Minimising energy use for baking

In a nutshell

Summary				
Best practice is to minimise the energy consumption for baking by either operating existing ovens in the most energy-efficient way or by selecting the most efficient oven to cater for the specific baking needs based on: production requirements, energy sources, space constraints, temperature requirements, operation mode and heat transfer mode.				
Target activities				
All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine
Applicability				
This best practice is applicable to all manufacturers of bread, biscuits and cakes.				
Environmental performance indicators				
• Energy use in the baking process, i.e. kWh per: • t of baked product, or • t of input flour used, or • m2 of baking area (oven surface)				
Benchmarks of excellence				
N/A				

Description

The energy use is the main environmental issue in the baking industry as the transition from dough to baked product requires large amounts of energy. The energy demand for baking can range from 3.7 MJ/kg to 7 MJ/kg (Purlis, 2012), accounting for 26 % to 78% of the total energy consumption of a bakery (Stanley et al., 2008; Khatir et al., 2013; Therkelsen et al., 2014).

This best practice deals with minimising the energy consumption for baking by either operating existing ovens in the most energy-efficient way or by selecting the most efficient oven to cater for the specific baking needs.

The ovens used for baking bread, biscuits and cakes mainly consist of four elements (all of which have an influence on the energy efficiency of the oven):

- Heat generation system: where fuel (or electricity) is converted into heat.
- Baking chamber: where the physicochemical changes to the dough are produced.
- Chimney: which allows gases to be vented out (i.e. flue-gas from the heat generation system and gases released by the dough during baking).
- Insulating frame: which limits the heat losses from the baking chamber and prevents damage to the oven.

A wide variety of ovens are used. They are characterised by:

- The heat generation system: ovens can be powered by fuels (i.e. natural gas, propane, liquefied petroleum gases, biomass) or electricity (Stanley et at., 2006). The most common heat generation systems are burners. The use of burners involves a combustion process where fuel is burned (mixed with air and the heat transferred to the baking chamber) (Gas Natural Fenosa, 2014). In artisan bakeries and small outlets, the ovens are usually powered by electricity instead (Garcia, 2014).
- The way in which heat is transferred and distributed: the ovens can use convection, radiation or conduction (Manhiça et al., 2012; Sakin et al., 2009).
- The operation mode: the ovens can operate by batch or in continuous mode.
- The charging system: see Table 1.

Table 1: The most representative ovens and characteristics according to their charging systems.

CHARGING SYSTEM	*ADVANTAGES*	*DISADVANTAGES*	*SUITABLE FOR*
Rack ovens (rotative)	• Versatile. • The air flow is sufficiently uniform. • Rotating carriage. • Large amount of steam production. • High degree of flexibility.	• High space requirements.	• Bakeries with production capacity below 5.000 - 6.000 kg product per day. • Ovens used for baking at the point of sale: small ovens with low capacity (discontinuous – batch systems)

Multi-deck ovens	• Lower space requirements.	• The height or thickness of the baked products is limited.	
Tunnels	• Good performance. • Process automation. • Can be combined with other food processing equipment to form a production line.	• Only suitable for large production of same-size pieces. • High investment and operating costs.	• Production higher than 6.000 kg product per day. • Industrial bakeries / installations (continuous systems).

Source: IDAE, 1998; Alvarez de Diego and H_2O renovables, 2013

Besides the different oven designs and features, the main parameters that determine an oven's energy consumption are listed in Table 1.

Table 1: Parameters that determine an oven's energy consumption.

PARAMETER	*DESCRIPTION*
FUEL	• Fuel type • Thermophysical properties and composition • Input temperature
FLUE GASES	• Output temperature • Measurements of oxygen (O_2) and carbon monoxide (CO) content. • Combustion efficiency
PRODUCT FOR BAKING	• Product type: products have different process energy requirements • Heat capacity • Input temperature • Input humidity • Output temperature

PARAMETER	*DESCRIPTION*
EXTERIOR OVEN FEATURES	• Height, length, diameter, width • Emissivity of the oven surface • Oven surface temperature • Ambient temperature surrounding the oven • Oven placement

Source: Energpyme, 2013; Pino, 2004.

An important key parameter of the baking process influences many of the parameters listed in Table 1: the baking temperature. Indeed, the heat losses from the oven are a main source of energy inefficiency and depend, among other factors, on: the temperature of the external surface of the oven, the temperature of the ambient air surrounding the oven, the air flow near the oven surface (Khatir et al., 2013; Le-bail et al., 2010; Ploteau et al., 2012; Therkelsen et al., 2014).

