Energy use in food refrigeration

Calculations, assumptions and data sources

FRPERC JOB NO. 2006013

by

Mark Swain

Produced by:

Food Refrigeration and Process Engineering Research Centre (FRPERC),

University of Bristol, Churchill Building, Langford, North Somerset,

BS40 5DU, UK

Tel : ++44 (0)117 928 9239 Fax : ++44 (0)117 928 9314

e-mail frperc-bris@bristol.ac.uk http://www.frperc.bris.ac.uk

Summary

The purpose of this report is to provide outline details of the calculations, assumptions and data sources used to produce the 'Top Ten' food sectors that use the most energy for refrigeration having the greatest potential for savings.

Contents

Introduction

In June 2006, a Defra funded project to "identify, develop and stimulate the development and application of more energy efficient refrigeration technologies and business practices for use throughout the food chain whilst not compromising food safety and quality" started. The project is a collaboration between four top University research groups, an industrial steering group and over a hundred stakeholders from the food and refrigeration industries.

The research programme has concentrated on three topics: 1 - mapping of energy use; 2 - Identifying new technologies and 3 - feasibility studies on promising technologies.

In the mapping exercise we have identified and ranked the 'Top Ten' food sectors/operations (Table 1) that use the most energy for refrigeration having the greatest potential for savings.

Table 1. 'Top Ten' food refrigeration sectors in terms of energy saving potential

	Sector	*Energy*		*Saving*	
		'000 t CO_2/y	GWh/y	%	GWh/y
1	Retail display	3098-6819	5768-12698	30-50	6349
2	Catering – kitchen refrigeration	2147	3998	30-50	1999
3	Transport	1206	4822	20-25	1206
4	Cold storage – generic	483	900	20-40	360
5	Blast chilling – (hot) ready meals, pie	16-330	29-614	20-30	184
6	Blast freezing – (hot) potato products	117-223	218-415	20-30	125
7	Milk cooling – raw milk on farm	53-169	99-315	20-30	95
8	Dairy processing – milk/cheese	134	250	20-30	75
9	Potato storage – bulk raw potatoes	77-100	144-187	~30	56
10	Primary chilling – meat carcasses	59-77	109-144	20-30	43

This report provides details of the calculations, assumptions and data sources used to produce this 'Top Ten' ranking.

1. Energy use in retail display

Estimate 1. Annual energy use of sector = 5,768 GWh/y

Estimate 2. Annual energy use of sector = 12,698 GWh/y

Estimate 3. Annual energy use of sector = 7,459 GWh/y

Estimated potential savings in the order of 30 to 50%.

Calculation method

Model developed by the UK Market Transformation Program (MTP) based on

$$E_{TOTAL} = C_{NUM} \times P \times T_{ON} \times 10^{-6} \quad (1)$$

$$E_{TOTAL} = C_{NUM} \times E_{CAB} \times 365 \times 10^{-6} \quad (2)$$

Where:

E_{TOTAL} = Total annual energy consumption of retail display cabinets in UK (GWh/y)
C_{NUM} = Stock of retail display cabinets in UK
P = Power demand (kW)
T_{ON} = On time (h/y)
E_{CAB} = Energy consumption of cabinet (kWh/24 h)

Estimate 1

Item	*E_{TOTAL} (GWh/y)*	*C_{NUM}*
Integral retail display cabinets	1,986	586,200
Remote retail display cabinets	3,782	207,600
Total for sector	5,768	793,800

Estimate 2

Item	*E_{TOTAL} (GWh/y)*	*C_{NUM}*	*P (kW)*	*T_{ON} (h/y)*
Integral retail display cabinets	7,306.85	586,228	1.42	8,760
Remote retail display cabinets	5,391.52	207,576	2.97	8,760
Total for sector	12,698.37	793,804		

Estimate 3

Item	*E_{TOTAL} (GWh/y)*	*C_{NUM}*	*E_{CAB} (kWh/24h)*
Chilled retail display cabinets	5,889	548,800	29
Frozen retail display cabinets	1,570	235,200	18
Total for sector	7,459	793,804	

Source of data

Estimate 1 – Equation (1)

The data for UK integral and remote retail display cabinets is extracted from the commercial refrigeration data (Market Transformation Programme, 2006), reference scenario for 2006. The breakdown of data to individual values for cabinet power demand (P) and on time values (T_{ON}) are not provided in the report.

