VENTILATION AND ENERGY ASPECTS OF FOOD RETAIL BUILDINGS

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ABSTRACT

Worldwide the food system is responsible for 33% of GHG emissions. It is estimated that by 2050, 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 accounts for a significant percentage of the energy use in food retail (supermarkets) and catering facilities service buildings 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 a primary importance for the business owners and designers. In particular, supermarkets and restaurants present design and operational challenges because the HVAC system has some unique and diverse conditions that it must handle.

This paper presents current information of energy use in food retail and catering facilities and continues by focussing 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, novel refrigeration systems using CO_2 combined with ventilation heat recovery can lead to significant savings with attractive investment return. Finally, the potential of ventilation coupled with sensible and latent energy storage for load shifting is proposed as an area worth investigating.

KEYWORDS

energy use, food chain, ventilation, supermarkets, heat recovery, refrigeration

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-27s 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 vrs 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 15 Mt of food waste, with households generating 7.2 Mt/year and 3.2 Mt/year from manufacturing. In terms of 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% on 2010 and employed 3.3 million people in the third quarter of 2012 (13% of GB employment), (Defra, 2012).

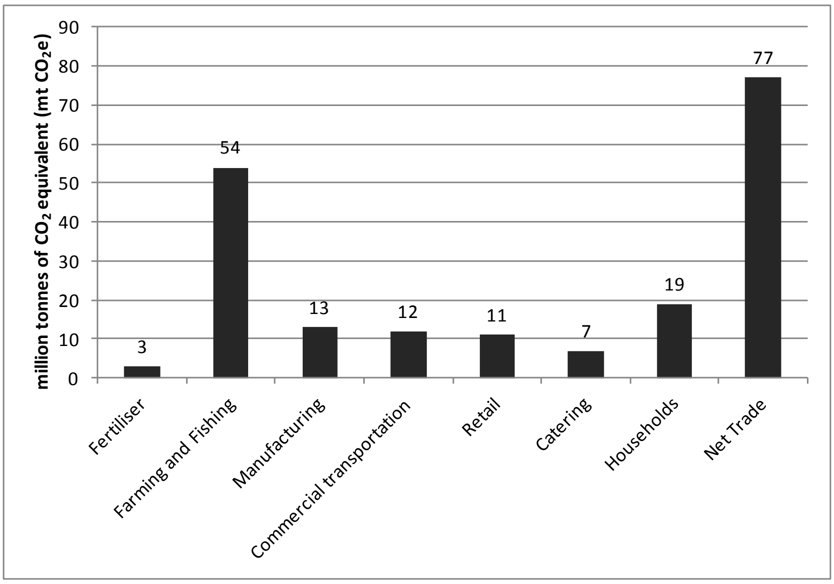

Figure 1: Greenhouse gas emission from the UK food chain (reproduced from Defra 2012, p43)

A study in the US (Canning et al, 2010) estimating changes in energy flows, shows the food-related share of the national energy budget 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 shows that food related aggregated energy flow rose by 12.7% vrs 3.8% of the total.

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 energy savings of the order of 50% are achievable in food chains by appropriate technology changes in food production, processing, packaging, transportation, and consumption. 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 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 part of the food chain, that of retail and public consumption. 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.

2 ENERGY USE IN FOOD RETAIL AND CATERING

Recent statistics of energy use in the UK, indicate that 40 MWh (21% of total energy use in 2011) are used by general retail buildings and 24 MWh (almost 13% of total energy use by non-domestic buildings) are used by hotel and catering buildings (Figure 2). Of this, 27% is for catering and 5 % is for ventilation and cooling (Figure 3). Ventilation also has an impact on the energy use of heating (32% of total) and lighting in many cases (15% of the total). (DECC, 2013).

