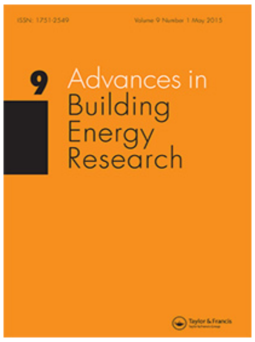

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Energy aspects and ventilation of food retail buildings

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Worldwide the food system is responsible for 33% of greenhouse gas emissions. It is estimated that by 2050, the total food production should be 70% more than current food production levels. In the UK, food chain is responsible for around 18% of final energy use and 20% of GHG emissions. Estimates indicate that energy savings of the order of 50% are achievable in food chains by appropriate technology changes in food production, processing, packaging, transportation, and consumption. Ventilation and infiltration account for a significant percentage of the energy use in food retail (supermarkets) and catering facilities such as restaurants and drink outlets. In addition, environmental conditions to maintain indoor air quality and comfort for the users with minimum energy use for such buildings are of primary importance for the business owners and designers. In particular, supermarkets and restaurants present design and operational challenges because the heating ventilation and air-conditioning system has some unique and diverse conditions that it must handle. This paper presents current information on energy use in food retail and catering facilities and continues by focusing on the role of ventilation strategies in food retail supermarkets. It presents the results of current studies in the UK where operational low carbon supermarkets are predicted to save 66% of CO_2 emissions compared to a base case store. It shows that low energy ventilation strategies ranging from improved envelope air-tightness, natural ventilation components, reduction of specific fan power, ventilative cooling, novel refrigeration systems using CO_2 combined with ventilation heat recovery and storage with phase change materials can lead to significant savings with attractive investment return.

Keywords: energy use; food chain; ventilation; supermarkets; heat recovery; refrigeration; UK

1. Introduction

The food chain comprises agricultural production, manufacturing, distribution, retail, consumption and waste disposal. In Europe, there were just over 48 million people employed within the EU–27's food chain in 2008; this equated to more than one in five of the EU's total workforce. The food chain was made up of close to 17 million different holdings/enterprises and generated EUR 751 billion of added value, equivalent to just under 6% of the EU-27's GDP (Eurostat, 2011). In 2010, the food and tobacco industry sector accounted for almost 10% share of the total-energy consumed by the EU-27 industry (29 Mtoe vs. 292 Mtoe total), (Eurostat, 2012).

In the UK alone, it is estimated that the food chain is responsible for 195 $MtCO_2e$ emissions from domestic food chain activity in 2010, of which 118 $MtCO_2e$ are from UK food chain activity and the remainder from food imports; retail and catering account for 7.7 Mtoe/year or 18 $MtCO_2e$ emissions. Figure 1 shows these statistics diagrammatically. The food chain is also responsible for

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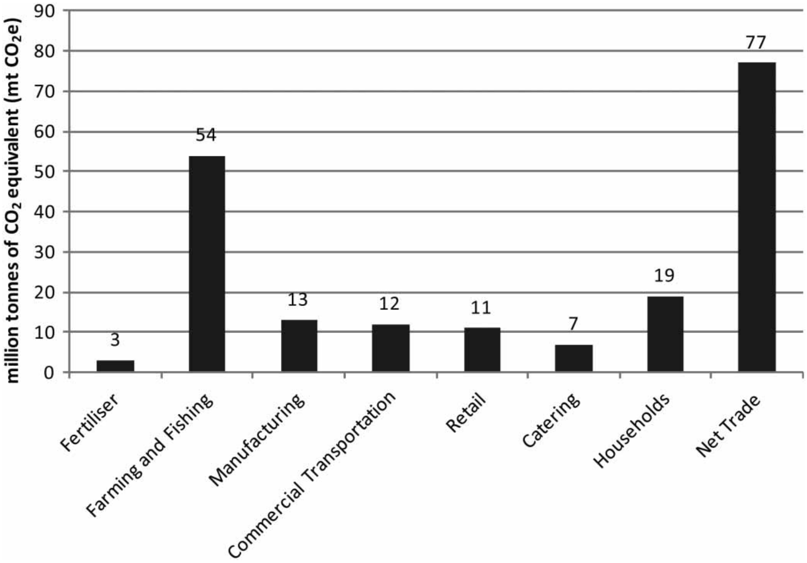

Figure 1. GHG emission from the UK food chain (reproduced from Defra, 2012, p. 43).

15 Mt of food waste, with households generating 7.2 Mt/year and 3.2 Mt/year from manufacturing. It should be noted that changing diet patterns and food imports have an impact on carbon emissions. Garnett (2011) suggests that although technological advancements will have significant importance in reducing the greenhouse gas (GHG) emissions of the food chain, shifts in pattern – especially the lower consumption of rich GHG-intensive products such as meat and dairy products – will also be necessary. The impact of food imports is product dependent; for example, imported fruits tend to have higher embedded energy values compared to domestically produced fruit (Lillywhite, Sarrouy, Davidson, May, & Plackett, 2013), but the relative benefits over the whole chain are product-specific. It should also be mentioned that according to Eurostat data in 2011, the UK had the 'largest food and beverage retail workforce and food services workforce among the EU Member States' (Martinez-Palou & Rohner-Thielen, 2011). In terms of the economic activity, the agri-food sector contributed £96.1 billion or 7.3% to national Gross Value Added in 2011, an increase of 7.8% in 2010 and employed 3.3 million people in the third quarter of 2012 (13% of Great Britain employment) (Defra, 2012).

This paper focuses on the UK but in terms of giving a wider context, a study in the US estimating changes in energy flows is referred to here (Canning, Charles, Huang, Polenske, & Waters, 2010); it shows that the food-related share of the national energy budget was at 15.7% for 2007 based on 2002 data. The authors note that this estimate does not account for any technology changes, including energy technologies that may have occurred after 2002. The study indicates that the food-related aggregated energy flow rose by 12.7% compared to 3.8% for the total-energy flow, relative to 2002.

