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Lot 22
Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers

Task 4: Technical analysis of existing products

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4. TASK 4 – TECHNICAL ANALYSIS OF EXISTING PRODUCTS

This document is the task 4 report of the DG TREN lot 22 ecodesign preparatory study on domestic and commercial ovens. Task 4 comprises a general technical analysis of the existing products on the EU-market. For each category of product defined in task 1, an item representing the average current product on the European market will be analysed (as identified in task 2). This analysis will serve as input for defining base cases (in task 5).

4.1. GENERAL TECHNICAL DESCRIPTION

An oven is an enclosed heating chamber for cooking food. The construction of most modern mass-produced domestic ovens is relatively simple. They are generally constructed from pressed steel to form a cavity that is wrapped in thermal insulation with a hinged and usually glazed door at the front[1] (for easy access to insert and remove food), and a vent or flue. To maintain external surface temperatures as low as possible the door is usually double glazed with an infrared reflective coating applied to the inner pane. Some commercial ovens have conveyers and pass the food on a conveyor belt through a heated chamber. Commercial ovens are usually made in batches and in much smaller numbers than domestic ovens. They are used for many more hours per day and have long service lives, however, and so the designs need to be robust and ensure that the ovens are reliable over many years of use. As described in task 3, most domestic ovens in the EU are electric and the choice of piped natural gas is limited by its availability which varies considerably within the EU although LPG (liquid petroleum gas) is available throughout the EU but is more expensive and less convenient as high pressure liquefied gas cylinders need to be transported. In the past, the majority of commercial ovens have been gas (in areas where piped gas is available) but commercial electric ovens are increasingly popular due to additional the cost of installing a gas supply. Steam ovens provide many benefits in commercial kitchens and so are also increasingly used.

There are three main methods of heating: gas, electric resistance or microwave[2]. In operation the oven temperature is regulated by thermostatic control of the gas burner or electricity supply or in the case of a microwave oven control of the magnetron. In an electric oven, heating elements are located in the base of the oven cavity - some also

[1] Bosch-Siemens market a domestic oven which can be attached to a wall or kitchen unit with the base of the oven lowering for food to be inserted or removed from the bottom (Liftmatic oven 2007).
[2] Specialist range style ovens, such as those marketed by the Aga Food Service Group (including Aga and Rangemaster) can operate on oil or solid fuels, although the number of units sold is low and therefore will not be considered as representative of the current EU market.

with an upper element that is exposed to also act as a grill. A further heating element can be located around a fan mounted on the back wall of the oven in a forced air convection electric oven. In a domestic gas oven the burner is typically located at the rear of the lower face.

There is also a different type of domestic "heat storage" range cookers which include ovens produced by Aga. Aga also own Falcon that produce commercial range ovens but these are a standard range oven design[3]. These ovens are designed to provide a constant temperature and are left on semi-continuously. Electric, gas, oil, coal and wood are used as fuels where some of the non-electric types are also the main house heating appliance. The electric versions are primarily range ovens with room heating as a secondary function. These are sold in relatively small numbers and so have not been considered in detail in this study. There are significant design differences to standard ovens:

- Oven cavities are made of well insulated heavy gauge cast iron to ensure that oven temperature is very uniform and does not vary. This is claimed to give superior cooking performance. This steel will however have a relatively high thermal mass so if it were possible to test the ovens using the wet brick test, they would perform very poorly. The number of oven cavities vary, Aga's typically have three each being at different fixed temperatures.
- The electric versions have very low peak load, typically 2.5 - 3kW per appliance and one brand has an average of only 500W. This is lower than standard electric ovens (typically 3 – 4 kW load for standard size built in oven) which is an advantage in remote locations where electricity is generated locally which may be photovoltaic panels on the house roof or from hydro or wind. In many EU States, maximum peak load is severely limited so that gas ovens have to be used but electric ovens with low peak load are an alternative option. There are two versions of oven, one uses a constant low current which is ideal for supply by photovoltaics and the other heats up at night when el;ectricity demand is low and stores this heat during the day.
- The manufacturers of this type of oven point out that this type of appliance can be used for other heating processes such as boiling water instead of using a kettle and also for drying clothes. Although this reduces the number of appliances needed in a domestic kitchen, this is not free energy and so overall consumption may not be reduced and total system energy is dependent on the relative efficiency of the oven and other appliances (such as a kettle which tend to be relatively energy-efficient).
- Heat storage ovens usually also have two fixed temperature hotplates and so a separate hob is not needed.

[3] For example http://www.falconappliances.co.uk/media/43943/1300%20spec%20sheet.pdf which has A and B energy labelled ovens

From electric and gas heating ovens, a large proportion of the energy input to an oven is lost through the walls, door, vent or flue. Less than 20% is transferred to the food being heated in gas and electric thermal ovens (typically 10%). The figure for microwave ovens is however much higher although depends on the type and size of food being cooked. According to measurements reported by CECED, as much as 55 - 60% may be transferred to "food" based on measurements using the IEC 60705 method, although 40 - 50% is a fairly typical figure for MWO using the new CENELEC measurement method that is being developed and is believed to be more representative of heating normal food. The percentage figure achieved depends not only on the quantity and type of food, but also the oven / food temperature and oven design.

Ovens are products at a stage of maturity with little change in the basic functionality of the product i.e. an enclosed chamber for cooking food. From a customer perspective, the basic requirements of the product have been met. Modern ovens cook properly, with low temperature on touchable parts (knobs, handle, etc.) and no side effects such as steam condensation on the door and control panel. Therefore, current developments in oven technology are driven by the market with minor changes in functionality and aesthetics. As a result, domestic ovens are often designed from the outside-in. First, the aesthetics are established and then the product characteristics are fixed. With this approach the appearance of the oven often takes priority over its performance and efficiency.

Although there has been development of methods to enhance the efficiency of domestic ovens (see section 4.2.2.1 on patents) the product developments currently being implemented focus on functionalities such as ensuring the oven door remains cool during operation, combined cooking (microwaves and conventional cooking) and steam cooking. This drive for functionality to differentiate products has lead to a wide diversity of product types and functionalities now being available. The main product types are summarised in Table 4-1.

Table 4-1: Main Oven Product Types

Electric	Gas
• Conventional only (natural convection) • Forced air convection • Microwave only • Steam • Combination microwave (with heating element) • Single or double cavity[4]	• Natural or forced convection • Single or double cavity • Free-standing or built In • Range style • Portable

[4] A 1999 report concluded that the presence of double ovens in a domestic kitchen is negligible outside the UK, suggesting that a second oven is considered an accessory to the principle oven by the purchaser.

Electric	Gas
• Grill (radiant heating) • Free-standing or built In • Range style • Portable	

Variations in functionality include the following functionality features:

- Integrated hob (free standing ovens)
- Integrated grill (electric and gas)
- Steam
- Humidity sensor
- Gas from food sensor
- Multi-level cooking positions (shelves and trays)
- Turntables (e.g. microwave ovens)
- Motorised splits (e.g. commercial ovens for joint roasting)
- Door glazing and opening
- Food temperature probe
- Ignition method (for gas ovens)
- Self cleaning functionality (catalytic, pyrolytic or hydrolytic)
- Type of control setting devices
- Time setting options
- Interior light
- Power control (microwave oven)

4.2. PRODUCTION PHASE

Domestic ovens are essentially internally heated cubes and most are of standard sizes although range cooker and portable and microwave oven sizes vary. Commercial catering oven designs are very varied in both size and design. Commercial catering ovens can be gas or electric, combination (steam / heat or microwave / heat, etc.). There are also some special types of ovens which have additional features. Rotisserie

"Double cavity built-in and free-standing ovens are only popular in the UK (confirmed by CECED). These ovens have a second cavity usually with a capacity about half that of the main oven. "
http://www.ceecap.org/img_assets/File/Ovens_st.pdf

ovens are usually used to cook chickens but have glass doors to encourage prospective customers to buy the cooked chickens. They are deliberately leaky to provide enticing odours. Restaurants and hotels use hot cupboards which are heated chambers and so could be included in most definitions used for ovens. These tend to be used for keeping cooked food warm, typically at 70°C and are not used to cook food and so cannot have the same eco-design requirements as ovens.

Details of the current technology applied in all oven types and for specific functionality are described below.

4.2.1. Non-energy-using components

4.2.1.1 Casing

- **Domestic convection ovens**

For domestic ovens the oven cavity and casing are generally formed from pressed mild steel as this fulfils the requirements for functional strength and ease of manufacture, being suitable for bending and piercing. In addition coated steel offers a durable surface with scratch resistance to prevent corrosion of the steel substrate.

The mass of materials inside the oven cavity including the steel of the casing as well as racks and other internal parts is proportional to the energy consumed when bringing the oven up to its operating temperature. For many domestic cooking processes this energy is the majority used and so manufacturers have reduced the mass of metal to reduce energy consumption during typical cooking processes and also during the wet brick test to achieve better energy ratings. Modern ovens use steel sheet of about 1 mm thickness whereas older models use heavier gauge metal of > 1 mm which absorbs more heat. “Heat storage” ovens as made by Aga, Rayburn, etc. are however different. As these are designed to operate at a uniform constant temperature, the oven cavities are made from heavy cast iron with a very high thermal mass.

For the oven cavity enamel-coated steels may also be utilised. Conventional porcelain enamels for low carbon steel substrates are generally based on alkali borosilicate glasses which are fired at temperatures of 750-850°C. This operation is normally undertaken on a continuous fast belt furnace, with the enamel being above 700°C for ~5 minutes to ensure that melting occurs with a total process time of 20 minutes. Due to excessive alkali ions in these enamels their insulation resistance degrades at increased temperature, especially above 200°C. As a result the enamels are effectively conductive at normal operating temperature of 200-350°C. There has been debate over the emissivity of the interior walls. A prototype low emissivity oven was demonstrated which the researchers claimed used 35% less energy than standard ovens although this was disputed at the time by CECED[5]. Earlier research showed that

[5] "Energy performance of a low-emissivity electrically heated oven" by B. M. Shaughnessy and M. Newborough, Applied Thermal Engineering Volume 20, Issue 9, June 2000, Pages 813-830

wall emissivity should be low (e.g. a highly reflective surface) to improve oven efficiency[6] but another study concludes that wall emissivity should be high as dark surfaces adsorb energy but are also efficient energy radiators[7]. The Cambridge paper calculates heat transfer of 161 watts to the food with high emissivity walls (ε = 0.95) whereas only 64 watts is transferred with low emissivity walls (ε = 0.15). As it is difficult to maintain the cleanliness of low emissivity, highly reflective surfaces, most modern ovens use dark high emissivity surfaces.

Cast iron is used in some traditional style housing components. Chromium plated racks are standard inside domestic ovens as this is a cheaper material than stainless steel and is easy to clean.

- **Domestic microwave ovens**

For microwave ovens, originally the steel was supplied uncoated and then painted by the oven manufacturer either prior to or after the oven assembly. More recently oven manufacturers have begun to use pre-finished steels that are supplied as blanks that have already been coated. The steel is pre-coated in roll form, firstly applying a corrosion protective zinc layer followed by a two layer paint system, consisting of an underlying textured base coating and smooth pigmented topcoat. Such pre-painted steels can survive salt spray test of up to 500hrs[8].

The interior of the microwave oven cavity and the external casing are designed as barriers to the electromagnetic fields generated by the magnetron. It is well known that some consumers are fearful of microwave radiation emitted by mobile phones but there is little evidence that consumers avoid microwave ovens because of a fear of escaping microwave radiation. The design of shielding acts as a complete barrier that is checked by microwave radiation meters. Leaks can occur when microwave ovens are serviced or repairs so this is recommended only by professionals who are able to test for leaks. It is well known that microwave ovens use less energy than standard ovens but consumers choose to use microwave ovens only for certain processes such as re-heating. Although there have been claims that microwave cooking might be harmful[9], there is little evidence that European consumers believe these claims.

- **Commercial ovens**

Stainless steel (e.g. grade 304) linings and casing are used extensively in commercial ovens (see Figure 4-1). The aesthetic properties of stainless steel have also made it desirable for domestic ovens, although its use can be limited to the oven door and

[6] US Department of Energy, Bi-Radiant Oven: A Low-Energy Oven System, March 1982. Retrieved from: http://www.ornl.gov/sci/engineering_science_technology/eere_research_reports/appliances/other_appliances/bi_radiant_ovens/ornl_sub_80_0082_3/ornl_sub_80_0082_3.html

[7] Cambridge University Press article download April 2011. http://www.cambridge.org/us/engineering/author/nellisandklein/downloads/examples/EXAMPLE_10.5-2.pdf

[8] Source: Corus Consumer Products.

[9] One example is http://curezone.com/foods/microwave_oven_risk.asp although there are many more that state that microwave cooking is not harmful.

fascia only. Corus market pre-coated mild steel that has the appearance of stainless steel called Motiva P. Porcelain enamel coatings are typically 100μm thick with density 2.7 g/cm^3. On 1 mm thick steel this accounts for 3.3% by weight of the material. External surfaces of ovens that do not become very hot can be coated with paints or plastic. Paint coatings are typically 25μm thick (~0.3% by weight of sheet material).

Figure 4-1: Typical commercial kitchen with stainless steel appliances (Courtesy HKI)

4.2.1.2 THERMAL INSULATION

Electric and gas ovens have a layer of insulation to restrict the loss of heat from the oven. This is not the case in microwave oven, which have only an electromagnetic insulation (see section 4.2.2.5 for more details). The performance of the thermal insulation depends on the thickness, density and thermal conductivity but using more insulation may result in higher energy consumption with shorter cooking times. With short cooking times, the insulation absorbs heat but very little is conducted to the exterior and so the mass of insulation material is proportional to the heat energy used by the oven. With longer cooking times, steady state conditions will be reached so that some heat is conducted through the insulation to the external surfaces of the oven, depending on insulation density, thickness and thermal conductivity.

The heat flow through the insulation material is important as this must be low to minimise heat losses and maintain a low external surface temperature. The heat flow is proportional to the thermal conductivity of the insulation material, the surface area and the temperature gradient between the internal and external surfaces. The temperature gradient is affected by the internal and external temperatures so that heat losses increase as the oven temperature increases. Insulation density is important as air trapped between fibres or particles acts as a good insulator (usually better than the glass or ceramic material). However this air must not be allowed to move as the flow of hot air from the interior to the exterior surfaces will cause heat flow. Potential new insulation materials are discussed in task 6. The best materials are microporous products which are low density with trapped porosity so no air flow is possible but these materials are less flexible. Flexible materials are preferable in ovens because of the large expansion and contraction that occurs during heat-up and cool-down. Expansion can be as much as 1 cm in pyrolytic ovens during their cleaning cycle. Where movement occurs, rigid insulation can be damaged and heat losses will occur through any gaps that are formed. The main approach currently being used to improve oven thermal insulation is to design the insulation with fewer holes and gaps through which heat can pass.

The thickness of thermal insulation layers is different for domestic and commercial ovens. Most heat consumption in the relatively short cooking times used for domestic ovens is by heating of internal materials such as racks, walls and the insulation and so relatively thin layers are used, typically 25mm thick. Commercial ovens are on for much longer periods and so good thermal insulation is necessary and so thicker layers for example about 45 mm thick layers may be are used but some models use less,

- **Domestic ovens**

In domestic ovens, insulation is based on flexible rolls or rigid slabs made of glass-fibre. For a non-pyrolytic oven typically 25mm thickness insulation is used and slightly thicker and denser insulation is used in pyrolytic ovens. Pyrolytic ovens also have a layer of aluminium foil which acts as a reflector of heat radiation. This has little effect at normal oven temperatures. Energy efficient oven design is often difficult due to the various connecting items such as fans, lights etc, all of which are potential heat leakage paths. Design of pyrolytic ovens becomes even more difficult due to the high temperature of the automatic cleaning process. A pyrolytic oven has a cleaning cycle that is able to destroy all cooking residues by holding a temperature of around 500°C (932°F) for up to 90 minutes (e.g. SMEG ovens use 530°C). All the oven "dirt" is carbonised leaving only a fine ash. This high temperature requires a superior insulation system to maintain the external surface temperature below safe limits and to comply with the applicable European standards. Insulation for pyrolytic ovens needs to withstand 500 °C and so resin binders cannot be used. Comparative tests between pyrolytic and non-pyrolytic ovens have shown that improved insulation can reduce energy consumption but overall pyrolytic ovens consume more energy if pyrolytic cleaning is regularly carried out[10].

- **Commercial ovens**

Ovens from commercial kitchens may be on for eight hours or longer, thus a good insulation is required. Mineral particles/fibres in thermosetting phenolic resins are used to insulate some commercial ovens.