The baking temperature depends not only on the product to be produced, but also on the scale of production. Indeed, products are often baked at temperatures between 230°C and 270°C for around 25 minutes where baking is carried out at the point of sale; whereas, at industrial scale baking temperatures are lower and residence times are higher (around 60 minutes) (Paton et al., 2013; Williamson and Wilson, 2008; Walker, 2005; Ploteau et al., 2012).

The first step for minimising the energy consumption for baking is to ensure that existing ovens are operated in the most energy efficient way. In the following table, the most important measures for improving the energy efficiency without oven substitution are reported.

Table 2: Main measures for improving the energy efficiency of existing ovens.

MEASURE	*DESCRIPTION*
Switch off the oven if the time between consecutive baking batches is long	Ovens with good insulation retain much of the heat produced during the last baking; 10 minutes is enough to reach optimum cooking temperature again.
Reduce operations between consecutive baking batches	Reduction of preheating periods and times for which the oven remains empty.
Regular cleaning of furnaces	This improves heat transfer and energy efficiency.
Optimisation of the use of the oven	A reduction of the daily baking times can be achieved by optimising the baking (e.g. oven at full load, bake all the batches consecutively).
Increase inspections and preventive maintenance of furnaces	Inspection allows the oven to be checked to ensure it works at the best efficiency and potential.
Burner maintenance	The system must operate with very low excess air, optimum combustion and low cold air infiltration.

MEASURE	*DESCRIPTION*
Oven insulation improvement	Oven performance can be improved by using more or better insulating material (low thermal conductivity), with a low coefficient of expansion at different temperatures, resistance to water absorption and combustion. Oven insulation can be improved in existing ovens.
Heat recovery from the oven's output products	Recovered waste heat can be used in different ways, including recirculating directly in the oven or in other bakery processes (e.g. proofing stage).
Repairing air leaks	Air leaks can be a major source of heat losses to the environment surrounding the oven. Moreover they can cause temperature imbalances, which decrease the quality of the final product.
Use of renewable energy	Changing only the fuel (e.g. biomass) can lead to a reduction in C0? emissions, but burners and the fuel feed system would often need to be changed too.

Source: Enerpyme, 2014; Therkelsen et al., 2014; Pino, 2004

When a company decides to replace its oven or install a new one, it is important to consider a number of key factors to ensure that the most suitable and energy efficient system is selected: production requirements, energy sources, space constraints, temperature requirements, operation mode, and heat transfer mode (See Table 3).

Table 3: Main factors that should be taken into account for selecting a new system.

FACTOR	*DESCRIPTION*	*MAIN POSSIBILITIES*	*ADDITIONAL INFORMATION*
Energy source	The heat generation system of an oven can be powered by electricity and/or fuels.	Electricity	Electric ovens allow an accurate temperature control and they can work in a wide range of temperatures. The associated environmental impact depends on the energy source used to generate the electricity.
		Fuel	Burning fuels requires a chimney or a vent to remove the exhaust gases. The main fuels used are: • Biomass (from an environmental point of view, combustion of renewable biomass is considered neutral in terms of CO_2 emissions). • Natural gas. • Liquefied petroleum gases. • Propane. • Diesel.

FACTOR	*DESCRIPTION*	*MAIN POSSIBILITIES*	*ADDITIONAL INFORMATION*
Operation mode	Ovens can operate in batch or continuous mode	Batch ovens	Recommended for small loads, for applications where production volumes change substantially, or when a high degree of flexibility is required. In small bakeries, batch ovens are the most commonly used. The main types of batch oven are: bench-top ovens, cabinet ovens and walk-in and truck-in ovens.
		Continuous ovens	Where a large quantity of similar products are processed. Continuous ovens usually have greater efficiency than batch ovens and, from the energy point of view, they are usually more efficient. The most commonly used continuous ovens in bakeries are tunnel ovens.
Chamber sizing	Chamber size depends on the number of pieces per batch and on the number of batches required to meet production requirements. If the interior space is too small, the performance of the baking is low while if it is too large, space, time and energy are wasted.	Benchtop/ countertop ovens	These ovens are used for small batch loads or when there are space constraints that do not allow bigger ovens. Sizes range from 28 L to 764 L.
		Cabinet ovens	These ovens are floor-mounted and are designed for easy loading and unloading. They are very efficient. Sizes ranges from 113 L to 2718 L.
		Walk-in and truck-in ovens	These ovens are suitable for large batches. They allow product loading either by forklift or manually.
Temperature requirements	Temperature is one of the most important parameters in the baking stage. The following pfactors should be taken into account:: • Minimum/maximum temperature. • Heat-up/cool-down requirements. • Temperature uniformity requirements.		Bakery products are usually baked between 230 °C and 270°C.

