ENERGY EFFICIENCY IN FOOD-SERVICE FACILITIES: THE CASE OF LÅNGBRO VÄRDSHUS

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KTH Industrial Engineering and Management

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Abstract

Food-service facilities have high energy intensities compared to other commercial buildings due to their energy use for cooking and refrigeration. Assessing the energy performance of such facilities has two main purposes. The first one is to evaluate how efficient food-service facilities are and to compare the results with other similar facilities. The second objective is to get a deeper analysis of the energy uses, what enables an easier identification of the processes whose energy efficiency can be improved. This thesis gives, in a first part, a general methodology of how such an energy performance assessment could be carried out. In a second part, a Swedish restaurant – Långbro Värdshus – is taken as a case study. This case study consists in an analysis of the cooking appliances' energy use and an energy performance assessment of the whole facility. A first result of this thesis is the importance of the definition of the system before to start the assessment. Lack of information about the considered processes or how energy use is estimated makes comparison and benchmarking difficult and potentially irrelevant. A second important aspect that stands out of the study when dealing with energy efficiency is the choice of a meaningful indicator. In the case of food-service facilities the amount of energy used per meal (typically expressed in kWh/meal) seems to be the most appropriate one. As regards the energy efficiency of Långbro Värdshus, it has been estimated at 5.9 kWh/meal when considering the total energy use of the facility and at 4.1 kWh/meal without HVAC systems' energy use. Concerning the cooking appliances, the monitored data of their electricity consumption have been analysed to identify the influence of the heating technology and behaviours on the energy use. It resulted, for example, that replacing two hot plate range tops by a solid top and an induction range top enabled 38 % energy savings. Moreover, training the personnel reduced by 7 % the total energy use of the monitored cooking appliances.

Acknowledgements

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Table of content

Figure index

Table index

1 Introduction

1.1 Background

With an average energy use almost three times higher than other types of commercial buildings (PG&E 2010), food-service facilities can be considered as energy intensive buildings, and consequently a sector with significant potential for improving its energy efficiency. Electrolux Professional AB, a world leading supplier of total solutions of professional food-service and laundry equipment, is making great efforts in creating environmental-friendly appliances. This aspect of Electrolux's Green Spirit is aimed at offering to their clients equipment having a lower use of energy, water and detergent (Electrolux Professional 2009). Electrolux Professional is not only focusing on technical solutions but also on other factors affecting energy use in food-service facilities such as personnel behaviour and work organisation. The combination of these different solutions shall lead to more energy efficient facilities and therefore higher benefits for the customer.

In order to evaluate the effectiveness of these solutions on energy efficiency, Electrolux Professional selected Långbro Värdshus' kitchen to carry out a life-size study. Långbro Värdshus is a medium size restaurant located south of Stockholm. The goal of Electrolux with this pilot project is to show that it is possible to save energy by installing new appliances as well as optimising personnel's behaviour and working techniques and organisation.

Based on this project, it has been the opportunity to evaluate the energy performance of the whole facility as a case study. This thesis consequently presents a methodology for performing such analysis and applies it to Långbro Värdshus.

1.2 Objectives

This thesis has two purposes. The first one is to carry out a deep study of the cooking appliances' energy use at Långbro Värdshus. In collaboration with Electrolux Professional and the restaurant's personnel, energy efficiency, behaviour and working organisation will be analysed. Training of the personnel and guidelines for improving energy efficiency of cooking appliances will be performed. The objective of Electrolux Professional is to show Långbro Värdshus as an example of efficient kitchen. This thesis analyses the energy performance of the Electrolux's cooking appliances installed at Långbro Värdshus and the possibilities to reduce even more their energy use.

The second purpose is related to the overall energy performance assessment of food-service facilities. The objective is to establish a general methodology for carrying out such assessment and subsequently to implement it for Långbro Värdshus. The energy performance assessment is intended to give a detailed understanding of the energy use of food-service facilities and to evaluate how efficient it is.

1.3 Scope of the study

In this thesis a food-service facility is considered as an energy system. This implies that the boundaries of the energy system correspond to the physical ones of the facility according to the definition given in the literature study. The energy taken into account in this thesis is consequently the one used within the facility, from the reception of foods to their service to the customer. This system does not include any transportation of food from or to the facility and the energy used for food preparation is only the one used in the food-service facility, which excludes the primary preparation by the food-processing industry. Considering the facility as a system, its energy use corresponds in most case to the total energy input. However, situations of internal energy sources will be discussed briefly.

Food-service facilities do not only use energy for food related processes, but also for other purposes such as space heating or domestic hot water. All these energy needs, within the facility, are also part of the study.

As regards the analysis of the cooking appliances, it is limited to the study of three ovens and two range tops. The energy use of the rest of the cooking equipment is estimated in the energy performance assessment of the facility.

1.4 Methodology

The preliminary task of this project has been to perform a literature study about food-service facilities with a focus on energy use. An important step is to introduce a specific definition of energy efficiency in kitchens and to know how it can be measured or estimated. The literature study is also aimed at providing good knowledge about the description of the processes and sub-processes involved in these facilities, the main parameters, requirements and issues related to energy use. Best practices and energy efficiency tools are presented as well.

As regards the methodology given for assessing the energy performance of food-service facilities, energy use is split into different energy systems. For each type of utilisation different methods are presented for calculating or estimating the energy use.

The analysis of the cooking equipment is more detailed and based on energy use measurements performed on two range tops and three ovens. The idea is to compare the measured electricity consumption with the actual needs for cooking in order to identify where and when energy is used with a low efficiency. Knowledge about the actual needs is obtained through talks with the staff and personal observations. From these comparisons it is possible to determine if the wasted energy is due to personnel's behaviour or appliances. The influence of the appliances on the energy use is studied more into details following the replacement of the cooking equipment.

The energy performance assessment of the whole kitchen is then established on available data, observations and assumptions when needed. The methods implemented for estimating the energy use and the energy performance are selected depending on the best available data.

2 Literature study

2.1 Food-Service Facility

A food-service facility is a place where food is prepared for sale or service on the premises or elsewhere (State of Maryland 2010). A food-service facility can be for example a restaurant, a cafeteria or a sandwich stand and have a commercial or institutional status. Its main purpose is to transform raw foods into cooked foods (Oshman 2009) and then to deliver it to the customer. These operations can be performed with different organisations and types of services: in "cook and chill" facilities, by opposition to "cook and serve" ones (INKISUP 2002a), food is prepared and then delivered to the customer elsewhere than in the premises. Within "cook and serve" facilities, sit-down and full-service restaurants have to be distinguished from fast/quick-service restaurants (APS 2010) (Oshman 2009) and from self service restaurants such as cafeterias. In a general way, the terminology for food-service facilities is not precisely defined. Alternative names such as extended/limited menu or table restaurants can also be found in the literature. In the case of preparation of many similar meals, e.g. in schools and hospitals, one single centralised food-production system can be operated and the food is then distributed to "finishing kitchens" where it is delivered to the customers. This organisation has mainly an economic interest (Newborough and Probert 1988).

All these commercial and institutional facilities have one common element: a kitchen. The kitchen is consequently the central part when dealing with food-service facilities.

2.2 Food-service processes

Food-service facilities comprise a certain number of processes aimed at satisfying, in a short period of time, clients' requests. Food-service processes are the final part of the whole food-process chain as shown in Figure 2.1. The food-service processes, which are the object of this thesis, include the storage of food once delivered to the food-service facility, its preparation and its service or distribution to the client. Dishwashing, though it is not strictly speaking a food process, can be considered as one of the food-service processes since it is directly related to the preparation and service activities.

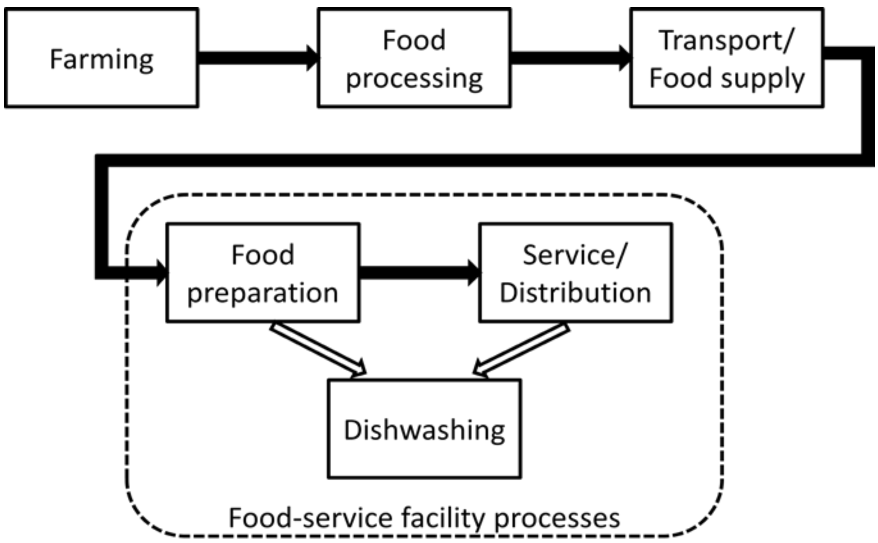

Figure 2.1: Food-process chain

Food preparation consists in several sub-processes which vary from a facility to another according to the type of food served and the cooking organisation (Sverige Kommuner och Landsting 2009). Figure 2.2 illustrates a typical food preparation process. Four steps can be identified from the delivery of the goods to the service or distribution of the meals. First the groceries are handled and stored, either in refrigerated space or dry space at ambient temperature. This first sub-process can include washing or pre-conditioning steps). Food is then prepared strictly speaking. This preparation can be cold (typically starters and desserts) or warm. The latter case implies cooking. Food is subsequently conditioned according to its final use. Plate garnishing and food packaging are intended to deliver the meals to the customer within a short period of time whereas blast chilling enables the storage of meals or semi-prepared food for a longer period. Finally, food is delivered to the final customer.

The sub-processes presented in Figure 2.2 are however a synthesis of how food is prepared in a typical food-service facility and do not present the specificities of each type of facility. More details are given for some of them in the following chapters (see Chapters 2.2.1to 2.2.3)

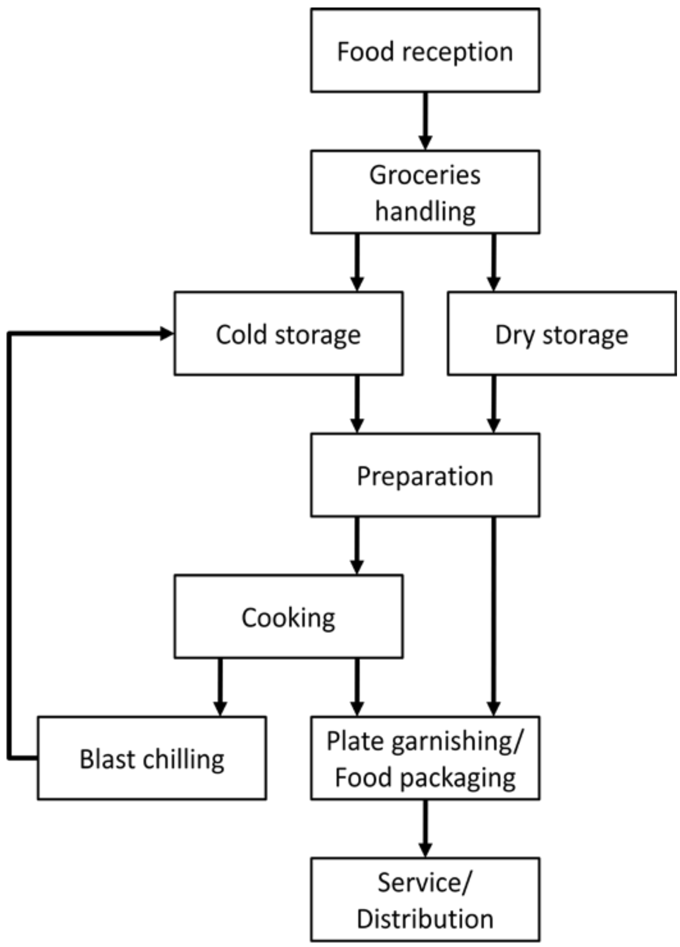

Figure 2.2: Food preparation sub-processes
Source: (Sverige Kommuner och Landsting 2009)

2.2.1 Food storage

Broadly speaking, storage is required for raw foods, semi-prepared food and prepared meals. This storage can be a cold storage, a warm storage or a dry storage at room temperature.

When raw foods are delivered to the facilities they are directly stored into dry rooms and cold rooms according to the nature of the products. Raw foods can be stored for several days or weeks (Danielsson 2010) . When the preparation of a dish requires several steps, e.g. chopping of vegetables and then cooking, or a preparation in advance, it is sometimes needed to store the semi-prepared food waiting for the next step. Semi-prepared food is usually stored for a short time, sometimes one or two days, in refrigerated environment. Warm storage is actually a warm food holding for a very short period of time, typically less than ten hours (Newborough and Probert 1988). In some facilities, storage of the meals may also be required. This variety of needs for food storage enlighten the fact that each facility may require a certain number of different storage appliances. The operation of these appliances depends mainly on the type of food-service facility and the food-preparation organisation.

2.2.2 Food distribution and service

The way food is delivered to the client can be very different from a facility to another one. In a full-service restaurant, meals are directly served to the client without any need for extra equipment besides plates and cutlery. In facilities such as self-service restaurants, cafeterias or fast-food restaurants, customers usually come and take themselves their meals. This latter organisation may require appliances intended to store and display food at the right temperature.

Food can also be delivered outside of the kitchen premises. In this case meals are stored in warm or refrigerated trolleys in order to maintain hygiene and culinary quality of food until they are served to the customer (Newborough and Probert 1988). This organisation applies for instance in health care institutions.

2.2.3 Washing and cleaning

In a food-service facility, kitchenware and tableware need to be washed. This task is done manually in a sink or with the help of a dishwasher. The dishwashing process is operated mainly at the end of each service but also during food preparation for washing the kitchenware. Dishwashers can be manually or automatically operated (Electrolux Professional 2010d) and different washing programs can be selected, what changes the water, energy and detergent using.

After each mealtime the kitchen is cleaned up, i.e. mopping the floor, washing of all the surfaces and cleaning the appliances. A common technique consists in using a hot water spray and manual rubbing of the surfaces. Some appliances are cleaned manually but others, such as ovens or dishwashers, can have an automatic cleaning programmes (Electrolux Professional 2010b), which adds extra energy use.

Some facilities, mainly full-service restaurants, wash table linens on the premises. This process can be taken into account in the energy use analysis since it is in close relation with the service activity.

2.3 Some hygiene and food safety rules

Like in any commercial building, food-service facilities must abide the regulations for both personnel and customers. Moreover, because they serve food to people at large, food-service facilities have high requirements for hygiene and food safety (Commission of the European communities 2000). In Europe, most of these regulations are published by the European Commission and transcribed in the national laws (Livsmedelsverket 2010). Here are presented some Swedish and European rules that have an impact on the energy use of the facilities.

First of all, according to the European regulation No 852/2004, the personnel must work in a suitable environment, which means a comfortable indoor air quality, temperature and working environment. This implies the installation of a suitable and sufficient ventilation system in order to extract most of the air pollutants emitted in the kitchen, if necessary, an air conditioning system to lower the indoor temperature in the kitchen, and a suitable and sufficient lighting system (The European parliament and the Council of the European Union 2004).

According to the same European regulation, food premises as well as equipment must be efficiently cleaned, which implies in particular daily use of hot water. The French regulation (Journal Officiel de la République Française 1997) mentions that the temperature and the humidity must be suitable for food storage, which means that several different cold rooms and cupboards are required according to the type of food.

Most of other hygiene rules which impact the energy use of food-service facilities are related to temperature matters. According to the Swedish regulation (Sverige Kommuner och Landsting 2009), cold holding of final products, fish and meat must be performed at a maximum temperature of + 4°C and + 8 °C for the other groceries. For frozen products, the maximum temperature is - 18°C. In the case of cooling down of cooked food, the temperature of + 8°C should be reached in less than four hours. Concerning the cooking of foodstuffs, the core temperature must reach at least 70°C for each heat treatment or reheating and in case of warm holding of cooked food, a minimum temperature of 60°C must be maintained and during a maximum period of two hours. These rules enlighten the fact that it is not possible to keep fresh products and cooked food at the ambient temperature but they must be stored either in a cold or a warm environment. This obviously influences energy using.

As regards dishwashers, sanitising of the ware is regulated. In the case of thermal sanitising, the National Sanitation Foundation standard specifies that, for commercial appliances, the rinsing water temperature should be at least 180°F, i.e. 82°C during 15 seconds (Nicolella, et al. 2010).

2.4 Food-service facilities equipment

Apart from air conditioning and space heating, most of the energy used in a food-service facility is used for appliances located in the kitchen. Here are presented the most common energy using appliances typically used in each of the food-service processes presented in Chapter 2.2.

2.4.1 Storage

As mentioned previously, storage of food can require both heating and cooling systems. The appliances described below are those aimed at maintaining a closed space at a different temperature than the ambient one. Storage furniture at room temperature is not part of the energy analysis.

2.4.1.1 Walk-in cold rooms

It is the name given to a closed zone of the building which is refrigerated at a given temperature and big enough to enable a person to enter it. The size of these rooms can vary significantly. Refrigerated rooms consist in insulated walls and door, shelves for food storage and a refrigeration system. The temperature of the room depends on the type of food stored. Typically -18°C for a freezing room, 0 to 5°C for meat, fish and prepared food and 8°C for vegetables (Newborough and Probert 1988). The energy use of a cold room depends on the walls insulation, the external temperature, the amount and initial temperature of food placed in the room, the time the door remains open and the energy performance of the refrigeration system.

2.4.1.2 Refrigerators

Contrary to cold rooms which are parts of the building, refrigerators are pieces of equipment placed in the working areas of the facilities. They can be similar to traditional vertical fridges or be placed under a counter. As for cold rooms, different temperatures can be set according to the needs. Some refrigerators, so called blast chillers, are specifically designed for cooling down food as fast as possible in order to preserve it in the best conditions (Sverige Kommuner och Landsting 2009).

2.4.1.3 Warm cupboards

These appliances are used for keeping prepared food warm before it is served or delivered to the client. They are also used for warming up the plates.

2.4.1.4 Display stands

In some food-service facilities where food needs to be displayed and directly accessible for the client, refrigerated and heated stands are necessary. The cold units generally consist in cold plates or glazed stands with cold air production whereas hot units are commonly bain-marie or hot plates (Electrolux Professional 2010e).

2.4.2 Food preparation

A large variety of appliances are used in the cooking of meals (INKISUP 2002a). Here are only presented the range tops and the ovens which are the most common cooking appliances that can be found in food-service facilities. The energy efficiencies mentioned in this part correspond to the definition detailed further on in Chapter 2.6, i.e. the ratio between the energy absorbed by the food and the one supplied to the appliance.

2.4.2.1 Gas and electric range tops

This central element of a kitchen is intended to heat up food contained in pots, pans and other metal containers. The heat is only supplied to the bottom of the container by different means: e.g. gas burner, hot plate, infrared or induction. The two available energy sources for theses appliances are therefore gas and electricity. Depending on the technology used, the knobs of the range tops can either directly control the heating power of the associated cooking zones – typically how a traditional gas burner works – or set a temperature that is maintained by means of a close-loop control system (Le 2008).

The choice of the technology used for the range tops impacts significantly the energy efficiency of the appliance. Indeed efficiencies can vary from 25% for standard gas burners to 85% for induction range tops (Fischer 2002). Table 2.1 presents a comparison of the energy performance of different range tops technologies, which enlightens the potential energy savings when using induction instead of conventional technologies such as gas or electric plates.

Table 2.1: Energy used by different types of range tops for heating 1.5L water from 20 to 95°C
Source: (INKISUP 2002a)

Stove technology	Energy use (Wh)
Induction	162
Radiant source	233 (+44%)
Cast iron el. plate	252 (+52%)
Gas ring	295 (+82%)

The energy performance of range tops also depends on the type and quality of the cookware used. In facts, for boiling water, a wrapped bottom cookware would need 50% more energy than a flat bottom one and a pressure cooker 50% less (APS 2010).

