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**Domestic and commercial ovens included  
when incorporated in cookers**

#### **Task 6: Technical Analysis BAT**

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## 6. TASK 6 – TECHNICAL ANALYSIS OF BEST AVAILABLE TECHNOLOGY (BAT)

This document is the Task 6 report of the DG TREN lot 22 eco-design preparatory study on domestic and commercial ovens. Task 6 comprises a technical analysis of best currently available technology and technologies that are expected to be introduced at product level within 2-3 years. Research into the best existing products and components available on the EU-market and outside the EU are assessed.

The main environmental impact of ovens is energy consumption and the associated emission of greenhouse gases. The technology that could improve the energy efficiency will be considered here. As described in Task 4, there is a wide variation in energy consumption of domestic gas and electric ovens on the EU market based on the standard test method from EN 50304 / 60350 (electric) and EN 15181 (gas). Microwave ovens are different and so will be considered separately. The energy consumed by an electric or gas oven is from heating the parts of the interior first and then from heat losses through the thermal insulation and the glass door. There are also losses due to ventilation. With shorter cooking times of less than 1 hour, the main consumer of energy is to raise the temperature of the internal parts and to achieve better energy label ratings, domestic oven manufacturers have concentrated their efforts in reducing the mass of these materials. It is probably impossible to make further significant mass reductions beyond those made to the best available ovens in the EU. With longer cooking times, heat conduction through the insulation becomes a more significant proportion of the total energy consumption and so insulation performance becomes a significant factor and so this will be considered here.

The main approaches to improvement of eco-design of ovens are thermal mass reduction and insulation but technologies that might give improvements in the future include different oven designs that require changes in cooking processes and recipes. Research that may deliver improved products and components for ovens are described in the next two subtasks and technology used only outside the EU that could be utilised in EU is discussed in subtask 6.3

### 6.1. STATE-OF-THE-ART IN APPLIED RESEARCH FOR THE PRODUCT (PROTOTYPE LEVEL)

The best available domestic and commercial oven designs are described separately because the designs used are very different. Most research is carried out by manufacturers, which is not published, except as patents but some independent studies have been carried out and published although some of these are now somewhat out of date. One was a summary of US research by the US Department of

Energy (DoE) which is described here to illustrate the variety of approaches that have been considered. This report on available new technology<sup>1</sup> that may provide further eco-design improvements was mainly for domestic but is also applicable to commercial ovens and these are summarised in Table 6-1.

**Table 6-1: Summary of technologies that may provide energy efficiency improvements**

Technology	Summary / comments
Bi-radiant oven (electric only)	Based on research from the late 1970s using two radiant elements, one in the roof and the other at the base. It also used highly reflective (low emissivity) cavity walls, in a prototype oven. Compared to standard ovens available at the time this gave significant energy consumption reduction but this may be much less if compared with a modern forced convection oven. Optimum emissivity of oven surfaces is discussed in task 4.
Forced convection	Now common for electric ovens but no benefit seen in domestic gas ovens. US research indicated that energy savings due to shorter cooking times may be possible.
Halogen lamp oven (electric only)	Research show that these are inferior to standard ovens although there may be advantages in using halogen lamps in standard ovens (as a radiant grill) to shorten cooking times although it will be effective only for thin and flat food grilling.
Improved and added insulation	US ovens tend to be larger and have thicker insulation than those in EU and so the test results may not be relevant for the EU market. However, testing showed that increasing the glass fibre insulation density from 1.09lb/ft <sup>3</sup> to 1.9lb/ft <sup>3</sup> reduced energy consumption by ~5%. Results for increased thickness from 2 to 4 inches were inconsistent with one source quoting a 1.4% improvement and another no change. These results will be affected by

<sup>1</sup> US DoE Report, 2007.

[http://www1.eere.energy.gov/buildings/appliance\\_standards/residential/pdfs/home\\_appliances\\_tsd/cha\\_pter\\_3.pdf](http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/home_appliances_tsd/cha_pter_3.pdf)

	cooking times as heat is adsorbed by thermal insulation initially and its benefits are seen only with longer cooking times.
Improved door seals	Door seals do not seal completely as some ventilation is required. However early research showed that a 7% energy efficiency improvement is possible whereas more recent work gave a 1% improvement.
Low-standby-loss electronic controls	Ovens are within the scope of the EU standby regulation so clocks and any other indications must be energy efficient.
No oven-door window	Discussed below.
Oven separator	Splitting large ovens so that a smaller cavity is heated when the full size oven is not required has been considered but early tests showed that energy savings of <1% were achieved. This has been commercialised but are not successful in domestic ovens although a few commercial ovens are able to heat parts of their interiors and so will reduce energy consumption.
Pilotless ignition (gas only)	Avoids significant energy consumed by gas combustion of the pilot light and replaced by occasional low energy consumption electric spark ignition. Pilot lights are not used in domestic ovens in EU but are used in some commercial ovens.
Radiant burner (gas only)	This refers to a gas fired infrared radiant grill inside the oven cavity. The authors do not report an energy saving
Reduced conduction losses	Metal connections between inner door panels and the outer door panels cause heat conduction losses. The use of thermal breaks to limit these losses gives only very small improvements.
Reduced thermal mass	This has already been adopted in EU and the most recent models have a lower thermal mass than older models. The potential improvements in energy consumption predicted in the DoE report appear to be rather low.
Reduced vent rate	Reducing vent rates (air flow though oven) to

	remove moisture would reduce energy consumption. DoE predict that if the vent diameter of non-self cleaning ovens were reduced to those used in pyrolytic cleaning ovens ( which cannot be reduced further), there would be a energy saving of 0.5 – 0.6%
Reflective surfaces	Highly reflective surfaces should reflect heat back into the oven but in tests this confused the temperature controller. Benefits may be achievable if a more suitable temperature control was installed but there are several problems with this option. Firstly, it will become dirty and so no longer effective. Secondly, the benefit is likely to be mainly with short cooking times which are used for the US standard tests.
Steam cooking	This technology is now common commercially giving faster cooking and lower temperatures resulting in a reduction in energy consumption according to US DoE of up to 50%. This type of oven is very rare in consumer ovens. Consumer steam cooking ovens are available but are different to commercial combi-steam ovens and so cannot be compared.

### 6.1.1. DOMESTIC

Most domestic ovens sold in the EU are of one basic design – an enclosed compartment with insulated walls, floor and roof, a glazed door and one or more heating elements or a gas burner. Most built-in and range electric ovens have a fan for convection and most have an internal lamp. Portable ovens are simpler; all/most are electric with a single-glazed door usually with no fan or lamp. The main feature that the best available domestic ovens have that differentiate these from average ovens is having a lower thermal mass of internal parts of the oven although a well designed convection fan will also reduce energy consumption. Reduction in thermal mass has been achieved by using thinner metal and designing the interior to have sufficient strength with relatively thin sheets of steel.

Heat is lost when oven doors are opened although air has a relatively low thermal capacity and so this does not constitute a significant heat loss if the door is opened infrequently. Some models on the EU market automatically switch off electrical heating elements and convection fans when the door is opened but most of the hot air from inside the cavity is lost. When manufacturers offered ovens with solid doors in recent years, sales were very low as unglazed doors are not a popular option with consumers.



Heat is lost through the glass windows in doors faster than through the thermal insulation and so if the solid door with no window is not opened during cooking, less energy would be consumed. However hot air escapes every time the door is opened causing an energy loss. DoE estimate however that with 4 or less door openings, there would be a benefit. One design used in the past with solid doors was to include an internal glass door that retains heat when the outer door is opened. This would reduce heat loss but could be a safety risk as the glass surface will be at the same temperature as the oven. The energy label is no incentive for solid doors because door opening is not part of the wet brick test. Tests carried out by oven manufacturers found that energy consumption measurements were very variable when door opening was included in versions of the wet brick test so that door opening could not be included as a part of a reliable and reproducible test method.

A possible solution to prevent loss of hot air has been patented by Unieldom Group for domestic built-in ovens in which air is drawn from below the door, travels under the floor, up the back and over the roof before being directed downwards over the open door space to limit heat loss<sup>2</sup>.

A study in 2000 (SAVE II)<sup>3</sup> included a literature search for possible technology improvements to reduce energy consumption and tests to measure the improvements that the authors concluded could be achieved. The costs of these improvements were also included in the report. CECED at the time pointed out that these tests were carried out with old oven designs so the potential for improvement was smaller than claimed in the report. Furthermore, in the ten years since this study was published, further improvements have been made so the percentage improvements claimed to be possible will in at least some cases be much too large. Several of the options will not have been implemented as they are unacceptable to users. Table 6-2 summarises the data from this study.

**Table 6-2: Possible technology improvements to reduce energy consumption according to Save II study**

Design option	Average improvement	Cost to implement / unit (Euros in 2000)	Comments
<b>Electric ovens</b>			
Improve thermal insulation (thicker)	6%	8	Would reduce cavity volume. May increase thermal mass and

<sup>2</sup> F. Dell'Oglio, et.al. "Food baking oven with airflow control devices of the heat dispersion from the baking chamber through the access span and with integrated ventilation system for the thermal insulation with thermal barrier of the access span" US Patent Application US 2010/0101556 A1, April 2010.

