Performance evaluation of integrated trigeneration and CO_2 refrigeration systems

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Abstract

Food retailing is one of the most energy intensive sectors of the food cold chain. Its environmental impacts are significant not only because of the indirect effect from CO_2 emissions at the power stations but also due to the direct effect arising from refrigerant leakage to the atmosphere. The overall energy efficiency of supermarkets can be increased by integrating the operation of CO_2 refrigeration and trigeneration systems. This paper compares three alternative schemes in a medium size supermarket. Experimental results and simulation studies have shown that the best scheme for energy and GHG emissions savings is the one where the cooling produced by the trigeneration system is used to condense the CO_2 fluid in the refrigeration system to ensure subcritical operation throughout the year.

Keywords: trigeneration, CO_2 refrigeration, performance evaluation

Introduction

Supermarkets have significant environmental impacts due to indirect emissions of greenhouse gases (GHG) from electricity generation in power stations and direct emissions from leakage of refrigerants with high global warming potential (GWP) to the environment [1]. The use of natural refrigerants such as CO_2 offers the opportunity to reduce the direct emissions of supermarkets compared to systems employing HFC (hydro-fluorocarbon) refrigerants that possess high global warming potential. In the application of CO_2 as a refrigerant to commercial refrigeration systems, a number of different design approaches can be adopted that fall into two major categories: subcritical cascade systems and transcritical systems. Subcritical cascade systems operate at moderate pressures and employ two refrigerants one for refrigeration and another for heat rejection, whereas, transcritical systems operate at high pressures during high ambient temperatures but employ only CO_2 as refrigerant.

The environmental impacts of supermarkets can also be reduced through local heat and power generation, CHP, which has the potential to reduce indirect emissions. There is, however, a significant mismatch between the heat and refrigeration requirements, particularly in the summer months, that reduces the effectiveness of CHP systems. Trigeneration, where the excess heat generated by a CHP system is used to drive a sorption refrigeration system for cooling or even refrigeration can overcome this disadvantage [2,3]. Research in recent years based on experimental investigations in the laboratory and simulation studies has shown that such systems can provide promising economic and environmental benefits when used in supermarket applications [4,5].

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A system developed by Brunel University can combine the advantages of transcritical CO_2 systems with those of trigeneration systems to reduce both the direct and indirect GHG emissions from supermarket energy systems. The system employs a CO_2 refrigeration system in a cascade arrangement with a sorption refrigeration system. The sorption refrigeration system which is driven by the heat rejected by the CHP system of the trigeneration arrangement is used to condense the CO_2 refrigerant of the Medium Temperature (MT) and Low Temperature (LT) refrigeration circuits.

This paper presents experimental results from a pilot plant in the laboratory and simulation studies which were used to investigate the energy and environmental performance of alternative system configurations in a case study supermarket.

1. Test facility

The test facility used for the experimental investigations is shown in Figure 1. The CHP system is based on an 80 kW_e CHP system with exhaust heat recovery heat exchanger. The performance characteristics of the CHP system are given in [5]. The absorption refrigeration system is based on a ammonia-water packaged direct gas fired chiller which was re-engineered to operate with a heat transfer fluid heated by the exhaust gases of the CHP system. The performance of the modified unit was found to be superior to the direct gas fired unit [4,5]. Further performance improvements can be achieved through better integration of the CHP system and absorption chiller to reduce pumping power and pipe heat losses.

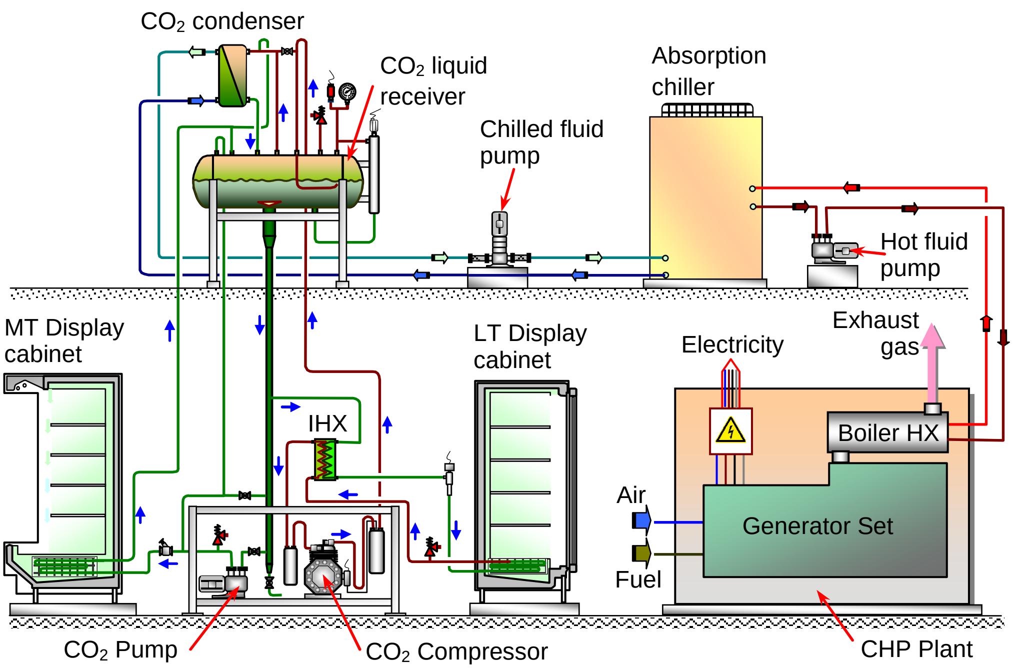

Figure 1: Simplified diagram of the integrated volatile/DX CO_2 refrigeration and trigeneration

