KES Transactions on Sustainable Design and Manufacturing II
Sustainable Design and Manufacturing 2015 : pp.426-437 : Paper sdm15-022

Energy Saving Opportunities in a Food Factory

Richard Greenough, Pedro Jesús Sánchez Fuentes

Institute of Energy and Sustainable Development, Queens Building, De Montfort
University, The Gateway, Leicester, LE1 9BH, UK
rgreenough@dmu.ac.uk

Abstract *This paper describes a case study of an energy efficiency project carried out for a UK manufacturer of ready meals. As well as a review of relevant literature the study collected and analysed data on energy and water use and analysed the possible use of waste heat in the effluent from the factory. The novelty in this project was the use of building simulation software to model the impact of modified temperature control, solar thermal collectors and absorption chillers on factory energy use. The results show the weather dependence of energy used by food factories where electrical energy is dominated by refrigeration, and the poor correlation of gas use with output due to the use of large volumes of hot water for cleaning.*

1. Introduction

Energy consumption in UK industry has been in continuous decline since 1970, and now stands at 60% of the 1970 figure. However, industry still accounts for 17% of national energy consumption (DECC, 2013) of which heating accounts for up to 72% of energy consumption. Despite the downward trend, an expected growth in output will require further improvements in energy efficiency, and manufacturing is seen as having the potential to accomplish this (Griffin et al, 2012). The decarbonisation of industry will rely on both energy demand reduction and the implementation of low carbon technologies. The latter alone will not be capable of achieving the targets (Kelly, 2006; DECC, 2010). Since energy costs can represent up to 40% of total production costs, measures to improve site energy efficiency or reduce CO_2 emissions, could also reduce operating costs and improve competitiveness of the UK business (Element Energy, 2014).

Research into industrial sustainability has developed significantly in recent years but there is still a need to better understand how to move from the high-level sustainability concepts to the selection of appropriate industrial practices (Despeisse et al, 2013). More systematic approaches to modelling energy, material and waste flows across a factory are needed (Ball et al, 2009). While the potential for improvement is estimated at 10-30% with currently existing technologies, there seems to be a gap between available solutions and deployment (Herrmann et al, 2011).

The 'food, beverages and tobacco' subsector is the second largest industrial energy consumer in the UK, with a 12% share, while the chemicals industry is the largest, at 14% (DECC, 2014). Although the energy intensity decreased in this subsector by 29% between 1990 and 2012 (DECC, 2013), total energy consumption in the UK agri-food sector increased in 2011, with food manufacturing accounting for 15% of total energy use across the sector. In terms of supply fuels, natural gas accounted for 62%, followed by electricity with 30% and petroleum, fuel oil and coal making up the remaining 8% (DEFRA, 2013).

This paper presents a case study of an industrial energy efficiency project, the aim of which was to find and analyse opportunities for energy efficiency and heat recovery in a food manufacturing facility. The objectives of the study were to:

1. Review literature on current trends in energy analysis and common energy efficiency measures in food manufacturing
2. Perform a preliminary energy audit of the manufacturing site in order to understand the main systems and resource flows
3. Model the factory using building energy software in order to analyse the energy performance of the factory as an energy system
4. Propose and analyse energy efficiency measures, based on the results of the energy survey
5. Compare the economic and environmental benefits of a number of improvements

2. Analysing industrial energy use

A range of tools exist that can be applied to analyse energy use in manufacturing. Duflou et al. (2012) provide an overview of research carried at different scales between machine, multi-machine, factory, multi-factory and supply chain. At the product level, Life Cycle Assessment (LCA) is often used to analyse the impact of product design upon the environment including energy consumption, but this technique is data intensive and implies many simplifications that can affect reliability of the results (Seow and Rahimifard, 2011). Alternatively, process optimisation methods such as discrete event simulation (DES) can be used to analyse the impact of manufacturing systems design and operations management upon system performance. The combination of DES with LCA can provide a framework to analyse the relationships within the process while promoting resource efficiency, however is it important to model the integration of different forms of energy and resource within one tool, including the energy needed for technical building services (Thiede et al, 2013). The term technical building services (TBS) refers to the auxiliary machinery that supports the production processes, such as compressors, boilers and HVAC equipment.

