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SID 4 Annual/Interim Project Report for Period 01/07/06-31/06/07

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Project details

1. Defra Project code: ACO403
2. Project title: Fostering the Development of Technologies and Practices to Reduce the Energy Inputs into the Refrigeration of Food
3. Defra Project Manager: Dr Christina Goodacre
4. Name and address of contractor:
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5. Contractor's Project Manager: Mr S James
6. Project: start date 01.07.06
   end date 31.06.09

Scientific objectives

7. Please list the scientific objectives as set out in the contract. If necessary these can be expressed in an abbreviated form. Indicate where amendments have been agreed with the Defra Project Manager, giving the date of amendment.

Objective 1 – Identify and rank 10 ‘operations’ (process/food combinations) in order of the potential by the use of improved technology and enhanced business practice to reduce energy usage in food refrigeration. Objective 2.1 – Develop generic technologies and business practices that have the potential to reduce refrigeration energy consumption. Objective 2.2 - Identify the features of the most efficient current systems and make them and their energy saving potential widely known to the industry. Objective 2.3 - Identify and overcome any barriers to the uptake of current technologies that have the potential to substantially improve the energy efficiency of the 10 operations identified in 1. Objective 2.4 – Quantify work being carried out to fill gaps in knowledge/technology identified to improve energy efficiency of the 10 operations identified in 1. Objective 2.5 – Develop programmes to obtain the funding required to provide the missing information if no current work identified in objective 2.4. Objective 3 – Carry out feasibility studies on current technologies that have the potential to achieve substantial energy saving in food refrigeration that are developed to a stage where they can immediately obtain funding from other sources.

Summary of Progress

8. Please summarise, in layperson’s terms, scientific progress since the last report/start of the project and how this relates to the objectives. Please provide information on actual results where possible rather than merely a description of activities.

Objective 1 – Identify and rank 10 'operations' (process/food combinations) in order of the potential by the use of improved technology and enhanced business practice to reduce energy usage in food refrigeration.

The aim of objective 1, carried out by FRPERC, was to map the relevant energy uses in different parts of the cold chain. By bringing together all available information the 10 processes with most potential to reduce the UK's energy consumption will be identified.

The initial approach was to investigate the data available concerning the UK production and consumption of food to obtain an indication of the major food commodities in the UK and to determine which were most likely to consume substantial amounts of energy for refrigeration. In parallel to this, data was also sought concerning the different sectors throughout the food chain to determine the scale of refrigeration processes in use and indications of the energy being consumed.

Major sources of UK energy consumption and food production information were the datasets made available by the DTI, DEFRA, The Office of National Statistics and numerous Trade Associations and Organisations.

Certain trade organisations within the food industry (e.g. The Food and Drink Federation (FDF), Dairy UK, The Cold Storage and Distribution Federation) are responsible for operating Climate Change Agreements (CCAs). These require the participating companies to providing details of their annual energy consumption figures. Although the detailed information is confidential, some of the operators of the schemes (members of project steering group) were able to provide data that could be used for estimation purposes. The companies have to provide a breakdown of the proportion of the annual energy consumption that is electricity, gas or oil, but the proportion used for refrigeration is not fully defined. The FDF have carried out surveys to assess refrigeration energy usage which provide a useful insight into the food manufacturing sector. The CSDF are due to finish analysis of a recent survey later this year, which will provide the most accurate assessment of energy usage in the cold storage and distribution sector.

Initial broad brush analysis based on UK production data (thousands of tonnes/year) and household consumption data (kg/week) indicated that dairy and meat were key sectors. They clearly required an in depth investigation since strict refrigerated temperature control is required from post harvest/post slaughter, during processing and all along the chill/frozen chain to the consumer.

Detailed data of the type needed to populate the energy mapping matrix at the individual process level is scarce. More sub-metering of electricity supplies is required in the food industry. We are encouraging greater awareness of their benefits at dissemination events (e.g. presentations at Food Climate Research Network (FCRN), Campden and Chorleywood Research Association (CCFRA), FDF, Food Processing Faraday events) and articles (e.g. IChemE newsletters) as they are key to promote energy saving measures. Contact was made with sub-metering companies and food companies that were believed to have sub-metering equipment already installed. Sub-metering was often only at the zone level and not at process level linked to throughput data. Meat and dairy companies known to have electricity sub-metering installed on refrigeration systems were contacted and data obtained. So far the data has highlighted faults and sub-optimal refrigeration system operation. This confirmed that there are significant energy savings potential from optimisation and applying good maintenance practice for existing plant before new or alternative technologies need to be considered. It also highlighted the benefits of sub-metering and the need for staff that have time and knowledge to interpret the data.

