# THE INSTITUTE OF REFRIGERATION

## Initiatives to reduce energy use in cold stores

by

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### Introduction

The cold chain is believed to be responsible for approximately 2.5% of global greenhouse gas emissions through direct and indirect (energy consumption) effects [1]. Cold storage rooms consume considerable amounts of energy. Within cold storage facilities 60-70% of the electrical energy can be used for refrigeration. Therefore cold store users have considerable incentive to reduce energy consumption.

It is estimated that there are just under 1.5 million cold stores in Europe ranging from small stores with volumes of 10-20 $m^3$ to large distribution warehouses of hundreds of thousands of $m^3$. The majority of cold stores (67%) are small stores of less than 400 $m^3$ [2].

In 2002 the IIR estimated that cold stores used between 30 and 50 kWh/m$^3$/year [3]. Previous detailed energy audits carried out by Evans and Gigiel [4][5] on a small number of cold stores have shown that energy consumption can dramatically exceed this figure, often by at least double. These audits also demonstrated that energy savings of 30-40% were achievable by optimising usage of the stores, repairing current equipment and by retrofitting of energy efficient equipment. Although there are few published surveys comparing the performance of more than a few cold stores, the limited information available corroborates the wide range in efficiency generally found in cold stores in the audits. The most comprehensive recent survey was carried out in New Zealand by Werner et al (2006) which compared performance of 34 cold stores. This demonstrated that there was a large variation in energy consumed by cold stores and that savings of between 15 and 26% could be achieved by applying best practice technologies.

Although it seems clear that savings in energy are achievable in many food cold stores it was found that cold store operators were often reluctant to install new equipment without sufficient information on savings that could be achieved. Due to this need a project to assist and advise cold store operators was developed and funded by (EACI) (Executive Agency for Competitiveness and Innovation). The aim of this project called ICE-E (Improving Cold store Equipment in Europe) was to overcome reservations to the uptake of new energy efficiency technologies and to reduce energy consumption and greenhouse gas emissions from the European food cold storage sector (Figure 1). The project had a number of technical initiatives which included:

- Benchmarking
- Auditing of cold stores
- Knowledge based information packages
- Mathematical models
- Education programmes and dissemination
- Financial advice to identify whether initiatives were cost efficient


**Figure 1. Initiatives within ICE-E project**

In additional to technical barriers to the uptake of new technology the project also considered non technical barriers preventing uptake of new technologies. Proven technologies are often not taken up due to wider social, political, economic and organisational contextual issues.

## Benchmarking of cold stores

### *Detailed survey*

The initial initiative within the project involved benchmarking stores to determine whether there were any common factors that affected performance of the cold stores. Two internet based surveys were developed and data collected to determine energy usage in different cold store types, sizes and configurations.

A first survey was developed using a NET web application. Development was carried out in Microsoft Visual Studio using c# (c sharp) which used .NET Framework 4.0. The data was saved in a Microsoft SQL database. The survey was available in a number of languages (Bulgarian, Czech, Danish, Dutch, English, French, Italian and Spanish). The survey was initially tested on a selected number of cold store operators to ensure that the questions were appropriate and relevant. Improvements were then made based on their comments.

The survey allowed participants to register their details and then to enter data on as many refrigeration systems as they wished. The survey consisted of 5 pages collecting basic information, information on the refrigeration system, the food stored, the facility and the refrigeration equipment at the facility. During the initial registration process, cold store operators could ensure that data was anonymous.

Once users had input data they could then compare the performance of their store through an automatic benchmark analysis. This enabled them to compare the energy used by their cold store system with systems of a similar size and product throughput. In addition users could compare the set point temperatures, food type, room function and refrigerant type with others in the survey. In all comparisons the user had the ability to define the range over which comparisons were carried out.

***Express survey***

In response to some end users requesting a simpler and more rapid means to benchmark their stores an 'Express Survey' was developed. This required only 5 minutes to complete. The tool was part of the ICE-E web site and written in HyperText Markup Language (HTML) using a web form to collect the data. As in the detailed survey all data collected was anonymous. A limited data set of the 5 critical parameters was collected (set point temperature, floor area and volume of the store, food throughput and energy usage per year) which reflected what were considered to be the most important factors affecting energy use in cold stores. Once data was submitted the information was input manually into the main benchmark survey and information sent directly to the cold store operator.