The statistics quoted above indicate that energy use in the food chain is a significant proportion of the total-energy use and estimates indicate that fossil energy savings of the order of 50% are achievable in food chains by appropriate technology changes in food production, processing, packaging, transportation, and consumption (Pimentel et al., 2008). In recent years, progress has been made in the reduction of energy consumption and emissions from the food chain primarily through the application of well-proven technologies, such as heat pumps (Seck, Guerassimoff, & Maizi, 2013), that could lead to quick return on investment. To make further progress, however, significant innovations will have to be made in approaches and technologies at all stages of the food chain, taking a holistic view of the chain and the interactions both within the chain and the external environment.

This paper focuses on the retail (supermarkets) part of the food chain. Through a literature review and a UK focus, it aims to show how low energy ventilation technologies can be used in food retail buildings in order to reduce their energy use. Section 2 presents some energy use statistics for both food retail and catering buildings whilst Section 3 focusses on the energy requirements of supermarkets. Section 4 presents examples of low carbon supermarkets in the UK and their ventilation features with separate sections on building design and refrigeration plant.

2. Energy use in food retail and catering

Recent statistics of energy use in the UK indicate that 42 MWh (20% of the total-energy use in 2011) are used by general retail buildings and 25 MWh (almost 12% of the total-energy use by non-domestic buildings) are used by hotel and catering buildings (Figure 2). Of this in the retail sector, 13% is for catering and 8% is for ventilation and cooling (Figure 3). In the hotel and catering sector, 26% is for catering and 5% for ventilation and cooling. Ventilation also has an impact on the energy use of heating (more than 30% of total) and lighting in many cases (33% of total in retail and 14% in hotel and catering) (DECC, 2013).

In addition, energy for cooking and refrigeration in the domestic sector is a sizeable percentage of the energy use. Cooking accounts for 5% of energy use in the home for a group of 19 IEA countries (IEA19), a number similar to energy use for lighting. The International Energy Agency (IEA, 2008) also notes that appliance energy use (mostly electricity) is growing very rapidly and has overtaken water heating as the second most important household energy demand; in 2005 home appliances used 21% of households energy (Figure 4(a)). In EU15, the diffusion of energy-efficient large appliances such as refrigerators and freezers is improving but is still a large percentage of the appliance energy use in households (IEA, 2008). Figure 4 shows that despite the improvement in the energy efficiency of large appliances (cookers, refrigerators, and freezers), the energy use of appliances is increasing due to an increase in the number of small equipments. It is also important to note that as the building fabric of dwellings becomes

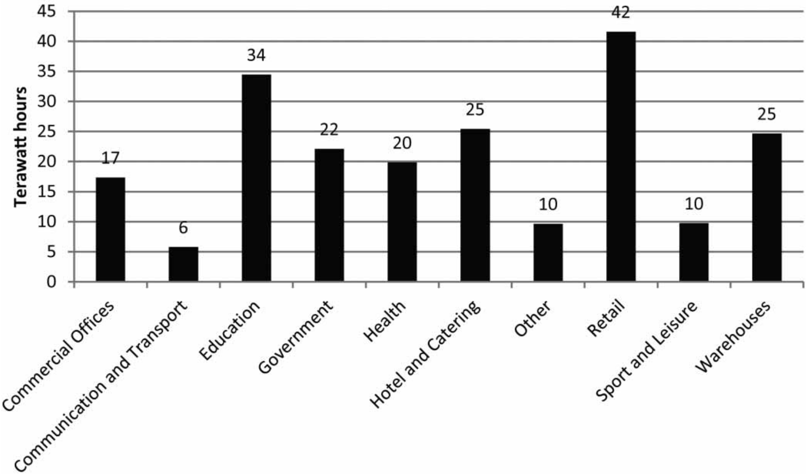

Figure 2. Final energy consumption in the service sector in the UK by sub-sector and end use 2012 (DECC, 2013, Table 5.09).

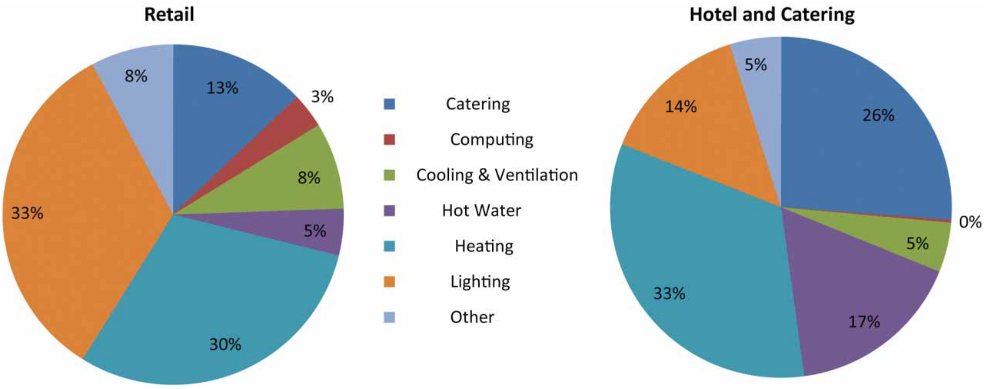

Figure 3. Final energy consumption in 'retail' and 'hotel & catering' in the UK by end use in 2012 (DECC, 2013, Table 5.09).

more energy efficient, space conditioning needs will reduce, thus rendering other end uses, such as cooking, much more important components of energy use and, as a result, there will be a shift of focus of energy-saving strategies towards these appliances.

In the light of the above statistics, this project will investigate energy use reduction technologies, starting with food retail buildings in the UK which are the focus of the remainder of this paper.

3. Energy requirements of supermarkets

There is evidence that UK supermarkets have significantly improved their operational efficiency over the period 2000–2010. Figure 5 presents (Sullivan & Gouldson, 2013) the total GHG emissions relative to the 2007 baseline of six supermarket chains; it can be seen that the majority have improved emissions; one of the supermarket chains reports increased emissions and this is mainly due to the expansion of operations outside the UK; its UK emissions were reduced by 5%. Sullivan and Gouldson (2013) suggest that this reduction stems from increased emphasis of these companies' sustainability strategies on climate change considerations since the mid-2000s as reflected in corporate responsibility reports with specific commitments to reduce operational emissions. A recent report (British Retail Consortium, 2014) suggests that progress since the mid-2000s is due to improvements in:

(a) retail operations by improving energy monitoring and control systems; developing investment models to support corporate energy demand reduction strategies; and improving the operational efficiency through placing doors on fridges and chillers and implementing auto-defrost processes to tackle waste energy consumption;
(b) energy use in buildings by deployment of energy-efficient technologies such as light-emitting diode (LED) lighting; trialling new and innovative technologies in refrigeration, heating, and ventilation equipment; and increasing the use of renewable energy on sites such as biomass boilers, solar power, and wind turbines;
(c) transport by increasing the use of alternative fuels in fleets, such as bio-diesel and fuels from waste; and developing better route optimisation models and increasing delivery efficiency; and
(d) staff training and behaviour change in energy use and efficient driving techniques were introduced.