Estimate 2 – Equation (1)

Using the MTP "What-If" web modelling tool the 2006 energy consumption reference scenarios for integral and retail display were selected. (Requires free registration).

Estimate 3 – Equation (2)

Evans et al. (2007) provides average consumption data based on a range of cabinets tested under standard laboratory conditions. It has been assumed that the energy consumption in retail outlets is about 25% less than under the more arduous test conditions. If the best average energy consumption value is used in the calculation E_{TOTAL} is reduced to 3,777 GWh/y, a potential saving of 49% compared to the estimate based on the average consumption value.

Additional information

Retail display is a temperature maintenance process. There is no separation of chilled and frozen cabinet data in MTP estimates. Currently awaiting response from MTP on reason for discrepancy between two sets of values.

References 1

Evans, J. A., Scarcelli, S. & Swain, M. V. L. (2007). Temperature and energy performance of refrigerated retail display cabinets under test conditions. *Int. J Refrigeration*. **30** 398-408.

Market Transformation Programme (2006). *MTP Sustainable products 2006: Policy analysis and projections - July 2006.* Report ID SP06. Appendix E.12 Commercial refrigeration p.139. www.mtprog.com/ReferenceLibrary/MTP_SP06_web.pdf

Market Transformation Programme (2008). " What-If" web modelling tool. http://whatif.mtprog.com

2. Energy use in catering – kitchen refrigeration

Estimate 1. Annual energy use of sector = 3,998 GWh/y

Estimate 2. Commercial service cabinets only - annual energy use = 2,527 GWh/y

Estimated potential savings in the order of 30 to 50%.

Calculation method

Model developed by the UK Market Transformation Program (MTP) based on

$$E_{TOTAL} = C_{NUM} \times P \times T_{ON} \times 10^{-6} \quad (3)$$

$$E_{TOTAL} = C_{NUM} \times E_{CAB} \times 365 \times 10^{-6} \quad (4)$$

Where:

E_{TOTAL} = Total annual energy consumption of refrigeration equipment item in UK (GWh/y)
C_{NUM} = Stock of refrigeration equipment item in UK
P = Power demand (kW)
T_{ON} = On time (h/y)
E_{CAB} = Energy consumption of cabinet (kWh/24 h)

Estimate 1

Item	*E_{TOTAL} (GWh/y)*	*C_{NUM}*	*P (kW)*	*T_{ON} (h/y)*
Commercial service cabinets	1,763.01	431,530	0.47	8,760
Walk-in cold rooms	2,234.88	201,413	1.90	5,840
Cellar cooling equipment	1,994.95	148,197	3.07	4,380
Ice-making m/cs	378.47	130,479	0.50	5,840
Refrigerated vending m/cs	224.14	76,761	0.50	5,840
Miscellaneous	107.44	102,205	0.18	5,840
Total for sector	3,997.89	632,943		

Estimate 2 – Commercial service cabinets only

Item	*E_{TOTAL} (GWh/y)*	*C_{NUM}*	*E_{CAB} (kWh/24h)*
Chilled commercial service cabinets	1,266	354,000	10
Frozen commercial service cabinets	1,261	236,000	15
Total for sector	2,527	590,000	

Source of data

Estimate 1 – Equation (3)

The data for UK commercial service cabinets and walk-in cold rooms was obtained by using the Market Transformation Programme (2008), "What-If" web modelling tool with the 2006 energy consumption reference scenarios.

