Preparatory Studies for Eco-design Requirements of EuPs

(Tender TREN / D1 / 40-2005)

LOT 13: Domestic Refrigerators & Freezers

Final Report

Draft Version

Tasks 6 - 7

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Table of Contents

NOTE: according to international standards dealing with quantities and units, the numbers in this study are written according to the following rules:

- the comma "," is the separator between the integer and the decimal part of a number
- numbers with more than three digits are divided by a blank in groups of three digits
- in case of monetary values the numbers are divided by a dot in groups of three digits.

0 Brief summary of the Study Tasks

A summary of the tasks included in this third part of the final report on the cold appliances study (tasks 6-7) is outlined in the following paragraphs

0.1 DESCRIPTION OF TASK 6

The analysis and evaluation of the foreseeable impact of the introduction of technological innovations in the design and manufacturing of base-case models, i.e. on the supply side, will be performed in this Task.

0.1.1 Subtask 6.1: Options, associated improvement, costs and impacts

The first step is the identification of a list of design options to be applied to the base-case models. To this end the information about possible options provided by the first GEA study (1993) and the COLD-II study (2000) will be analysed. Additional options will be defined through experts and stakeholders consultation and possibly further literature survey (mainly for the options not yet ready to be applied to the market). The aim is to evaluate which of the already known options have been successfully applied to cold appliances and to what extent (i.e. to the overall amount of models or to a fraction of the production), and which new options can be added to the list. Each option will be described in detail. It is possible that not all the options can be applied to all base-case models. Therefore, the initial option list will be focused on each base-case model.

After the consolidation of the options list(s), the associated environmental improvement (mainly decrease in energy consumption, noise decrease or changing in foaming and refrigerating fluids) and the increase in consumer price (of the improved model) will be defined for each single options to be applied to the base-case models. Environmental improvement and prices will be collected through the updating of the literature data and extensive experts and stakeholders consultation.

The quantitative assessment of the environmental improvement per option will be performed using the EuP EcoReport methodology and software. Starting from the inventory improved data, a LCA using SimaPro6 will be also performed, taking advantage of the environmental balance data and the evaluation methods available in the software itself. Output, both for EuP-Ecoreport and for SimaPro6, will be presented in specific terms (per appliance and per functional unit), and compared by damage category and by Life Cycle Phase. Comparison between EuP-Ecoreport and SimaPro6 is possible only up to the characterization (list of environmental indicators) phase. The subsequent phases (up to damage evaluation), as explained in Subtask 5.2, implemented by SimaPro6 software, will be carried out in order to evaluate the whole environmental balance.

Improved model environmental performance will be compared with results of the best case LCA. This comparison will be carried out by analysing the results of the characterization phase (both with EuP-Ecoreport and SimaPro6) and then of the subsequent phases, in particular using the results provided by the damage evaluation. The aim of performing comparative life cycle analyses is to understand in depth the effects of the environmental performances of each design improvement. This means to understand not only if the whole performance of improved model is better than the base case one, but also to understand for which life cycle phase this improvement is relevant. Using specialised LCA software (like SimaPro6) it is moreover possible to underline and analyse each contribution of both the impact factors (characterization phase) and the damage indicators (damage evaluation), for each inventory data and for the life cycle phases.

0.1.2 Subtask 6.2: Analysis LLCC and BAT

The evaluation of the LLCC and the BAT will be achieved applying the Marginal Net Present Value approach. Through NPV analysis the net benefits of the technological options to consumers are estimated. At this stage, the manufacturing cost increases are assumed to be passed completely to consumers through price increase. Manufacturing price increase will be calculated according to and agreed amount of mark-up from purchasing price increase. The increase in consumer price will be then compared to the discounted annual economic savings (on the electricity) due to higher machine performance for the presumed lifetime of 15 years, resulting in the Net Present Value.

The NPV and LCC will be evaluated first for each (single) technological option referred to the base case models. Then the optimum combination of technological options will be defined. First, the single options are sorted according to the payback period (or the ratio of NPV/investment) with the higher return options first. Second, the savings are calculated for the combined options. Evidently the potential savings decrease as subsequent technological options are added, since less energy/water is available to be saved due to the impact of the previously added technological option(s).

Net Present Value is then calculated for the combined options. In order to see the impact of adding each subsequent option, the net present value of adding a specific option is calculated. This is known as the **Marginal Net Present Value** (MNPV) of adding a given option. Since the options are added in order of their potential economic contribution, we may add options until their marginal net present value is zero or negative. This determines the optimum design and is also the point in which the total net present value of the combined options is a maximum (or the LCC is at minimum). The BAT is represented by the latest option combination.
The NPV and Life Cycle Cost methods are equivalent. This is due to the fact that the life cycle cost is a constant value (the base case) minus the NPV of the improvements, thus the maximum NPV gives the minimum life cycle cost (LLCC). The output of the NPV analysis is the input in the LCC analysis where the constant values are added.
The main difference between the more traditional Life Cycle Cost analysis developed and reported in previous studies and the Marginal Net Present Value analysis (which both use the same design options input from the technical/economic analysis) lies in the fact that in traditional LCC design option impacts (savings and costs) are calculated one independent from another and then their effects are added, while the MNPV analysis calculates the effects of any option taking into account that a previous option has already been implemented and part of the savings has already been achieved. The other difference is that in the traditional LCC the options sequence is decided by "clustering" the options according to an engineering, not necessarily following their simple pay back time, while in the MNPV approach the options are applied mainly considering their economic feasibility for consumers (in terms simple payback time) and initial engineering considerations about their compatibility.

0.1.3 Subtask 6.3: Long-term targets (BNAT) and systems analysis

Long-term technical potential for cold appliances, represented by the BNAT (Best Not yet Available Technologies) can be evaluated following the same approach used for the LCC. In fact, when the technological option list will be set, not only the available technologies will be collected,

but also some options needing further applied and/or fundamental research. For these options stakeholders will be asked to estimate the possible price increase and environmental impact decrease. With this information a MNPV analysis could be developed, leading to the ranking of the identified option and the evaluation of the long term potential. This analysis will involve options working within the same product archetype.
The long term potential on the basis of system changes will be attempted if such changes could be identified for this specific product. Possibly only the product-service substitution could be hypothesised for cold appliances.

0.1.4 Subtask 6.4: Environmental assessment of the technological improvements

The quantitative assessment of the environmental improvements for the identified targets will be developed in this subtask.

0.2 DESCRIPTION OF TASK 7

This Task summarizes and totals the outcomes of all previous tasks. It looks at suitable means to achieve the potential improvement for cold appliances.

0.2.1 Subtask 7.1: Worldwide Scenarios for Cold Appliances

In this Subtask the main policy measures existing and planned worldwide will be summarised and tentatively compared with those of the EU to evaluate the European position in the international context.

0.2.2 Subtask 7.2: Worldwide Compliance Assessment

In this Subtask, the different procedures followed worldwide for the declaration of the measured values, for the verification of the declared data and for the market compliance of policy measures will be described and tentatively compared, to evaluate the differences and the effectiveness of this fundamental aspect for an effective implementation of any mandatory or voluntary action.
Basic elements about statistics and measurement uncertainty will be also briefly described.

0.2.3 Subtask 7.3: EU Scenarios and Targets

The conclusions of the previous study Tasks will be the basis for the definition of a set of scenarios. Targets corresponding to the potential improvement resulting from the Life Cycle Analysis will be addressed, not only the LCCC and the BAT as requested by the eco-design approach, but also if necessary other points of the LCC.

The Use phase will be very likely the most addressed, since in general most of the environmental impact takes place during this phase, however should other life phases result in a real and proven significant environmental impact, they could be also addressed and further scenarios developed.

According to the clear indication of the Commission, the eco-design studies are intended to provide a factual basis to allow the Commission (assisted by the Forum and the Committee set in directive 2005/32/EC) to adopt implementing measures, if appropriate. The studies are supposed to identify options aiming at improving the environmental performance of the product under examination.

Nevertheless, during the kick-off meeting of the study the Commission asked to anyhow foresee some policy measure implementing the identified targets. For example, they could include the more traditional review of the labelling scheme (both in terms of declared parameters and thresholds of efficiency/performance classes) and the setting of energy/water requirements (energy/water consumption) to be achieved via the a further round of the industry voluntary commitments or the setting of a specific legislation; a combination of mandatory and voluntary measures could also be envisaged; noise reduction could also be used as a scenario, alone or in combination of the other measures and targets; stand-by power/consumption reduction will be also discussed.

A stock model has been developed to evaluate the improvements that can be achieved within each scenario compared to the Business as Usual baseline. Energy savings are the most important parameter, but also the environmental impact reduction due to other aspects could contribute. The time horizon is 1990-2030.

0.2.4 Subtask 7.4: Manufacturers Impact Analysis

The impact analysis on manufacturers has been run using the E-GRIM model, developed by ISIS-ENEA in the framework of previous SAVE projects and already successfully applied in the analysis of the COLD-2 project.

Cost data used in the NPV and Life Cycle Cost methods is further disaggregated and used as input in E-GRIM model. Quantitative market data, industry structure, consumers' habits provided by previous phases of the study or by literature will be used to establish a framework to describe the linkages of the market and the technological improvement. E-GRIM model is expressly designed to allow the analysis of the effects of a single policy measure upon a single product. By combining multiple iterations it is also possible to analyse multiple products with policy measures taking effects over a period of time and/or multiple policy measures on the same product. The program simulates the sales, all main elements of cost and the cash flow, each year for fifteen years and then determines the present value of those cash flows without policy measure – the *Base case* – and with policy measure – the *Policy Measure case*. Output consists in the complete cash flow calculations, summary statistics, and graphs of major variables, including net cash flow for industry and for consumers (due to electricity savings), employment, investments required and impact on profits.

Average values to be used as input to E-GRIM model are presented at the sector level in terms of the "typical manufacturer".

0.2.5 Subtask 7.5: Sensitivity Analysis

In the methodological approach chosen for the present study a sensitivity analysis is performed at each stage of data analysis. This applies to the economic and market analysis, to user defined parameters, to product system analysis, to definition of the base case, product-specific inputs, to base case environmental impact assessment and to base case life cycle costs. Also for all other options concerning life cycle costs, the EU totals and the EU25 Total System Impact a sensitivity simulation will be run.

Again the technical analysis, and in particular the analysis of LLCC and BAT, include a very specific sensitivity analysis for the key parameters affecting the outcome (appliance life time, electricity price). The same is true of long-term targets. For manufacturers' impact analysis a specific set of variables will be considered for sensitivity; this analysis includes an estimate of consumer behaviour for higher products purchasing prices and consumer net gains. The same is true for targets, scenarios and policy measures.

This final Subtask on sensitivity analysis the conclusion of sensitivity analysis performed in the study phases will be summarises and highlighted. For example, the sensitivity analysis for the LCC run considering (i) different lifetime (10, 12, 15 and 17 years) against a commonly agreed lifetime of, i.e., 15 years; (ii) different values of the energy price, where the EU average will be initially used and then the influence of the real prices in Member states will be evaluated.

Contemporarily a sensitivity analysis will be performed on the most important parameters affecting the identified targets, scenarios and policy measures, trying also to describe the impact of possible key alternatives previously identified. The robustness of outcome and the sensitivity of certain market segments will be discussed.

0.2.6 Subtask 7.6: Hypothesised Policy Measures for Cold Appliances

According to the last indication from the Commission, conclusions regarding possible policy measure scenarios for cold appliance will be drawn in this Subtask that will close the project.