Objective 2.1 - Develop generic technologies and business practices that have the potential to reduce refrigeration energy consumption.

Within objective 2.1 all the academic partners have worked to:

- Review new and emerging technologies (objective 2.1.1).
- Assess energy savings potential from efficiency improvements of current technologies (objective 2.1.2).
- Development of system models (objective 2.1.3).
- Assessment of business practices upon equipment requirements & performance (objective 2.1.4).
- Development of dynamic food models (objective 2.1.5).

Objective 2.1.1. Review new and emerging technologies.

Brunel University have reviewed new and emerging refrigeration technologies (Brunel report 1)

The general refrigeration technology review considered the following technologies: adsorption refrigeration, air cycle refrigeration, magnetic refrigeration, Stirling cycle refrigeration, thermoelectric refrigeration and thermoacoustic refrigeration.

Adsorption refrigeration, like absorption is a thermally driven technology. It has been available commercially for air conditioning applications for a number of years and recent interest has been in its application in tri-generation systems. Research is being carried out but as yet no systems are commercially available for low temperature commercial refrigeration applications.

Air cycle technology has been used, evaluated or proposed for a wide range of applications in the food industry. Recent interest in further development and application of the air cycle technology has been in combined heating and refrigeration and refrigerated food transport applications. No systems are available

off the shelf for these applications.
Considerable research and development is currently being carried out internationally on magnetic refrigeration, Stirling cycle, thermoacoustic and thermoelectric refrigeration by research establishments, universities and industry, but activity in the UK is limited. Prototype refrigeration systems based on these technologies have been developed but refrigeration capacities and COPs at present are very low compared to those of the conventional vapour compression cycle. It is likely that these technologies will be more suitable for low refrigeration load, stand alone refrigeration equipment such as domestic refrigerators, refrigerated cabinets and transport refrigeration.

FRPERC have worked to review technologies for food:
Retail display
The potential for saving energy used in supermarket retail display of foods is considered to be one of the most significant opportunities. The largest energy saving opportunity is concerned with overcoming the inefficiencies related to the operation of open fronted cabinets, especially the most common multi-deck units.
In June 2007 a workshop was run at FRPERC, Bristol to specifically target the potential for energy saving and reducing carbon emissions from retail display. The main outcome was a proposal to produce a prototype cabinet that would incorporate significant energy saving measures and meet the carbon emission savings demanded by modern supermarket chains.
Cold stores
Chilled and frozen cold storage and distribution operations have been identified as major users of energy. Recent work at three UK cold stores has shown that significant opportunities for energy savings exist, even with current technologies such as air curtains and other devices to reduce air infiltration, optimisation of existing plant operation and effective maintenance practice.
Further information due from the current CSDF survey will help quantify the total savings potential.
Dairy
In the initial stage of the energy mapping exercise the dairy industry was highlighted as a major user of energy for refrigeration indicated by the large quantity of dairy products produced and consumed in the UK. More detailed analysis of the cooling of UK raw materials immediately post harvest or post slaughter revealed that cooling of milk on the farm was the raw material requiring the most energy in total. Based on results of UK and US studies on different types and configurations of milk coolers estimated savings of over 50% between the average and best systems were indicated.
Meat
In the initial stage of the energy mapping exercise the meat industry was highlighted as second only to dairy as a user of energy for refrigeration indicated by the large quantity of meat and meat products produced and consumed in the UK. Therefore, the electrical energy consumption of refrigeration processes throughout a red meat abattoir and cutting plant has been measured in detail over a three month period. The primary chilling of meat immediately post slaughter was the process that used the majority of the electrical energy in the plant and used more energy than the sum of all the other monitored refrigeration systems. Energy saving measures most appropriate to primary chilling included significantly reducing infiltration through open doors, general optimisation of existing refrigeration plant and repair of faulty components and introduction of appropriate maintenance procedures.
Potatoes
The analysis of UK raw materials immediately post harvest or post slaughter identified that after milk, potatoes had the next highest production volume. Although in the past potatoes were not always cooled and stored under refrigeration there is an increasing trend towards total refrigeration. The British Potato Council has estimated that approximately 50% of the UK potato production (6.5 million tonnes) is refrigerated, but refrigeration contractors and design consultants contacted have commented that in their opinion this is an underestimate. Estimates of the total energy used for refrigerated potato cooling and storage have been made based on a previous study over a two year period recording energy used in a UK store. More recent data is required on the increasing number of refrigerated UK stores and their operating efficiencies to determine the potential savings that are greater than most vegetables due to the volume of production and the length of storage of the crop.
Products chilled/frozen after cooking
Within the manufacturing sector of the food chain it is estimated that the products requiring the most refrigeration are those having the highest production volume/throughput and require to be rapidly cooled over the greatest temperature range. More detailed analysis is underway to confirm whether this is borne out by data provided from CCA data that provides annual throughput (tonnes/year) data and sub-sector category.
Transport
Reliable data for energy use in refrigerated transport is still being sought. Studies tend to focus on total emissions from road haulage with less emphasis on specific energy for refrigeration of foods.
Catering sector
Due to the diversity of the catering sector and the vast numbers of catering outlets in the UK estimates of energy use and the potential for savings are the most variable. However, it is known that there are large