Estimate 2 – Equation (4)

Evans et al. (2007) provides average consumption data based on a range of cabinets tested under standard laboratory conditions. If the best average energy consumption value is used in the calculation E_{TOTAL} is reduced to 1,357 GWh/y, a potential saving of 46% compared to the estimate based on the average consumption value.

Additional information

There is no separation of chilled and frozen refrigeration equipment in the data. Equipment used for unknown mixture of temperature maintenance and cooling processes.

The energy consumption of the sector is much greater if a proportion of the additional commercial refrigeration equipment considered by the MTP is also included table (see data shown in lighter type in the table above).

Performance of equipment degrades over time especially with poor maintenance (leading to underestimate of energy use). Future estimates could be improved if more data were to be made available of efficiency under actual use conditions. Number and condition of equipment currently in use subject to large uncertainty (especially in large number of smaller catering premises).

Food Service includes; Licensed Public Houses, Restaurants, Cafes, Take Away Food establishments, Hotels, Staff Catering Facilities

References 2

Evans, J. A., Scarcelli, S. & Swain, M. V. L. (2007). Temperature and energy performance of refrigerated retail display cabinets under test conditions. *Int. J Refrigeration*. **30** 398-408.

Market Transformation Programme (2008). "What-If" web modelling tool. http://whatif.mtprog.com Last accessed Jan-08.

3. Energy use in refrigerated transport

Annual energy use of sector = 4,822 GWh/y

Estimated potential savings in the order of 20 to 25%.

Calculation method

$$E_{TOTAL} = C_{REFRIG} \times U_{DAYS} \times V_{NUM} \times E_{DIESEL} \times 10^{-6} \quad (5)$$

Where:

E_{TOTAL} = Total annual energy consumption of refrigerated vehicles in UK (refrigeration units only) (GWh/y)
C_{REFRIG} = Consumption of diesel fuel to run refrigeration unit per day (litres/day)
U_{DAYS} = Utilization of refrigerated vehicle (days/year)
V_{NUM} = Number of refrigerated vehicles in operation in UK
E_{DIESEL} = Energy density (volumetric calorific value) of diesel fuel (kWh/l)

Source of data

Data on diesel fuel consumption during refrigerated food transport (Excel spreadsheet) provided by John Hutchings from studies carried out by the Cold Storage and Distribution Federation (CSDF) and Herriot-Watt University (Prof. Alan McKinnon).

Number of UK refrigerated vehicles based on data provided by Tassou *et al.* (2006).

Energy content (kWh/l) of diesel fuel based on published fuel conversion factors (Defra, 2005).

Assumptions

C_{REFRIG} = 26 l/day (average of CSDF data)
U_{DAYS} = 350 days/y (estimate of maximum vehicle utilization)
Number of refrigerated road vehicles in Europe = 650,000
UK has 8% of Europe
V_{NUM} = 0.08 x 650,000 = 52,000
1 kWh diesel fuel produces 0.25 kg of CO_2
1 litre diesel fuel produces 2.63 kg of CO_2
E_{DIESEL} = 2.63/0.25 =10.52 kWh/l

Additional information

This is a temperature maintenance process. Food loads transported are chilled, frozen or mixed.

Articulated vehicles over 33 tonnes account for around 80% of the total tonne-km goods movements in the UK.

References 3

Defra (2005). Guidelines for Company Reporting on Greenhouse Gas Emissions, Annex 1 - Fuel Conversion Factors http://www.defra.gov.uk/environment/business/envrp/pdf/envrpgas-annexes.pdf

Tassou, S.A., De-Lille, G., & Lewis, J. (2006). Food transport refrigeration. Year 1, Report 2, Defra refrigeration energy project, Brunel University. p.10,11.

4. Energy use in cold storage

Annual energy use of sector = 900 GWh/y

Estimated potential savings in the order of 20 to 40%.

Source of data

Total energy consumed by UK cold storage for refrigeration figure was provided by John Hutchings of the Cold Storage and Distribution Federation (CSDF). The figure is based on the sector benchmarking exercise undertaken by CSDF/Carbon Trust in 2004. No formal report is available to provide a detailed breakdown of the figures.