The retail CO_2 refrigeration plant in Figure 1 consists of a cascade volatile MT and direct expansion LT CO_2 refrigeration system and associated test facilities which include an environmental test chamber and chilled and frozen food display cabinets located in the chamber to provide controlled load to the refrigeration systems.
The evaporator coil of the LT cabinet is a direct expansion coil whereas the coil of the medium temperature cabinet is a flooded evaporator coil which is designed to operate with CO_2 as a secondary (volatile) refrigerant. Condensation of the CO_2 from both the low and medium

temperature sections of the system is provided by the absorption refrigeration system of the trigeneration facility through a CO_2 plate heat exchanger. The test facility was comprehensively instrumented with power metres, pressure transducers, thermocouples and coriolis refrigerant flow meters to enable detailed investigations of the transient and steady state performance of individual components and the overall system.

2. Test results

Tests were performed for a number of circulation ratios (CR) and different evaporating temperatures of the MT CO_2 refrigeration system or condensing temperatures of the LT CO_2 system. The circulation ratio indicates the amount of refrigerant flowing through the flooded evaporating coil. The flow of refrigerant in the MT coil starts as liquid which gradually evaporates along the coil pipe and exits at certain 'quality'. The 'quality' is the inverse value of the CR. Circulation ratio 1 is equivalent to the quantity of refrigerant required for just complete evaporation in the coil. For the system tested a CR of 1.3 was found to give maximum refrigeration capacity with a good coefficient of performance (COP). The COP of the MT system, determined from eq. (1) was found to vary between 50 and 60 for evaporating temperatures between -6 ^oC and -10 ^oC respectively. This high COP is due to the low pump power required to circulate the refrigerant through the coil, which is much lower than the compressor power required for a direct expansion coil. The COP of the LT system was determined from eq. (2) and the overall COP of the system (combined LT and MT COP) was determined from eq. (3).

$$COP_{MT-CO2} = \frac{Q_{r-MT}}{W_{MT-pump}} \tag{1}$$

$$COP_{LT-CO2} = \frac{Q_{r-LT}}{W_{LT-comp.}} \tag{2}$$

$$COP_{Overall-CO2} = \frac{Q_{r-MT} + Q_{r-LT}}{W_{MT-pump} + W_{LT-comp}} \tag{3}$$

Figure 2 shows the variation of the LT COP, the MT COP and the overall system COP with time for a CR of 1.3, and evaporating and condensing temperature for the LT system of -32 ^oC and -7 ^oC respectively. The Figure shows the average COP of the MT system to be around 50.0. The figure also shows the cycling of the pump during defrost and when the coil air off temperature reaches the set point of -3 ^oC. From Figure 2 it can also be seen that the average overall COP of the CO_2 refrigeration system, MT and LT, varies in the range between 5.5 and 6. This COP can be increased further by optimising the sizing of the components in the system.

3. Case study supermarket

A medium size supermarket of 5000 m^2 sales area was used in the case study. The supermarket which is located near Manchester in the UK, uses a cascade transcritical CO_2 refrigeration plant. The energy system also employs: i) a biofuel engine based CHP system and a sorption chiller to provide space cooling utilising the heat rejected by the CHP; ii) a R-407C electric driven vapour compression refrigeration system as a back up to the sorption chiller; iii) gas fired boilers to supplement the heat from the CHP plant. The electrical and thermal energy demands of the supermarket are shown in Figure 3. From half hourly monitoring data, the peak and average electrical demand were found to be 463 kW_e and 312 kW_e respectively and the annual electricity consumption 2,731 MWh. The gas consumption was measured to be 874 MWh with peak demand during the winter time of 492 kW_{th} and average seasonal demand of

100 kW_{th}. The cooling demand is for air conditioning and was found to be 202 MWh with peak cooling energy requirement of 210 kW_{th}.

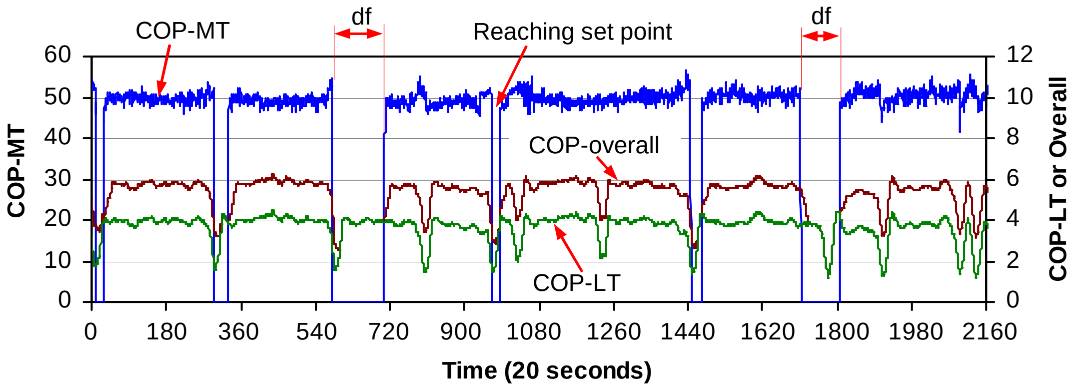

Figure 2: Performance of overall CO_2 refrigeration system (at CR = 1.3; T_{con} = -7°C ; T_{eva} = -32°C)

