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Telephone No. 020 7238 1612
E-mail: research.competitions@defra.gsi.gov.uk

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SID 4 Annual/Interim Project Report for Period 01/07/06-30/06/08

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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:
   FRPERC
   University of Bristol
   Churchill Building
   Langford
   Bristol
   Postcode BD40 5DU
5. Contractor's Project Manager: Mr S James
6. Project: start date 01.07.06
   end date 30.06.09

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 were 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 Food Storage and Distribution Federation) are responsible for operating Climate Change Agreements (CCAs). These require the participating companies to provide 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 FSDF 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 are 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 in published articles (e.g. IChemE newsletters) as they are key to promoting 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 have highlighted faults and sub-optimal refrigeration system operation. This confirmed that there is 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.

The review covered:

a) Technologies that could be applied to all types of refrigeration equipment in the food sector (Paper 1)

b) Technologies for constant temperature refrigeration that are or could be applied to the food distribution and food retail sectors. (Papers 2 and 3).

The general refrigeration technology review considered the following technologies: Sorption refrigeration systems (adsorption), ejector refrigeration systems, trigeneration, air cycle refrigeration, magnetic refrigeration, Stirling cycle refrigeration, thermoelectric refrigeration, thermoacoustic refrigeration, ground cooling and heating. The review established the current state of development of these technologies, their potential and barriers to their wide application and research and development needs.

What has been learnt – Some of these technologies have the potential to reduce significantly the environmental impacts of food refrigeration systems but it is unlikely that any will make significant inroads into the very well established conventional vapour compression market over the next five to ten years due to efficiency and capital cost considerations. Some of the emerging technologies will find applications in niche markets such as in trigeneration systems and thermal energy recovery to produce refrigeration. There is significant potential for energy savings from the improvement of the performance of vapour compression systems through the use of more efficient components and controls. Vapour compression systems also offer the potential for heat recovery from the condenser but care must be taken to ensure that the quantity of energy recovered outweighs the higher compressor power consumption that will arise from higher condensing pressures.
Further work required - To gain maximum impact, work is required through case studies to independently verify, quantify and publicise the energy saving potential of improved system design and controls, as well as use of energy recovery from the refrigeration system itself and food processing operations to produce refrigeration through sorption systems and ejector refrigeration.

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.
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 FSDF 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 are 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.
Transport
Reliable data for energy use in refrigerated transport are 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 has worked on energy saving in refrigerated transport and together with FRPERC on retail (retail refrigeration and transport reviews). Work on frozen storage, chilling and freezing and commercial refrigeration has been carried out by FRPERC.

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 concentrated of the modelling of display cabinet coils with alternative refrigerants: CO2, 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.

Commercial catering refrigeration:
A report on energy usage and performance of commercial catering cabinets has been produced (Commercial Service Cabinets.doc). The fundamental design of commercial service cabinets has changed little over the past 20 years. Step changes have occurred that have improved efficiency. There is still an emphasis on first cost of units rather than life cycle costing and manufacturers have difficulty justifying the higher costs of energy saving components against imported cabinets that have a low initial cost but higher energy consumption in use.
Potential exists to improve frozen CSCs as these compare unfavourably with other options. In a commercial kitchen frozen cabinets are usually only opened at the beginning and end of a day and therefore chest freezer should be a more efficient option that would not have a great influence on usability of the cabinet. Schemes such as the ECA have reduced compliance thresholds and are therefore encouraging manufacturers to implement DC fans and other energy saving features. There is still a large variation between the most, and least, efficient cabinets and there is considerable potential to save energy using currently available technologies.
There is considerable lack of data on performance of cabinets in use. Improved understanding of requirements in commercial kitchens would enable cabinets to be designed and optimised for usage.

Alternative technologies:
Reports have also been complied by FRPERC on alternative chilling and freezing technologies (Food chilling and freezing technologies.doc) and equipment operation and optimisation (Equipment operation and optimisation.doc). The report on alternative technologies included a review of operation of refrigeration systems, process optimisation and new/alternative refrigeration methods and systems. The review of equipment covers equipment optimisation and available energy efficient technologies.