[10] US Department of Energy report 10 CFR part 430 part III "Energy Conservation Program for Consumer Products: Energy Conservation Standards for Electric Cooking Products (Electric Cooktops, Electric Self-Cleaning-Ovens, and Microwave Ovens)" 8 September 1998

According to CESA, the most commonly used thermal insulation material used in commercial ovens is “Rockwool” mineral wool insulation with some fibreboard and polystyrene for lower temperature applications. Suppliers include H&H (Hodgson & Hodgson Group Ltd), Microtherm and Sealumet (who market a ceramic blanket material called Rocsulate).

4.2.1.3 Door glazing

Historically ovens did not have glazed doors but since the widespread introduction of this feature unglazed doors have become an unacceptable product feature in domestic ovens. The combination of a glass door and oven cavity light reduce the number of times that the oven door must be opened to check the progress of the cooking and thereby limit the amount of heat/energy lost each time the door is opened.

Oven doors are opened during cooking processes (as well as at completion) for several reasons:

- To examine food – glass doors avoid the need to open the door
- Turning and basting food – door visibility has no impact.

When the oven door is opened, most of the hot air from inside the oven escapes. The amount of heat lost in one oven volume of air is however relatively small and so heat losses are small as long as the door is not open for long or too often. Window size may influence opening frequency for examination of food if visibility is compromised by a small window. The relationship between window size and door opening frequency on heat consumption is complex and no data is available. There are conflicting effects that need to be considered:

- More heat is lost by heat conduction through windows than through insulated metal panels so ovens with no window or small windows lose less heat than those with large windows. This is counterbalanced however by the heat lost every time the door is opened.
- The outer layer of glass needs to be air cooled to limit the outer surface temperature to safe limits as described above. This is not necessary for insulated metal panels.
- Heat consumption is proportional to the mass of materials. Three layers of glass will absorb more energy than two and so with shorter cooking processes, two layers of glass will adsorb less energy than three and so will consume less energy overall. However with longer cooking times, the superior insulation of three or more layers would reduce energy losses and so lower total energy consumption. The amount of heat energy absorbed by insulated metal panels and by glass is different and depends on material thickness, composition, etc.

The effect of door opening is complex and difficult to account for in an energy consumption test reproducibly. Domestic ovens and many commercial ovens have glass windows in doors because these are required by users and this is not likely to change. The oven energy consumption tests include the effect of closed glazed doors effectively but cannot account for door opening.

For safety reasons it is necessary to have more than one pane of glass to reduce the temperature of the outer pane sufficiently that it does not cause burns when accidentally touched. Some manufacturers use multiple layers of glazing with both Miele and De Dietrich offering quadruple glazing on some models.

Two types of glass window are used. In one, the glass window is inserted into an opening in the metal door using heat resistant adhesives. In the other, the door itself is made of a sandwich of two or more sheets of glass and so there is no need to seal the glass to a metal door.

Schott AG manufactures glass for oven doors. For the outer door glass the varieties of glass that are available include clear float glass, tinted glass, coated (mirror effect) and white glass. For the middle and inner glass heat transfer is limited by use of low emissivity glass (e.g. infra-red reflective coating applied), clear float glass, Energy Plus glass or Borofloat[11] (used for ovens with a pyrolytic function where the oven temperature may be raised to 500°C). The inner glass panel of most new domestic ovens have an infrared reflective coating.

EN 60335-1:2008 for electric ovens (both domestic and commercial) and EN 30-1-1:2008 for domestic gas ovens include specifications for the maximum outer surface temperature that an exposed surface should reach. These temperature limits are being revised to lower temperatures and the changes also include pyrolytic ovens. CECED claim that this change will require additional air cooling across the outer glass layer, especially in pyrolytic ovens during the cleaning cycle and this will increase energy consumption. The outer surface of an oven is cooler than the inner surface because the rate of heat conduction is reduced by the layer of insulation. Heat is lost from the outer surface mainly by convection so that at the outer surface there is sufficient heat energy to raise the surface temperature only within safe limits specified by these standards. The only insulation in the windows is the air gap between the sheets of glass and this is much less effective than good quality glass or mineral fibre insulation and so the only way to prevent the outer surface of the glass exceeding the safe limit is by passing cold air between the two outer glass layers and this is a source of lost heat. CECED believe that the change in the maximum external surface touch temperature limit will increase energy consumption by as much as 5%.

Portable ovens are low priced products which are not covered by the EU energy labelling requirement and so energy consumption is not routinely measured and are probably less energy inefficient than ovens that are in scope of the EU Energy labelling scheme. Many portable ovens have single layers of glass as their doors and so. it would be surprising that they are able to meet the outer surface maximum touch temperature requirement.

11 Schott AG trade names

Commercial ovens are supplied with double or triple glazed doors having infrared reflective coatings and sometimes the better insulated triple glazed version is available as an option at a higher price.

4.2.1.4 Door seals

Cooking is a complex process involving a balance of heating and evaporation to achieve the required appearance, taste and texture in the food (browning and crisping). The door seal should be optimised to minimise heat loss from the cooking cavity but some flow of air may be necessary for correct evaporation if the oven is not equipped with a separate flue or uses forced air convection. The seal technology is generally simple involving a flexible flange that is pressed onto a flat surface or formed groove on the outer casing surrounding the door orifice or on the door itself. Bosch and Siemens have patented a seal that forms a suction joint when the oven door is closed[12]. Silicones are the most commonly used materials for door seal gaskets in domestic and commercial ovens but fluorosilicone elastomers may also used in some commercial ovens as this polymer has a higher temperature resistance than silicones. Pyrolytic clean ovens use glass-fibre seals instead of rubbers to withstand the high cleaning temperature although some use silicones which tend to be reliable. Glass-fibre door seals are relatively fragile and so need to be replaced more frequently than silicone rubber seals which often survive the life of the appliance. However silicone door seals are a common spare part.

Microwave ovens use different types of door seal, called “choke seals” as these need to prevent the escape of microwave radiation (a so-called “Faraday cage”). The door seal is tuned to the microwave frequency to provide a band stop filter to contain the microwave energy inside the cavity.

4.2.2. Main energy-using components

4.2.2.1 Heating Elements (Electric)

Electric heating elements convert electricity into heat through the process of joule heating. Electric current is passed through a wire within the element and encounters electrical resistance that heats the wire and surrounding bulk of the element. Heating elements for domestic and commercial electric ovens and combination microwave ovens use Nichrome wire 80/20 (80% nickel, 20% chromium) wire, ribbon, or strip. Nichrome 80/20 is an ideal material, because it has relatively high resistance and forms an adherent layer of chromium oxide when it is heated for the first time. Material beneath the wire will not oxidize, preventing the wire from breaking or burning out. The wire is generally wound into a coil that is surrounded by densely packed magnesium oxide powder and then encased in a protective sheath. Magnesium oxide

[12] http://www.wipo.int/pctdb/en/wo.jsp?wo=2001036877&IA=EP2000010813&DISPLAY=STATUS

powder provides excellent thermal conductivity and dielectric strength. Ceramic or mica insulators ensure the electrical insulation of the terminal stud from the sheath.

Figure 4-2 presents a schematic diagram of a heating element.

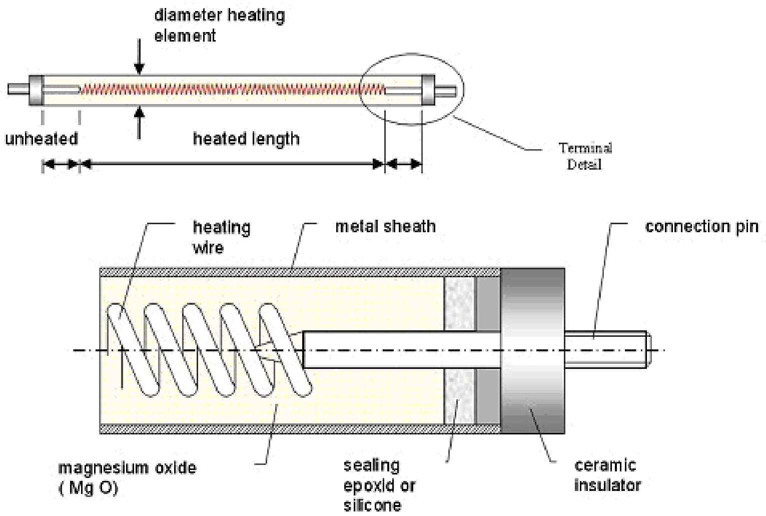

Figure 4-2: Schematic diagram showing the construction of electric heating element (Image courtesy of Elmatic [Cardiff] Ltd)

Research published in 1982 claimed that filament diameter can affect oven efficiency with narrower filaments being more efficient but is not clear why this should affect efficiency as in modern ovens, the filaments are always enclosed in a metal sheath[6].

Thick-film heaters are not used in domestic ovens although have been used in electric kettles for several years[13]. Thick film heaters offer little advantage in ovens as space and weight limitations are less significant than in a kettle although energy consumption would be slightly reduced if the mass of the thick film heater were less than tubular elements.

4.2.2.2 Forced air convection (Electric) and ventilation

In domestic electric fan ovens, cooking time and quality are dependent on the airflow in the oven. Areas of higher velocity accelerate evaporation and heat transfer, hence cooking speed. In a typical domestic electric fan oven a centrifugal fan is mounted on the back wall. The fan shrouding is normally minimal and the fan expels air on all points around its circumference. Often a circular heating element around the fan is the sole source of heat for the oven, although this can be used with bottom and top mounted elements in other heating modes. The fan circulates air in an attempt to achieve an even temperature and evaporation rate. Fan designs are typically forward-curved centrifugal shapes/tangential fans.

[13] http://www.backer-elektro.cz/en/tistena-telesa.shtml

Particle imaging of the airflow within an oven cavity was undertaken by Spence et al[14]. This showed that in an empty cavity a single vortex was established centred on the fan axis. When a tray was introduced the single vortex was replaced by three circulatory features. Shear flow was observed on both upper and lower surfaces of the tray, with a lower velocity and stagnation point on the upper side.

Convection in commercial oven may be more complex as ovens are designed to be stacked with greater number of trays and constant temperature must be maintained in larger volume.

In modern cookers the condensation of steam on the oven door and window and control panel of the cooker is avoided by using a steam exhaust chimney or vent that allows steam generated in the oven cavity to leave without condensing on cold parts of the oven. As the steam is extracted so is the heat, decreasing the overall efficiency of the oven. Heat loss through steam extraction can be as high as 10-20%.

Steam flow in the extraction vent is activated by the Venturi effect applied at one end of the vent, using a restriction in the air channel. The air used to cool the oven passes through the Venturi that activates a sucking effect in the oven cavity and extracts the steam (and heat) from the cavity. The steam is then mixed with the cooling air flow, diluted by it and dispersed in the ambient air away from the oven, to avoid condensation on the oven parts. Whirlpool have patented a method of operating the oven cooling fan in on / off cycles at lower fan speeds which avoids steam formation and also limits heat losses thus making the oven more efficient[15].

Forced air convection ovens have electric fans usually located at the back of the oven cavity. These fans need to operate within the oven although the fan motor is situated outside of the insulated enclosure and so is cooler although heat is conducted along the fan drive shaft. Electric motors are made mainly from steel and enamel coated copper wire.

4.2.2.3 Convection Heating (Gas Oven) and ventilation

Gas and electric oven have a lot of component in common. However, some components are found only on one type of oven.

Comparing the kWh consumption of gas and electric ovens would incorrectly give the impression that gas ovens are less energy efficient and consume more heat energy (see Annex I for an explanatory note on the environmental impact of energy source: electric or gas). Instead a comparison of the CO2 output would be necessary to show gas appliances are more carbon efficient as they use a primary energy source whereas electricity generation and transmission, mainly from fossil fuels in EU is only about 35% efficient.

[14] http://espace.library.uq.edu.au/eserv/UQ:120949/Spence_afmc_16_07.pdf
[15] Whirlpool patent, http://www.freepatentsonline.com/EP1457740.html

Domestic ovens

Most domestic gas ovens in the EU work by natural convection currents with only 7 models out of 529 (1.3%) in CECED's gas oven database having fan convection in 2008. The gas burner is located at the rear of the oven base, creating a circulation of hot gases that is eventually discharged from the rear of the oven by means of a flue. Owing to the relatively slow circulatory motion, temperature zones develop within the oven, the hottest regions being at the top. A domestic gas oven burner is presented in Figure 4-3.

For a limited number of domestic ovens and in many commercial ovens the gas burner is located outside the food compartment and hot air is allowed to enter via ports to produce a more even spread of heat temperature throughout the oven. This design is often used with additional fans to give improved efficiency.

The maximum energy consumption of domestic gas ovens ranges from 4.3MJ to 8.85 MJ[16]. Output power ratings of domestic gas oven burners are typically 2 – 3 kW. Burners for domestic ovens burn a stream of gas in air using various designs that generate stable and controllable arrays of small flames.

Ventilation of gas ovens is more important than electric as carbon monoxide, which is toxic, may be produced. Domestic ovens are usually vented into the kitchen although some ventilation should be installed. In the UK, an interlock is required to ensure the combustion gases are vented. In France, ventilation is obligatory for all buildings built after 1969 and so air flow rates are the same for both gas and electric ovens.

Figure 4-3: Domestic gas oven burner – note integral temperature probe (source: HKI)

Commercial ovens

Gas heated commercial ovens are more common than domestic ovens and use a variety of burner designs whereas domestic oven gas burner designs are more limited. Commercial oven burners are rated at up to 60kW or more[17]. Some commercial gas oven burners premix gas and air and these are typically used in combi-steamer ovens.

Concerning ventilation, it is necessary to exhaust combustion gases outside the building from most commercial gas appliances used in the EU although national legal

[16] Data from CECED oven database. 4.3 MJ = 1.194 kWh and 8.85 MJ = 2.46 kWh (3.6MJ = 1kWh).
[17] Information supplied by HKI.

requirements vary. Standard practice in commercial kitchens is to provide room ventilation with exhaust hoods over the appliances (common in UK but rare in Italy) or ceiling extraction (common in Germany). These approaches cause a large loss of heat from the building so that kitchens in northern Europe can be quite cold. Often, ventilation is not well controlled and one reported extreme example claimed that 40 changes of air in the kitchen per hour were used[18]. Some exhaust hoods have heat exchangers to recover a proportion of the lost heat but this is uncommon.

4.2.2.4 Grills in ovens

Grills are described in more detail in the task 4 report for DG ENER Lot 23 study into hobs and grills but grills used in ovens are different designs to standalone grills and so are briefly described here. Many electric ovens use the resistance heater located at the roof of the oven as an integral grill.

Many gas ovens also have integral grills. Those built into domestic gas ovens are generally of two designs. In the first design, referred to as a conventional grill, the grill consists of a pressed steel burner, fed via an injector at one end, located beneath an expanded metal fret. On leaving the burner the flames heat the metal fret and cause it to glow red-hot. The combustion products rise by convection through the holes in the grill canopy above the fret or are carried to slots near the front of the canopy. Modified designs of the conventional gas grill include a double-sided burner design, with burners running down the centre of the grill canopy and heating frets on both sides. With this design the combustion products are passed back to a central point above the burner for venting. The position of the burners in relation to the fret and the contour design of the fret determine how effective the grill is at producing even heating. Despite the burner port sizes and the spacing of the ports being varied to achieve even heating conventional gas grills often produce uneven cooking, as a result of the burners failing to heat the whole of the fret surface uniformly.

The second grill design is known as a surface combustion grill. This grill design has the advantage of having an even heat over the whole grilling surface. The design uses a natural draught radiant burner with an enlarged burner head that forms the complete area of the grilling surface. The burner head is made from either a perforated enamelled sheet steel or a fine steel mesh. Gas passes through the perforated surface with combustion taking place on the surface. The perforated enamel sheet steel type cooks the food by direct flame radiation and high flame temperature. The fine steel mesh type burners glow red cooking the food primarily by radiant heat.

Surface combustion grill designs feed gas into the primary air intake centred in the top of the burner to create lean gas/air mixtures containing about 80-90% air to 10-20% gas. If the percentage of gas is increased above this level the combustion flame “floats” over the surface and around the sides of the burner, producing uneven heating.