6 Task 6: Technical Analysis

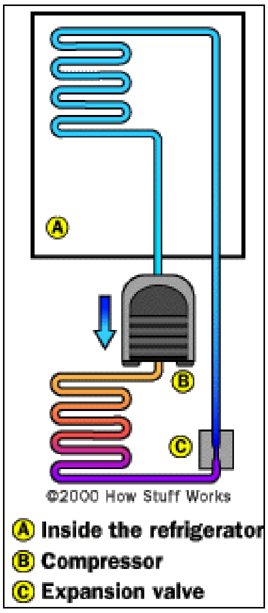
6.1 SUBTASK 6.1: OPTIONS, ASSOCIATED IMPROVEMENT, COSTS AND IMPACTS

The basic idea behind a refrigerator is very simple: it uses the evaporation of a liquid to absorb heat. The liquid – the refrigerant - used in a refrigerator evaporates at an extremely low temperature, so it can create freezing temperatures inside the refrigerator. There are five basic parts to any refrigerator:

- Compressor
- Heat-exchanging pipes - serpentine or coiled set of pipes outside the unit
- Expansion valve
- Heat-exchanging pipes - serpentine or coiled set of pipes inside the unit
- Refrigerant - liquid that evaporates inside the refrigerator to create the cold temperatures.

The basic mechanism of a refrigerator is:

- the compressor compresses the refrigerant gas. This raises the refrigerant's pressure and temperature, so the heat-exchanging coils outside the refrigerator allow the refrigerant to dissipate the heat of pressurization;
- as it cools, the refrigerant condenses into liquid form and flows through the expansion valve;
- when it flows through the expansion valve, the liquid refrigerant is allowed to move from a high-pressure zone to a low-pressure zone, so it expands and evaporates. In evaporating, it absorbs heat;
- the coils inside the refrigerator allow the refrigerant to absorb heat, making the inside of the refrigerator cold. The cycle then repeats.



6.1.1 Options definition and collection

A *Technological Option List* will be created through the consultation of the previous European studies on cold appliances, the specialised literature and the discussion with manufacturers and other stakeholders. Not only the presently available technologies will be collected, but also options needing further applied and/or fundamental research.

For all the identified options, the possible price increase and environmental impact, energy /water consumption decrease when applied to the base case(s) will be evaluated (for already applicable options) or estimated (for BNAT options), along with the percentage of their application to the market.

A specific *Technological Option Data Collection form* (an electronic sheet) will be used to facilitate the data collection and the collected information systematisation.

6.1.2 Design Options described in previous European studies

6.1.2.1 The technological options evaluated in 1993 (GEA study)

The GEA study in 1993 considered the following design options to raise cold appliance efficiency:
- increased door insulation
- increased cabinet insulation
- increased evaporator surface area
- increased condenser surface area
- increased evaporator heat capacity
- increased condenser heat capacity
- more efficient compressors
- decreased door leakage (better gaskets).

6.1.2.2 Technical options evaluated in 1998 (COLD-II study)

All of these design options were considered still applicable at the time the COLD-II study was developed. However, a wider range of options was considered, including:

1) Design options applicable to **all cold appliances**:
- higher-quality insulation (vacuum insulation panels, gas-filled panels or alternative foaming agents)
- low-wattage fans to increase heat transfer at the evaporator and condenser
- variable-speed compressors
- variable-capacity compressors
- rated-speed compressors
- linear (free-piston) compressors
- optimised electronic control
- alternative refrigerants (i.e. refrigerant mixes)
- flow regulation valves
- compressor-run capacitors
- phase-change materials in the evaporator and/or condenser
- off-cycle migration valve to prevent pressure equalisation of the refrigerant.

2) Design options for **cold appliances with a refrigerator compartment & a frozen-food storage compartment** (energy labelling Categories 4, 5, 6, 7 and 10):
- alternative cooling cycles, including the Lorenz and Stirling cycles
- optimised thermal balancing, reducing the need for thermal-compensation heaters in single-compressor appliances
- two compressors (alternative to the following option)
- two-way refrigerant control valves with twin evaporator system (alternative to the previous option).

3) Design options for **no-frost appliances** and **appliances using automatic defrosting**:

- lower-wattage fans
- intelligent adaptive defrosting.

Some of these design options are generally applicable, but others are mutually exclusive: for example, there is no value in using a "two-way refrigerant flow valve" and "two compressors" at the same time.

4) In addition to the above options there are many **minor design options** that could cumulatively lead to a few percent in energy savings, such as:

- optimised chimney effect for static condensers
- optimised positioning of the anti-sweat liquid line around the door edges
- optimised internal airflows to reduce thermal bridging.

5) Finally, a number of design options were identified as in principle leading to significant energy savings **under real usage conditions**, but the hypothesized savings could not be detected (and therefore proven and quantified) under the existing test condition of the standard EN 153. These include:

- more transparent temperature controls, such as accurate temperature displays, that could limit the number of instances where consumers mis-regulate the appliance;
- intelligent adaptive controls that sense the internal and external temperature conditions and only activate thermal-compensation heaters when needed
- freezer-compartment breather bags to slow frosting of the evaporator.

6) In addition, the COLD-II study spent few sentences in considering the possible energy savings deriving from the **reduction of the food storage temperature** to an intermediate temperature between -18°C and -10°C, especially in the freezer appliances/compartments. The reason for this proposal was that since bacteria does not propagate in foodstuffs stored below –10 °C there is no biological risk in such temperature increase, only enzymatic degradation continues, decreasing the food long term storage, which may in turn encourage consumers to hoard less[1]. This option has been discussed thoroughly in Task 1.

In the new ISO 15502 standard freezer temperature is confirmed at -18°C, but a living discussion is on-going among worldwide standardisation experts for the definition of a global standard for cold appliances, where elements such as freezer compartment temperature, test temperature at more than

[1] COLD-II study: "Furthermore it is worth noting that substantial energy savings could be achieved were changes to be allowed in the existing food-preservation rules. Bacteria does not propagate in foodstuffs stored below –10 °C, yet the current definition of a 3- and 4-star frozen-food compartment is one where the warmest food in the compartment is not above –18 °C. This requirement means that the average 3- or 4-star frozen-food compartment temperature is actually ~–21 °C, which is some 6 °C less than the average freezer-compartment temperature in a US refrigerator-freezer, for example. Providing food is frozen rapidly the size of ice crystals is minimised and the longevity of food preservation is maximised. Therefore, from a public health perspective, it is only important for the foodstuffs to be rapidly frozen and stored below –10 °C. Enzyme activity, which causes foodstuffs to degrade but poses no biological risk, still occurs at lower temperatures than this and is retarded the lower the storage temperature. However, were an intelligent freezing system that cooled rapidly before allowing the food storage temperature to rise to an intermediate level of between –18 and –10 °C permissible, it would save a considerable amount of energy compared to the current situation. Any associated reduction in the long-term storage time of food without degradation in food quality may encourage consumers to hoard less, but should not pose a biological risk. To realise these savings would require modification of the existing frozen-food storage rules, which could not be achieved without a substantial technical review and appreciable institutional effort" .

one ambient temperature, etc. which, once agreed and adopted will have an impact on the energy consumption values.

Some of the listed technological options are described in the following. The description is mostly taken from the COLD-II study report to allow the evaluation of the applicability of those options or part of those options today.

a) Door gaskets design options

Designing the air-tightness of door gaskets is a balance between competing concerns. If the door gasket is optimal from a thermal-efficiency perspective it can be difficult to open the refrigerator or the freezer, since the associated reduction in air leakage enhances the pressure difference caused by the difference in density of the internal and external air. As this pressure difference is a function of the difference in average air temperatures, this phenomenon is particularly significant for freezers.
Some handles have been designed specifically to facilitate door opening under large pressure differences, working by freeing a small section of the gasket before the whole door is opened. The improved handle design enables thermally optimised gasket design and easy door opening for the user.

Materials and design for improving the air-tightness of door gaskets do exist. The standard EN 153 includes a test of the maximum opening force for doors and lids from the inside as a security concern (it should not exceed 70N). A test of the quality of door gasket air-tightness is also included, but it would be useful were the standard to define the minimum adhesive strength of the gasket on the structure. As a result of the lack of quantitative test data it was impossible to fix a value for the gain associated with good gasket design because there is no test method to control the air-tightness of a given gasket and diagnoses must be made case by case. Nevertheless better gasket designs exist but no general criteria have been established to enable different gasket designs to be classified.

b) Evaluation of the edge effect

Studies of typical PU insulation (on the wall of an American refrigerator) found that the cabinet heat load stems not only from conduction in a perpendicular direction through the walls, but also from conduction **along** the external metal casing. The metal shell provides the structural rigidity, but direct heat loads are transferred along the metal shell itself to the inside of the cabinet. This phenomenon is called the ‘edge effect’. For the particular appliance investigated the edge effect represented 12% of the total cabinet heat load, 4 times higher than those coming from heat losses via the door gasket. Placing a plastic cover on the internal flange can reduce the edge-effect heat losses by ~50%; however, as these data are derived for US appliances it is not clear that the issue is so significant for typical European appliances, using natural convective heat transfer at the heat exchangers.

c) Gas-filled panels

This technology was developed at the Lawrence Berkley National Laboratory in California and comprises panels filled with low thermal conductivity gas at atmospheric pressure, for example argon and krypton. The panel is enveloped in a polymer-based sheet with a very low permeability to both air penetration and gas leakage. A cellular material prevents convection and limits radiative heat transfer.

Conductivity in the gas is the main mode of heat transfer in a gas-filled panel, hence it is important to choose the right gas. However, low conductivity is not the only consideration: in addition, the gas should not be toxic or flammable and should have no direct adverse environmental impacts, and it should be affordable for the application. The main application for gas-filled panels is in the building sector, but in principle nothing prevents their use in other applications such as water heaters. Unfortunately the ratio of conductivity to price was considered not sufficiently attractive for GFPs to be commercially viable in cold appliances.

d) Vacuum insulated panels

In 2000, VIPs were considered a mature technology with a proven performance and manufacturing in cold appliance applications. Several different configurations were commercially available, but a typical VIP includes three major components: a core insulating material, an airtight envelope and an absorber. The internal pressure of the panel is in the range of 50 Pa abs.; the airtight envelope and the absorber are intended to maintain this pressure range throughout the panel's lifetime. In general, VIPs are an efficient insulation system, with a conductivity in the core being as low as 2,4 mW/m.K depending on the material.
Several core materials have been used in the manufacture of VIPs: polystyrene, open-cell PU, silica powder and glass fibre. These materials are ranked according to their cost and other parameters, such as density and manufacturing time. Their characteristics are summarised in Table 6.1. The first two materials appear to have acceptable technical and economic characteristics for cold appliance applications.

Table 6.1: Comparison of various vacuum insulated panel core materials

Characteristic	Polystyrene	Open-cell PU	Silica powder	Glass fibre
Conductivity at 10 Pa abs. (mW/m.K)	4,8–5,8	9,7	5,8	2,4
Manufacturing time	Fast	Medium	Medium	Long
Density (kg/m^3)	80–144	64	192	128
Drying need	No	Yes	Yes	No
Thermal stability	Low	Medium	Good	Very good
Recyclability	Yes	Difficult	Yes	n.a.
Cost	Low	Medium	High	Very high

Abbreviation: NA = not applicable.