Objective 2.1.3. Development of system models.

The general objectives of modelling study are to develop scientifically based models of refrigeration systems common across the food chain, so as to allow study of performance and component choice. This part of the project is to be guided by the results of the Mapping Study, which will be used to provide both direction of the study and prioritise the development of system models. Specific objectives are:

1. Develop steady state system models using custom software e.g. Coolpack: Variables examined will be; refrigerant types, compressors, compression stages, intercooling, heat exchanger types, refrigeration system controls including those for part load.
2. Develop dynamic system models based upon their existing expertise and software.
3. Identify generic system types resulting from the mapping, prioritised for examination.
4. Develop refrigeration models of chilling and freezing, distribution and retail systems.
5. Test models for optima in regard to energy consumption, by varying component configurations and combinations.
6. Develop dynamic refrigeration system models for consideration with the dynamic food models developed by FRPERC

Deliverables:
1. A report that details the generic system types and priorities – End month 3
2. A range of generic refrigeration models – End month 7
3. A report and paper submission detailing sensitivity studies on component/ system configuration – end month 12.
4. A report, model and paper submission covering dynamic behaviour of systems – from end month 12- end month 24.
5. A report on the current best practice – Month 13
6. A report summarizing the case studies carried out by the team – month 20
7. A report summarizing the teams progress for improved generic best practice, based on the outcomes of the outcomes of the case studies. Month 24

Progress towards objectives and deliverables:
1. A literature review of refrigerator modelling techniques has been completed. (Objective 2.1, Deliverable

3.1, LSBU Report No 2)

2. A study has revealed at least 11 types of refrigeration system might be found in the food-chain. (Objectives 2.1 and 2.3, Deliverable 3.1, LSBU Report No 1)
3. 4.3 A number of case studies have been carried out and reported,(Objective 2.1, Deliverable 3.1, LSBU Report No 2):
   - Two cold-store systems (-26oC)
   - Chill store (5oC)
   - Supermarket chill pack
   - Supermarket frozen pack
   - Transport container application
4. EUROVENT data has been used to inform the design of the software and for comparative purposes. (Objective 2.1, Deliverable 3.1, LSBU Report No 2)
5. Comparative performance of a range of refrigerant fluids has been completed.
6. A study into the relative performance of proprietary condensers and evaporators has been carried out. A study into the efficiency performance of proprietary compressors has been carried out, (Objective 2.1, Deliverable 3.1, 3.2,and 3.3, LSBU Report No 2).
   Draft specification for dynamic system software model has been produced.
7. Following a review of existing generic software the Visual Basic development platform was agreed,(Objectives 2.2, 2.4 and 2.6, Deliverable 3.1,3.2, 3.3 and 3.4, LSBU Report No 1, No2)
8. Component models have been investigated,(Objective 2.2, 2.4 and 2.6 Deliverable 3.2, 3.3, 3.4 LSBU Report No 1)
9. A literature review of fault detection and diagnosis in refrigerator systems, (Objective 2.2, 2.4 and 2.6, Deliverable 3.2, 3.3 and 3.4 LSBU Report No 3)
10. A study has been undertaken to identify the most type of refrigerator system found in the food chain identified Air-Air DX systems. It was agreed that this type of system would initially be the subject of the dynamic modelling program, (Objectives 2.2, 2.3, 2.4 and 2.6, Deliverables 3.2, 3.3 and 3.4, LSBU Report No 4)
11. A detailed model of Cold store applications has been written.
12. A second detailed model of small-scale chill unit has been written.
13. Refrigerator model and Food Temperature model (produced by FRPERC) have been integrated. (Objective 2.2, 2.3, 2.4 and 2.6, Deliverables 3.2, 3.3 and 3.4, LSBU Reports No 3 to 6)
14. Dynamic modelling of system components and refrigerator fault detection have been reported. (Objectives 2.2, 2.3, 2.4 and 2.6, Deliverables 3.2, 3.3 and 3.4, LSBU Report No 5)
15. The VCR transient model was completed with the defrost option. The programming routines are being tested and some bugs were resolved, and debugging is still in process. Several transient simulations were done and the model is proving to be generating reasonable results. A case study is being prepared by FRPERC to validate the transient VCR model with actual case. More refrigerants and mechanical components will be required to be modelled in VCR model. (Objectives 2.2, 2.3, 2.4 and 2.6, Deliverables 3.2, 3.3 and 3.4, LSBU Report No 6)

