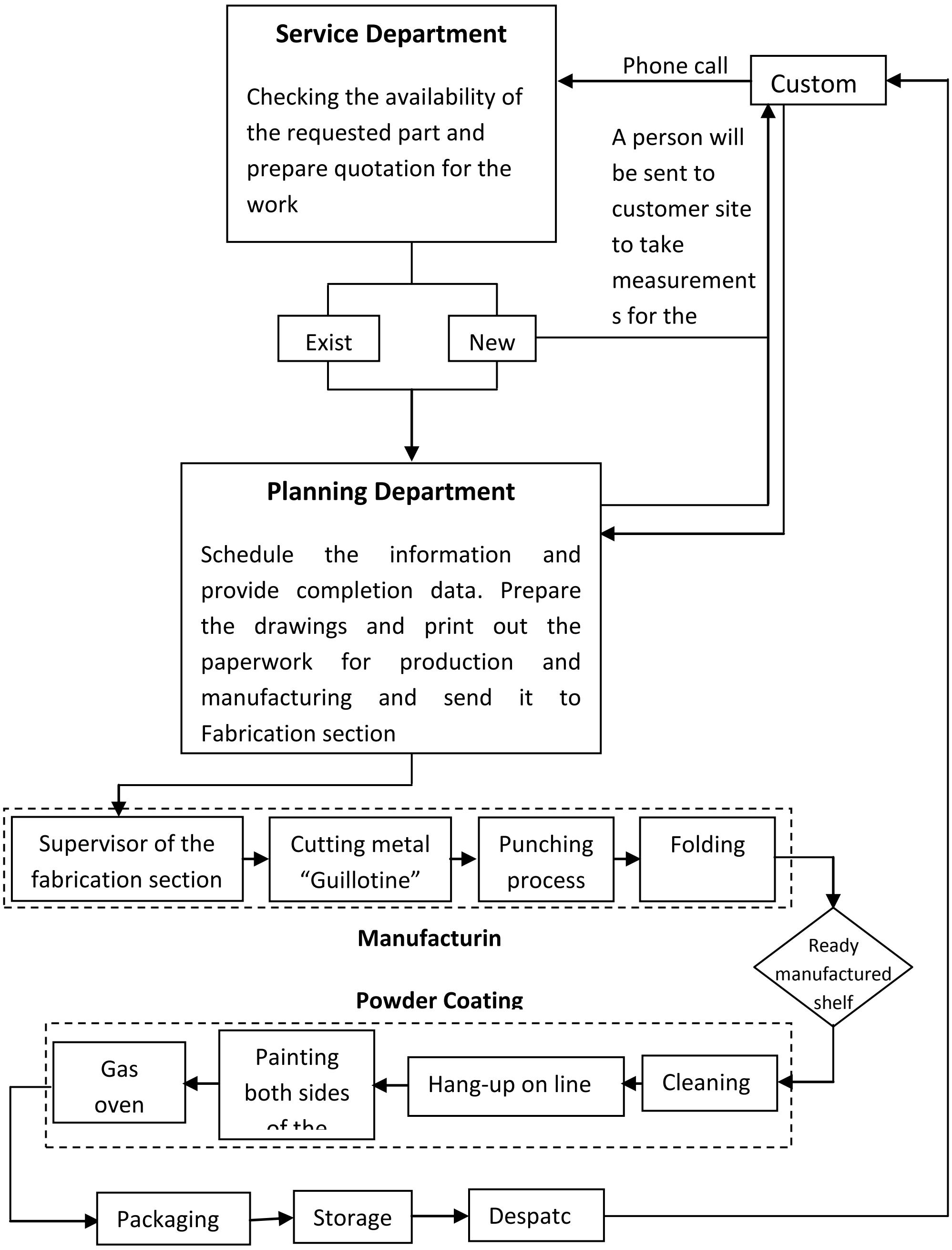


Figure 2: Cycle process map for a shelf

Figure shows the final flow chart considered for the calculation of the GHG emissions from the manufacture and supply of a display cabinet shelf.