Store efficiency by kWh/m^3/year varied dramatically with the most efficient stores using up to 78% less energy than the least efficient. This was largely a factor of store size; the larger stores being more efficient. However, age and type of operation also had some influence.

Additional information

This is a temperature maintenance process. Food loads are chilled, frozen.

Comment from CSDF on 2004 benchmarking exercise information - Since the last survey in 1994 there had been an overall reduction in energy consumption of 7.5%. Store efficiency by kWh/m^3/year varied dramatically with the most efficient stores using up to 78% less energy than the least efficient. This was largely a factor of store size; the larger stores being more efficient. However, age and type of operation also had some influence.

CSDF overview:

200 primary cold storage sites in UK (stores over 1,000 pallet spaces)
Approximately 9.65 m^3 of capacity
Estimated 2 million pallet spaces
50 % of stores over 20 years old (>50% of capacity)
Typical UK store 75,000 m^3
76% third party logistics providers
14% retailers
10% manufacturers
50% third party space owned by top 7 companies

Results from a more recent benchmarking exercise are due in 2008.

Evans & Gigiel (2007) predict savings in energy in three case studies of UK cold stores of between 23 to 39% using low cost improvements including door protection, use of pedestrian doors, liquid pressure amplification pumps, optimised defrosts and suction liquid heat exchangers.

Further data illustrating the range of cold store energy consumption and hence scope for savings are found in Werner *et al.*, Famarazi *et al.* and Market Transformation Programme who report energy consumption of between 370-560 kWh per square meter per year and 8-120 kWh per cubic metre per year for cold stores of similar sizes.

References 4

Evans, J.A., & Gigiel, A.J. (2007). Reducing the energy consumption in cold stores. Proceedings of the 22nd IIR International Congress of Refrigeration, Beijing.

Famarazi, R, Coburn, B.A. & Sarhadian, R. (2002). Showcasing energy efficiency solutions in a cold storage facility. Commercial Buildings: Technologies, Designs, Performance Analysis and Building Industry Trends – 3.107.

Hutchings, J. (2005). UK frozen market overview 05.ppt – CSDF presentation. Personal communication 21-Nov-06.

Hutchings, J. (2006). Temperature controlled storage energy efficiency.doc – comments on 2004 CSDF/Carbon Trust benchmarking exercise. Personal communication 21-Nov-06.

Werner, S.R.L., Vaino, F., Merts, I., & Cleland, D.J. (2006). Energy use by the New Zealand cold storage industry. *Proc. IIR-IRHACE Conference*. Auckland. 313-320.

5. Energy use in blast chilling – chilled prepared foods sector

Annual energy use of sector = 29 to 614 GWh/y

Calculation method

$$E_{TOTAL} = M \times E_{SPEC} \times 10^{-6} \quad (6)$$

Where:

E_{TOTAL} = Total annual energy consumption of blast chilled food products in UK (GWh/y)
M = Mass of chilled food product (tonnes/yr)
E_{SPEC} = Specific energy consumption for chilling (kWh/tonne)

Source of data

Data on volume (mass) of chilled food market for 2005 are in Thomas (2005) and draws on data collated by Leatherhead Food International.

Throughput (tonnes/y) of the "Frozen and Chilled" food manufacturing sub-sector and estimated refrigeration energy data (kWh/tonne) (Reeson, 2007).

Assumptions

The major foods in the chilled prepared foods sector include; chilled ready meals, prepared sandwiches, pizza, pies, coated foods, pasta, prepared salads, soups and sauces.