Summary of Progress:
Since our last report research (March 2008) effort has been concentrated on the further development of the computer model and its validation using data taken from commercial refrigeration system, as described in LSBU Report No 6.

1. Integrate the CDT model and VCR model: The revised version of the refrigerator model in CDT has now been fully integrated into the VCR model. Work on the CDT model has now been suspended to allow the LSBU team to concentrate on the VCR model.

2. Model developments: A number of model developments were required for the validation case study and included:

- Control functions: These are selected at the refrigerator design stage and now include:
- Automatic variable speed evaporator and condenser fans, either infinitely variable or step control.
- 6 compressors can now be selected with either speed control or step control used to switch compressors off and on.
- On/Off timer protection for the compressor has been added.
- Stage electric motor start-up has been added, (used in practice to prevent overloading electricity supplies during current surges on induction motor starting).
- In addition to timed defrost, 'Defrost On Demand function has been added.
- The refrigerant library has been extended to 5 common refrigerant fluids.
- TEV functionality has been improved and its time-constant and capacity can now be changed by the user during run-time.
- The Moist Air Data coding has been improved to speed up the iterative calculation.
- Some improvement to Error Trapping has been made.
- A number of coding errors have been corrected.

At this time the software appears to be robust.

Validation case study:
The LSBU team provided the FRPERC team (Pie cooling case study.doc) with a list of Input data required to run the model. The LSBU team used this data to set-up the model. The LSBU team also acquired manufacturer's performance data for the compressor. This was used to further develop the mathematical model of the compressor and its control. FRPERC recruited Pieminister Ltd for a Case Study. FRPERC recorded the electrical power consumption and temperatures around the subject refrigeration system over a period of weeks. One day's worth of data – the validation case – was supplied to the LSBU team for comparison against the models predictions. Close correlation between the validation data and model predictions has been shown, which is encouraging. The results of the validation study are reported in LSBU Report No6.

Evaporative condenser model.
An option to select an evaporative condenser has been included within the Refrigerator Design Screen. However, further work is required to make this function fully operable. condensers.

Future Research Programme
Case studies: Although the results of the Pieminister Case Study showed that the VCR model provided an accurate simulation of what is a very transient refrigeration system, (described in LSBU Report No 6), there is a need to extend the testing and validation of the software with further Case Studies if the software is to be used with confidence by designers of refrigeration systems.

Systems and components:
In order to allow designers to compare the performance of different types of refrigeration system it is necessary to add further components to the library that already exist within the software. These might include mathematical models for cooling towers, fan-coil units, water-cooled condensers, water cooling evaporators, liquid pumps and so on.

Error trapping and data output format:
It is thought that both these items require further work before the software is made generally available.

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

i) Maintenance practices:
Maintenance practices within the 10 process identified have been investigated. Companies were identified to investigate each process and their maintenance efficiency using Overall Equipment Effectiveness (OEE). This measured and benchmarked availability (actual operating time), efficiency (running temperatures) and quality (wastage due to failure, or energy loss) (data collection problematic due to lack of access to company and data. Three companies allowed access and an additional company in the North east supported data collection.
Maintenance strategies to increase OEE using modern maintenance practices and appropriate technology (Condition based maintenance) were identified.
It was expected that the organisations would be at varying stages of abilities, implementation, and technical complexity requirements for each of these activities.