The need for a holistic system perspective is acknowledged by many researchers (Herrmann et al, 2011; Trygg et al, 2006). Adopting a factory systems view allows the analyst to derive time-based consumption patterns that will be critical for sizing of technical building services, assessment of energy costs and environmental impacts, and design of an energy efficiency programme. In the construction of factory consumption profiles, simulation is recognised as the most effective means but still “there is significant room for improvement towards a comprehensive approach that integrates energy flows into simulation” (Herrmann et al, 2011). The inclusion of building performance in the analysis of industrial energy use is especially important for non-energy intensive industries like food and drink, where the building services energy might well exceed process energy (Duflou et al, 2012; Wright et al, 2013).

2.1 Energy use in food manufacturing

The industrial processes used in the food industry vary between different facilities, but a small set of processes are responsible for most of the energy use. Low temperature heating processes dominate, accounting for 64% of all energy uses, while refrigeration and drying/separation are also significant at 7% each (Figure 1).

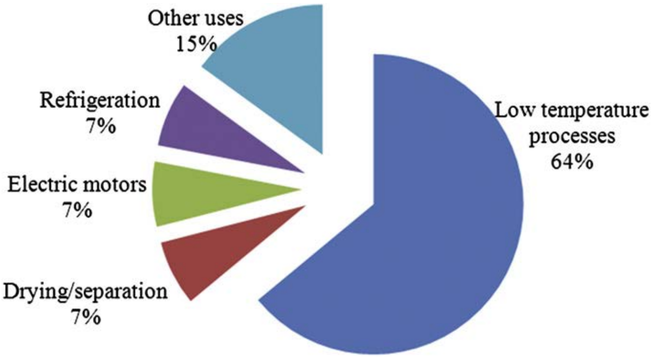

Figure 1 - Breakdown of food sector energy use (Law et al, 2013)

2.2 Waste heat from the food industry

Since most processes in the food industry are low temperature processes, the waste heat from these processes is also available at low temperatures. Nevertheless, there are a number of technologies that can be used to capture such waste heat so that it can be re-used. Five types of actions are possible for the reuse of heat: on-site recovery from a heat source to a lower grade sink using a heat exchanger, temperature uplift from a heat source to a higher grade sink using a heat pump, using heat for refrigeration via an absorption chiller, conversion of heat to power using the organic Rankine cycle (ORC), feeding waste heat into a local heat network for use somewhere else (Element Energy, 2014; Hammond and Norman, 2014). Commonly used technologies within food factories are economizers, which capture waste heat from are flue gases that can be used to pre-heat boiler feed water or for space heating; water cooled condensers in refrigeration systems, heat exchangers that, heat pumps and water cooled cylinder heads on air compressors (Law et al. 2013).

2.3 Industrial energy surveys and audits

The first step in the assessment of energy saving opportunities is an energy surveys. These are usually performed on a walkthrough basis, but time is usually limited to become knowledgeable about the different energy uses that occur in the facilities (Whiteley et al, 2012). Observations and measurements, including utility bills, plant drawings and the tacit knowledge of operators and managers, are used as a first step before the collection of more detailed data. One of the main difficulties for the energy analyst is the lack of information available from the factory, since generally only those data that are directly relevant to daily production have been collected already. It may be possible to compensate with some local data collection, but this must be done with the collaboration of the technicians on site in order not to disrupt production.

3. Case study

The case study company is a manufacturer of ready meals. The company has a dedicated on-site energy management team and is relatively resource efficient. It uses modern facilities and equipment and has adopted many energy efficiency measures including economisers on its gas fired boilers, heat recovery from oven exhaust gases, regular IR thermographic inspections and insignificant leakage of compressed air. Nevertheless, there was felt to be scope for energy savings and additional waste heat re-use.

Gas is used to raise steam for and to heat water for cooking. Electricity is used for refrigeration, air compressors, production machinery, lighting and amenities. The production processes used include potato cooking and mashing, a travelling oven, cooking pans, ovens, a blast chiller, assembly, packaging, washing and clean-in-place (CIP). Production takes place at ground level, while technical building services are located in the roof void.