***Data integrity***

For both surveys the data collected was checked and unreliable data excluded. Where possible any unreliable data was cross checked with the cold store operator and any anomalies corrected.

***Data collected***

Data from 329 cold stores was collected. One data point was the mean of 331 cold stores in the UK (i.e. the total data collection encompassed 659 stores). This point was excluded from the analysis as data was not available on the data variance. Therefore the data point could not be included at an equal weighting to the other data sets and so was used for purely comparative purposes in the analysis. Thirty-four data sets were removed as they were considered unreliable leaving 294 data sets with the minimum 5 critical parameters recorded. The data collected covered 21 different countries (Belgium, Bulgaria, China, Czech Republic, Denmark, France, Germany, Greece, Ireland, Italy, Mexico, Netherlands, New Zealand, Portugal, Romania, Serbia, Spain, Sweden, Switzerland, United Kingdom, USA). Seventy percent of the 295 data sets originated from EU countries.

***Cold store type***

Cold store function was divided into chilled, frozen or mixed stores (those with both chilled and frozen rooms operating from a common refrigeration system). Analysis of variance (ANOVA) showed a highly significant difference ($P<0.05$) between the SEC (Specific Energy Consumption) of all store types. Differences between chilled and frozen and chilled and mixed were greater ($P<0.01$) than between frozen and mixed stores ($P<0.05$) (Figure 2).

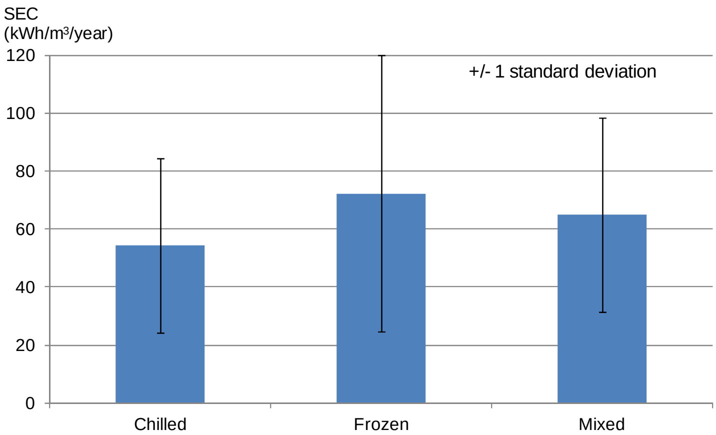


**Figure 2. SEC for cold store types analysed.**

***Country***

Large variations in SEC were shown between countries. However, this was most likely due to the limited number of data sets for some countries. Analysing the data from countries where a greater number of data sets were available did not show any correlation between location and ambient temperature at the location or any factor such as differences in design of the cold stores in each location. Due to the large variability in SEC it was not possible to analyse data from each country separately. Therefore all further analysis was carried out on data divided into chilled, frozen and mixed stores.

***Relationship between energy use and store size***

The relationship between store energy consumption and the information collected was investigated using multiple regressions. As part of this analysis the data was found to be near to a normal distribution.

**Chilled stores**

One hundred and twenty-six chilled stores were included in the analysis. These ranged in volume from 57 to 225,000 $m^3$. Regression demonstrated that 93% of the variation in annual energy consumption was related to store volume. Multiple regressions demonstrated that food type and food throughput had some impact on annual energy but that these factors only increased the $R^2$ value to 95% and therefore their impact was very low.

**Frozen stores**

One hundred and thirty-two frozen stores were included in the analysis. These ranged in volume from 100 to 291,280 $m^3$. Store volume accounted for 56% of the variability in annual energy consumption of frozen stores when a linear regression was applied. Applying a non linear power function to the data improved the regression $R^2$ value to 66%. This would indicate that for frozen stores that SEC reduced as the store size increased. None of the factors recorded had anything above a very minimal impact on annual energy consumption. Therefore approximately 34% of the variability in annual energy consumption was related to a factor that was not collected in the survey.

**Mixed use stores**

Thirty-six mixed use (frozen and chilled stores operating from a common refrigeration system) stores were included in the analysis. These ranged in volume from 9,100 to 180,000 $m^3$. A number of factors had an impact on mixed store annual energy consumption. As a linear regression, store volume accounted for 67% of the variability, however if a power function (non linear regression) was applied this increased to 76%. In addition throughput, thickness of the store insulation (wall, ceiling and floor) and insulation age also appeared to have a minor impact on annual energy consumption. However, for these data sets the number of replicates was low and so their impact needs further investigation. Mixed stores appeared to have a similar volume relationship with annual energy consumption as frozen stores and therefore the store SEC reduced for larger stores.