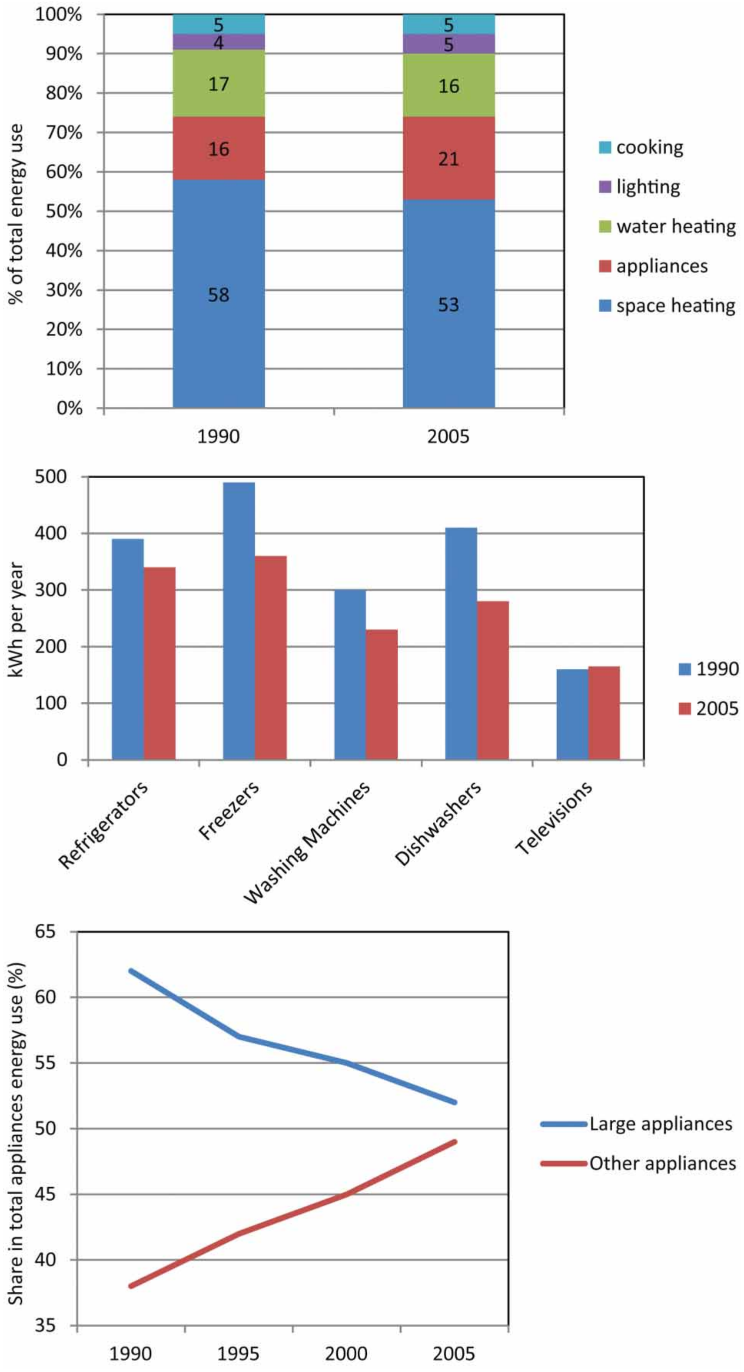

Figure 4. Household energy use by end use and appliances (a) IEA19, (b) EU15, and (c) the share of large and small appliances in EU15.
Source: IEA (2008).

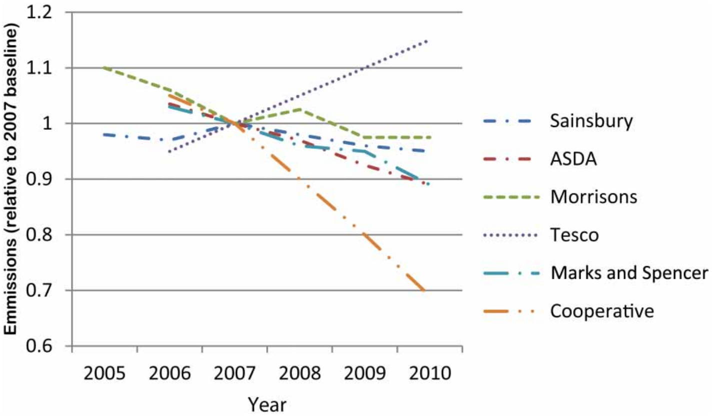

Figure 5. Total GHG emissions from UK retailers (2005–2010).
Source: Sullivan and Couldson (2013).

Supermarkets have supported research which will be useful for improving energy efficiency in their stores and statistical models have been recently developed to assist this. For example, Mavromatidis, Acha, and Shah (2013) describe a model based on artificial neural networks that can be used as a diagnostic tool in a specific store, and Spyrou, Shanks, Cook, Pitcher, and Lee (2014) present a regression model for the prediction of energy use in a number of supermarkets based on a few measureable parameters such as floor sales area, food: non-food ratio, volume of sales, year of construction, ceiling height, number of floors, and the existence or not of combined heat and power plant (CHP). Such models are by nature restrictive and static in their applicability, and depend on the original data which informed their development. Nevertheless, these simplistic tools are very useful to specific supermarket chains as they allow a quick evaluation of the energy performance of individual stores compared to the supermarket chain's mean energy values. They do, however, require regular updating to account for technological and policy changes.

