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Supermarket Energy Use in the UK

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Abstract

Recent data of energy consumption by supermarkets in the UK are presented and compared with existing benchmarks in the UK and data from other countries. It is shown that energy intensity has been reduced in large supermarkets (>750m^2) in recent years which is consistent with reductions in other countries due to installation of energy efficient technologies for all sub-systems (refrigeration, HVAC, lighting and building). Data for small supermarkets is not segregated in available databases; the presented modelling study, using a calibrated thermal model of a small supermarket, shows the interdependency of sub-systems, location and ratio of displayed products, which can inform system selection.

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1. Introduction

In the UK, energy consumption for heat and other end uses is estimated at 79.9 mtoe/year (56.8% of total) [1]. Of this 18.6 mtoe/year is used in the service sectors (13.2% of total) of which 3.33 mtoe/year is attributed to retail (2.3% of total). It remains unclear what percentage of the energy consumption is used by supermarkets alone; the energy use of large food shops is 31% of retail, while small shops (food and non-food) use 41% of retail. A similar uncertainty exists on the average energy use intensity of supermarkets, which depends on floor area size, display products (food or non-food) and energy demand for preservation and on-site preparation – hot (bakeries)/ambient/chilled/frozen. This paper first reviews and summarises available recent UK data and compares them with literature data from the UK and other countries. Data are collected through data mining of published information by supermarkets as well as specific data from two supermarket chains.

Small supermarkets (sometimes called convenience shops) have expanded in the last decade and have high energy use intensity [3]. Results on energy use by sub-system are presented as an example on how considering the building as a whole system can indicate opportunities for energy use reduction, taking into account interactions between subsystems and the building. These results are simulated by using a calibrated small supermarket model in Energy Plus [13].

Finally, the CaRB2 [17] non-domestic buildings energy model is used to investigate data that can be extracted and aggregated from the non-domestic building stock model relating to supermarkets (categorised by size) to potentially allow scale-up to regional/national level.

2. Recent data on energy use by supermarkets in the UK and internationally

UK data [2] indicate good practice annual energy consumption of 1034-1115 kWh/m^2 (based on sales floor area) depending on the fuels used and based on data from the 1990's. There is evidence that UK supermarkets have significantly improved their operational efficiency over the last 10 years. More recent data show a close dependency with size, with smaller stores having a larger energy intensity [3], while benchmarks from CIBSE [4] aspire to 505 kWh/ m^2 (based on sales floor area) for large food stores and 310 kWh/ m^2 for small food stores, the opposite of the trends shown by Tassou et al [3] and Foster et al [6]. Data after 2010 indicate 792 kWh/m^2 (based on gross floor area) based on energy bills for small size chains [5], while another study [6] reports 759 kWh/m^2 (based on sales area) for one retailer with a mean sales floor area of 3306 m^2. Foster et al [6] also presents tabulated data from a number of sources.

2.1. The UK Building Energy Efficiency Survey of non-domestic building stock

A survey of energy use in non-domestic buildings was carried out in England and Wales in 2014-15 (Building Energy Efficiency Survey (BEES)). The reports were published in 2016 [7]. The building stock is split into 10 sectors, one of which was retail. This classification included 'large food shops' as a sub-sector and 'small shops' as another sub-sector, which includes small food shops. Floor areas were recorded as gross internal area (GIA), which is measured from the internal face of each premises' wall: this is not the same as sales floor area (SFA), which is assumed to measure only usable floor area employed for sales.

The BEES average energy intensity of large food stores reported are presented in Table 1.

Table 1. Energy Intensity of large food stores [7]

Energy Intensity of large food stores	Total kWh/m^2.year	Electrical kWh/m^2.year	Non-electrical kWh/m^2.year
Average	565	403	162
Minimum	400	260	115
Maximum	740	560	250

2.2. Results presented at the International workshop on Energy Use in Food Retail

An international workshop took place in Beijing, China with some presentations and discussion focusing on international benchmarking of supermarkets. Results were presented derived from the IEA HPT Annex 44 project, SuperSmart European project [8] as well as work carried out by the authors of this paper from London South Bank University (LSBU).

