Cold store energy performance

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ABSTRACT

Data on the performance of cold stores was collected as part of a benchmarking survey. The results demonstrated the large variability in performance of cold stores. The volume of the cold store was found to have the greatest relationship with energy use with none of the other factors collected having any significant impact on energy use. The work can be used as an initial basis to develop benchmarks for cold stores and to compare energy performance.

# 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. Studies have shown that leakage of refrigerants may be higher than 17% in industrial plant (Clodic and Palandre 2004). Refrigeration energy consumed in the food chain has not been accurately quantified due to a lack of measured energy consumption and process throughput data in most sectors (Swain, 2006). Overall figures would indicate that excluding domestic refrigeration, approximately 50% of the energy is associated with retail and commercial refrigeration and 50% with chilling, freezing and storage (Market Transformation Programme).

Cold storage rooms consume considerable amounts of energy. Within cold storage facilities 60-70% of the electrical energy used is for refrigeration. Therefore cold store users have considerable incentive to reduce energy consumption. In Europe there are 60-70 million cubic meters of cold storage for food. 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 interest to end users. To enable end users to improve the performance of their cold stores a project called ‘Improving Cold storage Equipment in Europe’ (ICE-E) 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.

As part of the ICE-E project, two internet based surveys were developed and data collected to determine energy usage in different cold store types, sizes and configurations. Results from these surveys are presented in this report and the data analysed to determine whether there were any common factors that affected performance of the cold stores.

# MATERIALS AND METHODS

## Detailed survey tool

### Development of survey tool

The 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 initially tested on a selected number of cold store operators to ensure the questions were appropriate and relevant. Improvements were then made based on their comments.

The survey allowed participants to initially register their details and then to enter data on as many refrigeration systems as they wished. It was set up to collect information per single refrigeration system that might supply one of several cold stores. The survey was designed to be simple to complete with the aim that is should take a cold store operator less than 20 minutes to complete the survey. The final survey document 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 and could also register to participate in a detailed energy audit of their facilities. The detailed audits were selected to cover different locations, sizes, types and uses. The data from these audits were used in later studies, verification of the mathematical models and in the ‘case studies’ to show where improvements could be achieved.

### Data collected

The survey parameters collected are shown in Table 1. In all cases the users were asked to rate the accuracy of the data they submitted. The collected data was retained on a server where users could return to update information or add further data.

### Benchmark analysis

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 and 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.

Table 1. Information collected in survey.