Maintaining a low pressure in the VIP is a key factor because of its strong influence on the thermal conductivity. When pressure is higher than 100 Pa abs. the panel efficiency decreases rapidly down to a point where VIPs do not give any advantage compared to PU foam. Two technical solutions prevent pressure increase from being a serious problem in modern VIPs: improved envelopes and inclusion of an absorber, known as a 'getter', in the VIP.
Several types of VIP envelopes exist, each with different permeability and structures. For silica powder VIPs, because the pressure is relatively high (1000 Pa abs.), the envelope needs to be composed of several coats of various polymers. PU is not appropriate because its functional pressure range is 10-50Pa abs.; however, metallised polyester (PET) bonded to polyethylene (PE) is an acceptable solution. Nylon is added to prevent water penetration through the PET and aluminium barrier. PE ensures the integrity of the sealing weld.
The aluminium coat used in the envelope is a source of thermal conduction along the 'skin' of the panel (known as the 'skin' effect), acting to reduce the overall insulation efficiency of the VIP. The presence of both "edge" and "skin" thermal effects shows that the equivalent conductivity of the

panel depends not only on the insulation thickness but also on the envelope dimensions and material.

e) Fully vacuum insulated panels

Two patents defined a design where an open PU cellular structure, foamed with CO_2, for example, is evacuated by a small vacuum pump[2]. The vacuum pump is installed permanently inside the refrigerator niche and is activated when necessary to maintain a vacuum level in the range of 0,1mbar, which is the required level of vacuum for the panel to have a low thermal conductivity. It is claimed that this concept is more reliable than conventional VIPs, not only because the evacuation process is renewed when needed, but also because direct expansion of open-cell foams in walls gives better mechanical properties than the incorporation of VIPs in standard PU foam.

f) Increase the thickness of the PU foam

PU foam is an established insulation for cold appliances, which also provides the majority of the structural strength of the cabinet; however, an increase in its average conductivity due to CFCs phase out and substitution with hydrocarbons occurred after 1995. The cyclopentane foam conductivity is 19,5-20,5 mW/m.K at 10°C. The heat losses of some 20 different cold appliance types were measured in the COLD-II study using the inverse flux method. Simulations of the heat loads of these appliances, using the ENEREF® model (developed by Ecole des Mines, Paris, partner of the COLD-II project) found that an average ‘equivalent conductivity’ of 23 mW/m.K was an appropriate value for refrigerator walls, with an uncertainty in the range of ±5%. This value integrated (i) the perpendicular conductive heat loads through the side walls and door, (ii) the heat loads from the thermal ‘skin’ effect, sometimes called the ‘edge’ effect, which is the heat flux transferred directly via conduction through the external sheet metal casing to the internal volume and (iii) the heat load through the door gasket, which is normally a small component of the total cabinet heat losses.
Increasing the insulation thickness reduces the thermal load into the cabinet but leads to reductions in the storage volume of the appliance and/or to increases in its external dimensions. The following two cases were considered in COLD-II study:

- the internal volume is held constant, causing the addition of extra insulation to increase the external dimensions. This leads to the following disadvantages:
  - fitting of the appliance in the kitchen and kitchen furniture may become more difficult: in some cases it is possible to increase average insulation thickness by increasing the appliance height, but this is not applicable to built-in, to table top or to under-the-counter models; in other cases it is possible for free-standing appliances to extend the width beyond the 60cm standard (at constant height), but this is not applicable again to built-in and in standard kitchen furniture with a 60cm module;
  - in extreme cases, house-door dimensions might not allow passage of the appliance (for large models)
  - increased occupied floor area is considered to have a negative influence on refrigerator marketability. An opinion poll performed among US manufacturers showed that increasing ½” (1,27 cm) the external dimensions of a product would entail loosing 20-30% of the available market share. But, since these results were difficult to be quantified in a cost analysis, they were neglected in the COLD-II study;
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[2] EP0587548, 16.03.1994, insulation for refrigerators or freezers; EP0936428, 18.08.1999, vacuum insulated refrigerator or freezer cabinet.

- the external dimensions are held constant, causing the addition of extra insulation to reduce the internal storage volume. This leads to the following consequences:
  - the price of the unit under consideration will increase, compared to other models with the same external dimensions and original net volume, because the purchase price depends on the net volume (or in other words, the market value of the modified model will decrease because at constant external dimensions the internal useful volume is lower)
  - the reduction in energy consumption does not equate to an equal increase in efficiency as the net volume declines, i.e. the new (smaller) product will have to meet a lower energy consumption (energy policies for cols appliances are based on the net volume).

  The first effect could be taken into account by increasing artificially the purchase price of the modified options that result in a smaller net volume.

A parametric study on the implications of increasing the insulation thickness in steps of 5 mm was conducted via energy and cost simulations for a 2-door bottom-mounted refrigerator-freezer to assess the economically optimal thickness. If the external volume is held constant and a loss-of-internal-volume cost penalty is applied (1 Euro/litre for all appliance categories with the exception of chest freezers with 0,6 Euro/litre penalty), the economic optimum occurs for a 15mm increase in insulation thickness (investigated range was from +5mm to +20mm). If the insulation thickness is allowed to increase with the internal volume being held constant, no optimum thickness is found within the range +5mm to +25mm of because there is no loss of internal volume and hence no loss-of-volume cost penalty. In the following aggregate LCC analysis an increase of 15mm thickness with increase of the external appliance dimensions was used; the other technical option (decreasing the net volume) was not taken into account due to the fact that the net volume of the improved model is different and so the comparison with the base case model is unfair.

6.1.2.3 Accessories and defrost system

a) Anti-sweat heaters

In addition to the energy test, EN 153 requires refrigerators to be tested at a room temperature of 16 °C to ensure that no condensation takes place on the external walls. For many freezer compartments, and in particular on the panel close to the doors, heating is necessary to avoid dew formation. In addition, the part of the cabinet that includes the door gasket needs to be heated to prevent sticking.

Some models are equipped with electric resistance heaters that require additional direct energy consumption, but the most common solution is to pass the refrigerant discharge pipe through the insulation around the doorframe and close to the metallic shell, to prevent both dew and sticking problems. This solution creates an additional heat load into the cabinet of 2-5W but uses no direct energy and is less energy consuming than an electric resistance heater. The main disadvantage is that it delivers heat to the door seal in a way, which cannot be controlled according to real need. The option of a hot gas discharge tube embedded around the freezer door frame could be re-examined when the introduction of intelligent electronic controls enables heat loads to be reduced. In any case there is still scope to optimise the performance of these systems by careful positioning and design.

b) Low energy consumption fans

For no-frost and other cold appliances using forced air there can be energy savings from the use of high-efficiency, low energy consumption fans. The most common fans used in 2000 was shaded-pole AC fans with a low efficiency and an input power of 6-10 W. Higher-efficiency 4W AC fans with the same output power were available; however, the most efficient fans are 12V DC units that use as little as 1 W. Such fans were found quite common in Japanese appliances and were also found in some European products. A traditional 8W evaporator fan requires ~35 kWh of direct energy per year and an additional ~35 kWh for removal of the heat deposited in the appliance. This figure falls to just 9kWh for a 1W fan, which can significantly change the energy balance associated with the use of forced convective cooling.

c) High-efficiency defrost system and control for no-frost and forced air applications

There are a number of means to improve the efficiency of the evaporator defrosting process for no-frost appliances.

Most “adaptive”', or “demand” defrost systems have been developed and commercialised that only initiate a defrost cycle when it is needed rather than after a fixed number of compressor cycles as is common with traditional timer-defrost systems. These adaptive-defrost systems use sophisticated electronic controls that integrate analysis of several parameters (including the number of door openings, the compressor operation time and the room temperature) to optimise timing of the defrost cycle’s initiation. Some adaptive-defrost systems also aim to schedule defrosting to occur at night, when average room temperatures are lower, and thereby reduce the recovery energy needed to return the compartment to its design temperature. In addition, some adaptive-defrost systems use fuzzy logic to train the control system to initiate defrosting in an optimised way according to an appliance’s particular usage and environmental patterns.

In 2000 there was considerable uncertainty about the scale of *in situ* defrost energy savings arising from the use of adaptive defrosting and from the inadequacy of the EN 153 edition used at that time to properly reflect the savings. The estimation was made more complicated by a lack of good field measurements and the enormous array of potential adaptive-defrost systems.

ISO 15502:2005 defines adaptive defrost as “form of automatic defrosting system where energy consumed in defrosting is reduced by an automatic process whereby the time intervals between successive defrosts are determined by an operating condition variable (or variables) other than, or in addition to, elapsed time or compressor run time.”

The new ISO standard (and the new edition of EN 153) includes modifications to evaluate the benefit from adaptive-defrost systems under standard test conditions. Adaptive-defrost systems is required to initiate a defrost cycle at the beginning of the test period, which will run for either 48 or 72 hours depending on the appliance configuration:

- if the appliance is a freezer or a refrigerator-freezer with separate evaporators in the freezer and refrigerator compartments, a 72-hour test period will be used;
- if it is a pure refrigerator or a refrigerator-freezer where the two compartments share a single evaporator, a 48-hour test period will be used.

The expected savings are:

- if a 48-hour test period is used, an adaptive-defrost system is expected to use half of the defrost energy of a typical conventional timer-defrost system that defrosted once in a 24-hour period, and one-third of the defrost energy of a typical conventional timer-defrost system that defrosted an average of 1,5 times in a 24-hour period;
- if a 72-hour test period is used, an adaptive-defrost system is expected to use one-third of the defrost energy of a typical conventional timer-defrost system that defrosted once in a 24-hour period, and one-fifth of the defrost energy of a typical conventional timer-defrost system that defrosted an average of 1,5 times in a 24-hour period.

d) High-efficiency defrost system and control for natural convection applications

Most European appliances use natural, rather than forced, convection as the primary heat-transfer medium from the evaporator and hence have a different defrosting requirement. For the vast majority of European refrigerator compartments (+4 °C according to the revised standard) automatic defrosting is achieved simply by regulating the time between compressor ‘on’ cycles in such a manner that the evaporator temperature passively rises above 0 °C long enough for any frost to melt. This system uses no direct energy but does have implications for optimisation of the compressor cooling power, percentage running time, cycle duration and evaporator configuration that can influence the overall energy efficiency. There is scope to optimise these configurations beyond the average arrangement, but the scale of savings that might be expected cannot be easily generalised.

6.1.2.4 High-efficiency heat exchangers

Most design efforts to improve heat exchanger (i.e. evaporator(s) and condenser) performance are directed towards lowering manufacturing costs and limiting frost formation on the evaporator; however, there is still scope to improve the efficiency of standard designs.

Heat-exchanger technology is very different for (i) natural convection, which is the most usual European technology, and (ii) forced-convection exchangers (i.e. ventilated with a fan), which is the most usual technology in Japan, South Korea, North America and Australasia. The following natural-convection cold appliance heat exchangers are used:

- evaporators
  - roll bond
  - plate (foam-in)
  - serpentine;
- condensers
  - wire
  - louvered.

Wire condensers are more efficient than louvered condensers, but for all natural-convection systems it is always possible to improve the efficiency by increasing the surface area providing there is sufficient space to do so. For forced-air, no-frost systems, fin and tube evaporators are typically used, while the condenser can either be of a natural-convection or a forced-air type.

There are a variety of sophisticated heat exchange surface designs for finned heat exchangers, many of which have been used mainly in air-conditioning applications.

Efficiency improvements for fin and tube designs have enabled both the system weight and energy consumption to be reduced. In general the potential for further efficiency improvements was considered higher with forced-convection exchangers than with natural-convection exchangers; however, one high-efficiency design solution that is applicable to both natural- and forced-convection designs is the use of phase-change materials to increase the effective thermal capacity. The manufacturer Thomson, had a patent for this design option utilised it in class A, natural-convection upright freezers sold on the EU market for some years. The phase-change material, which is integrated into the heat exchanger, enables higher average evaporation temperatures to be achieved compared to a conventional heat exchanger, thereby producing significant energy savings. Additional savings can be realised by optimisation of the compressor on/off cycling to take account of the accumulation of cold in the heat exchanger.