Results by the IEA HPT Annex 44: Performance Indicators for energy efficient supermarket buildings [9]

The work focused on finding average values for the energy consumption of supermarket buildings, using easily available performance indicators. The objective of the work in this Annex was to provide an estimate for the energy consumption of a supermarket, based on a variable number of performance indicators. With only one performance indicator used, the energy consumption will be a first estimate, but with more performance indicators used the estimated energy consumption will be more precise. The most common performance indicators for supermarkets are size (total area or sales area), opening hours, refrigeration system type, installed refrigerating capacity and climate or geographical location. Less common performance indicators are sales volume (monetary value), year of construction (or refurbishment), management attitude and system control and dynamics.

Some findings and recommendations are:

- The study concluded that a primary performance indicator based on supermarket area provides a better estimate than indicators based on refrigerated volume(s) or installed refrigeration capacity.
- The performance indicator to best provide a first estimate of energy consumption is the yearly total energy consumption per sales area unit to be called Average Energy Intensity.
- Data sets from Denmark, Sweden, and The Netherlands indicate the current value of Average Energy Intensity to be 400 kWh/m^2.year (based on gross floor area).
- Supermarket in the sample had an average gross area of 1360 m^2 and 73 opening hours per week.
- Based on available data, corrections are proposed for: (a) size of the store (gross area), (b) opening hours per week, (c) refrigerant and refrigeration system type, (d) year of commissioning (e) optimisation of control settings
- Energy intensity decreases with increasing supermarket size (- 2 % for each 100 m^2 sales area increase)
- It was found that geographical location and sales volume do not influence the energy intensity.
- It was found that management attitude, optimisation of system dynamics, COP or SCOP values might warrant additional corrections but there was insufficient data within the sample to draw conclusions.
- Developments, especially in refrigeration systems and lighting, lead to an increase of energy efficiency in new or refurbished supermarkets ranging from 1 - 10 %. Refurbishment therefore is an effective management decision to increase energy efficiency.

Recent UK Data

Energy consumption data for 2015 were analysed for 565 supermarket stores from one retailer in the UK [6]. All of the stores considered in the analysis contained refrigerated food. Figure 1 presents the results from where it can be seen that average energy intensity increases for smaller gross and sales floor areas. The average energy intensity was 450 kWh/m^2.year (based on gross floor area). Additional recent data were analysed for one of the stores and it was found that there was a 3.3% per annum energy consumption reduction between 2013 and 2017. Over the five years there were total energy consumption reductions of 32% by lighting, 20% by refrigeration and 8% by HVAC systems.

Results by the SuperSmart European project [8]

The SuperSmart European project focuses on market uptake of energy efficient technologies in supermarkets to reduce energy use, environmental footprint and increase associated economic benefits. It has also worked in developing an EcoLabel for European supermarkets. The project has put forward guidelines on how to build a new eco-friendly supermarket [10]. The researchers consider building design, HVAC and refrigeration systems as well as non-technical barriers. They present six best practice examples, one of which was a small size supermarket (convenience store) from the UK with a sales area of 252m^2. The energy efficiency measures introduced were:

- Booster CO_2 system
- Intercooler (internal gas cooler)
- Heat recovery to water, utilized for DHW production, heating of ventilation air and over door heater