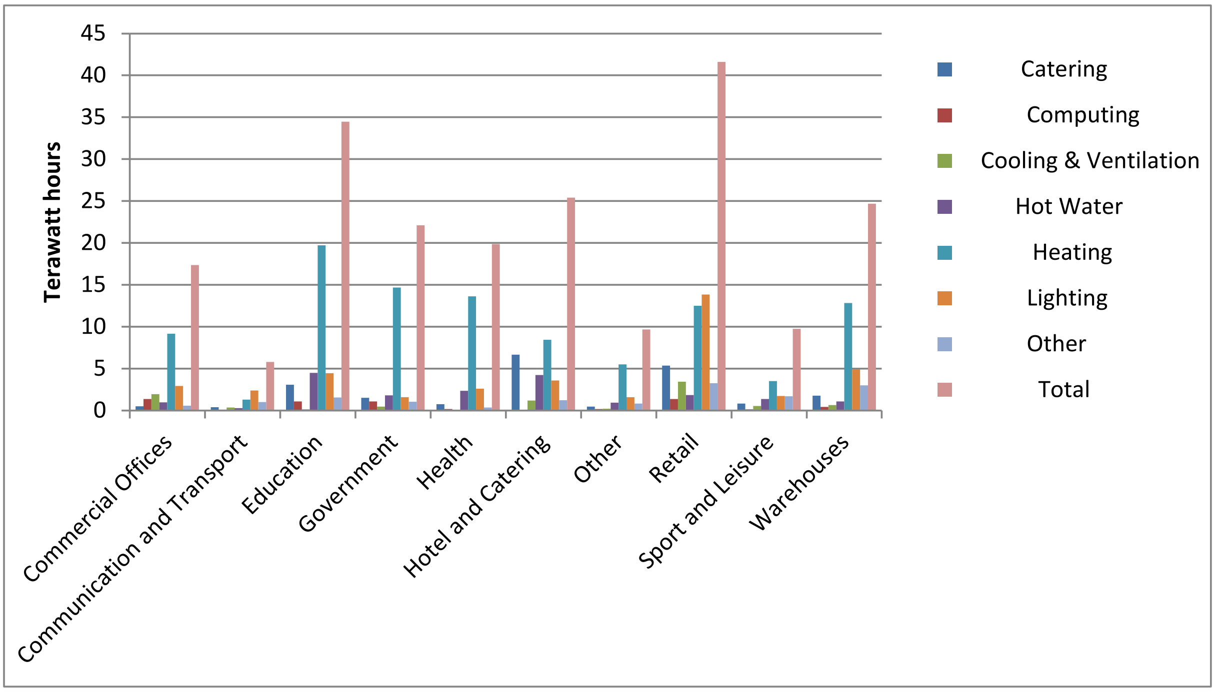

Figure 2: Final energy consumption in the service sector in the UK by sub-sector and end use 2012 (DECC 2013, Table 5.09).

Figure 3: Final energy consumption in 'retail' and 'hotel & catering' in the UK by end use in 2012. Legend categories are the same as in Fig 2. (DECC 2013, Table 5.09).

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 IEA publication (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 use 21% of households energy. 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).

In the light of the above statistics, this project will investigate energy use reduction technologies, starting with food retail buildings which is 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 4 presents (Sullivan and Couldson, 2013) total greenhouse gas emissions relative to 2007 baseline of six supermarket chains; it can be seen that the majority have improved emissions; the increased case is mainly due to the expansion of operations outside the UK but its UK emissions reduced by 5%.

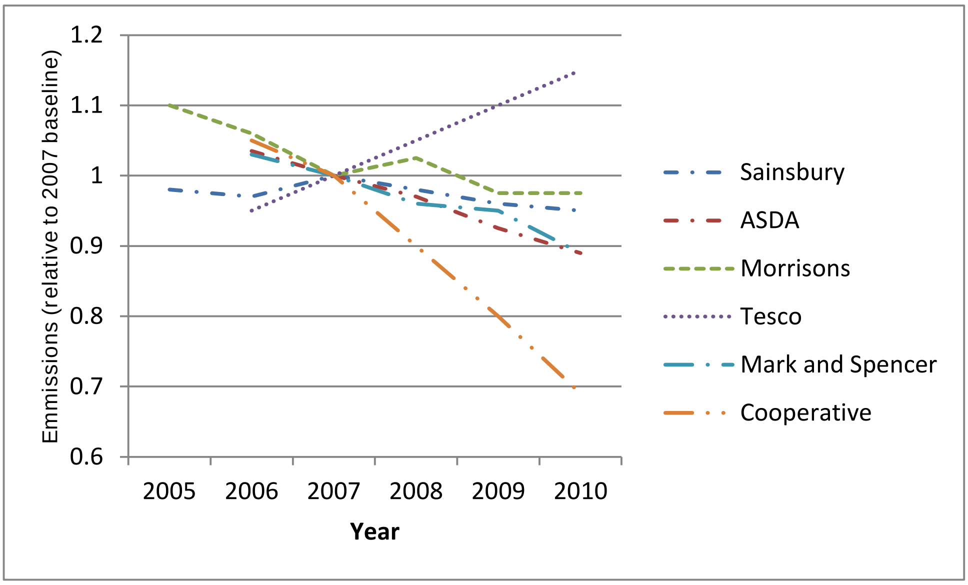

Figure 4: Total Greenhouse Gas Emissions form UK Retailers (2005-2010) (source Sullivan and Couldson 2013)

Despite this improvement, ***retail food stores*** are large consumers of energy. Food retailing in the UK is responsible for around 12.0 TWh and around 3% of total electrical energy consumption (Tassou et al, 2011). Estimates for GHG emissions from food retail operations vary between 6 and 9.5 $MtCO_2e$ (Stanford, 2010). Retail food stores are a part of the commercial sector of buildings which accounted 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 et al. (2008)). The corresponding figure for the U.K. varies between 700 kWh/m^2 per year for hypermarkets, to 2000 kWh/m^2 per year for convenience stores (Tassou et al., 2011). Current benchmarks (CIBSE, 2012) indicate 261 kWh/sales floor area of fossil fuel and 1026 kWh/sales floor area of electricity for typical supermarkets.