[18] Communication from stakeholder

4.2.2.5 Microwave Cooking

Microwave ovens are enclosures inside which food is exposed to microwave radiation at a frequency of 2.45GHz. To prevent microwave radiation from escaping, the interior of the oven is designed as a Faraday cage comprising a metal sheet / metallic mesh structure that prevents microwave radiation from passing through. This is used on the glass door and has gaps that are large enough for visible light to pass. Microwaves are generated by magnetrons powered either by transformers or inverters. Older ovens vary power output by changing the duty cycle (the period when the microwave energy is on or off), whereas newer inverter power supplies allow the power output to be varied and this can give better cooking performance. The majority of the electricity used by the oven is converted into microwave energy although about 30% is lost as heat from lamps, fans and the electrical circuitry.

The main parts of a “solo” microwave oven (no radiant heaters) are:

- The enclosure which is usually steel
- Glass door with metal “mesh” which provides visibility and a barrier to radiation
- Magnetron which generates microwave radiation. This is a device made mainly from copper metal with an electrode inside a specially shaped cavity
- Circuitry for converting mains input into microwave frequency for operating the magnetron. There is also control circuitry for timers, etc.
- Fans for cooling the circuitry and especially the magnetron
- The microwave radiation output from a magnetron can be uneven and cause uneven cooking and so some ovens have devices to ensure more even cooking. The two main approaches are turntables to rotate the food or mode stirrers at the top of the cavity which rotate and reflect microwave radiation.

Microwave cooking can offer substantial energy savings over traditional ovens, especially electric ovens, for those cooking processes where both types of oven can be used. However, consumers tend to use microwaves for defrosting and reheating only and not to cook whole meals. Cooking food with a microwave oven is quite different to traditional cooking and is not usually understood by the average cook. Many recipes were developed for traditional ovens and cannot be adapted to microwave ovens.

Although microwave ovens provide speed and convenience, microwave cooking can cause uneven heating, soggy food texture and does not produce browning. To overcome this manufacturers have added turntables and mode stirrers, have developed the use of active packages (shields and receptors) and have combined microwaves with other modes of heating but microwave ovens are still mainly used for re-heating precooked food and defrosting. Commercial microwaves are different to domestic models and many have radiant heaters as well as double magnetrons. These are used to cook food much more quickly than conventional ovens.

Microwave cooking relies on the susceptibility of water to microwave energy although fats and a few other substances also have some susceptibility. Food is mostly water and this heats up when exposed to microwave radiation although the efficiency depends on the temperature of the water. Water as ice is not very susceptible and so defrosting can be fairly slow whereas water at 10 - 20°C is most sensitive. The sensitivity decreases above the peak at about 15°C and so cooking becomes less energy efficient as the food temperature rises. The current EN60705 standard describes measurements of efficiency in domestic appliances, a test that heats 1000g of water from 10^{0}C to 20^{0}C but this is not representative of a real cooking process. A study by CENELEC is ongoing to change this standard in terms of amount of test load and finish temperature as well as measuring the energy consumption. The objective of this study is to define a test method that will be representative of representative microwave cooking processes.

A primary problem of microwave heating is undesirable moisture redistribution due to the faster rate of internal heating and the cold air surrounding the food that cannot remove the moisture. A combination of microwave cooking with other modes of heating can be used to improve the uniformity of microwave heating and to provide moisture transport control whilst increasing the heating speed.

One approach involves combining forced air convection with microwave cooking to cook food up to 15 times faster (a process known as jet air impingement). This increases the convective heat transfer coefficient at the surface of the food, provides a browning effect, seals in moisture and accelerates heat transfer by up to 60% by removing cool layers of air associated with moisture evaporating from the food. This technology has been used for a number of years in commercial ovens but is now being introduced in domestic ovens but is uncommon.

US research in 1998 found that some energy efficiency improvement may be achievable but the cost was not insignificant[19]. More recent Japanese research indicates that some improvements in energy efficiency are achievable[20]. Recent research by manufacturers[21] has found that modern microwave oven designs are close to the maximum energy efficiency. Cavity size has no effect whereas the internal coatings had an effect of only 1 – 2%.

An increasing number of microwave ovens are being produced with other functions such as:

- Convection heating
- Grill function

[19] Department of Energy Office of Energy Efficiency and Renewable Energy 10 CFR Part 430 Energy Conservation Program for Consumer Products: Energy Conservation Standards for Electric Cooking Products (Electric Cooktops, Electric Self-Cleaning-Ovens, and Microwave Ovens); Final Rule.

[20] Final Report by Microwave Oven Evaluation Standard Subcommittee, Energy Efficiency Standards Subcommittee of the Advisory Committee for Natural Resources and Energy.

[21] Information from members of CECED.

- Steam cooking.

Often the grill element is used as the heat source for convection cooking with a fan.

- **Domestic microwave ovens**

Domestic microwave oven power is typically 600 – 850W, and often have polymer or paint coatings. According to CECED, the electronics for generating microwave radiation is close to optimum at about 70 – 73% and so, in their opinion, if the worst 25% of domestic microwave ovens were removed from the market, the overall energy saving would be about 2% which is equivalent to a saving of 250GWh/year in EU (based on data in table 11 of the task 3 report). One design feature that did have an effect was that ovens which had integral grill elements consumed more energy as the metal parts of the grill absorb energy. EN 60705 can be used for microwave ovens with integral grills turned off but the results will be affected by the presence of the grill elements.

- **Commercial microwave ovens**

Domestic microwave ovens are often used in commercial kitchens but are often too slow and so commercial microwave ovens use “double magnetrons” to obtain higher power levels. Commercial ovens powers range from 900 to 2000W, which is higher than domestic models.

Commercial microwave ovens have a few specificities compared to domestic models. Their internal coatings are usually made of ceramic as this is easier to clean, but it can also be stainless steel. In order to spread heat more evenly to ensure that the food is correctly cooked, some commercial models of microwave ovens have also special devices.

4.2.2.6 Domestic Ovens with a combination of functions

As previously mentioned, one of the current trends is to integrate two or more cooking methods – conventional, forced air convection, microwave or steam – into one product. This is particularly the case with commercial ovens where the popular new models are steam ovens but other combinations such as cook-chill (with a refrigeration function) are also being marketed. Because the combination of methods is unfamiliar to the customer, manufacturers have embedded conversion programs and libraries of pre-programmed recipes, so that users do not have to consult recipe books and instruction manuals to determine the correct temperature and cooking times. An example of this is the manufacturer De Dietrich with their range of ICS (Intelligent Control System) single ovens, which use sensors to assess the weight and density of the food, then automatically set all parameters for cooking, including shelf level, temperature and duration. Electrolux have implemented similar technology with their Inspiro range of ovens (introduced 2008).

In 2008 Samsung introduced a Dual Cook single oven that allowed the user to divide the oven cavity in two, allowing just the top half of the oven to be used if only a small quantity of food was to be cooked. The reduced oven volume meant that the oven heated up more quickly, giving an energy saving of up to 25%. However this design option is very unusual and earlier US research indicated that savings would be negligible (see task 6).

Combination microwaves are also increasingly popular and these combine microwave heating with radiant or convection heating with microwave heating. Domestic microwaves with radiant heater elements are increasingly popular whereas commercial microwaves tend to use convection heating.

4.2.2.7 COMMERCIAL OVENS WITH A COMBINATION OF FUNCTIONS

- **Combi-steam ovens**

Combi-steam ovens are becoming much more common in commercial kitchens and these combine electric or gas and steam heating and form the largest percentage of commercial oven sales in the EU. Gas and electric models are available in the EU and some can be used as convection ovens (at up to 350°C), steam ovens (at up to 130°C) or as combi-ovens (typically up to 250°C). Most combination ovens use separate heaters for the oven and to generate steam. One manufacturer has claimed that the independent steam generators are not energy efficient and their removal could reduce energy consumption by 15% (a reduction of 1kWh/hour of use)[22].

- **Bakery ovens**

There are three main types of bakery oven used in the EU; deck, rack and convection. All three types are available as gas or electric and have steam input sometimes as an option. Baking is usually carried out using preset programs so door opening is not normally needed during cooking although part-glazed doors are fairly common.

Deck – these bake bread, cakes, confectionary, etc. directly on shelves or "decks" within the oven. Some are able to heat each deck independently to different temperatures. Several heating methods are used.

- Vapour tube –Each tube contains water and when heated these boils so that steam travels in the tubes around the cavity until it condenses and returns to the reservoir. These have the advantage of no moving parts and use sealed metal tubes that surround the oven but are used mainly for smaller cavities.
- Thermal oil – used for large ovens, oil is heated externally and pumped through each deck
- Ciclothermic – use fans to circulate hot air around the decks. Air is heated by gas or with heat exchangers. This type can suffer from larger temperature fluctuations.

[22] "Increasing Efficiency within the commercial kitchen, an environmental code for gas appliances", http://www.agafoodservice.com/SiteImages/Site_301/BigMedia/Green%20Policy%20Code.pdf

- Steam – used with one of the above heating methods. Steam is injecting into the oven during part or all of the cooking cycle. Steam generation can be by a separate generator or within the oven which is claimed to be more energy efficient. Mono claim that integral steam saves up to 1KW per deck in comparison with external steam generators[26].

Rack – These tend to be larger ovens often used for manufacturing bread as well as for larger-scale commercial catering. Food is loaded onto one or more racks which are inserted into the oven cavity. Racks may be suspended inside the chamber and rotated to obtain more even cooking. The interior of the rack oven cavity is heated and steam injected when needed.

Convection – these are similar to combi-steam ovens but are designed specifically for baking and so their dimensions and cooking programs are designed for bread, etc.

4.2.3. Other energy-using components

4.2.3.1 Control technology

- **Domestic appliances**

The user interface of modern ovens is generally electronic with oven settings established using one of three methods[23]:

- Touch control panel with a full keypad and no knobs i.e. non-mechanical selectors or encoders

- Semi-touch control panel i.e. a reduced keypad and a series of selector switches and/or encoders with knobs

- No touch control with only selector switches and/or encoders with knobs

- **Commercial appliances**

In commercial appliances, the same type of technology is used, even if the aesthetic aspect is less important than in domestic appliances. Usability and reliability are the main concerns when choosing a control technology for a commercial oven. Some manufacturers are now using a touch screen to control the appliance (see Figure 4-4).

[23] Images courtesy of Schott AG.

There is no permanent keyboard, and the interface displayed changes according to the actions of the user.

Figure 4-4: Control technology used in commercial appliances

Several control panels from commercial appliances are presented in Figure 4-4. In the left, the control panel from a CombiMaster produced by Rational, with knobs. In the middle, a touch control panel. Convotherm introduced in its latter product touch screens, which interface is evolving depending on the user's actions. This interface is presented in the right.

4.2.3.2 Oven temperature control

Control of oven temperature is important for energy consumption as too high a temperature wastes energy and too low risks undercooking food and may increase energy consumption by lengthening cooking times. Thermostatic control can be electro-mechanical (a declining market), bimetallic (low numbers) or electronic. Ovens and grills represent 32% of the total European thermostat market[24].

The working principle of electro-mechanical and bimetallic thermostats is the same, although bimetallic thermostats have some refinements improving the precision of temperature setting. There is a heating sensor which is full of a liquid. This expands through a capillary tube when heated, pushing a diaphragm, which in turn triggers a snap-action switch. Electric power is activated by this switch. There is often a calibration or adjusting mechanism, using a screw spindle, to offset the fabrication tolerances in the diaphragm.

Failure rate of electro-mechanical and electronic thermostats are ~16 and 6.53 failures per $1x10^6$ operating hours respectively. Electronic thermostats can prevent thermal overshoot by predicting evolution of temperature in the oven. Typical design is a microprocessor controlling a relay switch with a resistive temperature detector (RTD) monitoring the oven temperature.

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[24] European thermostat market data. Available at: www.fuse-network.com/fuse/demonstration/332/22888/22888.pdf

Table 4-2: European thermostats market
(millions of units in 1995 and forecast for 2002)

Thermostat type	1995	2002
Electromechanical	34.5	31.0
Bimetallic	12.1	15.6
Electronic	3.8	10.0

The maximum temperature of domestic ovens in the EU is 300°C although some are 270°C. Commercial ovens are usually 300°C but some are higher at 350°C.

Micro-switches may be installed on the doors of forced air convection ovens to switch off or reduce the speed of the fan and switch off heaters when the door is opened.

4.2.3.3 Gas oven burner ignition

Domestic gas appliances with covered burners must have flame failure devices. There are two main types of gas igniter available in EU ovens.

- **Pilot light igniter** - these are no longer used in domestic but are used in some commercial gas ovens. Igniters may be manual and so activated by the user or automatic and so actuate when the gas is flowing.
- **High voltage spark** – this is the main type of igniter used in the EU. It provides near-instantaneous ignition of the gas and is very reliable although it does suffer from several potential limitations. The high voltage required can cause electromagnetic interference and so systems need to be designed to comply with the EMC directive. This issue is well known and the correct design avoids any problems. The spark electrode surfaces erode and may be affected by contamination and moisture so that these igniters can gradually become less efficient although they usually last the life of the oven.

In addition to these two new innovations are used in USA, hot surface igniters and hot wire but neither are used widely in the EU.

Pilot lights are permanently on, small gas flames positioned close to burners to ignite gas. Pilot lights are not banned in the EU but are no longer used in domestic appliances. Pilot lights have been banned in the USA since 1990 by NAECA in appliances which have a main electricity supply[25]. The quantity of gas consumed by each pilot light is relatively large as they burn gas 24 hours per day, 365 days per year. Estimates from the USA claim that a pilot light can consume as much as 40 - 50% of the gas used by a domestic gas oven. No figures for commercial ovens are published but the proportion is likely to be less as commercial gas ovens are used for much longer periods and so overall more gas is consumed and thus the proportion used for pilot

[25] NAECA is National Appliance Energy Conservation Act
http://ees.ead.lbl.gov/projects/current_projects/home_appliances

lights will be much less. The amount of gas consumed also depends on the size of the flame and newer pilot lights have smaller flames than older designs. US estimates for each pilot light are quoted at "0.6m^3 gas / day" and "10 GJ/year" although it is not clear whether this refers to old, new or all types. Pilot lights are not uncommon in EU commercial ovens but many use alternative ignition technologies (high voltage spark) that will be more energy efficient. The replacement of gas pilot lights by automated high voltage electric spark igniters would appear to offer a significant improvement potential but the exact saving is difficult to calculate. EN203-1 imposes a limit of 250W heat output for gas pilot lights but it is not known what proportion of stocks of and new commercial ovens use pilot lights.

4.2.3.4 OVEN LAMPS

Many domestic ovens and any commercial ovens with glass doors will have internal lighting inside the oven so that the food can be seen without opening the glass door. Special high temperature resistance incandescent lamps are used as fluorescent lamps and most LEDs could not withstand the oven temperature. Some ovens have light switches that allow the lamps to be turned off. In electric ovens, this would extend the life of the lamp but does not save on energy because all of the energy consumed by the lamp is converted into heat which reduces the heat input from the oven's heating elements. The situation with gas ovens is not so straightforward. Heat is generated by the lamp in the same way which reduces the gas consumption but as the lamp consumes electricity and there are losses in electricity generation, overall more primary energy is consumed by the lamp to generate heat than from gas to generate heat. This different may however be fairly small in comparison with the energy that would be lost by more frequent door opening if no lamp were used.

Commercial ovens may use halogen lamps which are more efficient than incandescent lamps. LEDs have been considered but are not yet used[26].

LEDs could be used in microwave ovens where a saving in energy would be achieved

4.2.3.5 LOW ENERGY MODES

Ovens have a variety of low power modes including in some models a "standby mode". A low energy mode such as standby mode is required for electric household appliances such as ovens in the EU (but not for gas ovens). Currently ovens must consume less than 1 watt in standby mode or when in off-mode or an equivalent mode. 2 watts is permitted if the appliance has a display. From 7 January 2013 these energy consumption limits halve and all ovens will be required to have a power management facility to switch into standby mode after a period of inactivity. When cooking with an electric oven is complete, the user will normally turn the oven temperature setting to "off". However, the interior of the oven is hot and needs to be cooled in a way that avoids heat sensitive parts from being over-heated and to prevent condensation

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[26] www.monoequip.com

forming which could cause corrosion. Therefore a cooling mode is actuated in which fans operate until the oven temperature has decreased to a pre-set level and then the oven is switched to either standby or off-mode. Standby is more common than off mode as most ovens have a digital clock and some have built in timers.

Some commercial gas ovens having conveyors, for example for cooking pizzas, are available with sensors that detect the presence of food items. If none are detected, the oven switches automatically first into a lower power mode and then after a further period of time it switches the oven off. According to one manufacturer's literature[27] this can save at least 30% energy.

