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SPECIFIC ENERGY CONSUMPTION VALUES FOR VARIOUS REFRIGERATED FOOD COLD STORES

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ABSTRACT

Cold storage rooms consume considerable amounts of energy. Within cold storage facilities 60-70% of the electrical energy may be used for refrigeration. Therefore cold store users have considerable incentive to reduce energy consumption.

The performance of a large number of cold stores has never been compared in detail across a range of locations. With government targets to reduce energy and emissions of greenhouse gasses (GHG), the need to benchmark and understand potential energy and GHG reductions is of great interest to end users.

As part of a large project on cold store energy performance, internet based surveys were developed and data collected to determine energy usage in different cold store types, sizes and configurations. Mathematical models were developed to assist end users to reduce energy consumption and to identify how much energy a store should use in different usages and configurations.

The information previously collected on cold store energy performance has previously been presented (Evans, et al., 2014a). Since that time the original data set has been increased by 46% to a total of 758 stores. This enables further analysis of the data. The work compares energy usage of cold stores in different parts of the World (countries, continents and according to temperature zone). The energy use of the cold stores is compared to theoretical energy use figures generated from a mathematical model.

1. INTRODUCTION

Almost all chilled and frozen food is stored in a cold store at some stage throughout the food cold chain. Cold storage rooms consume considerable amounts of energy. Asano & Mugabi (2013) stated that within cold storage facilities, 60–70% of the electrical energy may be used for refrigeration. This means that there are considerable incentives for cold store operators to reduce energy usage.

Studies on the energy used in cold stores have demonstrated that energy consumption can vary considerably and that this was due to a variety of factors (Evans and Gigiel 2007) (Evans and Gigiel 2007) (Evans and Gigiel 2010) (Evans, et al., 2014b). These surveys also demonstrated that energy savings of around 30-40% were achievable by optimising usage of the stores, repairing current equipment and by retrofitting of energy efficient equipment.

Limited data is available on the energy performance of cold stores. Most published information is from relatively small data sets. Table 1 lists the specific energy consumption (SEC) of cold stores from different surveys that have been published. The largest survey was published by Evans, et al (2014a) where 294 data sets were collected covering chilled, frozen and mixed (chilled and frozen stores operated from one refrigeration system) cold stores. One data point was the mean of 331 cold stores in the UK (i.e. the total data collection encompassed a total of 624 stores). Since that time considerably more data on cold store performance has been collected bringing the data set up to 428 (or 758 if the 331 UK stores are counted individually).

The performance of such a large number of cold stores has never been compared in detail and there is little information to compare performance of stores Worldwide. With government targets to reduce energy and emissions of greenhouse gasses (GHG), the need to benchmark and understand potential energy and GHG reductions is of great interest to end users.

Table 1. Publications listing energy used in food cold stores.

Specific energy consumption ($kWh.m^{-3}.year^{-1}$)	**Country**	**Publication**
4.4 to 250.4	UK	Evans et al (2014a)
15 to 132	USA	Singh (2006)
19 to 88	USA	Elleson & Freund (2004)
26 to 379	New Zealand	Werner, et al. (2006)
30 to 50	Europe	Duiven and Binard (2002)
34 to 124	UK	ETSU (1994)
35	Netherlands	Bosma (1995)
101 to 1520	Germany	Carlsson-Kanyama & Faist (2000) reporting, BELF (1983)

2. MATERIALS AND METHODS

2.1 Survey data

Data was collected as part of a survey of cold store energy performance. The survey is described in detail in Evans, et al. (2014a). The survey data was collected through 2 formats: a web based survey that collected detailed information on the cold store and a web based express survey where only limited data was collected on each store. Although a large range of parameters were collected the main parameters used for the analysis in this paper were: temperature of the store, location of the store, volume of the store and energy usage per year.

2.2 Mathematical model

A mathematical model of cold store energy use was developed to predict energy used by cold stores. This was used to compare theoretical energy used by cold stores with the actual energy usage collected in the survey. Full details of the model are presented in Foster et al (2013).