**Cold store audits**

As part of ICE-E the performance of 38 cold stores were examined to determine how much energy could be saved, areas of common problems and the initiatives that could be implemented that would save energy. Audit sites were selected to provide a range of cold stores in terms of temperature setting, volume, products stored, refrigerants and location. A summary of the audited cold stores and their attributes is presented in Table 1.

Table 1. Summary of the cold stores audited.

| | |
|---|---|
| Country | Belgium (1), Bulgaria (4), Denmark (5), Italy (11), Switzerland (1), UK (16) |
| Products | Chips (1), Dairy (4), Ice cream (1), Meat (2), Mixed products (14), Pasta (1), Potato (5), Potato/celeriac (1), Salami (6), Smoked meat (1), Vegetable (2) |
| Temperature level | Freezer (14), Mixed (1), Chiller (23) |
| Volume ($m^3$) | <100 (7), 101-1000 (4), 1,001-10,000 (12), 10,001-100,000 (13), >100,001 (2) |
| Refrigerant | R22 (6), R22/R134a (1), R404A (13), R422D (3), R507 (1), R717 (12), R717/secondary (1), R744 (1) |
| Heat load (calculated) (kW)[1] | <5.0 (7), 5.1-20.0 (5), 20.1-50. 0 (8), 50.1-100.0 (6), 100.1-150.0 (10), 150.1-500.0 (6), 500.1-1000.0 (1) |

[1] Two heat loads are reported for 5 produce stores where there was a pull down heat load associated with initial temperature reduction after harvest and a stable heat load once 'field heat' had been removed.

***Data collection***

Data were obtained from a variety of sources depending on the cold store being audited. In some cases the cold store had their own on site data loggers that recorded sufficient information (temperatures in the cold rooms, energy consumed by each cold store and door openings) for the analysis. In other situations data loggers were attached by the auditors to the refrigeration system to measure temperatures, pressures and energy consumption. Temperatures were measured on individual evaporators to ascertain liquid and suction temperature and evaporator superheat. Air leaving and returning to the evaporators was recorded. The temperatures of the suction and discharge gas at the compressor and condensing temperature and level of condenser liquid sub cooling were also measured. In all cases temperatures were measured to an accuracy of ±0.5°C, pressures to ±2% of reading and power to ±2% of reading.

In all situations data was recorded for a minimum of one week and in some cases for several months. In the case of stores where heat loads were variable (for example in produce stores where there was a high heat load post the initial loading after harvest and a lower heat load once field heat has been removed) the audits were carried out twice to cover the high and low heat loads. Data logged from the refrigeration system were recorded at intervals of between 30 seconds and 2 minutes.

Meteorological data for the ambient conditions were obtained from the nearest weather recording station to the site or were recorded using data loggers.

**Heat loads**

Heat loads were calculated using either a steady state or dynamic heat load model developed as part of the ICE-E project (see below) and available from http://www.khlim-inet.be/drupalice/models [6]. The models did not predict latent heat load due to food freezing. In such cases (only the store containing chips) a heat transfer model similar to that developed by Evans et al [7] was used.

**Heat extracted by evaporators**

Heat extracted by the evaporators was calculated from measured temperatures and pressures using compressor manufacturers' data and was compared to the cold store calculated heat load (transmission, infiltration, food, fixed) to check that the 2 calculations generated similar results. If anomalies were found the calculations were checked and reasons for any non alignment identified.

**Efficiency of refrigeration plant**

The COSP (Coefficient Of System Performance) of the refrigeration system was calculated from the total calculated heat load (from transmission, infiltration, food, fixed) divided by the total energy used by the refrigeration system (including compressors, condenser and evaporator fans, defrosts and any refrigeration ancillaries). The efficiency of each cold store was compared and options to improve efficiency identified and the savings in energy calculated.