Commercial ovens usually do not have standby modes as these are either in use (but not necessarily always cooking food) or switched off. Some ovens are fitted with timers which can be set to automatically switch ovens on and off at preset times. Some commercial bakery ovens have a "sleep mode" which according to one manufacturer reduces energy consumption by up to 66%. These ovens switch to sleep mode after a predefined period of inactivity[26]. These ovens also have auto-shut down which can be used to switch them off after a longer period of inactivity, for example at night if the user forgets to turn them off.

4.2.3.6 OVEN CLEANING

Ovens need to be cleaned periodically and three methods are used:

Cleaning with chemicals – this is the most common overall in the EU. Chemicals containing sodium hydroxide are the most effective and are used as they react with grease (fatty acids) to create water soluble soaps. This is more effective with a warm oven but sodium hydroxide is a very corrosive chemical that attacks the skin causing serious harm so suitable gloves should be worn.

Pyrolytic cleaning – a process where the oven is heated by a special heating cycle to ~500°C. This causes fat deposits to pyrolyse mainly to gaseous by-products. The pyrolytic cleaning cycle has a high energy consumption which can be more than the energy saved by the improved insulation normally needed for these types of oven (in order to maintain a sufficiently low external temperature for safety purposes etc.). Annual energy consumption depends on the frequency of pyrolytic cleaning. Pyrolytic ovens are very popular in France (80% of electric ovens, see Task 2) but uncommon in all other EU States (e.g. 3 – 4% in Germany).

Catalytic cleaning – this is less effective than pyrolytic cleaning and is popular only in UK although sales are declining. It is effective only at higher temperatures and so extra cleaning cycles may be needed. The liners themselves cannot be cleaned and there are gaps where accessible surfaces need to be cleaned with chemicals. Catalytic liners require additional parts to be installed in ovens and add about 1 kg of extra mass. This absorbs heat and so increases energy consumption by about 10%, according to CECED.

[27] Middleby Marshall brochure, http://www.middleby.com/midmarsh/wow/WOWbroch_web.pdf

4.2.3.7 SOFTWARE AND CONTROL

Most ovens use fairly simple controllers that regulate the oven's temperature but a variety of innovative techniques have been developed. Traditionally ovens have been heated to a maximum set temperature and controlled simply with a thermostat. The food temperature tends to lag the oven temperature and as a result this method can lead to excessive use of energy.

4.2.4. BILLS OF MATERIALS

There are many different oven designs among the products available on the EU market. Five major categories of products were identified, according to their annual energy consumption at the EU level. For each category, an average product representative of an oven currently in stock in the EU-27 was determined. Thanks to questionnaires sent to stakeholders, bills of materials (BOM) were gathered. These BOMs are not detailed and the materials were selected from the ones available in the EcoReport database. Equivalence between materials had to be found, and will be explained in Task 5.

4.2.4.1 DOMESTIC APPLIANCES

- **Domestic electric oven**

The BOM presented in Table 4-3 refers to a built-in domestic oven, operated by electricity. This oven is able to use forced convection and has no self-cleaning functionality. Its capacity is of 54 litres.

Table 4-3: Bill of materials of a typical domestic electric oven

Component	Weight in g	Category	Material or Process
CASING			
Body	5820.0	3-Ferro	**25-Stainless 18/8 coil**
Casing	6490.0	3-Ferro	**25-Stainless 18/8 coil**
Supports	880.0	3-Ferro	**25-Stainless 18/8 coil**
INSULATION			
Body insulation	340.0	2-TecPlastics	**18-E-glass fibre**
Back insulation	110.0	2-TecPlastics	**18-E-glass fibre**
DOOR			
Casing	3130.0	3-Ferro	**25-Stainless 18/8 coil**
Glass	4120.0	7-Misc.	**54-Glass for lamps**
Joint	50.0		
Hinge	180.0	3-Ferro	**21-St sheet galv.**
Buttons	60.0	1-BlkPlastics	**8-PVC**
HEATING ELEMENTS			
Back heater 2100 W	220.0	4-Non-ferro	**28-Cu winding wire**

Component	Weight in g	Category	Material or Process
Top double heater 1200/1400W	500.0	4-Non-ferro	**28-Cu winding wire**
Bottom double heater 1000/500W	480.0	4-Non-ferro	**28-Cu winding wire**
HEAT DISTRIBUTION SYSTEM			
Casing	930.0	3-Ferro	**25-Stainless 18/8 coil**
Motor			
Aluminium	27.6	4-Non-ferro	**27-Al diecast**
Iron	193.2	3-Ferro	**24-Ferrite**
Copper	55.2	4-Non-ferro	**28-Cu winding wire**
CONTROL TECHNOLOGY			
Electronic board	125.0	6-Electronics	**98-controller board**
MISCELLANEOUS			
Internal cable (copper)	61.8	4-Non-ferro	**29-Cu wire**
Internal cable (insulation)	61.0	1-BlkPlastics	**8-PVC**
Main cable (copper)	90.0	4-Non-ferro	**29-Cu wire**
Main cable (insulation)	72.5	1-BlkPlastics	**8-PVC**
Trays	3750.0	3-Ferro	**25-Stainless 18/8 coil**
Motor convector	722.0	3-Ferro	**25-Stainless 18/8 coil**
Documentation	110.0	7-Misc.	**57-Office paper**
Packing	1200.0	7-Misc.	**56-Cardboard**
Screws	1080.0	3-Ferro	**22-St tube/profile**
TOTAL weight	**30858.3**		

Domestic gas oven

The BOM presented in Table 4-4 refers to a domestic gas oven with a 63 litres cooking chamber. It is part of a cooker and has no forced convection functionality.

Table 4-4: Bill of materials of a typical domestic gas oven

Component	Weight in g	Category	Material or Process
CASING			
cavity	5390.0	3-Ferro	**24-Ferrite**
side walls	5400.0	3-Ferro	**24-Ferrite**
rear wall	1584.0	3-Ferro	**21-St sheet galv.**
intermediate rear wall	1410.0	3-Ferro	**21-St sheet galv.**
flame spreader	1200.0	3-Ferro	**24-Ferrite**
INSULATION			
cavity insulation	1010.0	7-Misc.	
rear insulation	287.0	7-Misc.	
DOOR			

Component	Weight in g	Category	Material or Process
door inner glass	1140.0	7-Misc.	**54-Glass for lamps**
door outer glass	2660.0	7-Misc.	**54-Glass for lamps**
door main frame	1840.0	3-Ferro	**24-Ferrite**
door handle	418.0	4-Non-ferro	**26-Al sheet/extrusion**
HEATING ELEMENTS			
oven burner	420.0	3-Ferro	**21-St sheet galv.**
grill burner	500.0	3-Ferro	**21-St sheet galv.**
MISC.			
drawer tray	1376.0	3-Ferro	**21-St sheet galv.**
drawer panel	1160.0	3-Ferro	**21-St sheet galv.**
front panel	816.0	3-Ferro	**21-St sheet galv.**
knobs	90.0	2-TecPlastics	**12-PC**
metal lid	2330.0	3-Ferro	**24-Ferrite**
baking tray	1200.0	3-Ferro	**24-Ferrite**
pan supports	1846.0	3-Ferro	**24-Ferrite**
COMPONANTS PURCHASED SEPARATELY (BIO estimates)			
oven thermostat			
brass	160.0	4-Non-ferro	**31-CuZn38 cast**
aluminium	40.0	4-Non-ferro	**27-Al diecast**
gas tap for hob burner	480.0	4-Non-ferro	**31-CuZn38 cast**
silicone cables			
copper	50.0	4-Non-ferro	**28-Cu winding wire**
silicone	50.0	2-TecPlastics	**16-Flex PUR**
Oven lamp			
glass	40.0	7-Misc.	**54-Glass for lamps**
aluminium	5.0	4-Non-ferro	**26-Al sheet/extrusion**
Hob burners	1000.0	4-Non-ferro	**27-Al diecast**
Ignition Switch			
PTFE	112.5	2-TecPlastics	**11-PA 6**
copper	22.5	4-Non-ferro	**28-Cu winding wire**
ceramic	15.0	7-Misc.	**54-Glass for lamps**
Manifold	200.0	3-Ferro	**21-St sheet galv.**
Spark plugs			
Stainless steel	45.0	3-Ferro	**25-Stainless 18/8 coil**
PTFE	9.0	2-TecPlastics	**11-PA 6**
Ceramic	36.0	7-Misc.	**54-Glass for lamps**
Power cable			
copper	75	4-Non-ferro	**28-Cu winding wire**
PVC	50.0	1-BlkPlastics	**8-PVC**
Terminal block			

Component	Weight in g	Category	Material or Process
copper	37.5	4-Non-ferro	**28-Cu winding wire**
PTFE	112.5	2-TecPlastics	**11-PA 6**
TOTAL weight	**34,617**		

The gross weight of this oven is supposed to be 50 kg. The disparity between this weight and the total weight provided in the BOM will be clarified with the manufacturer who provided this information.

- **Domestic microwave oven**

The BOM presented in Table 4-5 refers to a domestic microwave oven with a capacity of 18 litres. This is a freestanding oven with no grill functionality.

Table 4-5: Bill of materials of a typical domestic microwave oven

Component	Weight in g	Category	Material or Process
PACKAGING			
Carton box	1017.0	7-Misc.	**56-Cardboard**
Polyfoam	215.0	1-BlkPlastics	**6-EPS**
Polybag	41.0	1-BlkPlastics	**5-PS**
Printed matters	99.0	7-Misc.	**57-Office paper**
CASING			
Chassis	683.0	3-Ferro	**21-St sheet galv.**
Foot	9.0	1-BlkPlastics	**4-PP**
Outer wrapping	1290.0	3-Ferro	**21-St sheet galv.**
Powder paint	70.0	5-Coating	**39-powder coating**
Cavity assy (back, ceiling, wrapping, front, hinges)	1497.0	3-Ferro	**21-St sheet galv.**
Cavity hinge	90.0	3-Ferro	**21-St sheet galv.**
Powder paint	120.0	5-Coating	**39-powder coating**
TT motor support	75.0	3-Ferro	**21-St sheet galv.**
Waveguide and lid	248.0	3-Ferro	**21-St sheet galv.**
Mica plate		7-Misc.	**54-Glass for lamps**
DOOR			
Door plate	430.0	3-Ferro	**21-St sheet galv.**
Powder paint	26.0	5-Coating	**39-powder coating**
Door hinge	58.0	3-Ferro	**21-St sheet galv.**
Plastic foil	8.0	1-BlkPlastics	**1-LDPE**
Outer glass	514.0	7-Misc.	**54-Glass for lamps**
Outer door frame	262.0	1-BlkPlastics	**10-ABS**
Door hooks	26.0	2-TecPlastics	**11-PA 6**
Door inner frame	52.0	1-BlkPlastics	**4-PP**
HEAT DISTRIBUTION SYSTEM			

Component	Weight in g	Category	Material or Process
Turntable	650.0	7-Misc.	**54-Glass for lamps**
TT Drive	25.0	1-BlkPlastics	**5-PS**
TT motor			
aluminium	7.2	4-Non-ferro	**27-Al diecast**
iron	46.8	3-Ferro	**24-Ferrite**
copper	14.4	4-Non-ferro	**28-Cu winding wire**
PVC	3.6	1-BlkPlastics	**8-PVC**
Magnetron			
copper	667.8	4-Non-ferro	**30-Cu tube/sheet**
ceramic	74.2	7-Misc.	**58-Concrete**
HV Capacitor	159.0	6-Electronics	**44-big caps & coils**
HV Transformer			
Iron	2118.6	3-Ferro	**24-Ferrite**
Copper	1412.4	4-Non-ferro	**28-Cu winding wire**
HV Diode	8.0	6-Electronics	**48-SMD/ LED's avg.**
CONTROL TECHNOLOGY			
Door switches	23.0	6-Electronics	
PCBA	300.0	6-Electronics	**98-controller board**
Mains filter	33.0	6-Electronics	**98-controller board**
Control panel	147.0	1-BlkPlastics	**10-ABS**
Buttons	14.0	1-BlkPlastics	**10-ABS**
Lens	15.0	2-TecPlastics	**12-PC**
MISCELLANEOUS			
Wire assy			
Copper	21.0	4-Non-ferro	**28-Cu winding wire**
PVC	42.0	1-BlkPlastics	**8-PVC**
Interlock assy	40.0	1-BlkPlastics	**8-PVC**
Power cord			
Copper	74.0	4-Non-ferro	**29-Cu wire**
PVC	73.0	1-BlkPlastics	**8-PVC**
Air guide, R	45.0	1-BlkPlastics	**4-PP**
Fan wheel	13.0	1-BlkPlastics	**4-PP**
Air guide, fan	53.0	1-BlkPlastics	**4-PP**
Fan motor			
Al	47.6	4-Non-ferro	**27-Al diecast**
iron	309.4	3-Ferro	**24-Ferrite**
Copper	95.2	4-Non-ferro	**28-Cu winding wire**
PVC	23.8	1-BlkPlastics	**8-PVC**
Thermostat	10.0	6-Electronics	**98-controller board**
Lamp	7.0	7-Misc.	**54-Glass for lamps**
Lamp holder	12.0	3-Ferro	**22-St tube/profile**

Component	Weight in g	Category	Material or Process
Screws and nuts	40.0	3-Ferro	**22-St tube/profile**
Plastic, various components	11.0	1-BlkPlastics	**1-LDPE**
Metal brackets	80.0	3-Ferro	**21-St sheet galv.**
TOTAL weight	**13546**		

4.2.4.2 COMMERCIAL APPLIANCES USED IN RESTAURANT

- **Commercial electric combi-steamer**

Table 4-6 presents the BOM of a typical combi-steamer powered with electricity, in which 10 GN 1/1 containers can be loaded.

Table 4-6: Bill of materials of a typical commercial electric combi-steamer

Component	Weight in g	Category	Material or Process
CASING			
Interior Cabinet	39000	3-Ferro	**25-Stainless 18/8 coil**
Housing	42000	3-Ferro	**25-Stainless 18/8 coil**
Hand Shower	300	2-TecPlastics	**11-PA 6**
Hose Reel	700	2-TecPlastics	**11-PA 6**
Plastic Parts	1500	2-TecPlastics	**11-PA 6**
Legs and Feet	1600	2-TecPlastics	**11-PA 6**
Water Distribution	2000	2-TecPlastics	**16-Flex PUR**
INSULATION			
Glass Wool needled	8000.0	7-Misc.	
DOOR			
Housing	9000.0	3-Ferro	**25-Stainless 18/8 coil**
Satefy glass	9000.0	7-Misc.	**54-Glass for lamps**
Handle	400.0	2-TecPlastics	**14-Epoxy**
Gasket	400.0	2-TecPlastics	**16-Flex PUR**
HEATING ELEMENTS			
Heating Element Convection	3000.0	3-Ferro	**25-Stainless 18/8 coil**
Steam Generator	6000.0	3-Ferro	**25-Stainless 18/8 coil**
HEAT DISTRIBUTION SYSTEM			
Fan motor			
Fan motor - Iron	2000.0	3-Ferro	**24-Ferrite**
Fan motor - Copper	400.0	4-Non-ferro	**28-Cu winding wire**
Fan motor - Al	1000.0	4-Non-ferro	**27-Al diecast**

Component	Weight in g	Category	Material or Process
Fan motor - Plastic	200.0	2-TecPlastics	**11-PA 6**
CONTROL TECHNOLOGY			
Control board	1500.0	6-Electronics	**98-controller board**
OTHERS COMPONENTS			
	2000.0	4-Non-ferro	**29-Cu wire**
	3000.0	3-Ferro	**24-Ferrite**
	500.0	1-BlkPlastics	**8-PVC**
	1000.0	2-TecPlastics	**11-PA 6**
	500.0	4-Non-ferro	**26-Al sheet/extrusion**
	100.0	2-TecPlastics	**11-PA 6**
	300.0	1-BlkPlastics	**4-PP**
	100.0	6-Electronics	**98-controller board**
TOTAL weight	**135500**		

- **Commercial gas combi-steamer**

The BOM of a 10 GN 1/1 combi-steamer heated with gas is presented in Table 4-7.