2.4.2.2 Ovens

Ovens can be defined as insulated boxes in which the temperature is raised in order to cook food. Different techniques are available: conventional ovens using natural convection and radiant heat, convection ovens where hot air is pulsed into the chamber with a fan and combination ovens – also called combi ovens – using forced convection and steam (Fischer 2002). Though electricity and gas can be both an energy source for these different ovens, electricity enables new technologies such as the addition of the microwaves technology to the combi ovens (Electrolux Professional 2010a). Ovens usually offer several control systems such as thermostat, timers, humidity sensors, probe and heating mode selection. All these parameters can be preset in cooking programs which enables autonomous operation of the oven once the trays loaded. The cleaning of the ovens can be done totally manually, partially with help of a short steam cycle, or automatically with preset cleaning functions (Danielsson 2010).

Contrary to stoves the standard energy efficiency of ovens is more complex to calculate due to the multiplicity of the parameters. Following the testing method suggested by the American Society for Testing and Materials (ASTM), gas ovens would have energy efficiencies around 30-40% and electrical ovens around 50-80 % (Fischer 2002). Values given by the ovens manufacturers lack transparency for the calculation, what prevents reliable benchmarking. However tendencies in relative efficiency can be noticed and show that convection ovens would be twice as energy efficient as standard ovens (INKISUP 2002a). This better efficiency is partly due to a shorter pre-heating and cooking time with convection ovens and a possibility to cook at a lower temperature with the same results (EPIC Conseil 2010).

2.4.3 Washing

2.4.3.1 Dishwashers

These appliances are aimed at washing tableware such as plates, cutlery and glasses as well as kitchenware such as pots, pans and trays. Whatever the type of dishes, these are generally washed in two steps: washing and rinsing, but some larger dishwashers can also have a pre-washing and a drying steps (Electrolux Professional 2010c). The intervention of an operator is commonly needed for a pre-rinse step consisting in spraying water on the dirty dishes in order to clean food items off soiled plates and kitchenware (EPIC Conseil 2010). Depending on the type of dishes and the size of the facility, different models are on the market, from small units where one tray of dirty dishes is placed manually in the device and undergo the whole washing process (batch operation), to advanced conveyor dishwashers where trays are continuously loaded on the conveyor belt and go through each of the washing steps (continuous operation). In both operation modes the washing process uses hot water at a temperature close to 60°C (Argulander and Aulik 2009) and the rinsing one requires – for hygiene security reasons – a water temperature higher than 82°C. For water and energy savings theses two steps are operated with a counter flow of water in continuous appliances (EPIC Conseil 2010).

The energy use of a dishwasher depends on the number of trays that are placed in the device – whatever the amount of dishes –, the number of dishing steps and their duration, the water inlet temperature and the insulation of the appliance. The water flow of the pre-washing spray valve influences the energy use for domestic hot water.

2.4.3.2 Clothes washing

Working clothes, napkins and towels may be washed within the facility. This operation implies the use of washing-machines and tumble dryers, what consequently increases the energy use of the facility.

2.4.3.3 Kitchen cleaning

For sanitary reasons the kitchen needs to be cleaned after each meal time, what implies a use of hot water.

2.4.4 Other equipment

2.4.4.1 Lighting

Kitchens commonly have linear fluorescent lighting which must fulfil the working conditions regulations for food preparation areas (see Chapter 2.3). Lighting is also used in the storage rooms and walk-in cold rooms. Lighting in customer areas can be very different from a food-service facility to another,

2.4.4.2 Ventilation

The main purpose of a ventilation system is to extract the fooled indoor air of the building and replace it by fresh air. The required amount of fresh air depends on the number of people within the facility, the production rate of air pollutants by cooking appliances and the needs for heat extraction (Jonsson and Bohdanowicz 2009). In a food-service facility the kitchen area has air characteristics which are significantly different than the rest of the facility due to considerable heat gains and emissions of water vapour, fat and odours. It is therefore necessary to have a specific control of the kitchen ventilation system (INKISUP 2002a).

The energy use of ventilation depends on the power consumed by the fan(s) used for air handling and the operation schedule of the ventilation system. Variable speed fans give the possibility to modify the air flow rate and therefore decrease the absorbed power (McQuiston, Parker and Spitler 2005). The fan speed can be controlled according to a preset schedule or according to the needs which can be measured by means of sensors (Melink 2006).

2.5 Energy inputs

Food-service facilities, and more particularly kitchens, have high energy requirements, in different forms. Here are introduced the final energy needs of a food-service facility. They are grouped according to the type of final energy, irrespective of the energy carrier and the way it is produced. This results in identifying three different final needs which are (i) heat, (ii) cooling and (iii) specific electricity. The following paragraphs present the different processes and applications requiring one of these final types of energy. As regards energy sources, they are briefly described in Chapter 2.5.5.

2.5.1 Heat needs

Heat can be needed and used in different forms such as hot water, hot air or food heat treatment.

A fundamental use of heat in a food-service facility is for cooking operations. Indeed food cooks under the influence of heat. Food also needs to be reheated or maintained at a certain temperature. A European survey estimated that the cooking of one single meal requires on average between 350 and 2 000 Wh, depending on the type of food-service facility (INKISUP 2002a). The share of cooking appliances' total energy use in food-service facilities varies significantly from a source to another: 25 % according to the U.S. Energy Information Administration (U.S. Energy Information Administration 2003a) and 54 % according to the California Energy Commission (California Energy Commission 2006).

Heat is also used in the form of hot water, mainly for sanitary use and for dishwashing. The energy required for heating water varies from 150 to 1 300 Wh/meal (INKISUP 2002a) and it is worth noting that up to 80 % of this hot water is used for dishwashing (Argulander and Aulik 2009). Domestic hot water is generally supplied by a central system producing hot water for the whole building (Jonsson and Bohdanowicz 2009). However, for dishwashers and some other appliances using hot water, they usually have an integrated hot water production. Nevertheless it is possible for some appliances to be fed directly with domestic hot water or with pre-heated water from any heat-recovery system (Flex your Power 2006).

Depending on the climate zone, food-service facilities can also require space heating to maintain a good thermal comfort. Though it is usually not necessary in kitchens since cooking appliances act as heating elements (Batty, Conway, et al. 1988), facilities whose customers eat on the premises may need space heating in the dining-rooms.

2.5.2 Cooling needs

Cooling has mainly two applications in a food-service facility: refrigeration and air conditioning.

Refrigeration is required for maintaining food in good hygiene conditions and holding cold some products such as ice creams and drinks at the good temperature. Depending on the type of food and the cooking organisation in the facility, different types and amounts of refrigeration appliances are required and thus variations in the energy use from a facility to another are observed. On average, food refrigeration represents around 16% of the total energy use in a food-service facility (U.S. Energy Information Administration 2003a), which corresponds approximately to 50 to 90 Wh/meal (INKISUP 2002a).

Thermal comfort of customers can require air conditioning in warm regions or during summertime. It can be also needed within the kitchen if temperature is too high, typically higher than 28°C (EPIC Conseil 2010), because of the heat released by cooking appliances, dishwashers and refrigeration systems. Technically, air conditioning can be supplied with stand-alone air conditioners or integrated in the ventilation system.

2.5.3 Specific electricity needs

Because it is an energy carrier, electricity is used for many applications, including heating and cooling purposes. Here are only presented the needs for specific electricity, which means applications that require electricity as such.

The main use of specific electricity in a food-service facility is for lighting since it represents around 10% of the total energy use (U.S. Energy Information Administration 2003a). Kitchens usually work all day long and require high lighting intensity in order to provide good working conditions (F. Sullivan and Atlas 1998).

Electricity is also used for electric motors such as fans in ventilation systems and air conditioning units, water pumps in dishwashers and other applications such as food processors and conveyors. Ventilation for instance accounts for approximately 5% of the total energy use in a food-service facility (SDGE 2007).

2.5.4 Total energy use

According to the European survey INKISUP (INKISUP 2002b), for facilities serving more than 500 meals/day, Equation 2.1 can be used for estimating the average energy use per meal.

$$E_{per\ meal} = 105 \cdot N^{-0.63} \qquad 2.1$$

Where:
$E_{per\ meal}$: average energy use per meal (kWh/meal)
N : number of meals prepared per day (-)

However, the study does not detail the content of the energy used. It might be in the present case only the energy used in the kitchen for the preparation of the meals but it could also include the energy used for heating, cooling, ventilating and lighting in customer areas. This lack of standard definition of what is included in the energy use of food-service facilities is actually a common issue when comparing data from different studies (Aebisher, et al. 2003).

Similar difficulties are also met when dealing with the breakdown of energy use in food-service facilities. As shown on Figure 2.3, the share of the energy used in food-service facilities varies significantly from a study to another. According to Batty, and Probert, climate variation is usually the major parameter leading to a change in the rate of energy using (1989), which can explain the considerable differences between studies. However, it appears that food preparation, i.e. mostly cooking when dealing with energy use, represents in general the largest part of the energy share, just before HVAC systems. In all three cases, these two usages account for more than the half of the total energy use whereas domestic hot water production, which is the third most energy intensive process, represents less than a fifth of the total energy use.

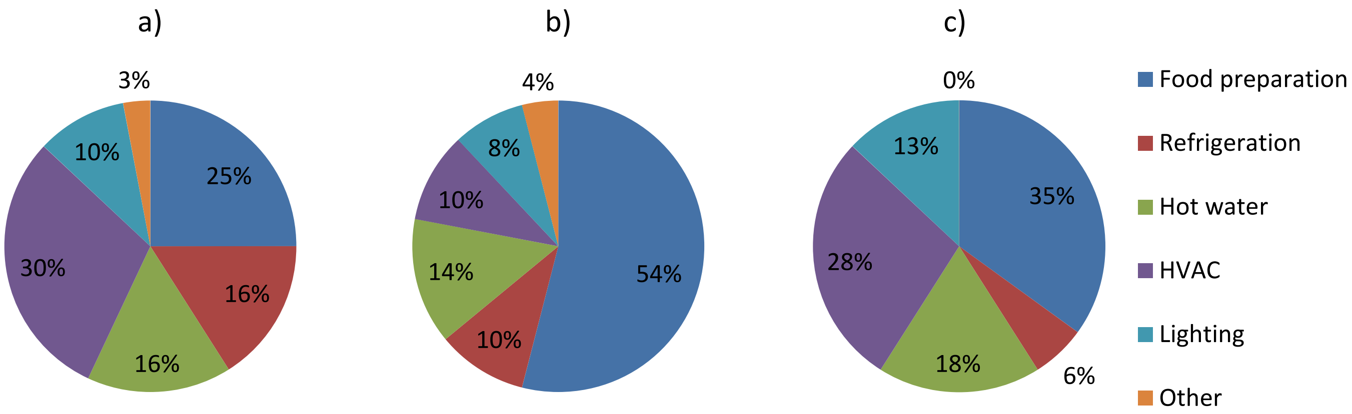

Figure 2.3: Energy break down in food-service facilities in the United-States
Sources: a) (U.S. Energy Information Administration 2003a)
b) (California Energy Commission 2006)
c) (United States Environmental Protection Agency 2009)

2.5.5 Energy sources

A food-service facility, as any commercial building, can be commonly supplied with electricity, gas or other fossil fuels and district heating/cooling. The combination of some of these sources enables the delivery of heat, cooling and specific electricity for all the usages presented previously.

Heat can be produced from electricity, fossil fuels, as well as district heating. The use of one or another depends mainly on the applications. In facts cooking appliances are heated up with gas burners or electricity by means of electric resistances which limits the flexibility in the choice of the energy source. Hot water, on the contrary, allows a wider range of heat sources; it can be an electrical resistance, a gas/fossil fuel boiler, a heat pump (powered by electricity), a solar water heater or a heat exchanger directly placed on the district heating system. Water also has the advantage to be easily stored, what enables a centralised production and possibilities to store heat. As regards space heating, air can be heated up directly with an electrical resistance or a heat pump, or via hot water produced. The choice of the source depends mainly on the type of heating system installed in the facility (Jonsson and Bohdanowicz 2009).

Cooling has a smaller range of possibilities than heat for its production. Refrigeration as well as air conditioning consist both in air chilling. Air can be directly cooled down with a heat pump extracting the heat from the zone intended to be refrigerated, or with chilled water obtained from the district cooling system and circulating in pipes. The use of district cooling is however limited by the minimum temperature of the supplied chilled water. In Sweden for example this temperature is around 6°C (Svensk Fjärrvärme 2004).

As regards specific electricity, it is directly supplied from the grid and distributed in the facility.

Some other sources, such as biomass fuels or sun for photovoltaic, thermal and cooling applications can also be considered for supplying heat, cooling and electricity to the facility (Boyle 2004).

2.6 Energy Efficiency

This term, though widely used, is seldom clarified. This leads to many different interpretations of it. The definition of energy efficiency given by the U.S. Energy Information Administration (U.S. Energy Information Administration 2010) states that it refers to programs aimed at reducing energy use without affecting the services provided. From this perspective energy efficiency in food-service facilities would consist in cutting down the overall energy use without changing anything for the final customer i.e. the client of the facility.

In 1996, Murray G. Patterson (Patterson 1996) published a thorough analysis about energy efficiency. According to his work, energy efficiency is the fact of "using less energy to produce the same amount of services or useful output". This can be measured, for a given process, using the definition presented in Equation 2.2.

$$Energy\ efficiency = \frac{Useful\ output\ of\ the\ process}{Energy\ input\ into\ the\ process} \qquad 2.2$$

This definition, apparently simple is, nevertheless, not so easy to apply. Indeed, if calculating the energy input of a process is currently common, the identification, definition and quantification the "useful output" is much more complex (Patterson 1996). It can be the amount of useful energy, which gives a thermodynamic energy efficiency and accounts for the direct energy losses, but also a physical or economical quantity.

As mentioned in Equation 2.2, the energy efficiency ratio is calculated for one process. In the case of food-service facilities, different processes can be considered and at various scales, from the energy efficiency of a cooking appliance to the overall performance of the facility. Outputs are consequently different. A common energy efficiency used in food-service facilities is for cooking appliances. It corresponds to the ratio between the energy absorbed by the food and the energy supplied to the appliance, as shown in Equation 2.3 (Fischer 2002).

$$\eta_{cooking} = \frac{E_{food}}{E_{appliance}} \qquad 2.3$$

Where:
$\eta_{cooking}$: Standard energy efficiency of the cooking appliance
E_{food}: Energy absorbed by the food
$E_{appliance}$: Energy supplied to the appliance for cooking the food

Because of the multiplicity of systems, it is not possible to create an absolute scale for energy efficiency with good and bad marks. Ratios should be used as indicators for (i) the quantification of the changes in energy performance and (ii) the comparison of systems or processes having similar outputs (Patterson 1996). The former point implies that efficiency can only be defined in relative terms (Kinney and Piette 2002) and the latter that energy efficiency matters are also based on precise identification of the systems and relevant definition of its outputs. However, defining an energy efficiency indicator does not only consist in technical issues, but in policy considerations too since it is also a structuring element of the decision making process when dealing with energy savings (Aebisher, et al. 2003).

In the case of heat pumps, typically in refrigeration appliances, the use of the energy efficiency is not relevant since it is the electricity consumption that is usually considered. The ratio that is used is therefore the coefficient of performance COP, as shown in Equation 2.4 (Jonsson and Bohdanowicz 2009).

$$COP = \frac{E_{useful}}{E_{appliance}} \qquad 2.4$$

Where:
COP: Coefficent of performance of the considered appliance
E_{useful}: Energy use for the intended purpose
$E_{appliance}$: Energy supplied to the appliance

2.6.1 Useful outputs and energy-efficiency indicators

As mentioned above, assessing the energy efficiency of a food-service facility requires the use of different indicators aimed at getting the energy use into proportions. These indicators, although called energy efficiency indicators, correspond actually to energy intensity ones. The common expression for these ratios is presented by Equation 2.5.

$$Indicator = \frac{Energy\ use}{Output} \qquad 2.5$$

To establish these indicators, one key factor is to find a suitable output (i.e. the denominator) to which energy use can be compared. This will result in normalising energy use, what enables then relevant comparisons between different facilities. The numerator (i.e. the energy use) corresponds to the total energy input of the considered system.

The more commonly used energy efficiency indicator used in buildings is the ratio of energy use per unit of surface area and per year (typically kWh/(m²·year)). However, other ratios, more suitable for food-service facilities can be used such as the energy use per meal, per seat, per guest, per employee or per cash flow (Aebisher, et al. 2003). Each of these indicators has advantages and limitations. For example, the energy per seat ratio is very dependent on the activity of the facility but also the seat turnover, what makes this indicator more suitable during the design stage of the facility. To compensate for this dependence, the use of energy per guest takes the activity into account, as well as the energy per meal ratio. According to Aebisher et al., this latter indicator appears to be the most suitable one for food-service facilities since it is directly linked to the activity of the kitchen. However, on top of requiring detailed data from the facility's operator, this indicator also needs a preliminary clear definition of what is considered as a meal: does it account for any meal, whatever the number of courses or does each course accounts for one meal? In case of comparisons between different facilities, the definition of meal in each facility needs to be established in order to make consistent comparisons.

At a smaller scale, appliances can also have energy efficiencies and indicators. Cooking equipment manufacturers, for example, are using standardised energy efficiencies presented previously in Equation 2.3. Another illustration of indicators that can be created is the development by the European Union of energy labels for households appliances. It is thus possible to assess the performance of a washing-machine by comparing its energy use per washing cycle, or the one of a refrigerator by means of an indicator related to its energy use and its volume (Europe's Energy Portal 2010).

2.6.2 Driving forces for energy efficiency schemes implementation

2.6.2.1 Energy benchmarks

Energy benchmarks are quantitative information about energy usages which can be implemented for many different systems, from individual appliances to whole facilities. Benchmarks are built with two elements which are (i) the selection of an indicator (e.g. the ones presented in Chapter 2.6.1) and (ii) the collection of data from existing systems. One major interest of benchmarking is that it enables the comparison of every individual system to the suitable benchmark and therefore constitutes a good starting point for targeting systems for energy-saving measures (Kinney and Piette 2002). On top of being a support for decision making, benchmarking is also a way of tracking performance and identifying best practices (Mills 2005). According to Aebischer *et al.*, the choice of the indicators used for benchmarking energy use is important since they will directly influence the behaviour of those who should conform to the target value. "What gets measured gets down" (2003). Using benchmark is however not as easy as it appears. The first reason is that little data is available in the literature. The second reason is that benchmarks are often given without any description of the parameters and assumptions used for calculating the energy efficiencies. These two downsides of benchmarks lower the reliability and the consistency of comparisons.

Here are presented some energy efficiency indicators gathered from several national studies by Aebischer *et al* (2003) and presented in Table 2.2 to Table 2.4 . These values are unfortunately given with no or little information about the parameters used for the different studies. It nevertheless appears that the energy use considered in the studies is the total one of the facilities.

Table 2.2: Energy use in Swiss restaurants
Source: (Aebisher, et al. 2003)

Type of restaurant	Energy/seat MWh/(seat·year)	Energy/meal KWh/meal
Hospital	0.9	3.0
Fast food	3.0	1.2
High standard rest.	2.3	4.6

Table 2.3: Energy use in Californian restaurants
Source: (Aebisher, et al. 2003)

Type of restaurant	Energy/square-meter MWh/(m²·year)	Energy/seat MWh/(seat·year)	Energy/meal KWh/meal
Fast food	1.05	4.33	1.88
Table service	1.26	4.49	4.93

Table 2.4: Energy use in Japanese restaurants
Source: (Aebisher, et al. 2003)

Type of restaurant	Energy/square-meter MWh/(m²·year)	Energy/seat MWh/(seat·year)	Energy/meal KWh/meal
Japanese rest.	0.66	2.09	4.09
Chinese rest.	2.03	6.50	5.59
Casual dining rest.	1.66	5.32	5.66
Fast food	1.74	4.20	3.43

The results of these different studies may be difficult to compare to each other for some reasons. One reason is the geographical location of the facilities which affects the energy use of the HVAC system according to the climate zone. Another reason is that some facilities have extra activities such as a bar, what increases the total energy use without involving the service of any meal. Instead of considering the total energy use of food-service facilities, is can be therefore interesting to restrict the energy use to activities which are directly related to the food-service activity. This implies however certain knowledge of the energy use breakdown. Table 2.5 presents for example the energy use in hotels for cooking, refrigeration and dishwashing only. This gives a better meaning and relevance to the "energy/meal" indicator.