6.1.2.5 High-efficiency compressors

a) Energy efficiency of compressors for refrigerating applications

Reciprocating compressors were the most common compressor technology used in domestic cold appliances.

In practice, average compressor efficiency is a function of the cooling capacity (size) such that the smaller the compressor, the lower the energy efficiency. According to a US-EPA source, in order to minimise manufacturing costs, common parts such as cylinder housing castings, crankshafts and connecting rods are mechanically optimised for the large-capacity models, with the result that higher additional efficiency potentials exist for small-capacity models. Whether this is also true of 230V, 50Hz compressors designed for the European market is less evident as the main market is for small- to medium-sized compressors. Most compressors are single-speed units with a typical reciprocating frequency of 3000 cycles per minute. For these units there a clear tendency for the COP to diminish non-linearly with the cooling capacity was shown.

b) Electric motors in cold appliances

The usual design of electric motor used for refrigerator compressors is a two-pole, AC, single-phase, squirrel-cage induction motor with a running speed of ~3000 rpm. The motor provides the energy to run the compressor for normal thermal loads but also needs to provide the starting torque. The motor's stator laminations have a series of slots for the winding, which are arranged into two sets such that one set of windings is 90° out of phase with the other. The principal winding is in series with the main current and is always active when the motor is running; however, three design options are used to supply power to the secondary winding, which is utilised for starting the motor and then running at normal speed. The options are:

- RSIR (resistance start induction run): RSIR and CSIR use the secondary winding for starting only. In the RSIR option, the secondary winding is made with smaller-diameter wire that can only carry current for limited periods of time. The RSIR costs very little and the COPs of compressors in which it is used, tested according to the ASHRAE test method, are typically around 1;
- CSIR (capacitor start induction run): CSIR use the secondary winding for starting only;
- RSCR (resistance start capacitor run): a capacitor can be inserted in the starting winding then operated continuously; this is called a "capacitor-run motor". In the RSCR option the secondary winding also operates when the motor is running because wires have the same diameter. Use of a run capacitor improves the COP by 6–10%.

c) Technical options for higher energy efficiency in motors

Motor improvement: the relatively low energy efficiency of cold appliance compressors mostly stems from inefficiencies in the electric motor. The main options for improving motor efficiency are: (i) increasing stack height and (ii) use of larger-diameter wire using low-loss steel in the laminations and using thinner laminations.

Rated-speed motor: Electrolux created a comparatively new high-efficiency rated-speed compressor which has an ASHRAE COP of 1,62 and a swept volume of 8,1 cm^3. This COP can be compared to that of Electrolux's single-speed compressor, at only 1,45. Rated-speed compressors modify current frequency so that the rotation speed is at 1800 rpm, compared to the usual 2950-rpm rotation speed. Through being tied to a single, high rotation speed, conventional compressors can only reduce their cooling capacity by reducing their swept volume; however, smaller swept volumes

lead to relatively higher mechanical losses, which explains why compressor COP usually diminishes with cooling capacity.
Electrolux's series of rated-speed compressors have the same mechanical components and relatively high swept volumes irrespective of their cooling capacity, but have different cooling capacities as a function of their rotary speed.
The same phenomenon of increasing mechanical losses with reduced swept volumes also explains why R134a compressors tend to have lower COPs than equivalent R600a compressors for small cooling capacities. More R600a is required than R134a to attain the same cooling capacity, and hence single-speed R600a compressors will have larger swept volumes than R134a models with equivalent capacity. The increase in mechanical losses with diminishing swept volumes is highly non-linear, such that for a comparatively broad range of higher displacement values there is a negligible difference in losses and only below a certain minimum displacement does there begin to be a significant difference. In summary, by lowering the rotation speed it is possible to avoid mechanical losses associated with small swept volume compressors.

Two-speed motor: in principle, using a two-speed motor gives the same advantage at low cooling capacities as using a rated-speed compressor but has the added advantage over the current generation of rated-speed compressors of allowing the same compressor to be used in an optimal way for two different cooling circuits with different cooling loads. There are two main designs of two-speed motor:

- consequent poles: consequent pole is simpler, more compact and costs less but the efficiency at half speed is approximately 10% lower than the efficiency at full speed;
- separate set of 2-pole and 4-pole windings.

Two-speed motors are used mostly for fans and pumps but seldom for cold appliances however, some Japanese compressor manufacturers have commercialised two-speed compressors with two different operating frequencies, typically 40 and 60 Hz.

d) Compressor improvements

Variable-speed compressors: in principle, a variable-speed compressor can match the delivery of its cooling capacity to the instantaneous cooling load and thereby avoid thermodynamic inefficiencies caused by operating at intermittently low evaporator temperatures in a standard on/off compressor cycle. Variable-speed compressors use electronics to change the rotational speed of the compressor in much the same way as for a rated-speed compressor. The main difference is that they can operate at any frequency, and hence cooling capacity, within a given range, whereas the rated-speed compressor can only operate at a single designated speed.

Variable-speed (or capacity) compressors are commercially available, but in 2000 it was claimed by some compressor manufacturers that there was no market for variable-speed compressors due to the high additional cost of the electronic hardware. Variable-speed compressor control systems are significantly more complex than for other compressor types and are also the subject of some patents. In particular, complex controls systems are required when a variable-speed compressor is being used to maintain two different evaporating temperatures (e.g. for the refrigerator and freezer compartments) through modulation of the compressor speed and hence refrigerant flow rate to each evaporator. The compressor speed control can also be integrated with variable evaporator fan speeds for forced-air systems.
The energy-efficiency gain from the use of a variable-speed compressor was considered substantial but can only be evaluated through consideration of the overall design of a given appliance, including the dynamic interaction of the control system and heat exchangers.
Three variable-speed technologies can be used in the small-capacity compressors required for domestic refrigeration applications:

- VSIM (variable-speed induction motor)
- BLDC (permanent magnet brushless direct current): BLDC is a better choice because it has the highest efficiency over the entire speed range. BLDC rotors do not have the rotor losses associated with induction rotors. The sensor less commutation techniques used in BLDC controllers were considered a mature technology in 2000. Patents indicates that it is possible to vary speeds between 2000 and 4000 rpm. At lower speeds there is a sharp drop in oil circulation, which prevents adequate lubrication.
- SR (switched reluctance): SR is not suitable because the noise of the motor is too high.

Direct suction: in the usual compressor design the vapour from the evaporator circulates around the motor before reaching the suction port. The superheat inside the compressor shell varies between 15-50 K. In the early 1990s a new design, known as 'direct suction inlet', was commercialised by a number of compressor manufacturers. Sometimes additional convection is necessary outside the compressor in order to avoid overheating of both the motor and oil. Matsushita have reported a 6-10% improvement in compressor efficiency with a 12K reduction in superheat. The limitation of superheat implies a higher mass flow rate and a higher volumetric efficiency. This implies a shorter running time for the same cooling capacity.
A complete analysis of heat transfers between discharge and suction components is necessary to evaluate energy and volumetric efficiency improvements. A number of technical options have not yet been analysed for small compressors, including optimised separation between suction and discharge valves and improved design of the suction and discharge mufflers in order to limit pressure losses. Depending on the refrigerant, the optimisation may be different .

Limitation of clearance volume: at the start of the 1990s CFC12 compressors were replaced by units using R134a and R600a. Because R134a has higher compression ratios, compressor manufacturers have devoted strong R&D efforts to limit clearance volumes.

Limitation of mechanical and pressure losses: the main losses in compressors are: (i) mechanical friction losses on the bearings and (ii) pressure losses through mufflers, valve ports and reeds. The highest losses occur on the suction side. Some detailed studies have indicated that there is a significant efficiency loss associated with pressure losses in the suction circuit. Those energy losses are especially significant for low-pressure refrigerants such as R600a.

e) Alternative technology to reciprocating compressors

Rotary compressors: in 2000, the sole competing technology with the reciprocating compressor was the rotary compressors, particularly favoured by Japanese manufacturers. Rotary compressors are thought to have lower suction gas heating but higher internal leakage losses than reciprocating compressors. A comparison between the compressor losses indicates there are some advantages and disadvantages to each technology; however, the best available rotary compressors in 2000 had a lower COP than the best reciprocating units. Furthermore, reciprocating compressors appear to have a greater potential for improvement than rotary ones.

Linear free piston compressors: the first version of non-lubricated linear free-piston compressor was developed by Sunpower, a small US technology company, in the early 1990s. The piston is driven by an electronically driven linear permanent magnet motor. The claimed COP under ASHRAE test conditions is 1,8, due largely to the fact that the friction losses are minimised by the use of gas bearings. Valve losses and piston blow-by are higher than with reciprocating technologies because of the absence of the sealing effect of the oil film. Reliability along the

operating lifetime has not been demonstrated for non-lubricated free-piston technology and this is likely to be the main reason why no such compressors are used commercially.
A development was reported in 2000, that the LG company was in the advanced development stages for a lubricated free-piston compressor. Oil is used for lubrication of the sliding parts and for extraction of heat during the compression phase. LG claimed that the capacity modulation is much easier for free-piston compressors and the total improvement is greater than 20% of the most-efficient actual reciprocating compressor. Some patents apply to the control of linear compressors, enabling a simple variation of the refrigerant mass flow rate by a limited expansion stroke.

f) Conclusions

The global efficiency, i.e. the ratio between the energy delivered to the compression gas and the electrical input power, varies by as much as 43% between the best and worst compressor technologies commercially available in 2000. The best technology available had efficiencies of slightly greater than 60% (ASHRAE COP 1,68). The asymptote of possible gains for small-capacity compressors corresponds to global efficiencies in the range of 70–75%, which expressed as an ASHRAE COP corresponds to a value of between 1,9 and 2. The LG company claimed that its new, lubricated linear compressor was able to reach a COP between 1,9 and 2.

6.1.2.6 Improvements to the control system

A number of patents have been filed on sophisticated control and defrosting systems and on the airflow distribution in refrigerator-freezers with two compartments, in particular those equipped with fans. These developments have mostly occurred in the USA and Japan, but may also become significant for European appliances. The following analysis considers:

- improved of temperature control
- improvement of both air distribution and control
- electronic controls with variable-speed compressors.

Some of those controls are interconnected and in certain cases the separation between them is artificial: for example, temperature control can easily be controlled electronically.

a) Temperature control

Conventional thermostats are thermo mechanical devices that are low cost but not very accurate, which leads to sub-optimally large differences between the lower and upper temperature set points. Larger temperature fluctuations not only lead to poorer food preservation but also give rise to thermodynamic inefficiencies. Electronic thermostats are much more accurate and hence allow the difference between the upper and lower set points to be reduced to an optimised level. This causes the mean evaporating temperature to be higher than for thermo mechanical thermostats and therefore saves energy.

Some patents concerning electronic temperature control take into account parameters other than just the compartment design temperatures, such as room temperature, and this enables the appliance operation time to be better regulated.

Electronic temperature control can also be used with multi-speed evaporator fans, enabling the fan operation to be dissociated from the compressor operation. This innovation could be particularly applicable for appliances using variable-speed compressors.

b) Air-distribution and temperature control

For two-compartment appliances, i.e. those with a frozen- and a fresh-food compartment, improved control of the air distribution can help save energy and improve the temperature control of the cooled spaces. In principle the operation of fans, mufflers and ducting systems can be intelligently regulated to give optimised efficiency levels.