- Destratification fans

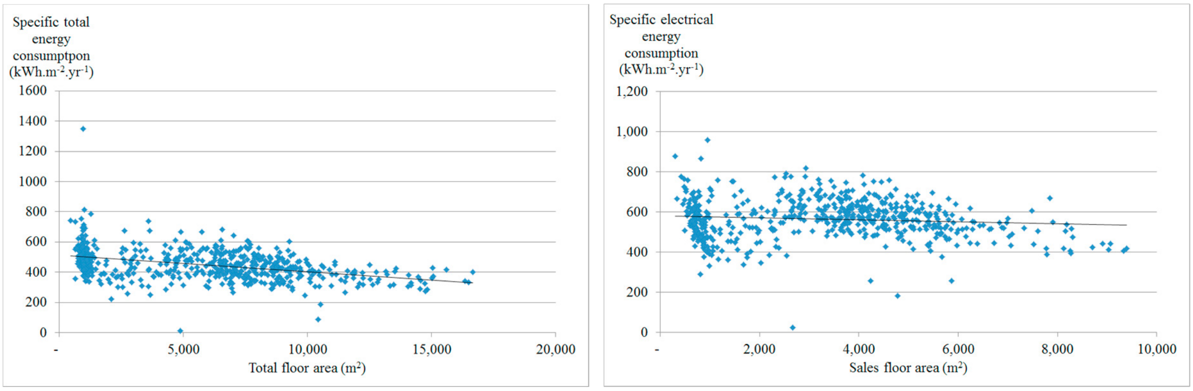

Fig. 1. Energy intensity for total floor area (left). Electrical energy intensity for sales floor area (right)

Total Energy use was reduced by 56% while refrigeration energy use was reduced by 37%. The average energy intensity for similar stores of this supermarket chain was 1039 kWh/m^2.year, which was reduced to 447 kWh/m^2.year for this store with a 14.5 months payback period.

3. Energy use of small supermarkets

In recent years there has been a shift towards new relatively small supermarkets (also termed convenience food shops), instead of out-of-town hypermarkets, which have appeared in urban areas or on main route arteries (usually combined with petrol stations). In 2014, IGD [11] estimated that spending in convenience stores will rise over the next five years but they also warned that supermarkets might have overestimated their profit potential as convenience stores are more expensive per floor area to build and operate. As presented in Section 2, analysis of supermarket energy data suggests that smaller supermarkets are more energy intensive. Some recent data from London [12] also indicate that supermarkets of around 300 m^2 sales area have an energy intensity of 840-1200 kWh/m^2/year, which is consistent with the case-study by the SuperSmart project presented in Section 2.

A calibrated small supermarket model was developed [13] within EnergyPlus, which combines thermal modelling of the building, alongside the HVAC and refrigeration systems; this was then used to evaluate the impact of the refrigeration equipment on the HVAC performance and consequently on total energy use. The baseline model has half of displayed products frozen or chilled and half in ambient temperature. Simulations were carried out for a range of refrigerated display product ratio; frozen (LT) to chilled (MT). These were simulated for three different refrigeration systems (a) the plug-in cabinets (b) R134a centralised system and (c) transcritical CO_2 booster system. All the technical information for the refrigeration systems used and details regarding their performance are analysed in [14]. Plug-in and R134a centralised systems are widely used in small supermarkets while transcritical CO_2 booster systems have promising results in the reduction of both energy use and environmental emissions [14].

The total energy use, as well as subsystem energy use, for different ratios of frozen/chilled food products and the three refrigeration systems are presented in Figures 2 and 3 [15]. Energy use for lighting and small appliances is not presented separately (as it is the same for all scenarios 147 kWh/m^2/year) but is included in the total. Figure 2(a) shows that for one ratio of frozen/chilled products, plug-in cabinets result in slightly higher total energy use, significantly higher for refrigeration but lower for the HVAC systems. This is due to reduced demand for heating because of the internal heat gains released within the store; for the same reason some cooling is required. Figure 2(a) and Figure 3 present the simulation results for various frozen/chilled food ratios. As expected, the higher the percentage of frozen food the higher the total energy use, due to the increase of the refrigeration energy use serving lower evaporating temperatures. For plug-in cabinets, this increase is higher due to the lower efficiency of the system.

Cooling energy demand increases only in the case of plug-in cabinets due to the increase of the heat released in the sales area. For the same reason the heating reduces.