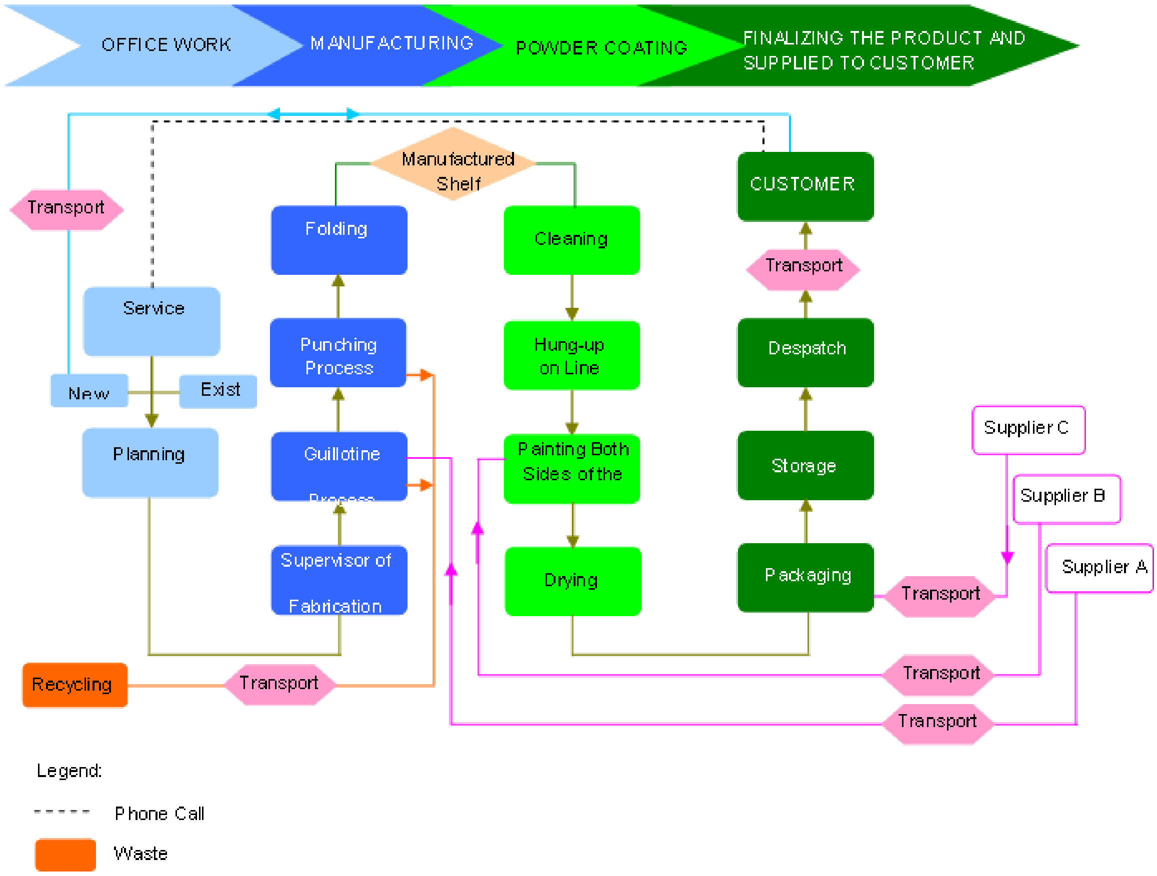


Figure 3: Final process map for shelf manufacture and supply

3. Input Data (collected data):

Data with regards to time required for the job, area, computer use, lighting and required power to operate the machines, were considered for each step of the manufacturing the display cabinet shelf. Tables 1 to 4 show the input data during the different steps of manufacture of the display cabinet shelf.