<sup>3</sup> "Efficient domestic ovens, final report" Save II project (4.1031/d/97-047) Pirkko Kasanen , 2000.

Design option	Average improvement	Cost to implement / unit (Euros in 2000)	Comments
			thereby energy consumption
Improve thermal insulation (superior type)	6%	37	No change in cavity volume but claimed increase in oven price was €111  Small improvements already made since SAVE II study (due to energy label)
Improve thermal isolation of cavity	8%	6	Widely adopted since 2000
Reduce thermal mass	14%	6	Has been widely implemented by industry
Unglazed door	16%	1	Unacceptable to users who would more frequently open door and so lose more heat (see above)
Optimised glazed door design	8%	20	At least partly adopted since 2000
Passive cooling of door glass	4%	29	Unacceptable, may not comply with safety legislation (external surface may exceed the touch temperature)
Forced convection	4%	20	Has been adopted by industry
Optimised vent flow	8 – 12%	4 - 14	Already optimised since 2000
Low emissivity oven design	35%	35	Would increase selling price by over €100 at 2000 prices. See task 4 section 4.2.1.1 and

Design option	Average improvement	Cost to implement / unit (Euros in 2000)	Comments
			below.
Uncover lower element	8%	8	Not all ovens have lower elements, may not be acceptable to users
Reduce auxiliary energy	3%	1	May already have been adopted (mainly lower standby energy reduction)
Fit reflector above upper heating element	10%	2	Impractical: Would soon become ineffective when dirty
<b>Gas ovens</b>			
Improved thermal insulation	19%	13	Small improvements since SAVE II study
Improved thermal isolation	5%	6	Improved since SAVE II study
Reduce thermal mass	9%	6	Shown to be effective and has already been achieved for electric ovens
Unglazed door	10%	1	Unacceptable to users who would more frequently open door and lose more heat
Optimise glazed door design	6%	20	At least partly adopted since 2000
Passive cooling for door fascia	3%	29	Unacceptable, may not comply with safety legislation
Forced convection	13%	15	Incorrect, fan gas ovens consume more energy
Reduce excess air	4%	10	Unacceptable to users according to SAVE II.

Design option	Average improvement	Cost to implement / unit (Euros in 2000)	Comments
			Probably as this would give too high humidity inside oven and could produce unacceptable carbon monoxide emissions
Pre-heat combustion air	8%	60	SAVE II states that this would increase purchase price by €180. Used in commercial ovens. It requires heat exchanger.
Reduce auxiliary energy consumption	2%	10	Standby energy consumption

The SAVE II energy saving predictions are based on pre-2000 ovens and so in many cases are considerably larger than could be achieved today with ovens currently on the EU market. The costs given are in many cases fairly significant which would increase product price unacceptably except for the most expensive models.

One of the largest improvements claimed by the SAVEII study is for low emissivity ovens based on research by Shaughnessy and Newborough<sup>4</sup>. The low emissivity oven has a standard cavity but the walls are covered with thick bright aluminium sheets that can be removed for cleaning. There are two electrical heating elements with one suspended below the roof and the other above the base. The electrical elements glow to emit heat mainly by radiation that heats the food directly. Radiation that strikes the walls, roof or base is reflected back into the oven. The prototype low emissivity oven and a standard convection oven were compared using the wet brick test:

Oven	Energy consumed (Wh)	Test time
Low emissivity	624	34 minutes
Convection	977	51 minutes

The low emissivity oven heated the test load more quickly (33% less) as heat transfer was more efficient and energy consumption was 36% less. The low emissivity oven has not been commercialised for the following reasons

<sup>4</sup> 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

- CENELEC dispute the size of the improvement claiming that the prototype oven included additional energy saving design features such as PTFE thermal bridges that support the internal cavity. They also claimed that the convection oven was an old model
- The 36% reduction in energy consumption can be explained mainly by the reduced heating time of 33%. It is unclear whether the internal parts of the oven would have adsorbed less energy than a conventional oven after use for the same time period
- Reflection of radiation to the food relies on very clean surfaces which will be difficult to maintain. Splashes onto the aluminium walls will rapidly char and then become difficult to remove.
- The articles states that cooking real food with the low emissivity oven gave mixed results, some recipes cooked with good quality whereas some gave unacceptable results.

CECED has provided its opinion for the design options that would reduce energy consumption based on representative currently available domestic ovens and the improvement potentials are lower than those indicated by SAVE II. This is mainly because oven technology has improved since the study was carried out and so CECED are comparing the best available technology with ovens designed during the last ten years. CECEDs data is presented in Table 6-3. The predicted costs provided by CECED are the increase in purchase price when the new technology is introduced.

**Table 6-3: Improvement options compared to an average product currently sold according to CECED.**

Modification	Percent improvement	Predicted cost	Comments
Thermal insulation	1 – 2 %	€5 - 10	Increase in density of insulation
Electronic temperature control	1%	€100	Electronic control saves 1% energy when compared with mechanical control
Cooking sensors	See comment	~€100	May save energy by changing user behaviour but improvement is not measured by wet brick test. Purpose of sensors are improved cooking performance
Infrared reflecting coatings on door glass	1 – 2 %	€10	One layer of coating is already used in most ovens
Standby energy consumption	See comment	Not applicable	Reduction in standby energy consumption required by EU

			legislation. Significant reductions beyond the maximum permitted levels not likely
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There are however a few innovative designs of domestic oven on the EU market which are distinctly different to most other ovens.

**Steam and combination steam** – these are very uncommon in the domestic market. Miele produce one steam oven which operates at 120°C under pressure and several manufacturers sell ovens of fairly standard design but which can include an accessory that generates steam. Most domestic kitchens have only one heat oven (plus a microwave oven) and so a pressure steam oven is impractical as it can cook only a limited range of recipes whereas a standard oven with a steam option is far more flexible.

**Ovens with microwave heating and microwave ovens with heat oven functions** –

There are a few ovens on the market that are standard electric heat oven but which includes a microwave magnetron and waveguide attached to the cooking chamber. The combination of heat and microwave energy consumes less energy than the heat oven would alone but produces food that is the same as from an electrically heated oven. This type of oven is not accurately assessed by the current EU energy consumption measurement methods in the EN standards because these measure energy of the heat oven separately (without microwave heating) and the microwave function only without thermal heat. The standard measurement method is not suitable for this type of oven as it gives a misleading result. The consumption in heat only mode is higher due to the extra thermal mass of the microwave parts and the heat consumption of the microwave function only is high because of the heat adsorbed by the heat oven parts. These measurement methods will give a misleadingly poor energy rating as the intended combined function will consumes less energy than a standard oven. More common on the EU market are domestic microwave ovens having radiant heaters and / or convection heating. These are essentially standard microwave ovens and the radiant elements and / or forced convection are used to brown food and so these are more flexible than solo microwaves. These will consume less energy overall for cooking a representative range of recipes when compared with a standard heat oven<sup>5</sup>. A new measurement method is being developed to assess the MW function but this type of MW-combination oven will perform less well using this test than solo microwave ovens. The domestic oven wet brick standard test is reliable for standard heat ovens and the new microwave oven standard test will be reliable for solo microwave ovens but neither of these measurement methods demonstrates the real

<sup>5</sup> [http://docs.google.com/viewer?a=v&q=cache:nTHmoqyY5e8J:efficient-products.defra.gov.uk/spm/download/document/id/786+mtp+microwave+oven&hl=en&gl=uk&pid=bl&srcid=ADGEEsi6PqXKEkqxK99kixqT71rG4TjTwtjJ\\_IgqGA0FNk\\_zUDoO26vas4\\_aG7QNhIk61goFkGnt1xTaTbPKfv-29tuhYX7uybBQ3pF4t\\_kPgRA5647FRFRDPAkWvgRqyKmBgPSb3ZzG&sig=AHIEtbTfnB-eAqLqOhuFo9LWQQ5wu\\_MbUg](http://docs.google.com/viewer?a=v&q=cache:nTHmoqyY5e8J:efficient-products.defra.gov.uk/spm/download/document/id/786+mtp+microwave+oven&hl=en&gl=uk&pid=bl&srcid=ADGEEsi6PqXKEkqxK99kixqT71rG4TjTwtjJ_IgqGA0FNk_zUDoO26vas4_aG7QNhIk61goFkGnt1xTaTbPKfv-29tuhYX7uybBQ3pF4t_kPgRA5647FRFRDPAkWvgRqyKmBgPSb3ZzG&sig=AHIEtbTfnB-eAqLqOhuFo9LWQQ5wu_MbUg)

benefits of novel types of ovens having combinations of microwave with grill or convection functions. .