According to Thomas (2005), the chilled prepared food sector was 1,200,000 tonnes/y (approx 20 kg/capita). However, total mass of FDF Chilled and Frozen sector is estimated to be 5.1 to 5.4 million tonnes/y. Frozen sector (retail and foodservice) accounts for approximately 3.2 million tonnes/y therefore it has been assumed that the balance is chilled product supplied to the foodservice market (i.e. 5,400,000–3,200,000–1,200,000 = 1,000,000 tonnes/y).

$$E_{TOTAL} = (1{,}200{,}000 + 1{,}000{,}000) \times 13 \times 10^{-6} = 29 \text{ GWh/y}$$

$$E_{TOTAL} = (1{,}200{,}000 + 1{,}000{,}000) \times 759 \times 10^{-6} = 614 \text{ GWh/y}$$

Assuming a value of 100 kWh/tonne

$$E_{TOTAL} = (2{,}200{,}000) \times 100 \times 10^{-6} = 220 \text{ GWh/y}$$

Additional information

This is a temperature changing process. Highest energy requirement is for chilling product from cooked temperature (e.g. 80°C) to chilled storage temperature (e.g. 3°C). FDF survey indicates that manufacturers producing chilled products have specific energy values between 13 and 759 kWh/tonne, with about a third below 100 kWh/tonne, a third between 100 and 250 kWh/tonne and a third above 250 kWh. However, the FDF survey data is based on estimates of refrigeration energy use as a percentage (in a range) of total site electricity which adds somewhat to the uncertainty of the data.

References 5

Reeson, S. (2007). Anonymous subset of FDF CCA/refrigeration survey data. Personal communication.

Thomas, J. (2005). Can convenience convince? International Food Ingredients. http://www.ifi-online.com/Tmpl_Article.asp?ContentID=383&ContentType=3

6. Energy use in blast freezing – frozen prepared foods sector

Annual energy use of sector = 218 to 415 GWh/y

Calculation method

$$E_{TOTAL} = M \times E_{SPEC} \times 10^{-6} \qquad (1)$$

Where:

E_{TOTAL} = Total annual energy consumption of frozen food products in UK (GWh/y)
M = Mass of frozen food product (tonnes/y)
E_{SPEC} = Specific energy benchmark for blast freezing (kWh/tonne)

Source of data

Data on volume (mass) of UK frozen food market are from British Frozen Food Federation (2006, 2007), 1,963,000 (tonnes/y retail) and 3,120,000 (tonnes/y retail and foodservice)

Specific energy for blast feezing data in Werner (2006), 133 kWh/tonne and Duiven & Binard (2002), 70 to 130 kWh/tonne.

Additional throughput (tonnes/y) of the "Frozen and Chilled" food manufacturing sub-sector and estimated refrigeration energy data (kWh/tonne) in (Reeson, 2007).

Assumptions

The major foods in the frozen prepared foods sector include; frozen potato products, ice-cream, vegetables, meat, ready meals, fish, poultry products and pizza.

$$E_{TOTAL} = 3{,}120{,}000 \times 70 \times 10^{-6} = 218 \text{ GWh/y}$$

$$E_{TOTAL} = 3{,}120{,}000 \times 133 \times 10^{-6} = 415 \text{ GWh/y}$$

Additional information

This is a temperature changing process. Highest energy requirement is for freezing product from cooked temperature (e.g. 80°C) to frozen storage temperature (e.g. -20°C). FDF survey indicates that manufacturers using blast freezing have specific energy values between 83 and 2744 kWh/tonne (not normally distributed) with only 10% using less than the 133 kWh/tonne value in the literature. This would indicate that the E_{TOTAL} is probably conservative. However, the FDF survey data does not quantify the additional refrigeration other than blast freezing that may be carried out at the same site.