variations between the energy efficiency of the best and worst of existing equipment and upgrading the current stock to the best of current technologies would have a significant impact on total energy use in the sector.
Overall it has been identified and confirmed by a number of experimental studies in specific food sectors that major potential savings in energy used for food refrigeration are often still available using a combination of existing technologies, improved process control, optimisation of existing refrigeration systems and components and the introduction and adherence to improved refrigeration maintenance procedures. However, as has been highlighted by recent surveys (FDF/Carbon Trust) there is a serious shortfall of suitably trained staff in the food (and refrigeration) industry that can implement these changes. It appears that there are existing opportunities for significant energy savings.

Objective 2.1.2. Assess energy savings potential from efficiency improvements of current technologies.

Brunel University have worked on energy saving within constant temperature areas of the cold chain (transport and retail) (Brunel reports 2 and 3).

Transport Refrigeration

- The COP of transport refrigeration systems is quite low, ranging for around 0.5 at –20°C space temperature to 1.5~1.75 at + 3°C space temperature and 30°C ambient temperature.
- Refrigeration systems in these vehicles are invariably driven by auxiliary diesel engines.
- Average fuel consumption of articulated vehicles (excluding the refrigeration auxiliary diesel engine) is 24 l/hr. Fuel consumption of auxiliary diesel engine is approximately 2 l/hr (8% of vehicle main engine consumption).
- Capacity and size of vapour compression refrigeration systems can be reduced through the use of thermal energy storage (eutectics). For small journeys the vapour compression system can be eliminated completely.
- Sufficient reject heat is available from the engine of articulated vehicles to drive sorption refrigeration systems at normal out of town driving conditions but insufficient heat will be available in town driving. This shortcoming can be overcome through the use of an auxiliary heat source or eutectic energy storage. Other issues to be addressed are the size and mounting of the sorption refrigeration system.
- The air cycle technology is quite promising for food transport applications. Main disadvantages at present is the low COP compared to that of the vapour compression system, particularly for chilled food distribution applications, and the unavailability of off the shelf components.
- Direct power generation from the heat in the exhaust of the engine to power refrigeration systems may be a promising technology for the future. Other technologies that need further investigation and consideration are Stirling cycle powered systems, magnetic refrigeration and solar energy driven systems.

Retail display:

- In recent years, considerable effort has been devoted to the development of refrigeration technologies using CO2 as a refrigerant. The application of the first such systems in large retail food stores has been based on the cascade technology with CO2 in the medium and low temperature refrigeration circuits and another refrigerant such as propane, ammonia or R404A for heat rejection. A very small number of trans-critical systems have also been installed which use CO2 for both refrigeration and heat rejection.
- Not enough field experience and performance data are yet available in the open literature from the application of sub-critical and trans-critical CO2 systems to food refrigeration. Results to date indicate that sub-critical CO2 systems for low temperature applications may be more efficient than conventional R404A systems. For high temperature applications where the system will operate in the trans-critical region the efficiency of CO2 systems has been found to be inferior to that of R404A. Overall, across the whole operating range in a retail food store, CO2 systems are though to be efficiency neutral compared to R404A systems.
- Other technologies, such as secondary loop refrigeration systems have also been employed to avoid the use of HCFC and HFC refrigerants. Results from installations to date are mixed but efficiency and cost comparisons between secondary loop and R404A systems are thought to be similar to those between CO2 and R404A systems.
- Irrespective of the type of refrigerant employed, significant energy savings can be achieved by improving the efficiency of the compressors, reducing the pressure ratio in the system, and continuously matching the refrigeration capacity to the load. The pressure ratio can be reduced by employing floating and suction pressure control or heat rejection to the ground.
- Considerable opportunities also exist from refrigeration and HVAC system integration, heat recovery and amplification using heat pumps and demand side management and system diagnostics.
- Another area that provides significant opportunities for energy savings is the design of more efficient display cabinets. Research and development areas to be addressed are the reduction of the infiltration rate, reduction of fan and lighting energy consumption, the design of more efficient evaporator coils to increase the evaporating temperature, reduce frosting rates and the implementation of defrost on demand.
- To prioritise research and development areas it is necessary to employ more sophisticated economic

analysis methods such as Life Cycle Cost or Annualised Life Cycle Costs rather than the simple Payback Period.

Supermarket refrigeration system and thermal environment modelling.

Work in the first 12 months has concentrate of the modelling of display cabinet coils with alternative refrigerants: CO_2, R404A and secondary fluids (propylene glycol). Work is currently being carried out on the integration of cooling coil and air flow modelling to enable simplified cabinet models to be developed to be used in supermarket refrigeration system and thermal environment models. These models will be used for the evaluation of alternative refrigeration technologies and the optimum integration and thermal management of refrigeration and HVAC systems in supermarkets.

Objective 2.1.3. Development of system models.

LSBU are developing transient models to test (and optimise) various refrigeration systems used in the industrial production chain for food.

A preliminary internet and literature study by LSBU concluded that there are very few proprietary refrigeration system design packages on the market. Those that exist appear to have come from university departments. Packages, which exist, do not appear to have all the systems configurations and sophistications that the project requires. Therefore, if used the source codes of these proprietary packages would have required significant modification useful to this project. This would have only been possible if the developers would provide the team with source code. As it this was unlikely it was proposed that a purpose written computer software would be developed. The software package now under development by the LSBU team has the working title, 'Vapour Compression Refrigeration' (VCR). It has been written on a Visual BASIC platform, which allows the development of a 'user friendly' interface with the mathematical codes.

A range of eleven typical refrigeration systems used in the food chain were identified. It was agreed by the consortium that LSBU's First Year objective was to develop a transient model of a refrigeration system commonly found in a cold-store batch freezing/chilling process. Enquiries to manufacturers revealed that the most common system used in batch freezing today is based on a single-stage direct air-cooling refrigerator.

Steady-state and dynamic models of compressors, heat exchangers and expansion devices have been developed. As part of this study a review of the efficiency performance of common refrigerants, compressors and heat exchangers has also been completed. During this First Year, following a detailed investigation of component models and the collation of refrigerant data, a transient model of the single-stage refrigeration system has been developed. A specification for this software has been prepared.

The refrigerator model, shown schematically in Figure 1, consists of a D-X evaporator and fan, dry-air cooled condenser and fan, semi-hermetic suction gas cooled compressor, suction-line heat exchanger and thermostatic expansion valve connected by refrigerant lines, which too have been modelled. Coil frosting and defrosting models are also included. A cold-store model has written and included within VCR V1. This takes account of both the design of a cold-store and its operation, in terms of loading and unloading schedules, door-opening effects and those produced by ancillary equipment, such as additional fans. In addition, a simple the food product cooling model has been included. The software also allows the user to select the location of the cold-store and the time of year for which the process is to be simulated. This facility is provided by the inclusion of ambient temperature data weather information for a number of UK locations. If required, however, a fixed ambient temperature may be selected.

In the future the cold-store and food-product coding will replaced by the FRPERC software models (see objective 2.1.5).

Output data from the software will include the transient data, such as, refrigerator energy consumption, store temperature, food-product temperature and moisture. During the Second year it is proposed to extend the VCR simulation software to include other refrigeration systems commonly used within the food-chain.