#### ■ Potential for energy saving in use

There is potential for reducing EU energy consumption of domestic heat ovens from the removal of the worst performing ovens from the market as well as utilising the technology options discussed here. The energy consumption of new domestic ovens currently being placed on the EU is given in Task 4 and shows a wide range of energy consumption for each cavity size. A reduction of ~20% energy consumption should be achievable by phasing out the least efficient ovens. Further improvements will be achieved by design changes although it is less clear to what extent this will be. Data from CECEC indicate that a reduction of 4 – 5% will be achievable using currently available technology but further research may identify other ways to reduce energy consumption. Completely amending the energy labelling of domestic ovens should give an added incentive to adopt the energy saving innovations that are not expensive to implement. Currently there is little incentive for manufacturers to make improvements to ovens that are “A” rated. Energy labelling of gas ovens could be more effective than electric as currently no label is required for gas ovens and the electric oven label has been effective at reducing energy consumption of domestic electric ovens. Gas ovens are required to meet maximum maintenance energy consumption limits as specified by EN 30-2-1 but this is not an incentive to improve performance. There are no technical reasons why extending labelling to portable ovens should not be possible, at least for ovens of >12 litres that can be measured using the wet brick test but this has not been sufficiently studied to determine if the standard measurement method can obtain reproducible results or if different labs will be able to obtain the same results for these smaller ovens. It is possible that the quality of some low price models will result in variable test results which would need to be taken into account by any labelling scheme.

#### ➤ HEAT STORAGE OVENS

Fixed temperature heat storage oven energy consumption could be reduced if they could be switched on and off so that they heated up from cold sufficiently to their fixed temperature settings. This would ensure that heat is not generated when it is not needed so that energy consumption would be significantly reduced.

#### ➤ OTHER METHODS FOR REDUCING ENERGY CONSUMPTION

Changes to user behaviour could reduce energy consumption but this is very difficult to achieve. However several design options are available that might achieve lower energy consumption. Sensors are mentioned as a possible option although these are intended to improve cooking performance, not reduce energy consumption. One example is a cooking sensor that measures temperature and stops cooking when this reaches a pre-determined level. This avoids overcooking and so prevents wasted energy consumption. There is no saving if the cooking were to be stopped at the correct time

but there is a benefit if it is stopped earlier than without the sensor as cooks may forget to stop cooking or over-estimate the cooking time needed.

Information to inform the user of the electrical energy consumed is increasingly available as power meters connected to the home mains supply that indicate cost per hour, etc. This type of indication could be used with domestic ovens and display cooking energy cost but no products of this type are on the EU market.

Another possible way of reducing EU energy consumption is with the instructions on pre-cooked food. To ensure uniformity as domestic oven performance varies, manufacturers of pre-cooked food instruct users to pre-heat ovens before inserting food for heating. Some stakeholders have claimed that this is not necessary and wastes energy as the oven is on for longer than necessary and pre-cooked dishes can be effectively heated without oven pre-heating. Although this will be longer than stated in the instructions, the total time that the oven is on will be less<sup>6</sup>. Moreover, this gives users the impression that pre-heating is always necessary for all recipes, which is not always correct.

### 6.1.2. DOMESTIC MICROWAVE OVENS (MWO)

Microwave ovens are already relatively energy efficient as the microwave radiation heats the food directly and quickly. Therefore there are fewer opportunities for further improvements over current best available technology. According to CECED, microwave energy in domestic ovens is generated with an electrical efficiency of between 55 - 62% whereas the magnetrons have an efficiency of up to 73%. There is little scope for improving magnetron efficiency and most losses are from the RF generating electronics where the scope for improvement is limited. CECED have provided possible changes that could give small improvements for domestic MWO although they estimate that each is potentially an improvement of ~<1% and these improvements together may not be additive. There are no opportunities for large reductions in energy consumption beyond the current best MWO designs reported by CECED. The design options are:

**Table 6-4: Improvement options for microwave ovens according to CECED**

Design change	Explanation	CECED's comments
Painted galvanised steel cavity	Already used in some BAT MWO. Paint does not absorb microwave energy and zinc coated steel absorbs less than stainless steel but this material is suitable only in solo	~1% energy saving (all other options below are claimed to be also 1% except LED lamps at ~2%)

<sup>6</sup> This is the opinion of several study stakeholders and is also stated at [http://www.treehugger.com/files/2007/10/three\\_myths\\_tha.php](http://www.treehugger.com/files/2007/10/three_myths_tha.php)



	microwave ovens as the paint is damaged by high temperatures from grills or convection	
Austenitic stainless steel	Already used in some BAT MWO. Does not absorb less microwave energy than ferritic steels. Common in commercial MWO	Stainless steel is much more expensive than painted zinc coated steel
No clock display	Clock displays consume energy and may never be used. However power consumption of MWO digital clocks is typically <1W	Time setting (of timers) would be less accurate
Mechanical controls	Already used in some BAT MWO. Still used in some low price models and consumes a little less energy than electronic controls	Not popular with consumers who prefer electronic controls
Improved microwave system designed for loads commonly used by consumers	Already used in some BAT MWO. Assumes standard loads are cooked so less efficient for different size loads	Evenness for standard loads OK but would be worse overall
Copper wire in HV transformer	Already used in some BAT MWO	Significant cost
Improved quality iron core of transformer	Already used in some BAT MWO	Significant cost
Inverter power supply	Already used in some BAT MWO	Increased cost and inverter needs cooling but will give overall energy saving (~1%)
Improved magnetron efficiency	Magnetron converts electricity into microwave energy	Magnetrons are mature technology with little scope for improvement. Best are already >70% efficient
LED cavity lamp	Inefficient filament lamps	Further development

	currently used. No alternative in MWOs with radiative heating but LEDs are possible in solo MWO although are not yet used	needed, small cost increase. LEDs will consume less energy than filament lamps
Reduction of impedance mismatch between feeding system and cavity	Used in higher frequency RF technology but not for MWOs	Significant R & D needed. Many technical issues
No turntable or stirrer	The turntable and stirrer give more even cooking and can also shorten cooking times. Turntable and stirrer motors consume energy	Research to provide a more even microwave feeding system without moving parts has been unsuccessful

The improvements claimed to be achievable by CECED for domestic microwave ovens totals 4% (the use of zinc coatings, cavity lamps and inverter power supplies). Further improvements may be achievable with cooking sensors but these are more difficult to assess as any improvements are not shown by the standard energy consumption measurement test. Further unquantified improvements from other technologies such as those in the above table may eventually be realised but are likely to be relatively small.

There are many recent patents for commercial microwave ovens but few for domestic. One recently published example from Panasonic<sup>7</sup> describes a technique to allow the magnetron to transfer heat more effectively by controlling its temperature by regulating its power output. This improves the energy efficiency of the magnetron. Several domestic microwave oven manufacturers (e.g. Panasonic, Samsung, Sanyo, etc.) produce ovens which include weight sensors and microprocessor controls. These calculate the cooking time and energy from pre-installed recipes and the weight of food in the oven. They will for example, calculate the time needed to defrost frozen food based on its weight. High temperature sensors are also used in microwave ovens but these are used only for safety to cut off the power if the ovens over-heat. Samsung and several other manufacturers sell ovens with humidity sensors (often combined with weight sensors), which monitor the humidity level and adjusts the cooking power level to compensate. These sensors are intended to improve cooking performance and may not affect energy consumption<sup>8</sup> although will save energy by avoiding over-cooking.

<sup>7</sup> K. Kouji, et. al. "Microwave Oven", Patent WO2010098038 A1, September 2010.

<sup>8</sup> [http://www.samsung.com/uk/consumer/home-appliances/microwaves/combo-combination-microwave-ovens/CP1395ST/XEU/index.idx?pagetype=prd\\_detail](http://www.samsung.com/uk/consumer/home-appliances/microwaves/combo-combination-microwave-ovens/CP1395ST/XEU/index.idx?pagetype=prd_detail)

A recent innovation from LG is a combination microwave which also provides steam cooking as well as microwave heating, infrared heating and grilling functions<sup>9</sup>.

Details of microwave ovens with radiant grills and/or convection heating are given in section 6.1.1 which describes conventional ovens having microwave functions as well as microwave ovens with standard oven and grill functions,

#### ■ Potential for energy saving in use

There is limited potential for reducing EU energy consumption of domestic solo microwave ovens from the removal of the worst performing ovens from the market as well as utilising the technology options discussed here but the potential energy saving is much less than with electric and gas heating ovens. The energy consumption of new domestic microwave ovens currently being placed on the EU is given in Task 4 and shows a range of energy consumption that is largely irrespective cavity size. If an energy labelling scheme were imposed on microwave ovens, sales of the small proportion of less energy-efficient microwave ovens would be discouraged and the adoption of the energy efficient design options described here would be more attractive. The energy consumption data in data produced by CECED shows that performance varies within a relatively small range. This would make it difficult to use energy labels because the labelling scheme would normally have seven bands and the range of energy consumption within each band, if all seven are used for the currently available ovens, would be smaller than the expected uncertainty of the measurement method.

Microwave ovens with grills and / or convection heating do not give good performance in energy measurements using the proposed standard method being developed for solo microwave oven but in a wide variety of recipes these consume less energy than conventional ovens whereas solo ovens could not be used. Therefore it would be unfair to compare combination microwave ovens with solo microwave ovens by one energy label unless the benefits of grill and convection heating functions are taken into account..