The methodology for identifying and calculating energy savings varied according to the cold store. However, in all cases evaporating and condensing temperature levels were investigated to determine whether condensing pressure could be reduced and evaporating pressure increased. Levels of evaporator superheat and condenser sub cooling were also assessed to determine whether they impacted on operational efficiency. The major heat loads were investigated to determine whether they could be reduced. Inefficiencies in the operation of equipment and design of the refrigeration plant and cold store were also investigated if relevant.

***Energy savings identified***

Issues identified in the audits were classified under 21 general headings (Figure 3). Overall between 2 and 12 issues were identified in each store with an overall mean of 8 issues identified per store. A list of the issues and the regularity that they were found is shown in Figure 3. No one issue dominated, but issues associated with control of the refrigeration plant (compressor control, condensing pressure, defrosts and evaporator fans) accounted for 33% of the issues identified.

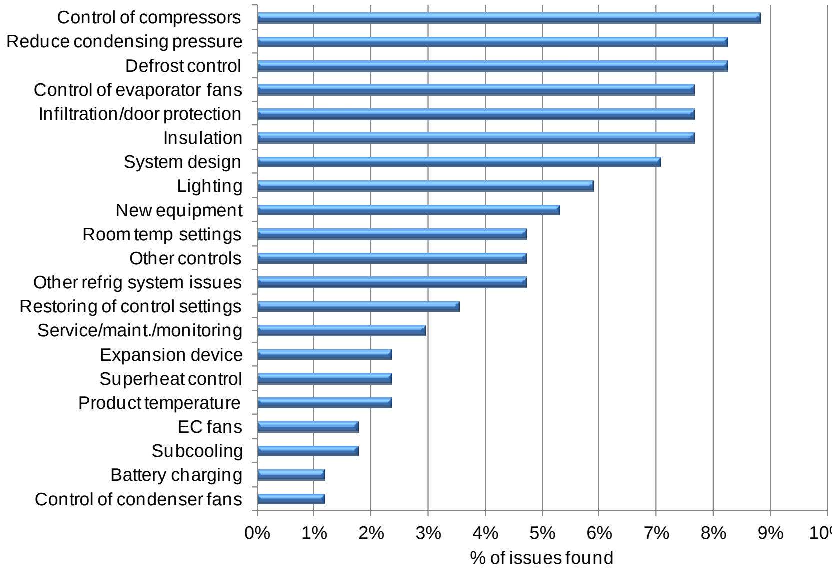


**Figure 3. Issues identified in the audits.**

***Potential energy savings identified***

The potential energy savings were calculated for each issue identified and are presented as mean % energy savings in Figure 4. Potential energy savings were found in all stores audited but the level of total savings varied between 8-72% of the annual energy consumption. Overall service, maintenance and monitoring had the greatest potential to save energy. Although the greatest potential savings were from maintenance and monitoring there were a limited number of maintenance and monitoring issues identified with maintenance and monitoring being only 3% of the issues identified (Figure 3).

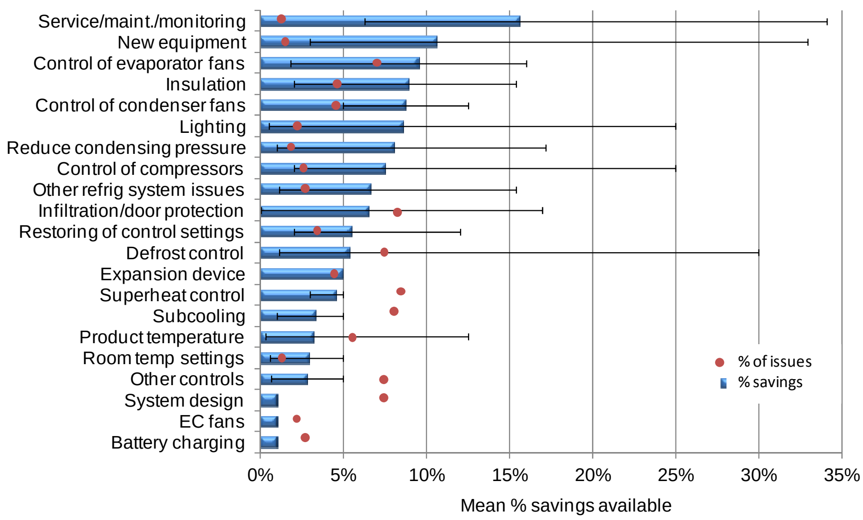


**Figure 4. Energy saving potential for each issue identified (bars: minimum and maximum % savings; red dots: mean % of issues identified).**

***Cost effectiveness of initiatives to save energy.***

The payback time for each of the energy saving initiatives were calculated. The calculation involved a straight comparison of direct cost and time to repay the cost of applying each initiative through energy savings. The energy costs used was 0.11 €/kWh. No account was taken of any future increase in energy costs or of the impact that any of the initiatives would have on improved product quality, reduced maintenance costs or improved logistics.