Table 1: Input data for the office work section

Section category	Time for the job (min)	Area of the section (m²)	Total power lighting (W)	HVAC	Computer use
Service Department	30	21	400	-	2
Planning Department	180	28	500	-	2

Table 2: Input data for the manufacturing section

Section category	Time for the job min	Area of the section m²	Total power lighting W	HVAC	Computer use	Nameplate power of the machine kW
Supervisor of the fabrication section	10	8	400	-	1	-
Cutting metal	2	48	500	-	-	9.5
Punching process	2.5	48	600	-	-	25.5
Folding Process	1	32	600	-	-	20
Total metal waste from cutting and folding processes is 10% of the shelf weight						

Table 3: Input data for the powder coating section

Section category	Cleaning	Hang-up on line	Painting both sides	Dryer
Powder Coating 250 g	Compressed air for 2 min	45 min	Compressed air 2 min	10 min at 200°C
Total area 625 m² Lighting 1200 W 2 Motors to run the line (0.24 kW each) 2 Extractor fans (0.75 kW each) Gas consumption for the dryer (92.0 kW) (8 min each shelf inside) Production capacity of the line is 24 shelf per hour The compressed air unit power consumption is 2.2 kW				

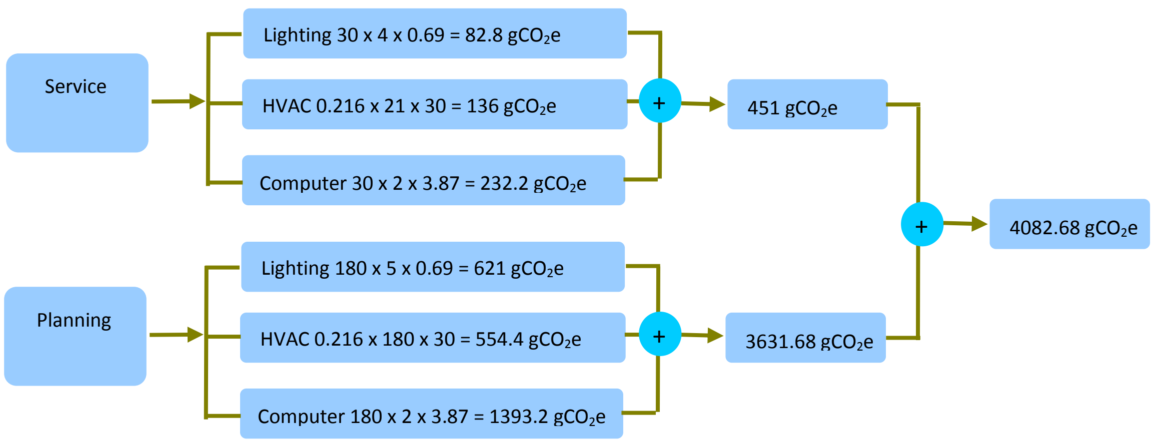
Table 4: Input data for packaging, storage and despatch

Section category	Time for the job (min)	Area of the section (m²)	Total power lighting (W)	HVAC	Note
Packaging	2	300	720	-	4 m long of bubble packaging paper used , around 300g
Storage	1440	2000	960	-	Total storage volume 12000 m³
Despatch	-	-	-	-	-