### 6.1.3. COMMERCIAL

The design of commercial ovens is more varied than domestic with several distinct types. Standard convection ovens are the more traditional type but increasingly steam and combi-steam ovens are used. There are also several types of bakery ovens – rack, deck and in-store convection being the main types, all of which utilise steam heating. Impingement is another design option in commercial ovens and is used in batch and continuous ovens such as pizza ovens with conveyors. Electric heating and gas burners are the most common heat source but oil burners are also used. Short cooking times

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<sup>9</sup> LG webpage for MP9289NSD steam microwaver oven <http://www.lg.com/uk/home-appliances/microwave-ovens/LG-MP9289NSD.jsp>

are very important for commercial catering, unlike domestic and various designs of oven have been developed to achieve fast cooking. Microwave ovens are used mainly for re-heating and normally have double magnetrons. For rapid cooking, combi-steam which is convection heat plus steam heat and combination microwave ovens with convection, radiant and microwave heating are used.

#### ➤ STEAM AND COMBI-STEAM OVENS

Combi-steam ovens are used to cook food quickly and this is achieved by controlled high humidity at a temperature that can be up to 350°C. Some models can be used in steam only, combi-steam and convection only modes for versatility which is important in smaller kitchens that may have only one oven. Steam is generated either in a separate boiler or continuously within the oven and the latter approach is believed to consume less energy. One article indicates that steam oven energy efficiency would be improved by phasing out separate boilers in combination steam ovens. This is claimed to give energy savings of 15% and would reduce water consumption by 21%<sup>10</sup>. Heat exchangers are fairly commonly used to pre-heat incoming water using flue gases (from gas burners) and by condensing water from excess vented steam. Water is usually pre-heated to 60°C, even though pre-heating to 90°C would be possible but this would cause scaling and the need to de-scale the heat exchangers where hard water supplies occur. Scale build up on heat exchanger surfaces can rapidly reduce their efficiency. One manufacturer claims that their design of heat exchanger which condenses steam to re-use condensate saves 16% of energy and 42% of water<sup>11</sup>. This manufacturer claims that up to 46% of energy can be saved by generating steam within the cooking chamber (presumably in comparison with older designs having separate boilers). Automated cleaning is also available. Various innovations have been developed to improve the energy efficiency of steam generation and humidity control and this could in principal affect energy consumption. Boiling water consumes a lot of energy (raising the temperature by 1°C requires 4.2 Joules per gram) so designs that avoid producing more steam than needed will be the most energy efficient. Good control of humidity will also minimise energy consumption. In combi-ovens, steam is generated from water and also from food and is retained within the chamber until cooking is complete. To avoid generating too much steam (and using more energy) humidity sensors such as Electrolux “Lambda sensor” are used. A different approach available from Electrolux is to use cooking sensors that measure the core temperature of food<sup>12</sup>.

Heat losses occur from steam and combi-steam ovens through insulation and the glass door as with any type of oven. Manufacturers offer double glazed and triple glazed

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<sup>10</sup> V. Cocker “Increasing Efficiency within the commercial kitchen – an Environmental code for gas appliances” March 2007.

<sup>11</sup> Technical information from Eloma’s website, April 2011. [www.eloma.com/enproducts/combi-ovens/genius-t/environment](http://www.eloma.com/enproducts/combi-ovens/genius-t/environment)

<sup>12</sup> Electrolux Professional data sheet for Combi LW 20 GN 2/1-gas

doors although double are more common and have higher sales due to their lower price. One manufacturer offers both double and triple glazed doors as options and has found that although triple glazing does consume less energy than with double glazing with a short payback time, sales of the cheaper double glazed door option are much higher. Wall insulation clearly retains heat but the amount used is usually limited as the insulation will retain heat after cooking and slow the cooling cycle at the end of cooking and delay opening of the oven door. The steam-ovens cannot be opened at  $>100^{\circ}\text{C}$  with steam for safety reasons. Extra insulation will adsorb more energy so that cooking times are increased and may consume more energy where the oven temperature is raised and lowered for each steam heating cycle. One stakeholder stated that a typical combi-steam oven will typically consume 7 kWh in a cooking cycle and heat losses through insulation will be 0.8 kWh (11.4%). It is clear that the best combi-steam ovens have high energy efficiency and that the designs of combi-steam ovens sold in the EU do vary in ways that affect energy consumption. There will be variation in performance between products on the EU market and so there is potential for reducing EU energy consumption.

#### ➤ **BAKERY OVENS**

There are several types of commercial bakery oven sold in the EU. The main types are deck ovens, rack ovens and in-store convection ovens, all of which can be electric or gas and involve steam generation and heating. These have been described in Task 4. Energy efficiency is affected by the same sources of heat loss and they use similar technologies to those described for commercial steam-ovens, integral steam generation, insulation, heat exchangers, etc. and so a similar variation in performance is likely.

#### ➤ **COMBINATION MICROWAVE OVENS**

Commercial ovens having a combination of heat convection and microwave heating are fairly common because they provide relatively fast cooking. There are several patents for innovative oven designs:

- **WO2010121067** “High-speed cooking oven with optimised cooking efficiency” – combines microwave and hot air impingement heating to optimise heat transfer to the food.
- **US 6872926** “Rapid cook oven with dual flow fan assembly” – Combines hot air impingement with microwave heating for fast cooking and also a method of removing air-born contaminants that produce odours and smoke before this clean hot air is then returned to the cooking chamber
- **WO 2008/143942 A3** “High speed cooking oven with optimised cooking efficiency” Another patent for an oven combining microwave and hot air impingement heating. This patent describes optimised dimensions of the impingement nozzles to give tighter hot air plumes which are intended to increase heat transfer and shorten cooking times.

- **US 2020/0193507 A1** “Speedcooking oven” – this patent describes a design of commercial microwave oven with ceramic convection heaters and infrared lamps situated in the “upper heating module” and also in the “lower heating module”. The oven has complex controls that operate these heat sources to cook a variety of types of food although this is not described as an energy efficient design.

There are many combination ovens on the EU market which include microwave and convection heating functions. An example is the Merrychef “eikon” which has microwave, convection and impingement heating to achieve cooking times claimed to be up to 15 times faster than conventional (convection) cooking. These ovens include a “catalytic converter that destroys odours and air-borne fats and so avoid the need for separate room ventilation.

Features that are used in some of the BAT commercial microwave ovens include programmable cooking with several stages with specific times, power levels, etc., rotating passive antennas, efficient double magnetrons and safety interlocks.

The variation in energy efficiency performance of this type of oven and the difference to commercial convection ovens is unclear as no published data is available. Users will choose combination microwave ovens where they are suitable for the types of food being cooked and fast turnaround is needed. Energy consumption in ovens having microwave heating is likely to be significantly lower than with other types of oven because food is heated directly and the cooking times are shorter so that there is less time for heat to be lost (through insulation, etc.) but not all recipes can be cooked in this type of oven.

#### ➤ **CONVECTION OVENS**

Stakeholders have indicated that >90% of energy input is used for heating food and the interior of the oven and the remaining <10% for fans, controls, lamps, etc. Some heat will however be lost via conduction through the walls, door and in vented gases. Commercial convection ovens tend to be left on continuously (unlike combi-steam ovens) even if they are not in use. This is because chefs want to be able to use them immediately without having to wait for them to heat to the required temperature. Therefore energy consumption will depend on the food being cooked and heat losses in use will depend on design of the oven, including the thermal insulation quality, door glazing, vents and temperature control accuracy. Commercial ovens with glass doors are used as well as solid doors that will have better insulation. Frequent door opening results in heat losses and so automatically stopping the convection fan should help to reduce heat losses.

#### ➤ **OTHER OVEN DESIGNS**

A patent describes the use of many parabolic reflectors behind the heat sources of a commercial oven with a conveyor. Although referred to as an oven, heating of food is part radiant as well as convection so this device could be classified as a grill<sup>13</sup>. This oven also has a forced convection fan and a sensor to detect food so that when the oven is not in use, it automatically turns down the heat supply and can also stop the conveyor. Commercial gas-heated catering ovens with conveyers designed for cooking pizzas can include “energy management” that use sensors to determine if there is anything in the oven and this can save at least 30% of energy according to the manufacturer’s literature<sup>14</sup>.

#### ■ Potential for energy saving in use

Eco-design improvements can be made to components of commercial ovens that result in lower overall environmental impact from ovens, particularly energy consumption. These component improvements will be discussed in section 6.5.2. However, according to information from one stakeholder, the best performing ovens consume as much as 25% less energy than average ovens and this is mainly due to good engineering design to avoid heat losses and minimise consumption. As reported in task 4, there is also significant variation in performance in low power “idle” modes with the best combi-steamer ovens consuming 27% less energy than the worst in tests with five commercial combi-steamer ovens.

As described in section 4.5 of Task 4 report, the “Freshbake” study found that the common practice of cooking frozen pre-baked bread at supermarkets consumes more than four times as much energy as making fresh bread in a single process. This is not an eco-design issue but labelling bread with an indication of energy consumption would provide consumers with information to make a better informed choice and potentially reduce EU energy consumption.

## 6.2. STATE-OF-THE-ART AT COMPONENT LEVEL (PROTOTYPE, TEST AND FIELD TRIAL LEVEL)

The main approach to reduce energy consumption in the best performing domestic ovens is to reduce the thermal mass of internal parts. CECED have said that this will have the most significant impact in reducing energy consumption of domestic ovens but this may not be as important with commercial ovens which are in use for much longer periods and so the insulation is more important.

Forced convection is also important for saving energy. This is reflected by the data in the Task 4 report for energy consumption in use by domestic ovens that shows that

<sup>13</sup> “Oven with convection air current and energy saving features”, Lincoln Food Service Products L.L.C. Worldwide patent WO 2008/033519 A2.