References 6

Anon. (2006). US Department of Agriculture, Agricultural Research Service. USDA Nutrient database for standard reference, release 19. Nutrient data laboratory home page, http://www.ars.usda.gov/nutrientdata

British Frozen Food Federation (BFFF) (2006). Retail frozen food statistics year on year to 11-Sep-05 (TNS Worldpanel) http://www.bfff.co.uk/Retail%20Frozen%20Food%20Statistics%20Sept%2006.pdf. Last accessed 20-Jan-07

British Frozen Food Federation (BFFF) (2007). Total frozen food markets – Value and Volume in 2006. (Food For Thought (FFT) SA) http://www.bfff.co.uk/International Stats 06.pdf. Last accessed 20-Jan-08

Duiven, J. & Binard, P. (2002). Refrigerated storage: New developments. *Bulletin of the IIR - No 2002-2*. http://www.iifiir.org/en/doc/1042.pdf

Reeson, S. (2007). Anonymous subset of FDF CCA/refrigeration survey data. Personal communication.

Werner, S.R.L., Vaino, F., Merts, I., & Cleland, D.J. (2006). Energy use by the New Zealand cold storage industry. *Proc. IIR-IRHACE Conference*. Auckland. 313-320.

7. Energy use in the dairy sector

Annual energy use of sector = 250 GWh/y

Calculation methods

$$E1_{TOTAL} = (M_{MILK} \times E_{MILK}) + (M_{CHEESE} \times E_{CHEESE}) \times 10^{-6} \quad (1)$$

$$E2_{TOTAL} = Elec_{DAIRY} \times Refrig_{DAIRY} \times 10^{-6} \quad (2)$$

Where:

$E1_{TOTAL}$ = Total annual refrigeration energy consumption of milk and cheese in UK (GWh/y)
M_{MILK} = Mass of liquid milk produced (tonnes/y)
E_{MILK} = Specific energy for liquid milk production (kWh/tonne)
M_{CHEESE} = Mass of cheese produced (tonnes/y)
E_{CHEESE} = Specific energy for cheese production (kWh/tonne)
$E2_{TOTAL}$ = Total annual refrigeration energy consumption of dairy sector UK (GWh/y)
$Elec_{DAIRY}$ = Reported electricity use by dairy sector (kWh/y)
$Refrig_{DAIRY}$ = Estimated fraction of electricity for refrigeration in dairy processing

Source of data

Data on volume (mass) of UK milk and cheese production for 2005/06 from Defra (2008).

Specific energy for milk and cheese production, Anon (2006), Gladis (1997) and Tuszyńsk *et al*. (1983).

Electricity used by dairy sector from data provided by Stace (2006), Dairy UK and estimated fraction for refrigeration in Plemper and Stace (2003) (20 to 40%).

Assumptions

$$E1_{TOTAL} = (6{,}859{,}620 \times 20) + (391{,}220 \times 280) \times 10^{-6} = 247 \text{ GWh/y}$$

$$E2_{TOTAL} = 841{,}222{,}176 \times 0.2 \times 10^{-6} = 168.2 \text{ GWh/y}$$

$$E2_{TOTAL} = 841{,}222{,}176 \times 0.4 \times 10^{-6} = 336.5 \text{ GWh/y}$$

$$\text{Mean } E2_{TOTAL} = 252.4 \text{ GWh/y}$$

Additional information

The specific energy requirement for processing 1 tonne of milk into cheese is given as 28 kWh/tonne in Tuszyński *et al*. (1983) and Gladis (1997). As it takes approximately 10 tonnes of milk to make 1 tonne of cheese the value E_{CHEESE} was taken to be 280 kWh/tonne.

References 7

Anon (2006). Confidential data. Personal communication, 16-Dec-06.

Defra (2008) Milk Development Council, Mdc Datum website, UK Dairy Production data. http://www.mdcdatum.org.uk/ProcessorDataPrices/ukdairyprod.html Last accessed 23-Jan-08

Gladis, S.P. (1997). Ice slurry thermal energy storage for cheese process cooling, Part 2, *ASHRAE Trans* 103, 725–729.

Plemper, G.S., & Stace, G. (2003). Climate change levy and its application within the dairy industry. *International Journal of Dairy Technology*. 56 (2), 68 – 75.

Stace, G. (2006). Dairy UK. Personal communication, 28-Nov-06.

