Improving the energy performance of cold stores

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ABSTRACT

Considerable energy savings can be achieved in cold stores and cold store users are extremely keen to identify these savings as energy is a major cost in the operation of any sized cold store. Work within the
ICE-E (Improving Cold storage Equipment in Europe) project examined methods to reduce energy use in cold stores. Results from 28 cold store audits carried out across Europe are presented. Common faults and issues are discussed and methods to improve performance elaborated.

The potential for large energy savings of at minimum 8% and at maximum 72% were identified by optimising usage of stores, repairing current equipment and by retrofitting of energy efficient equipment. Often these improvements had short payback times of less than 1 year.

# INTRODUCTION

The cold chain is believed to be responsible for approximately 2.5% of global greenhouse gas (GHG) emissions through direct and indirect (energy consumption) effects. 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 m3 to large distribution warehouses of hundreds of thousands of m3. The majority of cold stores (67%) are small stores of less than 400 m3 (Mudgal et al, 2011) and are owned by SME food producers, small retailers and local shops.

In 2002 the IIR estimated that cold stores used between 30 and 50 kWh/m3/year (Duiven and Binard, 2002). Previous surveys carried out on a small number of cold stores have shown that energy consumption can dramatically exceed this figure, often by at least double (Evans and Gigiel, 2007, 2010). These surveys 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. However, cold store operators are often reluctant to install new equipment without sufficient information on savings that could be achieved.

There are few published surveys comparing the performance of more than a few cold stores. 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.

The performance of European cold stores has never been compared in detail and there is little information to compare their performance with other stores Worldwide. With government targets to reduce energy and reduce emissions of greenhouse gasses the need to benchmark and understand potential energy and GHG reductions is of great interested to end users.

To enable end users to improve the performance of their cold stores the ICE-E (Improving Cold store Equipment in Europe) project was developed with 8 partners from across Europe. The initial aim of the project was to collect data to benchmark the performance of cold stores in Europe. From this a number of cold stores were selected for detailed auditing to determine how much energy could be saved, areas of common problems and the initiatives that could be implemented that would save energy.

# MATERIALS AND METHODS

Twenty-eight detailed energy audits were carried out by the ICE-E partners. Audit sites were selected to provide a range of cold stores in terms of temperature setting, volume, products stored, refrigerants and location. A list of stores audited and their attributes is presented in Table 1.

Table 1. Cold stores audited

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Site no. | Country | Volume (m3) | Product | Refrigerant | Calculated heat load (kW) | Set point temperature (°C) |
| 1 | Belgium | 180,000 | Chips | R717 | 950 | -22 |
| 2 | UK | 6,442 | Potato | R22 | 55/25 | 3 |
| 2 | UK | 7,068 | Potato/celeriac | R507 | 30 | 3 |
| 3 | UK | 3,588 | Potato | R22 | 115/45 | 3 |
| 3 | UK | 7,176 | Potato | R422D | 105/40 | 3 |
| 3 | UK | 5,544 | Potato | R422D | 45/20 | 3 |
| 3 | UK | 20,160 | Potato | R422D | 215/80 | 3 |
| 4 | UK | 36,036 | Dairy (mixed) | R404A | 150 | 2 |
| 4 | UK | 12,512 | Dairy (mixed) | R404A | 105 | 2 |
| 4 | UK | 43,758 | Dairy (mixed) | R404A | 270 | 2 |
| 5 | Bulgaria | 9,512 | Ice cream | R717 | 150 | -21 |
| 6 | Bulgaria | 2,983 | Mixed | R404A | 35 | -20 |
| 6 | Bulgaria | 1,741 | Mixed | R404A | 15 | 2 |
| 6 | Bulgaria | 1,200 | Mixed | R404A | 30 | 8 |
| 7 | Italy | 94 | Salami | R404A | 3 | 3 |
| 7 | Italy | 92 | Salami | R404A | 3 | 3 |
| 7 | Italy | 34 | Salami | R404A | 1.5 | 3 |
| 7 | Italy | 14 | Salami | R404A | 0.5 | 3 |
| 7 | Italy | 19 | Salami | R404A | 1 | 3 |
| 7 | Italy | 46 | Salami | R404A | 1.5 | 3 |
| 8 | Italy | 1,000 | Mixed | R717 | 10 | 3 |
| 8 | Italy | 14,000 | Mixed | R717 | 130 | -22 |
| 9 | Italy | 57 | Pasta | R404A | 3 | 1.5 |
| 10 | Denmark | 125,000 | Mixed | R717 | 250 | -20 |
| 11 | Denmark | 500 | Vegetable | R717/secondary | 43 | 4 |
| 12 | Denmark | 800 | Smoked meat | R22/R134a | 10.9 | 4 |
| 13 | Denmark | 98,500 | Meat | R717 | 140 | -21 |
| 13 | Denmark | 2,400 | Meat | R717 | 55 | -21 |

n.b. Stores where 2 heat loads are reported refer to a pull down heat load associated with initial temperature reduction after harvest and a stable heat load once ‘field heat’ had been removed.

## Audit procedure

### Data collection

Data used in the audits was collected from:

1. Site diagrams and blue prints.
2. From selected positions on the refrigeration systems using data loggers (temperature and energy loggers) placed there by the ICE-E team.
3. Manufacturers’ data.
4. Direct observation of the cold room use.
5. Direct measurement of specific temperatures in and around the cold rooms.