The average payback time for each initiative is shown in Figure 5 together with the range in payback times calculated.

Overall 54% of issues identified had paybacks of less than 1 year, 64% had paybacks of less than 2 years, 71% had paybacks of less than 3 years and 83% had paybacks of less than 5 years.

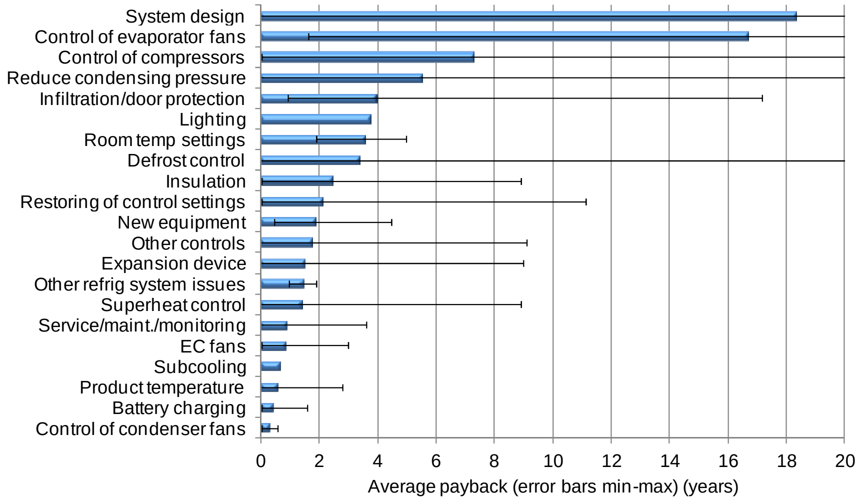


**Figure 5. Payback time for each issue identified in the audits.**
**n.b. The graph shows a maximum payback time of 20 years. This excludes maximum paybacks of greater than 20 years.**

***Energy saving potential for cold stores.***

Using the information generated from the audits the issues identified were ranked in terms of expertise required to identify and solve each issue. It was found that 24% of issues could be identified and quantified by a reasonably astute cold store manager who could use engineering knowledge and freely available modelling tools to identify the level of savings that could be achieved. A further 43% of the savings could only be achieved with the input of a refrigeration engineer as these involved handling refrigerant or modifications to the refrigeration system.

Above this there was a level where expert/specialist help was required.

**Cold store modelling tools**

As part of the ICE-E project two user friendly tools that could be used by cold store operators and technicians to identify energy savings were created. The models were intended to provide cold store operators with a means to simply identify whether a technology was appropriate for their cold store and whether it is likely to achieve suitable benefits. The models are freely available from the ICE-E website http://www.khlim-inet.be/drupalice/models. Both models are available in English, Italian, Dutch, Czech, Bulgarian and Danish languages.

***Simple model***

The simple model was a steady state lumped model where heat loads were averaged over one day. The shape of the cold store is a rectangular box. The user can input data about their cold store into a spreadsheet. The inputs include;

- Information about each wall (including ceiling and floor) of the cold store, e.g. face area, whether it is in the sun, outside ambient or internal and the type and thickness of the insulation.
- The size of the door, its opening schedule, whether it is protected (e.g. by strip or curtains), amount of traffic through the door and the outside conditions.
- The refrigeration system, refrigerant, type of condenser, condenser ambient, efficiency of compressor and number of stages.
- Heat loads inside the store, forklifts, lights, personnel, product (including respiration if applicable), defrosts, evaporator and condenser fans.

***Complex model***

The complex model was based on the simple model but with some enhancements to enable energy consumption to be calculated every hour for a whole year. Ambient temperature, relative humidity (RH), ground temperature, wind speed and solar radiation and the position of the sun in the sky are changed every hour with all other parameters being fixed throughout the year. This allowed a yearly profile of energy consumption to be evaluated. The hourly worldwide weather data can be imported from the U.S. Department of Energy, Energy Plus Energy Simulation Software, weather data (http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm).