The mathematical model was used to compare the survey data with modelled usage scenarios to determine the level of performance of each cold store. The usage consisted of 8 scenarios modelled over a range of store volumes between 10 and 350,000 m^3 (Table 2). The geometry of the store modelled was 5 m high with width and depth equal in all cases. For each scenario a chilled store at 2°C and a frozen store at -23°C were modelled. The 8 scenarios ranged from high efficiency where all heat loads were minimised (Scenario 1) to a scenario with an inefficient store with high heat loads from infiltration, lighting, fans, people, forklifts and external radiation (Scenario 8). Parameters for each scenario were selected based on information collected from energy audits carried out by Evans, et al. (2014b). These represented a range from what would be the most efficient configuration (Scenario 1) to the worst configuration that would be feasibly possible (Scenario 8). Further details of the configurations modelled are presented in Evans et al (2014c).

Table 2. Assumptions used in model.

Scenario 1	External walls	All walls shaded. All walls light coloured
	Wall insulation	Polyurethane, 100 mm for chilled stores 150 mm for frozen stores
	Air around store	Still
	Under floor heating	None
	Refrigeration system	R717 (ammonia), 2 compression/1 expansion stage, high isentropic efficiency (0.7). Evaporative condenser
	Defrosts	Off-cycle defrost for chilled stores, electric for frozen stores
	Product heat load	None
	Fork lift heat load	None
	Personnel heat load	None
	Lighting heat load	None
	Infiltration heat load	None
	Evaporator/condenser fan power	Created from correlation from Evans et al. 2013b
Scenario 2	*As Scenario 1, except:*	
	Product heat load	Food loaded at 1°C above store temperature Product density = 250 kg m^{-3}, product weight loss = zero Chilled stores: 25% of total mass loaded each day. Frozen stores: 10% of total mass loaded each day.
	Fork lift heat load	1 per 40,000 m^3 store volume, size=medium, electric, operated 12h per day
	People heat load	2 persons per forklift truck, 2 hours per day, person in store for short periods
	Lighting heat load	Fluorescent lights, 50 lumens.W^{-1}, 500 lux, operational 12 hours per day
	Infiltration heat load	Door height 2.5 m, width 2 m minimum, if > 50,000 m^3 store volume then door width = store volume/10,000, door opening time = 30 sec, volume of traffic during door opening = medium, door seal = good, strip curtains on door 48 door openings per day for chilled store, 24 for frozen store
Scenario 3	*As scenario 2, except:*	
	Refrigeration system	Medium isentropic efficiency (0.6)
Scenario 4	*As scenario 3, except:*	
	Fork lift heat load	1 per 40,000 m^3 store volume, size=medium, electric, operated 24h per day
	People heat load	2 persons per forklift truck, 6 hours per day, person in store for short periods
	Lighting heat load	Fluorescent lights, 50 lumens.W^{-1}, 500 lux, operational 24 hours per day
	Infiltration heat load	No door protection 96 door openings per day for chilled store, 48 for frozen store
Scenario 5	*As scenario 4, except:*	
	Product heat load	Food loaded at 5°C above store temperature
Scenario 6	*As scenario 5, except:*	
	Refrigeration system	Low isentropic efficiency (0.5)
Scenario 7	*As scenario 6, except:*	
	External walls	All walls non-shaded. All walls dark coloured
	Refrigeration system	Air cooled condenser
	Infiltration heat load	Volume of traffic during door opening = low, door seal = poor 192 door openings per day for chilled store, 96 for frozen store
Scenario 8	*As scenario 7, except:*	
	Wall insulation	Glass/mineral wool
	Evaporator/condenser fan power	Doubled
	Infiltration heat load	384 door openings per day for chilled store, 192 for frozen store
	Lighting heat load	Fluorescent lights, 30 lumens.W^{-1}
	Product heat load	Food loaded at 10°C above store temperature

2.3 Analysis

The data were analysed to determine whether there were differences in SEC between types (chilled, frozen or mixed) of store. A further analysis was carried out to determine whether there were differences in SEC that was related to the location of the cold stores. Location was assessed according to country and area (continent) and also according to temperature zone. Average annual temperature for each country was obtained from a weather database (LLC, Canty and Associates 2013). Three temperature zones were created based on the annual mean temperature for the country; cold which was below 7.5°C, warm which was above 10°C and temperate which was between these 2 values. Finally an assessment was made of the SEC, when compared to the scenarios modelled using the mathematical model.