Table 2.5: Energy use for cooking, conservation of food and dishwashing in French hotels
Source: (Aebisher, et al. 2003)

Category of hotels	Energy/meal (kWh/meal)
2**	2.77
3***	7.86
4****	6.58

2.6.2.2 The decision making process

"The first step to managing energy usage is knowing where your business consumes the most energy" (SDGE 2007). Indeed, according to the INKISUP European survey, the awareness of energy using is a preliminary requirement for willingness of implementing energy saving measures, and yet most of the kitchen operators and owners do not know how much energy is used by their appliances or even in the whole kitchen. Consequently, one of the main barriers for implementing energy efficient schemes in food-service facilities is the lack of information on available technologies and their benefits and the lack of good practical examples (INKISUP 2002b).

Once awareness risen, economical factors such as payback period or life cycle cost (LCC) are to be taken into consideration by the decision makers. When estimating the amount of money potentially saved by different measures, it can appear to be very low compared to the total expenditures or turnover. This simple comparison is however not relevant. Energy savings are in facts direct incomes and should be therefore compared to the profit margin of the facility (Flex your Power 2006). The median ratio of income before income taxes to total sale is around 5.9 % in limited service restaurants and varies between 1.8 % and 3.5 % in full service restaurants (National Restaurant Association and Deloitte & Touche LLP 2010). As regards the cost of energy it accounts for 3 to 5 % of the total operating costs in U.S. restaurants (Platts 2002). Consequently, assuming a profit margin of 3 % and an energy cost representing 4 % of the operating costs, saving 20 % energy per year would lead to 26 % increase of the profit margin. This example shows that with these considerations, the real savings are much higher than the apparent ones, what is an important factor of willingness for the implementation of energy efficiency schemes.

The next step is then to give decision makers tools for identifying the best measures and estimating their energy saving potentials and costs (INKISUP 2002b). The INKISUP summary also mentions that experience and case study analysis are of importance for creating reliable tools.

2.6.3 Energy saving schemes

A food-service facility offers many possibilities for saving energy and thus improving its overall energy efficiency. The literature is rich of many guidelines given by authorities, public or private organisations and companies aimed at reducing the energy use in food-service facilities. These measures can be technical solutions as well as operational ones such as changing the organisation of cooking processes or turning the light off when nobody is in a room. According to the European study INKISUP, these operational measures could enable savings up to 10 or 15 % without or with low investment (INKISUP 2002a). Although no publication made a thorough study about the influence of staff behaviour in a professional kitchen, the numerousness of energy savings tips found in the literature attests to considerable saving potentials.

2.6.3.1 Refrigeration systems

The aim of these systems is to maintain cold a certain zone, what means that any solution intended to prevent heat from entering this zone would improve the energy efficiency of the system. Simple ways of performing this is to have a good thermal insulation of the refrigerated area and to avoid direct air exchange with warm air. The use of strip curtains for example could cut air infiltration in walk-in cold room by about 75 %

when the door is opened (United States Environmental Protection Agency 2009). Another simple solution is to reduce the door openings and to use automatic door closure systems (Argulander and Aulik 2009).

The heat extracted by the refrigeration systems is often released directly in the kitchen area, what increases the cooling load in case of air conditioning of the kitchen. Two common solutions exist to this problem: either the heat exchanger should be placed outside of the facility or the waste heat should be recovered and used for other purposes, e.g. preheating the rinsing water of the dishwashing system (SDGE 2007).

Routine measures such as proper maintenance of the devices or regular cleaning of the condensers also contribute to the improvement of the refrigeration energy efficiency (INKISUP 2002a).

2.6.3.2 Cooking processes

Cooking consists in supplying heat to food. Consequently, heat which is produced but not absorbed by food is a loss. A reduction of these losses leads thus to a better energy efficiency. Many simple measures can be implemented such as cutting the idle time (Flex your Power 2006) or using lids. This last measure could enable 80 % savings for maintaining water at 95°C (Probert and Newborough 1985). Other operational solutions can be to turn off the electric burners several minutes before the allotted cooking time and use the lowest temperature setting possible (APS 2010), or to implement a daily "start-up" and "shut-down" schedule for cooking appliances (University of Hawaii 2005).

The cooking appliances themselves are also of importance because of their different energy efficiencies and it is always recommended to use them at full load, in particular for ovens (Flex your Power 2006). In other words, oversized appliances would affect the total energy efficiency.

2.6.3.3 Dishwashing

The main factor of the dishwashing process as regards energy is the consumption of hot water and its temperature. A simple and costless measure consists in always fully loading the dishwasher since the energy used by the washing cycles does not depend on the load of the trays. Another cost-effective measure is to install a low-flow pre-rinse spray valve on the food disposer hose and to use cold water instead of hot water (APS 2010).

Depending on the design of the dishwasher, it can be possible to install a heat recovery system in order to prevent energy from escaping the dishwasher and to preheat cold water. This heat can be recovered on the water vapour exhaust (Electrolux Professional 2010d), which would also prevent emission of hot humid air directly in the kitchen (INKISUP 2002a). Another way of recovering heat is, for some appliances, to use water with a counter flow (Argulander and Aulik 2009): the clean hot water is used for rinsing and then reused for washing at a lower temperature.

Dishwashers which are not directly supplied with hot water usually have a hot water tank equipped with an electric water heater. Reducing the size of the former and switching off the latter during the night enables energy savings.

2.6.3.4 HVAC systems

Recommendations for heating and cooling the facilities are similar to those made for other buildings, such as checking the insulation of the building and replacing the windows by more efficient ones. Installing a programmable thermostat in the dining rooms can be a way a saving energy by adapting the temperature to the activity (Flex your Power 2006).

Ventilation is also a significant part of the food-service facilities HVAC systems' energy use, especially in the kitchen. The major improvement that can be made on ventilation systems is to give them the possibility to be switched off when no cooking or dishwashing is performed in the kitchen, e.g. during nights (INKISUP 2002a). A more advanced way of implementing this solution is to combine a variable speed fan with sensors placed in the hood (Melink 2006). Though this technology is expensive, the manufacturers claim that it is profitable with a short pay-back period. Another way of improving the energy efficiency is to install heat recovery in the ventilation systems by means of a double-flow heat exchanger or a heat pump aimed at heating up water (France Air 2010). The limiting factor for the development of such technologies is the high water and grease content of the extracted air which is not suitable for heat exchangers. However new solutions exist for cleaning the grease such as Corona Glass Cell-module or UV light (Argulander and Aulik 2009). In the case of air conditioned spaces, the use of "free cooling" (i.e. extra supply of outdoor air) should be maximised (SDGE 2007).

2.6.3.5 Lighting

With sometimes more than 10 % share of the total energy use of a food-service facility, lighting needs to be taken into consideration when working on energy efficiency. Due to work regulations, a reduction of the illuminance in the working areas is not possible. Solutions for reducing the energy use are consequently based either on the installation of high efficiency lighting systems or routines consisting in switching off the light where and when it is not needed. Energy Star programme is currently promoting the use of T8 or T5 fluorescent lighting with electronic ballasts to replace the T12 lamps with magnetic ballasts and the incandescent bulbs (United States Environmental Protection Agency 2009). In order to limit unnecessary lighting, using occupancy sensor can be of interest in closets, storage rooms and walk-in refrigerators (Flex your Power 2006).

3 Assessing the energy performance of a food-service facility

3.1 Objectives and implementation

Assessing the energy performance of a food-service facility can be split into two parts which consist in (i) collecting and analysing data about energy use and activity and (ii) evaluating how efficiently energy is used. The energy performance of a building is not an absolute value but related to one, or several, indicators which can be compared to each other or to benchmarks. One of the most relevant indicators for food-service facilities is the energy per meal ratio since it is directly linked to the food-service activity. Other indicators such as the energy per guest and the energy per cash flow ratios are also relevant and the choice of one or another depends on the available data, the specificities of the facility and the final purpose of the assessment. Purposes are numerous. For some operators it is a means for comparing their business to other similar ones, to know how good they perform. In this case benchmarked indicators are more adequate. Others just want to identify the less efficient processes so they need a detailed breakdown of the uses and indicators – probably several different ones – assessing their specific efficiencies. Furthermore, other just want to have a picture of their energy use at some point, what constitutes a reference situation, in order to quantify the changes and improvements in the energy performance the next time an assessment is performed. In this latter case, the indicator only have an internal value and does not necessarily need to be consistent with benchmarked ones, as long as the same indicator is used for each assessment. When choosing an indicator it is also important to clearly and precisely define the terminology which is used. Indeed, some parameters such as the surface area, the number of meals and the profit margin can be measured or calculated in different ways according to how they are defined. Once an indicator is chosen and defined, data collection can start and consists in two parts: (i) the estimation of energy use, i.e. the numerator of the indicator (see Equation 2.5) and (ii) the estimation of the normalisation quantity, i.e. the denominator.

Calculation of energy use is the core part of the assessment since its result is the common element to all the energy efficiency indicators. Its objectives are (i) to estimate the total energy use of the facility, and (ii) to establish a break-down of the energy use. Before to launch into the calculation of the energy use of a food-service facility, it is important to identify the different processes that are directly linked to the food-service activity and to exclude, as far as possible, any other activity of the facility. This definition of the boundaries of the food-service activities is a necessary preliminary step for the obtention of relevant energy performance indicators representative of the food-service operations. Since the energy performance assessment is focused on the end-use of energy, bigger attention is paid to the uses than to the energy supply. Consequently the origin of the energy used will not be part of the analysis and the total energy use of the food-service facility will be split up into different energy usages. This break-down of the energy use is aimed at getting a better understanding of the distribution of the end-use energy within the building and to identify which are the more energy consuming processes.

Data collection for the normalisation quantity lies in finding the documents accounting for this quantity. Depending on the selected indicator, it can be activity reports, tax return documents, bank reports, etc. If quantitative information is lacking, estimations need to be performed.

3.2 General information about the facility

An important step when conducting an assessment is to establish a list of all the elements related to the energy use and the activity of the food-service facility and information about their utilisation. The preliminary definition of the system boundaries should help identifying which information is required and which one not. Conversely, this screening of the facility's available information can help defining the boundaries. The combination of these two tasks can be actually seen as an iterative process, what enables an optimisation of the assessment. This chapter presents the most common pieces of information which can be required in an energy performance assessment but it can be extended because of specificities of the interested facility. Depending on the type of assessment, the collection of all the elements presented in this chapter is not necessary. Two categories of data can be identified, (i) those related to the building itself and its equipment and (ii) those related to the operation of the facility. The former data can be collected by the assessor during a visit whereas most of the latter ones need to be provided by the facility operator.

3.2.1 Facility characteristics and equipment

The general data required about the building are those related to the outdoor climate, its surface area and its construction characteristics. A detailed repartition of the surface areas is of higher interest since it gives better information on the actual area related to the considered activity. Areas of rooms which are not part of the food-service activity may be subtracted. A detailed accounting of the surfaces is also a way of identifying areas that may not have been taken into account in the total surface area calculation (typically basement and storage rooms). The construction characteristics refers to information which enable an estimation of the space heating and air conditioning needs according to the weather data (without taken into account the ventilation). These characteristics can be presented in various forms, whose best ones are the overall U-value of the building or the U-value of each building element (e.g. walls, windows). Alternatives are to know the composition of the building elements or to estimate it from the type of building, its location and its construction year.

A description of the HVAC system is also required, in particular the types of heating and air conditioning system and heat recovery systems if applicable. Ventilation flow rates and fan characteristics (typically the power curve) are also important data. For domestic hot water, the type of production system needs to be known, as well as the consumption of hot water (e.g. dishwashers).

Finally, a list of all the energy and hot water consuming appliances which are included in the borders of the assessed system needs to be established. The list also includes technical data. According to the type of equipment, these data vary and Table 3.1 summarises the specific requirements of each group of appliances.

Table 3.1: Appliances characteristics required for each type of appliances

Type of appliances	**Information required**
Cooking	Heating technology, control system, rated power.
Refrigeration	Type of appliance, temperature, volume, rated power.
Dishwashers	Amount of hot water and energy used per cycle, type of hot water production system.
Food processors	Rated power.
Food displayers	Type of displayer (open, bain-marie…), temperature.
Lighting	Rated power of each lamp (or group of lamps).
Other appliances	Data that enable the calculation of their energy use from information on their utilisation.

3.2.2 Facility operation

Two types of data need to be distinguished: (i) those related to the operation of the facility's equipment and (ii) those related to the facility's inputs and outputs. The former ones enable the estimation of the annual energy use whereas the latter ones the establishment of the energy efficiency indicators.

The operation of the facility's equipment is very complex to assess since it is strongly related to the behaviour of the staff. Average values can be assumed but the more detailed the operation information the better the assessment quality. A common way for integrating the personnel behaviour into a model is to create profiles that convey the use of the appliances all over the year. Profiles define the level of use of each piece of equipment during a certain period which is typically a day, a week or a year. For a food-service facility, the annual profile presents the periods of the year when the activity is "normal" and not (e.g. holydays, summertime activity). For each of these periods, the weekly profile differentiates the days of the week that have different opening times, types of serving, etc. Finally, for each type of day, equipment daily profiles can be created. These profiles describe how long each appliance is used during the considered day and in which way (e.g. full/partial load). By combining these daily profiles with the equipment characteristics, it is possible to get the estimated energy use for each type of day of the year, and by extrapolation of these results according to the weekly and annual profiles to the annual energy use.

Data related to the inputs and outputs of the facility have to be provided by the operator and depend on the indicators selected for the assessment. Some data, though not necessary for calculating the indicators, can also give a wider understanding of the facility's energy performance and be therefore interesting to collect as well. The inputs of the facility which can be of interest in an energy performance assessment are the energy bills and the prices of energy. This latter is required only if cost estimation of energy efficiency improvements is to be made. The outputs are more varied; it can be the number of clients, the number of meals served (according to the definition of "meal" established in the preliminary step of the assessment), the cash flow of sells or the profit margin. All of these data can be expressed over a given period which can be an annual or monthly average but also a daily accounting.

3.3 Energy use data collection

Before to make any calculation it is important to identify the different energy systems that have to be included in the assessment as well as the best method for collecting the data.

3.3.1 What to collect

The total energy use of the facility is, of course, an important element to know when assessing the energy performance. However, as mentioned previously it is necessary to get also information about the different uses of energy within the facility. These uses are commonly grouped together into categories which are:

- Cooking, food heating purposes and food preparation
- Refrigeration
- Lighting
- HVAC systems
- Domestic hot water

This categorisation of uses can nevertheless be modified according to the specificities of the facility or the available data. This is relatively common for the HVAC part which can be split into space heating, air conditioning and ventilation. It can also be interesting, in the case of central food-production units and self-service facilities to distinguish the energy used for cooking and for holding food warm. The same operation can be made with refrigeration used for storage and for food display. Energy used for dishwashing purpose can also be extracted from the domestic hot water consumption. Food-service facilities may also have other energy consuming processes which are not part of the aforementioned categories such as computers, washing machines or processes which are not directly linked to the food service activity. According to the preliminary definition of the boundaries of the food-service system and the relevant sub-systems to be analysed, these processes can either constitute a new category, be place in the "other" category or simply ignored in the energy assessment.

A second parameter of the energy data collection is the choice of a common period of time for the energy use of all the end-uses. A commonly used period is the year since it is basically the only time cycle which is common to all the applications. However, for practical purposes, it is possible to use daily or weekly energy using and then to extrapolate it to the whole year. For some uses, this extrapolation of average values must be done carefully if annual variations are observed.

3.3.2 How to collect

It exists different possibilities to collect information about the energy needs. The more direct and accurate one is the energy bill since it gives the exact amount of energy bought by the facility. However, the bills usually do not give any information about the final energy uses but only the share of each energy source in the total energy supply. Nevertheless, if one energy source is used for one purpose exclusively, the associated bill is, in this situation, representative of the energy needs of this purpose. Billing methods give therefore an overview of the overall energy use. One exception to this are the energy sources that do not have a commercial status (i.e. the user does not pay for it) and thus do not appear in any bill. This is for instance the case for solar thermal energy since it produces warm water which is part of the facility energy use but has no cost. This example raises the issue of the consideration of this energy: should it be, or not, included into the total energy use of the food-service facility? This issue is discussed further on in Chapter 3.5.3.

If no detailed billing is available, an analysis of each use is necessary. The method giving the best results is obviously the use of sub-meter intended to measure the energy use of one type of usage. Though very accurate, this solution is mainly suitable for electricity powered systems and is difficult to implement for applications using different energy sources (e.g. hot water production in some cases). This method has also a cost which cannot be neglected. Nevertheless, it remains the only possibility to obtain actual values about the energy use of each process. If energy monitoring cannot be implemented all over the year, an analysis over a shorter period can be carried out and the results are extrapolated to the whole year.

The alternative solution to direct energy use measurement is to estimate the final needs of each application and then calculate the corresponding energy use. The estimation of the final needs is not an easy task and is very different from a usage to another. Depending on the considered need, it is sometimes easier to look for benchmarks or average values in the literature or in the manufacturers' documentation. Some publications can give, for example, the annual energy use of refrigeration appliances commonly used in food-service facilities or usual air flow rates for kitchens. Because of the strong relation between behaviour and energy use for some appliances (e.g. cooking equipment), discussion with the personnel of the facility and personal observations can be useful for estimating the energy needs. If the facility has already undergone an energy audit – compulsory in some European countries –, the resulting energy declaration can contain relevant data and information for the calculations.

3.4 Energy use calculations

In the case of detailed energy billing or monitoring, calculations can be used to assess if the actual energy use is reasonable. This section focuses on the estimation of the needs for each category of usage and the corresponding energy use. Depending on the use, the technology and the available data, different methods can be applied.

3.4.1 Food preparation equipment

Cooking appliances have been the subject of a deeper analysis which is developed in the results of the case-study (see Chapter 4.2.3). Here are presented general conclusions about how to estimate the energy use of such appliances. The energy use considered for cooking appliances is not the energy absorbed by the food but the one delivered to the appliances.

Standard energy efficiency of cooking appliances is defined as the ratio between the energy absorbed by the food and the energy delivered to the appliance. This information is however not particularly relevant when calculating the total energy use of cooking appliances. The first reason is that it requires knowing how much energy is needed for the food. The second one is that this standard efficiency only accounts for the energy which is used when actually cooking food. The periods when the appliances are just held warm is not taken into account. The best method for estimating the energy needs of cooking appliances is obviously by means of electricity meters. Other techniques can be also used, as presented below. The case-study also showed that standard energy efficiency can be part of calculations for estimating the energy use. This is developed in Chapter 4.2.3.3.

3.4.1.1 Range tops

The possibilities for estimating the energy use of any range top from its technical characteristics and its operation profiles depend on the technology used for its control. Power controlled range tops (e.g. hot plates, induction tops) offer good possibilities for estimations since the absorbed power is directly related to the position of the control knob of each cooking zone. Multiplying the corresponding power to the time of use – described in the daily profiles – gives a daily estimation of the considered range top's energy use, as shown in Equation 3.1. This equation is adequate for both electricity and gas powered appliances and usually requires technical data from the manufacturer to know the power supply corresponding to each knob position. In the case of gas fired range tops, this value can be estimated from the gas flow supplied to each burner and using the lower heating value of the considered gas in order to convert the gas flow value into kW. These daily estimations can be then extrapolated to the whole year according to the adequate profiles.

$$E_{Range\ top,p\ ctrl} = \sum_{i,j} \left(P_{i,j} \times t_{i,j}\right) \tag{3.1}$$

Where:
$E_{Range\ top,p\ ctrl}$: Daily energy use of a power controlled range top (kWh/day)
$P_{i,j}$: Absorbed power corresponding to position i of the knob controlling the cooking zone j (kW)
$t_{i,j}$: Cumulated daily use of the knob of cooking zone *j* in position *i* (Hours/day)

Some power controlled range tops have more advanced control systems, what makes Equation 3.1 slightly more complex to use. Induction tops and some gas burners deliver power only when a cookware is placed on the cooking zone, respectively the burner. In this case, the time of use of the knob in a given position should take into consideration periods when a cookware is placed on. Some electric hot plates are equipped with a sensor in order to reduce the absorbed power when no cookware is placed on the plate. In the case of continuous power selectors, typically for gas burners, associating each position of the knob to the closest unit enables the use of Equation 3.1 as such.

Thermostat controlled range tops do not enable such analysis since they adapt their power absorption in order to maintain the cooking zones at the required temperature. Estimations from the appliances characteristics and the operation profiles are thus inappropriate and the use of electricity meter appears to be the more adequate solution.