<sup>14</sup> Middleby Marshall website for pizza ovens. April 2011. [http://www.middleby.com/midmarsh/wow/WOWbroch\\_web.pdf](http://www.middleby.com/midmarsh/wow/WOWbroch_web.pdf)



overall, electric ovens consume less energy with fan convection than without the fan. Gas ovens were different however and consumed more energy with fan convection (see figure 4.7 of the Task 4 report).

### 6.2.1. INSULATION

Thermal insulation of pyrolytic ovens has to be more efficient than non-pyrolytic to maintain the external surfaces at a safe temperature during cleaning cycles so as a result, less energy is used for cooking. US DoE research found that standard ovens have an efficiency of 12.15% whereas self-clean (pyrolytic) were 13.79% energy efficient<sup>15</sup>. Additional energy is used however for the pyrolytic cleaning cycles so that the annual energy consumption of pyrolytic ovens is more than non-pyrolytic ovens if more than ~ 4 cleaning cycles are carried out per year. The improved performance of pyrolytic oven insulation performance is due to its higher density as the same thickness is used as in standard ovens.

CECED have said that the type, density and quantity of insulation has only a minor impact on the energy consumption of domestic ovens. This assumes average cooking times similar to those used for the EN energy consumption measurement standards (<1 hour). CECED say that the insulation of pyrolytic ovens is more important however when the ovens are in the pyrolytic cleaning cycle at high temperature.

Rational claim in one of their publications that their “Self-Cooking Centre” commercial combi-steamer ovens use at least 10% less energy than normal combi-steamers which they say is achieved by the use of various innovations which include the use of effective thermal insulation<sup>16</sup>.

Glass and mineral wool are the most commonly used insulation in ovens for cooking as they have relatively low heat capacity and thermal conductivity. There are however, materials with superior thermal conductivity but these are more expensive and have limited flexibility so are difficult to use. Some examples are presented in Table 6-5:

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<sup>15</sup> Appendix 6A to US DoE report downloaded April 2011.  
[http://www1.eere.energy.gov/buildings/appliance\\_standards/residential/pdfs/home\\_appliances\\_tsd/appendix\\_6a.pdf](http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/home_appliances_tsd/appendix_6a.pdf)

<sup>16</sup> British Bakery Magazine website published May 2010.  
[http://www.bakeryinfo.co.uk/news/fullstory.php/aid/6870/Is\\_green\\_your\\_colour\\_.html](http://www.bakeryinfo.co.uk/news/fullstory.php/aid/6870/Is_green_your_colour_.html)



**Table 6-5: Thermal conductivity of some materials**

Material	Thermal conductivity
Mineral wool	0.04 W/mK at 25°C (0.1 at 350°C)
Microtherm (silica-based)	0.02 W/mK at 100°C
Aspen Pyrogel	0.02 W/mK at 25°C

If a material with a thermal conductivity of 0.02 W/mK is used instead of the same thickness and density material with thermal conductivity of 0.04 W / mK, the oven will lose energy at only half the rate through the insulation layer. Increasing insulation thickness also reduces heat conduction but the larger mass of insulation increases its heat capacity. Increasing thickness also either reduces cavity volume or increases the external dimensions, which is not an option for domestic ovens which are of standard sizes. Mineral wool density can be increased to some extent and this will improve thermal insulation (the density of pyrolytic oven insulation is usually higher than standard ovens).

Most types of thermal insulation rely on trapped air pockets to provide the thermal insulation. And although air is an excellent thermal insulator, vacuum is the best as no heat convection or conduction can occur and at <250°C heat radiation is minimal. Bosch & Siemens have patented a method to produce a vacuum sealed casing made from pressed steel that could be used in an oven muffle or with insulation for an oven casing. The vacuum between the inner and outer steel sheets of the casing would limit heat transfer and could be used to make a more efficient oven or an oven with reduced wall thickness to increase the internal capacity. (US Patent 6408841 – Heat insulated housing for a refrigeration device and a domestic oven). There are technical problems with ovens. One is that metals expand when heated and so the thermal insulation panels must expand to the same extent as the rest of the oven to avoid gaps forming at edges from where hot air leaks would occur. Thermal expansion may also cause distortion and damage the panels. These panels would need to be flat whereas the shapes required inside ovens are not flat as they need to accommodate lamps, fans, thermocouples, etc. Vacuum panels have not yet been used commercially in domestic or commercial ovens although if these technical difficulties can be overcome, they would give a large improvement in thermal insulation although this would show energy saving benefits mainly where longer cooking times are used.

Vacuum insulation is also proposed in a patent from Samsung for steam ovens. Steam ovens operate at lower temperature than convection and combi-steam ovens and so thermal expansion of the vacuum insulation panels is less of an issue with this type of oven<sup>17</sup>.

<sup>17</sup> Hyung Min Kim, Samsung Electronics, US Patent US 2005/0121433 A1, 9 June 2005.

Another possible option that has not been used in cooking ovens is nano-aerogel filled panels<sup>18</sup>. This is a type of vacuum insulated panel which is used for insulation of refrigerators and freezers<sup>19</sup>. These are pairs of metal panels that form “pockets” that are filled with an inert material and then evacuated and sealed. Various filler materials are used some of which are unsuitable in ovens but silica, nano-gels and glass fibre are suitable. Thermal conductivity of vacuum insulated panels is 0.005 – 0.01 W/mK (at ambient) which is much less than mineral wool insulation<sup>20</sup>. This would result in even lower heat losses through external surfaces than microporous and aerogel insulation (see Table 6-5). These are already used in commercial freezers<sup>21</sup> but not in ovens.

One issue raised by manufacturers is that thermal insulation cannot be too good as this delays cool-down of the oven which can be a problem in busy restaurant and hotel kitchens. Industrial furnaces and ovens however overcome this problem by using forced air cooling as this is overall more energy efficient than using inferior insulation although the use profile of industrial ovens is quite different to commercial catering ovens.

### 6.2.2. GLASS DOORS

Heat losses through glass of doors are much greater than through the insulated walls, back, floor and roof of the oven. However, consumers will not accept doors without glass except for steam ovens where cooking times are fixed and so there is no need to view the food while it is being cooked. Furthermore, the cooler glass surface would be obscured by condensation.

Some domestic ovens on the EU market have three or even four layers of glass but some “A” rated ovens have only two. One layer only would not be safe as the outer surface would become too hot and would cause burns if touched although some low price portable ovens have only one layer. Where two layers of glass are used, cooling air flows between the two layers to maintain the outer surface at a safe temperature. Insulation is achieved therefore by a single layer of heat reflective e-glass. This type of glass has high visible light transmission but low infrared light transmission and high infrared reflection properties. This is achieved by special coatings such as fluorine-doped tin oxide or sputtered silver with tin oxide being the most commonly used due to its good visible light transparency. Heat insulation by the glass is improved by using additional layers. With triple glazing the outer layer is cooled as with double glazed doors but additional insulation is achieved by the air gap between the two inner layers

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<sup>18</sup> Nonogel™ VIP cores – Cabot Corpn. Retrieved January 2011 from:

[www.ecbcs.org/docs/Ann39\\_2001\\_1\\_hipti\\_proc%20.pdf](http://www.ecbcs.org/docs/Ann39_2001_1_hipti_proc%20.pdf)

<sup>19</sup> Preparatory Studies for Eco-design Requirements of EuPs Lot 12 Commercial Refrigerators and Freezers Draft Final Report Task 6: Technical Analysis BAT October, 2007

<sup>20</sup> Website of “Single Iteration”, a division of Watlow. <http://www.singleiteration.com/library/document.cfm?id=57>

<sup>21</sup> Sanyo website downloaded April 2011. <http://eu.sanyo.com/biomedical/Products/Product-Information/Core-Technologies/Conservation/Patented-VIP-Vacuum-Insulated-Panel/>

of glass in the same way as double glazed windows for buildings. Adding further layers of glass provide further thermal barriers of trapped air. Therefore triple and quadruple glazed doors will have better thermal insulation properties than double glazed doors. However, in domestic ovens with relatively short cooking times, energy is consumed by heating the internal parts and this will include the glazing of the door. Triple glazed doors will have a higher thermal capacity than double glazed and this additional energy consumption can offset the benefit from improved thermal insulation.

Heat is therefore retained within the oven by two methods i) by reflection of infrared using low emissivity coatings and ii) by the thermal barrier of trapped gas between two (or more) layers of glass. In general, infrared reflectivity is inversely proportional to visible light transmissivity, i.e. the better the thermal insulation, the darker the glass will appear. This is shown in Table 6-6 by data for glass made by Schott for oven doors.

**Table 6-6: Proprieties of some glass made by Schott**

Product name	Surface resistivity (inversely proportional to coating thickness)	Emissivity
Schott Energy	20 ohm / square	0.22
Schott Energy Plus	10 ohm / square	0.18
Schott Borofloat Energy	30 ohm / square	0.30

Emissivity is on a scale of 0 to 1 where 0 is a perfectly reflective surface and 1 is equivalent to a “black body” which adsorbs 100%. The orientation of the coating is important. If it faces inwards towards the heat, reflection of heat (infrared radiation) is the dominant effect. If it is on the external surface of the glass, reduced emission of heat is the dominant effect. Glass with coatings on both surfaces is also available and combines both effects and so gives superior performance<sup>22</sup>. Standard ovens use soda glass windows but this cannot be used for the inner layers of pyrolytic ovens which use Borosilicate glass that is suitable for use at up to 500°C.