Results to date:
- Predominantly reactive maintenance
- Little or no planned maintenance activities
- Costs of maintenance (planned or unplanned) not recorded
- OEE data not recorded
- 25% of maintenance outsourced
- Operators lack basic skills in maintenance activities
- No clear route to maintenance development
- Energy consumption not recorded
- Space utilisation is poor (increased running costs including maintenance costs)

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 models. A VisualBasic GUI (Graphical User Interface) is being developed to create a user friendly interface to the software.

Objective 2.2. Identify best practice and transfer.

Food transport refrigeration (Paper 2).
Food transport refrigeration is responsible for substantial energy consumption, difficult to quantify accurately, and environmental impacts. The vapour compression refrigeration system is predominantly used but there are also vehicles operating using cryogenic fluids (total loss systems) and hybrid cryo-mechanical systems or eutectic-mechanical vapour compression systems. The vast majority of medium to large vehicles use an auxiliary diesel engine built into the refrigeration system to drive the compressor but all electric systems are becoming more popular.
The review and analysis carried out so far, indicate that greenhouse gas emissions from conventional diesel engine driven vapour compression refrigeration systems commonly employed in food transport refrigeration can be as high as 40% of the greenhouse gas emissions from the vehicle’s engine (assumption of refrigerant R404A and 10% leakage rate-leakage rates of between 10% and 40% have been reported). For articulated vehicles over 32 ton, which are responsible for over 80% of refrigerated food transportation in the UK, the reject heat available form the engine is sufficient to drive sorption refrigeration systems and satisfy most of the refrigeration requirements of the vehicle.

Retail Food Refrigeration Systems (Paper 3)
Retail food store are large consumers of energy. Work to date has quantified electrical energy consumption in different type/size of stores, identified refrigeration system technologies currently employed in the UK and likely technologies and energy conservation measures for the future.
What has been learnt - The electrical energy intensity of retail food stores can vary substantially even for stores of similar sales area and of the same food retail chain. The variation reduces as the sales area increases and the store becomes less food dominant. For smaller food dominant stores, refrigeration energy dominates total energy consumption, 60% or higher, whereas, for superstores or hypermarkets refrigeration can account for only 30% of total energy consumption.
Greenhouse gas emissions from refrigerant leakage (R404A) can be significant and in certain cases much higher that the emissions due to energy consumption.
In the vast majority of cases, new ‘energy efficient’ stores employing new technologies and practices have failed to deliver the expected energy savings if any at all.
There is still considerable uncertainty with regards to centralized refrigeration technologies for food retail refrigeration for the future but what is almost certain is that systems in the future will be based on natural refrigerants.
Further work required – Work is required to identify the best current technologies and system configurations to use in terms of both energy consumption and environmental impacts for the different type/size of stores.
The benefits and impacts of refrigeration and HVAC system integration, heat recovery and amplification using heat pumps and demand side management and system diagnostics should also be investigated and the outcomes promoted. Another area that provides significant opportunities for energy savings is the design of more efficient display cabinets.

Supermarket refrigeration system and thermal environment modelling.
Work over the first 24 months has concentrated on the modelling of display cabinet coils with alternative refrigerants: CO_2, R404A and secondary fluids (propylene glycol), 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 are now being used for the evaluation of alternative refrigeration technologies and the optimum integration, control and thermal management of refrigeration and HVAC systems in supermarkets and food processing facilities.

Case studies
The Brunel Team is currently involved in 4 case studies -

Retail:
Retail food (supermarket) refrigeration systems: A 700 m2 urban food store is being used to investigate the impact of alternative technologies and energy conservation measures on store energy consumption and environmental impacts. These supermarkets are food dominant and present special problems in terms of equipment space and location, space temperature control and thermal comfort and lack of resources and technical expertise.