3. RESULTS

3.1 Survey data

The cold stores were divided into chilled, frozen or mixed stores. One data point was the mean of 331 cold stores in the UK (i.e. the total data collection encompassed 758 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. The data set analysed was therefore 167 chilled stores, 187 frozen stores and 75 mixed stores.

Differences between the SEC of each store type were analysed using analysis of variance (ANOVA). The results showed that frozen and mixed stores were not significantly different ($P=0.44$) but that frozen and mixed stores had a higher SEC than chilled stores ($P<0.05$). Therefore the frozen and mixed store data was combined and analysed as one data set. The SEC for the cold stores examined varied considerably. Data from all stores and for all stores with the 10% and 20% upper and lower values removed are shown in Table 3. By removing a relatively small number of data points the range in SEC reduces considerably. For the full data set the range for chilled stores was 246.0 and for frozen/mixed stores it was 385.6 $kWh.m^{-3}.year^{-1}$. By removing the top and bottom 10% of data this reduced to 64.4 for chilled and 88.2 $kWh.m^{-3}.year^{-1}$ for frozen/mixed stores. This indicated that a small number of stores had a high or low SEC and operated differently from other stores in the database.

Table 3. Range in SEC values for cold stores examined.

		Chilled ($kWh.m^{-3}.year^{-1}$)	**Frozen and mixed ($kWh.m^{-3}.year^{-1}$)**
	Number of replicates	167	262
All stores	Mean	55.7	71.5
	Minimum	4.4	6.0
	Maximum	250.4	391.6
	Standard deviation	34.7	40.6
Upper 10% removed	Mean	50.9	67.2
	Minimum	21.7	31.1
	Maximum	86.1	119.4
	Standard deviation	16.1	21.5
Upper 20% removed	Mean	50.2	66.2
	Minimum	31.3	40.0
	Maximum	70.6	93.0
	Standard deviation	10.3	14.8

3.2 Location of the store

Data was collected on cold store energy use in 23 different countries. The mean SEC and standard deviation (where available) for each location is presented in Figure 1 for the chilled stores and Figure 2 for the frozen/mixed stores.