Tuszyński, W.B., Diakowska, E.A.A., & Hall, N.S. (1983). *Solar energy in small-scale milk collection and processing*. Food and Agriculture Organization of the United Nations (FAO), Rome. ISBN 92-5-101339-X. http://www.fao.org/DOCREP/003/X6541E/X6541E00.HTM. Last accessed 23-Jan-08.

8. Energy use in primary chilling of meat

Annual energy use of sector = 109 to 144 GWh/y

Calculation method

$$E_{TOTAL} = M \times C_p \times \Delta T \times COSP \quad (1)$$

$$E_{TOTAL} = M \times \Delta H \quad (2)$$

$$E_{TOTAL} = M \times E_{MEAT} \quad (3)$$

Where:

E_{TOTAL} = Total annual energy consumption for primary chilling of meat in UK (GWh/y)
M = Mass of meat product (tonnes/y)
C_p = Specific heat (at constant pressure) of chilled food product (kJ/kgK)
ΔT = Temperature difference between initial and final product temperatures (K)
COSP = Coefficient of system performance
ΔH = Enthalpy difference between initial and final product temperatures or $C_p \times \Delta T$ (kJ/kg)
E_{MEAT} = Specific energy consumption of primary meat chilling (kWh/tonne)

Source of data

Data on volume (mass) of UK meat production for 2005 are from FAOSTAT (2007).

Enthalpy data - The enthalpy change of the product over the required chilling process was calculated from nutritional composition data (Anon, 2006) using an FRPERC proprietary computer program (FoodProp). This is based on the COSTHERM equations (Miles, van Beek & Veerkamp, 1983) relating thermal properties to a foods composition.

Assumptions

Total mass M of meat includes production figures for beef, pork, lamb, chicken, turkey and duck. E_{MEAT} based on mean measured values for beef and pork primary chillers.

$$E_{TOTAL} = 3{,}377{,}960 \times 116\ (E_{BEEF}) = 108.9\ \text{GWh/y}$$

$$E_{TOTAL} = 3{,}377{,}960 \times 153\ (E_{PORK}) = 143.6\ \text{GWh/y}$$

Additional information

This is a temperature changing process.

References 8

Anon. (2006). US Department of Agriculture, Agricultural Research Service. USDA Nutrient database for standard reference, release 19. Nutrient data laboratory home page, http://www.ars.usda.gov/nutrientdata Last accessed 30-Aug-07.

Collett, P. & Gigiel, A. J. (1986). Energy usage and weight loss in beef and pork chilling. Recent advances and development in the refrigeration of meat by chilling. In: *Proceedings of International Institute of Refrigeration*, Commission C2, Bristol (UK) 171-177.

FAOSTAT. (2007). UK annual fish, fruit, meat, milk, starchy roots and vegetable production quantities for the United Kingdom 2005. FAOSTAT, Statistics Division, Food and Agriculture Organisation of the UN. http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340. Last accessed 30-Aug-07.

Gigiel, A. J., & Collett, P. (1989). Energy consumption, rate of cooling and weight loss in beef chilling in UK slaughterhouses. *Journal of Food Engineering*, 10, 255-273.

Miles, C. A., van Beek, G., & Veerkamp, C. H. (1983). Calculation of Thermophysical Properties of Foods. In: *Physical Properties of Foods*. Applied Science Publishers, New York. 269-312

9. Energy use in primary cooling of potatoes

Annual energy use of sector = 144 to 187 GWh/y

Calculation method

$$E_{TOTAL} = M \times E_{POT} \times 10^{-6} \qquad (1)$$

Where:

E_{TOTAL} = Total annual energy consumption for cooling and storing potatoes in UK (GWh/y)
M = Mass of potatoes cooled by refrigeration (tonnes/y)
E_{POT} = Specific energy consumption of potato stores (kWh/tonne)

Source of data

Data on volume (mass) of UK potato production for 2005 are from FAOSTAT (2007).