Dairy:
Dairy plant: One case study in progress is the evaluation of the performance of liquid pressure amplification systems and the energy savings potential from their wide application to the food processing and retail sectors of the industry. It is also hoped to investigate the potential energy savings from heat recovery from ammonia refrigeration plant and the use of this energy to reduce the heat requirement for process heating. Both case studies are based on the Ballemena Dale Farm milk processing plant.

Meat processing

Meat processing: It is hoped that this case study will be based on a Moy Park poultry farm where new ammonia plant has been installed based on semi-hermetic screw compressors and employing heat recovery using heat pumps. The heat recovered is used to preheat water for steam production. We do have some design data on the plant but have not managed as yet to obtain data on refrigeration load variation and refrigeration plant performance data for model validation. The case study will be used to assess hat recovery using heat pumps compared to direct heat. Other opportunities also exist to use absorption refrigeration/heat transformers for cooling an heating.

Transport refrigeration.
A spreadsheet model has been developed and some analysis has been performed on the evaluation of the performance of energy conservation measures and the use of alternative technologies such as cryogenic (total loss-refrigeration). Results on energy and environmental impacts of conventional systems are given in paper 2.

FRPERC have been completed the following 4 case studies and are currently working on case studies on potato storage, milk cooling on farms and food freezing –

Catering:
A case study on commercial service cabinets was carried out in a commercial kitchen (Langford canteen case study.doc). Mean daily energy consumption data for a range of five different refrigeration systems (240 V, 50 Hz) under "actual use" conditions in a working catering kitchen was measured. Values of energy consumption varied from a minimum of 3.9 kWh/24 h for the ice cream freezer to a maximum of 12.7 kWh/24 h for the upright freezer (commercial service cabinet). The trial also demonstrated that a simple low cost measure (cleaning the condenser) achieved an energy saving of 8%.

Red meat chilling:
A study of the current performance and operation of the refrigeration systems and their energy use at a red meat abattoir was undertaken (12 top tips for energy saving in meat chilling.doc). The main results of the study were :

1. Primary chilling of carcasses used the majority of electrical energy for refrigeration at the abattoir (mean 64%, maximum 82%).
2. The current performance of the primary chilling refrigeration system is not able to cope with the peak heat load during carcass loading into the primary chillers.
3. Air temperatures returning to the evaporators in the beef primary chiller remained well above the set point for extended periods.
4. Chilling times for beef down to a maximum temperature of 7ºC in excess of 48 hours were recorded. There is a risk of bone taint occurring.
5. Mean weight loss recorded after chilling beef carcasses in the primary beef chiller was 2.19%.
6. Issues with operation efficiency of evaporators, evaporators icing up and operation of the refrigeration plant were identified.
7. Door opening times were often for extended periods during the day allowing considerable infiltration of warm moist air adding a significant extra heat load that needs to be extracted by the refrigeration systems. It can also contribute to the quantity of moisture condensing/freezing on to the evaporator coils and further energy consumption.
8. Scheduled maintenance and checks on the performance of the refrigeration systems appeared to be limited.
9. There was no permanently installed temperature recording/logging system for chillrooms or refrigeration systems in use..
10. Energy consumption per kg of meat chilled was above the mean published values for other abattoirs, however, the comparison has limited validity as it assumes that the production is all beef.

Frozen storage:
Work has been carried out to assess energy saving measures in cold storage facilities. A report has been produced on energy currently used in cold stores and options to improve energy usage through optimising performance, updating components or retrofitting new components (Cold storage energy usage and optimisation.doc). The work showed that cold store energy varied considerably and that there was considerable potential to reduce energy by at least 30% in the 5 stores examined. Options to reduce energy in 3 direct expansion refrigeration system stores and 2 ammonia stores were presented in the report.
Substantial savings could be achieved if operation of the direct expansion cold storage facilities were optimised in terms of heat loads on the rooms and the operation of the refrigeration system. Many improvements were low in cost (improved door protection, defrost optimisation and repairs) whereas most other improvements were cost effective and had short pay back times. The most efficient store in terms of heat removed by the refrigeration system was due to it being operated by a low pressure receiver system. However, the plant used more energy per m^3 and this was partly due to it being a small store and also to