Despite recent improvements in energy efficiency, *retail food stores* are large consumers of energy. Food retailing in the UK is responsible for around 12.0 TWh and around 3% of the total electrical energy consumption (Tassou, Ge, Hadawey, & Marriott, 2011). Estimates for GHG emissions from food retail operations vary between 6 and 9.5 MtCO2e (Stanford, 2010). Retail food stores are a part of the commercial sector of buildings which account for 7% of the total delivered energy consumption worldwide, with an expected yearly increase of 1.5% up to 2035 (IEA, 2011). It remains unclear what percentage of the energy consumption is covered by supermarkets alone, since very few studies make a distinction between building types in the non-domestic or commercial sector. In the USA, the average energy use intensity of supermarkets is 631 kWh/m^2 per year (Energy Information Administration, 2003 cited in Pérez-Lombard, Ortiz, and Pout (2008)). The corresponding figure for the UK varies between 700 kWh/m^2 per year for hypermarkets and 2000 kWh/m^2 per year for convenience stores (Tassou et al., 2011). Current UK benchmarks (CIBSE, 2012) indicate 261 kWh/sales floor area of natural gas and 1026 kWh/sales floor area of electricity for typical supermarkets. The energy use has been normalised per floor area of the supermarket building used for sales; this is done so that comparisons reflect the energy use that is normalised for the main business (sales) and excluding 'auxiliary' areas such as offices, storage, customers' facilities, etc. In these benchmarks the height of the building is not included which could vary between supermarkets; it is suggested that energy

Table 1. Food retail shops' classification according to their floor area (Defra, 2006; IGD, 2013).

Category	Floor area
Convenience store – usually in a dense urban location, sometimes part of a building	<280 m^2
Supermarket – usually in an urban location, part of another building or a stand-alone building	280–1400 m^2
Superstore – usually in a suburban location, mostly a stand-alone building	1400–5000 m^2
Hypermarket – usually in an out-of-town shopping area; often with no food items included	>5000 m^2

use is also normalised per building volume to take this into account. It should also be noted that Energy Performance in Buildings Directive recast calls for the display of energy performance certificates of buildings such as supermarkets and restaurants (Directive 2010/31/UE, 2010, paragraph 24 and article 13).

The energy use in supermarkets will depend on business practices, store format, product mix, shopping activity, the equipment used for in-store food preparation, preservation, and display. This can be reflected in a current classification according to their location/function and sales floor area that are described in Table 1 [Defra, 2006; IGD, 2013]. Energy use varies but current benchmarks do not reflect this. Research has been carried out for individual categories and Figure 6 shows diagrammatically the energy use by various parts in a hypermarket. In general, the refrigeration systems account for between 30% and 60% of the electricity used (taking into consideration smaller stores), whereas lighting accounts for between 15% and 25% with the heating ventilation and air-conditioning (HVAC) equipment and other utilities such as bakery, for the remainder. Gas is normally used for space heating, domestic hot water and in some cases for cooking and baking and can be as high as 250 kWh/m^2 per year in hypermarkets.

Therefore, significant energy savings can be achieved by improving the efficiency of refrigeration systems, refrigeration and HVAC system integration, heat recovery and amplification using heat pumps, demand side management, system diagnostics and local combined heat and power generation and trigeneration. Energy-saving opportunities also exist from the use of low energy lighting systems, improvements in the building fabric, integration of renewable energy sources, and

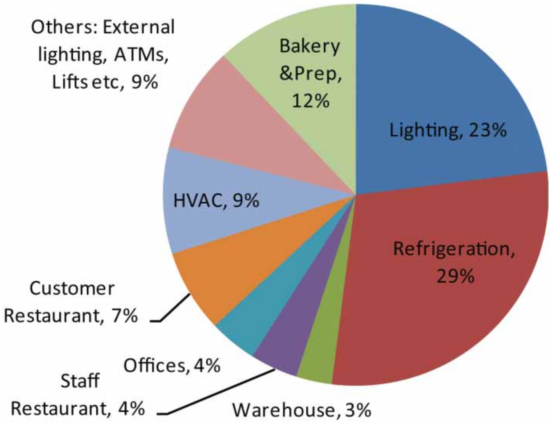

Figure 6. Percentage contribution of electrical energy use processes in a hypermarket.
Source: Tassou et al. (2011).

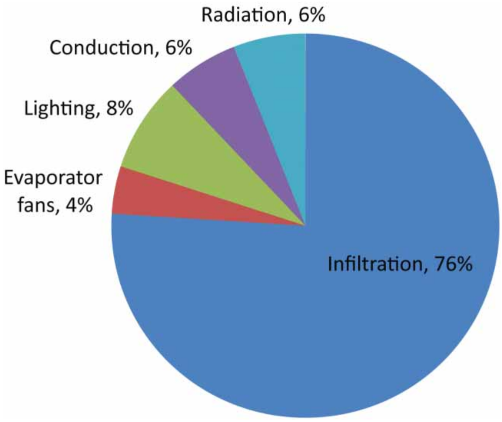

Figure 7. Contributions to the energy load of a vertical multi-deck open front chilled food display cabinet. (Tassou et al., 2011).

thermal energy storage (Carbon Trust, 2010; Tassou et al., 2011). Another area that provides significant opportunities for energy savings is the design of more efficient refrigerated display fixtures. Figure 7 shows the contribution to the energy load of a vertical multi-deck open form chilled food display cabinet. As indicated, infiltration accounts for more than 75% of the energy load which has led to proposed and implemented solutions on how to minimise it (Tassou et al., 2011).

4. Examples of low carbon supermarkets in the UK and ventilation features

A study carried out in 2010 investigated the potential for a zero energy store (Hill, Courtney, & Levermore, 2010) based on available data from supermarkers and thermal modelling. It suggests that:

- Refrigeration accounts for 40–50% of electricity consumption, with lighting and store heating/cooling systems accounting for most of the remainder.
- The need to heat or cool air introduced for ventilation purposes may account for around twice as much energy consumption as the heat lost or gained through conduction across the walls, roof, and floor of the store.

Therefore, ventilation is an area where further energy efficiency improvements are possible and natural ventilation systems have started being introduced in UK stores in many cases linked with natural lighting systems.