Since 1995 almost twenty patents addressing this subject have been filed in the USA by either South-East Asian or American companies. Improving the distribution of cold air within the appliance allows the temperature difference between the air and the foodstuffs to be minimised, enabling the average evaporation temperature to be raised and thereby saving energy. Furthermore, since the air that will be used to cool the refrigerator compartment in single-evaporator systems must be supplied at the freezer evaporating temperature, improved air-recirculation control and the ability for this to occur independently of the compressor 'on' cycle lead to further energy savings.
In general it can be said that the use of, and ability to regulate, complex air-distribution systems can produce significant energy savings. Such air-distribution controls aim at the limitation of the temperature difference between compartments, or on the contrary, at creating or maintaining temperature differences inside a single compartment in order to store food at the optimum preservation temperature.

c) Electronic control and variable-speed compressors

The simultaneous advent of variable-speed compressors and electronic controls provides new opportunities to adapt the refrigerant mass flow rate to the thermal loads of the refrigerator and freezer.

Moreover, the use of electronic controls enables variable-speed fans to provide air handling that is independent of the compressor operation, which can give further energy savings and helps solve some defrosting-control issues for variable-speed systems.

6.1.2.7 Design options for two-compartment refrigerator-freezers

Two-compartment refrigerator-freezers present some challenging design problems and as a result a large variety of hardware-orientated energy-saving design options (concerning the heat exchangers, the compressor and expansion devices) have been considered. There are two principal cooling-system approaches for two-compartment appliances: the single-compressor, two-heat-exchanger approach; and the two-compressor, two-heat-exchanger approach.

a) Two-compartment, one-compressor appliances

Using a single compressor saves on component costs and hence is the most common approach. Conventionally there is a single cooling circuit and the refrigerant is passed first through the freezer evaporator and then through the refrigerator evaporator. This solution is simple and cheap but is not optimal from a thermodynamic perspective. As smaller compressors generally have a lower COP than larger ones, it might be reasoned that using a single-compressor solution could be more efficient than using two compressors, providing it were possible to isolate the refrigerant flow to the refrigerator and freezer into separate cooling circuits.

Bistable solenoid valve: a bistable solenoid valve is which is a 3-way valve used in association with two capillary tubes, one for each evaporator. The refrigerant flowing from the condenser can be regulated to circulate either through a cooling circuit including the freezer evaporator or through one including the refrigerator evaporator. One design also allows refrigerant circulation in both loops simultaneously.

Tests performed at the University of Maryland indicated that energy gains of up to 8,5% could be achieved compared to a base-case model where the refrigerant mass flow goes through the two evaporators successively. One limitation of this approach is that it is not possible to optimise both the freezer and the refrigerator loops and as a result this option is less efficient than a conventional two-loop design with two compressors. Some Candy class A refrigerator-freezers used a bistable solenoid valve and were tested through the course of the COLD-II study. The temperature curves of the two evaporators show clearly that a lower evaporating temperature is reached in the freezer evaporator compared to usual freezers and as a result the overall energy gain is limited.

Other technical options: other patents concern the independent operation of fans and evaporators alternatively on the refrigerator and the freezer. This enables higher average evaporating temperatures in the refrigerator. There were many other patents covering variations of the same concept.

b) Two-compartment, two-compressor appliances

Tests performed on the Electrolux Energy+[3] refrigerator-freezer show that the use of a rated-speed compressor at 1800rpm for the refrigerator compartment in conjunction with a normal high-efficiency compressor for the freezer compartment is highly instrumental in allowing the appliance to reach an EEI of 36. This technical option implies higher compressor costs (for the rated-speed one) but leads to an end of the debate on the most energy-efficient solution for two-volume appliances. Using two compressors, rather than one, allows higher energy efficiencies to be reached.

Another design option that was studied, patented and used in the 1990s, was two compressors arranged in series, to avoid low COPs associated with small-capacity compressors. The refrigerator compressor sucks the discharge vapour out of the freezer compressor and the vapour exiting from the refrigerator evaporator. The two mass flow rates are blended and the change in average density improves the compressor capacity and hence COP. The ‘small’-capacity compressor is actually the freezer compressor, but due to the low density of the gas exiting from the freezer, the swept volume can be maintained at high levels. No direct measurements were available to compare this solution to the previous one using a rated-speed compressor.

6.1.2.8 Alternative technologies and Lorenz-Meutzner cycle

a) Non-azeotropic refrigerant mixtures (Lorenz-Meutzner cycle)

The basic idea of the Lorenz–Meutzner cycle is to use refrigerant blends with a large temperature glide during the phase change at constant pressure. It is possible to begin evaporation at a low temperature, typically –25°C, and to finish it at –15°C. In fact, evaporation begins in a first heat exchanger located in the freezer and ends in the evaporator located in the refrigerator. Simulations and experiments performed at the end of ‘90s showed that some blends give no improvement compared to the base case and that the maximum gain compared to the base case was ~20%, but this is for a relatively low efficiency appliance, when different higher-efficiency design options were deployed, such as improved insulation, a high-efficiency compressor and improved heat-exchanger design, the additional improvement from the use of blends is reduced to ~5%.

[3] Energy+ was a European voluntary programme for high efficiency appliances ended in 2005

In summary, the energy gain that can be obtained with the Lorenz–Meutzner cycle is only applicable for Category 7 appliances, especially two-door refrigerator-freezers but when compared to the use of a single compressor with the freezer and refrigerator evaporators in series.

It is always difficult to quantify the energy gains associated with using refrigerant blends compared to pure refrigerants or other blends because the final results depend on the sum of technical design options deployed and not just on a given refrigerant independently of the appliance technology.

b) Thermo acoustic, pulse tube and Stirling cycles and thermoelectric cooling

Several alternative cooling cycles to the vapour compression cycle have been re-examined during the COLD-II study, including the thermo acoustic, pulse tube and Stirling cycles.

Thermo acoustic, pulse tube and Stirling cycles: these three technologies have some common aspects, among which they are all gas cycles. Usually, helium or hydrogen is used at various pressures, often higher than 80 bar. In fact the Stirling cycle stands apart from the other two as they comprise wave propagation in gas media rather than true cycles. The regenerator is a key component for all these technologies and allows a large temperature difference to be obtained between the hot and cold ends. Several studies show that energy efficiency of gas cycles is unquestionably superior to vapour compression when the temperature difference between source and sink is higher than 80K; however, this difference is much higher than the standard temperature difference for freezer operation, which typically ranges between 60 and 70 K.

Except for the key point of refrigerants, compared to the vapour-compression cycle, no clear advantage exists in favour of these technologies regarding their use in domestic refrigerators and freezers. The available test results of prototype domestic refrigerators using each of the three technologies indicate that, at best, the system COPs obtained are in the same range as those using standard vapour-compression technologies.

One of the major technical problems with gas cycles is that the cooling capacity is produced on a very limited heat-exchange area. This requires new heat exchangers to be designed to be able to transfer the cooling capacity into the refrigerator or freezer volume.

Thermoelectric cooling: the COP of thermoelectric modules depends strongly on the difference in temperature between source and sink. The smaller the temperature difference, the higher the COP. With a standard 20K temperature difference between the internal refrigerator space and the ambient, a thermoelectric cooling system would be expected to have a COP in the range of 0,33. Commercial products have been developed for niche applications such as portable coolers and small drink coolers.

6.1.2.9 The LCC analysis in 1998 (COLD-II study)

a) Base cases and selected options

The energy-consumption implications of various higher-efficiency design options were evaluated using cold appliance simulation software that was specifically developed for use in the COLD-II study. Economic data on the manufacturing cost of each design option were assembled from numerous sources and were critiqued by industry to ensure a high level of agreement on the core values. Information on costs and mark-ups through the distribution chain is used to convert incremental manufacturing costs associated with higher-efficiency design options into incremental final consumer prices.

In general it is assumed that there is a mark-up factor of 2,9-3,2 between the manufacturing cost and the final purchase price: where a 1,5 factor was used between the manufacturing cost and the manufacturing price and a factor of 1,9-2,1 between the manufacturing price and the final purchase price.

The approach followed some key guidelines:

- actual base-case appliances were acquired, measured and tested to gain accurate and highly detailed data to prime the simulation models prior to the analysis of each design option
- the simulation tools were extensively validated against detailed test results from more than 20 cold appliances and an acceptably high degree of accuracy was confirmed
- higher-efficiency design options were not only simulated but were identified, tested and quantified from among higher-efficiency appliances currently available on the European and wider international markets
- a large variety of appliance types were investigated to ensure the comprehensive applicability of the results; the potential drawback of using real appliances is that it is difficult to select any one appliance that is fully representative of the broader group from which it is drawn; however, attempts have been made to ensure the appliances considered are as representative as possible.
- design-option costs included estimates of amortised retooling, higher transportation, and labour and burden costs in addition to the standard incremental material and component costs.
- The selection of the base-cases tried to select real appliances with market-average storage volumes but with efficiencies just exceeding the minimum requirements set in directive 96/57/EC. In this way the resulting energy-engineering lifecycle cost analyses would have given an insight into the design and cost implications of attaining higher efficiency levels for all the models on the 1999-2000 market.

The details of each of the final selection of base-case models are given in Table 6.2. It was not always possible to find models on the market that had features consistent with the ideal ones. However, providing the volumes of the real models are not too extreme and the energy-engineering analysis identifies a least lifecycle cost at a higher efficiency level than the base-case model then the results will be applicable for the current needs.

Once the energy consumption of the base-case models had been simulated, relevant higher-efficiency design options were identified and simulated. The incremental manufacturing costs and associated purchase prices for each of these design options were estimated and the options ranked in order of energy-saving cost-effectiveness (payback time). Finally, for each base-case appliance, simulations of combined design options were conducted in order to identify the lowest-cost pathways to higher efficiency levels and the associated life-cycle cost curves. Life-cycle cost evaluation was performed using a software tool specifically developed for the task.

The developed lifecycle cost analysis did not use unproven technology or savings that cannot be proven. If there was any doubt regarding universal access to a technology, its widespread commercial availability, or the benefits that may accrue from its deployment, it was not considered. Some of the describe potential energy-savings technologies were not considered:

- variable-speed compressors with electronic controls (because of the complexity of analysing their benefits and generalising from them to all products in the same category)
- phase-change materials in the heat exchangers (the same reason)
- optimising convective and/or forced airflows (because of their complexity and case-specific nature)
- improved gaskets

- ‘off’-cycle migration valves
- energy optimisation of thermal balancing
- intelligent adaptive defrosting
- optimisation of hot gas anti-sweat lines
- optimised insulation distribution.

Table 6.2: Characteristics of the base-case models used in the energy-engineering analysis in COLD-II study in 2000

Cat.	Type	Model brand & code	Net volume Frozen food (litre)	Net volume Fresh food (litre)	Net volume Total (litre)	Equivalent volume (litre)	Energy consumption (kWh/year)	EEI (%)	Climate class	Energy efficiency class
1	Simple refrigerator	Bosch KTR 1430	-	142	142	142,0	223	80,2	N	C
2	refrigerator chiller	Gram KS 400-04	136[1]	241	377	343,0/ 329,4[2]	241	74,2/ 74,9[3]	N	B
3	0-star	Zanussi ZI 1611	7	151	158	159,8	226	80,1	SN	C
4	1-star	Fagor FDS 1140	15	97	112	120,3	201	74,9	N/ST	B
5	2-star	Thomson TOP 15	17	119	136	150,4	219	70,0	N	B
6	3-star	Whirlpool ARG 422	15	123	138	155,3	251	74,5	N	B
7	1-door, 4-star	Art. Martin AR 7334	17	195	212	231,6	292	60,5	ST	B
7	2-door, BM	Whirlpool ART868G	100	195	295	410,0	555	89,3	N	C
7	2-door, TM (NoFrost)	Candy CF 400 FF[4]	75	304	379	497,5	617	89,5	N	C
7	2-door, TM (manual defrost)	Brandt ADF 357	68	283	351	429,2	511	80,3	N	C
7	2-door, SbS (NoFrost)	Maytag GS 2124SEDW	177	389	567	923,5	710	69,6	ST/T	B
8	Upright freezer	Bosch GSD 1343[5]	92	–	92	197,8	361	95,2	N	D
9	Chest freezer	Thomson S20	179	–	179	384,9	270	76,6	N	C

Abbreviations: BM = bottom-mounted; def. = defrost; EEI = energy-efficiency index; NF = no-frost; SbS = side-by-side; TM = top-mounted.