Specific energy consumption values extracted from Devres & Bishop (1992) (71.8 kWh/tonne, 73.7 kWh/tonne) and Pringle & Cunnington (2003) (93.4 kWh/tonne).

Assumptions

Assumed approximately 2,000,000 tonnes of total potato production of 6,000,000 tonnes is stored refrigerated (British Potato Council estimate).

$$E_{TOTAL} = 2{,}000{,}000 \times 71.8 \times 10^{-6} = 143.5 \text{ GWh/y}$$

$$E_{TOTAL} = 2{,}000{,}000 \times 73.7 \times 10^{-6} = 147.4 \text{ GWh/y}$$

$$E_{TOTAL} = 2{,}000{,}000 \times 93.4 \times 10^{-6} = 186.7 \text{ GWh/y}$$

Additional information

This is a temperature changing process followed by a temperature maintenance process.

References 9

Devres, Y. O., & Bishop, C. F. H. (1992). *A computer model for weight loss and energy conservation in a fresh produce refrigerated store.* Research memorandum 134, Faculty of Engineering Institute of Environmental Engineering. South Bank Polytechnic, England.

FAOSTAT. (2007). UK annual fish, fruit, meat, milk, starchy roots and vegetable production quantities for the United Kingdom 2005. FAOSTAT, Statistics Division, Food and Agriculture Organisation of the UN. http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340. Last accessed 30-Aug-07.

Pringle, R., & Cunnington, A. (2003). *British Potato Council store managers guide.* 17. Energy management. BPC, Sutton Bridge, UK. http://www.potato.org.uk/department/sbeu/smg/index.html?content=17&lite=32. Last accessed 21-Jan-08.

10. Energy use in primary cooling of milk (on the farm)

Annual energy use of sector = 99 to 315 GWh/y

Calculation method

$$E_{TOTAL} = M \times E_{MILK} \times 10^{-6} \qquad (1)$$

Where:

E_{TOTAL} = Total annual energy consumption for primary cooling of milk in UK (GWh/y)
M = Mass of milk (tonnes/y)
E_{MILK} = Specific energy consumption of milk cooler (kWh/tonne)

Source of data

Data on volume (mass) of UK milk production for 2005 are from FAOSTAT (2007).

Specific energy consumption values extracted from Legett et al. (1997) (6.82 kWh/tonne, 11.86 kWh/tonne) and Milk Development Council (1995) (11.2 kWh/tonne, 21.6 kWh/tonne).

Assumptions

$$E_{TOTAL} = 14{,}577{,}000 \times 6.82 \times 10^{-6} = 99.42 \text{ GWh/y}$$

$$E_{TOTAL} = 14{,}577{,}000 \times 11.66 \times 10^{-6} = 170.0 \text{ GWh/y}$$

$$E_{TOTAL} = 14{,}577{,}000 \times 11.2 \times 10^{-6} = 163.3 \text{ GWh/y}$$

$$E_{TOTAL} = 14{,}577{,}000 \times 21.6 \times 10^{-6} = 314.9 \text{ GWh/y}$$

Additional information

This is a temperature changing process.

References 10

FAOSTAT. (2007). UK annual fish, fruit, meat, milk, starchy roots and vegetable production quantities for the United Kingdom 2005. FAOSTAT, Statistics Division, Food and Agriculture Organisation of the UN. http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340. Last accessed 30-Aug-07.

Legett, J. A., Peebles, R. W., Patoch, J. W., & Reinemann, D. J. (1997). USDA DMRY forage research center milking system improvements. Paper No. 973037. Presented at the ASAE Annual International Meeting, Minneapolis Convention Center Minneapolis. Minnesota August 10-14, 1997. http://www.uwex.edu/uwmril/pdf/RuralEnergyIssues/Dairy/ASAE_973037_USDA_Energy.pdf. Last accessed 30-Aug-07.

Milk Development Council (1995). *Bulk milk tanking cooling efficiency*. Project No. 95/R1/19 report.