Envelope infiltration: In the UK, air-tightness tests are mandatory for buildings with a floor area of more than 1000 m^2 and should be less than a maximum (or limiting) air permeability of 10 m^3 h^{-1} m^{-2} at a test pressure differential of 50 Pa (ATTMA, 2010, Part, 2013). In general, the envelope area of the building is the total area of all floors, walls, and ceilings bordering the internal volume subject to the test. Overall internal dimensions are used to calculate this area. The limiting air permeability is the worst allowable air permeability. The design air permeability is the value used in establishing the building emission rate (expressed as $kgCO_2/(m^2$ year)), and is based on a specific measurement of the building concerned. Therefore, air-tightness of the supermarket envelope is regulated under the energy efficiency building regulations and in many cases 5.0 m^3 h^{-1} m^{-2} at 50 Pa is the desirable design value for low carbon supermarkets.

Ventilation strategies can be divided to those (a) integrated with other low carbon design strategies for the building and (b) integrated with the equipment of the supermarket.

4.1. *Low carbon design and ventilation*

There are examples of low carbon supermarkets and guidelines on how to achieve such buildings. Two reports sponsored by leading UK supermarket chains have been published in the last few years (Hill et al., 2010; Target Zero, 2011). In both reports, a base case supermarket was created based on the operational details of an existing store and energy efficiency measures were investigated, including renewables. In this paper, only the energy efficiency improvements are reviewed.

The results of the (Target Zero, 2011) study are shown in Table 2; the energy efficiency improvements introduced were divided into three packages, each with increased energy savings. Table 2 shows that all three energy efficiency packages are predicted to save money. Package B which includes ventilation features such as reduction of specific fan power and ventilation heat recovery has a lower net-present value (NPV) than Package A and therefore is more attractive. For package C which includes additionally highly improved air-tightness at 5 m^3 h^{-1} m^{-2} at 50 Pa, despite the greater reduction in carbon emissions, its economic performance is less attractive.

(Hill et al., 2010) report has summarised low energy design initiatives as:

- Enhanced utilisation of daylight.
- A combination of natural and mechanical ventilation, with heat exchange.
- Improved refrigeration cabinets, with doors on frozen food cabinets.
- Improved control over lighting and ventilation, and acceptance of a wider range of internal temperatures.
- LED display lighting.
- Renewable energy sources, such as biomass or wind power.

The overall effect of these measures is typically to reduce energy consumption to around 400 kWh/m^2, with the proportional reduction in energy use for lighting and refrigeration being slightly higher than for heating and cooling. This sets a baseline for considering future reductions in energy use and emissions.

The same report (Hill et al., 2010) has identified a number of low carbon supermarkets and in particular an exemplar low carbon supermarket was constructed by one of the leading supermarket chains in the UK which has been monitored and studied by a number of research teams in the UK (Hill et al., 2010). The low carbon features of this supermarket are presented in Table 3.

A parametric simulation analysis was carried out using this supermarket as a case study (Charalambous, 2013) by changing envelope characteristics such as air-tightness, heat transfer, and roof lights. The simulation results (using IESVE) were calibrated with operational energy data of the store; the predicted energy use was 718 kWh/m^2 of the sales area with a break down for end-use consumption of 101 kWh/m^2 for lighting, 21 kWh/m^2 for cooling, 269 kWh/m^2 for heating, 227 kWh/m^2 for refrigeration, and 100 kWh/m^2 for auxiliary and equipment. Some simulations were carried out using a future weather file for 2050 to investigate the effect of the proposed measures in the future. We chose to carry out simulations for 2050 rather than 2020 because they focus on characteristics of the envelope of the building (air-tightness, *U*-values, and roof lights) which are not easily changed once the building is constructed; so long-term evaluation of the performance is relevant. The weather file used for 2050 has been created (Prometheous project, 2010) according to UKCP09 (Met Office, UK, 2013) predictions for the high emission scenario (A1F1); the TRY

Table 2. Energy efficiency measures for zero-carbon stores.

Option	Energy efficiency measures	Total operational CO_2 emissions ($kgCO_2$/yr) [change from base case total emissions]	Change in capital cost from base case building (%)	Change in 25-year NPV from base case building (£)
Base case building	–	6,99,289	–	–
Package A	Composite internal floor High efficiency lamps and luminaires Specific fan power reduced by 20% Motion sensing control throughout Improved chiller efficiency SEER = 6 Improved boiler efficiency to 95% Building oriented so that glazed façade faces south	5,08,196 (−27%)	(−0.36%)	−9,73,545
	Package A plus (or superseded by):	4,19,895		−1,053,332
Package B	Very high efficiency lamps and luminaires Specific fan power reduced by 30% Roof lights 10% with daylight dimming Improved chiller efficiency SEER = 7 Ventilation heat recovery (60% efficient) Improved air-tightness 7 m^3/h per m^2 at 50 Pa	(−51%)	(0.90%)	
	Package B plus (or superseded by):	3,79,548		−4,95,153
Package C	Specific fan power reduced by 40% Roof lights 15% with daylight dimming Improved chiller efficiency SEER = 8 Highly improved air-tightness 5 m^3/h per m^2 at 50 Pa Active chilled beam/radiant ceiling Advanced thermal bridging (0.013 W/m^2 K) Improved wall U-value to 0.25 W/m2 K	(−46%)	(5.1%)	

Source: Target Zero (2011, p. 21).

Table 3. Emission reduction measures for zero-carbon stores (Hill et al., 2010, p. 22)

Envelope/glazing	Nanogel sandwich skylights 1200 mm clerestory glazing
Lighting	900 Lux instead of 1200 lux DALI control system – individually addressable fittings LED lighting in display cabinets
Ventilation/cooling	Windcatchers roof vents Control by CO_2 concentration
Refrigeration	Doors on freezer cabinets Anti-sweat coatings CO_2 refrigerant
Energy supply	CHP system powered by biofuel derived from wastes Micro-wind turbine
Forecast energy savings	50% energy use reduction compared with the base case (2006 regulations store) 66% emissions reduction

weather file for Manchester was used for the current year simulations, and the UKCP09, A1FI, 50th percentile for Manchester was used for 2050.

The results are shown in Figures 8–11. Figure 8 shows the energy use predictions using current and 2050 weather files for different levels of external envelope air-tightness. The value used was 1 ACH (which is just below the UK limiting value of 10 m^3/h per m^2 of the external building envelope). The values of 7, 3, and 1 m^3/h per m^2 were used for the simulations. As expected, increased air-tightness results in a reduction in the total-energy use in all cases. However, it is also shown that improvement beyond 3 m^3/h per m^2 yields diminishing results. It also shows that although the energy demand for heating is reduced in all cases, electricity demand increases due to lower heat losses through the envelope increasing the cooling demand in the summer. However, this increase could be overcome by carefully controlling the building using ventilative cooling.