[1] The refrigerator and the chiller volumes can be changed by moving a special shelf in the refrigerator.

[2] The adjusted volume is calculated to be 343 litres under the energy labelling directive 94/2/EC and 329,4 litres under the efficiency requirements directive 96/57/EC. The latter value is technically more correct because it is based on the actual design temperature of the chiller compartment (12°C), whereas the labelling directive assumes that 10°C is the design temperature for these compartments.

[3] In light of note 2 above, if the appliance is rated as Category 2 its EEI = 72,2%; however, if it were rated as Category 10 its equivalent volume would be lower and its EEI = 74,9% under the energy label directive.

[4] With automatic defrosting for the freezer compartment.

[5] The upright freezer Bosch GSD 1343 has not been tested. Another upright freezer (Brandt CVE 6250) was tested and the results have shown that it is sufficient to use data gathered at the retail outlet to simulate this category of appliance, i.e. the cabinet and heat-exchanger geometries, brand name and type of compressor.

The applied design modifications were:

1. increase in the thickness of the door insulation
2. increase in thickness of the wall insulation
3. inclusion of VIPs in the door insulation
4. inclusion of VIPs in the wall insulation
5. increase in the evaporator heat exchange area
6. increase in the condenser heat exchange area
7. increase in the efficiency of the compressor(s)
8. application of electronic controls
9. application of low-energy fans for the heat exchangers.

The first four options are concerned with reducing the thermal loads into the cabinet, while the next four options are concerned with raising the efficiency of the refrigeration system. The last option is only applied to no-frost appliances. The details of these options are discussed below.

1&2) Increase in the wall and door insulation thicknesses: reduces the thermal load into the cabinet but leads to reductions in the storage volume of the appliance and/or to increases in the external dimensions of the appliance. For simulation purposes the following two cases were considered:

- the internal volume is held constant, causing the addition of extra insulation to increase the external dimensions
- the external dimensions are held constant, causing the addition of extra insulation to reduce the internal storage volume.

Increasing the external dimensions has the following disadvantages:
- fitting of the appliance in the kitchen may become more difficult
- in extreme cases, house-door dimensions might not allow passage of the appliance
- increased occupied floor area is considered to have a negative influence on refrigerator marketability;

while decreasing internal volume has the following consequences:
- the price of unit net volume will increase because the purchase price depends on the net volume
- the reduction in energy consumption will not equate to a relatively equal increase in efficiency as the net volume will have declined.

Following an investigation of the range of base-case appliances, an increase in the average insulation of **15 mm** was found to be both reasonable and economically viable in all cases except for upright freezers, for which a **25 mm** increase in the average insulation thickness above the base case was found to be justifiable. In all cases it is assumed that the thermal conductivity of PU foam is equal to 0,023 W/(m.K) taking into account both the edge-effect and skin-effect losses.

3&4) Vacuum insulated panels: provide an option to increase the thermal resitivity of the cabinet without requiring changes in either its dimensions or net volume. The thermal conductivity of VIPs is less than, or equal to, half that of pure PU foam, depending on the type considered. In general, however, the lower the VIP conductivity the more expensive the panel. The most significant factors that constrain the use of vacuum insulated panels is that conventional VIPs need to be used in combination with standard foam insulation because the latter provides the mechanical support for the cabinet and for any accessories inside the cabinet. For this, and other, reasons it is assumed that VIPs cover 50% of the total cabinet insulation area. Based on a detailed simulation of the real integration of VIPs in the cabinet walls and door, the equivalent thermal conductivity of this material has been set at **16 mW/m.K**. This is a lower equivalent heat conductivity than that derived from a simple averaging calculation, which implies a value of 18 mW/m.K.

5&6) Increase in heat-exchange area of the evaporator and condenser: improves their heat transfer and lowers the difference between the evaporation temperature and the compartment design temperature on the one side and the condensation temperature and the ambient on the other. Both these changes produce efficiency gains.

Simulations of the impact on energy consumption of increasing the evaporator and/or condenser surface area showed that on average the optimum energy consumption occurs for both heat exchangers when their surface area is about 45% above the base-case area. In fact this surface area increase is model-dependent and is not always feasible because of geometric considerations. The potential energy savings are larger for an increase in the evaporator surface area than for an increase in the condenser surface area. Practical constraints limit the **increase in surface area to 20% or less** for the majority of base-case models considered.

- *Increase in the evaporator heat exchange area*: for all the base-case models considered, changes in the evaporator configuration were applied by respecting the existing architecture. As a consequence the heat-exchange area and the heat capacity vary simultaneously, as would be the case in reality. The exact changes considered vary from one appliance to the other. For base-case models with separate evaporators in the freezer and refrigerator cabinets, both evaporators were modified as a design option.
- *Increase in the condenser heat-exchange area*: as is the case for the evaporators, design-option modifications to the condenser are only valid when expressed in terms of changes to the physical dimensions. The exact changes are different from one model to another..

7) Higher-efficiency compressors: the energy performance of compressors is usually evaluated in terms of their COP. Under the ASHRAE 23 test standard, compressor COP usually ranges from 1 to 1,6 depending on the specific compressor. The actual COP under EN 153 test conditions is quite different and was calculated dynamically in the simulation software from manufacturer-supplied formulae. The energy savings resulting from the use of more energy-efficient compressors were analysed for each base-case model, using either R134a or R600a as a refrigerant. The average incremental costs of higher-efficiency compressors were supplied by European compressor manufacturers.

b) The LCC analysis results and conclusions

Two aggregated analysis pathways were performed in COLD-II study for each of the base-case appliances. The first includes the option of increasing PU foam thickness while the second only allows the option of using VIPs to improve the insulation. In every category it was found that the first pathway leads to the minimum LCC point. This is a result of the high cost of VIPs compared to increments in foam insulation in 2000; however, the second pathway can produce higher overall energy savings and the cost-effectiveness of VIPs increases significantly if the increment in final price is considered to be less than 2,9 times the increment in manufacturing costs that was assumed as mark-up value in the study.

Furthermore, there are likely to be some viable VIP applications for specific design problems such as appliances with little room to reduce volume or increase exterior dimensions, or cases where thermal hot spots have been identified. In the longer term VIP costs may well decrease as sales volumes increase and this would also favourably influence their cost-effectiveness.

The LCC analysis results for the base-case appliances in Table 2 are summarised in Table 6.3.

Table 6.3: Energy efficiency index (EEI), energy consumption and incremental purchase price for cold appliances with the LLCC for each cold appliance category

Parameter	Lifetime (years)	Real discount rate (%)	Electricity tariff (Euro/kWh)	Actualising rate for the electricity tariff (%)
Value	15	5	0,13	0

Appliance type	Base-case model	Energy consumption			Purchase price		
		Base case (kWh/year)	Improved model at LLCC (kWh/year)	EEI for LLCC (%)	Base case (Euro)	Improved model at LLCC (Euro)	Increase (%)
Simple refrigerator	Bosch KTR 1430	252,7	112,1	40,3	303,4	350,0	15,4
Refrigerator chiller	Gram KS 400-04	256,6	165,0	51,1	914,6	960,4	5,0
0-star refrigerator	Zanussi ZI 1611	225	139,7	49,6	303,7	342,5	12,7
1-star refrigerator	Fagor FDS 1140	204,7	123,5	45,0	216	258,6	19,7
2-star refrigerator	Thomson TOP15	212,4	131,1	41,9	281,7	326,2	15,8
3-star refrigerator	Whirlpool ARG 422	252,7	163,7	54,2	390,2	421,7	8,0
1-door 4-star refrigerator-freezer	Arthur Martin AR7334	313,3	213,9	44,3	455,8	494,2	8,4
2-door BM refrigerator-freezer	Whirlpool ART868G	603,4	289,0	46,5	608,3	748,7	23,0
2-door BM (built-in) refrigerator-freezer		603,4	290,0	51,1[1]	1105,2	1402,2	27,0
2-door TM (NF) refrigerator-freezer	Candy CF 400 FF	643	357,5	51,9	608,2	675,3	11,0
2-door TM (manual defrost) refrigerator-freezer	Brandt ADF 357	530,7	268,0	42,1	501,5	561,2	11,8
2-door SbS (NF) refrigerator-freezer	Maytag GS 2124 SEDW	823,9	514,0	50,4	1065,9	1167,8	9,55
Upright freezer	Bosch GSD 1343	371,6	209,0	55,0	379,6	433,4	14,2
Upright freezer (built-in)		371,6	203,6	56,2[1]	777,4	884,4	14,0
Chest freezer	Thomson S20	271,4	182,3	51,5	394,9	443,0	12,2

Abbreviations: BM = bottom-mounted; NF = no-frost; SbS = side-by-side; TM = top-mounted.
[1] EEIs for built-in models after taking into account a higher volume-loss penalty.

The results in Table 6.3 show that in 2000:

- the least life-cycle cost occurs for appliances that are rated A class or better for all categories except the built-in upright freezer, which has an EEI of 56,2%
- all one-door refrigerators with a 0- to 2-star internal compartment are small-volume appliances and reach the least life-cycle cost at EEIs of less than 50%;
- for upright freezers, chest freezers and medium-sized, no-frost two-door appliances, the least life-cycle cost occurs for an EEI between 55% and 50%;
- the estimated sales-weighted average EEI for all cold appliances at the point of least life-cycle cost is 46,8% [Estimated sales-weighted cold appliance market-average values are computed by assuming the following cold appliance market shares: Category 1 = 12,6%; Category 2 = 0,3%; Category 3 = 1,6%; Category 4 = 3,0%; Category 5 = 5,.8%; Category 6 = 5,6%; Category 7 = 45,9% (of which 2-door bottom-mounted = 33,7%, 2-door side-by-side no-frost = 1,0%, 1-door = 10,6%, 2-door top-mounted = 49,9% and 2-door top-mounted no-frost

= 4,8%); Category 8 = 15,4%; Category 9 = 9,8%; Category 10 is assumed to have no market share in this calculation as these were not specifically investigated in the life-cycle energy-engineering analysis].

- the EEI at the life-cycle cost minimum for built-in appliances is an average of 5,7% (in relative terms) greater than that for the equivalent free-standing models due to the influence of a higher loss-of-volume penalty factor.

An analysis of the cost-effectiveness and energy savings associated with different higher-efficiency design options showed that:

- increasing the condenser surface area is almost always the most cost-effective design option
- increasing the door and cabinet insulation thickness by 15mm was usually cost-effective, sometimes by up to 25 mm
- increasing the compressor efficiency was usually cost-effective
- increasing the evaporator heat capacity was often not possible due to design constraints
- the energy gains from using two compressors for bottom-mounted refrigerator-freezers are significant
- the energy gains from using low-energy fans for no-frost refrigerator-freezers are significant
- geometrical constraints limit chest freezer energy gains
- geometrical constraints and the historical deployment of relatively high-efficiency design options constrains the cost-effectiveness of higher-efficiency design options for upright freezers.