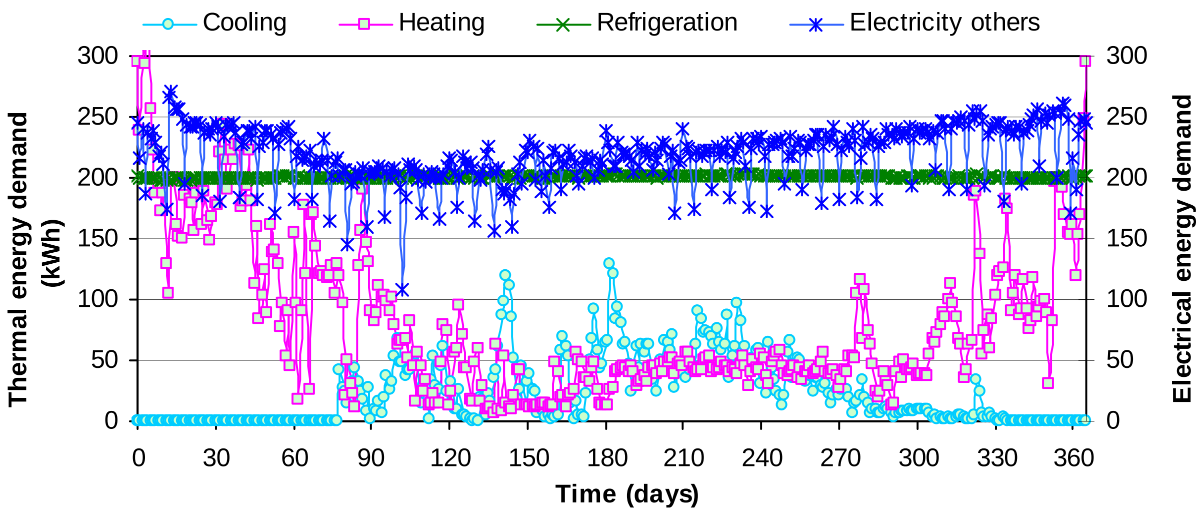

Figure 3: Daily average energy demand of the case study supermarket

4. Supermarket energy systems and simulation models

Energy systems in supermarkets normally comprise heating for HVAC (heating, ventilation and air conditioning), and domestic hot water and electrical power for refrigeration, cooling, lighting, food preparation, and HVAC systems. In the UK, the heat demand is normally satisfied by gas boilers and the electrical demand by power 'imported' from the national grid. Most supermarkets utilise R-404A as refrigerant in multi-compressor 'remote' type refrigeration systems with separate parallel systems employed for the MT and LT refrigeration loads.

This study considers 3 alternative systems to replace the conventional energy system in supermarkets. Scheme 1 is the integrated CO_2 refrigeration and trigeneration energy system proposed by the authors. A schematic diagram of this scheme is shown in Figure 4. 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 which in turn is used in a cascade arrangement to condense the CO_2 refrigerant of the subcritical CO_2 refrigeration system. The sorption refrigeration system considered in this study is a single effect lithium bromide-water system which can deliver chilled water at 7 °C. The CO_2 refrigeration system employs a pumped CO_2 arrangement for the MT cabinets and direct expansion for the LT cabinets. To bridge the difference in temperature provided by the sorption system and that required condense the CO_2 refrigerant of the LT and MT circuits, an MT CO_2 compressor pack is used to operate between the two temperature levels of -7 °C and +7°C, as shown in Figure 4.

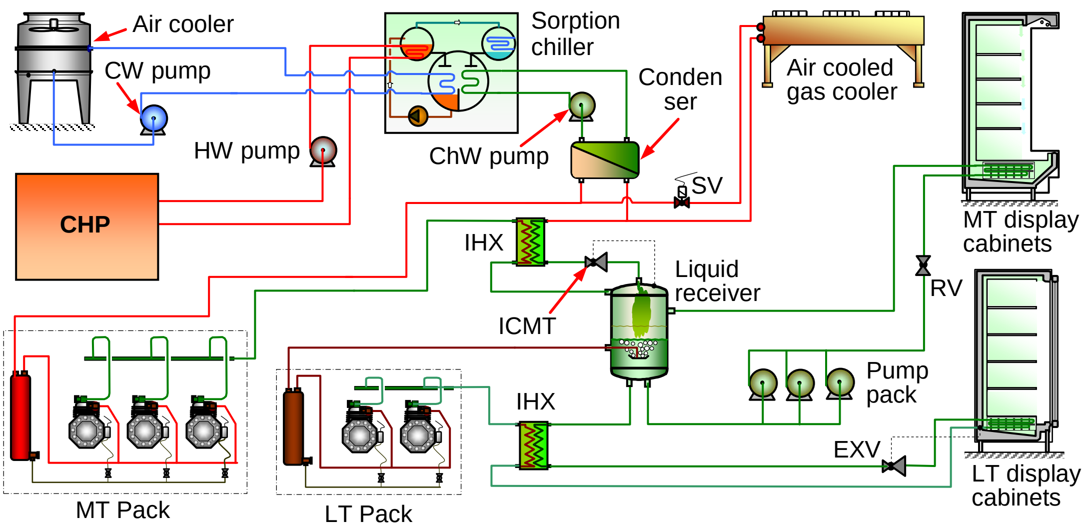

Figure 4: Simplified schematic diagram of proposed integration of CO_2 refrigeration and trigeneration systems