the way the store was operated with high transmission, infiltration and fixed heat loads. Improvements to its operation could be made by fitting better door protection and reducing fixed loads. Substantial improvements could be made to all cold stores by fitting better door protection and pedestrian doors, installing liquid pressure amplification pumps and suction liquid heat exchangers and by optimising defrost settings.
The survey of the ammonia plants illustrated how a plant that was originally designed for efficient operation has altered over the years and now consumed approximately 43% more energy than was originally intended. It was expected that a two-stage ammonia plant with flash intercooler, pumped recirculation and evaporative condensers would be very efficient. However, poor part load isentropic efficiency of the compressors, a lack of balance between high and low stage compressor capacity and the need for maintenance has turned what should have been an efficient plant into an inefficient one.

Chilled ready meals:
A report detailing the cooling of hot food products – specifically pie fillings – has been produced and is appended to this report (Pie cooling case study.doc). The cooling of hot products utilising air blast chillers is one of the most common refrigeration processes in the food manufacturing sector and is equally relevant to the manufacture not only of pie fillings, but also ready meal manufacture and any hot solid/liquid food products.
The specific energy consumption (kWh/t) for this refrigeration process was determined, and the contribution of the component elements to the electrical energy consumption analysed. The baseline power consumption of the process (i.e. the power required to run the blast chiller with no product load) was also determined highlighting the significant level of non-product related (considered parasitic) loads (i.e. evaporator fans, transmission through the walls, ceiling, floor, door etc.).
The study highlighted the opportunities for reducing the significant energy being consumed by the refrigeration system relative to theoretical energy to remove the product heat load. Alternative cooling methods were investigated and their potential for energy saving considered. The investigation lead to questioning whether air blast chilling should be so commonly used and whether alternative cooling methods could offer a practical option with better energy efficiency.
Little information is available concerning the energy consumption of blast cooling processes, especially accompanied with data detailing the product and the process under study. A study was carried out in order to provide more detailed data required to verify the model being jointly developed between LSBU and FRPERC.
Long term refrigerated storage of raw food materials was considered an area worthy of further investigation for potential energy saving. Long term refrigerated storage of potatoes is a specific area that is being studied with the particular focus on measuring the difference in energy consumption of what is considered a state-of-the-art store, a good conventional store (built at the same time on the same site) and an older basic refrigerated store. There is no data currently available for the potato industry to judge whether the newer passive up flow (PUF) design provides the expected energy savings in practice compared to the current systems using conventional evaporator fans.

Objective 2.3. Identify and overcome current barriers.

Identify barriers to development and implementation of new maintenance strategies
A methodology called Advanced Maintenance Management System (AIMMS) was used to explain the new maintenance strategy and how this provides cost and resource effective maintenance solutions by reducing the impact of the barriers identified earlier. (Pilot software complete and tested in local F&D company. Results are positive. Once Objective 2 is complete software can be used in case study company PieMinister)

Barriers to maintenance strategy development

- Lack of finance
- Lack of time to develop and implement new initiatives
- Lack of skilled engineers and equipment operators

Progress and results to date.
Produce a “road map” to allow simple maintenance tasks to be developed and implemented.
Simple single point instruction template designed and used in local Food and Drink Company. Data collected includes approximate cost of planned maintenance, cost of un-planned maintenance, OEE (availability and performance figures). Instruction sheets developed by maintenance and equipment operators. However, this needs to be tested within Pieminister
Introduce new techniques (cost permitting) to monitor energy usage which will benchmark normal operating usage
This has proven difficult as early results have shown that Condition based Maintenance is preferred (work carried out by DSL described in yearly report). The report suggested that the core of any refrigeration plant is the chiller compressor set, this also constitutes the most expensive and safety critical element in the refrigeration chain. Experience within this DEFRA project and throughout the last 24 months of on-line

monitoring has resulted in the following conclusions from a reliability viewpoint:-