Table 4-7: Bill of materials of a typical commercial gas combi-steamer

Component	Weight in g	Category	Material or Process
CASING			
Interior Cabinet	39000	3-Ferro	**25-Stainless 18/8 coil**
Housing	42000	3-Ferro	**25-Stainless 18/8 coil**
Hand Shower	300	2-TecPlastics	**11-PA 6**
Hose Reel	700	2-TecPlastics	**11-PA 6**
Plastic Parts	1500	2-TecPlastics	**11-PA 6**
Legs and Feet	1600	2-TecPlastics	**11-PA 6**
Water Distribution	2000	2-TecPlastics	**16-Flex PUR**
INSULATION			
Glass Wool needled	8000.0		
DOOR			
Housing	9000.0	3-Ferro	**25-Stainless 18/8 coil**
Satefy glass	9000.0	7-Misc.	**54-Glass for lamps**
Handle	400.0	2-TecPlastics	**14-Epoxy**
Gasket	400.0	2-TecPlastics	**16-Flex PUR**
HEATING ELEMENTS			
Heating Element Convection - Gas	12000.0	3-Ferro	**25-Stainless 18/8 coil**

Component	Weight in g	Category	Material or Process
Steam generator - Gas	14000.0	3-Ferro	**25-Stainless 18/8 coil**
Gas valve and fan	2000.0	4-Non-ferro	**27-Al diecast**
HEAT DISTRIBUTION SYSTEM			
Fan motor			
Fan motor - Iron	2000.0	3-Ferro	**24-Ferrite**
Fan motor - Copper	400.0	4-Non-ferro	**28-Cu winding wire**
Fan motor - Al	1000.0	4-Non-ferro	**27-Al diecast**
Fan motor - Plastic	200.0	2-TecPlastics	**11-PA 6**
CONTROL TECHNOLOGY			
Control board	1500.0	6-Electronics	**98-controller board**
OTHER COMPONENTS			
	2000.0	4-Non-ferro	**29-Cu wire**
	3000.0	3-Ferro	**24-Ferrite**
	500.0	1-BlkPlastics	**8-PVC**
	1000.0	2-TecPlastics	**11-PA 6**
	500.0	4-Non-ferro	**26-Al sheet/extrusion**
	100.0	2-TecPlastics	**11-PA 6**
	300.0	1-BlkPlastics	**4-PP**
	100.0	6-Electronics	**98-controller board**
TOTAL weight	**154500**		

4.2.4.1 COMMERCIAL APPLIANCES USED IN BAKERIES

- **Commercial in-store convection oven**

A typical 4 trays in-store convection oven is made out of the components presented in Table 4-8.

Table 4-8: Bill of materials of a typical commercial in-store convection oven

Component	Weight in g	Category	Material or Process
CASING			
Baking chamber	25000.0	3-Ferro	**22-St tube/profile**
Casing	35000.0	3-Ferro	**22-St tube/profile**
INSULATION			
Glass needle	6000.0	7-Misc.	
Fixation	600.0	3-Ferro	**22-St tube/profile**

Component	Weight in g	Category	Material or Process
DOOR			
Door glass	24000.0	7-Misc.	**54-Glass for lamps**
Fixation	5000.0	3-Ferro	**22-St tube/profile**
HEATING ELEMENTS			
Heating	2600.0	3-Ferro	**25-Stainless 18/8 coil**
Seal	60.0	2-TecPlastics	**16-Flex PUR**
HEAT DISTRIBUTION SYSTEM			
Fan	5400.0	3-Ferro	**22-St tube/profile**
CONTROL TECHNOLOGY			
Casing	4600.0	3-Ferro	**22-St tube/profile**
Control element	800.0	6-Electronics	**98-controller board**
TOTAL weight	**109060**		

- **Commercial electric deck oven**

The BOM of a typical electric deck oven (4 decks, 2 doors) is presented in Table 4-9.

Table 4-9: Bill of materials of a typical commercial electric deck oven

Component	Weight in g	Category	Material or Process
CASING			
Aluminized steel	260000	3-Ferro	**21-St sheet galv.**
	125000	3-Ferro	**22-St tube/profile**
	96000	3-Ferro	**25-Stainless 18/8 coil**
	52000	3-Ferro	**25-Stainless 18/8 coil**
INSULATION			
Rock wool 80 - 55kg/m3	161000	7-Misc.	
	14000.0	3-Ferro	**25-Stainless 18/8 coil**
Pre-lacquered sheet steel	145000.0	3-Ferro	**21-St sheet galv.**
Aluminized steel	59000.0	3-Ferro	**21-St sheet galv.**
DOOR			
Glass	8000.0	7-Misc.	**54-Glass for lamps**
Fixation	2800.0	3-Ferro	**25-Stainless 18/8 coil**
HEATING ELEMENTS			
Heating resistance	160000.0	3-Ferro	**25-Stainless 18/8 coil**

Component	Weight in g	Category	Material or Process
HEAT DISTRIBUTION SYSTEM			
Steam generator	158000.0	3-Ferro	**22-St tube/profile**
CONTROL TECHNOLOGY			
Silicone cables	7500.0	2-TecPlastics	**16-Flex PUR**
	7500.0	4-Non-ferro	**29-Cu wire**
Electric components	2000.0	4-Non-ferro	**29-Cu wire**
	5000.0	1-BlkPlastics	**8-PVC**
Electronic components	0.0	6-Electronics	**98-controller board**
MISCELLANEOUS			
Cooking deck	450000.0	7-Misc.	**58-Concrete**
Fastenings	5000.0	3-Ferro	**25-Stainless 18/8 coil**
Silicone filler	2800.0	2-TecPlastics	**14-Epoxy**
TOTAL weight	**1720600**		

Commercial gas deck oven

Table 4-10 presents the BOM of a typical gas deck oven (4 decks, 2 doors).

Table 4-10: Bill of materials of a typical commercial gas deck oven

Component	Weight in g	Category	Material or Process
CASING			
	443000	3-Ferro	**22-St tube/profile**
	495000	3-Ferro	**22-St tube/profile**
	104000	3-Ferro	**25-Stainless 18/8 coil**
	165000	3-Ferro	**25-Stainless 18/8 coil**
INSULATION			
Rock wool	280000	7-Misc.	
	14000.0	3-Ferro	**25-Stainless 18/8 coil**
Pre-lacquered sheet steel	145000.0	3-Ferro	**21-St sheet galv.**
Aluminized steel	59000.0	3-Ferro	**21-St sheet galv.**
DOOR			
Glass	16000.0	7-Misc.	**54-Glass for lamps**
Fixation	6800.0	3-Ferro	**25-Stainless 18/8 coil**
HEATING ELEMENTS			
	36000.0	3-Ferro	**25-Stainless 18/8 coil**

Component	Weight in g	Category	Material or Process
	35000.0	3-Ferro	**25-Stainless 18/8 coil**
Burner			
HEAT DISTRIBUTION SYSTEM			
Steam generator	494000.0	3-Ferro	**23-Cast iron**
CONTROL TECHNOLOGY			
Silicone cables	3000.0	2-TecPlastics	**16-Flex PUR**
	3000.0	4-Non-ferro	**29-Cu wire**
Electric components	2500.0	4-Non-ferro	**29-Cu wire**
	6500.0	1-BlkPlastics	**8-PVC**
Electronic components	1000.0	6-Electronics	**98-controller board**
MISCELLANEOUS			
Baking deck	450000.0	7-Misc.	**58-Concrete**
Fastening	18000.0	3-Ferro	**25-Stainless 18/8 coil**
Silicone filler	3500.0	2-TecPlastics	**14-Epoxy**
TOTAL weight	**2780300**		

4.3. DISTRIBUTION PHASE

The package volume is the most relevant parameter when it comes to describing the distribution phase. This volume directly determines the number of products that can be carried in a specific means of transportation, which contributes to the impacts of the distribution phase. The total weight of the packaged product is also a key element influencing the impacts of the distribution phase, but it is available though the Bill of Materials presented in section 4.2.4. , and thus will not be covered here.

4.3.1. DOMESTIC APPLIANCES

Domestic appliances manufacturers provide data about the package volume of the appliances they sell. The data available on the websites of the main manufacturers (identified in Task 2) were analysed and are presented in Table 4-11.

Table 4-11: Package volume of some domestic ovens available on the market in 2010

Type of appliance	Capacity (L)	Package volume (m^3)		
		Lower	Higher	Average
Built-in oven	50 - 60	0.256	0.328	0.292
Cooker	50 - 60	0.374	0.518	0.418

The size of built-in ovens ranges from 0.256 m^3 to 0.328 m^3, with an average of 0.292 m^3. No built-in gas oven was included in this panel, so no conclusion can be drawn concerning the influence of the energy source on the package volume. For cookers, the package volume ranges from 0.374 m^3 to 0.518 m^3 with an average of 0.418 m^3. The size varies from a manufacturer to another, but gas and electric appliances are of comparable size.

Table 4-12 presents data about the package volume of some free-standing domestic microwave ovens available on the market in 2010, gathered from the websites of three manufacturers; Brandt, LG and Samsung.

Table 4-12: Package volume of some domestic microwave ovens available on the market in 2010

Type of appliance	Capacity (L)	Number of models	Package volume (m^3)		
			Lower	Higher	Average
Combined	26 – 37	19	0.092	0.169	0.140
Grill	23 – 28	12	0.083	0.105	0.092
Solo	20 – 28	17	0.075	0.105	0.092
Steam	32 – 40	3	0.161	0.184	0.171

Combined microwave ovens (ovens able to cook with microwave but also with forced convection) usually have a bigger capacity and thus a bigger package volume. The grill feature does not seem to have an effect on the size of the appliance.

4.3.2. COMMERCIAL APPLIANCES

For commercial appliances, websites and brochures of 18 European manufacturers[28] have been studied. Commercial appliances manufacturers usually do not provide information about the dimensions of their packaged product, so only the external dimensions of the appliances were analysed. Table 4-13 presents the external dimensions of combi-steamers categorised by energy source. Commercial appliances exist in many different capacities, depending on the client's need, so the external dimensions are presented in subcategories of capacity (in number of GastroNorm containers[29]).

Table 4-13: External dimensions of combi-steamers available on the market in 2010

Energy source	Capacity*		Number of models	External dimensions (m^3)		
	GN 1/1	GN 2/1		Minimum	Maximum	Average
Electricity	6 - 7		46	0.251	0.664	0.583
	10 - 11		45	0.343	0.871	0.797
	12	6 - 7	8	0.463	1.119	0.859

[28] Angelo Po, Bartscher, BKI, Bonnet, Bourgeois, Convotherm, Electrolux Professional, Eloma, Elro, Fagor Industrial, HansKampf, Hobart, Küppersbusch, Lincat, Metos, Rational,Thirode, Unox.
[29] See Annex II.

Energy source	Capacity*		Number of models	External dimensions (m^3)		
	GN 1/1	GN 2/1		Minimum	Maximum	Average
	20	10 - 11	59	0.820	1.749	1.427
	40	20	26	1.870	2.739	2.223
Gas	6 - 7		22	0.558	0.684	0.630
	10 - 11		24	0.701	1.365	0.882
	12	6 - 7	5	1.026	1.119	1.066
	20	10 - 11	35	1.304	2.278	1.612
	40	20	14	2.171	3.389	2.578

* Appliances of comparable size were regrouped under the same category. For example, the third line refers to combi steamers with a capacity of either 12 GN 1/1, 6 GN 2/1 or 7 GN 2/1.

Gas combi-steamers are usually bigger than electric ones, due to the draught diverter which is present on the former but not on the later. The external dimensions are only indicative; the package volume will be bigger but the actual volume depends on the package design and cannot be determined from this data alone.

4.4. USE PHASE (PRODUCT)

Electric and gas ovens consume energy to cook food and the quantity they consume depends on several variables including:

- The quantity and type of food inside the oven (more energy is needed to cook 5kg of meat than 1 kg of meat, etc.)
- The temperature difference between the interior of the oven and ambient temperature
- Insulation of the oven (this prevents losses to the environmental)
- Removal by ventilation of hot air from inside the oven and hot combustion gases for gas ovens
- Heat absorbed by interior of oven (air, walls, racks, etc.)
- Type of energy source (gas or electricity).

The energy efficiency on the other hand is a ratio of the energy used to cook the food and the total energy consumed according to:

Oven energy efficiency = $H_1/(H_1 + H_2 + H_3)$ where:

H_1 = heat supplied to food

H_2 = heat supplied to interior of oven (internal air, racks, internal panels, insulation, etc.)

H_3 = heat lost to exterior of furnace or oven.

H_2 is mainly dependent on the internal panels, racks and other internal parts during short cooking times whereas the impact of insulation material becomes increasingly important with longer cooking times such as in commercial kitchens where ovens could be on for over eight hours. The effect of the properties of oven materials (metal, insulation, etc.) on H_2 according to:

$$H_2 = m.T_m.C_p \text{, where}$$

m = mass of material

T_m = mean temperature of material

C_p = specific heat capacity of material.

Therefore low mass of materials and low density insulation with low specific heat are ideal for minimising energy consumption.

H_3 depends mainly on the dimensions and properties of the cavity materials including the walls, mainly due to the insulation as $H_3 = \lambda \, \Delta T \, (A/d) \, t$ where:

λ = thermal conductivity of materials (Insulation)

ΔT = temperature difference between the inside and outside of the oven

A = cross-sectional area of insulated surface

d = thickness of insulation

t = time (process time).

Therefore H_3 is lowest with:

- Low thermal conductivity insulation – select appropriate insulation material
- The lowest practical oven temperature – limited by cooking requirements but forced convection does allow a temperature reduction
- Small oven cavity size – needs to accommodate food. A full oven is therefore more efficient than one only part full but this depends on the amount of food required so cannot be regulated
- Thick insulation
- A short cooking time – depends on recipe. Cooking times are shortened by not pre-heating ovens but many pre-cooked meals have instructions that specify oven pre-heating.

Measurement of oven efficiency is relatively difficult as this will depend on how the oven is used whereas it is straightforward to measure energy consumption and this is used for a comparison of all ovens on the EU market for the EU oven energy labelling scheme.

4.4.1. Domestic Electric and Gas Ovens

- **Domestic electric ovens**

Measurement of oven energy consumption must be based on a standard test procedure for the results to be comparable and so two versions of the wet brick test are used. One standard size brick is used for testing electric ovens larger than 12 litres and a similar test is used for gas ovens although there is no energy label for gas ovens and the test conditions are different.

The current EU energy labelling scheme uses seven energy bands which relate to three oven size ranges, small, medium and large. This could introduce some inconsistencies because ovens with sizes that are close to the maximum size of the small or medium range, i.e. just below 35 or 65 litres, must have lower energy consumption to be in band A than ovens that are just above the smallest size within the medium and large ranges as presented in Table 4-14.

Table 4-14: Maximum allowed energy consumption to be in band A

Oven volume (litres) and size range	Maximum energy consumption for band A (Wh)	Maximum consumption calculated as watt-hours / litre (Wh/l)
34 (small band)	600	17.6
36 (medium band)	800	22.2
64 (medium band)	800	12.5
66 (large band)	1000	15.2

This system allows ovens that are just above the minimum size within a size range to be in the same energy band but use more energy in watt-hours and in terms of Wh/l than ovens that are only slightly smaller and in a smaller size range. Examination of data supplied by CECED for over 5000 oven models does not show any evidence that oven manufacturers are using this potential loophole (see Figure 4-6 and Figure 4-7) although there is a cluster of ovens accounting for 7% of the ovens in the CECED database with cavity volumes of 65 – 66 litres so just in the large-size band. The three size ranges were originally defined to correspond to the three main sizes – small, medium and large. Below are described results from testing ovens using the wet brick tests and it is worth describing here the origins of these tests.

- Origins of “wet brick tests”

The aim of the tests is to measure the energy consumption of typical cooking. However, cooking is very variable with difference foods being common in different EU States. It was decided therefore to simulate roasting a chicken removed a refrigerator by using a standard ceramic brick that had absorbed water. The test conditions were based on results of the SAVEII study which obtained data for average energy consumption for cooking in western European countries. These varied but the average was 1.25 KWh per cooking cycle. CECED developed a database of energy consumption using the then draft standard method and the average energy consumption of ovens on the EU market at that time was 1296 KWh. Therefore the average cooking time was slightly longer than 1 hour. The SAVE II study checked its results for total EU oven energy consumption and from several sources, thought to be reliable, concluded that the energy consumption result of the study may be too low, i.e. cooking times are in reality on average longer than 1 hour. Since the SAVE II study was published in 2000, domestic electric oven designs have improved so that they consume less energy on average in the wet brick tests (there have been less change in gas ovens because there is no energy labelling requirement). The current CECED database of 1460 electric oven models shows that average test time is now 49 minutes. This would imply that cooking may be quicker in newer more energy efficient ovens but in reality this is very unlikely and cooking times for specific recipes may not have decreased in Europe although oven heating of pre-cooked food is increasingly common so that the average cooking time probably has decreased. Consumers probably cook specific recipes for the same length of time today as they did 10 years ago. This means that the wet brick tests are quicker than cooking the types of food that was typical 10 years ago in the EU although only by 10 or so minutes.