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. Figure 5 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 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.

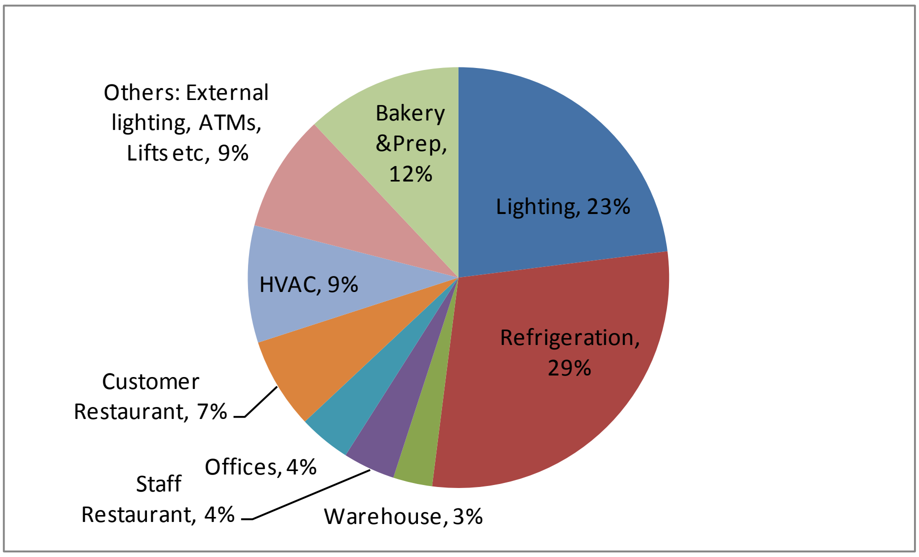

Figure 5: Percentage contribution of electrical energy use processes in a hypermarket.(source Tassou 2011).

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 tri-generation. Energy saving opportunities also exist from the use of low energy lighting systems, improvements in the building fabric, integration of renewable energy sources, and thermal energy storage (Tassou et al 2011, Carbon Trust 2010). Another area that provides significant opportunities for energy savings is the design of more efficient refrigerated display fixtures. Figure 6 shows the contribution to the load of a vertical multi-deck open form chilled food display cabinet. As indicated, infiltration accounts for more than ¾ of the energy load which has led to proposed and implemented solutions on how to minimise it (Tassou et al 2011).

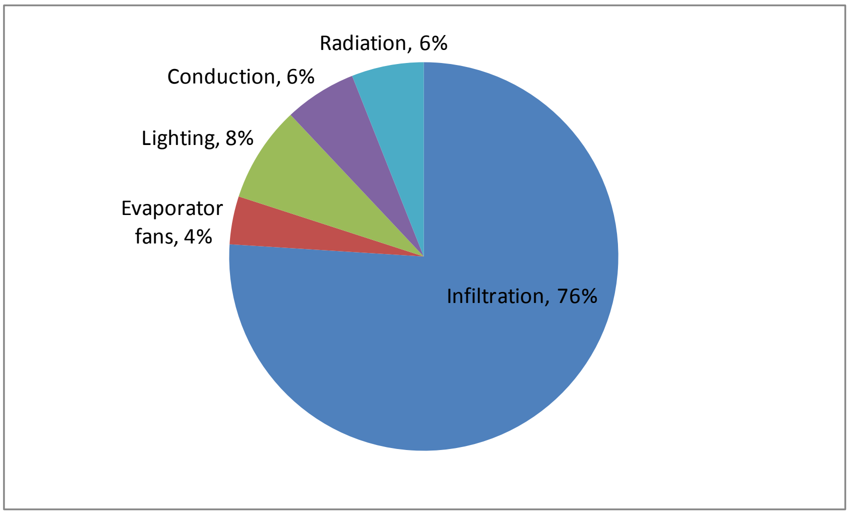

Figure 6: Contributions to the load of a vertical multi-deck open front chilled food display cabinet. (Tassou 2011)

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 et al, 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 1000m^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 L, 2010). 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 (BER expressed as $kgCO_2/(m^2.year)$), and is based on a specific measurement of the building concerned. So, air-tightness of supermarket envelope is regulated under the energy efficiency building regulations and in many cases 5 $m^3.h^{-1}.m^{-2}$ at 50Pa 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 1; the energy efficiency improvements introduced were divided into three packages each with increased energy savings. Table 1 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 NPV than Package A and therefore more attractive. For package C which includes additionally highly improved air-tightness at 5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa, despite the greater reduction in carbon emissions, its economic performance is less attractive.