- Motor bearing and coupling problems cater for 100% of the problems observed
- Compressor data should be collected close to 100% load

The following recommendations are made based on the assessment completed within this project and the experience DSL have gained over the last 2 years of monitoring refrigeration compressor related equipment:-

- Low cost on-line monitoring is ideal to ensure compressor data are measured under load
- It would be more efficient to log compressor process and energy data at the same time as vibration such that all pertinent data elements could be compared and analysed
- Spectral vibration is required to adequately categorise the failure modes, hence at the very least a monthly walk around vibration assessment would be required.

However, this has proven difficult to implement due to cost to obtain equipment, companies were not willing to purchase the required equipment. To obtain positive results it may be possible to acquire equipment from other project partners or ask Pieminister to purchase necessary equipment.

Issues
During the summer months access to case study companies has been limited and in several companies non-existent, therefore several objectives have not been met. Data has not been collected from equipment used within the retail sector and PIEMINISTER have been difficult to contact. Anticipated results at this stage have not been met.

Objective 2.4. Fill knowledge gaps.
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. This was submitted to LINK but was not funded.

Objective 3 – Feasibility studies on unexploited technologies.
Feasibility of unexploited technologies has been included in objective 2.2. The most attractive technologies are:

Food transport refrigeration:
There are a number of energy conservation measures which when applied individually or in combination can lead to substantial energy savings. Further work is required to determine their technical and economic viability as well as their environmental performance in comparison to current practice. Further work is also required to develop cost effective technologies to recover the energy rejected in the exhaust gas for refrigeration and/or on-board power generation.

Supermarket refrigeration system and thermal environment modelling:
Validation of CO_2 refrigeration system models and their use in the design and optimization of CO_2 cascade and transcritical systems.

Retail display:
Work to optimise air flows within retail cabinets would provide substantial energy savings. Reduction in radiant heat gains to frozen cabinets could potentially increase evaporating temperatures by 5°C.

Food cooling:
The use of ambient cooling hot product has been shown to reduce heat loads by up to 50%. Further work is required to optimise processes. Considerable potential exists for energy saving in meat chilling by use of perfusion cooling.

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	End month 3	Yes	Yes
2	Objective 1 achieved operations ranked	End month 13	Yes	No
3	Objective 2.1. Generic methodologies to improve energy developed	End month 13	Yes	No
4	Objective 2.2 achieved. Current best technology and practice transferred	End month 24	Partially	No
5	Objective 2.3 achieved. Barriers to uptake overcome,	End month 24	Partially	No

(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.

Papers:
Tassou, S.A.; De-Lille, G. and Ge, Y T. Food transport refrigeration – Approaches to reduce energy consumption and environmental impacts of road transport, Applied Thermal Engineering, (2008), doi:10.1016/j.applthermaleng.2008.06.027
Ge, Y.T and Tassou, S.A. Control Optimisation of CO2 Cycles for Medium Temperature Retail Food Refrigeration Systems, under review, International Journal of Refrigeration.
Tassou, S.A.; Ge, Y.T.; Hadawey, A.; Lewis, J. and Chaer. I. Review of Emerging Refrigeration Technologies for Food Refrigeration Applications, To be submitted for publication in the Journal of Applied Thermal Engineering, October 2008.
Swain, M.; Evans, J.A. and James, S.J. Energy consumption in the UK food chill chain – primary chilling. Food Manufacturing Efficiency (in press).

Book chapters:
Evans, J A. Minimising energy consumption associated with chilling, refrigerated storage and cooling systems (including integrated heating and cooling systems). Book: Improving water and energy management in food processing ed by Professor Robin King, Dr Jiri Klemes and Dr Jin-Kuk Kim. Woodhead Publishing Ltd.
Tassou, S.A. and Ge, Y. Reduction of refrigeration energy consumption and environmental impacts in food retailing, Chapter 20, In improving water and energy management in food processing., Woodhead Publishing, CRC Press, 2008
Evans, J. A. Technologies to reduce refrigeration energy consumption in the food industry. Handbook of waste management and co-product recovery in food processing vol 2. Editor Keith Waldron (Woodhead Publishing). In press.