The study took the form of analysis of energy and water data from utility companies with supplementary monitoring using an ultrasonic heat meter to measure waste heat and effluent water flow, correlation with production and degree days; and thermal modelling of the factory using the building simulation software IES-VE.

4. Results

Utility data were collected and extrapolated for the last four years of production and shown in Table 1.

Year	Gas (MWh)	Electricity (MWh)	Total Energy (MWh)	Water (m^3)
2011	47,492.83		47,492.83	171,705.20
2012	35,323.07	11,694.71	47,017.78	173,405.30
2013	37,869.38	11,666.26	49,535.64	184,200.60
2014 (est)	38,849.50	11,245.95	50,095.45	186,115.09

Table 1 – Annual consumption of gas, electricity and water

Considering the energy used in 2013 (the most recent year for which complete data are available), one can observe that energy carried in the form of gas is more than 3 times the energy carried as electricity. Based on current emissions factors, electricity use in 2013 therefore represented 43% of total GHG emissions, which were over 12 kt of CO_2e.

4.1 Electricity use

Site electricity data were recorded using installed energy monitoring equipment and are categorised as shown in Table 2. The largest single usage category is the high temperature fridges where the consumption pattern showed a marked increase in the summer months, suggesting that this was influenced by weather effects more than the other types of electricity use (Figure 2). This was confirmed by a scatter plot of electricity use against production and a degree day analysis which showed a strong correlation (R^2 = 0.8448) between high temperature refrigeration and cooling degree days (Figure 3). This result demonstrates the importance of thermally efficient factory buildings in this industry as well as the value of building simulation using tools such as IES-VE.

Consuming block	Weekly average (kWh)	Weekly peak (kWh)	Total (kWh)
Busbars LR	28,234	33,200	1,496,430
Busbars HC	25,438	30,190	1,348,220
Mechanical Serv.	16,458	18,371	872,272
Amenities	13,737	14,956	728,036
New land	6,579	7,336	348,662
LT fridges	34,513	44,930	1,829,170
HT fridges	43,195	67,390	2,289,350
Others	55,703	89,672	2,952,249

Table 2 - Breakdown of weekly average, peak and total electricity consumption

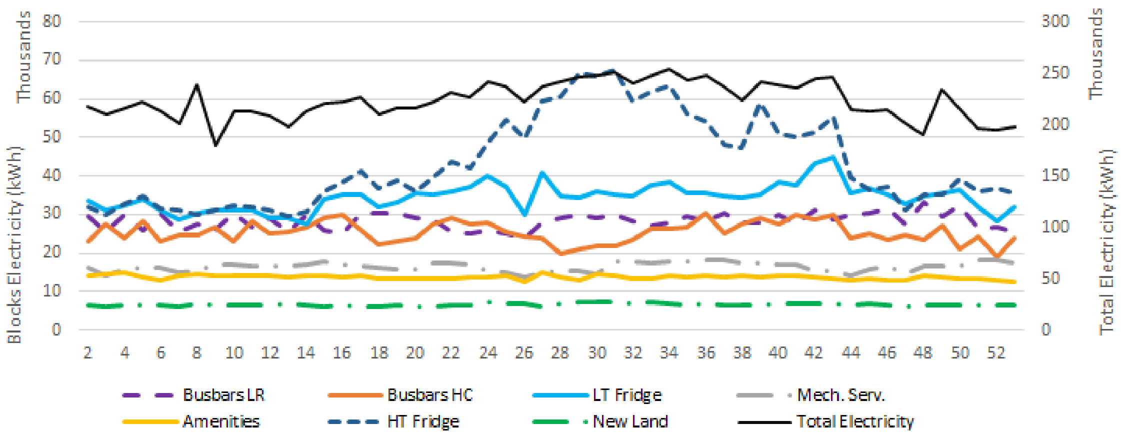

Figure 2 - Electricity loads throughout the year

4.2 Gas consumption

Analysis of gas consumption shows that it is dominated by the boilers, with boiler 3 using 71% of all gas consumed in 2013 (Figure 4). A plot of gas consumption against production (Figure 5) shows a stronger correlation than electricity vs.

production, although it is still low (R^2 = 0.2395). This is explained by the use of large volumes of hot water for cleaning operations at night regardless of that day's production output.