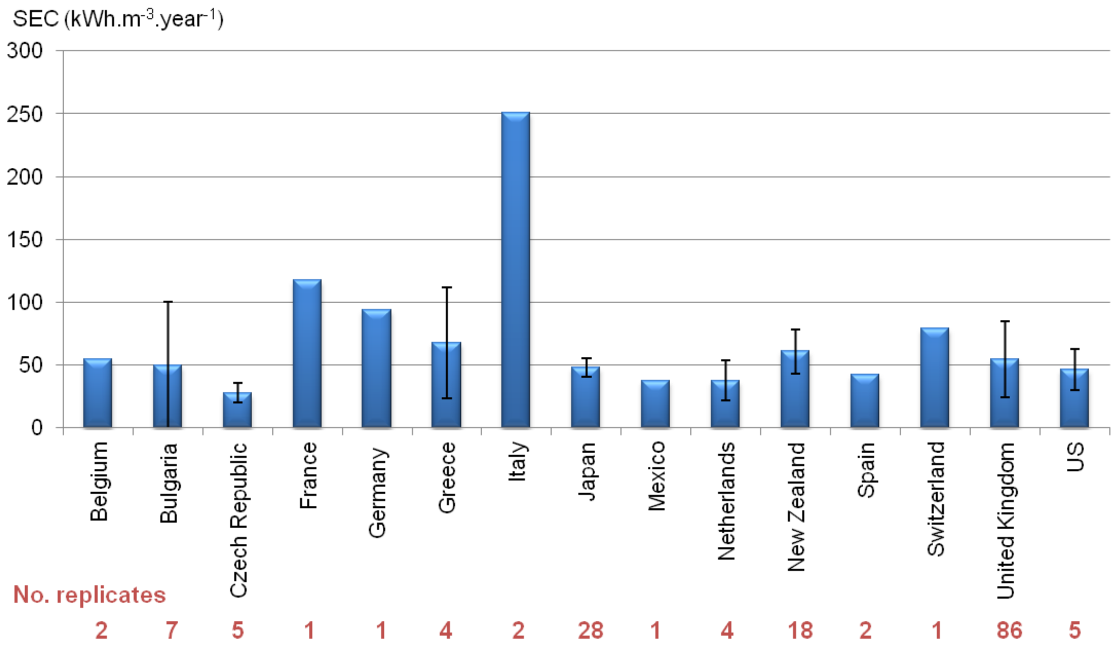

Figure 1. SEC for chilled cold stores in different locations

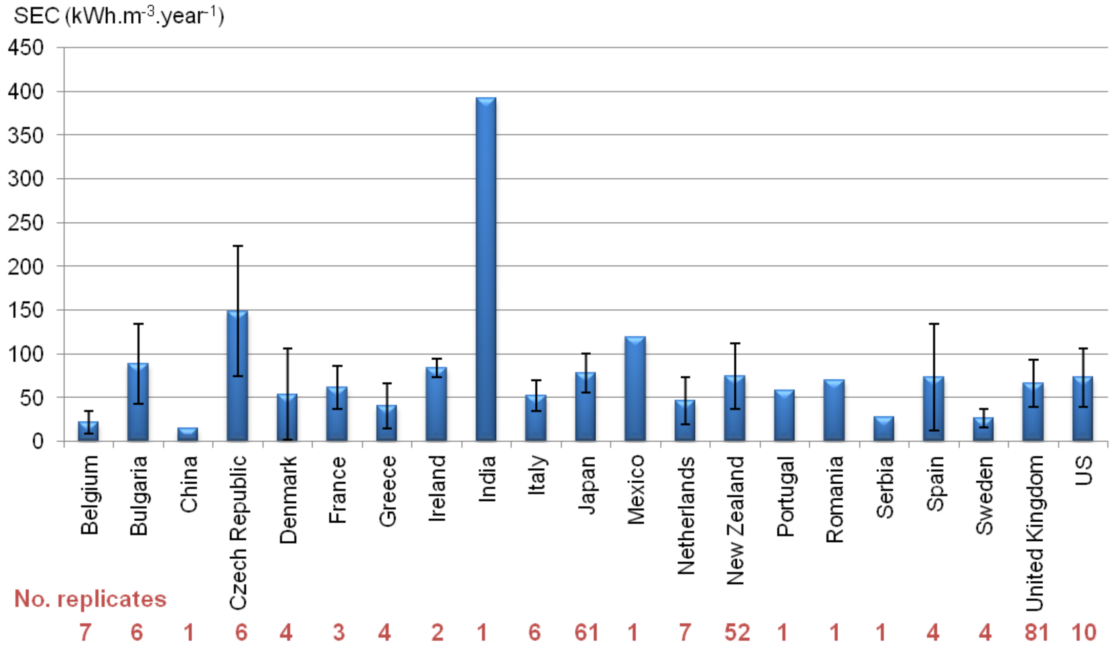

Figure 2. SEC for frozen/mixed cold stores in different locations.

The number of replicates for each country was rather low in many instances. Therefore the data was divided into larger areas (continents) and into temperature zones to investigate whether there was any relationship between location and SEC. When divided into continents ANOVA showed no significant differences between SEC and continent for chilled or frozen/mixed stores (Figure 3, Figure 4). When divided into temperature zones there was no significant difference between zones and SEC for the chilled stores. For the frozen stores there was a significant difference ($P<0.05$) between the cold and temperate located stores and the warm and temperate located stores. There was however, no difference between the cold and warm located stores (Figure 5, Figure 6).