|  |  |
| --- | --- |
| Survey page heading | Units |
| Basic information: |  |
| Total electricity usage for the system in 2009?  Does the electricity energy figure of the system submitted include?   1. Compressor 2. Lights 3. Fans 4. Pumps 5. Fork/lift charging 6. Blast freezing 7. Floor heating   If figure supplied includes blast freezing what is energy use EXCLUDING blast freezing?  What is the total volume of the room(s) supplied by the system?  What was the throughput in 2009?  What is the main function of the room(s)?  What is stored in the room(s)?  What is the chilled set point temperature of room(s)?  What is the frozen set point temperature of room(s)?  Do you plans to invest in energy saving equipment? | kWh  Yes/No/Don’t know  Yes/No/Don’t know  Yes/No/Don’t know  Yes/No/Don’t know  Yes/No/Don’t know  Yes/No/Don’t know  Yes/No/Don’t know  kWh  m3  Ton  Chilled/frozen/mixed storage/blast freezing/loading  Mixed foods/Meat/Fish/Fruit/Vegetables/Dairy/Cereal products  °C  °C  Yes/No/Don’t know |
| Refrigeration system: |  |
| Primary refrigerant  Refrigerant quantity/charge  Amount of refrigerant added to primary system in 2009  Secondary refrigerant  Refrigerant quantity/charge  Amount of refrigerant added to primary system in 2009 | Don't know/R22/CO2/Ammonia/Other  kg  kg  Don't know/R22/CO2/Ammonia/Other  kg  kg |
| Food stored: |  |
| Average intake temperature for chilled products  Average intake temperature for frozen products  Does the room have controlled atmosphere?  Does the room have humidity control?  How is the food stored in the area?  How much food can be stored in the storage area  How many pallets/containers can be stored in the storage area  What is the number of pallets/containers INTAKE in 2009  What is the number of pallets/containers RELEASE in 2009  What is the average size and weight of one pallet/container | °C  °C (for mixed system fill both)  Yes/No/Don’t know  Yes/No/Don’t know  Don't know/Pallets/Bins/Dolavs or containers/Placed on shelves  Kg  Number  Number  Number  Width/Height/Depth all in m /kg |
| Facility: |  |
| How many separate rooms does the system supply?  What is the total floor area supplied by the system?  How much of the floor area is used for:   * Chilled storage * Frozen storage * Blast freezing storage   How many doors (total) are there on the room(s)?  How many times on average will each door be opened per day?  Do the doors have any protection?  Is product automatically or manually loading into the room?  Where are the room (s) positioned?  What is the age of insulation?  What is the thickness of the:   * Wall insulation * Ceiling insulation * Thickness of the floor | Number  m2  m2  m2  m2  Number  Number  Don't know/No protection/Strip curtain/Air curtain or Air lock/Automatic doors  Don't know/Manual (hand or fork lift)/Automatic (robot crane)  Don't know/Inside a building/Outside  Don't know/<5 years/ 5 to 10 years/ 10 to 20 years/>20 years  mm  mm  mm |
| Refrigeration equipment: |  |
| Type of refrigeration cycle?  Type of refrigeration system?  Type of compressors?  Do you have economized compressors?  What is the compressor control system?  How are compressors controlled?  Type of condensers?  Defrost type?  Do you use any heat from the refrigeration plant?   * If yes, what for   What is the year of installation of the system? | Don't know/Single stage/Multi stage/Cascade/Absorption cycle/Air cycle  Don't know/Dry evaporator with thermostatic valve/Flooded-pumped/Flooded-natural circulation  Don't know/Reciprocating/Screw or Scroll/Rolling piston/Centrifugal  Yes/No/Don’t know  Don't know/VSD/Unloading/Other  Don't know/Suction pressure/Room air temperature/Other  Don't know/Air cooled/Evaporative/Water cooled/Cooling tower/Other  Don't know/Hot gas/Electric/Passive/Other  Yes/No/Don’t know  Water heating/Floor heating/Other heating  Year |

## Express survey tool

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.

## Development of survey tool

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.

## Data collected

A limited data set was collected (set temperature, 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.

## Benchmark analysis

Once data was submitted the information was input manually into the main benchmark survey and information sent directly to the cold store operator.

# RESULTS

## 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. After removal of data that was considered unreliable (i.e. data that was obviously wrong, inputs not completed etc) this left 295 data sets.

Not all data sets had complete data as many users had not replied to every question asked. However, the core data set had the 5 main attributes collected (temperature of the store, area and volume of the store, food throughput and energy usage per year).

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 294 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 specific energy consumption (SEC) 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).

## Country

Large variations in SEC were shown between countries. Significant differences were found between chilled and frozen stores but not mixed stores in the countries within the survey. Due to the limited number of data sets for some countries it would not have been possible to analyse data from each country separately. 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 (in kWh/year) and the information collected was investigated using multiple regression. As part of this analysis the data was found to be near to a normal distribution.

### Chilled stores

Regression demonstrated that 93% of the variation in annual energy consumption was related to store volume (Figure 1). Multiple regression demonstrated that food type and food throughput had some impact on annual energy but that these factors only increased the R2 value to 95% and therefore their impact was very low. All other factors collected had no influence on annual energy consumption.

Applying non linear relationships to the data did not improve the regression R2 value. This indicates that SEC is independent of store volume.



Figure 1. Relationship between store volume and total energy use per year (kWh/year) for chilled stores.

### Frozen stores

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 R2 value to 66% (Figure 2). This would indicate that for frozen stores that SEC reduced as the store size increased.

None of the factors recorded that 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.



Figure 2. Relationship between store volume and total energy use per year (kWh/year) for frozen stores (non linear regression).

### Mixed stores

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 was applied this increased to 76%. (Figure 3). 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.



Figure 3. Relationship between store volume and total energy use per year (kWh/year) for mixed stores (non linear regression).

## All stores

It is interesting to note that mixed and frozen stores had a relatively similar relationship between volume and annual energy (although statistically the regressions lines were significantly different at P<0.01). At volumes below 22,000 m3 chilled store used less energy than frozen or mixed stores but at volumes above 22,000 m3 chilled stores used more energy than frozen or mixed stores. This was mainly due to a cluster of smaller chilled stores that had low energy consumption.

