Energy and Buildings 74 (2014) 141–151

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Specific energy consumption values for various refrigerated food cold stores

J.A. Evans[a,*], A.M. Foster[a], J.-M. Huet[b,1], L. Reinholdt[b,1], K. Fikiin[c,2], C. Zilio[d,3], M. Houska[e,4], A. Landfeld[e,4], C. Bond[f,5], M. Scheurs[g,6], T.W.M. van Sambeeck[h,7]

[a] Faculty of Engineering, Science and the Built Environment, London South Bank University, Langford, Bristol BS40 5DU, UK
[b] Danish Teknologisk Institut, Kongsvang Allé 29, 8000 Aarhus C, Denmark
[c] Technical University of Sofia, 1000, 8 Kliment Ohridsky Str., Sofia, Bulgaria
[d] University of Padova, Department of Industrial Engineering, Via Venezia, 1, I-35131 Padova, Italy
[e] Food Research Institute Prague, Radiova str. 7, 102 31 Prague 10, Czech Republic
[f] Carbon Data Resources Ltd., Carbon House, 15 The Batch, Bath, Batheaston, Somerset BA1 7DR, UK
[g] Catholic University College Limburg, Campus Diepenbeek, Agoralaan Gebouw B, 3590 Diepenbeek, Belgium
[h] Cold Chain Experts in ColdstoreExpertiseCenter, Van Dongenshoeve 10, 8052 BJ Hattem, The Netherlands

ARTICLE INFO

Article history:
Received 15 February 2013
Received in revised form
18 November 2013
Accepted 22 November 2013

Keywords:
Refrigeration
Cold store
Food
Energy
Specific energy consumption
Mathematical model

ABSTRACT

Two benchmarking surveys were created to collect data on the performance of chilled, frozen and mixed (chilled and frozen stores operated from a single refrigeration system) food cold stores with the aim of identifying the major factors influencing energy consumption. 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. For chilled cold stores, 93% of the variation in energy was related to store volume. For frozen stores, 56% and for mixed stores, 67% of the variation in energy consumption was related to store volume. The results also demonstrated the large variability in performance of cold stores. This was investigated using a mathematical model to predict energy use under typical cold store construction, usage and efficiency scenarios. The model demonstrated that store shape factor (which had a major impact on surface area of the stores), usage and to a lesser degree ambient temperature all had an impact on energy consumption. The work provides an initial basis to compare energy performance of cold stores and indicates the areas where considerable energy saving are achievable in food cold stores.

1. Introduction

Refrigeration is one of the most energy-intensive technologies used in the food supply chain and poses a number of sustainability-related challenges. It accounts for about 35% of electricity consumption in the food industry [1], worldwide this equates to a consumption of about 1300 TWh year^{-1} [1].

Energy issues are among the main concerns in Europe today. The main challenge is to meet the binding target set by the Heads of States and Governments of the 27 EU Member States in March 2007 to increase energy efficiency by 20% and to increase the use of renewable energies by 20%, by 2020 [2].

All chilled and frozen food and temperature controlled pharmaceutical products are stored in a cold store at least once during their journey from production to the consumer. Chilled stores generally maintain products at temperatures between −1 and 10 °C whereas frozen stores generally maintain product at below −18 °C. The cold store market is extremely diverse consisting of small stores of 10–20 m^3 up to large warehouses of hundreds of thousands of cubic metres. All cold stores have the function of storing a product at the correct temperature and to prevent quality loss as economically as possible. In Europe there are approximately 1.7 million cold stores totalling 60–70 million m^3 of storage volume. Of these, 67% are small stores with a volume of less than 400 m^3 [3].