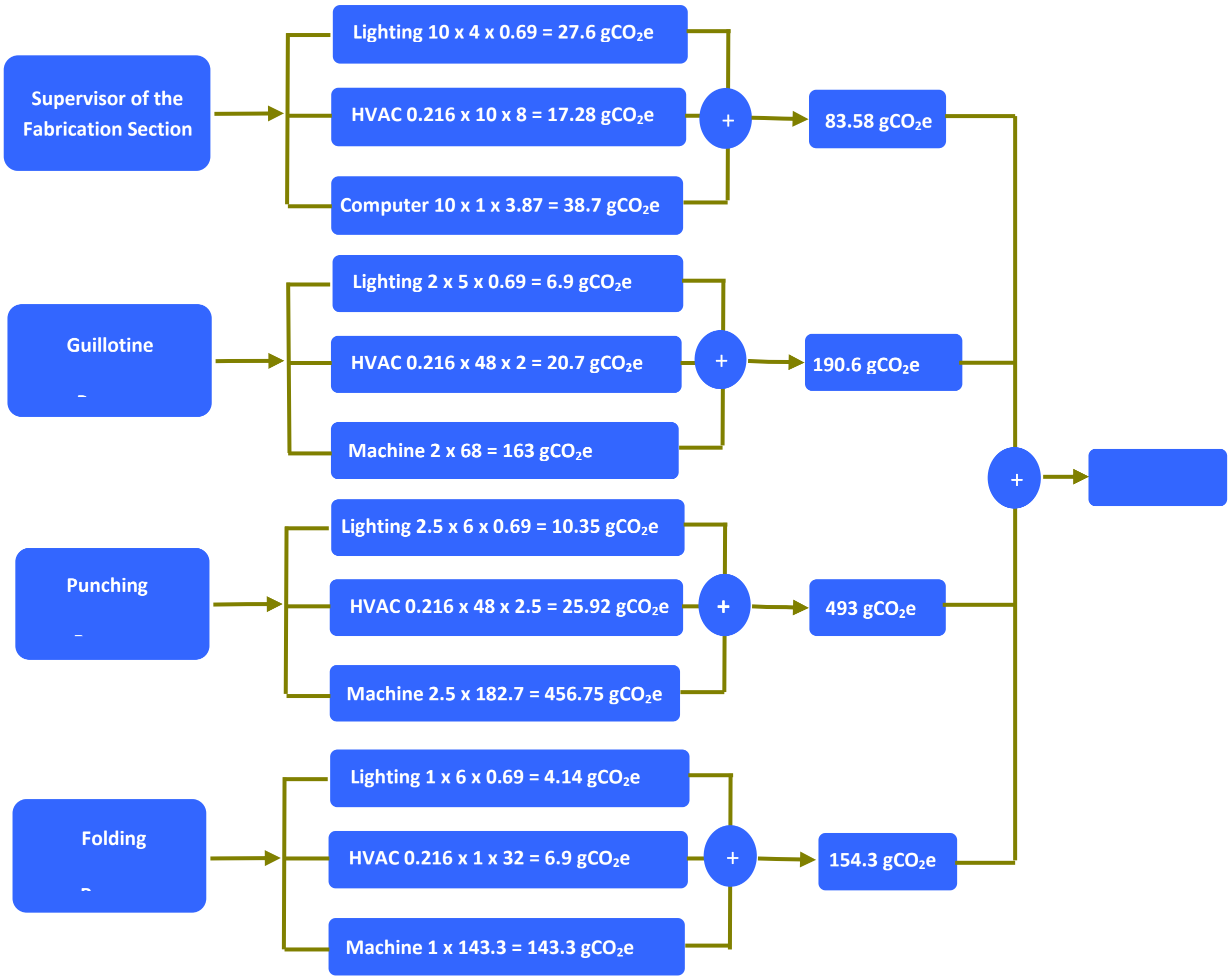
4. Calculation of CO_2e emissions from manufacturing and office operations

The data in Tables 1 to 4, the time taken and energy consumed by each operation and the emission factors for gas and electricity, were used to calculate the GHG emissions from each operation.