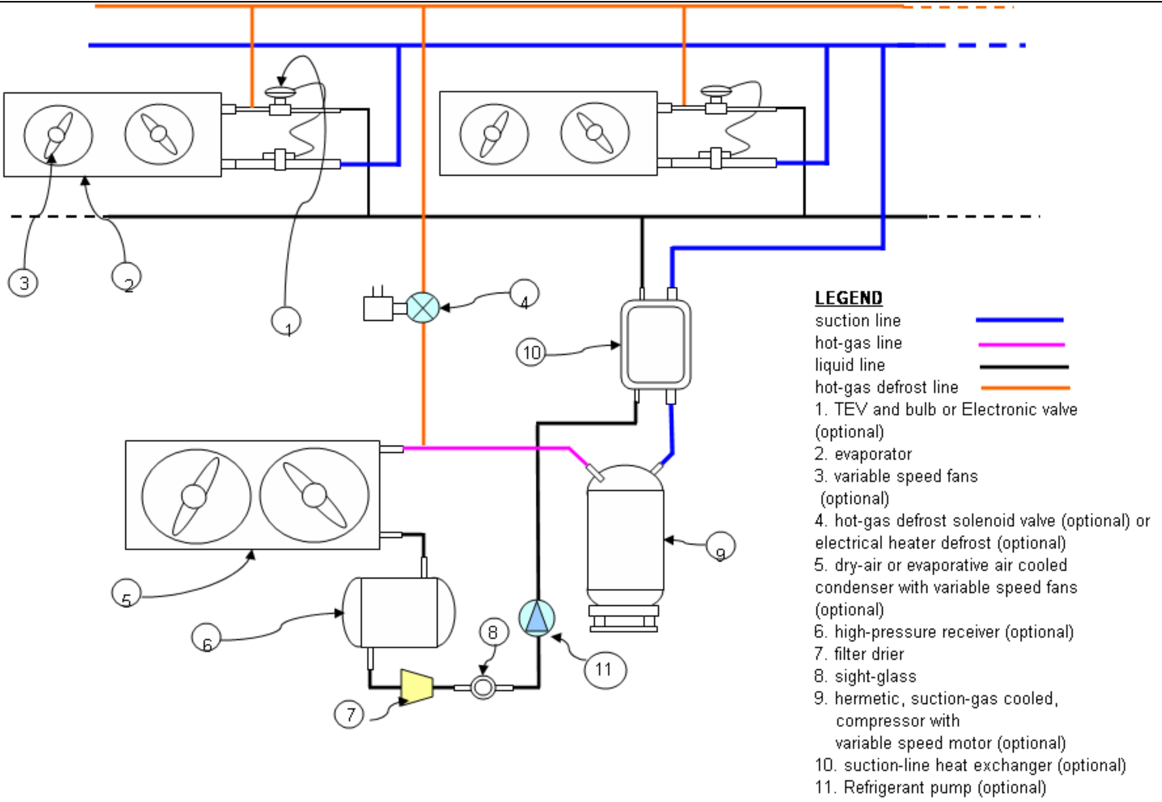

Figure 1: Schematic view of the air-cooling, single-stage, refrigerator model developed by LSBU.

Objective 2.1.4. Assessment of business practices upon equipment requirements & performance.

Sunderland University has two specific roles, a) assess the effectiveness of existing maintenance practices and develop appropriate maintenance strategies and b) analyse food manufacturing supply chains to identify areas where energy savings can be made.

With regard to maintenance activities, 10 organisations have been contacted and have agreed to participate. An interview guide has been developed (for one to one interviews with senior management) and questionnaires will be distributed to maintenance and production staff. Due date: October 07. A new approach to collecting and analysing maintenance data for refrigeration will be completed late August 07.

With regard to the food supply chain, the same 10 organisations as above have been contacted and have agreed to participate. These consist of 5 dairies, 4 meat manufacturers and 1 fresh produce factory. The Value Stream Mapping approach has been adopted to identify key areas of waste in the food supply chain that contribute to unnecessary refrigeration usage. This approach involves walking around the factory floor and recording the processes involved in the production of goods from start to finish as well as the cycle times (the time it takes an operator to go through all of their work elements before repeating them) and lead times (the time it takes for one piece to move all the way through a process from start to finish).

To gain further information about each of the companies with regards to its suppliers, customers, products, storage areas etc an interview guide has also been developed for one to one interviews with senior management or whoever they deem to be the most knowledgeable in these particular areas.