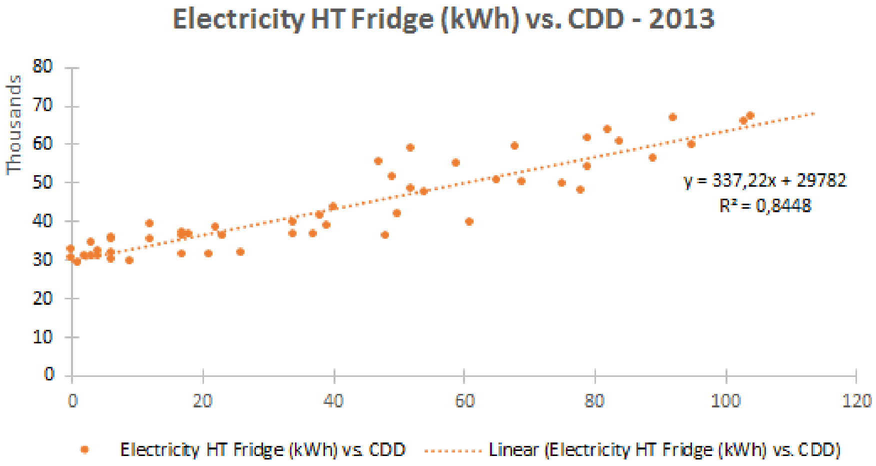

Figure 3 - HT fridges electricity vs. cooling degree days

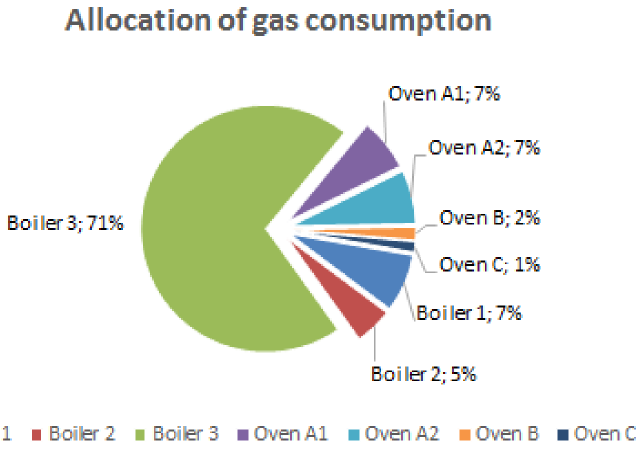

Figure 4 - Breakdown of gas consumption

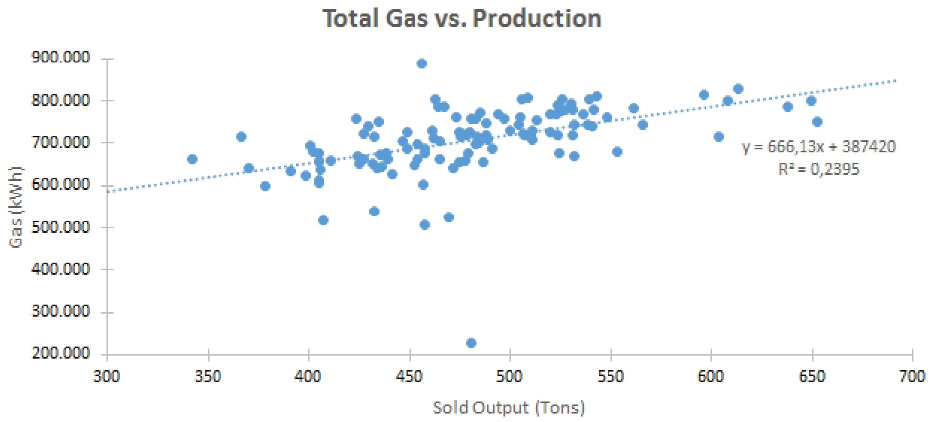

Figure 5 - Total gas consumption vs. production

4.3 Water consumption

Water was the third utility to be analysed in the project. Water is used to transport heat around the factory and for cleaning. There are over 90 cold water points and over 60 hot water points in the factory, but only 31 water meters. This means that some of the water use remains unaccounted for. Nevertheless, it was found that incoming water was allocated to hot water, cold water and a water softener in the proportions 26%, 44% and 26% with the remaining 4% being unaccounted. Only 4% of the softened water and 9% of the hot water remain unaccounted, but 53% of the cold water is unaccounted, demonstrating the requirement for extra meters.