Two other energy alternatives, Scheme-2 and Scheme-3, were also investigated for comparison purposes. Both alternative schemes utilise CO_2 refrigeration and trigeneration systems but of different system configuration. Scheme-2, which is the system currently employed in the supermarket consists of: bio-fuel engine based CHP, sorption refrigeration system and electric chiller, cascade transcritical CO_2 refrigeration and gas boiler. Heat released by the CHP system drives the sorption chiller in a trigeneration arrangement to generate cooling for the HVAC system. If cooling generated by the trigeneration system is not enough to satisfy the space cooling needs, the balance is provided by the electric vapour compression chiller. The heat demand is satisfied by heat from the CHP system, when it is not used for cooling, and the balance by the gas fired boiler. The electrical demand is satisfied by a combination of local power generated by the CHP system and power imported from the grid.

Scheme-3 is similar to the proposed energy system (Scheme-1), but the CO_2 refrigeration system utilises a cascade transcritical CO_2 refrigeration system. The energy released by the gas engine CHP system is used to drive a sorption chiller which is cascaded to a CO_2 condenser to cool and condense the CO_2 refrigerant of the cascade transcritical CO_2 refrigeration system. This arrangement ensures operation of the CO_2 refrigeration system in the subcritical region but the system can revert to transcritical operation in the event of trigeneration system failure. Cooling demand in scheme-3 is fully satisfied by an electric vapour compression refrigeration system.

Simulation models based on the Engineering Equations Solver (EES) software and a spread sheet programme were established to determine the performance of the energy systems for the case study supermarket in terms of primary fuel energy utilisation, GHG emissions and economic viability. Figures 5 and 6 show the energy flow diagrams of the conventional and proposed energy systems respectively. Energy flow diagrams for Schemes 2 and 3 are not very dissimilar to Scheme-1 so they are not shown in this paper.

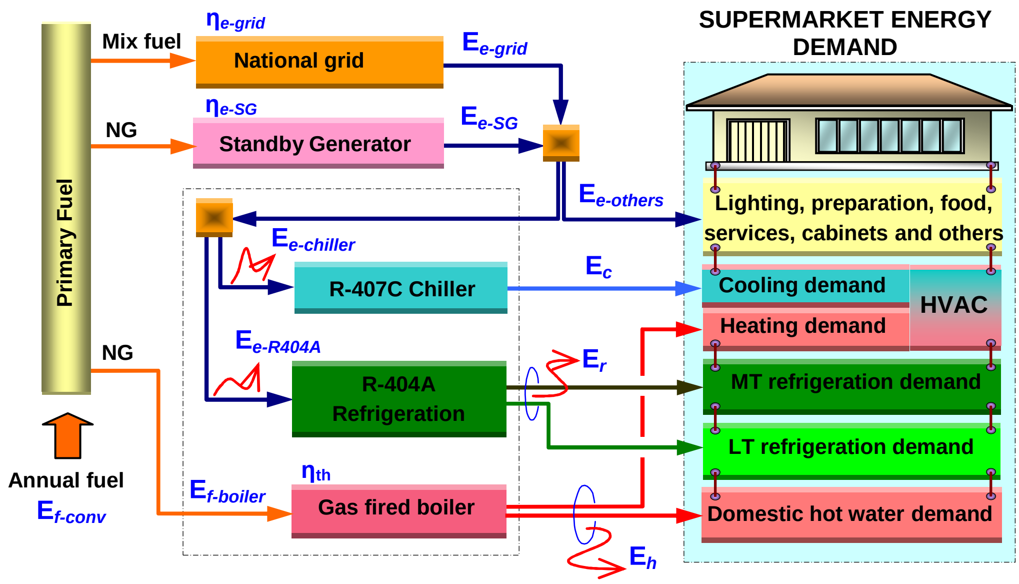

Figure 5: Energy flow diagram of case study supermarket with conventional energy system

The primary fuel energy utilisation ratio (FEUR) is a ratio of the summation of the energy used for heating, refrigeration, cooling and electricity to primary fuel energy and can be calculated from:

$$FEUR_{conv} = \frac{E_h + E_r + E_c + E_{e-others}}{E_{f-conv}} \; x\; 100\% \tag{4}$$

$$FEUR_{prop} = \frac{E_h + E_r + E_c + E_{e-others} + E_{e-\text{export}}}{E_{f-prop}} \; x\; 100\% \tag{5}$$

The primary energy of the conventional and alternatives energy systems can be determined from:

$$E_{f-conv} = \frac{1}{\eta_{e-grid}}.E_{e-grid} + \frac{1}{\eta_{e-SG}}.E_{e-SG} + E_{f-boiler} \tag{6}$$

$$E_{f-prop} = \frac{1}{\eta_{e-grid}}.\,E_{e-grid} + E_{f-tri} + E_{f-boiler} \tag{7}$$