In June a preliminary test using the above methods was carried out on three dairies in Northern Ireland. Results from this show that creameries use substantial amounts of energy however this could be reduced by making some minor changes in the production processes, the aim being to reduce lead cycle times thus reducing the amount of energy used/required

Initial findings identifying key areas of waste, which contribute to unnecessary refrigeration usage, will be developed by November 07.

Objective 2.1.5. Development of dynamic food models.

FRPERC have been working with LSBU to create a dynamic refrigeration and food model. Based on existing code FRPERC have rewritten the software to be compatible with the LSBU software and have worked to develop a DLL to interact between the 2 model. A VisualBasic GUI (Graphical User Interface) is being developed to cerate a user friendly interface to the software.

Amendments to project

9. Are the current scientific objectives appropriate for the remainder of the project? .... **YES** ☒ **NO** ☐

If **NO**, explain the reasons for any change giving the financial, staff and time implications.

Contractors cannot alter scientific objectives without the agreement of the Defra Project Manager.

Progress in relation to targets

10. (a) List the agreed milestones for the year/period under report as set out in the contract or any agreed contract variation.

It is the responsibility of the contractor to **check fully that all milestones have been met** and to provide a detailed explanation when they have not been achieved.

Milestone		Target date	Milestones met	
Number	Title		In full	On time
1	First operations to be investigated identified	31.09.06	Yes	Yes

(b) Do the remaining milestones look realistic?..**YES** ☒ **NO** ☐

If you have answered **NO**, please provide an explanation.

Publications and other outputs

11. (a) Please give details of any outputs, e.g. published papers/presentations, meetings attended during this reporting period.

Articles:
Swain, M. J. Improving the energy efficiency of food refrigeration operations. IChemE Food and Drink Newsletter, 4 Sept. 2006.

Book chapters:
Evans, J. A. Minimising energy consumption associated with chilling, refrigerated storage and cooling systems (including integrated heating and cooling systems). In: Improving water and energy management in food processing. Editors; Professor Robin Smith, Dr Jiri Klemeš and Dr Jin-Kuk Kim. Part 3: Improving the efficiency of energy use in the food industry. In press.

Conference papers:
Evans, J. A. and Gigiel, A. J. Reducing the energy consumption in cold stores. ICR 2007, Beijing. Accepted.
Swain, M.J., Evans, J.A. and Brown, T. Improving the energy efficiency of food refrigeration operations. CIGR, Naples, Sept, 2007 (accepted).
Maidment G. IOR Annual Conference 2006 - Smaller, Colder, Smarter.
Maidment G. CFDS National Conference 2006.

Presentations:
Prepared by Evans, J. A., presented by George, M. Fostering the Development of Technologies and Practices to Reduce the Energy Inputs into the Refrigeration of Food. CCFRA, 23.05.06.
Evans, J. A. Fostering the Development of Technologies and Practices to Reduce the Energy Inputs into the Refrigeration of Food. FCRN, 08.09.06.
Swain, M. J. Defra food refrigeration – energy mapping exercise. FRCRN, 08.09.06.
Maidment, G. Interview on Radio 4 Material World.

(b) Have opportunities for exploiting Intellectual Property arising out of this work been identified? .... **YES** ☐ **NO** ☒
If **YES**, please give details.

(c) Has any other action been taken to initiate Knowledge Transfer?........ **YES** ☒ **NO** ☐
If **YES**, please give details.

One day retail refrigeration workshop involving 10 companies was held on 26.06.07.
Presentations have been made to meetings organised by the IOR, CCFRA, FCRN and Food Processing Farady.
A Moodle web site has been set for the partners and steering group and another for the stakeholders group. Information on the project, presentations, articles and details of meetings are available to download.

Future work

12. Please comment briefly on any new scientific opportunities which may arise from the project.

The partners have identified that supermarkets are high users of energy and therefore have begun development of a research project to optimise and develop novel retail display refrigeration. Through a one-day workshop a proposal was develop that has been submitted to Tesco innovation fund. The possibility of extending this into a full LINK project with additional supermarket and manufacturing partners is currently being investigated.

Declaration

13. I declare that the information I have given is correct to the best of my knowledge and belief.

Name	Stephen James	Date	15/08/07
Position held	Director		