3.4.1.2 Ovens

The energy use of ovens is complex to estimate due to the use of programmes which adjust automatically the heating power and to the differences in utilisation from a facility to another. Deeper analysis of ovens' energy use is developed in the case study.

3.4.1.3 Other cooking appliances

For power controlled appliances such as broilers and griddles, the estimation of their energy use is very similar to the one presented for the stoves (see Equation 3.1). For those which are thermostatically controlled (e.g. steamers, fryers, pasta cookers), benchmarks or monitoring is required.

3.4.2 Refrigeration

Refrigeration devices are thermostatically control and are usually on twenty-four hours a day. The method for calculating their energy use depends on the type of appliance since some are intended to store cold products, other to cool them down and other to produce ice. In some countries, due to new regulations, manufacturers must estimate the energy use of their products and publish it. Access to these values enables a better precision of the estimations. As for cooking appliances, the energy use considered here is not the final cooling need but the electricity consumption of the refrigeration appliances and systems.

3.4.2.1 Refrigerators and freezers

A common way for estimating the energy use of appliances such as upright refrigerators and refrigerated cupboards is to identify their rated power and to multiply it by a usage factor. The usage factor corresponds to the fraction of the time when the appliance is actually consuming energy (typically when the compressor is working). ASHRAE for example gives a usage factor of 0.25 for upright refrigerators and 0.40 for upright freezers in restaurants (ASHRAE 2009).

For some appliances it is also possible to estimate their energy use according to corresponding energy standards. Authorities, for example the Department of Energy in the USA, publish energy use values that appliances must not exceed. These values are usually calculated according to the type of appliance, the refrigeration technology and the volume.

3.4.2.2 Walk-in cold and freeze rooms

For such installations, the energy use is closely related to the volume and the number of doors of the refrigerated rooms. A study carried out in Sweden estimated the average power to be 0.06 kWh/m² for cold rooms and 0.16 kWh/m² for freeze rooms with a three meter high ceiling and an extra power of 1 kW per door (Björklund and Marin 2008).

3.4.2.3 Blast chillers and freezers

Blast chillers are intended to cool down food in a short period of time but not storing it. Their energy use can be estimated by calculating the heat which is extracted from the food, as shown in Equation 3.2 in the case of blast chilling and Equation 3.3 in the case of blast freezing. Summing the values obtained for each type of food during the whole year gives the annual estimated energy use of the blast chillers and freezers.

$$E_{Blast\ chiller} = \left[m \cdot c_{above\ freezing} \cdot \left(T_i - T_f\right)\right]/COP \qquad 3.2$$

$$E_{Blast\ freezer} = m \cdot \begin{bmatrix} c_{above\ freezing} \cdot \left(T_i - T_{freezing}\right) \\ + c_{below\ freezing} \cdot \left(T_{freezing} - T_f\right) + L_{fusion} \end{bmatrix} / COP \qquad 3.3$$

Where:

$E_{Blast\ chiller}$: Energy used by the blast chiller (kWh)

$E_{Blast\ freezer}$: Energy used by the blast freezer (kWh)

m : Mass of food to be cooled down (kg)

$c_{above\ freezing}$: Specific heat of the food above the freezing point (kWh/(kg·K))

$c_{below\ freezing}$: Specific heat of the food below the freezing point (kWh/(kg·K))
L_{fusion}: Latent heat of fusion (kWh/kg)
T_i : Initial temperature of the food before cooling down (°C)
T_f : Final temperature of the food after cooling down (°C)
$T_{freezing}$: Initial freezing point of the food (°C)
COP :Average Coefficient Of Performance of the chilling process (-)

3.4.2.4 Ice machines

The energy used by an ice machine depends mainly on the amount of ice it produces. Manufacturers usually give values of their appliances' energy use in Wh/100lbs ice. According to technical data gathered from different manufacturers, an ice machine with a capacity of about 150 kg/day would use between 1.2 and 1.8 kWh per kilogramme of ice produced (Ice-O-Matic 2010) (Scotsman 2010) (Manitowoc 2010).

3.4.2.5 Display stands

According to a European study, the energy use of display stands can be estimated at 1kWh/day/meter and does not depend on the amount of food displayed (INKISUP 2002a).

3.4.3 HVAC system

3.4.3.1 Space heating

Estimating the energy needs for space heating can require heavy calculations if choosing to perform a heat balance of the building. If the energy source for space heating is not used for any other application, it is possible to deduce the energy needs directly from the billing. In order to make the value independent from the weather during the billing year, it is important to use the weather normalisation adjustment factor, if available. In the case of a water system, it is possible that one bill accounts for the energy used for both space heating and domestic hot water. The needs for space heating can be obtained by deducting the energy used for domestic hot water from the bill. Summer months can for example give good information about the domestic hot water consumption since generally no space heating is required. If there is no possibility to deduce the needs for space heating from the bills, they can be estimated with a heat balance of the building. The calculations require data related to the building characteristics (U-values, ventilation flow rates, heat gains…). This last method requires however time.

3.4.3.2 Air conditioning

As well as for space heating, energy needs for air conditioning can be deduced from billing, typically in the case of installations supplied by a district cooling system. If this is not the case, similar methods to the ones presented for space heating need to be used.

3.4.3.3 Ventilation

Energy using for ventilation depends mainly on the pressure drop and the fans efficiency. A first step is to map the ventilation system and to know the air flow rates passing through each fan. Such data can be gathered from installation specifications or directly read on the air handling units. If no data is available estimations can be made according to the capacity of the dining rooms, the cooking equipment of the kitchen and the current regulation when the system has been built (EPIC Conseil 2010). The second step is to determine what is the actual power absorbed by each fan. It can be assumed that it corresponds to the maximum value allowed by the legislation or calculated according to the fan's specifications given by the manufacturer.

3.4.4 Domestic hot water

Hot water can be produced in different ways and in different places, and it is not common for facilities to have a "domestic hot water bill" or "hot water meter". A first step consists consequently in identifying how and where hot water is produced in order to know which energy inputs of the facility are impacted by its consumption. In some cases it can be possible to get the domestic hot water energy use directly from the billing if one of the commercial energy sources of the facility is used exclusively for its production. Apart from this situation, the methodology for assessing the energy use associated to domestic hot water consists in estimating the hot water needs and then in calculating the energy required to meet these needs. The amount of energy required for a given need depends on the energy source and the production system. A general way of calculating it is to multiply the energy required for heating up the water at a given temperature by the inverse a coefficient which corresponds to the energy efficiency of the water heating system, as shown in Equation 3.4. This efficiency can be quantified by the energy factor of the water heater, which is the ratio of useful energy output from the water heater to the total amount of energy delivered to the water heater. The higher the energy factor, the more efficient the water heater. The energy factor takes into account the losses due to the storage of the hot water but not through the piping system. Pumps work can usually be neglected (Jonsson and Bohdanowicz 2009).

$$E_{DHW} = \frac{1}{\eta_{prod}} \cdot C_{DHW} \cdot c_{water} \cdot (T_{DHW} - T_{CW}) \qquad 3.4$$

Where:
E_{DHW}: Annual energy use for producing domestic hot water (kWh/year)
η_{prod}: energy factor of the production system (-)
C_{DHW}: Annual domestic hot water consumption (L/year)
c_{water}: Specific heat of water (kWh/(L·K))
T_{DHW}: Domestic hot water average temperature (°C)
T_{CW}: Cold water average temperature (°C)

3.4.4.1 Central water heaters

It exists traditionally three types of central water heaters, depending on the energy source: (i) electric water heaters, by means of an electric resistance, (ii) fossil fuel or biomass fuel fired water heaters, (iii) and heat exchangers, where the heat source can be district heating or a heat pump. The hot water distribution piping and the optional storage tank which are associated to these central production systems are responsible for heat losses, hence an extra energy use which is not directly related to the hot water consumption. The choice to include the heat losses or not in the calculation depends on the intended accuracy of the assessment.

In the case of a central electric water heater, the energy efficiency coefficient is close to 1. Fossil fuel or biomass water heaters, unlike electric ones, have a lower efficiency in the transfer of energy from the fuel to the water due to losses related to the combustion of the fuel. For the same hot water consumption, the actual energy use of these water heaters is consequently higher. This drawback is however balanced by the fact that they have a higher exergy efficiency than electric ones (ECBCS Annex 37 2003) and that biomass fuels can be considered as renewable energy. With district heating systems, assuming no heat losses at the heat exchanger, the energy efficiency coefficient is close to 1. Table 3.2 summarises the standards energy factors which are minimum requirements for new equipment since 2004 in the US (National Archives and Records Administration 2010). In the case of heat pumps, the coefficient η_{prod} of Equation 3.4 corresponds to the coefficient of performance (COP) of the device. This choice of using the COP can be questioned since it does not represent the actual energy needed for heating up the water. This issue is discussed in chapter 3.5.3.

Table 3.2: Energy factors for new water heaters sold in the USA since 2004
Source: (National Archives and Records Administration 2010)

Product class	Energy factor (EF)
Gas-fired storage water heater	EF = 0.67 – (0.0019 x Storage volume in gallons)
Oil-fired storage water heater	EF = 0.59 – (0.0019 x Storage volume in gallons)
Electric storage water heater	EF = 0.97 – (0.00132 x Storage volume in gallons)
Gas-fired instantaneous water heater	EF = 0.62 – (0.0019 x Storage volume in gallons)
Instantaneous electric water heater	EF = 0.93 – (0.00132 x Storage volume in gallons)

3.4.4.2 Decentralised water heaters

Hot water is sometimes produced directly by the appliance which uses it. This is typically the case of dishwashers supplied with cold water. For dishwashers the water heating system usually consists in an electric heater with a small storage tank. The estimation of the energy use can be made in the same way than with a central electric storage water heater. Decentralised water heaters can also be used for showers with instantaneous electric water heaters (Prado and Gonçalves 1998).

3.4.4.3 Solar water heater and heat recovery

Water can be warmed up or preheated with sun or spare heat from another system of appliances, e.g. from ventilation or condensers of refrigerators. These two energy sources are usually not part of any billing and are therefore "free" energy sources. However, the hot or warm water produced by means of these systems is part of the hot water energy use of the facility. It can be therefore legitimate to take it into account in the assessment (see Chapter 3.5.3). Estimating the energy use (i.e. the energy they receive) of such systems is very complex since they act as energy collectors and they generally need a backup system (typically a traditional water heater) to compensate the energy they cannot supply to perfectly meet the needs. Nevertheless, both systems are originally intended to save energy, what gives an alternative possibility for estimating their hot water production: When these systems are installed, the manufacturer usually claims for a certain amount of energy saved per year if they replace a traditional water heater. This value, corrected by the energy efficiency coefficient of the replaced water heater, corresponds actually to the amount of energy they collect and transfer to the water, assuming an energy efficiency coefficient of 1.

3.4.5 Lighting

Since lighting only requires specific electricity, its energy use is a part of the total electricity bill of the facility.

Lighting commonly has only two working states: on and off. The idea is consequently to multiply the rated power of each lighting element or group of elements by their operation time. Lighting energy use can be in most of cases estimated as shown in Equation 3.5.

$$E_{Lighting} = \sum_i \left(P_{Lighting,i} \times t_{Lighting,i}\right) \tag{3.5}$$

Where:
$E_{Lighting}$: Annual energy use for lighting (kWh/year)
$P_{Lighting,i}$: Rated power of lighting element *i* (W)
$t_{Lighting,i}$: Annual cumulated operation time of lighting element *i* (Hours/year)

Food-service facilities, as many other commercial buildings, have an operation schedule of leading light which corresponds to the working periods of the facilities; typically, lights are turned on when the first employee arrives and are switched off when the last one leaves. For other areas than working spaces (e.g. changing room, bathrooms, corridors), lighting time depends on the frequency and time of use. In the case of automated light control, the lighting time corresponds to the time of utilisation. When dealing with cold rooms and storage spaces, it appears that the lighting time does not necessarily correspond to the frequency these rooms are accessed since the light may be controlled by the central system or sometimes simply remains on because nobody switches it off. This can be also the case for other spaces having a manual control and remaining lighted all day long. The best way for estimating it is to make personal observations and/or ask the staff about the common operation of the lights.

If the lighting system of the facility is equipped with a daylight harvesting control systems, the resulting energy savings need to be withdrawn from the previously calculated energy use.

Attention must also be paid to the extrapolation of daily or weekly data to the whole year. Indeed, the use of daylight during summer time (in the northern hemisphere) will need to be compensated by artificial lighting during winter time. This introduces seasonal variations in the energy use for lighting.

3.5 Energy performance of a food-service facility

It exists many different ways of evaluating the energy performance of a food-service facility. Calculating the energy efficiency of a facility from energy using data and quantifiable outputs gives values which can be placed in a ranking list and compared with benchmarks. This method shows how energy efficient the food-service facility is but requires quantified parameters. If, by nature or for other reasons, some parameters cannot be quantified, a qualitative analysis of the performance needs to be performed. In this situation rankings and benchmarks cannot be used. Results can just enable qualitative comparisons (internal ones or with other similar facilities). In both situations the energy performance analysis has a relative value since, as mentioned in Chapter 2.6, it is not possible to place the results on an absolute scale.

3.5.1 Quantitative performance

This energy performance is basically calculated as the ratio between the energy use of the facility and the output. According to the literature, the most suitable quantitative output for a food-service facility is the number of meals. A global approach of the energy performance is consequently to divide the annual energy use by the total number of meals served during the year. This results in a value commonly expressed in Wh/meal or kWh/meal. Instead of doing this calculation for the total energy use, it is possible to evaluate how much energy per meal is used for cooking or for refrigeration. There is also the possibility to analyse the energy performance over shorter periods of time, e.g. per month. The interest of this analysis is that it can make visible some variations in the energy efficiency according to changes in the activity of the facility or in the type of food served. This second possibility suffers however one major drawback: It requires a monthly accounting of both the number of meals served and the energy used per month. If some energy uses have been estimated by means of extrapolation of data all over the year, they may not take into account some changes such as the type of food served. Results would be thus biased.

If the number of meals served is unknown, an alternative way of assessing the energy performance is to use the sales cash flows instead. Although these data are easier to collect than the number of meals, the results may not be as relevant. Considering an energy efficiency expressed in Watt-Hour per unit of sales cash flow enable comparisons only with facilities offering the same range of prices. A solution can be to convert the cash flow into a number of meals according to the meal average price of the facility. This would be relevant only if there are not significant prices gaps, typically between lunch and dinner courses or between different periods of the year.

3.5.2 Qualitative performance

Qualitative assessment of the energy performance is more focused on the sub-systems and appliances of the facility. It has two main purposes which are (i) to identify systems that have low energy efficiency and could be therefore improved and (ii) to discuss the quantitative results. This second purpose consists in adjusting, qualitatively, the calculated energy uses by analysing what makes the considered system different from the typical one used for making the calculations. In other words, it is a critical discussion of the calculated results. This is for example the case if the cold rooms has been extra insulated but the available data for such equipment only refer to typical cold rooms. Qualitative assessment is also necessary for what is related to behaviours since it is not always possible to estimate how much energy an appliance would use if changing the staff behaviour, compared to its typical energy use.

3.5.3 The case of non-commercial energy sources

When a facility is using non-commercial energy sources (i.e. which are not subject to invoicing), the question is to know whether its use should be taken into consideration in the energy performance analysis. In other words, when estimating the energy use of the facility, which energy flows should be taken into account. Here is one example which illustrates this issue: Assuming that a facility is equipped with solar water heaters for domestic hot water production. The energy input would be here the amount of energy supplied by the sun through the solar heater. If a second facility, having exactly the same needs for domestic hot water, uses instead a heat pump for heating up the water, the energy use would correspond then to the amount of electricity consumed by the heat pump. The second facility has in this case an apparent lower energy use for domestic hot water – as regards the bill – than the first facility and is consequently more energy efficient. This result can be discussed for two reasons. The first reason is that both facilities have actually the same final use of domestic hot water. The second reason is that the second facility has to buy energy whereas the first one is self-sufficient.

Figure 3.1 gives an overview of this difficulty to define the energy system. The “Energy end-use” box represents the energy uses presented in Chapter 2.5, for example how much cooling is used for refrigeration purposes. This energy can be supplied directly for its final purpose or transformed within the facility to match the type of need. There are consequently several alternatives when setting the boundaries of the studied energy system.

A first method to solve this problem would be to consider only the final use of energy. This first method is however not suitable for every energy system. Refrigeration appliances for instance are mostly driven by heat pumps. Their energy use is commonly calculated as the electricity consumption of the compressor and not the amount of heat extracted. A second method would be to consider only the energy inputs that are subject to invoicing. Although the energy performance assessment is about the final use of energy, it remains consequently more convenient for some systems. The use of other sources of energy such as solar energy, absorption chillers or heat recovery systems is not taken into account and contributes thus to better energy efficiency. The drawback of this second method is that it can hide inefficient uses of energy. For example, assuming a facility using tremendous amounts of domestic hot water compared to its real needs. If it produces the totality of its hot water with solar heaters, it would be considered as more energy efficient, as regards domestic hot water, than any other facility.

There are consequently two different approaches when dealing with non-commercial energy sources: One approach focuses on the efficiency of the uses, and the other one the efficiency of the systems. The first one is more appropriate for analysing energy uses where the behaviour or the equipment is of importance. The second one, on the contrary, is more suitable for energy uses where the final-energy production system is important, such as refrigeration or domestic hot water production. Figure 3.1 illustrates the difference between the total supply of commercial energy and the total final use of energy. Implementing the first method consists in summing the energy flows arriving to the "energy end-use" whereas for the second one, only the "commercial energy input" is taken into account.

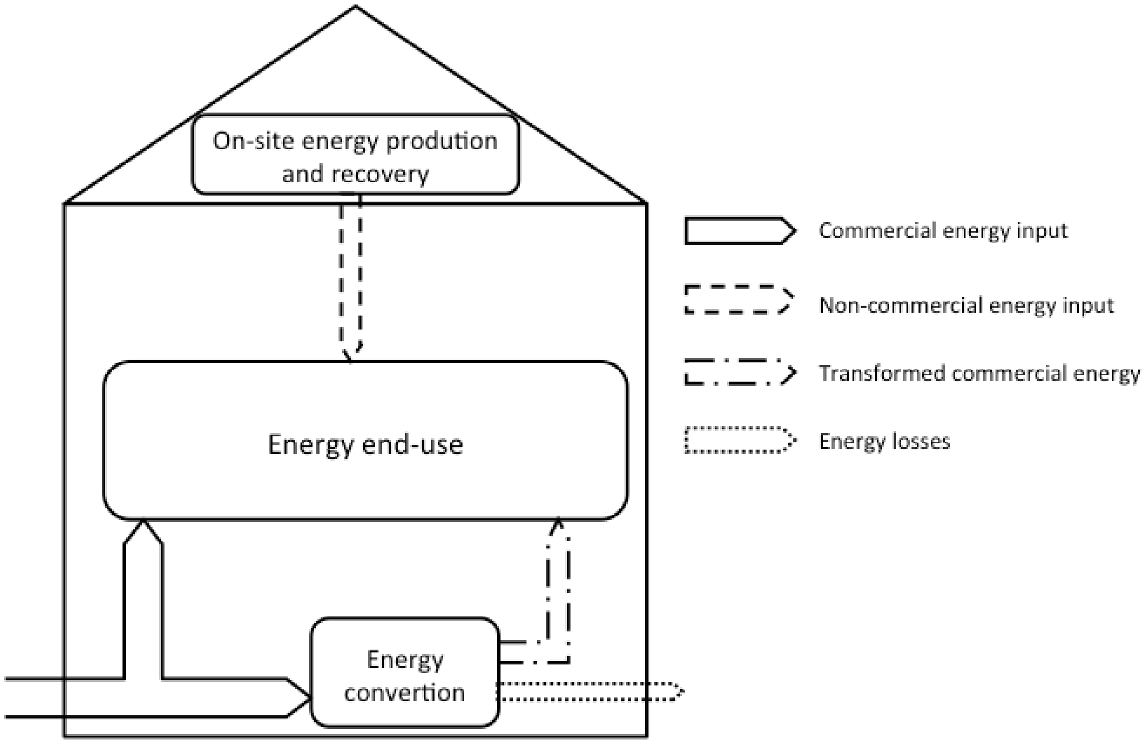

Figure 3.1: Commercial and non-commercial energy flows in a food-service facility

4 The case of Långbro Värdshus

The case study is consists in two steps. The first one is the monitoring of five cooking appliances, two range tops and three ovens. Individual energy meters have been temporarily installed on these appliances for the study. The second step is the energy performance assessment of the whole facility, as an application of the previously presented methodology.