Cleaning accounts for 76% of the hot water, which carries a significant amount of low grade heat. Using an ultrasonic heat meter, it was shown that during a week in July, the average flow rate of water was 1.29 litres per second at an average temperature of 57.9ºC. The total volume for the week was 780m^3, which is typical for July but significantly less than the annual weekly average of 923m^3.

Waste water exits the factory in an open channel before being collected in a storage tank prior being treated and released to the utility company. The heat meter was used for a week to measure the waste heat contained in the effluent. The week's volume of effluent was 2744m^3 at a temperature of 28.9ºC. Compared to the mean ambient air temperature outside the factory of 9ºC (www.metoffice.gov.uk) it can be shown that this effluent contained 63.4MWh of waste heat, which is approximately 9% of the average weekly gas consumption in 2003 (728.2 MWh). Obviously not all this waste heat can be captured for re-use, but the figures are significant; furthermore, since the effluent temperature was measured after the open channel, the result is an underestimate of the maximum heat that it contains.

5. Building energy model

The factory was modelled in 3D based on plan drawings and some assumptions of elevation. Building zones were assigned to different purposes such as plant room, offices, roof void, production (maintained at 12ºC), chill rooms (maintained at 4.5ºC) and fridges (kept below 0ºC). A weather file was generated from a local weather station and the thermal characteristics of the building fabric were estimated based on interviews with plant engineers, observations and guidelines published by Killip (2005) and ASHRAE (2006). An office schedule was assumed of 100% occupancy between 9-5 during the week and no weekend working. A production schedule of 24x7 was assumed with lower occupancy at night and weekends.

The model was validated against the real data, which gave a simulated annual energy use for the HT chillers that was 27% below the real value, but a hot water demand that was only 1.3% above the real value. The error in simulated energy for the HT chiller could be due to faulty assumptions about building fabric, internal gains and poor allocation of the energy represented by missing data from the company. Nevertheless, the technique used showed promise and allowed the analysis of potential savings from the use of increased temperatures in the production areas, the use of solar thermal collectors to provide hot water and absorption chillers for refrigeration. Such energy technologies are modelled as standard in popular building energy software such as IES-VE.

5.1 Results of modelling

Brief experimentation with the thermal model showed that 54MWh per year could be saved for every degree Celcius that the factory temperature was raised above 12ºC. This is very unlikely to be possible due to agreements between the company and its customers. The model also showed that if half the available roof space were used for solar thermal energy collection, this could displace 12% of the energy used for annual hot water. This rather disappointing figure might be due to very low assumptions about the volume of available hot water storage in the factory.

The use of absorption chilling was also modelled, but since all the technologies available in the software required a much higher source temperature than that available from the effluent, this was not pursued. If a waste heat source at 90ºC could be identified, then the model showed that absorption chilling could save the company 613MWh and 303 tonnes of CO_2 per year, equivalent to annual cost savings of £49K not counting the financial benefit of emissions reduction.

6. Conclusions

The food and drink industry remains a vital source of revenue and employment in the UK as well as a very significant energy user. There are many examples of good energy practice at the case company and elsewhere within the sector, but still room for the deployment of more energy efficient processes and the use of advanced energy modelling to optimise the design and use of these processes.

Building modelling can significantly enhance the value of a factory energy audit providing that factory geometry data and a complete collection of energy data are available, and the building fabric is well understood. Unfortunately these conditions are seldom met today, even in very well managed factories; however the cost of energy and emissions as well as legislation such as the EU Energy Directive and the Energy Saving Opportunities Scheme (in the UK) will encourage all manufacturers to collect more and better quality data as well as considering less conventional sources of energy including renewable energy technologies and the re-use of waste heat. To this end, the FP7 project REEMAIN is developing techniques for modelling the application of energy technologies including concentrated solar thermal energy and the organic Rankine cycle, using IES-VE as a basis. The project will demonstrate the use of the resulting techniques at three factories – a Spanish biscuit manufacturer, a Turkish textile plant and an Italian foundry. Details can be found at http://www.reemain.eu/

References

ASHRAE (2006). ASHRAE refrigeration handbook SI Edition. Chapters 13-14. American Society of Heating, Refrigeration and Air Conditioning Engineers. US: ASHRAE.