* Corresponding author. Tel.: +44 117928 9300.
E-mail addresses: j.a.evans@lsbu.ac.uk (J.A. Evans), a.m.foster@lsbu.ac.uk (A.M. Foster), JHU@teknologisk.dk (J.-M. Huet), lre@teknologisk.dk (L. Reinholdt), agf@tu-sofia.bg (K. Fikiin), claudio.zilio@unipd.it (C. Zilio), milan.houska@vupp.cz (M. Houska), ales.landfeld@vupp.cz (A. Landfeld), carole@carbon-data.co.uk (C. Bond), marc.schreurs@khlim.be (M. Scheurs), tvansambeeck@ColdstoreExpertiseCenter.com (T.W.M. van Sambeeck).
[1] Tel.: +45 72201270.
[2] Tel.: +359 895586030.
[3] Tel.: +39 0498276893.
[4] Tel.: +420 296792306.
[5] Tel.: +44 1225852533.
[6] Tel.: +32 11230770.
[7] Tel.: +31 384446186.

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.11.075

Cold storage rooms consume considerable amounts of energy. Previous unpublished work by the authors has shown that 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. There are few published surveys comparing the performance of more than a few cold stores. In addition surveys rarely differentiate between type of store, storage temperature, location, room size or room function. In 2002 the IIR estimated that the SEC (Specific Energy Consumption) of cold stores was between 30 and 50 kWh m^{-3} $year^{-1}$ [4]. The minimum value from this study was similar to values from a study carried out in the Netherlands by Bosma [5] which found energy consumption of cold stores to be 35 kWh m^{-3} $year^{-1}$. In the UK ETSU (Energy Technology Savings Unit) [6] also found that stores consumed at minimum 34 kWh m^{-3} $year^{-1}$ but that consumption could also be up to 124 kWh m^{-3} $year^{-1}$. Other studies in the USA by Elleson and Freund [7] and Singh [8] found SECs of between 19 and 88, and 15 and 132 kWh m^{-3} $year^{-1}$ respectively. In one of the most comprehensive recent surveys carried out in New Zealand by Werner et al. [9] the performance of 34 cold stores was compared. The SECs recorded varied from 26 to 379 kWh m^{-3} $year^{-1}$ demonstrating that there was a large variation in energy consumed by cold stores. Savings of between 15 and 26% were found to be achievable by applying best practice technologies. This large range in performance was also found by Carlsson-Kanyama and Faist [10] who report data from BELF [11] for energy use for freezers per litre net volume per day to be 1.0 kJ (equivalent to 101 kWh m^{-3} $year^{-1}$) when food was stored in rooms of 10,000 m^3 whereas in rooms of 10 m^3 the energy was 15 kJ (equivalent to 1520 kWh m^{-3} $year^{-1}$). In both surveys a factor difference of 15 was apparent.

Limited information has been published on throughputs and storage and often information is difficult to compare due to the metrics used by the authors. Carlsson-Kanyama and Faist [10] report energy used for long-term cold storage of apples may vary between 0.9–1.7 kJ electricity per kg per day. Swain [12] reported figures for potato storage collected over a 3 year period from 8 stores as being between 0.1 and 0.29 kWh $tonne^{-1}$ day^{-1}. On average the energy ranged from 0.12 to 0.15 kWh $tonne^{-1}$ day^{-1} within each of the 3 years where monitoring took place. The results showed a massive difference in energy consumption between the best and worse stores. It should be noted that the data included all energy used and that in cold weather potato farmers need to heat stores to maintain the potatoes at the usual storage temperatures of 3 °C. In addition there was no information presented on store temperatures and so the stores that appear most efficient may be those that stored the potatoes at a higher temperature.

Previous detailed audits carried out on a small number of cold stores has confirmed that energy consumption can vary considerably and that this was due to a variety of factors [13,14]. 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.

The performance of 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. 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. In addition a mathematical model was developed to predict energy used in cold stores. Results from these surveys and the predictions made by the model are presented in this paper and the data analysed to determine whether there were any common factors that affected performance of the cold stores.

2. Materials and methods

2.1. Detailed survey tool

2.1.1. 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 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 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 collected 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 it should take a cold store operator less than 20 min 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.

2.1.2. Data collected and benchmark analysis of survey tool

The survey parameters collected are shown in Appendix 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.

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.

2.2. 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 min to complete.

2.2.1. 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.

2.2.2. Data collected and benchmark analysis of survey tool

A limited data set of 5 parameters 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. In all cases blast freezing of product was excluded from the data collected.

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