Figure 9 shows the energy use predictions using current and 2050 weather files for different levels of insulation of the external envelope of the building (walls, roof, and glazing, including roof lights). The simulations included three scenarios (a) the building as is (walls and roof: 0.27 W/m^2K and glazing 1.95 W/m^2K), (b) improved insulation to current building regulations (walls and roof: 0.15 W/m^2K and glazing 1.2 W/m^2K), and (c) further improvement to insulation (walls and roof: 0.1 W/m^2K and glazing 0.8 W/m^2K). The results show that as in the case of air-tightness, improved insulation of the external envelop might yield diminishing results, if a suitable ventilative cooling strategy is not implemented.

Roof lights have been used increasingly in low energy supermarkets in the UK (Figure 10).

Figures 11 and 12 show the energy use predictions using current and 2050 weather files for different sizes of roof lights as a percentage of the roof area. Four percentage areas were simulated: 6% of the roof area which is the current area of roof lights in the case-study building, 10%, 15%, and 20% of the roof area. Figure 11 shows that increasing the area of the roof lights will result to a reduction of energy required for lighting. However, Figure 12 shows that when the total-energy demand is considered, an increase in energy demand is observed for roof light areas more than 10% in all examined cases.

In addition, roof vents have been included in low energy supermarkets which might be a suitable solution in combination with roof lights to provide an easily controlled ventilative cooling strategy. A recent example of such installation is in a superstore which opened in January 2013 (Figure 13). This followed the installation of bespoke windcatchers at the Cheetam Hill Store which has achieved 37% energy use reduction based on energy efficiency measures and

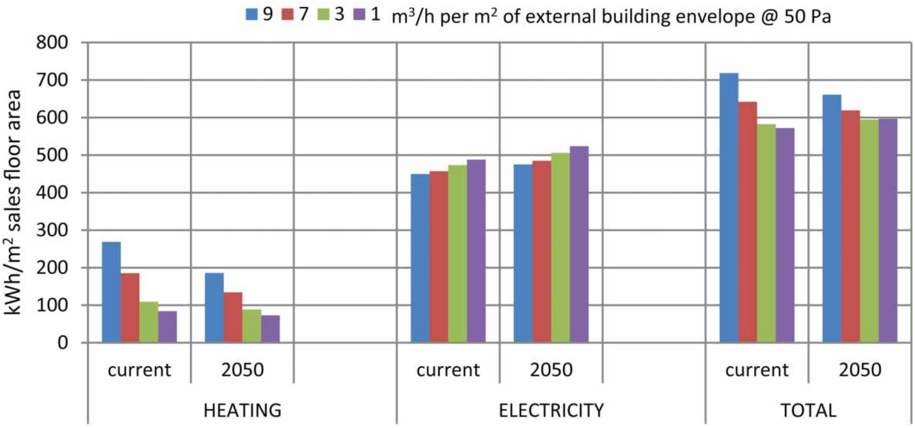

Figure 8. Effect of increased envelope air-tightness (m^3/m^2 of envelope area at 50 Pa) on heating and electricity energy demand for current and 2050s weather data.

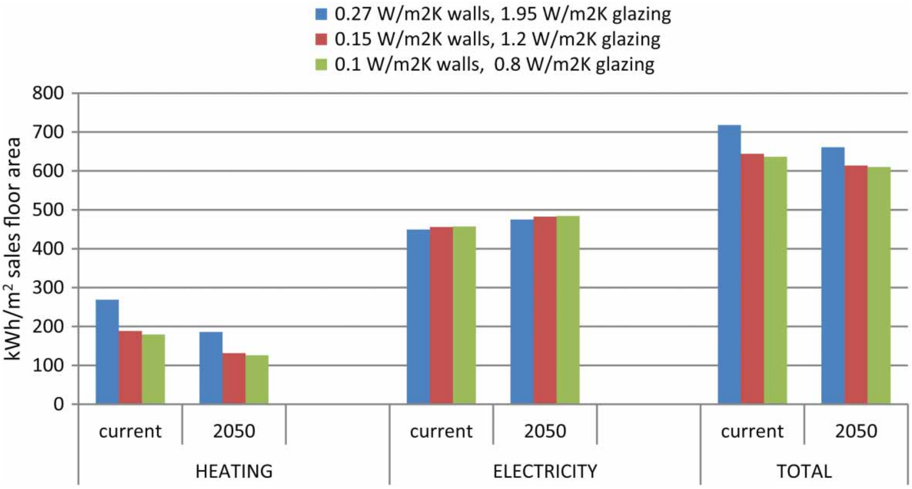

Figure 9. Effect of reduction of envelope (first number) and glazing (second number) heat transfer (W/m^2K, *U*-values) on heating and electricity energy demand for current and 2050s weather data.

a total of 66% CO_2 reduction if the combined cooling heating and power plant room utilising absorption chiller technology is included (Campbell & Riley, 2009).

4.2. *Refrigeration plant and ventilation*

CO_2 refrigeration systems have been used in recent years because of the environmental benefits they offer in terms of energy use reduction and avoidance of harmful refrigerant leakage to the atmosphere. At Brunel University, novel CO_2 refrigeration systems have been developed for supermarkets, notably with the integration of CO_2 refrigeration and trigeneration systems where the refrigeration generated by the trigeneration system is used to condense the CO_2 refrigerant in a cascade arrangement (Suamir, Tassou, & Marriot, 2012; Suamir & Tassou, 2013, Ge,

Figure 10. Roof lights of a supermarket opened in December 2012 (courtesy of Monodraught Ltd).