4.1 Description of Långbro Värdshus

4.1.1 The building and its equipment

Långbro Värdshus is a medium-size full-service restaurant located south of Stockholm. The facility offers lunch and dinner with a capacity of 300 to 450 customers per day. The building is an old villa which now consists in dining rooms, a conference room, a kitchen and a basement where storage rooms, and personnel's offices and changing rooms are located.

From an energy point of view, the facility is supplied with electricity and district heating only.

4.1.1.1 <u>The kitchen</u>

The kitchen, with a surface area of 50 m², has been equipped in 2005. It is divided into four zones which are the preparation room, the cooking one, the cold preparation area and the dishing one. Each zone has its own equipment, working organisation and requirements.

The preparation room is designed for many purposes such as unpacking and washing of the groceries, preparation of semi-prepared food – e.g. chopping vegetable –, conditioning of food and some space requiring tasks such as baking. The room mainly consists in a large central board and three 6.5 m^2 walk-in cold rooms designed for storage of vegetables at +8°C, meat, fish and prepared food at +4°C and deep-frozen products at -18°C. It is also equipped with a blast chiller and a large food processor.

The cooking room is the central part of the kitchen and contains the most energy intensive appliances of the facility. The equipment of Långbro Värdshus' cooking room is totally electric and has been partially replaced on the 9^{th} August 2010. On top of the five cooking appliances which have been monitored - two range tops and three ovens - the room also has a tilting braising pan, two boiling tops (hot plates), a salamander, a heated cupboard for holding plates warm at 60°C and two under-counter refrigerators at +2°C. The range tops, ovens and braising pan are all installed under ventilation hoods.

The cold preparation area is intended to the preparation of starters, salads, sauces and desserts and is therefore not furnished with any heating appliance. The equipment consists in two upright refrigerators, two under counter refrigerators, one under counter deep freezers and one small blast chiller.

The dishing area consists in one sink and two hood type dishwashers supplied with hot water from the domestic hot water system of the facility. The dishing process is consequently a batch operation and a pre-washing step is performed by the operator in the sink with a warm water spray valve. Similarly to cooking appliances, the dishing area is equipped with a ventilation hood.

The kitchen area does not have any heating element except a heating floor in the preparation room because it is not built directly on the ground but over. No air conditioning is installed neither and the ventilation is handled by two fans; one for air supply and the other for extraction through the hoods. The lighting installation consists in 36 fluorescent tubes and two 250 W incandescent bulbs above the plate garnishing zone.

4.1.1.2 The basement

In the basement of the building are located storage areas, a laundry, changing rooms and offices. There are installed two 6.5 m² walk-in cold rooms for food storage at +4°C, one upright refrigerator, one upright deep freezer, a chest freezer and two ice machines. There are also one washing machine and one tumble dryer and six computers. The lighting installation consists in 26 fluorescent tubes, similar to those used in the kitchen. The ventilation system is connected to the same one as for the dining rooms.

4.1.1.3 The dining rooms

The dining rooms are located on the ground floor of the building and account for about 250 m². Apart from the bar's equipment, the dining rooms only have spots for lighting and hot water radiators which maintain the indoor temperature around 22°C. There is no air conditioning. The bar's equipment is made up of two small, and one large upright glazed door refrigerators and two under counter glazed sliding door refrigerators for drinks and one under counter solid door refrigerator.

4.1.1.4 The conference room

The facility also has dining rooms located on the first floor which are used for seminars or conferences. These rooms are not used every day but around one day out of three. The first floor has approximately the same surface area as the dining rooms, i.e. around 250 m².

4.1.2 Operation of the facility

According to the day of the week and the season the opening times can vary and therefore influence the daily energy use of the facility. However, the operation of the restaurant is base on a weekly basis which is modified during some short periods, e.g. in July and for Christmas. Since the energy efficiency analysis is based on ordinary operation of the facility, here is only described the operation during the ordinary periods.

4.1.2.1 Operation schedule

Långbro Värdshus offers lunch every weekday and brunch during weekends. Dinner is served every day apart from Monday. The dining rooms are usually open from 11:00 to 22:00 (14:00 on Mondays) but the facility is operated during longer periods. On Mondays only lunch is served, from Tuesday to Friday lunch and dinner are served and on week-ends, brunch and dinner. Depending on the menus and the number of clients, the working time of the personnel can vary, especially as regards the ending time. On average, the operation of the facility begins at 6:00 and ends around 23:00 or 24:00. Within this operation time, the number of personnel members and the activity change. Outside opening hours, most of the activity is located in the kitchen of the restaurant. The total operating time of the facility is of importance when dealing with the energy use of some appliances such as lighting or stoves.

During summer time the cooking activity is located outside of the kitchen, with barbecues, and only for lunch. This change in the activity modifies significantly the energy use and must be considered in the annual energy use. For each appliance, the operation profile consists therefore in 11 months (or 47 weeks) of normal activity and 5 weeks of summer activity.

4.2 Monitoring of the cooking appliances

This first step of the case-study consisted in measuring the instant energy use of the five main cooking appliances of the facility. Electricity meters equipped with a GPRS transmitter enabled a reading of the energy used every five minutes. These measurements have been analysed with two objectives: (i) to get actual values of the daily energy use for each piece of equipment and (ii) to know how appliances are used by the personnel. A refurnishment of these appliances has been performed as well as a training of the kitchen's personnel. This enabled an analysis of the impact of the cooking equipment and its utilisation on the energy use. The monitoring of the cooking appliances also consisted in on-site observations during working time, discussions with the personnel and information gathering from the administrative personnel of Långbro Värdshus.

The initial monitored appliances were:

- A range top of four hot plates of 4 kW each
- A range top of three hot plates of 4 kW each (the fourth plate did not work)
- A small combi oven with 9 kW rated power
- A medium-size combi oven with 17 kW rated power
- A large convection oven with 35 kW rated power

And they have been replaced, respectively, by:

- A solid top with four cooking zones of 4 kW each and an ECOTOP[1] coating
- A induction top with two cooking zones of 7 kW each
- A small combi oven with 9 kW rated power and precise steam control
- A medium-size convection oven with 17 kW rated power
- A large convection oven with 35 kW rated power

The range top replaced by the solid top is called range top 1. The one replaced by the induction top is called range top 2. The solid top is sometimes called ECOTOP.

Though the new ovens have the same characteristics than the previous ones, their technology is up-to-date and offers new programmes and solutions such as automatic cleaning.

The monitoring has been performed during a period of five months, including five weeks of summer activity when the cooking appliances are seldom used due to outside cooking on barbecues. During this summer period the equipment has been replaced. In the very end of September a first meeting with Fredrick Eriksson, manager of the facility and Petter Danielsson, cook and responsible for the kitchen was intended to present them suggestions

[1] The ECOTOP coating is a technology developed by Electrolux and intended to reduce the heat transfer by radiation. The heat losses of the solid top are consequently reduced when no cookware is placed on it, compared to traditional hot plates.

for lowering the energy use of the cooking appliances. Three weeks later a training of the personnel has been performed.

4.2.1 Operation of the monitored appliances

At Långbro Värdshus the cooking process is usually organised as follows: In the morning, i.e. the period preceding lunch time, the range tops are used to cook vegetables, sauces, soups and stews that will be served for lunch. The ovens are also mainly used for the same purposes during this period. This organisation implies that the range tops are turned on in the early morning and switched off only at the end of the day in order to keep these heating surfaces always hot. During lunch time, the range tops are only used for preparing the dishes on demand (i.e. reheating what has been cooked in the morning), the small oven for holding fish and some vegetables warm with 100 % steam, and the medium size oven is maintained warm for cooking meat when required. Once the lunch time finished, the same scheme can be observed for the preparation of the dinner. During the five weeks of summer activity, the data have not been analysed since the appliances are seldom used and in an erratic way. Only the total energy uses have been reported.

4.2.2 Results of the monitoring

4.2.2.1 Detailed energy analysis of each appliance

Since the energy use is read every five minutes, it is possible to calculate the average absorbed power during these periods and thus draw curves representing the activity of each appliance, from an energy point of view. Figure 4.1 to Figure 4.5 present typical daily energy use observed for each of the old and new appliances before and after the refurnishment respectively and before any training. Similar curves have been drawn for each day of the monitoring period and used for analysing the operation of the equipment and the influence of the behaviour.

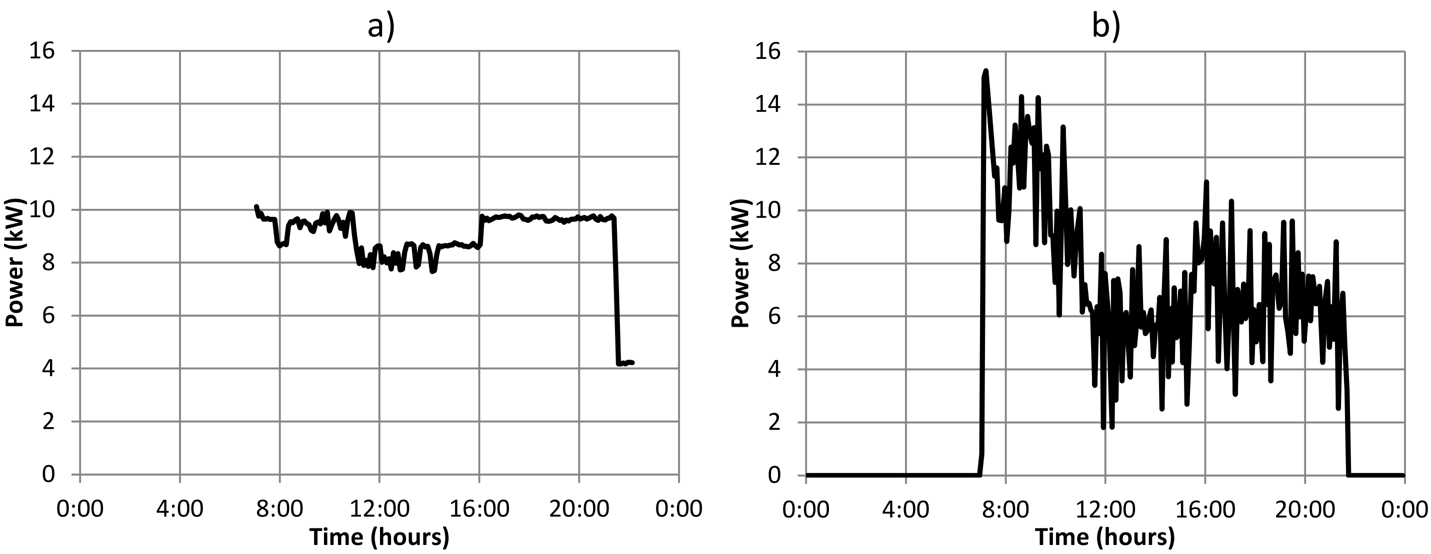

Figure 4.1: Typical daily energy use of a) the range top 1 and b) the solid top

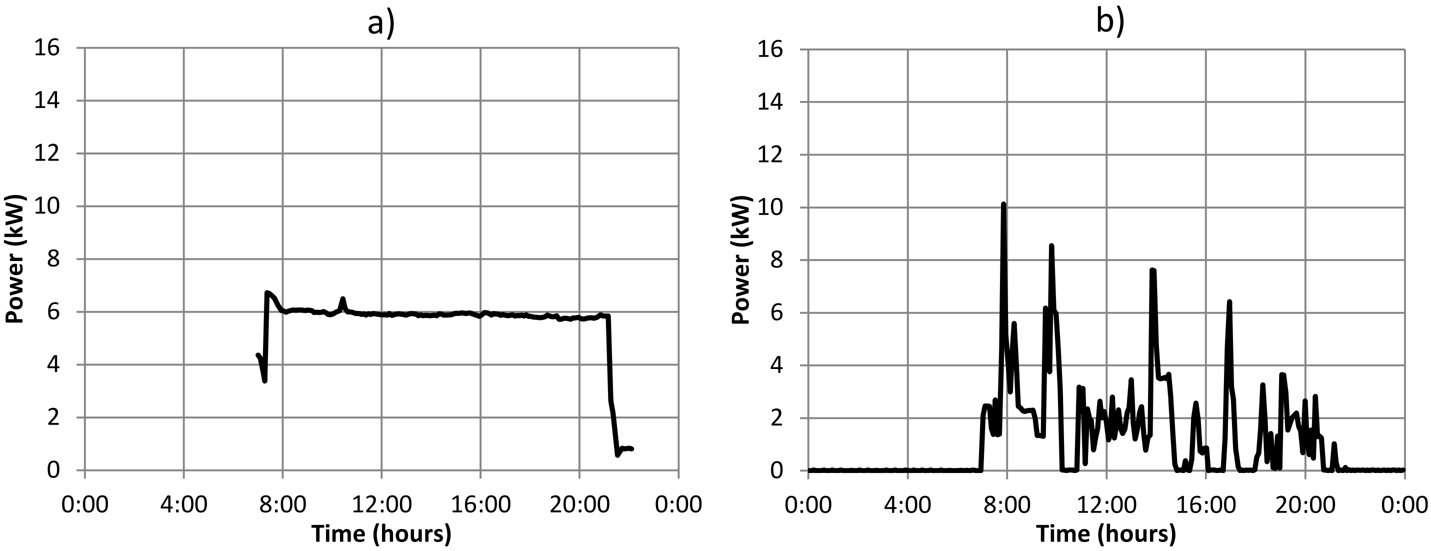

Figure 4.2: Typical daily energy use of a) the old range top 2 and b) the induction top

As regards the old range tops (see Figure 4.1a and 4.2a), the maximum available power for each hot plate seemed to be limited, to the half of the rated power. This technical failure has not been investigated but could be the reason of the flatness of their power curves since changing the position of the knobs between different high power levels would not change the actual power supply. Figure 4.1 also enlighten the differences between the power-controlled appliance and the temperature controlled one. The energy use profiles of the old range tops present levels according to the position selected by knob. The temperature control of the solid top is visible through the peak reaching the rated power when switching on the four cooking zones for the first time in the early morning and the constant variations of the absorbed power. The induction top (see Figure 4.2b), though power controlled, does not show obvious levels of power due to short cooking times and automatic switching off of the heating when the pot or pan is removed.

The comparison between the old range top 1 and the solid top shows a similarity in the shape of the profile (see Figure 4.1). A high amount of energy is required in the morning until lunch time where the energy use is lower and relatively constant. More energy is then required in the afternoon but not as much as in the morning. During dinner time, energy using is however not lower as it was during lunch time. The induction top tends to follow this tendency since its energy use is usually higher in the morning than in the afternoon. The total energy use of the induction top is not only due to a better cooking efficiency but also to a lower use of the appliance.

As regards the ovens the difference between the old ones and the new ones (see Figure 4.3 to Figure 4.5) is not as obvious as with the range tops. The new small oven's profile (see Figure 4.3) shows on one hand much higher peaks but on the other hand the average power in idle mode appears to be slightly lower.

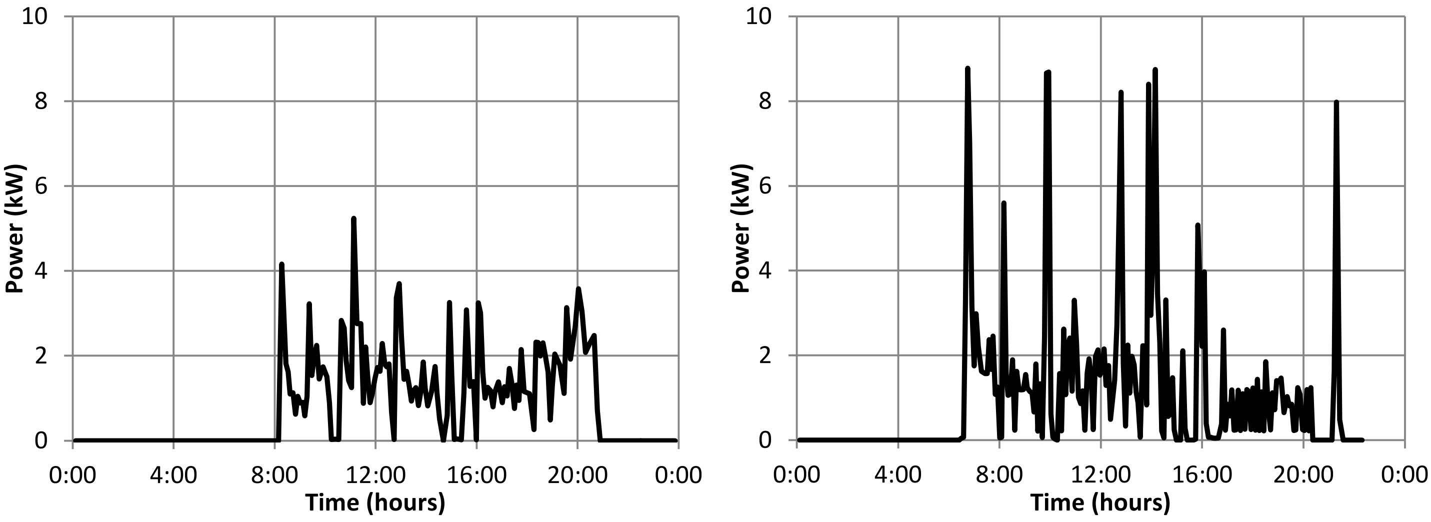

Figure 4.3: Typical daily energy use of the old small oven (left) and the new one (right)

The medium oven (see Figure 4.4), on the contrary, works in a very similar way than the previous one but its power absorption in idle mode is around 50 % higher. According to Electrolux, this new oven, though using a similar technology than the old one and having a better door, has a new design. Its fan is not placed at the back any more but on the side of the oven's cavity.

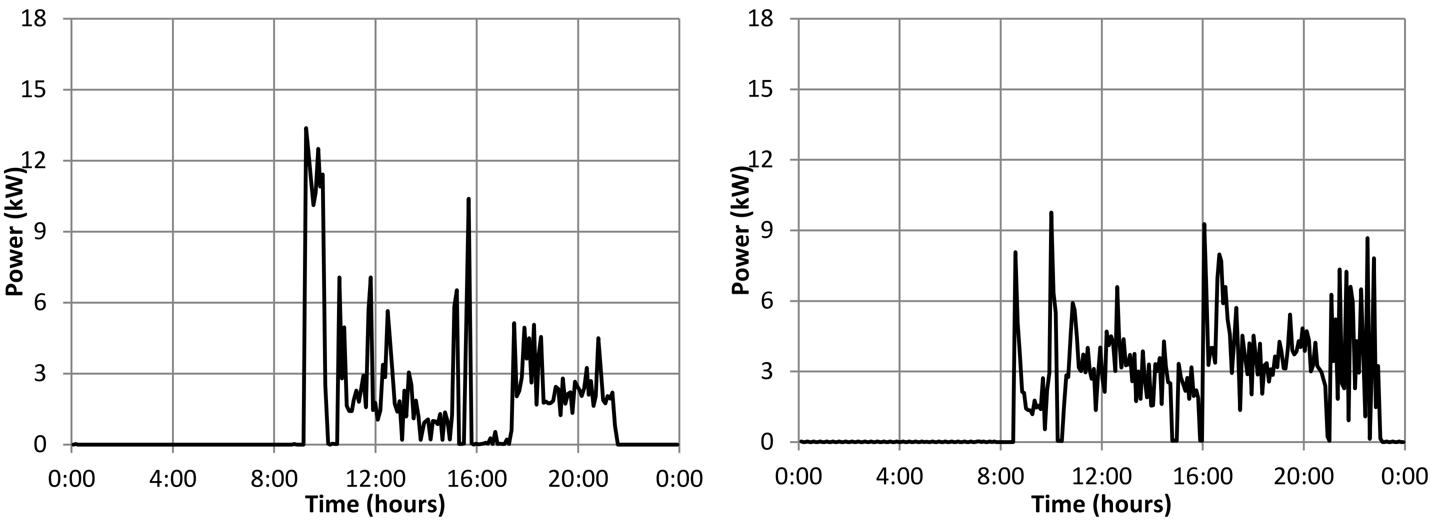

Figure 4.4: Typical daily energy use of the old medium size oven (left) and new one (right)

The large oven's curve (see Figure 4.5) remained similar after the refurnishment and presents typically single high peaks with sometimes a short period of idle mode. The use of this oven consists indeed in cooking food with programmes lasting around 20 to 40 minutes but not in holding food warm as the two others do.