The fuel energy saving ratio (FESR) can be determined from:

$$FESR_{prop} = \frac{E_{f-conv} - E_{f-prop}}{E_{f-conv}} \, x\; 100\% \tag{8}$$

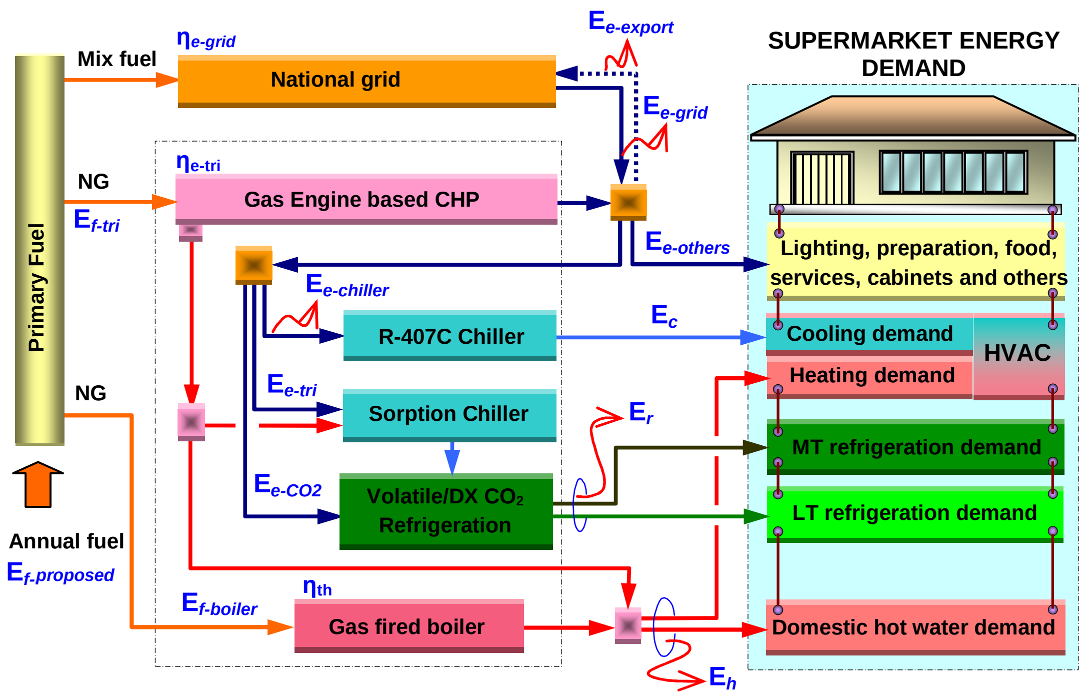

Figure 6: Energy flow diagram of proposed energy system

The electrical efficiency of the UK national grid was assumed to be 33% and the efficiency of commercial gas boilers, 81%. Electrical efficiency of bio-fuel engine CHP and gas engine CHP were respectively assumed to be 35% and 36.6%. The total impact of the conventional and alternative energy systems on the environment was calculated over the life time of the systems and was assumed to be equally distributed over their life time. The calculation was based on the direct effect of the refrigerant leakage and recovery losses as well as indirect effect of the energy consumed by the systems. These effects are combined and expressed as a total equivalent warming impact (TEWI) as defined by [6].

$$TEWI = GWP.L_{annual}.n + GWP.m_{charge}.(1-\alpha_{recovery}) + n.E_{annual}.\beta \tag{9}$$

Payback period for proposed and new energy system alternatives investment (years) was calculated from:

$$Payback = \frac{Extra\ investment\ of\ energy\ system\ alternatives}{Annual\ net\ saving} \tag{10}$$

The assumptions made in the calculations are detailed in Table 1.

5. Model results and discussion

5.1. Performance of the conventional system

Seasonal simulation results of the conventional R404A refrigeration system showed an average seasonal COP for the MT refrigeration of 2.51 and 1.53 for the LT refrigeration system, giving a combined seasonal COP of 2.17. The average daily fuel energy utilisation ratio (FEUR) of the conventional supermarket's energy system is shown in Figure 7. The overall FEUR varies between a minimum of around 41% in the winter to a maximum of 60% in the summer, giving an overall seasonal FEUR of 49.6%. The total primary fuel energy required by the conventional system was found to be 9,411 MWh per year 91% of which was due to electricity use (Table 2).