6.1.2.10 Stakeholder comments to the COLD-II LCC results

According to CECED[4], the COLD-II study simulation overestimated the effect of some potential technical improvements, notably relating to sizing of compressor and condenser: the gap is larger for some categories:

EEI at LLCC for:	COLD-II study	CECED analysis
Simple refrigerator	40,3	50
Refrigerator chiller	51,1	51
0-star refrigerator	49,6	52
1-star refrigerator	45,0	48
2-star refrigerator	41,9	45
3-star refrigerator	54,2	57
1-door 4-star refrigerator-freezer	44,3	47
2-door BM refrigerator-freezer	46,5	59
2-door TM (NF) refrigerator-freezer	51,9	58
2-door TM (manual defrost) refrigerator-freezer	42,1	52
2-door SbS (NF) refrigerator-freezer	50,4	53
Upright freezer	55,0	55
Chest freezer	51,5	53

According CECED, the least life cycle costs for the products occur at efficiency indexes ranging

[4] Source: "Voluntary agreement on domestic fridges & freezers, and their combinations", CECED, 2001, presentation at the Regulatory Committee on the indication by labelling and standard product information of the consumption of energy and other resources of household appliances.

from 47% to 58% with an average of 52,9. The main differences on LLCC estimation derives from:

1. an overestimation of the effect of the condenser size on efficiency;
2. an underestimation of the effect of the need for smaller (and less efficient) compressor sizes after having reduced the thermal loads;
3. an overestimation of the benefit of a two compressor system versus a single compressor version;
4. the appliances studied can not be considered as “average appliance” for the category.

In general the over- and underestimation’s are most probably due to some shortcomings in the simulation tools applied. The model has been analysed by CECED and some of the problematic areas have been identified.

6.1.3 Cold Appliance Technological Trends in 2005 and onwards

6.1.3.1 The state of the art of cold appliances in 2005

The technological level, in terms of volume, energy consumption/efficiency and noise reached in 2005 by the different categories of cold appliances are summarised in Table 6.4. Categories 7 and 10.7 have been disaggregated into the main type of appliances: ‘1-door models’, ‘2-door-1-compressor models’ and ‘2-door-2-compressor models’, to evaluate if these main differences in construction lead to significant differences in energy consumption/efficiency. No major differences in EEI are found on average between models with 2 doors and 1- or 2-compressors, while 1-door appliances are on average more efficient (of about 4 efficiency points) than 2-door ones. In Figures 6.1-6.3 the difference between the average, the minimum and the maximum for energy consumption, EEI and specific energy consumption for the appliance categories are shown.

In Table 6.5 the difference between the average and the minimum/maximum values are presented. For the four model groups identified in Task 5 for the definition of the standard base cases, the difference between the average and the minimum EEI is about 25 points (or about 47% over the average) for Categories 1-6, 27 points (or about 50%) for Categories 7&10.7, about 27 points (or about 48%) for Category 8 and 37 points (or about 58%) for Category 9.

The EEI as function of the appliances net volume is presented in Figures 6.4-6.7 for the four product groups. These Figures show that for appliances belonging to Categories 1-6, very efficient models (energy efficiency class A++) were available in 2005 for all the volumes higher than about 150 litre, but not for smaller (100 litre) and very small refrigerators (50 litre).

For upright freezers (Category 8) the same happens, with very efficiency models available for volumes higher than 100 litre but not for lower volume models, while for chest freezers (Category 9) A++ models do exist in the volume range 150-450 litre, but not for lower and higher volumes. For Categories 7&10.7, very efficient models are available for volumes up to about 360 litre, where the appliances in the Category arrive to a volume of 627 litre, this means that the larger refrigerator-freezers were less efficient in 2005 than the smaller models.

Table 6.4: Net volume, energy consumption, specific energy consumption, energy efficiency index and noise for cold appliance categories in CECED 2005 technical database

Categories	Net volume			Energy consumption			Specific en. cons.			En. efficiency index			Noise		
	min	max	average	min	max	average	min	max	average	min	max	average	min	max	average
(n)	(litre)			(kWh/year)			(kWh/year litre_Veq)			(EEI)			(dB(A))		
1	88	403	231	83,0	241,0	159,7	0,222	2,239	0,746	29,6	78,3	52,9	33	46	38
2	150	390	314	131,0	226,0	164,2	0,352	1,298	0,664	40,4	72,4	53,0	33	40	37
3	67	155	123	102,0	211,0	182,1	0,976	2,826	1,511	38,9	74,9	66,3	35	41	39
4	45	155	91	120,0	208,0	177,4	1,027	3,320	2,054	53,3	79,2	69,6	35	40	38
5	106	290	145	165,0	277,0	217,6	0,787	1,824	1,456	53,2	75,0	68,8	35	44	39
6	118	202	150	207,0	285,0	249,9	0,95	1,751	1,514	54,7	74,9	72,2	34	42	39
7	98	627	277	124,1	786,0	324,1	0,393	2,354	0,918	28,0	89,8	54,4	33	48	40
8	45	335	177	135,0	540,2	274,5	0,252	2,562	0,782	29,1	105,1	56,3	35	45	40
9	57	572	254	134,0	595,0	300,1	0,215	2,080	0,572	27,4	108,2	64,4	37	49	42
10.7	160	501	289	190,0	657,0	336,1	0,431	1,409	0,806	27,3	77,7	50,6	32	45	40
1-6	45	403	223	83,0	285,0	163,7	0,222	3,320	0,827	29,6	79,2	54,4	33	46	38
7&10.7	98	627	277	124,1	786,0	324,4	0,276	2,354	0,915	27,3	89,8	54,3	32	48	40
1-door	98	382	184	124,1	493,0	241,9	0,416	2,354	1,179	28,0	77,7	50,9	32	44	38
2-doors, 1 compr.	170	627	292	168,0	786,0	339,0	0,393	1,595	0,873	27,3	81,4	55,2	32	48	41
2-doors, 2 compr.	180	522	315	181,0	584,0	348,6	0,407	1,368	0,808	29,9	89,8	54,2	34	44	40

Table 6.5: Difference between the average and the minimum and maximum for net volume and energy efficiency index for cold appliance categories in CECED 2005 technical database

Category		Net volume (litre)							Energy Efficiency Index						
(No)	(models)	min	diff.	(%)	aver.	diff.	(%)	max	min	diff.	(%)	aver.	diff.	(%)	max
1	2 204	**88**	143	61,9	**231**	-172	-42,7	**403**	**29,6**	23,3	44,0	**52,9**	-25,4	-32,4	**78,3**
2	97	**150**	164	52,2	**314**	-76	-19,5	**390**	**40,4**	12,6	23,8	**53,0**	-19,4	-26,8	**72,4**
3	107	**67**	56	45,5	**123**	-32	-20,6	**155**	**38,9**	27,4	41,3	**66,3**	-8,6	-11,5	**74,9**
4	46	**45**	46	50,5	**91**	-64	-41,3	**155**	**53,3**	16,3	23,4	**69,6**	-9,6	-12,1	**79,2**
5	78	**106**	39	26,9	**145**	-145	-50,0	**290**	**53,2**	15,6	22,7	**68,8**	-6,2	-8,3	**75,0**
6	23	**118**	32	21,3	**150**	-52	-25,7	**202**	**54,7**	17,5	24,2	**72,2**	-2,7	-3,6	**74,9**
7	9 535	**98**	179	64,6	**277**	-350	-55,8	**627**	**28,0**	26,4	48,5	**54,4**	-35,4	-39,4	**89,8**
8	2 441	**45**	132	74,6	**177**	-158	-47,2	**335**	**29,1**	27,2	48,3	**56,3**	-48,8	-46,4	**105,1**
9	879	**57**	197	77,6	**254**	-318	-55,6	**572**	**27,4**	37,0	57,5	**64,4**	-43,8	-40,5	**108,2**
10.7	229	**160**	129	44,6	**289**	-212	-42,3	**501**	**27,3**	23,3	46,0	**50,6**	-27,1	-34,9	**77,7**
1-6	2 555	**45**	178	79,8	**223**	-180	-44,7	**403**	**29,6**	24,8	45,6	**54,4**	-24,8	-31,3	**79,2**
7&10.7	9 764	**98**	179	64,6	**277**	-350	-55,8	**627**	**27,3**	27,0	49,7	**54,3**	-35,5	-39,5	**89,8**
1-door	1 620	**98**	86	46,7	**184**	-198	-51,8	**382**	**28**	22,9	45,0	**50,9**	-26,8	-34,5	**77,7**
2-doors, 1 compr.	6 757	**170**	122	41,8	**292**	-335	-53,4	**627**	**27,3**	27,9	50,5	**55,2**	-26,2	-32,2	**81,4**
2-doors, 2 compr.	1 312	**180**	135	42,9	**315**	-207	-39,7	**522**	**29,9**	24,3	44,8	**54,2**	-35,6	-39,6	**89,8**

continues

Table 6.5: Difference between the average and the minimum and maximum for specific and absolute energy consumption for cold appliance categories in CECED 2005 technical database (continued)

Category		Specific energy consumption (kWh/year Veq)							Energy consumption (kWh/year)						
No	models	min	diff.	(%)	aver.	diff.	(%)	max	min	diff.	(%)	aver.	diff.	(%)	max
1	2 204	**0,222**	0,5	70,3	**0,746**	-1,5	-66,7	**2,239**	**83,0**	76,7	48,0	**159,7**	-81,3	-33,7	**241,0**
2	97	**0,352**	0,3	47,0	**0,664**	-0,6	-48,8	**1,298**	**131,0**	33,2	20,2	**164,2**	-61,8	-27,3	**226,0**
3	107	**0,976**	0,5	35,4	**1,511**	-1,3	-46,5	**2,826**	**102,0**	80,1	44,0	**182,1**	-28,9	-13,7	**211,0**
4	46	**1,027**	1,0	50,0	**2,054**	-1,3	-38,1	**3,320**	**120,0**	57,4	32,4	**177,4**	-30,6	-14,7	**208,0**
5	78	**0,787**	0,7	45,9	**1,456**	-0,4	-20,2	**1,824**	**165,0**	52,6	24,2	**217,6**	-59,4	-21,4	**277,0**
6	23	**0,95**	0,6	37,3	**1,514**	-0,2	-13,5	**1,751**	**207,0**	42,9	17,2	**249,9**	-35,1	-12,3	**285,0**
7	9 535	**0,393**	0,5	57,2	**0,918**	-1,4	-61,0	**2,354**	**124,1**	200,0	61,7	**324,1**	-461,9	-58,8	**786,0**
8	2 441	**0,252**	0,5	67,8	**0,782**	-1,8	-69,5	**2,562**	**135,0**	139,5	50,8	**274,5**	-265,7	-49,2	**540,2**
9	879	**0,215**	0,4	62,4	**0,572**	-1,5	-72,5	**2,080**	**134,0**	166,1	55,3	**300,1**	-294,9	-49,6	**595,0**
10.7	229	**0,431**	0,4	46,5	**0,806**	-0,6	-42,8	**1,409**	**190,0**	146,1	43,5	**336,1**	-320,9	-48,8	**657,0**
1-6	2 555	**0,222**	0,6	73,2	**0,827**	-2,5	-75,1	**3,320**	**83,0**	80,7	49,3	**163,7**	-121,3	-42,6	**285,0**
7&10.7	9 764	**0,276**	0,6	69,8	**0,915**	-1,4	-61,1	**2,354**	**124,1**	200,3	61,7	**324,4**	-461,6	-58,7	**786,0**
1-door	1 620	**0,416**	0,8	64,7	**1,179**	-1,2	-49,9	**2,354**	**124,1**	117,8	48,7	**241,9**	-251,1	-50,9	**493,0**
2-doors, 1 compr.	6 757	**0,393**	0,5	55,0	**0,873**	-0,7	-45,3	**1,595**	**168,0**	171,0	50,4	**339,0**	-447,0	-56,9	**786,0**
2-doors, 2 compr.	1 312	**0,407**	0,4	49,6	**0,808**	-0,6	-40,9	**1,368**	**181**	167,6	48,1	**348,6**	-235,4	-40,3	**584,0**