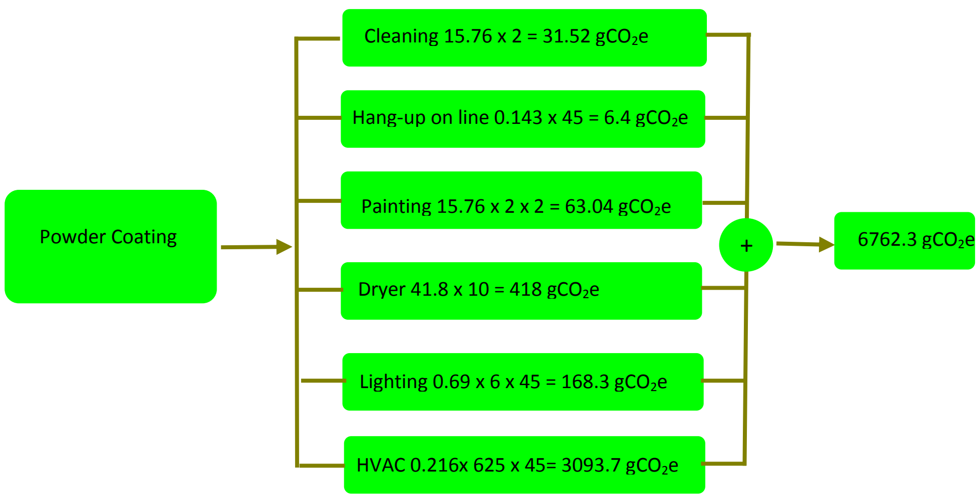
Office Work



Manufacturing



Powder Coating



Packaging

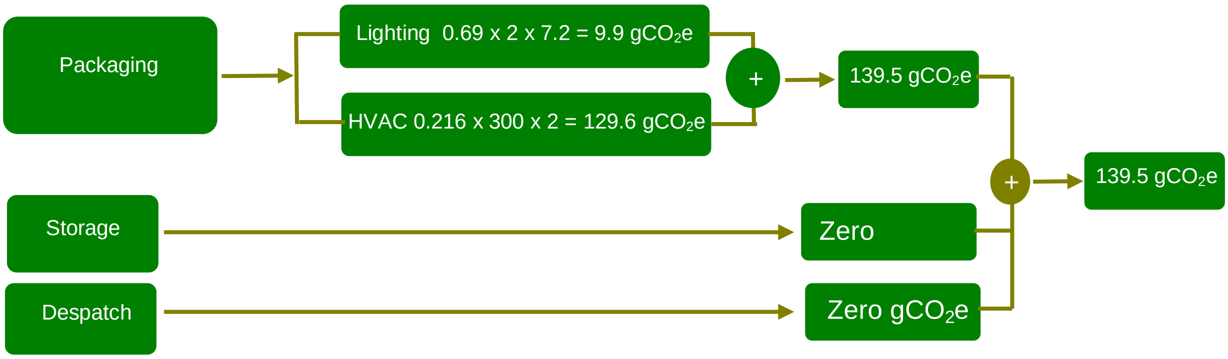


Figure 4: GHG emissions from manufacturing and service base operations

5. Calculation of CO_2e emission from transport operations

To calculate the GHG emissions a number of assumptions were made on the type of vehicles used for the delivery of raw materials to the company and their loading. It was assumed that heavy goods, fully loaded vehicles were used for delivery of raw materials whereas a transit van was used by the company for the service operations. The emission factors considered for transportation are given Table 5. The company also carries out more than one job, usually 2-3 jobs in one journey. To account for this, the job cycle illustrated in Figure 5 was considered.

It will be assumed the CO_2e emission factor for the collection of wasted metal is 2 times higher compared to the emission from metal transportation. The shelf weight is around 12 kg of steel and requires around 250 g of powder coating (assumption) and 4 m length of bubble wrapping paper required for packaging,.

Table 5: Transport vehicles and emissions

GHG emissions from transportation			
Company	**Activity**	**Vehicle used**	**Emission factor**
Bond	Transport the shelf	Diesel Transit	0.208 kgCO_2e/km [49]
Supplier A	Supply stainless steel metal sheets	Trailer 32 tonne	0.048 kgCO_2e /pallet-km
Supplier B	Supply powder Coating for shelf painting	Large rigid	0.085 kgCO_2e /pallet-km
Supplier C	Supply packaging wrapping bubble plastic paper	Large rigid	0.085 kgCO_2e /pallet-km
Waste collection	Collect the metal waste for recycling	Trailer 32 tonne	0.048 kgCO_2e /pallet-km