The daily and hourly heat loads for the 12 months of the year are presented as outputs. Electrical consumption and power are also presented for each month and hour.

***Validation***

The simple model was validated against data measured at a cold store during an extensive energy audit. The cold store was monitored and audited during a 4 week period in February/ March 2012. The audited facility consisted of a single cold room having an internal volume of 60 $m^3$. The refrigeration system was a dry expansion R404A unit with air cooled condenser. It operated at positive temperature (from 2 to 4 °C) and had a rectangular lay-out with a room height of 2.9 m. It had a single, hand operated door, with strip curtains. The cold room was installed inside a building and the space around the cold store was not temperature controlled. The cold store was built in 2011. Data obtained from site plans showed that the cold room walls and ceiling were 80 mm Polyurethane foam (density: 39 $kg.m^{-3}$, thermal conductivity (@ 23°C): 0.029 $W.m^{-1}.K^{-1}$) and that the floor consisted of granolithic concrete.

Water consumption for a steam cleaning process was measured. It was assumed that the steam was fully condensed over the surfaces cleaned inside the cold room. This gave an average heat load of 100 W.

The energy consumed by the plant was evaluated from the logged data. Energy meters were used for recording the energy consumption of the condensing unit (compressor and condenser fans), evaporator fans and of the electrical defrost. Lighting power consumption was evaluated from manufacturer's data.

The measured electrical consumptions of the different components were compared with those predicted by the simple model and results shown in Figure 6.

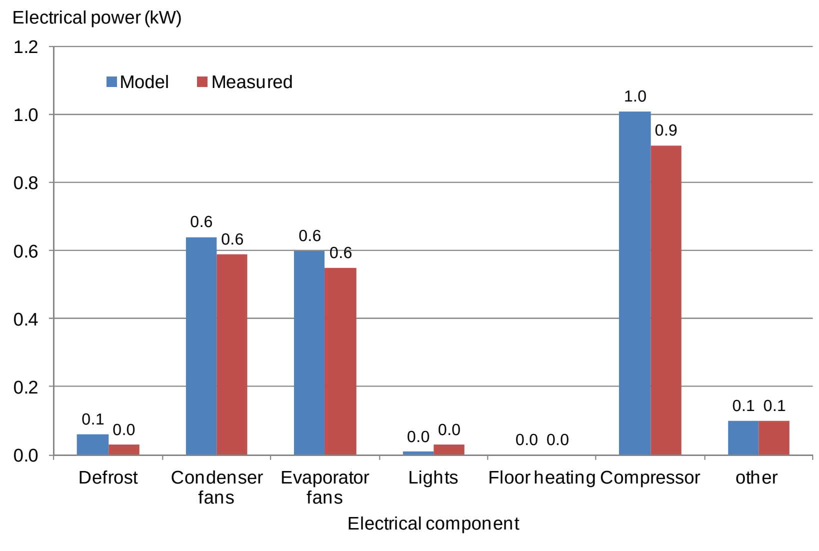


Figure 6. Measured vs. predicted power consumption.

The simple model was shown to be accurate to approximately 10% of the total power consumption of the validation cold store. The largest electrical power was from the compressor. The model over-predicted this power by 11%. Condenser and evaporator fans formed the majority of the rest of the electrical power. The model over predicted these powers by 8%. Defrosts were heavily over-predicted (100%), however, they only accounted for about 1 or 2% of the total power. Light power was heavily under-predicted (33%), however, this was also a minor part of the total power. The total electrical power of the store was over predicted by 10% (2.42 kW instead of 2.21 kW).

**Non technical barriers work**

The premise of the non technical barriers work was that in addition to technical barriers to the uptake of new energy efficient, low carbon technologies there are also *non* technical barriers preventing their uptake. This is often due to wider social, political, economic and organisational contextual issues, including such things as:

- human skills and motivations
- cultures and organisations
- professional and social conduct
- how we see and define the issues
- how we mobilise information, energy and resources
- institutional structures
- power, politics and vested interests

Any project/movement to create change toward low carbon takes place in a context that offers constraints and enablers. Contextual issues are those that lie outside the direct scope of the project or activity in question but which have a significant effect (typically a constraining effect) on its likelihood.