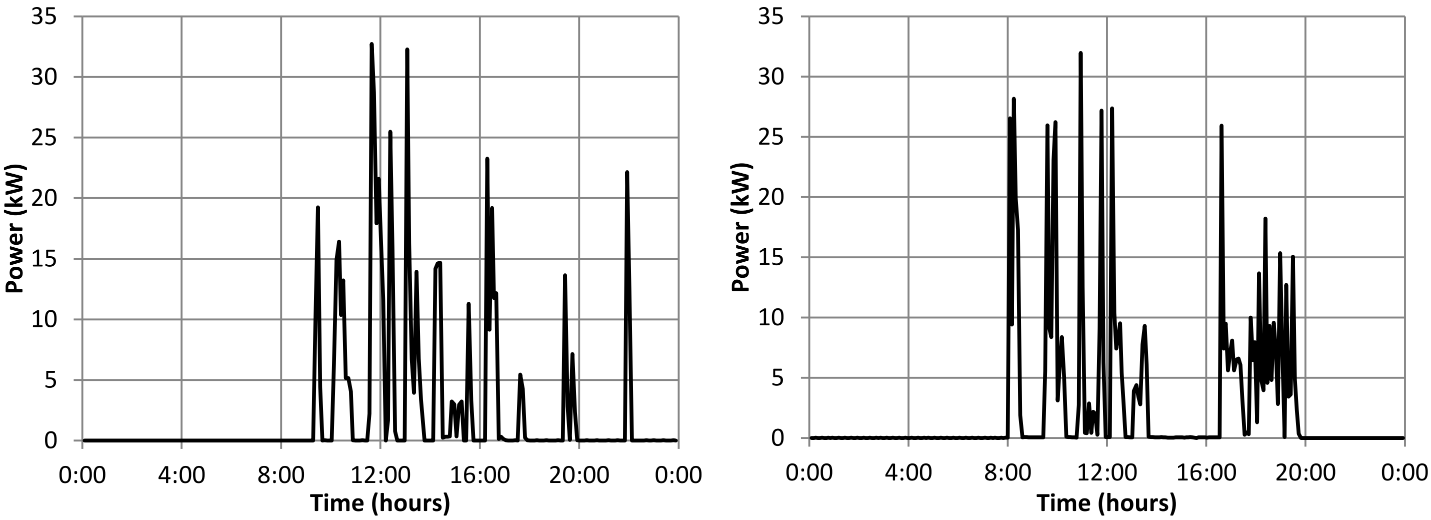

Figure 4.5: Typical daily energy use of the old large oven (left) and the new one (right)

4.2.2.2 Energy use during the study period

Since the restaurant has a weekly based activity cycle, a daily comparison of the appliances could be biased. Therefore, the analysis is carried out with the weekly energy use of each appliance. Figure 4.6 presents an overview of the weekly energy use of the range tops (called stoves in the diagram) and the ovens during the monitoring period. It shows in particular the impact of each step on the energy used. Table 4.1 summarises this overview by presenting the average weekly energy use for each appliance after each step of the study. Remarks and assumptions related to the data are presented in Appendix 1. This analyse assumes a similar activity of the restaurant during all the weeks, apart from the last one of June and the first one of July (*Jun 4* and *Jul 1* in Figure 4.6).

The values presented in Table 4.1 show that, assuming the same overall activity during the whole monitoring period, the refurnishment of the kitchen enabled 21 % energy savings and reached 26 % compared to the old equipment's energy use after training of the personnel. This savings vary however significantly from an appliance to another.

As regards the range tops, the new ones are much more efficient since without any behaviour change, their total energy use is 38 % lower. The induction top appears to be responsible for very high savings compared to the solid top but this is partly due to a new sharing out of the cooking activity between the two range tops. The old range top 1 handled, according to on-site observation, around 60 % of the pots and pans and the old stove 2 around 40 %. This difference in use is due to a faulty hot plate on the range top 2 and the position of the range top 1 closer to the plate garnishing zone. The new solid top and induction top handle now around 75 % and 25 % respectively of the range tops activity (according to on-site observations). The adjusted savings after refurnishment would be then 31 % for the solid top and 59 % of the induction top

As regards the ovens, they are responsible for an increase in the energy use, particularly the medium size oven which presents an extra energy use of 36 %. Despite considerable percentages, the actual energy use of the ovens varies to a lesser extent compared to the range tops since their energy uses are lower. The other two new ovens have energy uses close to the ones of the old ovens. Further energy savings have been achieved by modifications of behaviours and cooking organisation. These changes are only related to the operation of the appliances and not with the cooking techniques and menus. Table 4.1 shows the impacts of both a discussion with the kitchen managers and a training of all the staff members on energy using. It reveals that even if the preliminary discussion leaded to some savings, higher ones are achieved when training everybody.

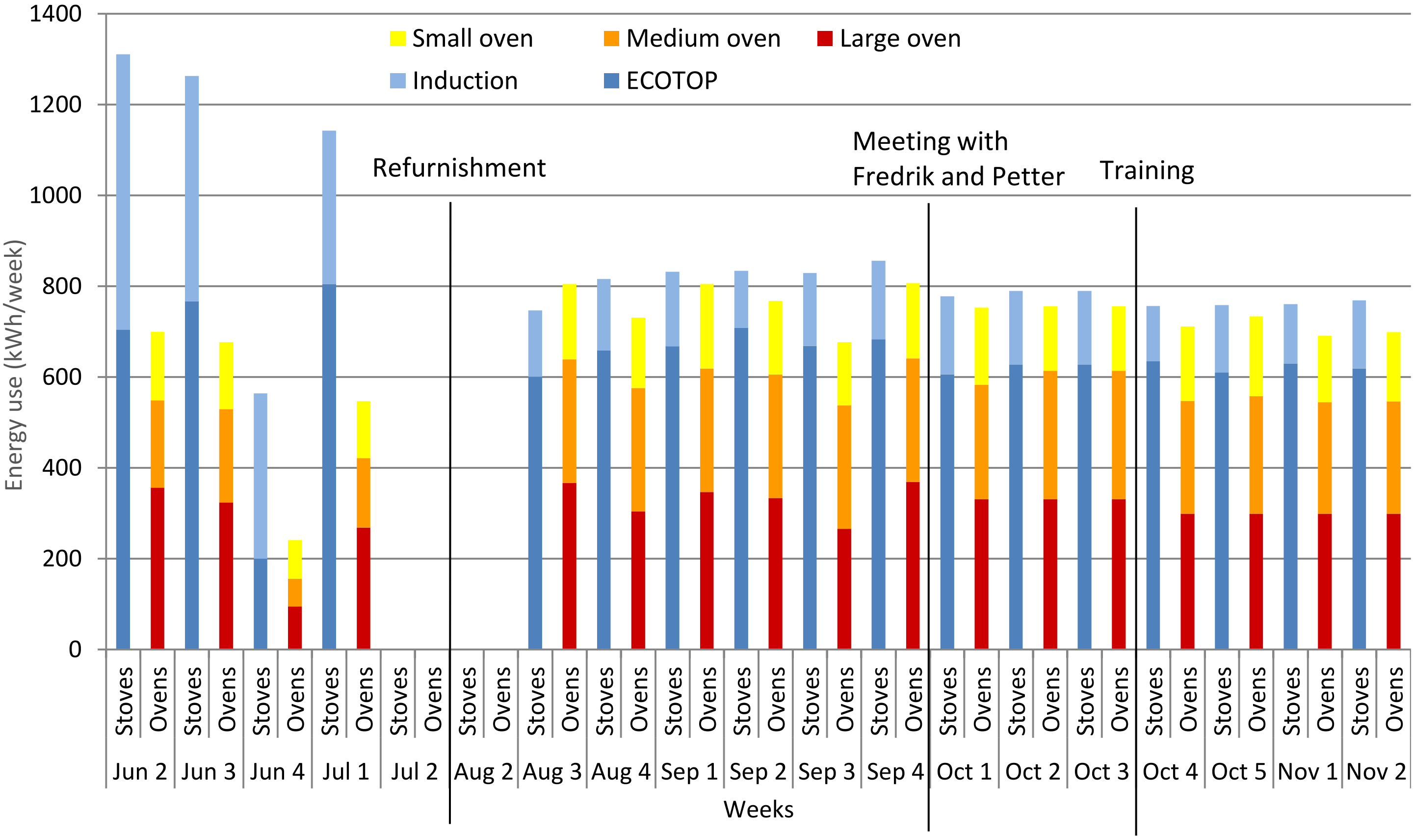

Figure 4.6: Energy use of the cooking appliances during the monitoring period

Table 4.1: Variation of the cooking appliances energy use after each step of the monitoring period (Old appliances as reference)

	Average weekly energy use (kWh/week) and variations²						
	Old app.	New app.		1st meeting		Training	
Range top 1 / Solid top	736	665	-10%	620	-16%	624	-15%
Range top 2 / Induction	551	132	-76%	166	-70%	138	-75%
Total stoves	**1 287**	**797**	**-38%**	**786**	**-39%**	**762**	**-41%**
Small oven (9 kW)	149	162	+9%	151	+1%	150	0%
Medium oven (17 kW)	201	272	+36%	272	+36%	250	+25%
Large oven (34 kW)	341	331	-3%	331	-3%	299	-12%
Total ovens	**690**	**766**	**+11%**	**755**	**+9%**	**699**	**+1%**
Total cooking appliances	**1 977**	**1 563**	**-21%**	**1 541**	**-22%**	**1 460**	**-26%**

4.2.2.3 Cleaning of the ovens

The new ovens installed at Långbro Värdshus incorporate preset cleaning programmes with different cleaning levels. The cleaning process is launched every day at the end of the working time and is therefore easy to identify in the energy use profiles. Depending on the programme and the selected options (e.g. skipping the drying step), the energy use varies. The old ovens were cleaned manually and just required sometimes a short heating up of the oven. This operation can be observed as well on the energy use profiles which present a single peak at the very end of the day. As showed in Table 4.2, the cleaning process of the new ovens accounts for a significant part of the daily energy use of the ovens. If the heavy-duty cycle is selected, its energy use can represent up to 25 % of the energy used by the oven during the day. The cleaning energy use of the new ovens compared to the old ones is 4.5 times higher for the large ovens and 7 times higher for the small and medium-size ovens.

Table 4.2: Energy used for the cleaning of the old and new ovens

	Average energy use (kWh/day) and percentage of the average daily use			
	Old ovens		New ovens	
Small oven	0,34	1,6%	2,37	10,2%
Medium oven	0,75	2,6%	5,32	13,7%
Large oven	1,31	2,7%	5,93	12,5%

4.2.2.4 Behaviour and cooking organisation

Combining the monitoring of each appliance with observations in the kitchen enabled a detailed analysis of the equipment use intended to identify how behaviours and cooking organisation can be improved from an energy point of view. A list of suggestions (see Appendix 2) has been first presented during a meeting with the chef and the manager of the facility. Then some energy efficiency measures have been presented to the kitchen staff of the restaurant during the training. These suggestions were for example to use lids, to delay the start-up time of the solid top in the morning as long as the induction top can handle the work, to reduce the temperature of the solid top's cooking zones and to avoid using heavy-duty cleaning programmes for the ovens. After the training the equipment has been monitored during one more month and discussions with the personnel enabled a feed-back as regards the relevance and the efficacy of the suggestions. Figure 4.7 illustrates how the training of the personnel influenced the energy use of the solid top. According to the present study, combining the use of lids with a reduction of the cooking zones temperature in the morning, a delayed start-up time and a lowering of the average power during lunch time enables around 28 kWh savings per day. These savings account for almost 25 % of the solid top's energy use during normal days before training. These significant savings were unfortunately not as high during the following weeks, probably due to the fact that the effort made by the staff during the first has not been continued.

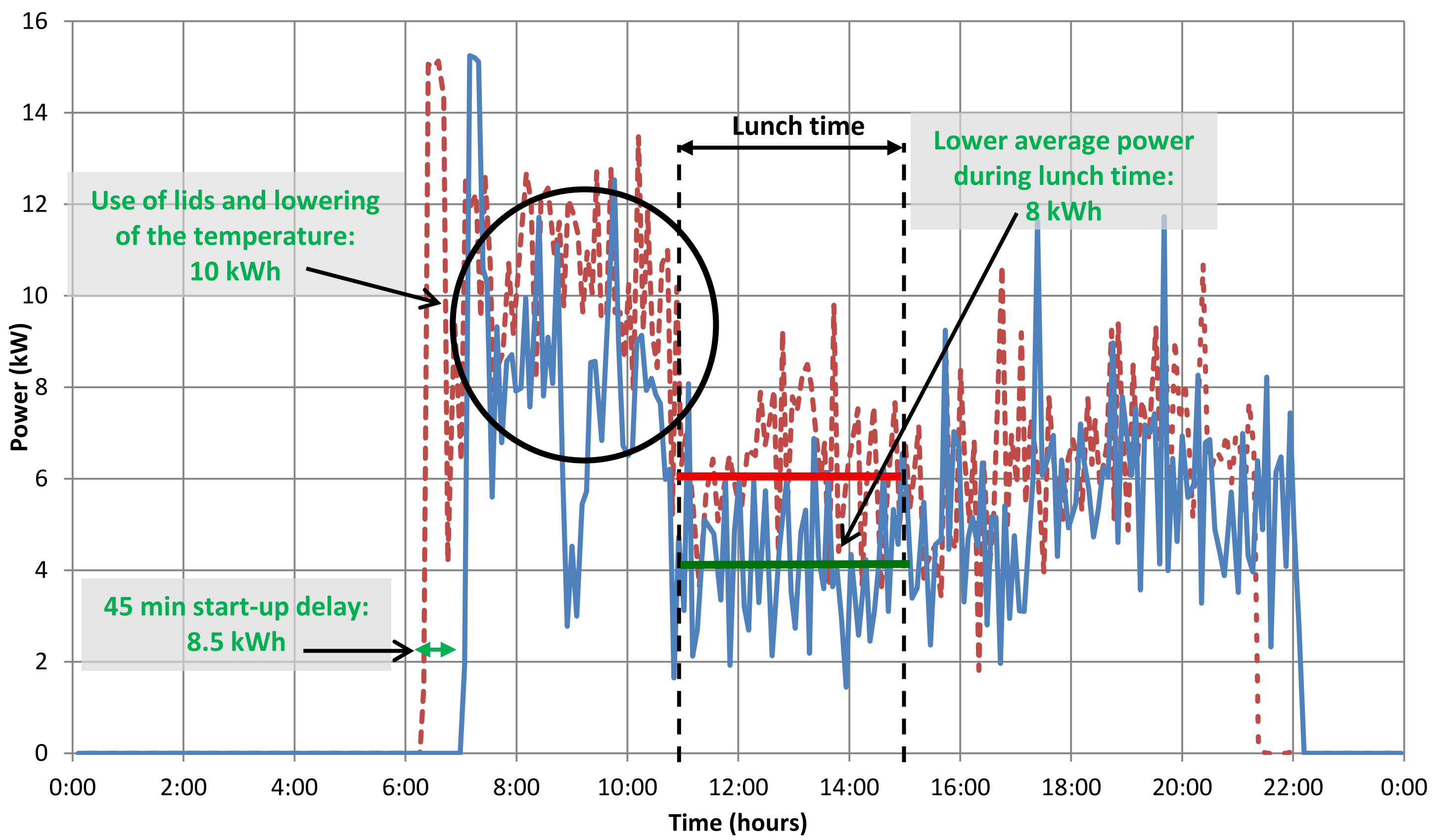

Figure 4.7: Energy use of the solid top between a Tuesday before the training (dotted line) and a Tuesday after the training (continuous line) and analysis of the energy savings due to behaviour changes.

The average weekly energy savings due to the training are summarised in Table 4.3. It appears that the training enabled 100 kWh extra savings each week, especially with the ovens. The 9 % savings achieved by these latter are mainly due to not using anymore the cleaning programmes.

Table 4.3: Variation of the energy uses before and after the training of the personnel (New appliances before the training as reference)

	Energy use (kWh/week)		
	Before	After training	
Range top 1 / Solid top	665	624	-6%
Range top 2 / Induction	132	138	+4%
Total stoves	**797**	**762**	-4%
Small oven (9 kW)	162	150	-8%
Medium oven (17 kW)	272	250	-8%
Large oven (34 kW)	331	299	-10%
Total ovens	**766**	**699**	-9%
Total cooking appliances	**1 563**	**1 460**	**-7%**

4.2.3 Discussions and conclusion of the monitoring

Before discussing any result, it is worth reminding that cooking appliances are first of all intended to prepare food and should therefore not be only evaluated on their energy performances. Parameters such as quality of food, ease of use, air quality are qualitative outputs of the cooking equipment and therefore not taken into account in the present data. An increase of one of these outputs for a same energy use leads to a higher energy efficiency according to the definition given in Chapter 2.6. although it does not appear in the measured values. In the case of Långbro Värdshus, the new ovens are more user-friendly, equipped with a better temperature control than the old ones and offer automatic cleaning programmes. As regards the new range tops, on top of having a lower energy use, they also emit much less heat to the room by radiation than the old ones, which improves significantly the thermal comfort of the personnel.

4.2.3.1 Variations of the energy use

Concerning the range tops, replacing the equipment enabled a significant reduction of the energy use, whereas training the personnel had a much lower impact. On the contrary, replacing the ovens did not enable any savings but training the personnel did (based on the energy use of the new appliances before training). This opposite behaviour between these two types of cooking appliances is mainly due to the very different way in which these appliances are used. Since ovens mainly use energy when food is placed in them, replacing the old appliances would save energy thanks to lower heat losses or a shorter cooking time of the new ovens. These savings are consequently relatively low. As regards the range tops, the hot plates' energy use was irrespective of the presence of food on the cooking zones whereas the induction top automatically stops heating when the cookware is removed. This property of induction tops enabled savings that correspond at least to the energy that was used by the old range tops when no food was placed on them. Once the kitchen refurnished, it was much easier to save energy with the ovens by ceasing the use of cleaning programmes than with the induction top where energy was already only used for food. The case of the solid top is in between the hot plates and the induction top cases since energy is used when no cookware is placed on it but at a lower rate due to the temperature control and the coating which reduces the radiation losses.

These different efficacies when refurnishing the kitchen enlightens an important factor to take into consideration when analysing the energy efficiency of a food service facility: Energy used when no food is cooking is a loss. This may look absolutely obvious but identifying where and when these losses occur helps finding the most effective measures for improving the energy efficiency.

4.2.3.2 Influence of the activity

The results given in this thesis assume the same activity all along the study. The sales of the facility appear however to be higher in June than in August but a lack of detailed accounting for the activity and a too short monitoring period before the refurnishment did not allow a relevant adjustment of the results according to the restaurant's activity.

4.2.3.3 Efficiency of the range tops

According to the values given by the literature, the hot plates have a standard energy efficiency around 60 % and the induction top around 85 %. Considering these values, the replacement of the old range top 2 by the induction one should have theoretically enabled around 30 % energy savings. As seen in Table 4.1, these savings reach 76 %. If taking into account the variation of the activity share between the two range tops, then the savings are actually around 59 %. The reason why this latter value does not match the theoretical one lies in the definition of the standard efficiency. This definition only accounts for the energy use when cooking food but not when no cookware is placed on the cooking zone. That makes a significant difference between the hot plates which continue using energy and the induction top which stops heating. This reason enlightens that it is absolutely not relevant to use the standard efficiencies of cooking appliances for estimating the potential energy savings when changing the equipment.