The scope of avoiding heat losses by transparent coatings on the door glass is however limited and so multiple glazed doors are needed to improve insulation further although this can also increase thermal capacity as mentioned above. Technology used for windows of buildings could in the future be considered for the oven market. Two options are used to improve thermal insulation.

- Vacuum insulated panels – consist of two sheets of glass sealed with a glass frit and evacuated (see also section 6.2.1). This technology is used for plasma televisions. Vacuum is an excellent thermal insulator as it does not conduct heat or allow convection. There will be technical issues to resolve in oven

<sup>22</sup> Schott Flat Glass – Product information. Retrieved January 2011 from: [www.schott.com/flatglass/english/download/product\\_information\\_schott\\_energy.pdf?highlighted\\_text=energy plus](http://www.schott.com/flatglass/english/download/product_information_schott_energy.pdf?highlighted_text=energy plus)

doors as the inner glass would be much hotter than the outer layer which would impose stresses on the glass which if too large could cause failure. Low thermal expansion coefficient glass would minimise the stresses imposed. Vacuum insulated glass panels are not currently used for ovens.

- Another technique used for double glazed windows of buildings is to fill the space between the layers of glass with a noble gas which have lower thermal conductivity than air. High atomic mass Xenon would be the best but is too rare and so Argon and Krypton are used. Krypton is fairly expensive as it is present in air at a very low concentration whereas Argon is more abundant. Argon filled double-glazed windows are commercially available but the benefit of Argon over air is relatively small. Pilkington<sup>23</sup> supply air filled and argon filled “optitherm” window units:
  - Air filled            Heat transmission = 1.4 W/m<sup>2</sup>K
  - Argon filled        Heat transmission = 1.2 W/m<sup>2</sup>K

There are no indications in the published literature that either of these two technologies are being considered for oven door glazing.

### 6.2.3. ELECTRIC HEATING ELEMENTS

Electric heating elements are best located inside the oven but this can be inconvenient and so they are often located behind the metal panels that are the sides, top, bottom or back. This reduces thermal transfer from the element to the interior of the oven as heat has to pass through the metal walls. An exception is the round elements around convection fans at the rear of electric ovens. The air flow from the fan effectively transfers heat to the interior of the oven. This is resolved in some models by using an additional radiant heating element at the top of the oven. This is used to improve cooking performance but should not affect energy consumption significantly.

An alternative type of heating element is thick-film heaters (TFH) that are in the enamel coating of an oven casing (joint development by Ferro Electronic Materials Systems and Electrolux). This could result in reduced energy consumption (as the elements are in the oven) and facilitate easier cleaning of spillages in the oven cavity (compared to tubular elements in the cavity). The design would use the existing mild steel substrate with an enamel coating to provide electrical insulation between the heating element and the casing. The resistive film would be deposited on the enamel and then over glazed with a layer to protect the resistive traces. The normal alkali borosilicate glasses used for standard enamelling of oven cavities are not suitable for this application as their insulating resistance degrades at the normal operating temperature of the oven. To overcome this alkali free glasses have been developed

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<sup>23</sup> Pilkington website April 2011.  
<http://www.pilkington.com/europe/uk+and+ireland/english/products/bp/bybenefit/thermalinsulation/optitherm/default.htm>

that fire under the same furnace conditions as those used for standard enamels. The electrostatic spray process used for standard enamels was also found to be unsuitable as the enamel thickness could not be accurately controlled, bubbles often formed in the enamel and the enamel cracked after firing. Instead, dielectric enamel screen printing pastes were developed. The resistive screen pattern was also screen printed onto the enamel before firing.

Initial trials of this technology have only implemented the TFH as a bottom heating element in combination with a top conventional tubular heating element. The energy consumption of the oven using the TFH for heating was <800Wh. The temperature of the TFH did not exceed 300°C, versus 400°C for the bottom of a conventionally heated oven

TFH heaters are widely used to provide local heating in other industry sectors but are not used in domestic or commercial catering ovens. CECED have concerns over their long term reliability and have stated that energy savings achievable would be small.

Electrolux have patented the use of two or more heating elements used on two or more air ducts to optimise the oven temperature for different foods<sup>24</sup>.

#### 6.2.4. GAS BURNERS

Gas burners need to be designed to ensure that the gas / air ratio is close to stoichiometric for complete combustion of the gas without forming carbon monoxide. If there is too much secondary air, this cools the flame and dilutes the hot combustion gases. Control of gas / air ratio is well understood by the industrial furnace industry where 15% excess air is regarded as optimum for minimising energy efficiency and that as the amount of excess air increases, gas consumption needs to increase to compensate. Gas ovens need to have variable heat output and this makes burner design more difficult as the gas and air flow both need to be controlled to maintain an optimum energy efficiency. SAVE II identified gas / air ratio as a method of reducing energy consumption<sup>3</sup> but domestic gas ovens are not filled with combustion gases, these are diluted by air inside the oven to achieve the desired oven temperature. Air flow through the oven is needed however to provide secondary air to the burner flames and to allow some flow through the oven to remove steam and combustion gases in a controlled manner. Combustion of gas produces water and carbon dioxide and heating food also emits some water vapour. It is desirable to maintain humidity inside the oven but avoid condensation on cooler surfaces and to allow some browning and crisping of the food surface. If there is inadequate air flow through the oven, food does not brown and will not “crisp”. Good burner design combined with suitable ventilation will contribute towards better energy efficiency and this is important for domestic gas ovens and commercial convection ovens.

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<sup>24</sup> Electrolux patent. Retrieved January 2011 from :[www.freepatentsonline.com/EP1918647.html](http://www.freepatentsonline.com/EP1918647.html)

Steam, combi-steam and bakery ovens that use gas heating are however quite different. This is because the gas burners provide heat into the oven usually via heat exchangers and so the gas / air ratio can be controlled more precisely by suitable design for optimum efficiency. Another option is to feed these gas burners with pre-heated air if this is available from heat exchangers as this will also reduce energy consumption.

### 6.2.5. HEAT EXCHANGERS

#### ■ Gas heating

Commercial bakery ovens need to provide very uniform heating internally so that all of the bakery products are cooked simultaneously. Gas burners cannot be used directly inside rack ovens unlike electric heating elements and so heat exchangers are used. Various heat exchanger designs have been developed. One from Baxter is claimed to give very uniform heating by using a combination of many small gas flames with specially designed “U” shaped heat exchanger tubes<sup>25</sup> with heated air being circulated with an axial fan. Electrolux claim that gas burners with heat exchangers increase energy efficiency reducing gas consumption by 20% when compared with traditional gas burners<sup>26</sup>.

#### ■ Heat re-use

Convection ovens require air to remove steam and for gas combustion. Usually cold air is used and this results in wasted heat as it has to be heated to the oven temperature whereas vented gases are at least as hot as the oven. Heat exchangers are used with manufacturing ovens and some commercial cooking ovens but these are not used in domestic or most commercial convection ovens or for preheating air for gas burners. The cost would be significant but based on manufacturing ovens, the energy savings may also be significant although these may not be practical in domestic ovens.

### 6.2.6. OTHER INNOVATIONS FOR DOMESTIC AND COMMERCIAL OVENS

#### ■ Power control

Electrolux have patented a method of cycling the heat supplied to food when it is cooked from cold. The Electrolux method pulses the power to the oven elements during intermediate heating temperatures to enable the food to “catch up” with the oven temperature and thus reduce the time that the oven must be operated at maximum input before reaching the set temperature<sup>27</sup>.

<sup>25</sup> Baxter’s website April 2011, [www.baxterbakery.com/Technology/Patented-Heat-Exchanger-System/](http://www.baxterbakery.com/Technology/Patented-Heat-Exchanger-System/)

<sup>26</sup> Electrolux press release May 2010. <http://www.electrolux-touchline.com/files/press.pdf>

<sup>27</sup> (WO/2003/056242) Procedure for controlling the energy uptake in a cooking oven

### ■ Oven cleaning

Kuppersbusch GmbH has developed a novel and more energy efficient cleaning system for domestic ovens. This uses a catalyst that surrounds the circular rear heating element which converts air-borne grease and other odours to CO<sub>2</sub> and water. The catalytic decomposition reactions are exothermic and so generate some additional heat as well as avoiding the need to clean the oven pyrolytically or with chemicals by removing air-borne grease before it can settle. This technique will not however remove dirt and grease that is deposited oven walls by splashed or spray from cooking food. Thermal grease and odour removal is patented for commercial ovens, see section 6.1.3. Kuppersbusch ovens have smooth anti-stick internal surfaces that they claim inhibits cooking residues from adhering<sup>28</sup>.