### Meteorological data.

The meteorological data used in the analysis were obtained from data logged during the survey by the ICE-E team. Longer term data was obtained from local weather stations.

### Heat loads.

Heat loads across the cold store walls, due to infiltration (from doors, gaps in the insulation and any air extraction), product (sensible, latent and respiration where applicable) and from people and equipment (forklifts, lighting, fans, defrosts) were calculated from the observed and recorded data.

The following methods were used to assess heat loads:

The heat load on each room through the cold store fabric was obtained by calculation of room U values (from known store wall material properties), wall/floor/ceiling areas and temperature difference between inside and outside the cold store (usually from measured data).

Air infiltration was estimated using the method described by Gosney and Olama (1975).

Heat load from food was calculated using bespoke heat transfer models.

The heat load on the room due to forklifts was calculated from fork lift manufacturer’s data.

The heat load due to pedestrians was calculated from ASHRAE (2006).

The fixed heat loads on the rooms (lights, defrost heaters, evaporator fans) were measured.

### Efficiency of the refrigeration system.

Investigation of the operation of the cold store refrigeration systems was carried out by direct measurement using data loggers. Temperature sensors were attached to each data logger. Temperature sensors were placed at the following location on each refrigeration plant:

1. First or second turn (from evaporator inlet) of evaporator coil to measure evaporating temperature.
2. Suction line at evaporator discharge.
3. Air return temperature onto evaporator.
4. Suction line at compressor.
5. Discharge from compressor.

Energy meters were attached to electrical panels to measure total and individual power to lights, fans, defrosts and other energy using equipment in the cold store.

Data were logged for each plant over a period of at least 12 days. During that period the logging interval was varied from 1 to 5 minutes. Additional manual readings were taken of temperatures and pressures on each plant.

### Assessment of energy usage and efficiency.

The energy consumed by each plant was calculated from the data logged. Using the information and data collected an assessment was made of the options to reduce energy use in each cold store. The COSP (Coefficient Of System Performance) for each refrigeration system under stable operating conditions was calculated (this included the total energy consumption of compressors, evaporator and condenser fans). The energy and efficiency of each energy using component was assessed against manufacturers’ data and its potential to use less energy assessed.

The options available to reduce energy consumption were evaluated in terms of projected energy savings.

# RESULTS

## Areas where energy savings were identified

Issues identified in the audits were classified under 21 general headings. Overall between 1 and 12 issues were identified in each store with an overall mean of 6 issues identified per store. A list of the issues and the regularity that they were found is shown in Figure 1. No one issue dominated with issues being spread across store location, store function, store size and temperature setting.



Figure 1. Issues identified in the audits.

## Energy savings identified

The potential energy saving (% of annual energy ) was calculated and is presented as mean % energy savings for each energy saving issue identified in Figure 2. 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 no one issue dominated in terms of energy saving potential although control issues, lighting, insulation and service/maintenance related issues demonstrated the greatest savings potential.



Figure 2. Energy saving potential for each issue identified in the audits.

Further analysis of the data collected showed that there was potentially greater savings available in chilled stores than frozen stores (Figure 3) and the greatest energy savings were from smaller stores of less than 5,000 m3 (Figure 4). Greater savings were found in some store types (Figure 5) but the variability in the potential savings was quite high. It should be remembered that the audits covered only 28 stores and that this may not be an extensive enough data set to provide conclusive results.



Figure 3. Potential savings related to store temperature.



Figure 4. Potential savings related to store volume.



Figure 5. Potential savings related to product type stored.

## Cost effectiveness of initiatives to save energy.

The payback time for each energy saving initiative was 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 6 together with the range in payback times calculated. Some interventions required minimal time (e.g. resetting of a cold store thermostat) and therefore no costs were attributed as the time to implement would be less than 15 minutes. In some cases the range in payback time varied considerably making the option in some cases attractive financially and in others making the option non viable. In all the cold stores audited there was at least one intervention that had a payback of 1 year of less.

Overall 54% of issues identified had paybacks of less than 1 year, 69% had paybacks of less than 3 years and 78% had paybacks of less than 5 years. Depending on the company structure, paybacks of up to 10 years were acceptable to the companies that were audited. If 10 years was an acceptable payback time only 6% of the initiatives would be unacceptable financially. Interventions with longer term paybacks tended to be application of large scale new equipment and improvements to insulation which were major capital projects (although there was a large range in these paybacks).



Figure 6. Payback time for each issue identified in the audits.

n.b. The graph shows a maximum payback time of 26 years. This excludes maximum paybacks of greater than 26 years as was assumed that these would not be of interest to end users.

## 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 or the ICE-E modelling tools to identify the level of savings that could be achieved. A further level of 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 (Figure 7).



Figure 7. Level of expertise required to identify and quantify issues identified in the audits.

# CONCLUSIONS

The audits carried out demonstrated that savings were achievable in all the stores examined. The level of savings varied considerably with no one issue dominating. The potential energy savings varied widely with issues related to control of the refrigeration system, lighting, insulation and maintenance providing the greatest energy savings. Twenty-four percent of the savings could be identified by a reasonably able cold store manager and a further 43% by 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. Some of this could be automated and many of the issues identified in the audits could be simply highlighted to cold store managers through automated monitoring systems.

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.

The overall result of this study demonstrates that generic advice is of limited use to cold store operators. Each cold store must be assessed individually to fully optimise performance and to maximise energy savings.

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Further information on the ICE-E project can be found at www.ice-e.eu.

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