In the present situation of Långbro Värdshus, it is however possible to introduce another efficiency, so called *overall energy efficiency* in this thesis. The overall energy efficiency of a range top during operation depends both on its standard efficiency and on the amount of energy lost while no cookware is placed on its cooking zones. The idea is now to use an equation very similar to the one for the standard efficiency but with the total energy used during the working period (typically a day) instead of the energy used for cooking food only (see Equation 4.1).

$$\eta_{appliance,overall} = \frac{E_{food}}{E_{appliance,total}} \qquad 4.1$$

Where:
$\eta_{appliance,overall}$: Overall energy efficiency of the cooking appliance
E_{food}: Energy absorbed by the food cooked on the appliance
$E_{appliance,total}$: Total amount of energy used by the cooking appliance

The main drawback of this equation is that it is very difficult to estimate the amount of energy absorbed by the food. In the present case, the induction top is very helpful since its overall energy efficiency can be assumed to be very close to its standard one – energy is only use to cook food. The energy used for cooking the food handled by the induction top can be calculated as shown in Equations 4.2 and 4.3.

$$E_{food,induction} = \eta_{indution,overall} \cdot E_{induction} \qquad 4.2$$

$$\eta_{indution,overall} = \eta_{indution,standard} \qquad 4.3$$

Where:
$E_{food,induction}$: Energy absorbed by the food cooked on the induction top
$\eta_{induction,overall}$: Overall energy efficiency of the induction top
$\eta_{induction,standard}$: Standard energy efficiency of the induction top
$E_{induction}$: Total amount of energy used by the induction top

Equation 4.2 gives however the amount of energy absorbed by the food cooked on the induction top only. For the other appliances, this value needs to be corrected by a factor related to the relative cooking activity of the appliances, as shown in Equation 4.4.

$$E_{food,appliance} = \frac{\alpha_{appliance}}{\alpha_{induction}} \cdot E_{food,induction} \qquad 4.4$$

Where:
$E_{food,appliance}$: Energy absorbed by the food cooked on the considered appliance
$E_{food,induction}$: Energy absorbed by the food cooked on the induction top

$\alpha_{appliance}$: Fraction of the range tops' activity handled by the considered appliance
$\alpha_{induction}$: Fraction of the range tops' activity handled by the induction top

At Långbro Värdshus, the overall energy efficiency of the hot plates and the solid top can be calculated according to Equations 4.5 and 4.6. The old hot plates range tops are considered as one single appliance.

$$\eta_{old\ range\ tops,overall} = \frac{\alpha_{old\ range\ tops}}{\alpha_{induction}} \cdot \frac{\eta_{induction,standard} \cdot E_{induction}}{E_{old\ range\ tops}} \qquad 4.5$$

$$\eta_{solid\ top,overall} = \frac{\alpha_{solid\ top}}{\alpha_{induction}} \cdot \frac{\eta_{induction,standard} \cdot E_{induction}}{E_{solid\ top}} \qquad 4.6$$

Where:
$\eta_{old\ range\ tops,overall}$: Overall energy efficiency of the old range tops
$\eta_{induction,standard}$: Standard energy efficiency of the induction top
$\eta_{solid\ top,overall}$: Overall energy efficiency of the solid top
$\alpha_{old\ range\ tops}$: Fraction of the range tops' activity handled by the old range tops
$\alpha_{induction}$: Fraction of the range tops' activity handled by the induction top
$\alpha_{solid\ top}$: Fraction of the range tops' activity handled by the solid top
$E_{old\ range\ tops}$: Energy supplied to the old range tops
$E_{indution}$: Energy supplied to the induction top
$E_{solid\ top}$: Energy supplied to the solid top

Equations 4.5 and 4.6 can be used in other cases than Långbro Värdshus with some conditions:

- There must be a range top such that it does not use energy when no cookware is placed on. This in order to have as a reference value for the estimation of E_{food}.
- The total activity of the range tops should be the same before and after the replacement of the equipment.

At Långbro Värdshus, the induction top handles around 25 % of the range tops activity while the remaining 75 per cent are handled by the solid top. The two old range tops handled of course the totality of the activity. This activity is supposed to be the same before and after the refurnishment. According to these assumptions and the energy use values of Table 4.1, the overall energy efficiencies of the old range tops and the solid top are respectively 35 % and 50 % – and 85 % for the induction. These values are not only a property of the appliances but also related the way the equipment is used. For this reason only the formulas (Equations 4.5 and 4.6) can be extrapolated to other facilities but not the resulting overall energy efficiencies. The results depend indeed strongly on the behaviour and the cooking organisation with the range tops. Furthermore the overall energy efficiencies are not suitable to directly calculate the energy use of any range top but to compare the energy savings when using different types of range tops for a same activity or to estimate the expected energy use when refurnishing a kitchen. Although approximate, overall efficiencies give much better estimations of the energy use than standard efficiencies.

4.2.3.4 Energy use of the ovens

In accordance with what results from the literature study, estimating the ovens' energy use is not very relevant when basing the calculations on technical and operational data of the ovens. Knowledge about their actual energy use is required. A monitoring of each oven during a short period can provide a rough estimation of how much energy the ovens use for each cooking programme, what once related to the corresponding operation profiles gives the annual energy use of the ovens. This method applies, however, only if the considered ovens present energy use curves where the cooking cycle can be easily identified. At Långbro Värdshus, the meter was read every five minutes. These intervals of time unfortunately too long for this type of analysis since the ovens were often used for short programmes (around 10 to 15 minutes). With a finer energy measurement it would be possible to identify the different operation modes of the ovens which are (i) the cooking of food, (ii) the warm holding and (iii) the cleaning process. Since ovens can be operated with cooking and cleaning programmes, it is possible to match each programme with its corresponding average energy use. In the case of manual utilisation, e.g. for warm holding, what is required is the set temperature and the average energy use per unit of time. The total energy use is calculated by multiplying this latter value by the time of use.

As regards the energy used for cleaning the ovens, though it is not, strictly speaking, part of the cooking process, it should nevertheless be considered in the energy analysis of the ovens.

4.2.3.5 Influence of behaviour on energy efficiency

Since a part of the overall energy efficiency of the cooking appliances is related to their operation, the behaviour of the personnel and the working organisation have a considerable impact on it. The monitoring of Långbro Värdshus' cooking appliances enabled the identification of several typical behaviours that lower the energy efficiency of the range tops and the ovens.

In the case of simple power controlled systems, typically the old range tops, the user has a strong impact on the energy use since the operator directly selects the power input and therefore has a full control of the energy use. When no food needs to be cooked, the operator has the possibility to switch off the appliance. If not, the energy is used with an efficiency equal to zero. In the case of a thermostatic control of the appliance, e.g. with ovens or with the considered solid top, the energy efficiency is also zero when no food cooks but, because of the temperature control, the energy use is lower. However, for systems having a thermal inertia, typically hot plates and solid tops, switching off a cooking zone implies a lowering of its temperature and an extra time required for heating it up when needed again. This is the reason why this type of appliances is usually never switched off by the user, what contributes to a lower overall energy efficiency.

4.2.3.6 Conclusion

Monitoring the energy use of range tops and ovens offers two major advantages. The first one is that it gives the actual values of the energy use, what prevents from any uncertain estimation. The second advantage is that it also enables a detailed analysis of the way the appliances are used. Although, for power controlled appliances, energy use can be estimated by means of the rated power and operation profiles, this is not possible for temperature controlled appliances. Monitoring appears in this latter case as an essential method for assessing the energy performance.

As regards the energy efficiency of cooking appliances, the ratio of the energy transferred to the food to the total energy supplied to the appliance seems, to be the most relevant one. Indeed, cooked food is the main output of such equipment. However, measuring or estimating the energy absorbed by the food is very difficult in real working conditions. The use of standard efficiencies of the cooking appliances appears to be necessary but cannot be used as such to assess the efficiency of the cooking process. The energy which is used by the cooking appliances when not cooking food absolutely needs to be taken into account. This energy lost when not cooking food does not directly depend on the heating technology of the appliances but on the way they are used and controlled. This introduces consequently the efficiency of the cooking organisation and behaviour into the energy performance assessment.

4.3 Energy performance assessment of Långbro Värdshus

4.3.1 Energy use at Långbro Värdshus

In this study, the energy use is considered as the total amount of energy which enters the building. Embedded energy is not taken into account. The only energy sources of Långbro Värdshus are electricity and district heating. The sum of the energy supplied by these two sources represents the total energy use of the facility. The aim of this part is to establish a break-down of this total energy use between the different processes.

The overall energy use of the facility was 565 426 kWh in 2009 and 593 678 kWh in 2010. These values correspond to the sum of the electricity and district heating bills all over the year.

The facility's appliances and equipment are grouped in seven categories which are (i) cooking, (ii) refrigeration, (iii) lighting, (iv) domestic hot water, (v) space heating, (vi) ventilation and (vii) others. The estimation of the annual energy use of each category enables the drawing of the break-down of the facility's energy use. Since the calculations are made for a typical year, the final result may not correspond exactly to the total energy use of the previous or the current year.

Depending on the type of appliance, different methods are implemented for estimating their energy uses. For some of them, their operation time is described with a weekly schedule presenting how long the appliance is used every day. Due to a change in the activity in summer time, two schedules are usually necessary to describe the annual activity. The facility has 5 weeks of summer activity and the remaining 47 weeks are considered as normal activity.

4.3.1.1 Cooking

The energy used for cooking corresponds to the sum of the energy uses of all the cooking appliances which are:

- two range tops
- three ovens
- two boiling tops
- one bratt pan
- one salamander

The energy use of the range tops and the ovens is calculated by means of an extrapolation of the monitoring results whereas the one of the three other appliances is estimated according to the rated power and the operation profiles of each of them.

During normal activity periods, the new range tops and new ovens use all five on average 6 279 kWh/month. During summer time, the total energy use of the old appliances is summarised in Table 4.4. The energy use of the new appliances is estimated, assuming that the savings are exactly the same as in normal activity.

Table 4.4: Total energy use of the monitored old cooking appliances during summer time and estimated energy use of the new appliances

	old app. (kWh)	savings	new app. (kWh)
Range top 1/ECOTOP	0	-31 %	0
Range top 2/Induction	25,0	-59 %	10,0
Small oven	40,5	0 %	40,5
Medium oven	45,2	+25 %	56,5
Large oven	329,0	-12 %	289,5
TOTAL	439,7		396,5

The boiling tops, the bratt pan and the salamander are used on average at a constant power level, as shown in Table 4.5. Since the boiling tops are used for long lasting cooking, an average daily operation time has been estimated (see Table 4.6). For the bratt pan and the salamander, the daily operation schedules are used (see Table 4.7 and Table 4.8). Operation schedules have been estimated according to on-site observations and discussions with the personnel.

Table 4.5: Average power levels for the other cooking appliances

	Rated power (kW)	Average power level (% of the rated power)
Boiling tops	2 x 2	100 %
Bratt pan	19	60 %
Salamander	4.5	100 %

Table 4.6: Daily operation of the boiling tops during normal and summer periods

	Normal activity	Summer activity
Average per day	12 hours/day	8 hours/day

Table 4.7: Daily operation of the bratt pan during normal and summer periods

	Normal activity	Summer activity
Monday	7:00 - 14:00	9:00 - 14:00
Tuesday	7:00 - 22:00	9:00 - 22:00
Wednesday	7:00 - 22:00	9:00 - 22:00
Thursday	7:00 - 22:00	9:00 - 22:00
Friday	7:00 - 22:00	9:00 - 22:00
Saturday	9:00 - 22:00	9:00 - 22:00
Sunday	9:00 - 22:00	9:00 - 22:00

Table 4.8: Daily operation of the salamander during normal and summer periods

	Normal activity	Summer activity
Monday	11:00 - 14:00	11:00 - 22:00
Tuesday	11:00 - 14:00 ; 17:00 - 22:00	11:00 - 22:00
Wednesday	11:00 - 14:00 ; 17:00 - 22:00	11:00 - 22:00
Thursday	11:00 - 14:00 ; 17:00 - 22:00	11:00 - 22:00
Friday	11:00 - 14:00 ; 17:00 - 22:00	11:00 - 22:00
Saturday	12:00 - 22:00	11:00 - 22:00
Sunday	12:00 - 22:00	11:00 - 22:00

Summing up the annual energy uses of the cooking appliances gives the amount of energy used per year at Långbro Värdshus for cooking purposes (see Table 4.9). It appears that the three ovens and two range tops account for 45 % of the cooking energy use but the bratt pan itself represents more than a third of the cooking energy use.

Table 4.9: Annual energy use of the cooking appliances

Cooking appliance	Energy use (kWh/year)
Range tops	36 024
Ovens	33 442
Bratt pan	54 560
Boiling tops	16 912
Salamander	13 365
TOTAL	154 303

4.3.1.2 Refrigeration

At Långbro Värdshus, the refrigeration equipment consists in refrigerators, freezers, cold rooms, blast chillers and ice machines. Depending on the type of appliance and the available data, different methods are used for estimating their annual energy use. Apart from the blast chillers, no profile is used for the refrigeration equipment since it is working continuously all over the year.

For the reach-in refrigerators and the freezers, their energy use is based on their rated power, modulated by a usage factor which corresponds to the fraction of the time the compressor is actually working. This usage factor is assumed to be 0.25 for the refrigerators and 0.4 for the freezers (ASHRAE 2009). The energy use of each refrigerator and freezer is presented in Table 4.10.

Table 4.10: Annual energy use of the refrigerators and freezers

Type	Rated power (kW)	Usage factor	Quantity	Energy use (kWh/year)
Under-counter refrigerator	0,34	0,25	4	2 979
Upright refrigerator	0,38	0,25	2	1 664
Upright refrigerator	0,17	0,25	1	372
Upright refrigerator	0,33	0,25	1	723
Upright freezer	0,64	0,4	1	2 243
Upright freezer	0,13	0,4	1	456

Other refrigerators have a glazed door and are used for storing fresh drinks. Their energy use is calculated according to the values given by the manufacturer (Norcool 2010a) (Norcool 2010b). Three other glazed-door refrigerators from another brand are assumed to have the same energy consumption than the first ones (see Table 4.11).

Table 4.11: Annual energy use of the glazed refrigerators used for drinks

Type	Average daily energy use (kWh/day)	Quantity	Energy use (kWh/year)
Large glazed refrigerator (Norcool)	0.76	1	277
Small glazed refrigerator (Norcool)	0.384	3	420
Small glazed refrigerator (other brand)	0.384	3	420

In the basement is also a chest freezer whose energy use can be calculated according to Equations 4.7 and 4.8 (Hakim and Turiel 1996). The freezer has an average volume of 300 L and therefore an energy use of 325 kWh/year.

$$E_{chest\ freezer} = 0.35 \cdot AV + 143.7 \qquad 4.7$$

$$AV = 1.73 \cdot V \qquad 4.8$$

Where:
$E_{chest\ freezer}$: Annual energy use of the chest freezer (kWh/year)
AV: Adjusted volume of the freezer (L)
V: Actual volume of the freezer (L)

On top of these appliances, the facility is equipped with built-in cold rooms. For these rooms, the method suggested by Björklund and Marin (2008) and presented in chapter 3.4.2.2 is used and the results are presented in Table 4.12.

Table 4.12: Annual energy use of the walk-in cold rooms

Type	Surface area (m^2)	Quantity[a]	Energy use (kWh/year)
Refrigerated room	6.5	4	48 706
Freeze room	6.5	1	15 593
Freeze room	4.0	1	12 965

a: Each cold room has in one single door

The blast chillers use energy according to the amount and type of food they cool down, the initial and final temperatures as well as the average coefficient of performance (COP) of the appliance during the chilling process. In this study the calculation has been simplified. During the normal activity, an average amount of 500 kg of food is chilled every week by the two blast chillers to a temperature of 3°C. The majority of this food is meat, but also fish, sauces and sometimes vegetables. In order to account for all these types of food, an average specific heat of food above freezing point of 3.4 kJ/(kg·K) has been selected according to the data published by ASHRAE (2010). The initial temperature is 150°C. Regarding the COP, very little information can be found in the literature. In the present case the COP has been assumed to be the ratio between the refrigeration power and the installed electric power. Långbro Värdshus' blast chillers have consequently an estimated COP of 1.9. Annual energy use of the blast chillers is calculated according to Equation 4.9. Since they are not used during summer activity, only 47 weeks of normal activity are considered. This results in an energy use of 1 717 kWh/year.

$$E_{blast\ chillers} = \frac{m_{food} \cdot c_{food} \cdot \Delta T}{COP} \cdot N_{weeks} \tag{4.9}$$

Where:
$E_{blast\ chillers}$: Annual energy use of the blast chillers (kWh/year)
m_{food}: Average mass of food cooled down per week (kg/week)
c_{food}: Average specific heat of food above freezing point (kJ/(kg·K))
ΔT : Temperature difference between hot and chilled food (K)
COP: Average coefficient of performance (-)
N_{weeks} : Number of weeks per year the blast chillers are used (weeks/year)

The two ice machines used at Långbro Värdshus have a capacity of about 130 kg/day. According to the values gathered from different manufacturers, the machines are assumed to use 0.15 kWh per kg of ice cubes. Estimating the average daily ice production all over the year at 70 kg of ice per machine, the total energy use for ice making is 7 665 kWh/year.

Summing up the annual energy uses of the refrigeration appliances gives the amount of energy used per year at Långbro Värdshus for refrigeration purposes (see Table 4.13). Cold rooms are obviously responsible for the major part of the refrigeration energy use – almost 80 %. The ice machines are also considerable energy intensive appliances.

Table 4.13: Annual energy use of the refrigeration appliances

Type of appliance	Energy use (kWh/year)
Refrigerators and freezers	9 880
Cold rooms	77 263
Ice machines	7 665
Blast chillers	1 717
TOTAL	96 525

4.3.1.3 Lighting

The lighting system consists in four sub-systems which are:

- The kitchen and the basement with 62 fluorescent tubes of 40 Watt each
- The plate garnishing zone with 2 incandescent bulbs of 250 Watt each
- The dining room with a lighting density assumed to be 23 W/m² (ASHRAE 2009)
- The conference room with the same type of lighting as the dining room

Each sub-system has its own operation schedule (see Table 4.14 to 4.16). The lights of the kitchen and the basement work as long as there is someone working in the facility whereas the ones of the dining rooms are switched on when the personnel in charge of the service arrives. The incandescent bulbs used for the plate garnishing zone are theoretically on only during lunch and dinner time. It is however very common that they remain on during the whole afternoon. For the calculations, the two bulbs are assumed to be on from the beginning of the lunch to the end of the dinner (except on Mondays). The lighting of the dining rooms is switched on earlier on week-end due to weekly cleaning of the rooms. As regards the conference room, it is assumed to be used on average one day out of three. In order to make the calculations simpler, its lighting energy use corresponds to one third of the dining rooms' lighting energy use. During summer activity, only the lights of the kitchen and the basement are used since service is located outside.

Table 4.14: Daily operation of the kitchen and basement's lighting system during normal and summer periods

	Normal activity	Summer activity
Monday	6:00 - 17:00	9:00 - 17:00
Tuesday	6:00 - 23:00	9:00 - 23:00
Wednesday	6:00 - 23:00	9:00 - 23:00
Thursday	6:00 - 23:00	9:00 - 23:00
Friday	6:00 - 24:00	9:00 - 24:00
Saturday	7:00 - 24:00	9:00 - 24:00
Sunday	7:00 - 23:00	9:00 - 23:00

Table 4.15: Daily operation of the plate garnishing zone's lighting system during normal periods

	Normal activity
Monday	11:00 - 17:00
Tuesday	11:00 - 23:00
Wednesday	11:00 - 23:00
Thursday	11:00 - 23:00
Friday	11:00 - 24:00
Saturday	11:00 - 24:00
Sunday	11:00 - 23:00

Table 4.16: Daily operation of the dining rooms' lighting system during normal periods

	Normal activity
Monday	9:00 - 17:00
Tuesday	9:00 - 23:00
Wednesday	9:00 - 23:00
Thursday	9:00 - 23:00
Friday	9:00 - 24:00
Saturday	6:00 - 24:00
Sunday	6:00 - 23:00

Summing up the annual energy uses of the lighting systems gives the amount of energy used per year at Långbro Värdshus for lighting purposes (see Table 4.17). Although the kitchen an basement areas have longer lighting operation, the dining rooms' lighting systems use twice as much energy and represents more than the half of the total lighting energy use. This is mainly due to a larger area of the dining rooms and a lower efficiency of the spots of the dining rooms compared to the fluorescent tubes (United States Environmental Protection Agency 2009).

Table 4.17: Annual energy use of the lighting systems

Lighting sub-system	Energy use (kWh/year)
Kitchen and basement's tubes	14 337
Plate garnishing zone's bulbs	1 880
Dining room's spots	27 025
Conference room's spots	9 008
TOTAL	52 250

4.3.1.4 Domestic hot water

The domestic hot water of the facility is provided by a district heating system and is used for dishwashing, for the showers and for the sinks of the kitchen and the bathrooms. The energy used for producing domestic hot water is consequently part of the district heating bill which also includes the energy used for space heating. Since there is no space heating in July and August, it has been possible to estimate the average energy use for domestic hot water from the invoices of these two months in 2009 and 2010. Taking into account the summer activity periods for these two years, it appears that the energy used for domestic hot water represents on average 223 kWh/week during normal periods and 110 kWh/week during summer periods. To this value should be added the energy used by the rinse boosters of the dishwashers. These electrical heaters are intended to heat up the rinsing water from the water supply temperature (assumed to be 55°C) to 83°C. According to the manufacturer's data, one cycle uses 3 litres of rinsing water. According to the operator of the dishwashers at Långbro Värdshus, 380 cycles are performed per day on average during normal periods and 190 during summer periods.