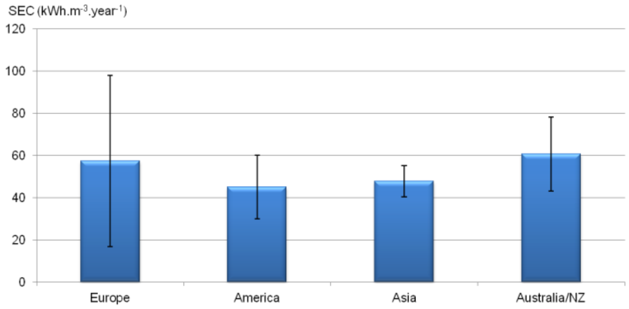

Figure 3. Mean SEC and standard deviations for chilled stores in different locations.

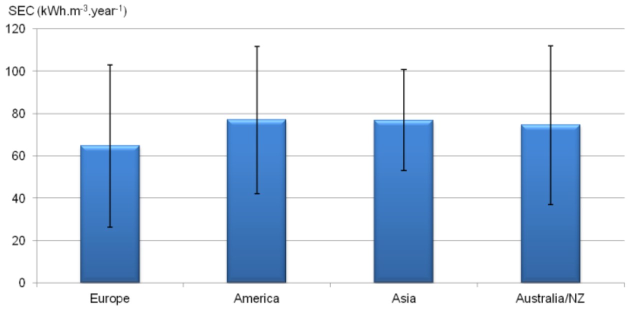

Figure 4. Mean SEC and standard deviations for frozen/mixed stores in different locations.

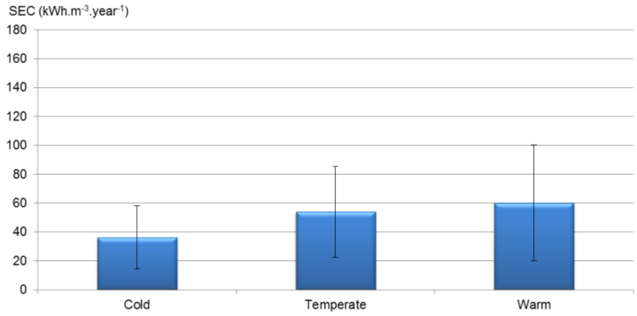

Figure 5. Mean SEC and standard deviations for chilled stores in different temperature zones.

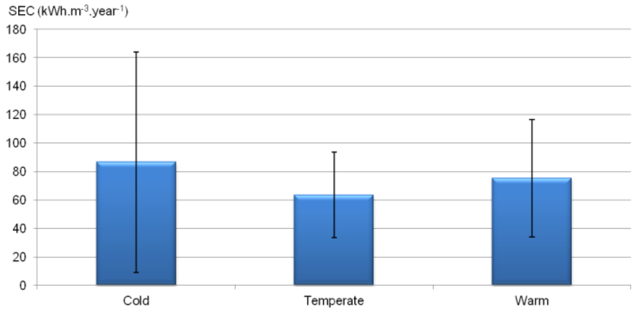

Figure 6. Mean SEC and standard deviations for frozen/mixed stores in different temperature zones.

2.4 Mathematical model

A comparison between the volume of each store and the energy used per year are shown in Figure 7 for the chilled stores and Figure 8 for the frozen/mixed stores. The 8 results from the modelling scenarios are superimposed on each graph (and numbered 1-8 as described in (Table 2). Approximately 2% of the chilled and the frozen/mixed stores performed below scenario 1 and appeared to be extremely low energy using. Thirteen percent of the chilled stores and 5% of the frozen/mixed stores performed worse than scenario 8. Not enough information was available to be able to further analyse these stores. Although they appeared to use far more energy than they would be predicted to do there may have been circumstances that caused the high energy usage such as high product load.