Extending the test by 10 minutes would result in a larger energy consumption in the test, although by significantly less than the time difference of 20%, as most heat energy is used in the earlier stages to bring the interior of the oven up to the operating temperature (which takes about 20 minutes). After 20 minutes, energy input is greatly reduced as heat is consumed by raising the temperature of the wet brick and from losses (from external surfaces, leaks etc.). It is estimated that only 10 – 20% of total input energy is consumed cooking food (so also for raising the brick temperature). An important question is whether the shorter cooking time is representative of domestic cooking in the EU. No quantitative measurements have been carried out so it is only possible to speculate but this is reasonable as in the past 20 years, there has been a large increase in cooking of pre-cooked meals with cooking times typically ranging from 15 to 30 minutes. This is shorter than times for baking and roasting meats which are believed to be less common than previously, so on average, cooking times are shorter. It is important that the wet brick test heating time is representative of average cooking times because if were to be too long, ovens would be designed with thicker insulation to prevent wall losses whereas this will increase the oven's thermal mass so that more heat energy is consumed during shorter cooking processes.

One final point to note is the results of tests with gas ovens are primary energy input whereas results from electric ovens is electrical energy and so primary energy consumption values would significantly larger.

- **Wet brick test results, MTP and CECED**

Recently the UK MTP published energy consumption test results for 36 ovens available in the UK including range and built-in ovens[30]. Each oven of double ovens was tested separately. Volume was also measured and did not always agree with manufacturers fi[…]lts sh[…]

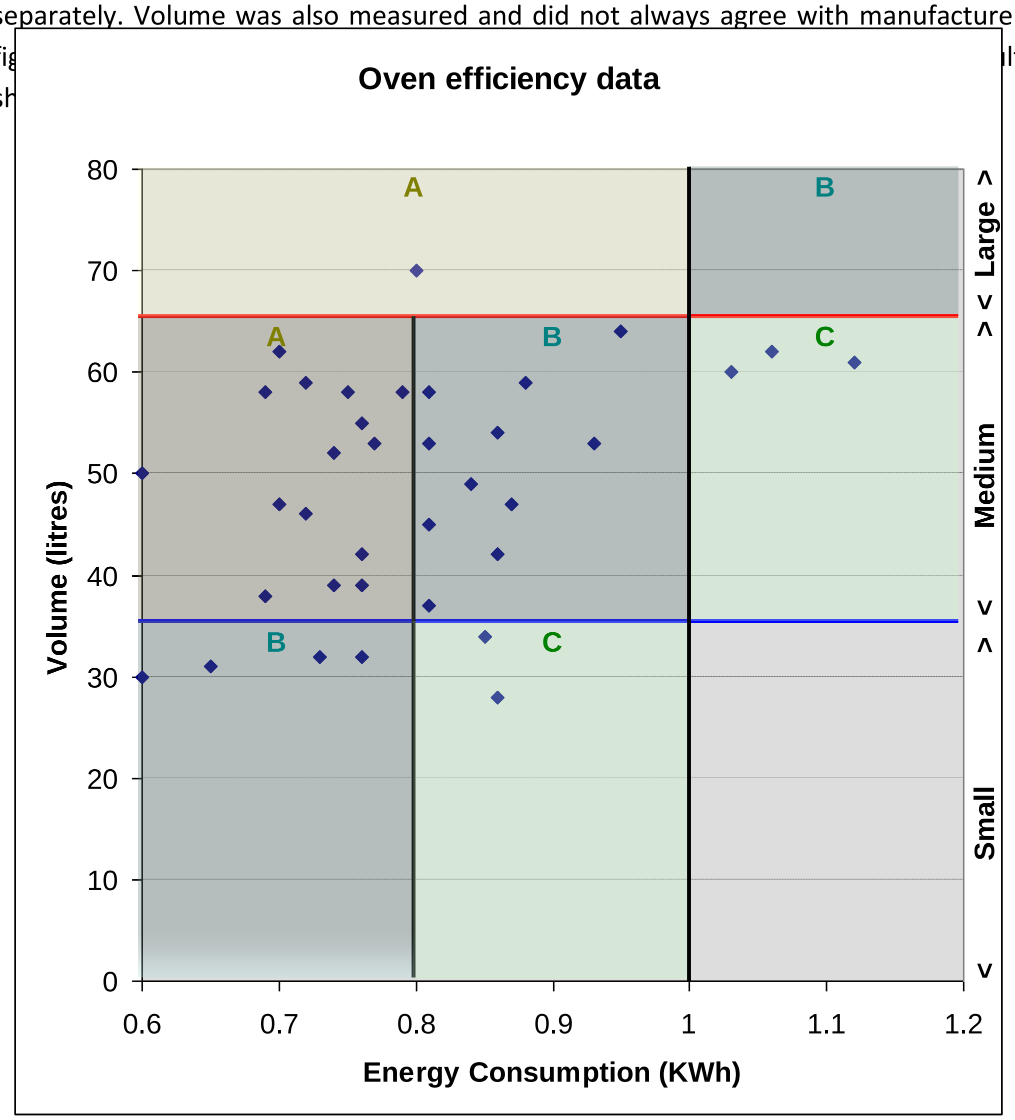

Figure 4-5: Energy consumption test results for domestic electric oven on the UK market (Source: MTP)

Figure 4-5 shows the test results, the size ranges and the A, B and C energy label bands. Most ovens are in bands A and B and most consumed between about 0.7 and 1.0 kWh irrespective of oven size. Other observations from the tests were:

Electric ovens with fans operating during tests consumed on average less energy than ovens without fans although this was most noticeable in the band A ovens. This may not be because fans ovens are more intrinsically energy efficient than those without fans but because ovens without fans tend to be cheaper and so of lower performance (or they may be older models in these tests). The effect of fans in ovens is reliably

[30] "2008/2009 Energy Label Market Picture Testing – Domestic Electric Ovens" Market Transformation Program report. Download from http://www.mtprog.com/cms/compliance follow link: "2009: Market Picture Testing 2008-2009 Ovens Report"

shown by the wet brick test result because when cooking food, fan ovens are usually set at a lower temperature than ovens without fans and so should consume less energy (except for the energy to operate the fan) if all other characteristics are the same.

Band A built-in ovens and band A range ovens have similar energy consumption but band B built-in ovens performed better than band B range ovens although the number of ovens in each group is statistically small, as presented in Table 4-15

Table 4-15: Built in vs. range ovens average energy consumption per energy band

Energy band of oven	Average energy consumed built-in	Average energy consumed range
A	0.72 kWh (9 ovens)	0.75 kWh (7 ovens)
B	0.78 kWh (9 ovens)	0.89 kWh (7 ovens)

More comprehensive data has been supplied by CECED for both electric and gas ovens.

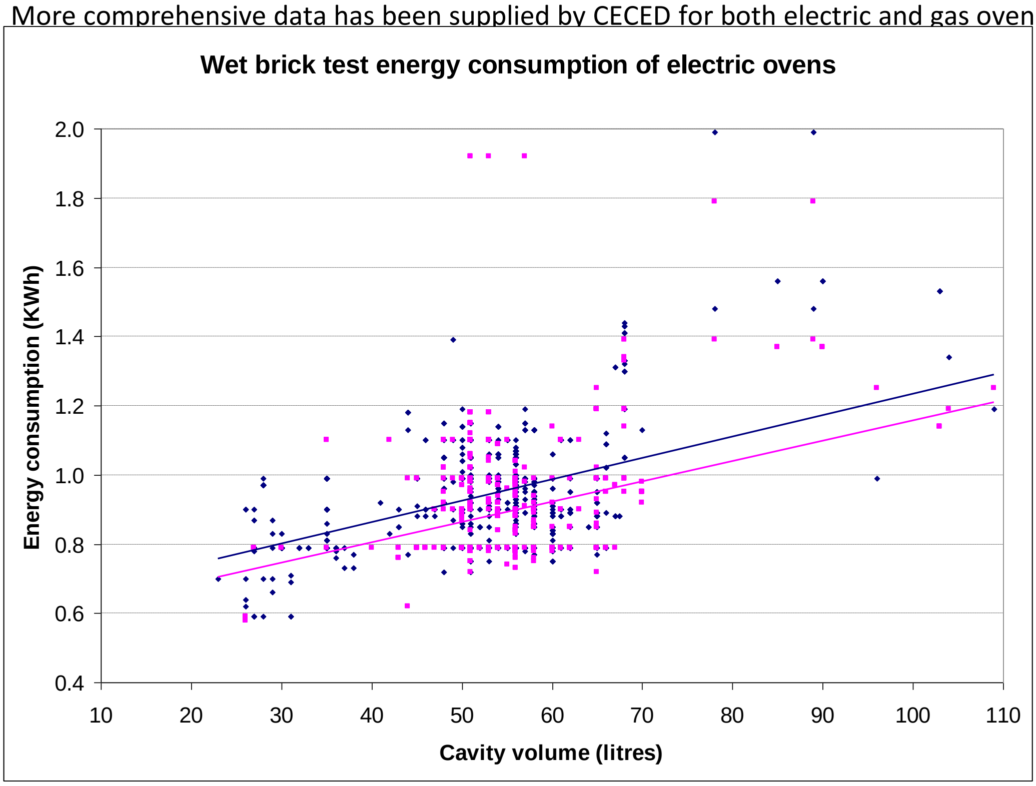

Figure 4-6: CECED wet brick energy consumption data for domestic electric ovens (blue dots and trend-line – no fan, pink dots and trend-line – with fan)

Figure 4-6 differentiates natural convection (blue dots and trend-line) and fan convection (pink dots and trend-line). Clearly there is a wide range of energy consumption within any oven size range and there is a relationship between oven volume and energy consumption for the natural convection ovens and for the ovens with fans. Larger ovens would be expected to consume more energy as there is more material within the oven to absorb heat and there would be expected to be more heat losses from a large external surface area than a small external surface area but the trend lines in Figure 4-6 show that the energy consumption per litre is lower for larger ovens than small ovens. For example with forced convection ovens:

- 40 litre cavity = 20Wh/l (800Wh consumed)
- 75 litre cavity = 13 Wh/l (1000Wh consumed)

CECED data for electric ovens also shows that:

- 70% of ovens with fans consumed less energy in the test
- 18% of ovens with fans consumed more energy in the test than without the fan
- 12% of ovens consumed the same amount of energy with and without a fan.

The electrical energy input into domestic electric ovens (main ovens only) ranges as shown in Table 4-16[31].

Table 4-16: Maximum and minimum energy consumption of domestic electric ovens on the EU market (Source: CECED)

Oven type	Characteristic	Energy consumed in wet brick test	Oven volume	Time to cook standard load (minutes)
Natural convection	Minimum energy consumption	0.59 kWh	All ovens that consume <0.7 kWh were ≤31 litres	41 or 45
	Maximum energy consumption	1.99 kWh	Two models with volumes of 78 and 89 litres	Not measured for 1.99 kWh oven but for 1.56 kWh oven with volumes 85 – 90 litres, time was 53 minutes
Fan convection	Minimum energy consumption	0.58 kWh	26 litres (one ovens that consumed 0.62 kWh was 44 litres)	41.0
	Maximum energy consumption	1.92 kWh	57 litres	46.5

There appears to be little direct relationship in Table 4-16 between oven energy consumption measured by the wet brick test and oven volume although a clear trend is visible when data for all ovens on the EU market are plotted. Cooking times (for a standard load) range from 41 to 58 minutes with natural convection and 41 to 57 minutes with fan convection although times with fan convection were usually, but not always, shorter.

As portable ovens are excluded from the electric oven energy labelling, there is no data in figure 4-6 for portable ovens. As there has been no incentive for portable ovens to

[31] Data from CECED.

have low energy consumption, it is possible that they will have relatively high energy consumption per litre of cavity volume compared to ovens that are required to display an energy label.

- **Domestic gas ovens**

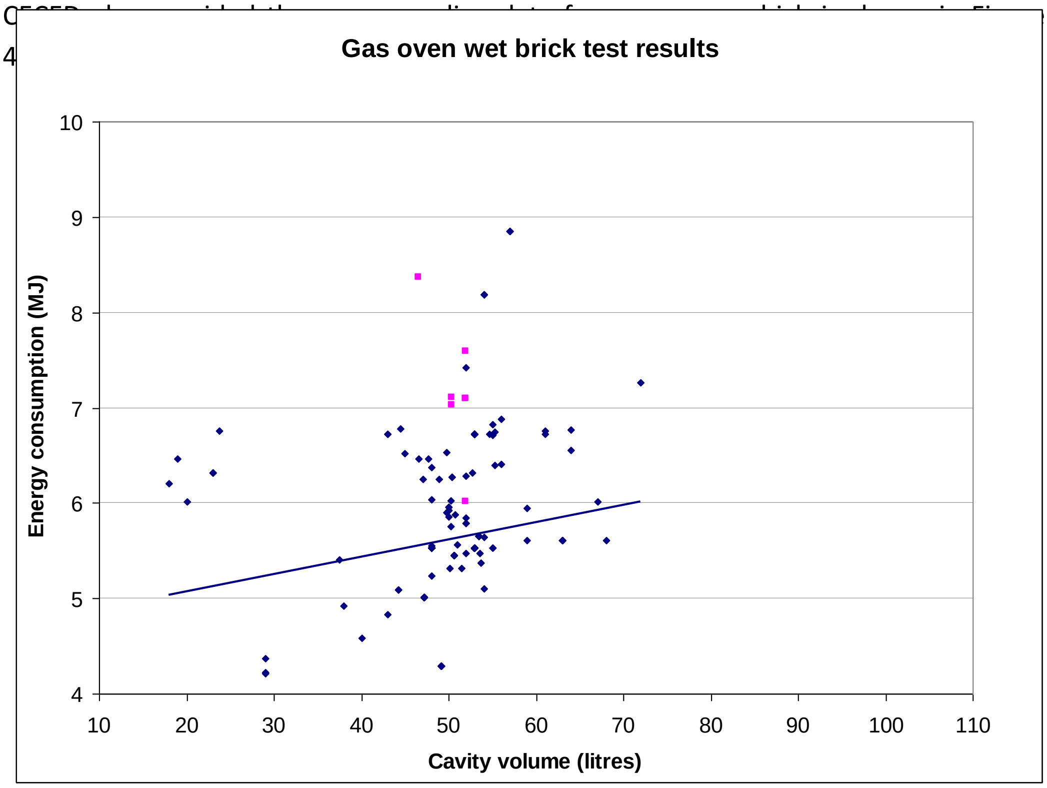

Figure 4-7: CECED wet brick energy consumption data for domestic gas ovens (blue – no fan, pink – with fan)

The gas oven data from CECED also shows a wide range of energy consumption within any size range, particularly between 50 and 60 litres. There is a relationship between energy consumption and oven volume as shown by the calculated trend-line (very wide scatter of data points) but there are some small gas ovens that consume as much energy as relatively large gas ovens. The data in Figure 4-7 for ovens of <30 litres correspond to secondary ovens whereas the larger ovens are mostly the main ovens. Unlike electric ovens, all gas ovens with fans consumed more energy than without fans. Several ovens can be operated with or without the fans and in all cases; energy consumption with the fan running was significantly higher.

The gas energy input into domestic gas ovens (main ovens only) ranges as showed in Table 4-17[32].

[32] Data from CECED.

Table 4-17: Maximum and minimum energy consumption of domestic electric ovens on the EU market (Source: CECED)

Oven type	Characteristic	Energy consumed in wet brick test	Oven volume	Time to cook standard load (minutes)
Natural convection	Minimum energy consumption	4.29 MJ	49 litres	51.6
	Maximum energy consumption	8.85 MJ	57 litres	59.2
Fan convection	Minimum energy consumption	6.01 MJ	52 litres	69.5
	Maximum energy consumption	8.37 MJ	47 litres	91.3

Heat storage ovens (as made by Aga, etc) appear to have higher annual energy consumption than traditional ovens. From task 3, the average energy consumption of a standard oven is 121kWh per year for electric and 183 kWh for gas. According to Aga's website, one double heat storage range oven consumes 220 kWh per week (11,440 kWh per year) and the same size of gas ovens 425 kWh per week[33] or 22,100 kWh per year although some of this heat energy is utilised for room heating and for the hob and so they cannot be directly compared to standard ovens. With control systems, the energy consumption of heat storage ovens can be reduced by 20% and the electric versions can heat up at night when electricity demand is low[34]. The models of heat storage oven described here are not intended for water heating and so are primarily for cooking in the double (or triple) ovens and also on the hob although there is excess heat that will be utilised for building heating when this is needed in cold weather.