The extrapolation of these values all over the year gives a total energy use for domestic hot water of 89 871 kWh/year. 77 556 kWh are delivered by the district heating system and 12 316 kWh by the electrical heater.

4.3.1.5 Space heating

Space heating is performed only with hot water circulating in radiators and floor heating systems. The total energy use for space heating is consequently a part of the district heating bill. Since the energy used for domestic hot water is already known, the rest of the energy use reported on the invoices corresponds to the space heating energy use.

In 2009, 142 473 kWh has been used for space heating and 151 001 kWh in 2010. Since the climate correction factor is not freely available, the annual energy use for space heating is estimated, in this analyse, at the average value of years 2009 and 2010, i.e. 146 737 kWh/year.

4.3.1.6 Ventilation

Due to lack of information and data related to the ventilation system at Långbro Värdshus, assumptions had to be made according to personal observations. The system consists in:

- an air exhaust and supply system with heat recovery in the dining rooms. The exhaust is also collecting air from the kitchen
- an air exhaust system for the hoods in the kitchen
- an air supply system in the kitchen
- air inlets and outlets on the external walls of the kitchen for natural ventilation

The air flow rates for the three systems requiring mechanical ventilation are presented in Table 4.18. The balance of the air flows is assumed to be achieved thanks to the natural ventilation inlets and outlets of the kitchen.

Table 4.18: Air flow rates of the building

Air system	Air flow (m^3/s)	Remarks
Dining rooms exhaust and supply	1.05 [a]	Air flow corresponding to the supply. The exhaust air flow is assumed to be the same.
Hoods exhaust	0.8	Rated value of the system. The fan is switched off during the nights (see Table 4.19).
Kitchen supply	0.56	Actual air flow.

(a) Assuming a required air flow rate of 7 L/(person·s) according to the current Swedish legislation in 2005 (Boverket 2002) and a capacity of 150 persons.

As mentioned in Table 4.18, the hoods exhaust is switched on only during working hours. The schedule of the corresponding fan is detailed in Table 4.19. The other fans work all day long.

Table 4.19: Daily operation of the hoods exhaust fan

	Normal activity	Summer activity
Monday	6:00 - 17:00	9:00 - 17:00
Tuesday	6:00 - 23:00	9:00 - 23:00
Wednesday	6:00 - 23:00	9:00 - 23:00
Thursday	6:00 - 23:00	9:00 - 23:00
Friday	6:00 - 24:00	9:00 - 24:00
Saturday	7:00 - 24:00	9:00 - 24:00
Sunday	7:00 - 23:00	9:00 - 23:00

The energy use of the fans is calculated according to the maximum specific powers imposed by the Swedish legislation. Such values are available only since 2008 (Boverket 2008) but will be nevertheless assumed to be close the current ones in 2005.

The values that have been used in this study are reported in Table 4.20. Table 4.21 summarises the annual energy use for each of the mechanical air systems of the facility.

Table 4.20: Maximum specific power of fans in Swedish facilities
Source: (Boverket 2008)

Type of ventilation system	Max. spec. power (kW/(m^3/s))
Exhaust and supply with heat recovery	2
Exhaust and supply without heat recovery	1.5
Exhaust without heat recovery	0.6

Table 4.21: Annual energy use of the ventilation system

Air system	Flow rate (m^3/s)	Power (kW)	Energy use (kWh/year)
Dining rooms exhaust/supply	1.05	2.31	18 396
Hoods exhaust	0.8	0.48	2 775
Kitchen supply	0.65	0.52[(a)]	4 415
TOTAL			25 586

(a) The specific power for an air supply system is assumed to be the difference between an air exhaust and supply system without heat recovery and an air exhaust without heat recovery. This gives a value of 0.8 kW/(m^3/s).

4.3.1.7 Others

The other appliances of the facility which have a considerable impact on the annual energy use are:

- A hot cupboard for warm holding of the plates
- A washing-machine
- A tumble dryer
- 5 computers

The hot cupboard has a rated power of 2.4 kW and a usage factor of 0.04 (Pedersen, et al. 1998). It does not work during summer periods.

The washing-machine is used on average 8 times a day during normal periods and 4 times a day during summer periods and, according to the manufacturer it uses 1.19 kWh per normal washing. The tumble dryer is not used as often as the washing-machine. Its utilisation is estimated to be on average 5 drying cycle per day on normal periods and 2.5 on summer periods. According to the manufacturer the tumble dryer uses 3.34 kWh per normal drying cycle.

The five computers have an average power of 80W each (50 W for the computer itself and 30 W for the screen) (ASHRAE 2009). Since some are used only part time during the week, an average value of 3.4 hours of operation per computer and per day has been estimated, and they are not used during week-ends and summer periods.

All these other appliances represent on total, an energy use of 9 770 kWh/year and individual energy using is presented in Table 4.22.

Table 4.22: Annual energy use of the other appliances

Type of appliance	Energy use (kWh/year)
Hot cupboard	758
Washing-machine	3 156
Tumble dryer	5 536
Computers	320
TOTAL	9 770

4.3.1.8 Total energy use

All the different energy usages presented previously represent the total energy use of the facility. Knowing the individual energy use of each of them enables determining their share of the total energy use (see Table 4.23) and to draw the energy use break-down of the facility (see Figure 4.8). The annual energy use is estimated at 575 042 kWh. For comparison, the facility used 565 426 kWh in 2009 and 593 678 kWh in 2010 according to the energy bills.

Table 4.23: Annual energy use of the energy uses

Energy uses	Energy use (kWh/year)	Total share
Cooking	154 303	26.8 %
Refrigeration	96 525	16.8 %
Lighting	52 250	9.1 %
Domestic hot water	89 871	15.6 %
Space heating	146 737	25.5 %
Ventilation	25 586	4.5 %
Others	9 770	1.7 %
TOTAL	575 042	100.0 %

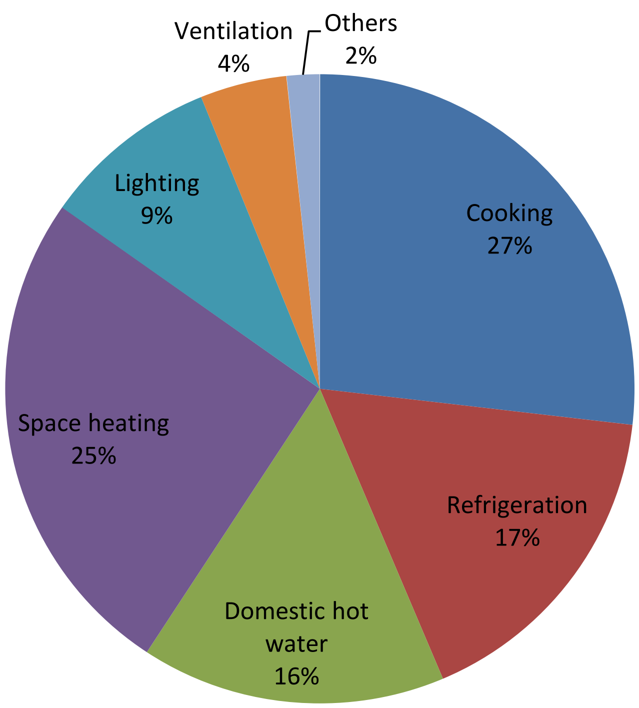

Figure 4.8: Energy end-use break-down of Långbro Värdshus

At Långbro Värdshus, cooking and space heating are the two major energy end-uses and account for more than the half of the total energy use. End-uses directly related to the food-service activity, i.e. cooking, refrigeration and domestic hot water, represent around 60 % of the total energy use. HVAC systems use about 29 % of the total energy use. These results can be easily compared with those from the U.S.A presented in Figure 2.3. The present case has an end-use energy break-down very similar to the one established by the U.S. Energy Information Administration in 2003 (2003a). As regards the Californian study (California Energy Commission 2006), the shares are very different since cooking represents 54 % of the total energy use and HVAC 10 %. The singularities of Långbro Värdshus are its rather high share for space heating and a considerable energy use for refrigeration.

4.3.2 Energy performance

Långbro Värdshus is not reporting anymore the number of guests since 2008. The estimated amount of guests per year for this study is based on the 2008 values, corrected according to the activity growth of the facility. In 2008, around 94 870 persons ate at Långbro Värdshus. This value would be comprised between 95 000 and 100 000 guests now. In the following calculations, each guest counts for one meal. Although the restaurant has a bar activity, this assumption is relevant since the large majority of the guests come to the facility for eating.

According to these assumptions and the total annual energy use calculated in Chapter 4.3.1, the energy efficiency of the facility is around 5.75 to 6.05 kWh/meal. These values can be compared to results of different studies reported by Aebisher et al. (2003) and presented in Chapter 2.6.2.1 of this thesis. In Switzerland, high standard restaurants have an average energy use of 4.9 kWh/meal and half of the Californian table restaurant use between 3.58 and 6.15 kWh/meal with a median value of 4.93 kWh/meal. In Japan this value reaches 5.66 kWh/meal for casual dining restaurants. Energy using per meal at Långbro Värdshus appears to be up to 23 % higher than in countries like Switzerland and California, but actually close to the Japanese value.

However, these surveys have been carried out in totally different climate zones of the world. This can induce deviations in the energy use per meal due to the share of HVAC energy use. Since Stockholm is located in a cold climate zone, space heating represents a significant share of the total energy use. This can cause lower energy efficiency despite cooking and refrigeration processes that may be very efficient. The survey from Japan states for instance that casual restaurants use 4.8 kWh/meal when excluding HVAC energy use. The value without HVAC for Långbro Värdshus is between 4.0 and 4.2 kWh/meal. This last comparison is interesting because Långbro Värdshus is then 15 % more efficient than Japanese casual dining restaurants. A similar study has been carried out in France in restaurants of hotels. When taking into account only the energy used for cooking, refrigeration and dishwashing, two stars hotels use on average 2.77 kWh/meal and three stars hotels 7.86 kWh/meal. At Långbro Värdshus, assimilating the domestic hot water use to the dishwashing use, this energy use is between 3.4 and 3.6 kWh/meal. These latter values account for the energy use which is directly related to the food-service activity and is therefore very relevant for comparisons.

Although the energy use per unit of surface area is not very relevant for food-service facilities, it is possible to calculate it. Including the basement, Långbro Värdshus has about 990 m^2 of heated floor area. This gives an energy use around 581 kWh/(m^2·year). In the USA the average energy use in food-service facilities is 814 kWh/(m^2·year) (U.S. Energy Information Administration 2003b), 1 095 kWh/(m^2·year) in California (California Energy Commission 2006) and 1 669 kWh/(m^2·year) in Japan (Aebisher, et al. 2003). According to a recent Swedish study (Energimyndiheten 2011) the average of Swedish restaurant is 596 kWh/(m^2·year), what places Långbro Värsdhus slightly below the national average.

5 Discussions and conclusions

According to the present energy assessment and the values given by different surveys, Långbro Värdshus appears to be a food-service facility having rather good energy efficiency. Compared to other facilities, e.g. in California, its needs for heating are high but compensated by the absence of air conditioning needs. As regards its energy use per meal, it is rather high but apparently due to space heating. The energy use per meal directly related to the cooking activity is indeed rather low. Although the results of this case study are coherent with other ones, the accuracy of some data about energy uses can be discussed. The energy use for the reach-in refrigerators and freezers, for instance, is based on average values for normal use of the appliances. In the present case some refrigerators are located in the cooking area and others in the basement where the temperature is rather high (around 25-26°C). This would be responsible for an underestimation of the refrigeration energy use. The ventilation energy use has also been assumed to be the maximum value allowed by the Swedish regulation. If the ventilation system installed in 2005 was more efficient than required, the present energy use for ventilation is consequently overestimated. These uncertainties impact nevertheless only the shares of the energy uses since the total energy use of Långbro Värdshus is given by the sum of the electricity and district heating bills.

Due to a lack of available data, the influence of the restaurant's activity has not been taken into account in this study. It is very likely that the energy uses for cooking, dishwashing and washing and drying of the clothes would be higher in December and June when the activity is higher. The activity may also have a significant impact on the energy use per meal. The energy use per meal given in this study is therefore only an average value calculated over the year.

To tackle this uncertainty of the estimations, monitoring appears to be an excellent solution. Monitoring should not only consist in measuring the actual energy use of the equipment but also the variation of other parameters such as the activity in the kitchen, the number of meals served, in incomes cash flows, etc. The cooking appliances of the case study are a very good example of this solution. First, it enabled an accurate estimation of the cooking appliances energy use, which would not have been the case without monitoring. Secondly, it brought a deep knowledge of the way the appliances work and how they are used. This secondary aspect of monitoring, though requiring longer analysis time, can be considered as an added value to the accuracy of the energy performance assessment. As illustrated in the in the case study, it enables a detailed tracking of the inefficient behaviours of cooking methods. Improvement of the energy efficiency can be subsequently easily implemented.

This technical consideration should however not hide a fundamental step of the energy performance analysis of a food-service facility which is the definition of the system. This step should define, as precisely as possible, the boundaries for two groups of elements: (i) the activities and (ii) the energy flows. Defining the activities lies in removing from the considered system activities which are not related to food service. When defining the boundaries for the energy flows, one possibility is to focus on the final use of energy, irrespective the energy source. This gives direct information about what is actually used and it is very relevant when analysing behaviour or working organisation. The other possibility is to consider only the energy which enters the facility as a commercial good. In this situation, energy produced on-site, e.g. solar water heater or heat recovery systems, is not taken into account in the total energy use. This would consequently results in higher energy efficiency.

This second solution is more relevant when analysing how efficient the facility is from an energy system point of view. This precise definition of the food-service facility as a system and the considered energy flows is usually not presented in association with benchmarks, what makes comparisons potentially inconsistent. When dealing with energy usage, existing benchmarks also lack transparency in the description of the energy sub-systems which are included or not in the calculation. It is indeed important for the consistency of comparisons to assess the same energy uses.

The break-down of the energy use, though not necessary for calculating the overall energy performance, is of interest for more in-depth analysis of the energy performance. It gives for example the possibility to restrict the energy use to the sub-processes which are directly related to the food-service activity. This is typically the case with the energy used for HVAC systems. Excluding this energy usage results in an energy performance which does not depend on the climate. Considering only cooking and refrigeration gives a precise value of how efficient the food preparation activity is.

All in all, assessing the energy performance of a food-service facility needs a methodology and a homogenisation of the methods employed. Preliminary investigations such as the system and energy use definitions are absolutely necessary for the relevance and the benchmarking of the results. The energy efficiency of a food-service facility cannot be summarised by a single absolute value but by a deeper analysis and comparisons with other similar facilities.

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Appendix 1 : Remarks and assumptions for Figure 4.6: Energy use of the cooking appliances during the monitoring period

- The old appliances are in use from the second week of June (*Jun 2*) to the first one of July (*Jul 1*) and the new ones from the third week of August (*Aug 3*).

- The terms "ECOTOP" and "Induction" are not suitable for the old appliances since the two old range tops were identical, but in order to simplify the presentation of this graph, "ECOTOP" and "Induction" are associated to the old range tops they respectively replaced.

- The fourth week of June presents much lower energy use due to Midsommar.

- The last three weeks of July and the first one of August (from *Jul 2* to *Aug 1* included) correspond to the summer activity and are therefore not part of the survey

- No data are available for the second week of August (technical reasons).

- Data collection for the new medium size oven only began the first week of October. Its energy use for the previous weeks is assumed to be the average one measured before the "eco-training" (weeks *Oct 1*, *Oct 2* and *Oct 3*).

- Data collection for the new large oven stopped the first week of October. Its energy use for the following three weeks (weeks *Oct 1* to *Oct 3*) is assumed to be the average one measured before (from week *Aug 3* to week *Sep 4*). After the eco-training (from week *Oct 4*) its energy use is the average one of the previous weeks but without the extra energy use which was due to the preset cleaning programmes (extra energy use assumed to be around 32 kWh/week).

- Weeks *Oct 2* and *Oct 3*, data are missing so the presented energy uses for each of these two weeks correspond to the average ones over the two weeks.

Appendix 2 : List of suggestions for the improvement of the energy efficiency of the cooking process at Långbro Värdshus

General remarks

Temperature control of the stoves: With ECOTOP, talking about the "power selected by the user" or saying "position 10 = full power" makes no sense since the position of the knob correspond to a temperature of the stove and not a heating power. Consequently "position 10 = maximum temperature" is more appropriate.

Heat which is produced but not used for cooking food is a loss. However, some are necessary losses: preheating of the stoves and ovens or stoves maintained warm during meal time.

Every single member of the personnel should know how to use the appliances efficiently: Since everybody in the kitchen has his/her own responsibilities, nobody modifies what another one did. It is not possible that someone moves a pot or changes the settings of someone else in order to save energy.

Stoves

Delay the starting time in the morning
Since the ECOTOP has a higher heating power than the previous hot plates, food can cook in a shorter time than previously which enables to delay the starting time. The energy savings could reach 1.2 to 1.5 kWh for each delay of 10 minutes.

Prioritise the use of the ECOTOP
Since the ECOTOP range is always warm, any empty space on it leads to heat losses and thus energy losses. Induction should be only used in the following cases: no place anymore on the ECOTOP, needs for fast heating (e.g. boiling water), preheating or reheating, and panic situation.

Avoid using the induction stoves to maintain something warm
The ECOTOP surface is always warm so it is perfectly appropriate for keeping food or kitchenware (e.g. steaking pan) warm.

Avoid position 10 of the knob
Contrary to the previous stoves, the ECOTOP one have a temperature control system, which means that the heating power is permanently adjusted to maintain the temperature asked by the user via the knob. As long as this temperature is not reached, the stove uses the maximum heating power. So if a plate temperature lower than 450°C is enough for cooking, a lower position of the knob should be selected.

Switch off a stove for keeping warm
Since the ECOTOP range consist in one single heating surface, a cooking zone (1/4 of the surface) which is switched off remains warm if the other ones are at a high temperature (heat transfer inside the board) and can be used for maintaining food warm.

Reduce the number of cooking zones working at full power during meal time

During meal time, three of the four stoves of the ECOTOP range are at maximum temperature for short and fast reheating of the pots content. Maybe the third one (back stove) can be used at a lower temperature (or switched off) and if there is a need for an extra stove the induction back stove can be used. If the third stove is switched off, the potential energy savings correspond to the energy used for maintaining the stove at the maximum temperature. For example, switching it off during two hours (from 11:00 to 13:00) saves around 3 kWh per lunch.

Use lids

Heat is kept within the pot and it prevents steam and odours to be released in the kitchen. Lids are not always used for different reasons: since one hand is required for lifting the lid, it is not convenient when ingredients need to be added frequently; Lids are located far from the stoves.

Ovens

Use the ovens at the maximum capacity

During meal times the two smaller ovens are used for specific needs (steam and meat cooking) and filled according to the demand. When the demand is low the ovens are almost empty so other trays can be added for cooking or preheating. This requires a good communication between the cooks.

Minimise door openings

Even if the fan stops when the door is opened, a lot of heat is lost, especially when cooking with steam (around ten times more than with a convection oven). Minimising door openings means reducing their number and duration. When unloading and loading the ovens, it is better to let a warm tray for longer time outside with an oven door closed rather than letting is out for a short time but with the door opened.

Keep the ovens closed

When an oven is not used, it is better to keep the door closed so that the heat remains inside. It has two advantages: it reduces the preheating time (and energy) and it keeps hot air in the oven instead of releasing it in the kitchen (better indoor climate).

Avoid the manual "fast cooling"

Since this operation is done automatically by the oven if it is needed, there is no need to do it manually. The energy lost during this process is equivalent to the energy required for preheating the oven at the same temperature.

Optimise the ovens schedule

When several cooking are planned for an oven begin by the one with a lower temperature and finish with the highest temperature. This avoids fast cooling of the oven between two programs.

Reduce the steam ratio

If cooking with 80 % steam gives the same result than with 100 % steam, this should be done since producing steam requires significant amounts of energy. A lower temperature can also reduce the produced amount of steam.