### ■ Gas igniters

All domestic ovens have electric high voltage spark igniters in EU. However many commercial gas ovens use pilot lights as these are viewed as being more reliable. Some stakeholders have said that automatic electric ignition is less reliable due to the higher temperature that the electronics would experience in commercial equipment than in domestic but some commercial ovens with electric ignition are sold in EU<sup>29</sup>. Several manufacturers produce automatic control systems. And these are commonly used in EU as gas boiler igniters but one US manufacturer states on their datasheet that these are suitable for commercial catering<sup>30</sup>. The datasheet states that the electronics are suitable for use at up to 80°C which should be suitable for most ovens as long as the circuitry is located at a suitable location. Gas pilot lights should consume a maximum of 250W of energy according to EN 203-1 although a stakeholder is indicated that some may use larger amounts of gas. The energy that would be consumed by a high voltage spark igniter would be far less as these are used only a few times per day to ignite gas whereas pilot lights are on continuously.

### ■ Ventilation

All heat ovens, except those with steam input, need some ventilation to remove excess steam from cooking although the incoming air is cold and so needs to be heated whereas the vented gases are hot and so are a source of heat loss. The amount of ventilation therefore needs to be carefully controlled by vent size, design and location.

<sup>28</sup> Downloaded March 2011 [www.kueppersbusch.de/englisch/produkte/oekootherm.htm](http://www.kueppersbusch.de/englisch/produkte/oekootherm.htm) See also downloaded April 2011 <http://www.kueppersbuschusa.com/%D6kootherm-plus-page-21?zenid=a2ef88e0b45ecfe0c74f6512840d9f74> downloaded April 2011

<sup>29</sup> Rosinox Royal Chef Modulaire equipment download April 2011. <http://www.rosinox.com/cuisson/?p=5>

<sup>30</sup> Fenwel Controls, Series 35-60 & 35-71 datasheet.



### 6.3. STATE-OF-THE-ART OF BEST EXISTING PRODUCT TECHNOLOGY OUTSIDE THE EU

Domestic and commercial heat and microwave ovens sold in the EU are essentially of similar designs to ovens sold outside the EU and few different technologies that are superior to those available in the EU have been identified.

### 6.4. EQUIPMENT WITH SIMILAR FUNCTIONS TO OVENS

Commercial combi-ovens are used to cook vegetables, cook steaks and many other cooking processes that are also carried out with hobs and grills. One oven manufacturer has claimed that a modern combi-steam oven consumes typically 60% less energy and than would be used by a hob for cooking vegetables<sup>31</sup>. This is a reasonable figure because much less water needs to be heated and the large heat losses that occur from the sides and lids of cooking pots are eliminated whereas heat losses through oven insulation will be far lower.

There are several other alternatives to ovens but with many such as Sous-vide and “slow-cookers” can require much longer cooking times.

#### 6.4.1. SOUS VIDE COOKING

Sous vide cooking was developed in France in 1974 as an alternative way of cooking that uses relatively low temperature but often over much longer cooking times. Sous vide cooking is carried out in a water bath which is an enclosed chamber in which food is cooked. Some websites and manufacturers refer to these appliances as ovens but they would not normally be regarded as ovens, being more similar to a pan of warm water on a hob. There are many claims on the Internet that Sous vide cooking uses much less energy but no reliable comparable quantitative data could be found and so this claim cannot be substantiated. As much lower temperature is needed than oven cooking, it is reasonable that Sous vide would consume less energy as long as cooking times are not significantly longer, however much longer cooking times are often used. A difference is that Sous vide cooking results in a different result. Food cooked in this way is reported to be superior with more flavour and better texture. Sous vide cooking also requires that the food is vacuum packed and this will consume some energy.

Most energy is consumed during heat up and this depends on the amount of water and the cooking temperature. Once the operating temperature is reached, heat input is required to replace heat losses and so this is minimised by good thermal insulation including a well fitted lid. Some Sous vide available on the EU market are very similar to laboratory designs of water bath and do not have lids.

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<sup>31</sup> Information provided by Rational AG



Sous-vide is an option for certain types of food and recipe and the results are different to conventional ovens and microwave ovens. Sous-vide cannot be used for roasting, grilling or baking. No comparative energy consumption data could be found so it cannot be confirmed that the widely published claims of energy efficiency are correct.

## 6.5. POTENTIAL FOR ENERGY SAVING

The variation in energy consumption of domestic ovens is clearly apparent from energy consumption measurement data supplied by CECED. These variations are due to the oven design with the better performing ovens have some of the eco-design features discussed in the task 6 report. Manufacturers have provided some data (mainly for domestic products) on expected improvement potential from eco-design changes. These figures are the improvements that they are confident can be achieved and so further improvements may be possible but this is less certain. Potential energy saving is used as a marketing tool, especially for commercial equipment and many examples have been found and included in this report. Clearly, predicted energy savings used in marketing will be optimistic and is usually a comparison of the new innovation with relatively old technology and may not be the same as the improvement potential that would be obtained by modification of current representative products. Some of the claimed improvements are due to eco-design improvements and others are from features that alter user behaviour.

Based on the data supplied by CECED and described in the Task 4 report (figures 4-6 and 4-7), it is clear that the energy consumption of domestic gas and electric ovens as measured by the standard methods vary considerably and total EU energy consumption would be reduced by removal of the worst performing ovens as well as providing an incentive to improve ovens further by changing the energy bands of the energy label for electric ovens and extending energy labelling to gas ovens. Removal of the worst performing ovens could reduce energy consumption by as much as 20% based on CECED's data but this depends on the minimum energy consumption limit that is chosen as this determines the proportion of currently available ovens that would be affected. There is an issue however with some types of innovative ovens that perform poorly in the standard energy measurement tests but in practice consume less energy for cooking. These include convection ovens with additional microwave heating and microwave ovens having convection heating. These perform poorly using the applicable measurement methods (i.e. conventional ovens without microwave heating and combination microwave ovens in microwave only mode). As these types of oven in practice consume less energy for cooking, they should be credited in some way so that their true performance is shown on energy labels.

Incentives for improvement are currently limited for electric convection ovens as most on the market are in either energy band A or B. Further technology improvements will occur if there is an incentive from the energy label. As discussed above, the variation in

performance of solo microwave ovens currently sold in the EU is too small for energy labels to be practical. Inclusion on combination microwaves with solo microwaves would be misleading to consumers and combination versions will perform worse than solo ovens using the microwave oven energy measurement method whereas combination ovens can consume less energy for some recipes when compared to convection ovens.

Data on the variation in energy consumption of commercial ovens is not readily available although from this study it is apparent that some variation in performance will exist, possibly as much as for domestic convection ovens. Standards for measuring energy consumption are being developed which could be used for energy labels or for the basis of minimum energy performance standards.

### 6.5.1. DOMESTIC

There will be reductions in energy consumption of domestic ovens in the EU for several reasons. Some will occur as business as usual whereas others would occur only as a result of eco-design requirements:

Business as usual trends:

- Older models will be withdrawn from the market and new models introduced. New electric ovens tend to be more energy efficient than models that were introduced more than 10 years ago because of the effect of the energy labelling scheme although the same improvement may not have occurred with gas ovens as there is no energy labelling obligation.
- EU Regulation 1275/2008 imposes maximum standby energy consumption limits on household appliances including domestic electric ovens and microwave ovens. The first stage requirements have already affected new ovens and a further reduction in standby energy consumption will be imposed in 2013.

Technology developments will continue but without changing the current energy labelling of electric ovens, improvements will be small as the current energy labelling scheme provides little incentive for electric ovens as most of the best performing ovens introduced to the EU market in recent years are “A” rated and further improvements will not change this rating. CECED has indicated that a total decrease of ~ 6 or 7% in energy consumption for electric and gas ovens is achievable and a decrease of ~4% for microwave ovens (both figures exclude reductions in standby energy consumption). These technology changes to reduce energy consumption are more likely to be implemented if the energy label for electric heat oven were to be revised with higher ratings and new energy label schemes for gas and microwave ovens are introduced. Moreover, some of the other technology improvements discussed in this report may be achievable giving larger energy consumption decreases if there were sufficient incentive.

The 7% and 4% are figures provided by CECED and so are likely to be conservative estimates and larger improvements may be achievable in the future and so the above figures could be considered to be realistic but minimum values. Using the more, optimistic estimates of energy consumption used for task 7, reductions may be higher at as much as 14% for electric ovens. As there is currently no energy label for gas ovens, mass reduction has not been encouraged and so the improvement potential for gas ovens could be larger than for electric ovens and over 20% may be achievable. Improvement potentials are discussed in task 7. Significant further improvement of microwave ovens seems less likely in the next 2 – 3 years using existing BAT although data from CECED shows that the best solo MWO consume 8.9% less energy than the average and the best combination MWO consumes 10.8% less energy than the average.

#### **Portable electric ovens:**

Unlike built-in and range electric ovens, portable ovens are not subject to energy label requirements and so there has been no incentive to design for low energy consumption. Portable electric ovens are usually fairly low priced products. Therefore the potential for energy savings will be very significant as door design (multiple glazing, etc.), door seals, insulation, cavity isolation, vent flow control, forced-convection and good engineering design could all be improved to give lower energy consumption. Reduction of thermal mass may be less important as manufacturers will have reduced metal thickness to save on material costs. The size of energy savings is not known but the potential difference between the worst performing appliances and the best design achievable is likely to be similar, as a percentage, to the difference between pre-energy label 1990's full-size ovens and modern BAT designs. This difference could be as much as 40% but the actual potential will not be known until independent measurements are available.