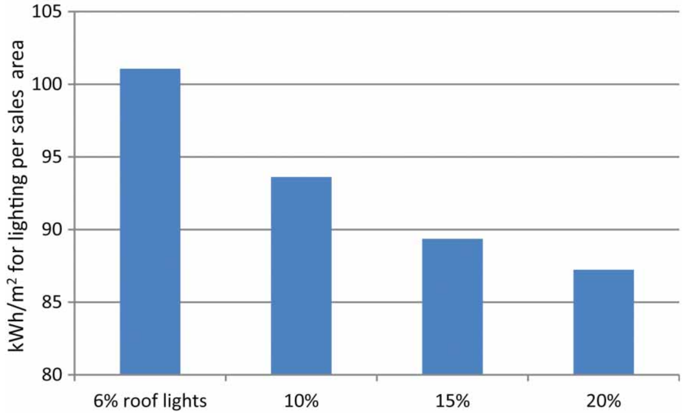

Figure 11. Effect of increasing the area of roof lights as a percentage of the roof area on electricity energy demand for lighting

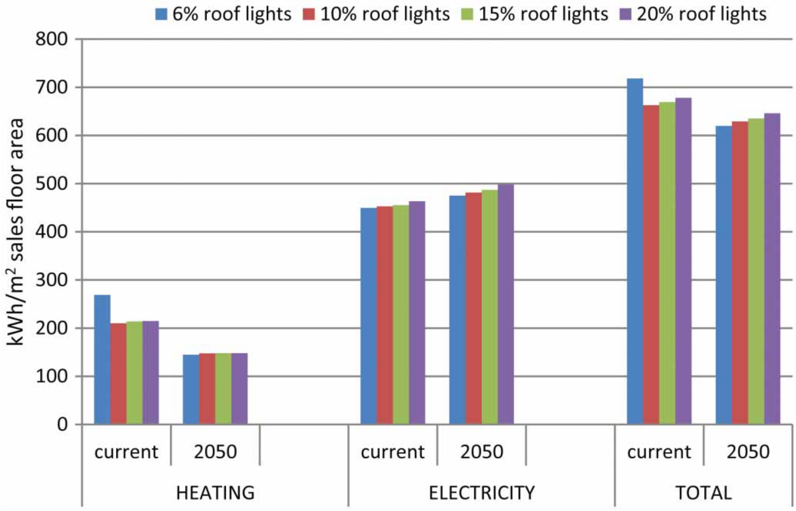

Figure 12. Effect of increasing the area of roof lights on heating and electricity energy demand for current and 2050's weather data.

Tassou, & Suamir, 2013). The trigeneration system consists of a natural gas engine-based CHP system and a sorption refrigeration system. The heat rejected by the CHP system is used to drive the sorption chiller, with the cooling energy produced that is employed to condense the CO_2 refrigerant of the subcritical CO_2 refrigeration system. Table 4 shows energy performance of a conventional system and the proposed system for a case-study supermarket and it indicates 30% fuel energy savings; the case-study supermarket is the Cheetam Hill Store, also referred to in the previous section. Figure 14 shows a conventional and the proposed supermarket energy systems.

The cooling/heating demands for the building are usually provided by an air handling unit (AHU) with pre- and re-heat and cooling coils supplied by the gas fired boiler and compression chiller. The integration of the CO_2 cascade refrigeration system with the HVAC system and the AHU for heat recovery was investigated using the supermarket simulation model 'supersim' developed under the TRNSYS simulation environment (Ge & Tassou, 2011). The results show that by controlling the head pressure of the refrigeration system, a proportion or all the heat demand of the supermarket can be satisfied with heat recovery (Ge & Tassou, 2013).

Finally, in recent years phase change materials (PCM) have been used in passive and active ventilation systems to maximise heat recovery applications and free cooling using external air. There is a vast amount of research in this area but it has not been applied directly to supermarkets. The authors have developed a modelling method using computational fluid dynamics and thermal modelling to investigate the impact of active PCM systems in displacement ventilation (DV) in large enclosures. It was found that the addition of the PCM-heat exchanger (HX) in the DV diffuser reduces the energy requirement for heating in the intermediate and summer periods when 'no-night-ventilation' and 'limiting-control ventilation' night charging strategies for the PCM are used (Figure 15). These PCM charging strategies lead to annual energy demand reductions of 34% and 22%, respectively, compared to the conventional DV system. The full night ventilation strategy for the DV-PCM-HX system will result in 20% higher energy consumption compared to the DV-only system (Figure 16). This higher energy results from higher HVAC energy

Figure 13. Windcatchers of a supermarket opened in January 2013 (courtesy of Monodraught Ltd).

Table 4. Energy savings systems for supermarkets.

Fuel utilisation components	Supermarket energy systems Conventional	 Proposed	Unit
Trigeneration fuel	–	7,450,016	kWh
Boiler fuel	874,068	24,670	kWh
Imported electricity	2,817,321	62,343	kWh
Fuel of imported electricity	8,537,338	188,919	kWh
Exported electricity	–	332,962	kWh
Fuel saving to grid supply	–	1,008,975	kWh
Total fuel required	9,411,406	6,654,630	kWh
Fuel Energy savings	–	2,756,776	kWh/year
Fuel energy savings ration	–	29.29	%

Source: Suamir et al. (2012).