4.4.2. COMMERCIAL OVENS

In UK, 70 - 75% of commercial ovens are gas with 25 - 30% electric although electric ovens are increasingly popular for new sales due to the issues associated with connecting gas supplies and venting combustion gases[35]. Commercial gas ovens are also popular in France (60 – 65%) but electric is more common where piped gas is not so widely available such as in Germany. No comparable energy consumption data such as has been provided by CECED is available for commercial ovens. An Energy Star standard exists for commercial electric and gas ovens and Energy Star claim that

[33] http://www.aga-web.co.uk/183.htm
[34] http://www.aga-web.co.uk/SiteImages/Site_111/Pdf/Aganomics_V3.1.pdf
[35] Information from CESA (Catering Equipment Suppliers Association)

Energy Star approved ovens are 30% more energy efficient than other ovens[36]. This applies to ovens on the US market only which are different models to those sold in the EU but does suggest that energy efficiency will also vary in the EU. CESA report that tests by European manufacturers show that heating in commercial ovens can be uneven within the cavity which would be due to insulation, air convection and leaks.

No test standard exists to measure the energy consumption of electric commercial ovens but these are being developed by EFCEM. The only information provided by manufacturers which can give an idea of the energy consumption is the power of the appliances and comments made on manufacturers' websites.

Most of the commercial ovens sold on the EU market are programmable, meaning that they are not used at their full power throughout the cooking cycle. Having a higher available power could even reduce the total energy consumption by heating the cavity more rapidly, thus reducing the heating time although this potential benefit will not be realised when ovens are left on for long periods as is standard practice in restaurants and hotels where food needs to be cooked quickly on demand.

Websites and brochures from 18 European manufacturers[28] have been studied. Combi -steamers were identified as being the most relevant type of commercial oven to analyse as these are sold in the largest numbers. Data presented in the following are exclusively related to gas and electric combi-steamers.

- **Commercial electric combi-steamers**

Figure 4-8 presents the installed electric power of 202 commercial electric combi-steamers. The capacity of appliances designed to be used with GN 2/1 containers was measured in GN 1/1 containers considering a GN 2/1 container to be equivalent to two GN 1/1 containers.

[36] http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COO

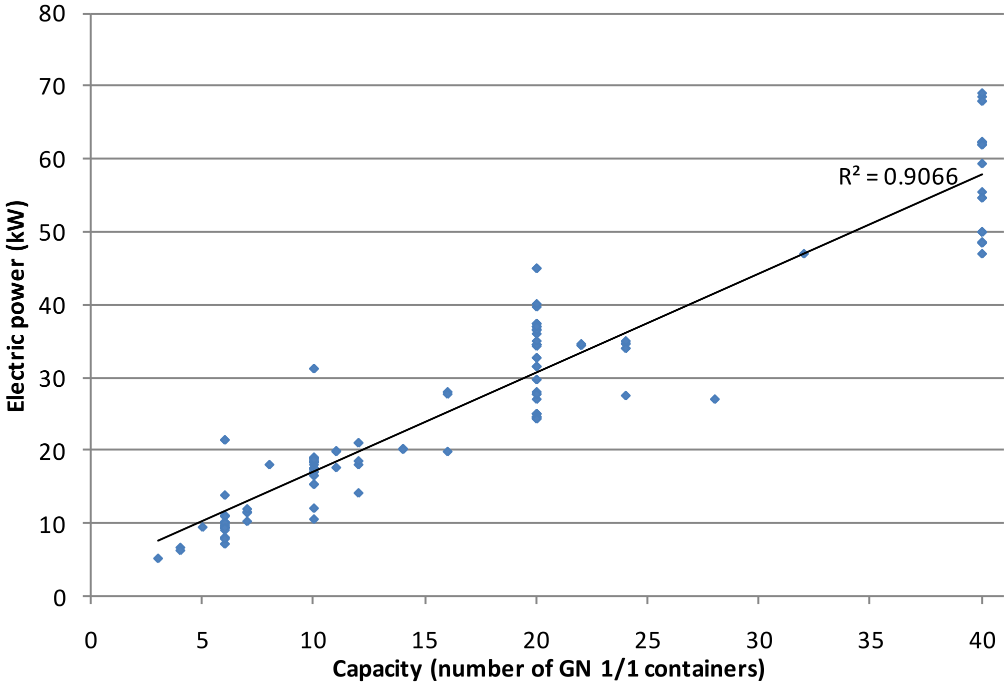

Figure 4-8: Installed power in commercial electric combi-steamers from 18 European manufacturers[28]

For the same capacity, the installed power of a commercial electric combi-steamer can vary widely. For example, the power of appliances of 20 GN 1/1 varies from 24.3 kW to 45 kW.

There seems to be a much clearer relationship between capacity and power for commercial appliances than between oven volume and energy consumption for domestic appliances. The correlation between the trend-line and the points is high enough to pinpoint this relationship.

- **Commercial gas combi-steamers**

Figure 4-9 presents the installed gas power of 114 commercial gas combi-steamers. As for electric appliances, the capacity of appliances designed to be used with GN 2/1 containers was measured in GN 1/1 containers considering a GN 2/1 container to be equivalent to two GN 1/1 containers.

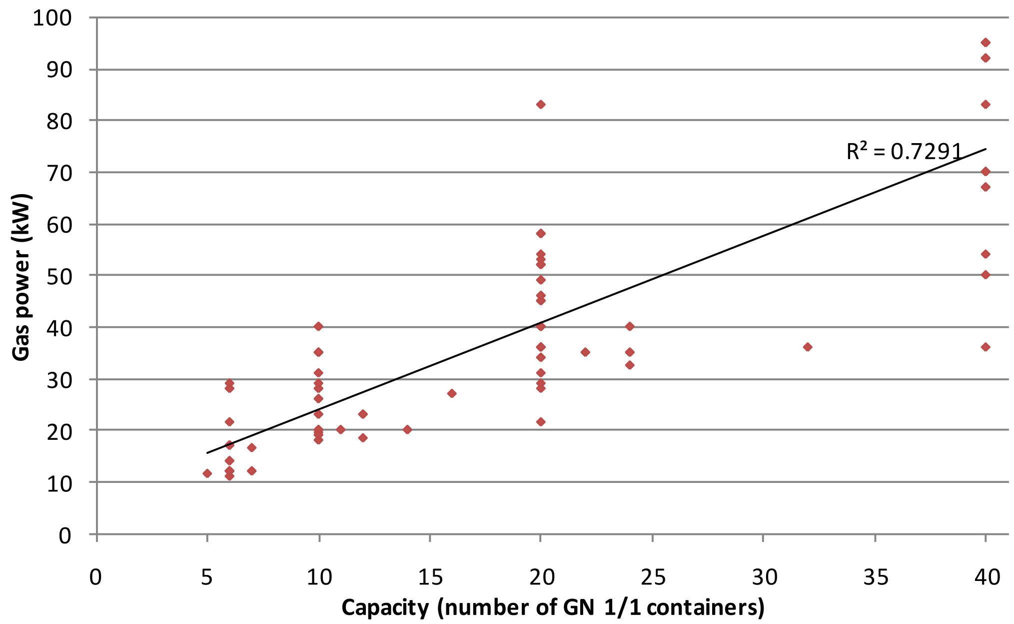

Figure 4-9: Installed power in commercial gas combi-steamers from 18 European Manufacturers[28]

Some aspects of the graph presented in Figure 4-9 are questionable:

- The 20 GN 1/1 appliance with the highest gas power might not be correct. On the manufacturer's website, this appliance has indeed the same gas power as the appliance of 20 GN 2/1, which is twice its capacity. This could be an error.
- The appliance of 20 GN 2/1 with an installed gas power of 35 kW also has an installed electric power of 9 kW, whereas all the comparable appliances have less than 2.7 kW of electric power. The technology used might be different and thus this appliance might not be comparable to the other ones.

The correlation coefficient of a linear regression is not high enough to conclude that there is a clear relationship between the capacity of the appliance and its installed power. Even without the questionable points, it is below 0.8.

- **General observations**

It appears from the graphs presented in Figure 4-8 and Figure 4-9 that there are many different designs of combi-steamers. The power of the appliance is not directly related to its energy consumption, and appliances with the highest power are not necessarily the least efficient appliances.

Nevertheless, those variations are sufficient to conclude that there are also variations in the energy efficiency of these appliances, and so there is potential for improvement for the most inefficient appliances currently available on the market. Without a standard to measure the energy consumption of commercial combi-steamers, it is impossible to compare them accurately. However, there are clear indications from manufacturers marketing (described earlier in this report) that some models are more energy efficient than others. Design features such as external boilers, multiple door glazing, insulation and low power modes all affects energy consumption in the use phase. Variation in the energy consumption performance of baking ovens is also likely based on information from manufacturers and their marketing.

- **Low power modes**

The European Commission has confirmed that commercial ovens do not need to comply with the standby and off- mode power consumption Regulation 1275/2008/EC but many models of combi-steamer oven have low power modes that maintain the ovens at ~200°C. Tests of five combi-ovens by the Danish Technology Institute show that energy consumption in this mode varies significantly (measured over 24 hour periods) from 37.6 kWh/24 hours to 51.4 kWh/24 hours. In these limited tests, the best consumes 27% less energy than the worst in these tests with five brands of oven[37] although there were too few ovens tested to determine the overall improvement potential.

4.4.3. Microwave oven cooking

The energy efficiency of microwave ovens is higher than that of electric resistance or gas heated ovens. Industry estimates that typically up to about 40% of the input energy is transferred to the food although this figure depends on many variables particularly the size of the load and whether it is being heated to raise its temperature or extended cooking is being carried out. US research from 1996 indicates that efficiency could be as high as 56%[38]. MTP has compared microwave oven energy consumption with electric ovens for a range of cooking processes[39]. MTP measured the energy consumed by the microwave oven and by a conventional electric oven for each cooking process to determine the potential energy saving. A few selected examples are:

Table 4-18: Potential energy saving by cooking with microwave oven instead of conventional cooking (MTP study)

Food cooked	Energy saved by microwave oven*
Frozen pizza (defrosting and heating)	22%
Lasagne ready meal (heating pre-cooked)	40 – 81%
New potatoes with little water in microwave compared with cooking on hob with more water	70 - 75%
Whole chicken (cooking with microwave plus convection heating)	23%

* Solo microwave ovens used for above tests except for cooking the whole chicken where a Panasonic NN-A725 MBBPQ convection microwave was used.

[37] Unpublished data provided by the Danish Technological Institute.
[38] http://www.sabaf.it/opencms/opencms/Risorse/News/eventi/carbJMcMahon.pdf
[39] MTP report BNCK07: Comparing energy use in microwave ovens with traditional electric fuelled methods, July 2009, available at http://efficient-products.defra.gov.uk/spm/download/document/id/786

The results of cooking with a microwave and a heat oven are not always identical and consumers often prefer to use heat ovens for this reason. However, there is little or no difference for heating pre-cooked food and defrosting. VHK has measured total primary energy for heating water by several methods including an electric kettle and three types of hob as well as with a microwave oven[40]. The theoretical minimum energy required to raise the temperature of water does not depend on the heating method but the total energy consumed depends on a wide variety of heat losses. The VHK work found that heating water in a microwave oven had very similar primary energy efficiency to an electric kettle at 19% but was more efficient than the two types of electric hob. In terms of primary energy, heating water on a gas hob was more energy efficient at 23% than with a microwave oven as gas energy incurs no electricity generating losses, which are considerable for all of the electric heating methods. The main advantage of the microwave oven is that easier to heat the correct amount of liquid with no unused heated water whereas with kettles and pans, there is often some water heated unnecessarily.

There is no published comparative energy consumption data for microwave ovens on the EU market. US test results which correspond to microwave ovens sold in USA in the 1990s has been published but is inevitably somewhat out of date[38]. This showed that microwave oven energy efficiency using a US test method varied between 51.5% and 63.5% and was not dependent on cavity volume. Japanese tests for the Top Runner standard also showed variation in energy consumption with the best Japanese oven consuming 19% less than the one with the highest consumption[41]. Also, energy consumption does not appear to be related to cavity volume in Japanese microwave ovens.

CECED has provided test result data from the development of the new microwave oven energy consumption measurement standard. 123 microwave ovens including solo ovens, ovens with grills, ovens with convection heating and a few where microwave heating is not the primary function. In the test, water is heated and the energy consumption in Wh is calculated using a formula intended to reflect average use. Results range from 48.7 to 79.6 Wh for all ovens but for solo ovens the range is inevitably smaller from 48.7 to 64.4 with an average of 53.5 Wh. For all ovens, the largest energy consumption value is 63% more than the least and for solo ovens, the largest was 32% more than the least. No dependency on cavity size was found for solo ovens. The addition of a grill was found to have only a very small effect whereas the addition of convection heating increased average consumption from 53.5 (for solo ovens) to 60.6Wh (an increase of 13%).

There does therefore appear to be potential for improvement although this is smaller than for heat ovens. Also, the number of ovens with the higher energy consumption

[40] http://www.vhk.nl/downloads/Energy%20analysis%20Quooker%20main%20final%20april%202010.pdf
[41] http://www.eccj.or.jp/top_runner/pdf/tr_microwaveoven.pdf

values is a relatively small proportion of the market with most models being fairly similar in performance.

Clearly, an increased use of microwave ovens instead of conventional cooking would reduce energy consumption in the EU but consumers are resistant to change, especially if they perceive that the microwave cooked food quality is inferior. Although some food cooked in a microwave is very similar to that cooked by traditional methods, consumers are slow to change, and especially as the energy saving benefits are not immediately obvious or significant. Attempts in the past to encourage greater microwave oven use have been fairly unsuccessful.

Commercial kitchens use microwave ovens much more frequently because there are functional benefits; heating pre-cooked meals is much more common and much shorter cooking times increase throughput. Although microwave ovens can potentially save energy and reduce energy costs, this is not the reason why they are purchased or used.

Domestic combination microwaves ovens that include radiant grills are sold in relatively small numbers but commercial combination ovens with convection heating are common as these shorten cooking times and give similar results to convection ovens. Although some domestic microwave ovens are used in commercial kitchens, commercial microwaves are more robust, higher powered and tend to cook food faster. Smaller commercial combination ovens have single cavity magnetrons but bigger commercial microwave ovens (both standard and combination) have double magnetrons and rotating passive antennas to obtain uniform heating.

4.4.4. ENERGY CONSUMPTION IN STANDBY MODE

All domestic ovens are in scope of EU Regulation 1275/2008 that limits the energy consumed in standby to 2W with a display. Most ovens on the EU market have a clock which is a display as understood by the regulation. This maximum allowed power consumption in standby halves to 1 W in 2013 and all new ovens will have to comply with these limits. The maximum calculated energy consumption of ovens in the EU based on stock levels for 2008 from table 22 of the task 2 report, but excluding portable ovens, and using the 2 and 1 watt maximum energy consumption limits is presented in Table 4-19.

Table 4-19: Maximum energy consumption of EU domestic ovens in standby mode

Type of oven	Total maximum standby energy consumption assuming 2 watts per appliance	Total maximum standby energy consumption assuming 1 watt per appliance
Microwave oven	2.45 TWh/yr	1.22 TWh/yr
Range oven	0.79 TWh/yr	0.39 TWh/yr
Built in oven	3.07 TWh/yr	1.53 TWh/yr
Total	**6.31 TWh/yr**	**3.14 TWh/yr**

It is currently not clear to commercial appliance manufacturers whether commercial appliances are covered by any kind of regulation concerning the energy consumption in standby mode.

4.5. USE PHASE (SYSTEM)

Ovens in domestic and commercial kitchens

Ovens are usually used inside buildings and the heat generated by the oven influences the temperature of their surroundings and can affect local energy use. Situations where this can occur include:

- In cool climates where buildings are heated (with thermostatic temperature control). Heat from the oven offsets and reduces the amount of heat energy required to maintain the required ambient temperature.
- In warm climates, the heat generated by the oven may raise the local temperature so that ventilation by fans or cooling by air-conditioning is required.
- In commercial kitchens, much more heat can be generated than in domestic kitchens so that air conditioning may be needed even in cool climates although many kitchens use extraction hoods or ceiling ventilation to extract air from the kitchen.
- Where gas cooking is used, ventilation to remove combustion gases may be used. This is common in commercial. kitchens and will be required by legislation in some EU States in domestic kitchens (e.g. France).