Table 1: Assumptions

Parameters	Assumptions	References	
		Range	Source
Annual refrigerant leakage for centralised system (% of charge)	15	15 - 30	[7]
Refrigerant charge for DX centralised refrigeration system:			
- Charged with HFC or HCFC (kg kW^{-1} refrigeration capacity)	3.5	2 - 5	[8]
- Charged with CO_2 (kg kW^{-1} refrigeration capacity)	1.75	1 – 2.5	[8]
CO_2 emissions factor:			
- Grid electricity ($kgCO_2$ kWh^{-1})	0.547		[9]
- Natural gas ($kgCO_2$ kWh^{-1})	0.184		[9]
Global warming Potential (100 years interval time horizon):			
- R-404A ($kgCO_2$ kg^{-1})	3900		[7]
- R-407C ($kgCO_2$ kg^{-1})	1800		[7]
- R-744 ($kgCO_2$ kg^{-1})	1		[7]
Refrigerant recovery factor (%)	70		
Live for conventional and proposed system (years)	15		

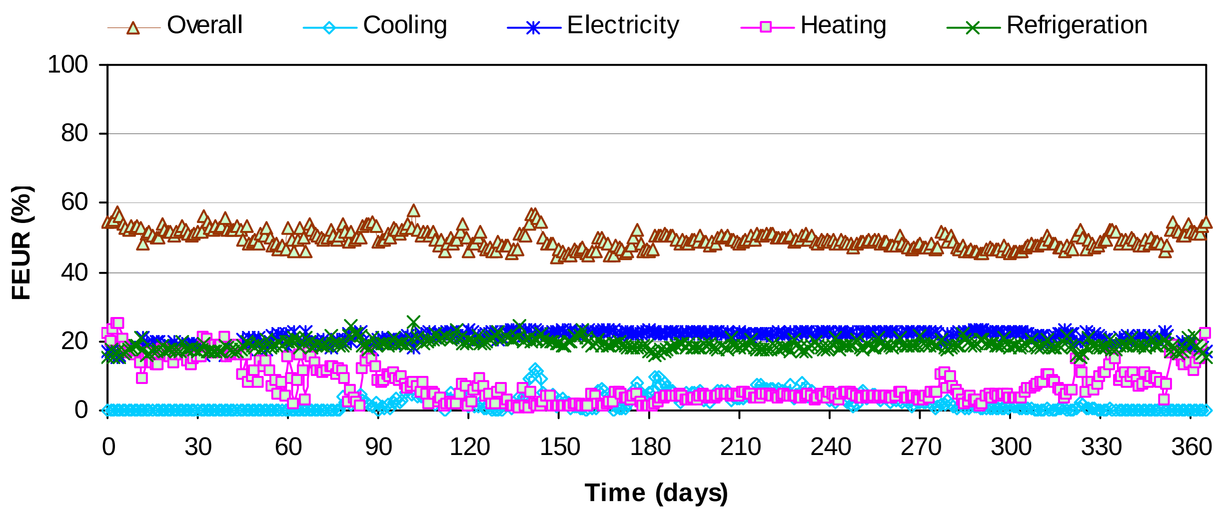

Figure 7: **Daily average fuel energy utilisation ratio of conventional energy system**

5.2. Performance of the proposed and alternative energy systems

Preliminary sizing for the proposed system (Scheme-1) has shown the following system sizes for best results: trigeneration arrangement with a 350 kW_e gas engine based CHP and an absorption chiller with a design cooling capacity of 310 kW_{th}. Refrigeration capacity of 152 kW_{th} for the MT volatile CO_2 refrigeration for the MT packs and 50 kW_{th} refrigeration capacity for the LT packs. The scheme is backed up by an electric 200 kW_{th} capacity R-407C chiller for space cooling and 2 x 200 kW_{th} capacity gas boilers for heating.

The daily variation of the FEUR of Scheme-1 over a whole year is shown in Figure 8. The annual average FEUR of the system was found to be 64.3% and its total fuel demand 6,655 MWh, providing savings of 2,757 MWh (29.3%) over the conventional system (Table 2). With Scheme-1, 96.8% of the electricity demand of the supermarket can be satisfied by the local power generation system. The trigeneration system can also satisfy 97% of the store's heat demand with the remainder supplied by the auxiliary gas boiler system.

Table 2: Results of fuel energy savings analysis

Fuel utilization components	Supermarket energy systems				Unit
	Conventional	Scheme-1	Scheme-2	Scheme-3	
Trigeneration fuel	-	7450	4431	7907	MWh
Boiler fuel	874	25	21	194	MWh
Imported electricity	*2817*	*62*	*1160*	*44*	MWh
Fuel of imported electricity	8537	189	3515	135	MWh
Exported electricity	-	*333*	*0.120*	*379*	MWh
Fuel saving to grid supply	-	**1009**	**0.364**	**1148**	MWh
Total fuel required	9411	6655	7967	7088	MWh
Fuel energy savings	-	2756	1444	2323	MWh year^{-1}
Fuel energy saving ratio (FESR)	-	29.3	15.3	24.7	%