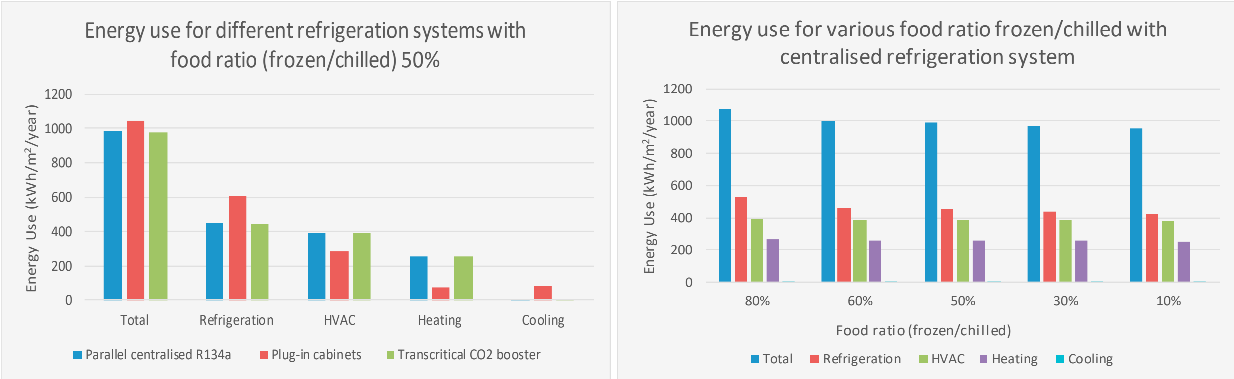

Fig. 2. (a) Energy use comparing three refrigeration systems for ratio frozen/chilled 50% (50% of all displayed products), (b) Total energy use and subsystems for various ratio of frozen/chilled with the centralised refrigeration system

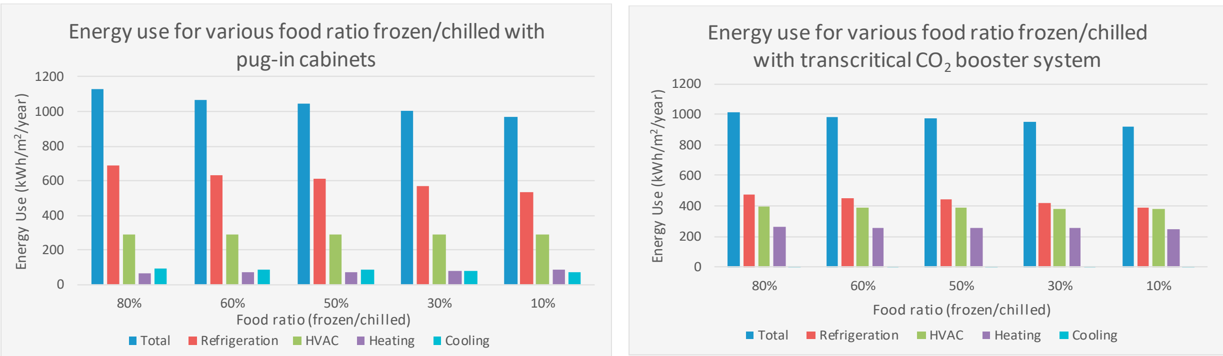

Fig. 3. Total and subsystems energy use for various ratio of frozen/chilled with (a) plug-in cabinets and (b) transcritical CO_2 refrigeration systems for various ration of frozen/chilled products.

As convenience stores are often within cities with urban heat island (UHI) present, the UHI impact was also investigated. For London, weather files have been developed [16] to include the UHI effect when simulating energy demand; the central London weather files together with a Heathrow weather files were used to carry out simulations for the three refrigeration systems and different ratios of frozen and chilled food.

Figure 4 presents the percentage change of the total and refrigeration annual energy use for different refrigeration loads in comparison to simulation results using Heathrow Test Reference Year (TRY) weather file. Positive change indicates reduction in energy use while negative change indicates increase. Overall there is a reduction in the total energy use for every refrigeration system and load (MT, LT or mixed refrigerated food). However, an increase is observed in the refrigeration energy use; efficiency of the centralised refrigeration systems is affected more by the higher ambient temperatures, while (as expected) the increase is smaller for the plugged-in cabinets. Regarding changes in the heating/cooling requirements (Figure 4), an increase is observed in cooling energy use for central London locations for the whole load range with higher increase for the plugged-in cabinets. On the contrary, heating energy use which is dominant in stores with centralised systems, reduces for all refrigeration systems, and is more pronounced for centralised systems. This leads to a net reduction in the HVAC annual energy use for centralised systems while it is unaffected for plugged-in cabinets as increased cooling balances with heating reduction.