The actual EU – wide improvement that is achievable will be discussed in task 8 and will depend on the form of eco-design implementing measures. If a minimum energy performance standard were to be introduced that removed the least efficient models from the EU market, the overall energy consumption would decrease. The size of this decrease would depend on the size of the energy consumption limit that is imposed.

### **6.5.2. COMMERCIAL OVENS**

Manufacturers of commercial ovens advertise their products with claims of energy efficiency savings due to good eco-design and this data provides an indication of the improvement potential. Some changes are the same as are used in domestic ovens and others which could be adopted in the future could be based on industrial oven technology. The main eco-design improvements are as follows:

- Steam generation – replace separate boilers by internal steam generation is estimated to reduce energy consumption by more than **15%** and reduce water consumption by 21%<sup>10</sup>.

- Use heat exchangers to recover waste heat – condenses steam and recovers heat of evaporation, one manufacturer estimates that this can save **16% of energy** and up to 42% of water. One report claims that heat exchangers that recover heat from hot exhaust gases to preheat incoming fresh air water for steam generation **reduces energy consumption by 30%**<sup>32</sup>. Another supplier claims savings of 20 – 30% based on older models<sup>33</sup>.
- Humidity sensors – avoids generation of too much steam, estimated energy saving **~5%**
- Cooking sensors – stop heating when food is cooked so saves energy if this is earlier than would otherwise be the case. Estimated energy saving **~5%**
- Improved thermal insulation – by using lower thermal conductivity materials, thicker layers and higher density, heat losses through insulation could be halved estimated at **~5%**. This is correct only where ovens are on for long periods. During heat up, increased thermal mass from thicker insulation would increase energy consumption. Vacuum insulated panels and vacuum insulated glass windows are not yet used in commercial ovens and would be BNAT. Further research will be needed to determine if these can be used in commercial ovens.
- Glass doors – as with domestic ovens, adding one extra sheet of glass (double to triple glaze) saves **~1 - 2%**. Addition of another sheet may save another **1%**. Addition of extra and improved infrared coatings could save an additional **1 – 2%**. This is applicable only to those ovens with glass doors. One report claims that the use of triple glazing and automatically switching off convection fans can save up to 40% of energy consumed<sup>32</sup> but this will depend on door opening frequency.
- Stop using gas pilot lights – would save ~6KWh of gas energy per day per gas oven (250W for 24 hours). The power consumption of the Honeywell S4560 automatic ignition control consumes a maximum of 10VA (10 watts electricity). This therefore consumes 0.24 KWh per day (maximum) of electricity equivalent to ~0.6KWh/day of primary energy (assumes electricity to primary ratio is 2.5). Saving by changing from pilot light to electronic ignition is 5.4KWh/day per appliance. Many EU gas ovens already use high voltage spark ignition but the more basic models with no mains power use pilot lights.
- Use LED lighting instead of halogen lamps – this would save energy as LED lamps are more energy efficient but these cannot be used at >70°C. Some manufacturers are considering these in some types of oven and use in solo

<sup>32</sup> Caterer search website article by Kevin Tyson 20 October 2010. <http://www.caterersearch.com/Articles/2010/10/20/335563/making-the-kitchen-greener.htm>

<sup>33</sup> Rack oven manufacturer's website, download April 2011. <http://www.modernbaking.co.uk/rackoven.html>

microwave ovens is a possibility. Savings would be ~1 – 2% where this change is possible

- Power management – This is very uncommon in commercial ovens as these tend to be used for long periods and then switched off. However automatic switching into low power modes is used in some continuous pizza ovens and in at least one brand of bakery oven. These have a “sleep mode” which reduces the temperature to 100°C and auto shutdown if the oven is left on for beyond a predetermined time (e.g. if users forget to turn off at night)<sup>34</sup>. The energy saved by these options is however difficult to estimate.
- Gas burner efficiency – as with domestic gas burners, some improvement may be achieved by the design of the gas burner to reduce the amount of excess air used. Narrower gas jets are one design option. However technology used with industrial ovens may be applicable such as pre-heating burner air using warm air from the heat exchanger. Currently the gas flow rate is controlled with mechanical valves but the primary air flow rate is less accurately regulated. Active air flow control as well as gas flow control would optimise the gas / air ratio but may be too costly. This is currently not used in commercial catering ovens and is currently used only in larger industrial equipment.
- The potential for improvement of microwave ovens is relatively small and similar technology modifications as described for domestic ovens would be appropriate.

Many of the above eco-design options can be used in one type of oven but the individual improvement potential will not always be additive. If all possible options were to be used, the energy saving would be significant but probably less than 50%. Also, many commercial ovens on the EU market already use at least some of the design options described above. Triple glazed glass is often available as an option and heat exchangers, sensors and internal steam generation are used in some models. Some technologies are not yet available and more research will be needed. Also, some of the technologies described here may also be too expensive for commercial catering ovens. One stakeholder has provided data that indicates that the best commercial ovens may consume 25% less energy than average ovens based. In addition to the above listed design options, good engineering will also improve performance. This probably also influences energy consumption in low power “idle” modes where large differences between combi-steamer ovens has been measured (see task 4).

## 6.6. CONCLUSIONS

Significant reductions in energy consumption appear to be achievable for ovens by ecodesign. Changing from electric to gas is a potential option but it can be

<sup>34</sup> Monoequip is a manufacturer of commercial ovens [www.monoequip.com](http://www.monoequip.com)

inconvenient to implement as piped natural gas is not available in all parts of the EU, although using LPG bottles remains an alternative. On the other hand, there are also limits to electric supplies in some EU Member States which makes gas the only viable option. Also, gas cooking sometimes gives different results to electric cooking and so is not always directly comparable. Electricity is of course the only option for microwave ovens.

### 6.6.1. RELATIONSHIP BETWEEN GAS AND ELECTRIC HEATING

The main environmental advantage of gas is that it is a primary energy source and electricity has to be generated and in most EU States, this is predominantly from fossil fuels. Cooking in an oven using average EU electricity will emit more CO<sub>2</sub> than when cooking the same recipe with gas. This is because electricity generation and transmission is only about 30% efficient whereas a high proportion of the heat from burning gas is generated inside the oven although some is lost in the flue gases. Only a few EU States generate most of their electricity from sources other than fossil fuels but the EU aims that CO<sub>2</sub> emissions per kWh of electricity generated should decrease in future, but it is likely to take many years before the use of electricity in the EU as a whole for ovens will emit less CO<sub>2</sub> than from the use of gas for ovens. Therefore energy saving technologies for electric and for gas appliances have been considered separately in this report.

### 6.6.2. DOMESTIC

A wide variety of technologies have been identified that affect the eco-design of ovens, particularly their energy consumption. Some of these technologies have already been widely adopted such as reduction of thermal mass in electric heat ovens. Other BAT are utilised only in a small proportion of ovens which are regarded as the best available ovens on the EU market. For example quadruple glazing is used in a few electric ovens to give the lowest possible heat loss through the door glazing although this gives an increased thermal mass that offsets this benefit. There are other technologies that are not currently used in ovens but are used by other industry sectors. Some of these will not be applicable to ovens for cooking due to their complexity or cost and others will be unsuitable for technical reasons. However, it is possible that with a suitable incentive from energy labels, that some of these technologies could be utilised giving larger energy consumption reductions than those currently envisaged by oven manufacturers. Before any changes are made to ovens, designers need to consider all of the types of cooking process used which range from short periods to warm pre-cooked food, long periods for cooking casseroles, baking of bread and cakes, etc. whereas some of the eco-design improvements described here will benefit only some of these types of cooking process and may increase energy consumption in others. For example, if the change increases the oven's thermal mass, the heat consumed in short cooking processes will increase whereas it will decrease for long cooking times.

### 6.6.3. COMMERCIAL OVENS

As with domestic ovens, there are many eco-design options that could reduce energy consumption and some also reduce water consumption in the use phase. Many of the BAT options available are already used in some products although some are fairly uncommon. Several BNAT design options have also been identified but it is not clear whether some of these will be viable for commercial catering ovens. This may be because energy savings are too small, because the changes are too expensive or due to insoluble technology problems.

Large energy savings may be achievable by changing user behaviour but this is not always possible by eco-design of ovens but including sensors and power management should reduce energy consumption where ovens are not being used in the most energy efficient manner. Large energy savings are already being achieved however by using alternative methods of cooking. Combi-steam ovens consume less energy than traditional catering ovens (one report claims by as much as 50%<sup>32</sup>) and cooking with combination microwave ovens is also faster and more energy efficient for some cooking processes.

The size of energy savings from some eco-design options are very difficult to estimate. This is because there is currently no data on actual energy consumption of commercial ovens and this is because no EU standard energy consumption method is available although these are being drafted. Also, oven design and use patterns vary considerably. For example some ovens have glass doors but others do not and so the energy saving potential for the glass door options apply only to those ovens with glass doors. Ovens tend to be used differently in restaurants and in institution kitchens. In restaurants the oven will be switched on at start of service and left on until service is complete irrespective of whether it is in use. It is much easier however at institutions to plan the workload so that the oven need be on only when in use. This different behaviour could affect the size of the improvement potential of some options.