Conference papers:
Swain, M.J., Evans, J.A. and Brown, T. Improving the energy efficiency of food refrigeration operations. CIGR, Naples, Sept, 2007.
Maidment G. IOR Annual Conference 2006 - Smaller, Colder, Smarter.
Maidment G. CFDS National Conference 2006.
Baglee, D. Value Stream Mapping: A Dairy Industry Prospective. Paper presented at the IEEE EMC - EUROPE 2008. International Engineering Management Conference, "Managing engineering, technology and innovation for growth" June, 28 to 30, 2008 - Estoril, Portugal.
Baglee, D. The Development of Sustainable Maintenance practices for SMEs. Comadem June 2009 San Sebastian Spain (Abstract accepted).
Baglee, D. SMEs and the Need for Maintenance. A case study perspective. Paper to be presented at WCEAM October 2009. Athens Greece.
Swain, M.J.; Evans, J.A. and James, S.J. Energy consumption in the UK food chill chain – primary chilling. Food Manufacturing efficiency Journal (in press).
Evans, J.A. and Gigiel, A.J. Reducing the energy consumption in cold stores. The 22nd IIR International Congress of Refrigeration. Beijing, China. August 21-26, 2007.
Brown, N, T., Swain, M.V.L. and Evans, J.A. Use of vacuum insulated panels to improve performance of refrigerators and insulated shipping containers. The 22nd IIR International Congress of Refrigeration. Beijing, China. August 21-26, 2007.
Gigiel, A J and Evans, J A. Experience of operating an older ammonia plant and the energy consumption. Ammonia Refrigeration Technology for Today and Tomorrow, Ohrid, Macedonia, 2007.

Journal articles:

Swain, M. J. Improving the energy efficiency of food refrigeration operations. IChemE Food and Drink Newsletter, 4 Sept. 2006.
Evans, J A. Future food refrigeration technologies. IChemE Newsletter, Oct 2008.
Evans, J.A. and Gigiel, A.J. Reducing the energy consumption in cold stores. FRIO-CALOR-AIRE ACONDICIONADO S.L. 2008 (in Spanish).

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.
Swain, M.J. Energy saving opportunities in meat refrigeration. RMIF (Red meat Industry Forum), Dec. 07.
Evans, J. A. Energy consumption in the cold store sector: How can we reduce it? ECSLA Conference, Brussels, 2008.
Evans, J. A. Rapid chilling of carcasses using vascular perfusion. ADIV Conference, Clermont Ferrand (France), Sept. 2008.
Evans, J. A. Refrigeration research at FRPERC. British Soft Drinks Association. Sept, 2008.
Evans, J. A. Air cycle refrigeration. RAC Future-proof Cooling, March 2008.
Swain, M.J. and Evans, J.A. Energy use in food refrigeration. Waitrose Supplier Partnership Group, Odney, Apr 2008.
Swain, M.J. Energy use and its potential reduction in food refrigeration processes. Energy Efficient Processing Conference, 1 & 2 Nov 2007.
Swain, M.J. Energy efficiency in the cooking and cooling of food - who knows what is best practice?. CCFRA Food Service Panel Meeting, Harrogate, May 2008.

(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, BSDA, ADIC, ECSLA.
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.
A project web site has been set up to enable information to be disseminated more widely.
The stakeholder group now has 113 members.
A workshop was held in Feb 08 to disseminate information from the project that was attended by 40 industry participants.
Sector focus reports have begun to be developed for each of the 'top 10' energy using areas of the cold chain.

Future work

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

A project on retail display cabinet optimisation was developed but currently a funding mechanism has not been identified.

Declaration

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

Name: Stephen James
Date: 13/10/08

Position held: Director