In 2000 American author Ken Wilber's [8] integral theory identified different aspects of reality according to whether they were internal or external, individual or collective. David Ballard [9] developed this idea to create a comprehensive way of mapping contextual issues along two dimensions individual-collective and subjective-objective. *Complementarities theory* shows how change is created when 'doing more of one thing increases the returns of doing more of another' or 'investing in one variable makes more profitable investing in another, setting off a potentially virtuous circle' [10]. Similarly the Limits to Growth analysis shows interacting layers of limits creating vicious cycle [11].

During the ICE-E project ten non-technical audits were conducted alongside the technical audits. The ten cold stores worked with were spread across Belgium, Bulgaria, Denmark and the UK. In each case the cold store operators and, where possible, a selection of their staff were interviewed on site over time in order to discuss and determine the non-technical issues and conditions, which were either forming a barrier to energy efficiency practices or conversely, were actively helping to promote good energy efficiency practice within the cold stores. From the information gathered, opportunities for positive change were identified and ideas and suggestions were fed back to the cold store operators.

The key findings from all ten stores were amalgamated to produce a 'non-technical checklist for energy efficiency in cold stores', which complements the results and outcomes from the technical strands of the project, and will help inform, motivate and enable cold store operators to attend to non-technical issues and create positive change for more energy efficient working.

Table 2 shows an amalgamated thematic analysis of the non-technical issues impacting energy efficiency, incorporating the prime barriers and enablers that were identified across all ten cold stores. The thematic analysis reveals the key non-technical issues that have been identified from interactions with our sample of ten companies, and which, when working together, create the potential for a virtuous circle of high performance in energy efficiency.

Table 2. Contexts for change – complementarities matrix from ICE-E.

| | |
|---|---|
| **Person**<br>Awareness held at a personal level of energy efficiency issues both at home and at work.<br>Attitude that energy efficiency is important, and not only because it saves money. Product quality and safety and energy efficiency are linked.<br>Agency - individuals feel willing and able to make suggestions and to have a positive influence on energy efficiency.<br>Action for energy efficiency is incentivised and normalised; part of the company's DNA. | **Job**<br>Communication - energy efficiency relates to each role through simple connections to job specifications. Incorporated into induction training, on the job training, specialist training and into maintenance contracts.<br>Targets – energy efficiency KPIs created for all posts. Results measured, monitored and rewarded. Bonus schemes based on energy/ tonne of throughput or productivity or similar and designed to overcome any cultural barriers.<br>Change agents and energy efficiency champions are nurtured and supported. |
| **Company**<br>Enabling culture encourages workers to innovate, instigate bigger energy efficiency wins, optimise equipment and share information top down and bottom up.<br>Energy policy for efficiency and green energy generation drives delivery of cost reduction and energy security benefits.<br>Standards – Company is benchmarked for energy efficiency and adopts energy management standards incorporating continual improvement and measuring and monitoring methodologies.<br>Energy efficiency credentials shared with customers and other stakeholders and used to retain and grow customer base and maintain competitive edge.<br>Investment – realistic payback terms adopted and innovative approaches developed for funding of energy efficiency projects. | **Sector**<br>Best practice shared within sector (including clients) and economies of scale realised through joint working. Sector wide partnerships facilitate joint energy efficiency and renewable energy investment and project opportunities.<br>Influence of sector agenda through development of relationships with key sector associations and stakeholders including refrigeration equipment manufacturers and installers.<br>Opportunities offered by emerging local, regional or national Government schemes anticipated, cultivated and taken up. |

## Conclusions

The efficiency of cold stores has been shown through surveys and audits to vary widely. From the ICE-E survey it was found that the least efficient stores used 11-13 times more energy of the most efficient stores.

When the performance of a smaller selection of cold stores was analysed in detail it was found that the level of savings varied considerably with no one issue dominating. The potential energy savings varied widely with issues related to the way in which the refrigeration system was controlled and operated having the lowest paybacks. Many energy savings could be identified by the cold store operator or their refrigeration engineer. This highlighted the need for regular checks of the operation of the refrigeration system to check set points, superheat, sub cooling and controls.

By far the majority of the savings identified had paybacks of less than 3 years. However, the payback period for each issue identified varied considerably and could range from being a very economic option to not being economically feasible. Therefore it was not possible to unequivocally state that certain technologies were economically attractive as a greater level of understanding of each refrigeration systems operation and use was required to fully quantify the energy savings that could be achieved.

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