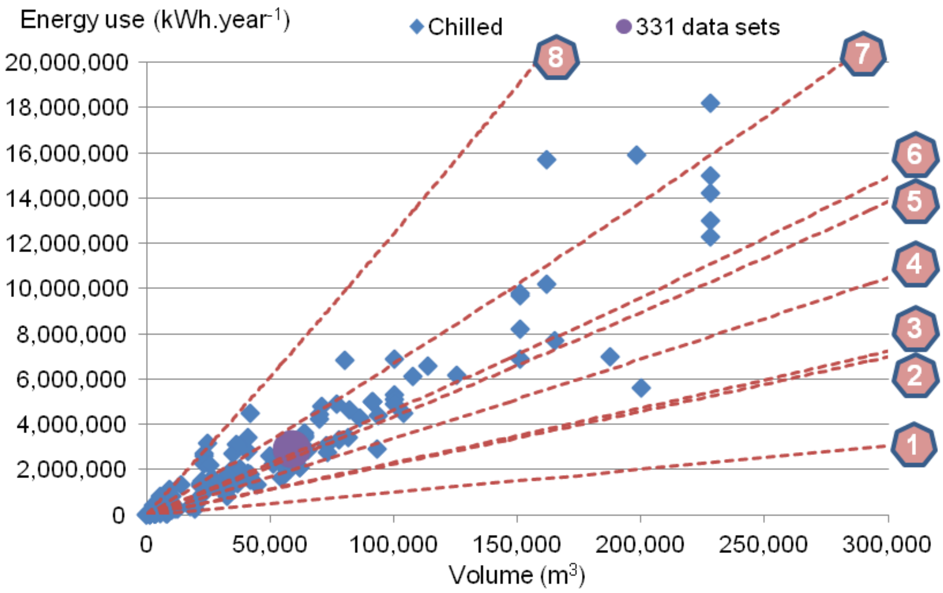

Figure 7. Comparison between energy used by chilled cold stores against model predictions.

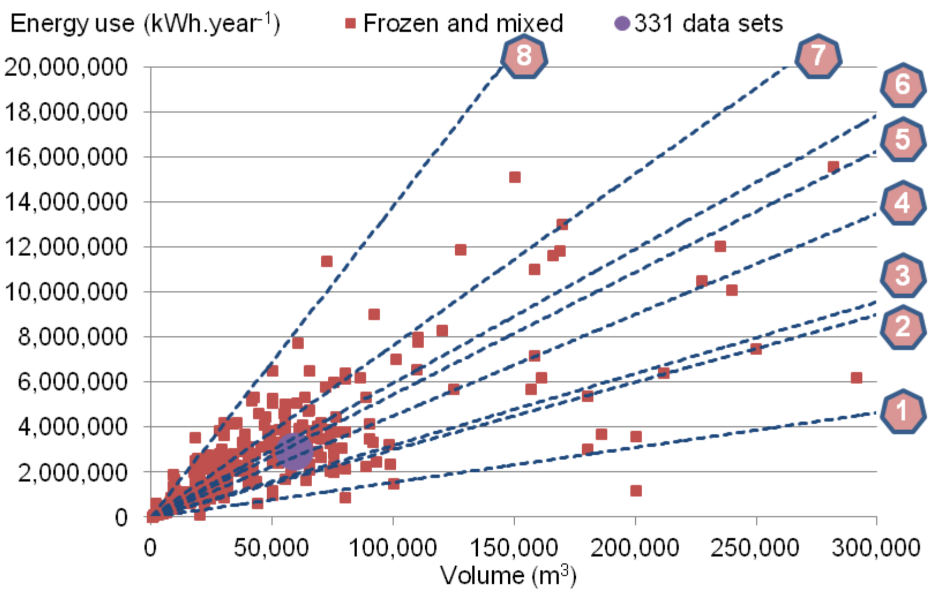

Figure 8. Comparison between energy used by frozen/mixed cold stores against model predictions.

4. DISCUSSION AND CONCLUSIONS

The additional survey data collected since 2014 has expanded the data set by 44%. This has enabled further analysis and an improved the relationship between energy use for frozen and mixed stores. However, large differences between performances of similar sized stores were still apparent indicating that energy used in similar sized stores varies considerably. The impact of location (country or continent) of the store on energy usage was minimal but may be due to the lack of replicates for some locations. A difference in location related to ambient temperature was found for the frozen stores but not the chilled stores.

The mathematical model provided a better understanding of the variations in cold store energy consumption and helped identify the stores with low energy usage and those with extremely high usage. The model was shown to be a useful tool to estimate energy use of a cold store and provided a mechanism to generate metrics that can be used to assess efficiency of a cold store.

5. ACKNOWLEDGEMENTS

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