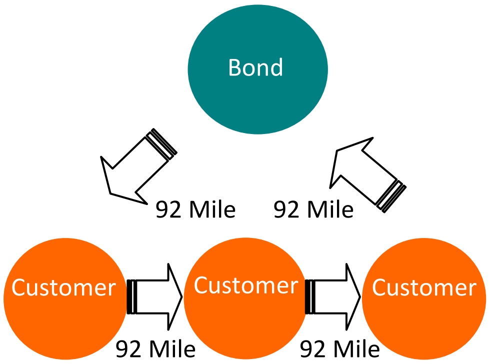


Figure 5: Route for service vehicle

Table 6: GHG Emissions from transportation

Company	Return travelled distance (Mile)	Emission ($gCO_2e/kg_{product}$)	Notes
Bond	3 jobs, total millage 376	29328 per job	Including the reduction factor
Steel	220	21	-
Powder coating	540	100	-
bubble wrapping paper	220	149 $gCO_2e/m_{product}$	-
Wasted metal	260	40	10% waste of the total shelf weight
The delivery vehicle of the company performs 3 jobs, total travels return distance 368. The three customers A, B and C are in equal distances from the company of 92 miles			

The emissions from transport operations are summarised in Figure 6.

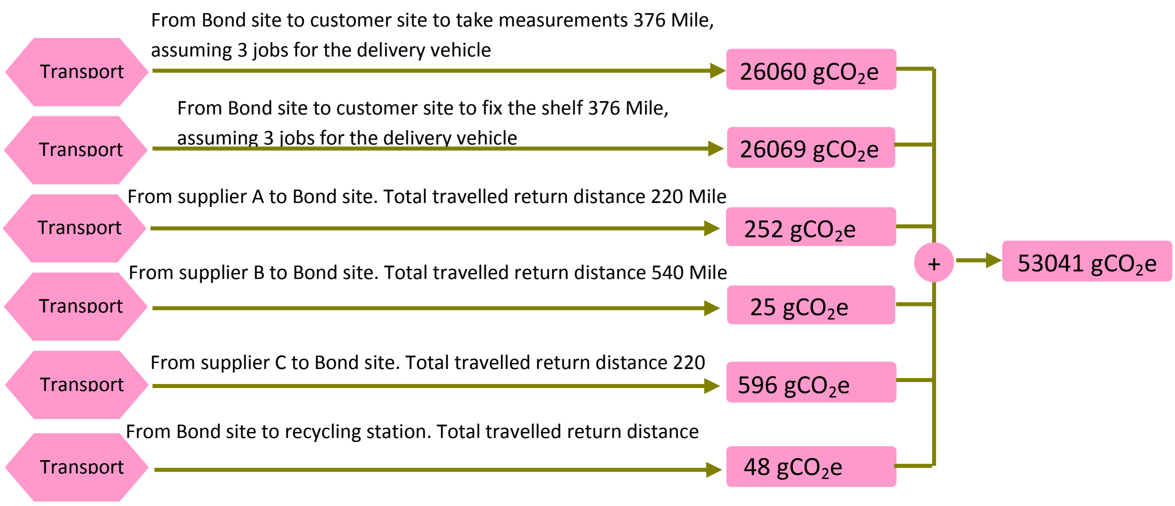


Figure 6: Emissions from transport operations

6. CO_2e Emissions from raw materials and packaging

Data in the open literature were used to determine the emissions from raw materials and packaging. It was assumed that the manufacture of 1000 kg of steel will emit approximately 850 kg CO_2e, giving and emissions factor of 0.85 kg CO_2e/kg_{steel}. Assuming the bubble wrapping paper is from LDPE, then the release emission factor for producing 1kg LDPE bubble wrapping plastic will be around 3.87 kg CO_2e/$kg_{plastic}$ (see emission factor for plastic bags earlier in this report). The emission factor for the manufacture of powder coating was taken as 2 $kgCO_2$e/kg_{powder} and recycling of one tonne of steel was assume to save 490 kg CO_2e. The emissions from raw materials and manufacturing is summarised in Figure 7.