The overall impact of heating buildings by ovens in cool climates depends on the type of fuel / energy source used for building heating and for the oven. If the building heating and the oven both use natural gas as the energy source, the quantity of energy used and global warming gas emissions evolved (mainly CO2) is the same whether heat is from the building's heating or from the oven. Similarly, there is no difference if the building heating and the oven are both electrically powered. However, if the building is heated by natural gas, oil or coal and the oven is electrically powered, there is a significant difference. The energy consumed to heat the building (using gas, oil or coal) will be less than the energy consumed to generate and transmit the electricity to operate the electric oven and provide equal heating. This is mainly because of the inefficiencies and losses from electricity generation and transmission which overall is about 30 - 35%. Building heating efficiency tends to be 75 – 90% (highest with modern condensing boilers). The relative CO_2 emissions are more varied as electricity is generated from a variety of fuels in the EU. Published figures vary between 0.45kg CO_2/kWh[42] (for all of Europe) and 0.39 kg CO_2/kWh (2007)[43] (EU estimate). Most of the

[42] Carbon Monitoring for Action (CARMA), www.carma.org

electrical energy supplied to an electric oven is converted into heat which is eventually lost to the interior of the building (unless removed by fans or air-conditioning). Published figures for the amounts of CO_2 emitted from fossil fuels used for building heating are presented in Table 4-20.

Table 4-20: CO_2 emissions per kilowatt hour of chemical energy from combustion of different fossil fuels

Energy source	kg CO_2 / kWh[44]
Natural gas	0.184
Oil	0.265
Coal	0.30

Comparison of heat from ovens with heating using heat pumps is even more complex. Heat pump heating efficiency can be > 100% and some can achieve better than 300%. This means that 3kWh of energy is released inside the building for every 1 kWh of electricity consumed. Clearly heat pump heating of buildings is more energy efficient than heating using an electric oven which cannot exceed 100% efficiency but the difference compared with gas ovens depends on the heat pumps actual efficiency. The comparison of heat source for buildings described above ignores the location of the kitchen and additional ventilation required to remove odours and combustion gases where gas is used. This has however been studied by UK Market Transformation Programme (MTP) although the results are applicable only to the UK's climate.

The so-called "heat replacement effect" has been studied by MTP[45]. MTP define the heat replacement effect as "the contribution to heating made by lighting and appliances in heated living space". This research shows that heat from appliances such as ovens is generated throughout the year but building heating may be required for only part of the year (41% in UK). Also, MTP state that for electric and gas cooking (ovens), ventilation is required so that only 60% of the heat is utilised within the building. They also find that the heat from cooking is generated away from the main living area so that only 75% is transferred to the living area. MTP calculate the heat replacement factor by multiplying these three factors = 60% x 75% x 41% = 18%. MTP have also looked at commercial buildings but there is very limited data and none for cooking.

Where domestic ovens are used in warm climates, the heat produced may have to be removed. This may only require an open window but ventilation fans or air conditioning may be required. The energy consumed will depend on the cooking time (for ventilation fans) and the amount of heat generated (for air conditioning).

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[43] Eurelectric calculation

[44] MTP report BNXS01, 2010 and D. Mackay, "Sustainable Energy without the hot air", http://www.withouthotair.com/

[45] MTP report BNXS05 version 9.0 updated 15th March 2010.

In commercial kitchens much larger amounts of heat are produced but where gas appliances are used, ventilation is required to remove combustion gases. This is not usually well controlled or selective, so in cool climates, large quantities of heat from buildings are lost which may need to be replaced. Overall therefore energy is used for operating the appliance and energy is consumed to heat air to replace air lost by ventilation.

The total energy consumption from cooking is often greater than the energy used by the oven alone although the total amount of energy will depend on the oven design. For example, if a gas oven can draw in air from outside the building and expel combustion fumes directly outside of the building, these will have little impact on the energy used for building heating or cooling. Energy efficient appliances that consume less energy should also have a smaller impact on energy needed for building temperature control than less energy efficient appliances.

Commercial baking

Commercial bakeries increasingly use frozen dough or frozen part-cooked dough for breadmaking, particularly in supermarkets. The EU freshbake study found that the energy required for making bread from frozen part cooked dough consumes more than four times as much energy as traditional breadmaking[46].

4.6. END-OF-LIFE PHASE

Cooking appliances such as ovens contain a high proportion of metals and are usually shredded at end of life and the metals separated for further treatment and recovery, usually with high yields. Ovens contain very little plastic but glass is used in large quantities and, if removed and separated, can be recycled efficiently. Recycling is mandatory in the EU for all collected ovens and as these are fairly large, collection rates are relatively high. It is necessary to remove hazardous parts before recycling; the only part that will need to be removed from appliances that are currently being sold is the capacitor in microwave ovens as these are oil-filled. To facilitate recycling, these capacitors are located in a convenient place (at least by the manufacturers who are members of CECED) for easy removal.

4.7. RECOMMENDATIONS ON MANDATES

Although several European Standards exist for ovens, there are many products not covered by existing standards. New standards will be needed if implementing measures requiring minimum energy efficiency or maximum energy consumption are to be imposed. The following table describes existing standards and their limitations.

[46] http://eu-freshbake.eu/eufreshbake/brochure%20FRESHBAKE%20rz.pdf

Table 4-21: Existing EN standards relating to energy consumption and their limitations

Number	Scope	Limitations
EN 30-2-1 & 30-2-2	**Domestic gas hobs and ovens.**	Maintenance consumption of gas ovens specified – empty gas oven used to maintain specified temperature. Not a realistic test.
EN 50304:2009 / EN60350:2009	**Electric domestic ovens** Built-in or standalone but not portable. Wet brick test measures energy consumption of ovens. Electric domestic built-in and standalone (range).	Test realistic for shorter cooking times but may not assess performance of insulation adequately which is more important for longer cooking times (>1 hour). Not applicable to **portable** ovens (see comment below) although can be used with ovens having cavity of >12 litres.
EN61817	**Portable electric ovens, hobs and grills**. Performance tests only.	Need energy consumption measurement procedures for portable ovens of <12 litres.
EN60705 (under review)	**Domestic microwave ovens**. Includes an energy efficiency measurement procedure based on heating water and quoted as %.	Excludes non-domestic appliances. CENELEC working on improved test.
EN15181	Wet brick test for **domestic gas ovens.**	Excludes small size ovens. Allows ~10% variation from value quoted by manufacturer.

The "wet brick tests" may be used for domestic ovens with cavity size larger than 12 litres whereas the energy label is not applicable to portable ovens which are defined as being less than 18kg. Most portable ovens are <18 kg and >12 litres and so these tests are suitable for measurement of energy consumption of most portable ovens on the EU market. For those that are <12 litres, the standard brick is too large and there is a risk that the thermocouples can touch the heating elements.

The wet brick test relies on a temperature increase of 55K in the wet brick and this takes about 46 minutes (45 – 58 minutes) for electric ovens[47]. This was originally chosen to represent an average cooking time but many recipes require much longer times, some are 2 – 3 hours. During the initial ~30 minutes, most energy is absorbed by the interior of the oven and very little is conducted through the insulation. With longer cooking times, the interior parts do not absorb more heat but heat is conducted through the insulation to the exterior as well as being lost by ventilation. More efficient insulation with a lower thermal conductivity may have little impact on a test with duration of 46 minutes but is likely to have an impact after 2 hours oven use. However

[47] Actual test results supplied by CECED.

there are practical difficulties in extending the time of the current test significantly (e.g. drying out of the brick, limited thermal capacity of the brick) and small time increases will have a negligible effect on total energy consumption. If domestic electric oven use is typically about 46 minutes then the current test is meaningful and will give a good assessment of performance. If longer cooking times are uncommon then these can be ignored but no reliable data on actual cooking practices in households is available. If long cooking times are not uncommon then some modification of the test would be needed to assess insulation performance more reliably. Conversely, if the heating time of the test is much longer than real cooking, this will encourage more insulation which will increase thermal mass and more energy will be consumed in the EU than necessary for average cooking processes. This is why it is essential to use realistic cooking times for these measurements. The Save II study[48] reports (table 1) that average energy consumption per dish by electric ovens in EU States varied between 0.94 to 1.56 KWh. This was in 2000 when most ovens would consume ~0.8KWh in the wet brick test (most being B or C energy rated) and so the cooking times would be 70 to 117 minutes, i.e. slightly longer to more than double the time that is currently typical of the wet brick test. It is possible therefore that the current wet brick test period is too short and so under-estimates the energy consumed per real average EU dish.

EN 50304 and EN 15181 (the wet brick tests) exclude ovens without adjustable temperature control and so fixed temperature heat storage ovens are not tested by these standard methods. It would be very difficult to test these ovens by these methods and they would perform very poorly.

A latest draft version of the EFCEM standard test method that is being prepared for the measurement of energy consumption of commercial combination ovens gives procedures for convection ovens, combi-steam and steam only ovens. This is suitable for both electric and gas heating and uses two stages for testing. In the first, the ovens are heated up to 160°C empty and then maintained at this temperature for 2 hours and the energy consumed during the second hour is measured. This will give a measure of the insulation and heat retention performance of the oven. The next step is in dry heat, steam or combi steam modes and "wet bricks" as used for the domestic test are used. The number of bricks used is based on the oven size. For the dry heat test, the wet bricks are loaded into the oven at 160°C and the energy consumed to raise the internal wet brick temperature by 60K is measured. The EFCEM test method is different to the domestic oven tests because commercial ovens are used differently. The test procedure appears to reflect the way that commercial ovens are used fairly well and the measurements of energy to heat up, heat the empty oven maintaining 160°C and heat wet bricks should give useful data to assess the performance of commercial ovens. Research by CETIM to compare the EFCEM/ENAK test method with cooking real food showed that the energy consumed is not the same. CETIM compared the results of heating wet bricks and several types of real food for convection only and

[48] "Efficient domestic ovens, final report". Save II Project (4.1031/D/97-047), Pirkko Kasanen, 2000

convection plus steam with one type of commercial oven. In convection mode, the energy consumption results were similar although not surprisingly depended on the type of food. In tests with steam plus heat, using a type of roasting meat (not a chicken on which the wet bricks are intended to simulate), the real food consumed much more energy than the wet brick. One reason is that real food contains much more water than wet bricks and so would be expected to require more energy. Although the EFCEM/ENAK test method may under-estimate the amount of energy required to cook food, it is possible that the method should give a reproducible comparison of commercial ovens as it does simulate how these are used in practice and the energy consumed is proportional to the main sources of heat loss i.e., adsorption by interior of oven, though insulation and from vents.

Standards not currently available:

Energy consumption test methods for:

- Commercial ovens – electric and gas (all types)
- Commercial ovens – microwave
- Portable and small ovens – all types

Trade associations representing commercial catering equipment are developing energy measurement standards for several types of commercial ovens. These will be different to the tests used for domestic ovens because these tend to be much larger and are used differently, commonly for much longer periods and so insulation performance and ventilation control are more important.

New standards would be needed because:

Energy labels must be based on standard energy consumption test methods. Energy labels could use the same approach as is used to support the eco-design regulation for washing machines and several other products where an Energy Efficiency Index (EEI) is used. An EEI could be calculated based on the wet brick test result plus energy consumed in other modes (standby, cool-down, etc.). Existing energy consumption measurement standards ignore cool-down mode energy consumption.

Energy labels are needed if the number of appliances is significant and the potential for eco-design improvement is large:

- Commercial ovens – Little data is available on sales (Prodcom codes are too broad in scope) and no data on energy efficiency. Numbers sold will be less than domestic but used much more intensively.
- Portables – Prodcom code 27.51.28.90 includes portable ovens. This gives an average product price of only €20 whereas UK retail prices range between €24 (£20[49]) and >€240 (£200) and the PRODCOM Eurostat figure may be too high.

[49] Exchange rate used: 1.00 GBP = 1.20 EUR, as for 1st September 2010.

Most portable ovens (mini-ovens or table-top ovens) are imported into the EU (from Asia and Turkey) and are widely sold at least in Italy and UK. 2008 EU consumption was 11.9 million units, which would have a large total energy consumption. Some models also have two hotplates which are always of the solid plate type that are the least energy efficient.

- Gas ovens – sold in large numbers although fewer than electric. CECED data shows a correlation between cavity volume and energy consumption and variation in energy consumption that indicates that there is a significant potential for improvement.

Unreported tests carried out by CECED showed that the door seals of portable ovens were unreliable so that energy consumption could not be measured consistently. This observation along with the lack of an energy label indicates that there could be a significant potential for energy reduction for these products.

The current energy label is based on the standard wet brick test carried out with standard ovens without accessories. If accessories are available and are popular they could consume significant energy but this is excluded from these tests so that the user has no indication of their impact on energy consumption.

4.8. CONCLUSIONS

This task presented a general technical analysis of the existing products on the EU-market. It details the technical solutions used in domestic and commercial ovens and their characteristics relevant for the distribution phase. It presented an analysis of their use phase both at the product and at the system level, and of their end-of-life.

Domestic and commercial ovens use many components, which represent as many possibilities to reduce the environmental impact. For a significant reduction, it will be necessary to improve each component, keeping in mind the possible cross-effects which could decrease the global efficiency of the oven by using the most efficient technology for a single component.

New measurement standards will be needed for commercial ovens and small portable ovens as well as new labelling standards if implementing measures requiring minimum energy efficiency or maximum energy consumption, are to be imposed.

The information gathered in this report will serve as input for defining base-cases in task 5.

The British thermal unit (BTU or Btu) is a traditional unit of energy, commonly used in USA which is equal to about **1.06 kilojoules**. It is approximately the amount of energy needed to raise the temperature of one pound of water by one degree Fahrenheit.

The standard unit of energy in the International System of Units (SI) is the joule (J), equal to one watt second (1 watt.s = 1J) or inversely, one watt is equal to 1 J/s. One kilowatt hour is 3.6 megajoules, which is the amount of energy converted if work is done at an average rate of one thousand watts for one hour.

Also note:

The kilowatt-hour (kWh) is not a unit of power, it is a unit of energy.

The kW is a unit of power = 1000 W or 1000 J/s.

Energy = power × time

If we choose to measure power in kW and time in hours, we have:

Energy (kWh) = power (kW) × time (h)

Joules and Btu are also both units of energy and therefore Btu, MJ and kWh are directly convertible. However, there are several complicating factor when considering the relationship between gas and electricity. Electricity has to be generated and this is only about 30% efficient from fossil fuel power plant. Also, there are four recognised types of natural gas in EU and some town gas is also used. These have different chemical compositions and as a result have different energy values as well as emitting different amounts of carbon monoxide. The standard energy consumption tests use "standard gas" to avoid inconsistent results.

Carbon dioxide emissions

Electric oven energy consumption is usually quoted as KWh whereas this is a measure of electricity but not of primary energy which depends on conversion efficiency. The relationship with CO2 emissions is more complex as the range of energy sources used for electricity generation in EU States varies considerably. In most States fossil fuels predominate but France has a high proportion of nuclear and Sweden has a high proportion of hydro-electric power. One option would be to quote all energy consumption figures as primary energy. The Energy Services Directive (2006/32/EC) uses a European Energy factor of 2.5 whereas the MEEUP Ecotool uses 2.9. In practice, it is difficult to compare gas and electric oven energy efficiency and CO2 emissions because:

- Piped gas is not available throughout the EU although bottled LPG is available
- Users have preference for gas or electricity

- The kg CO2 emissions / KWh of electricity varies across EU and over time will change as EU States make changes to meet the targets for 20% reduction in GHG by 2020 and 80% reduction by 2050. Some EU States will make these changes faster than others. National electricity grids are gradually being connected so that differences between national kgCO2/kWh differences will decrease but it is preferable not to transfer electricity over very long distances because there are losses due to the electrical resistance of the transmission cables.

In contrast to the domestic sector where the capacity of an oven is usually measured by the inner volume of the appliance, the capacity of commercial ovens is given in number of GastroNorm containers that can be loaded.

GastroNorm sizes are standard sizes of containers used in the catering industry specified in the EN 631 standards:

- GN 1/9: 108 x 176 mm
- GN 1/6: 176 x 162 mm
- GN 1/4: 265 x 163 mm
- GN 1/3: 325 x 176 mm
- GN 1/2: 325 x 265 mm
- GN 2/3: 354 x 325 mm
- GN 1/1: 530 x 325 mm
- GN 2/1: 650 x 530 mm

For a given size, there can be different heights. The most common heights are:

- 20 mm
- 40 mm
- 65 mm
- 100 mm
- 150 mm
- 200 mm

GastroNorm containers allow to stock, transport, cook, serve up, etc. They can be made out of stainless steel, enamelled steel, metal covered with anti adhesive, composite plastics, ceramic, porcelain. Examples of such containers are presented in Figure 4-10.

Figure 4-10: GN 1/1 GastroNorm pan (left) and a GN 2/1 perforated container (right)