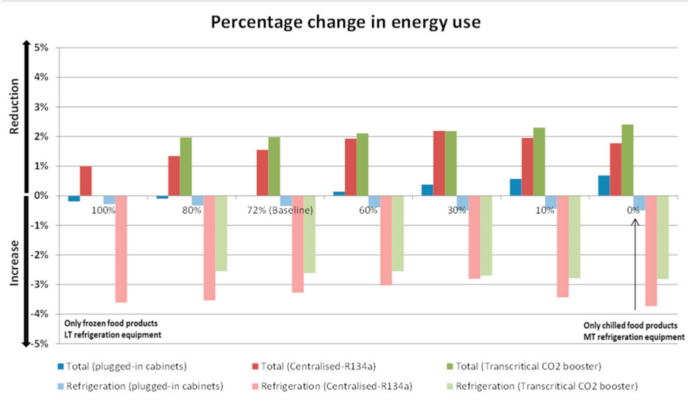

Fig. 4 Percentage change in total and refrigeration annual energy use per unit sales area in central London for different refrigeration systems and loads in comparison with a typical weather file site (Heathrow) [16]

4. Applying the analyses to England and Wales

In England and Wales, the Valuation Office Agency (VOA) is responsible for collecting data on 'hereditaments', which are basically the same as 'premises', for property taxation purposes. However, premises can be one building, part(s) of a building, or multiple buildings (or even just land), but premises do tend to align with what might be thought of as an operational unit in terms of energy use and its management. Extrapolating the results of this study across all supermarkets in England & Wales is problematic due to the manner in which the VOA classifies premises. The principal problem is that many supermarkets occupy premises that are not specifically identified as 'Food Stores' or 'Large Food Stores', as the premises can easily be altered from one use to another. Table 2 shows an analysis of VOA data for October 2015, using the CaRB2 activity classifications [17, Table S1). These data appear to be undercounting the number of supermarkets and smaller food stores, when compared to company data such as [18]. On this basis, a number of supermarkets and convenience stores must be recorded under the columns headed 'Non-Food Stores', but the exact proportion cannot currently be known. A further difficulty with the VOA data is that many shops larger than 750m^2 do not have their gross floor area subdivided to identify sales floor area, such that EUI can only be applied to the premises' gross area, whereas small premises tend to have records of sub-activities such as sales floor areas, offices, storage etc.

Table 2: Counts and areas of relevant shops (stores) within Valuation Office Agency data for 2015, in England & Wales. Aggregate areas have been adjusted to gross internal area (GIA). The upper part of the table shows stores >750m^2, the lower part <750m^2. The right side of the table indicates shop premises that are not specifically identified as relating to the retailing of food.

Measured area >750m^2	Food Store (shop)	Hypermarket/ superstore (over 2500 m^2)	Large Food Store (750 - 2500m^2)	Large Shop (750 - 1850m^2)	Large shop (over 1850 m^2)	Retail warehouse	Shop
Count	51	2,160	2,359	421	2,031	5,784	4,740
Total area (m^2 GIA)	58,043	13,526,145	3,297,639	540,972	9,444,512	12,446,831	6,174,252
Mean area (m^2 GIA)	1,138	6,262	1,398	1,285	4,650	2,152	1,303
Measured area <750m^2							
Count	1,183	2	92	15	8	3,395	423,597
Total area (m^2 GIA)	442,690	667	57,870	9,892	1,639	1,548,615	51,769,974
Mean area (m^2 GIA)	374	334	629	659	205	456	122