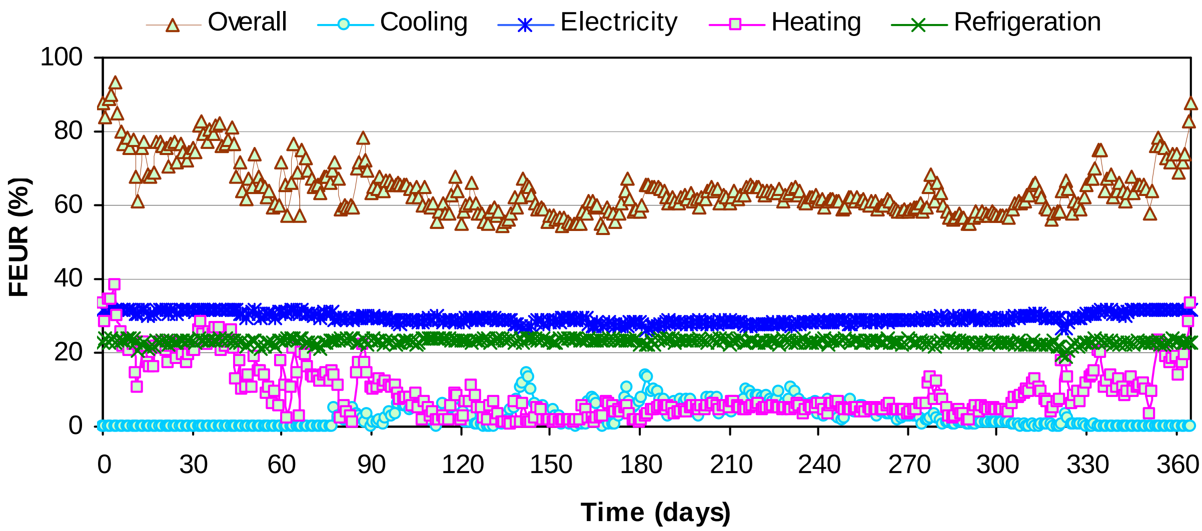

Figure 8: **Daily average fuel energy utilisation ratio of Scheme-1**

Scheme-2 is the current system in the supermarket which employs: a trigeneration arrangement with bio-fuel engine based CHP of 200 kW_e capacity and a sorption chiller with a cooling capacity 250 kW_{th}, a 200 kW_{th} R-407C electric chiller for air conditioning and 2 gas boilers of 200 kW_{th} capacity each. The analysis has shown that with this arrangement the trigeneration system can satisfy 97.5% of the heat demand with only 2.5% provided by the gas boilers. The electricity generated by the trigeneration arrangement in this scheme is 1,555 MWh which is 57.3% of total electricity requirement of the store. The annual primary fuel requirement of scheme-2 is 7,967 MWh and the average FEUR is 58.7%. Compared to the conventional energy system, scheme-2 can provide primary fuel energy saving of 1,445 MWh with FESR of 15.3% (Table-2).

Scheme-3 is a modification to the existing scheme in the supermarket. It utilises a trigeneration arrangement with a 342 kW_e gas engine based CHP and a sorption chiller of 310 kW_{th} integrated with a CO_2 refrigeration plant similar to that of Scheme-2. Scheme-3 also employs a 200 kW_{th} R-407C refrigeration system for space cooling and 2 x 200 kW_{th} gas boilers for space and domestic hot water heating. This scheme was found to have a FEUR of 60.7% and FESR of 24.7% compared to the conventional system.

Table 3: CO_2e emissions of investigated supermarket energy systems

CO_2 emissions	Annual leakage 15% of charge				Units
	Conventional	Scheme-1	Scheme-2	Scheme-3	
Indirect CO_2 emissions	1,702	1,227	638	1,308	$tCO_2e\ year^{-1}$
Direct CO_2 emissions:					
Refrigerant leakage	411	20	20	20	$tCO_2e\ year^{-1}$
Refrigerant recovery losses	75	-	-	-	$tCO_2e\ year^{-1}$
Total annual emissions	2,188	1,247	658	1,328	$tCO_2e\ year^{-1}$
Net CO_2 emissions saving		941	1,530	860	$tCO_2e\ year^{-1}$
		43.0	69.9	39.3	%

Table 3 shows a comparison between CO_2e emissions of the conventional and the three energy system alternatives. The analysis assumed annual refrigerant leakage rate of 15% of system charge. It can be seen that the proposed system will lead to CO_2e emissions savings of 941 tCO_{2e} which represents 43% savings over the conventional system. Scheme-2 will result in savings of 1530 tCO_2e mainly because of the use of biofuel and the assumption that the emissions factor of biofuel is zero.

5.3. Economic analysis

To establish the economic viability of the proposed energy system, prices of fuel energy and the capital cost of the equipment were based on UK prices obtained from equipment suppliers and end users. For the data used, the proposed energy system will need additional investment of £382,000 compared to the conventional energy system but will produce running cost savings of the order of £121,000 per year, giving a payback period of 3.2 years. The payback period of scheme 2 will be very long, in excess of 8 years, due to the high cost of biofuel, whereas the payback period of scheme 3 will be 4.3 years. The payback period is strongly influenced by the ratio of electricity to gas prices known as the `spark ratio'. Figure 9 shows the variation of the payback period of the proposed energy system with spark ratio. It can be seen that the payback period drops sharply as the spark ratio increases with the payback period reducing from 8 at a spark ratio of 2.7 to 2.5 at a spark ratio of 4.0. The spark ratio in the UK varied between 2.7 and 4.6 in the period 2007-2009 [10]. The spark ratio used in the analysis was 3.6.