The SEC for the cold stores examined varied considerable. Data from all stores and for all stores with the 10% and 20% upper and lower values removed are shown in Table 2.

Table 2. Range in SEC values for cold stores examined.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Chilled (kWh/m3/year) | Frozen (kWh/m3/year) | Mixed (kWh/m3/year) |
| All data | Mean | 56.1 | 73.5 | 61.2 |
| Minimum | 4.4 | 6.0 | 15.7 |
| Maximum | 250.4 | 240.4 | 115.8 |
| 10% upper and 10% lower values removed | Mean | 52.2 | 66.7 | 52.0 |
| Minimum | 20.7 | 27.0 | 29.9 |
| Maximum | 95.3 | 134.6 | 107.0 |
| 20% upper and 20% lower values removed | Mean | 51.5 | 63.7 | 55.9 |
| Minimum | 29.6 | 37.5 | 37.4 |
| Maximum | 78.0 | 100.0 | 87.3 |

# CONCLUSIONS

The data collected in the ICE-E survey showed that there was large variability in the energy used by cold stores. The SEC varied between 4 and 250 kWh/m3/year for chillers, between 6 and 240 kWh/m3/year for freezers and between 23 and 157 kWh/m3/year for mixed stores. Duiven and Binard (2002) estimated that cold stores should use between 30 and 50 kWh/m3/year.The data collected in this survey demonstrated that 47% of chilled stores, 35% of frozen stores and 50% f mixed stores had an SEC of less than 50 kWh/m3/year. This demonstrates that there is considerable potential to reduce energy consumption in cold stores.

Differences were found between chilled, frozen and mixed usage cold stores. The major influence on annual energy consumption in all store types was the volume of the store. For chilled stores volume accounted for 93% of the variation in annual energy consumption. In frozen and mixed stores, volume accounted for 66-76% of the variation in annual energy consumption but this was a non linear relationship. In frozen and mixed stores other factors had minimal impact on variation in annual energy consumption. This may have been due to lack of replicate data for some factors recorded. Further work is required to examine the impact of some of these factors. There also appears, especially with frozen and mixed stores, a factor or factors affecting annual energy consumption that were not collected in the survey. The survey was not able to assess heat loads from chamber freezing or processing in chamber (although this information was requested it was rarely provided). Therefore the variations in energy consumption may be explained by the additional heat loads in some chambers. This requires further investigation.

The performance of all stores (chilled, frozen and mixed) was statistically different. However, there was more relationship between the performance of frozen and mixed stores than there was between chilled and frozen or chilled and mixed stores. The energy used by chilled stores was less than frozen or mixed stores at volumes below 22,000 m3 but was higher above this value. This might indicate that large frozen stores tend to be long term stores with less usage and that larger chilled stores have high usage (e.g. large regional distribution centres). This again requires further investigation.

It would be expected that larger stores would be more efficient and have a lower SEC than smaller stores. The indications were that this was only the case for frozen and mixed stores. For chilled stores the relationship between volume and store size was linear. This indicates that chilled and frozen/mixed stores are affected by transmission heat loads in different ways. It is possible that transmission is more dominant in stores with lower temperatures and so the impact of surface to volume ratio (which is less in a larger store) is greater than in chilled stores. It might also be expected that usage of chilled stores may be greater than that of frozen stores (more movement of food, more door openings etc) and that this may be a more dominant factor affecting energy than transmission. However, there was no relationship between annual energy consumption and food throughout in chilled stores and so this does not appear to be the answer.

The analysis demonstrated a surprising lack of relationships between the factors recorded (apart from volume) and annual energy consumption. There was for example no relationship for any store types with temperature of the store even though the range in temperatures recorded were relatively wide ranging (13°C for chilled and 5°C for frozen) and there was an extensive data set. In other instances the lack of any relationship may have been due to the restricted data sets available. It would therefore be useful to collect further data on the factors that were indicated to be important by the regression analysis.

The data collected provides an indication of the factors that most affect the energy used by cold stores. This provides a useful framework to develop labelling of cold stores and the factors that should be considered when creating a benchmarking or labelling scheme. In addition it would be beneficial to collect information from a greater number of countries to enable comparison of cold store performance Worldwide.

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

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