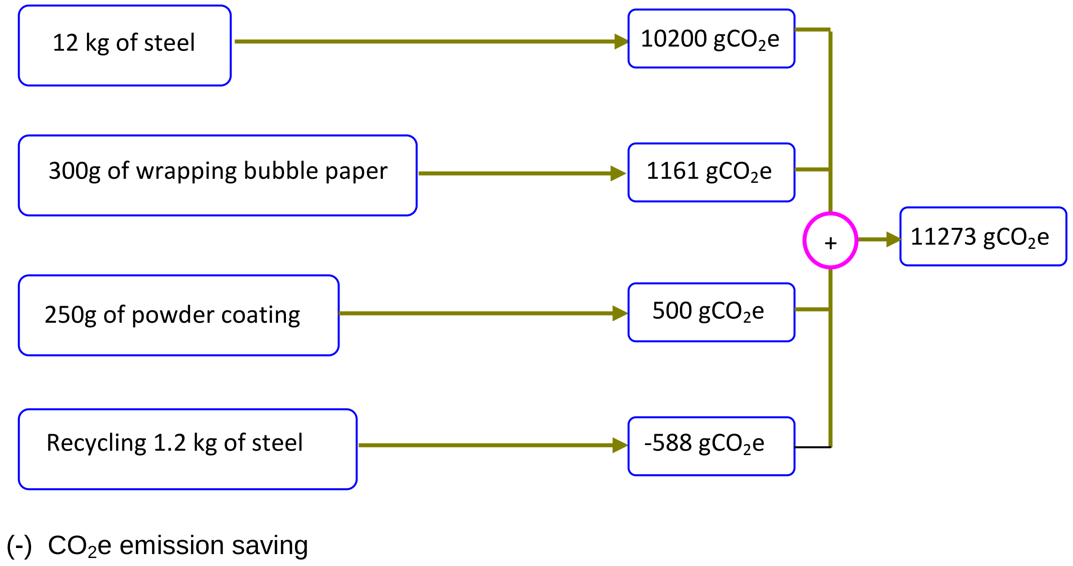


Figure 7: Emissions from raw materials and recycling

7. Discussion of results

The total CO_2e emissions from the manufacture and supply of a refrigerated display cabinet shelf of 12 kg weight as a service operation for supermarkets were determined to be approximately 76 $kgCO_2$e. The actual emissions in gCO_2e and the contribution of each element of the process is shown in Figure 8. It can be seen that despite the energy input to produce the raw materials and manufacture the shelf, transport accounts for the greatest emissions (70%). Office operations account for around 5% of the emissions and manufacturing in the factory for about 10%. The remainder 15% is from the manufacture of steel and packaging materials.

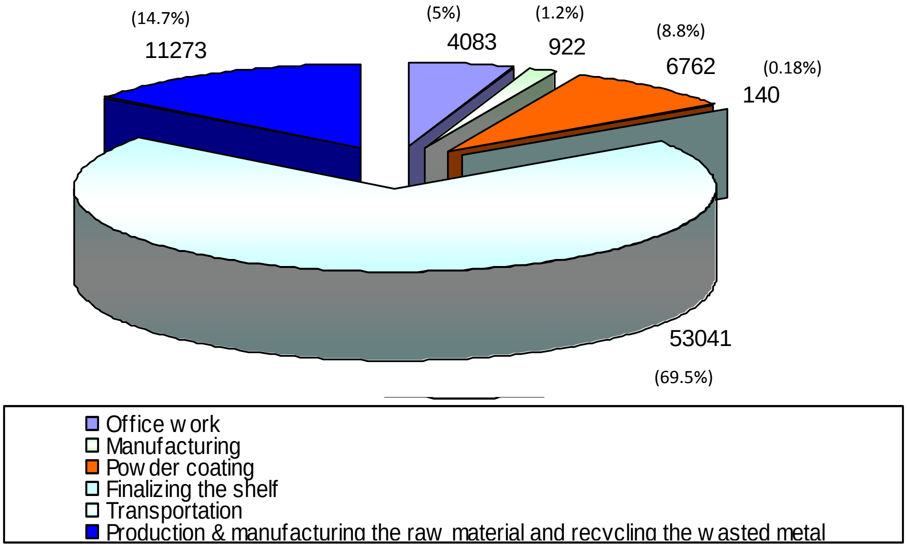


Figure 8. Summary of emissions from the manufacture and supply of a shelf for a refrigerated display cabinet