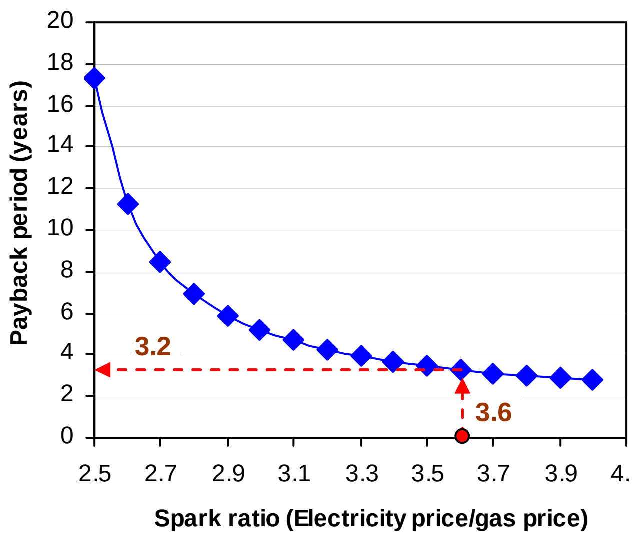

Figure 9: **Variation of payback period with spark ratio**

6. Conclusions

Three supermarket energy system alternatives to a conventional system have been investigated using experimental data from a pilot plant in the laboratory and simulation studies. The results indicate that:

1. Integration of CO_2 refrigeration with trigeneration systems can produce significant energy and GHG emission savings over conventional systems utilising electricity from the national grid and thermal energy from gas fired boilers.

2. From the 3 alternative systems investigated, the most energy efficient configuration is the one that utilises the cooling produced by the sorption system of the trigeneration plant to condense the CO_2 refrigerant of the MT and LT refrigeration systems. The MT system is a secondary 'volatile' pumped system whereas the LT system is a conventional direct expansion system.

3. The use of biofuels to drive the trigeneration plant can be attractive in terms of overall reduction in GHG emissions. However, the cost of biofuels can be higher than that of conventional fuels which will have a negative impact on the economic attractiveness of the system.

Acknowledgements

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Nomenclature

CHP:	Combined heat and power
COP:	Coefficient of performance
CR:	Circulation ratio
DX:	Direct expansion
E_f:	Fuel consumption [kWh]
E_{annual}:	Annual energy consumption [kWh]
EXV:	Electronic expansion valve
FESR:	Fuel energy saving ratio
FEUR:	Fuel energy utilization ratio
GWP:	Global warming potential [$kgCO_2\ kg^{-1}$]
GHG:	Green house gases
HVAC:	Heating ventilating and air conditioning
HX:	Heat exchanger
ICMT:	High pressure expansion valve
IHX:	Internal heat exchanger
L_{annual}:	Annual refrigerant leakage (kg)
LT:	Low temperature
m_{charge}:	Mass of refrigerant charge (kg)
MT:	Medium temperature
n:	System operating time (years)
NG:	Natural gas
Q:	Heating or refrigerating load (kW or kWh)
RV:	Regulator valve
SV:	Solenoid valve
T:	Temperature (°C)
TEWI:	Total equivalent warming impact ($kgCO_2e$)
W:	Electrical power/energy (kW or kWh)

Greek symbols

α:	Recovery factor
β:	CO_2 emissions factor ($kgCO_2\,kWh^{-1}$)
η:	Efficiency

Subscript

abs:	Absorption chiller
c:	Cooling
ChW:	Chilled water
comp:	Compressor
con:	Condensing
conv:	Conventional
CW:	Cooling water
df:	Defrost cycle
e:	Electrical
eva:	Evaporating
h:	Heating
htf:	Heat transfer fluid
others:	Other than refrigeration and electric chiller
prop:	Proposed
r:	Refrigeration
SG:	Standby generator
th:	Thermal
tri:	Trigeneration

References

[1] Tassou, S.A., Ge, Y.T., Hadawey, A., Marriott, D., 2011, "Energy consumption and conservation in food retailing", Appl. Therm. Eng., Vol 31, pp. 147-156.
[2] Sugiartha, N., Tassou, S.A., Chaer, I., Marriott, D., 2009, "Trigeneration in food retail: An energetic, economic and environmental evaluation for a supermarket application", Appl. Therm. Eng., Vol. 29, pp. 2624-2632.
[3] Tassou, S.A., Chaer, I., Sugiartha, N., Ge, Y.T., Marriott, D., 2007, "Application of trigeneration systems to the food retail industry", Energy Conversion and Management, Vol 48, pp. 2988–2995.
[4] Tassou, S.A., Chaer, I., Sugiartha, N., Marriott, D., Suamir, IN., 2008, "Trigeneration – a solution to efficient use of energy in the food industry", Proceeding of Inst. R. 2007-08 7/1-16.
[5] Suamir, IN., Tassou, S.A., Hadawey, A., Chaer, I., Marriott, D., 2009, "Investigation of the performance characteristics of an ammonia-water absorption chiller in a trigeneration system arrangement", Proceedings of HPC Conference, Berlin, Germany, ISBN 978-0-9563329-0-5, paper HPC430, 6 pgs.
[6] British Standard BS EN 378-1, 2008, "Refrigerating systems and heat pumps – safety and environmental requirements", BSI, 68 pgs.
[7] TOC, 2006, "Report of the refrigeration, air conditioning and heat pumps", UNEP, Nairobi, 223 pgs.
[8] MTP, 2008, 'BNCR36: Direct emission of refrigerant gases', Market transformation programme, http://efficient-products.defra.gov.uk/cms/product-strategies/subsector/commercial-refrigeration.
[9] DEFRA, 2009, "Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors", DEFRA, London, 59 pgs.
[10] Moorjani, M., 2009, 'CHP in industrial and commercial sectors, a case study', http://chp.decc.gov.uk/cms/presentations-archive/.