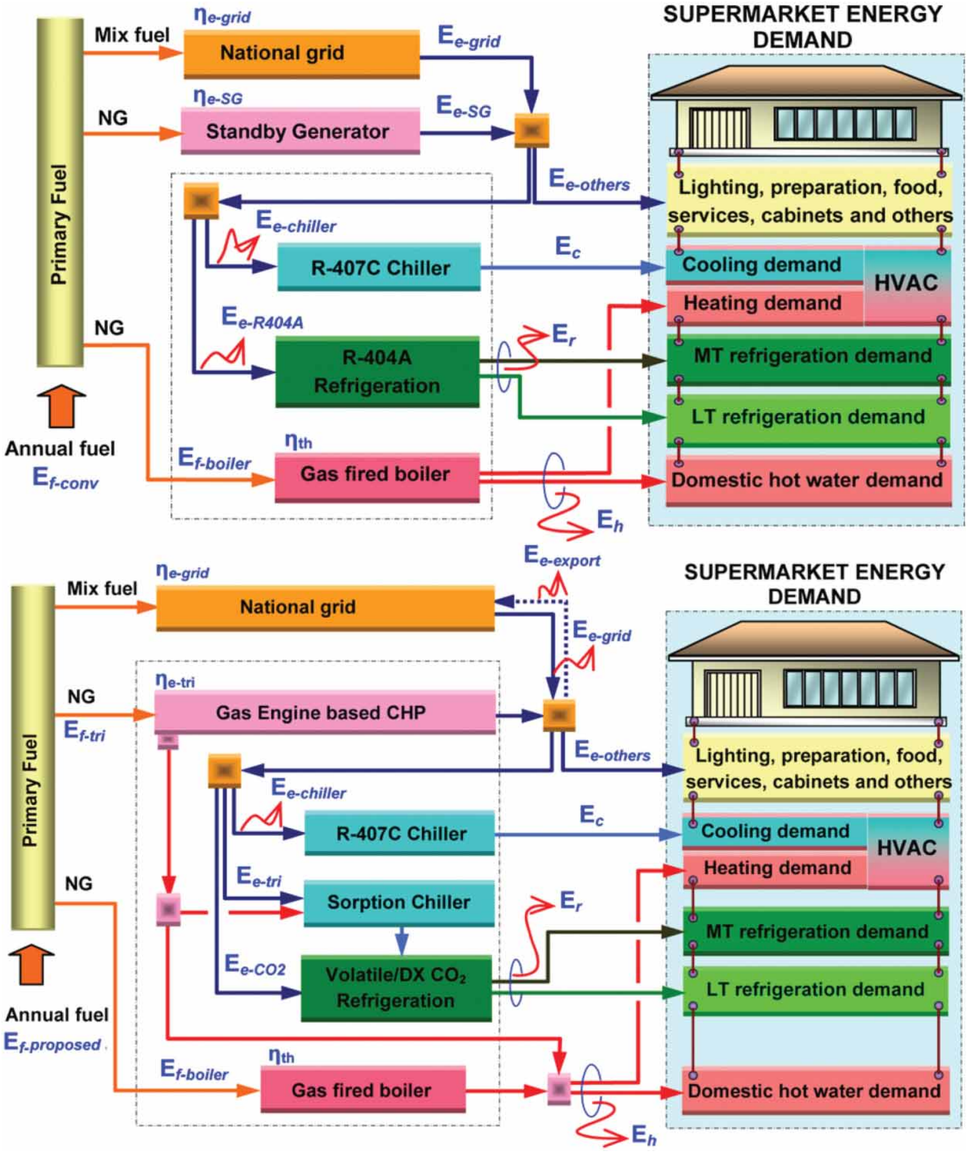

Figure 14. Energy flow diagram of a case-study supermarket with conventional and proposed energy system. Source: Suamir and Tassou (2013).

due to overcooling of the space and higher fan power. These strategies might have good effectiveness in specific areas of a supermarket such as refrigerated warehouses for occupant comfort as well as the general customer areas.

5. Conclusions and planned work

This paper presented the current energy use statistics of food retail buildings to demonstrate the high potential for the application of energy-efficient technologies in the design of these buildings

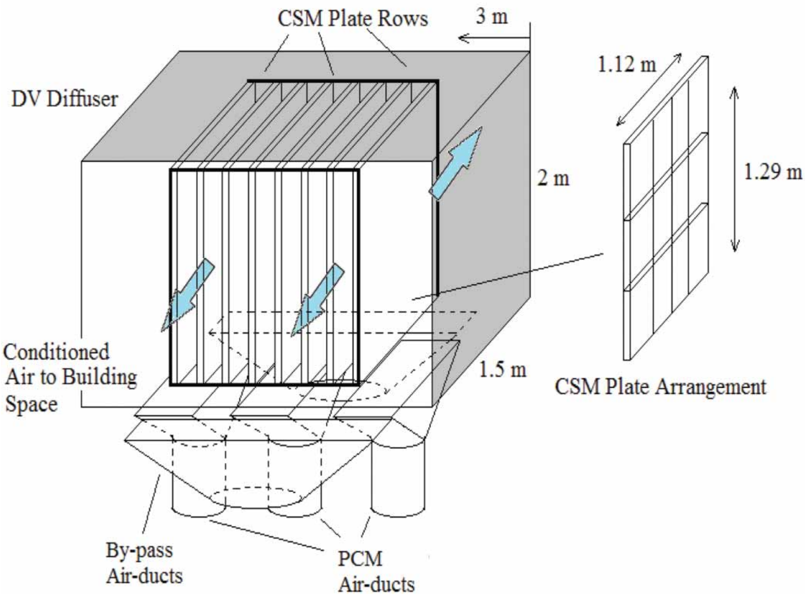

Figure 15. Diagram of the PCM DV diffuser, ducts and CSM plate arrangement inside the diffuser. Source: Gowreesunker, Tassou, and Kolokotroni (2013).

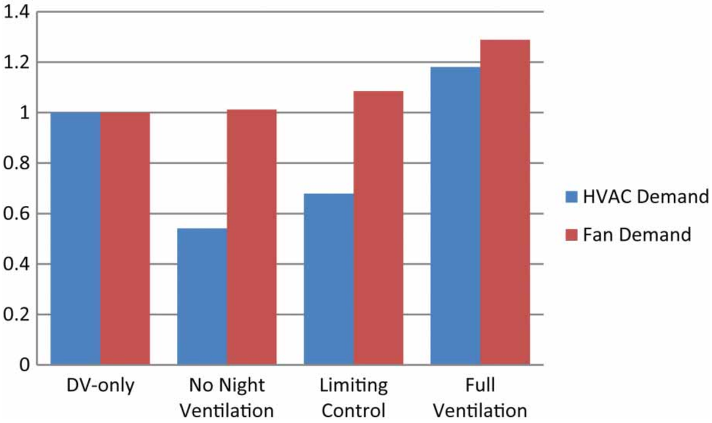

Figure 16. Comparison of energy demand of alternative controls for the PCM system and the full ventilation system in comparison to the DV system.

and their HVAC equipment. It focussed on UK examples of latest ‘low carbon’ supermarkets and showed that there is potential for significant energy savings with attractive financial return. It outlined the current development in refrigeration systems and their integration with the energy management of the building for potential savings in the provision of environmental conditions.

Future work will target the goal of zero or near-zero emission stores whilst improving service and shopper experience. Investigations will involve future concept store design and building envelope for both small urban and out-of-town hypermarkets, to improve thermal performance and allow optimum integration of renewable energy and natural technologies (such as natural ventilation, day-lighting, and thermal storage using PCMs) with the HVAC equipment and their optimum integration within the constraints and objectives to provide flexibility and lower environmental impacts. Shopper surveys will be carried out to assess and improve their shopping experiences, whilst reducing their carbon footprints.

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