Ball, P.D.; Evans, S.; Levers, A. and Ellison, D. (2009). Zero carbon manufacturing facility – towards integrating material, energy, and waste process flows, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 223(9), pp 1085-1096.

CIBSE (2006). CIBSE student's handbook. UK: CIBSE.

DECC (2010). 2050 Pathways Analysis, available from: https://www.gov.uk/2050-pathways-analysis [accessed 18/03/2014]

DECC (2013). Energy Consumption in the UK. Department of Energy and Climate Change, available from: https://www.gov.uk/ [accessed 18/03/2014]

DECC (2014), Digest of UK Energy Statistics, Department of Energy and Climate Change, available from https://www.gov.uk [accessed 14/11/2014].

DEFRA (2013). Food Statistics Pocketbook 2013. UK: DEFRA.

Despeisse, M.; Oates, M. R. and Ball, P. D. (2013). Sustainable manufacturing tactics and cross-functional factory modeling, *Journal of Cleaner Production*, 42(11), pp. 31-41.

Duflou, J. R.; Sutherland, J. W.; Dornfeld, D.; Herrmann, C.; Jeswiet, J.; Kara, S.; Hauschild, M. and Kellens, K. (2012). Towards energy and resource efficient manufacturing: A process and systems approach. *CIRP Annals - Manufacturing Technology*, 61, pp. 587-609.

Element Energy (2014). The potential for recovering and using surplus heat from industry. London: DECC.

Griffin, P. W.; Hammond, G. P; Ng, K. R. and Norman, J. B. (2012). Impact review of past UK public industrial energy efficiency RD&D programmes. *Energy Conversion and Management*, 60(3), pp. 243-250

Hammond, G. P. and Norman, J.B. (2014). Heat recovery opportunities in UK industry. *Applied Energy*, 116(11), pp. 387-397.

Herrmann, C.; Thiede, S.; Kara, S. and Hasselbach, J. (2011). Energy oriented simulation of manufacturing systems - Concept and application. *CIRP Annals - Manufacturing Technology*, 60, pp. 45-48.

Kelly, N. (2006). The role of energy efficiency in reducing Scottish and UK CO2 emissions. *Energy Policy*, 34(9), pp. 3505-3515.

Killip, G. (2005). Built fabric and building regulations [Online]. Environmental Change Institute, University of Oxford, available from http://www.eci.ox.ac.uk/ [accessed 13/08/2014]

Law, R.; Harvey, A. and Reay, D. (2013). Opportunities for low-grade heat recovery in the UK food processing industry. *Applied Thermal Engineering*, 53(3), pp. 188-196.

Seow. Y. and Rahimifard, S. (2011). A framework for modelling energy consumption within manufacturing systems. *CIRP Journal of Manufacturing Science and Technology*, 4(6), pp. 258-264.

Thiede, S.; Seow, Y.; Andersson, J. and Johansson, B. (2013). Environmental aspects in manufacturing systems modelling and simulation - State of the art and research perspectives. *CIRP Journal of Manufacturing Science and Technology,* 6(12). pp. 78-87.

Trygg, L.; Gebremedhin, A. and Karlsson, B. G. (2006). Resource-effective systems achieved through changes in energy supply and industrial use: the Volvo-Skövde case. *Applied Energy*, 83, pp. 801-818

Whiteley, M; Stuart, G. and Greenough, R. (2012). Energy efficiency study of industrial factories using time-series data analysis and thermal imaging. ECEEE 2012 summer study on energy efficiency in industry, Arnhem, (Netherlands), 11-14 September 2012.

Wright, A. J.; Oates, M. R. and Greenough, R. (2013). Concepts for dynamic modelling of energy-related flows in manufacturing. *Applied Energy*, 112(2), pp. 1342-1348.