Table 2 indicates that the number of recorded 'Food Stores' >750m^2 is small, which is probably due to non-classification as this type, by the VOA, as the above analysis is based on the recorded floor area. However, even the number of premises <750m^2 seems extremely low, suggesting that many small convenience stores are categorised as generic 'Shops', thus hiding their true function. Table 3 shows a comparison of the EUIs from the current research sample and the BEIS BEES analyses. Based on this current research's analysis of 593 food stores, of which 446 were >750m^2 (recorded as 'store gross surface' and assumed here to be GIA), there is a significant decrease in the electricity and gas consumption of large food stores. Average total energy use is 21.3% lower than the BEES results for Large Food Stores (>750m^2), whilst gas consumption is 29% lower and electricity consumption 18.3% lower. Multiplying the mean EUIs of Table 3 by the floor areas for all food stores >750m^2 in the VOA data (Table 2) and applying the BEIS CO_2 conversion factors [19], there is a decrease in CO_2e emissions of approximately 580,000 tonnes per year, as shown in the bottom row of Table 3..

Table 3: Energy use intensities (kWh/m^2.yr) for Food Stores and Large Food Stores calculated from a sample of 593 (EUIs greater than mean + 3 standard deviations in the original 609 samples are omitted), compared to the BEES analysis. Values in parentheses indicate the sample size. Also shown are the carbon dioxide equivalent (CO_2e) emissions related to mean EUIs and the floor areas given in Table 2.

	Current sample of 593 Food Stores						BEIS BEES Large Food Stores (>750m^2)		
	Food Stores <750m^2			Food Stores >750m^2					
	Total (147)	Electricity (147)	Gas (37)	Total (446)	Electricity (446)	Gas (405)	Total	Electricity	Non-electricity
Minimum	209	209	0	83	83	0			
Lower Quartile	417	401	22	368	291	77	483	322	138
Median	512	485	52	431	321	111	581	387	180
Upper Quartile	604	577	171	518	366	152	629	454	217
Maximum	950	921	371	914	646	268			
Mean	524	499	102	444	329	115	565	403	162
CO_2e (tonnes/yr)	97261	87889	9373	2311303	1953585	357718	2895446	2391795	503651

Further analysis shows that in the sample stores <280m^2 (the area above which opening hours are restricted, on Sundays and Bank Holidays, in England and Wales), the mean electrical EUI increases to 511 kWh/m^2.yr, with a gas EUI of only 85, compared to 329 and 115 respectively for stores >750m^2. This increase in the electrical EUI in smaller stores is likely to be the consequence of their extended opening hours and a greater proportion of their floor area being used for the display of refrigerated foods, compared to the much larger stores, where more non-foods are displayed. On the theme of comparisons, it is also important to note the various floor area measurement conventions used in benchmarks. Defined processes for the measurement of areas are critical as differences/errors in area measurements affect a benchmark values just as such differences/errors in energy use also affect benchmarks

4. Conclusions

Recent data from supermarkets in the UK indicate reduction in energy use. This is attributed to a range of energy efficient installations targeting the sub-systems of refrigeration, lighting, HVAC and building envelope design. Aggregated data indicate energy intensity of 565 kWh/m^2/year for large supermarkets; this could be as low as 400 kWh/m^2/year. Analysis of data of individual chains and stores indicates similar tendencies with further reductions during the last 3-4 years.

Small supermarkets (which are more energy intensive) were modelled as a case-study, showing that the choice of refrigeration system has an impact on the energy consumed by other sub-systems, which could inform the choice of fuel used for heating in relation to costs. The ratio of refrigerated/chilled/ambient temperature products and the location of the supermarket (urban/rural) impacts on energy use depending on the refrigeration system.

In conclusion, the sample of supermarkets >750m^2 examined in this paper demonstrates lower electrical and gas use intensities than those in the BEIS BEES sample, suggesting that energy use in the supermarket sector is reducing, assuming that both the BEES and current sample premises are representative of the stock. However, with a growing trend toward supermarket chains also operating smaller convenience stores (<280m^2), it seems likely that the higher energy intensity of these stores may offset the energy improvements made by the retailers.

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