FACTOR	DESCRIPTION	MAIN POSSIBILITIES	ADDITIONAL INFORMATION
Airflow type	The most common way in which heat is transferred and distributed in the baking chamber is by convection. This is because bread loaves and individual cakes often have better results when baked in convection ovens. Convection can be: • natural • forced: ▪ by circulation ▪ by recirculation	Natural convection	This is the easiest and less expensive way: heated air rises and once it is cooled by transferring heat to the product, it returns to the heat source. It is mainly applied when chamber temperature uniformity is not essential.
		Forced circulation	This system incorporates a fan to create an airflow that improves the temperature uniformity of the chamber and speeds up the heat transfer. It requires proper spacing of parts to ensure optimal airflow between them.
		Recirculation	It is recommended for applications involving tray-loaded products that require precise temperature uniformity. The fan produces recirculation between the heat generation system and the baking chamber leading to a fast and uniform heat transfer, even when the product is densely loaded.
Design and quality	A good oven design and a selection of high quality materials allow: • Better temperature uniformity in the chamber. • Reduction of heat losses. • Simplification of maintenance operations.		
Charging system	The charging system conditions the production capacity of the system.	Rack ovens (rotative)	Rack ovens operate in batch mode. Production capacity below 5000 - 6000 kg of product per day. Oven with high space requirements.
		Multi-deck ovens	Multi-deck ovens operate in batch mode. Production capacity below 5.000 - 6.000 kg of product per day. These ovens have lower space requirements than rack ovens.
		Tunnels	These ovens operate in continuous mode. Production capacity higher than 6.000 kg of product per day.

Source: Adapted from Despatch Industries, 2013; FSW, 2014.

Environmental benefits

The main environmental benefits are a reduction in energy consumption and the related reduction in CO_2 and other air emissions (e.g. particles).

Energy savings can vary depending on the type and number of measures implemented. For the measures to improve the efficiency of existing ovens, Table 4 provides an indication of the energy savings that can be achieved.

Table 4:-Energy savings achieved by implementing the proposed measures in existing ovens.

MEASURE	*SAVINGS IN TOTAL ENERGY CONSUMPTION OF THE FACILITY (%) (*)*
Switch off the oven if the time between consecutive baking batches is long	7.5
Reduce operations between consecutive baking batches	Up to 8.5
Regular cleaning of furnaces	Up to 3.5
Optimisation of the use of the oven	Up to 11
Increase inspections and preventive maintenance of furnaces	Up to 4
Burner maintenance	Up to 2.7
Oven insulation improvement	Up to 7
Heat recovery from the oven's output products	N/A
Pipes thermal insulation	Up to 7
Repairing air leaks	N/A
Use of renewable energy	Between 25 and 75**

Source: Enerpyme, 2014; Therkelsen et al., 2014; Pino, 2004

N/A: Data not available

* Data calculated on the basis of a rotary oven with four batches/day

**Stanley et al., 2008; Khatir et al., 2013; Therkelsen et al., 2014

Side effects

There are no environmental cross-media effects associated to the implementation of these measures.

Applicability

This best practice is applicable to all manufacturers of bread, biscuits and cakes.

Economics

Implementation costs may vary depending on the nature and number of measures implemented. Substitution of ovens is generally more expensive than measures to improve the energy efficiency, but high energy savings can also lead to short pay back periods for oven replacements.

In Table 5, the investment costs linked to the improvement of the energy efficiency of existing systems are classified as follows:

- Zero costs (Zero)
- Low investment costs (Low)
- Relatively high cost (High)

Table 5: Investment costs of the proposed measures.

MEASURE	INVESTMENT REQUIRED	PAYBACK PERIOD
Switch off the oven if the time between consecutive baking batches is long	Zero	Immediate
Reduce operations between consecutive baking batches	Zero	Immediate
Regular cleaning of furnaces	Zero	Immediate
Optimisation of the use of the oven	Zero	Immediate
Increase inspections and preventive maintenance of furnaces	Low	5 - 8 months
Burner maintenance	Periodic control system: EUR 2200 (approx.)	0,3 - 1 year
Oven insulation improvement	Low	Less than a year
Heat recovery from the oven's output products	High	2 - 4 years
Repairing air leaks	Low	Less than a year

Source: Enerpyme, 2014; Therkelsen et al., 2014.

Driving forces for implementation

Improved energy efficiency leads to cost reductions, increased competitiveness of the company and in improved market image.

Reference organisations

The bakery Hornipan Rangel, S.L. (Alvarez de Diego and H_2O renovables, 2013) has successfully implemented renewable energy sources (biomass) in their baking process.

There are several examples of bakeries that have successfully implemented heat recovery systems, using the recovered waste heat in their proofing chambers (Therkelsen et al., 2014).

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