Table 1: Energy Efficiency Measures for zero carbon stores (source Target Zero, 2011 p. 21)

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	-	699,289	-	-
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	508,196 [-27%]	[-0.36%]	-973,545
Package B	Package A plus (or superseded by): 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 7m3/hr per m2 @ 50 Pa	419,895 [-51%]	[0.90%]	-1,053,332
Package C	Package B plus (or superseded by): Specific Fan power reduced by 40% Roof lights 15% with daylight dimming Improved chiller efficiency SEER = 8 Highly improved air tightness 5m3/hr per m2 @ 50 Pa Active chilled beam / radiant ceiling Advanced thermal bridging (0.013W/m2K) Improved wall U-value to 0.25W/m2K	379,548 [-46%]	[5.1%]	-495,153

(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 400kWh/m², 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 2.

Table 2: Emission Reduction Measures for zero carbon stores (Hill et al, 2010 p 22)

Envelope/Glazing	Nanogel sandwich skylihgts 1200mm 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 CO2 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

It can be seen that roof vents were used as well as CO_2 ventilation control. A recent example of such installation is in a superstore which opened in January 2013 (see Figure 7). 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 a total of 66% CO_2 reduction if the combined cooling heating and power plant room utilising absorption chiller technology is included (Campbell and Riley, 2009).

Figure 7: Windcatchers of a supermarket opened in January 2013 (courtesy of Monodraught Ltd).

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 et al, 2012). 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 employed to condense the CO2 refrigerant of the subcritical CO_2 refrigeration system. Table 3 shows energy performance of a conventional and the proposed system for a case study supermarket and it indicates that 30% fuel energy savings; the case-study supermarket is the Cheetam Hill Store, also referred to in the previous section. Figure 8 shows a conventional and the proposed supermarket energy systems.

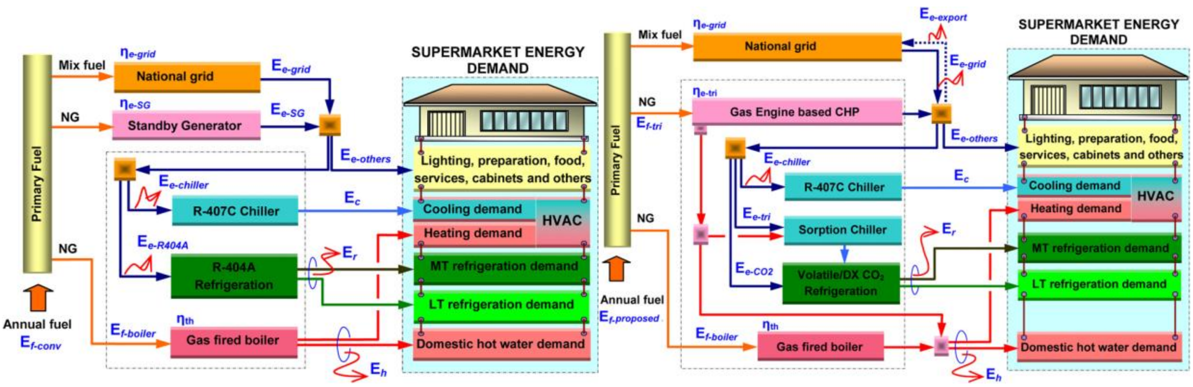

Figure 8: Energy flow diagram of case study supermarker with conventional and poroposed energy system, (Source Suamir and Tassou, 2013).

Table 3: Energy savings systems for supermarkets [Source Suamir et al, 2012]

Fuel Utilisation Components	Supermarket energy systems		**Unit**
	Conventional	Proposed	
Trigeneration Fuel	-	7,450,016	kWh
Boiler Fuel	874,068	24,670	kWh
Improted 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 (FESR)	-	29.29	%

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 and Tassou 2011). The results show that by controlling the head pressure of the refrigeration system a proposrtion or all the heat demand of the supermarket can be satisfied with heat recovery (Ge and 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 has not been applied directly to supermarkets. The authors have developed a modelling method using CFD and thermal modelling to investigate the impact of active PCM systems in displacement ventilation in large enclosures. It was found that the addition of the PCM-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. These PCM charging strategies lead to annual energy demand reductions of 22% (Gowreesunker et al, 2013). 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 current energy use statistics of food retail and catering facilities buildings to demonstrate the high potential for the application of energy efficient technologies in the design of these buildings 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 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 store 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 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 find how to improve their shopping experience.

6 ACKNOWLEDGEMENTS

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