8. Conclusions for Part B

The case study carried out has shown that the PAS 2050 can be applied to services as well as goods. Explanations and guidance given in the PAS 2050 documents are sufficient for the application of the specification but experience is required for the selection of the most appropriate functional unit for the determination/specification of emissions for a service operation.

In cases where a number of different service functions/operations are provided by the same company, difficulties may arise in the apportionment of emissions to the different operations. For example, a number of different components can be transported in a single journey which may be manufactured in house, bought in and distributed, bought in and installed etc. In these cases the application of PAS 2050 becomes more difficult but not impossible.

In the case study considered in this project, emissions from transport operations were found to be the most significant, around 70%. Significant savings can be achieved by optimising the logistics of the service operations so that number of journeys are minimised or operations performed in a single journey are maximised.

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Appendix A

Designation of refrigerated display cabinets (ISO23953-1)

Application	Temperature positive		Temperature negative	
To be used for	Chilled foodstuffs		Frozen, quick frozen foodstuffs and ice cream	
Horizontal	Chilled, serve-over counter open service access	HC1	Frozen, serve-over counter open service access	HF1
	Chilled, serve-over counter with integrated storage open service access	HC2		
	Chilled, open, wall site	HC3	Frozen, open, wall site	HF3
	Chilled, open, island	HC4	Frozen, open, island	HF4
	Chilled, glass lid, wall site	HC5	Frozen, glass lid, wall site	HF5
	Chilled, glass lid, island	HC6	Frozen, glass lid, island	HF6
	Chilled, serve-over counter closed service access	HC7	Frozen, serve-over counter closed service access	HF7
	Chilled, serve-over counter with integrated storage closed service access	HC8		
Vertical	Chilled, semi-vertical	VC1	Frozen, semi-vertical	VF1
	Chilled, multi-deck	VC2	Frozen, multi-deck	VF2
	Chilled, roll-in	VC3		
	Chilled, glass door	VC4	Frozen, glass door	VF4
Combined	Chilled, open top, open bottom	YC1	Frozen, open top, open bottom	YF1
	Chilled, open top, glass lid bottom	YC2	Frozen, open top, glass lid bottom	YF2
	Chilled, glass door top, open bottom	YC3	Frozen, glass door top, open bottom	YF3
	Chilled, glass door top, glass lid bottom	YC4	Frozen, glass door top, glass lid bottom	YF4
	Multi-temperature, open top, open bottom			YM5
	Multi-temperature, open top, glass lid bottom			YM6
	Multi-temperature, glass door top, open bottom			YM7
	Multi-temperture, glass door top, glass lid bottom			YM8

R	Remote condensing unit	V	Vertical
I	Incorporated condensing unit	Y	Combined
A	Assisted service	C	Chilled
S	Self service	F	Frozen
H	Horizontal	M	Multi-temperature

General classification can be used as follows: HC1, VF1, YM5. When necessary, the classification can be more precise for example, RHC1A, IVF1S

NOTE Serve-over counters are primarily in assisted service but can be in self-service. Chilled multi-deck cabinets are primarily in self-service but can be in assisted service.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Publications arising from the project:

[1] Tassou, S.A., De-Lille, G., Ge, Y. T. (2009)., Food transport refrigeration – Approaches to reduce energy consumption and environmental impacts of road transport, Appl. Therm. Eng. 29(2009) 1467-1477, doi:10.1016/j.applthermaleng.2008.06.02.

At least two more publications will result on GHG emissions from retail food operations.