Figure 6.1: Difference between the average, the minimum and the maximum for energy consumption for cold appliance categories in CECED 2005 technical database

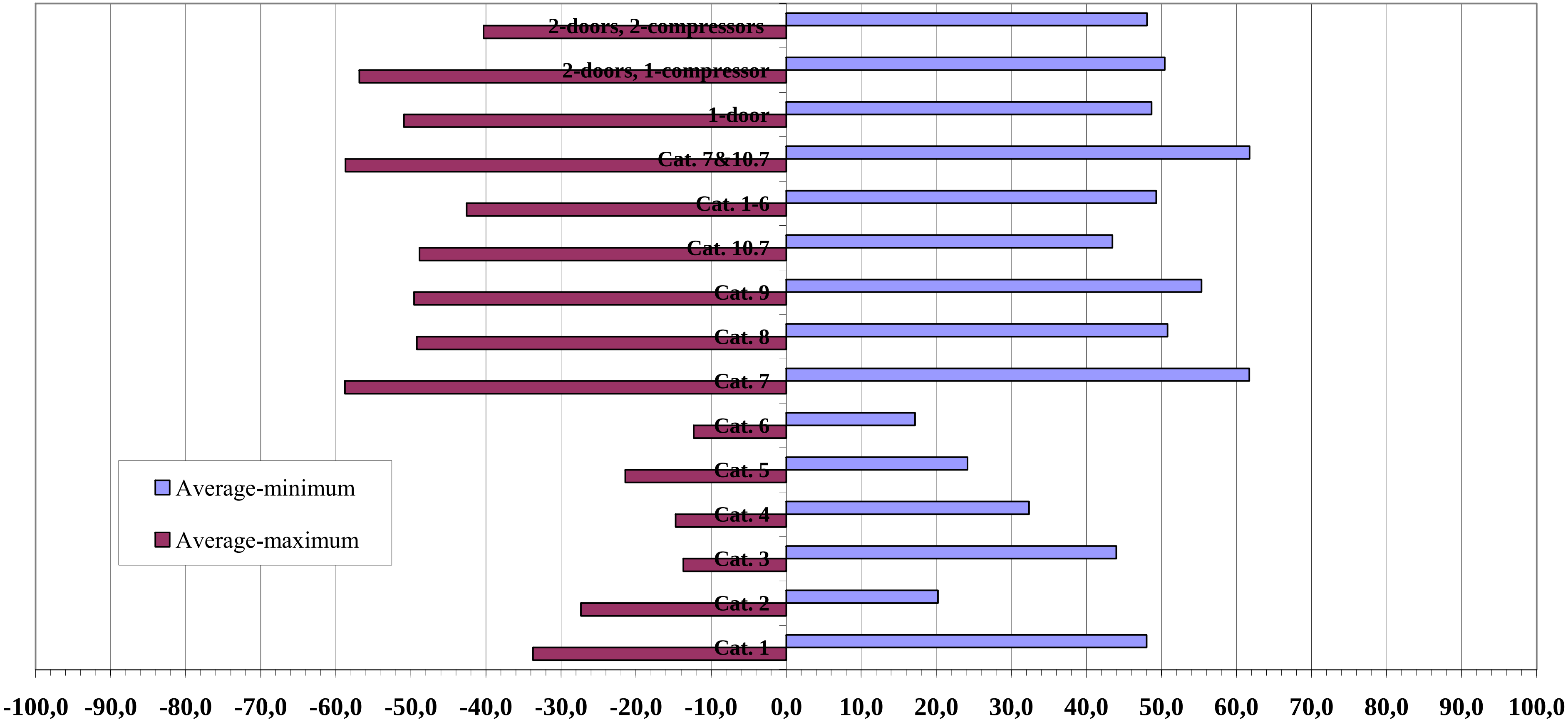


Figure 6.2: Difference between the average, the minimum and the maximum for Energy Efficiency Index for cold appliance categories in CECED 2005 technical database

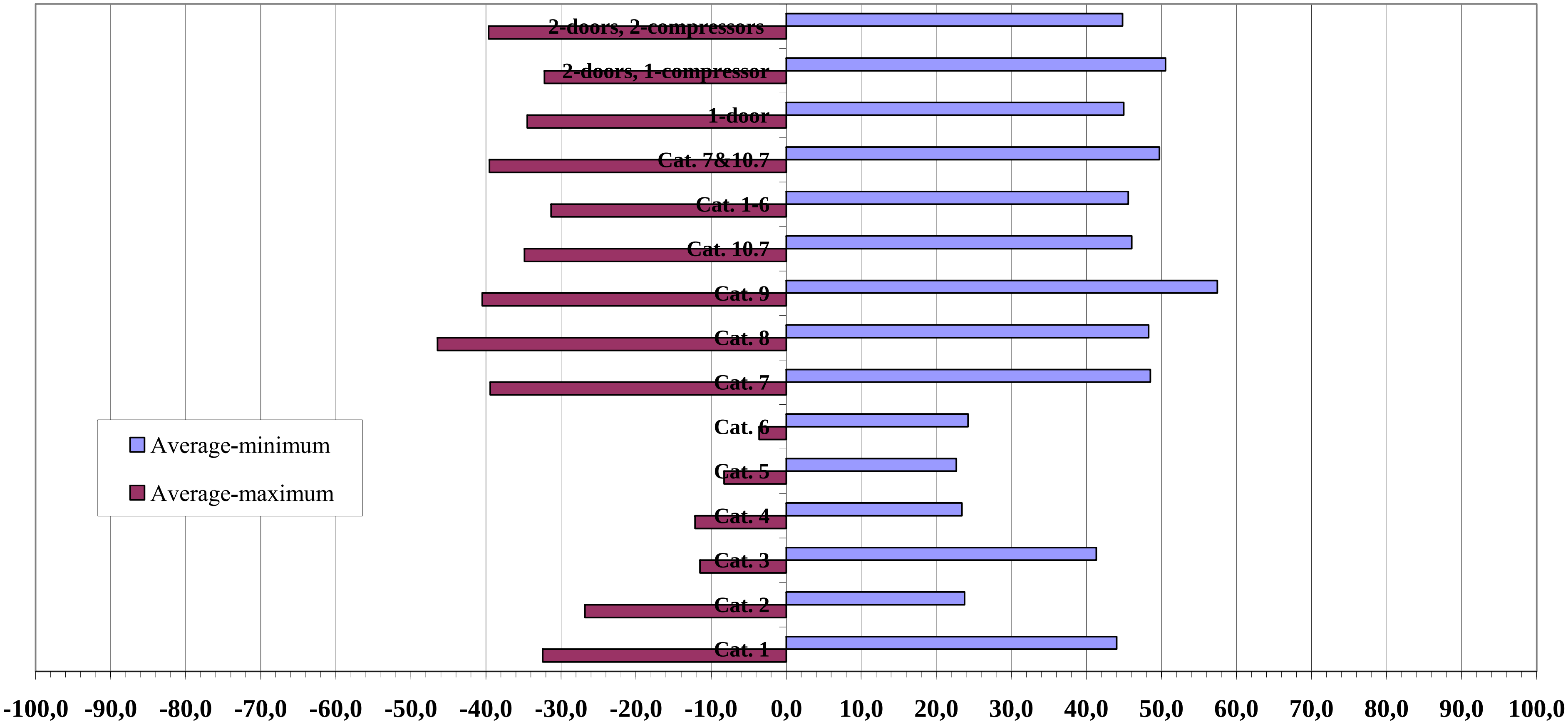


Figure 6.3: Difference between the average, the minimum and the maximum for the specific energy consumption for cold appliance categories in CECED 2005 technical database

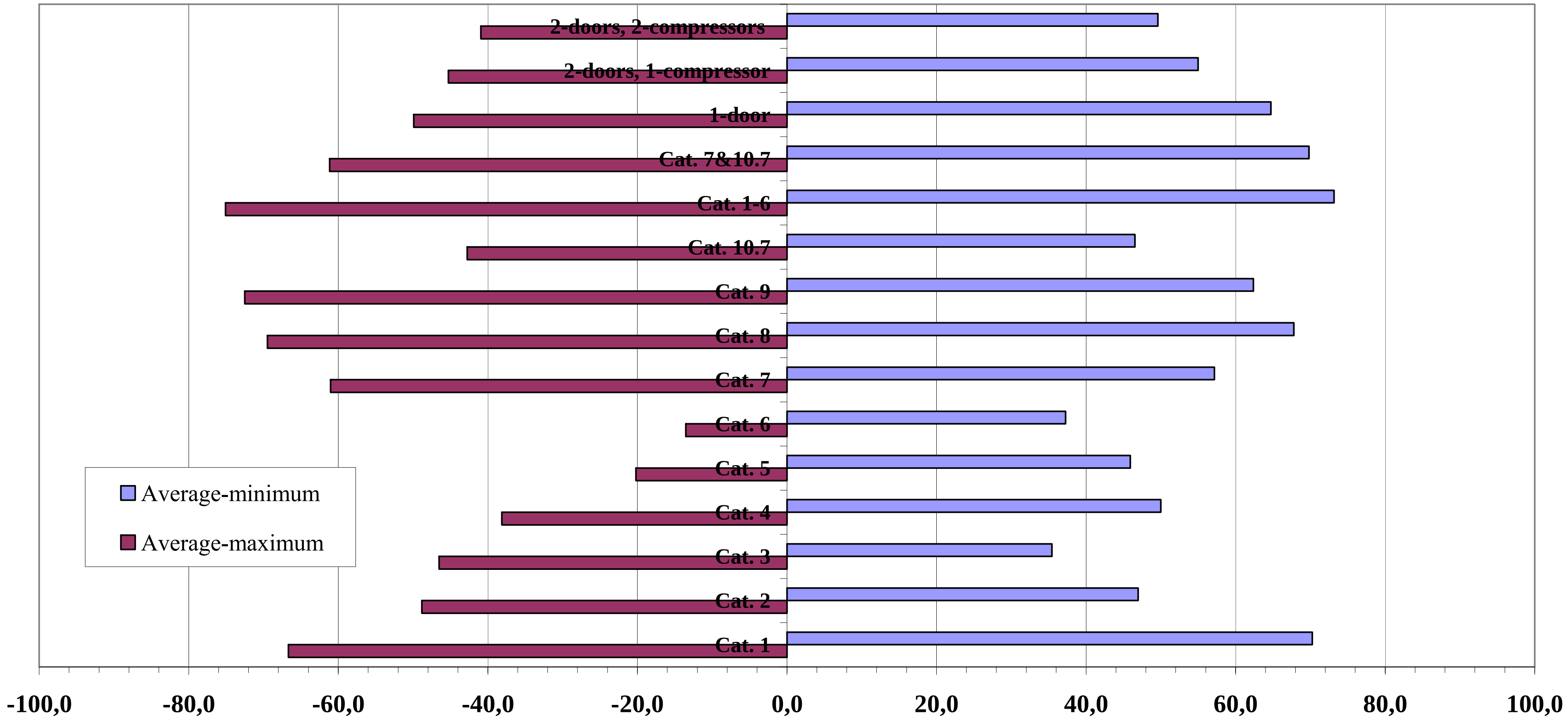


Figure 6.4: Energy Efficiency Index as function of the total net volume for Categories 1-6 in the 2005 CECED technical database

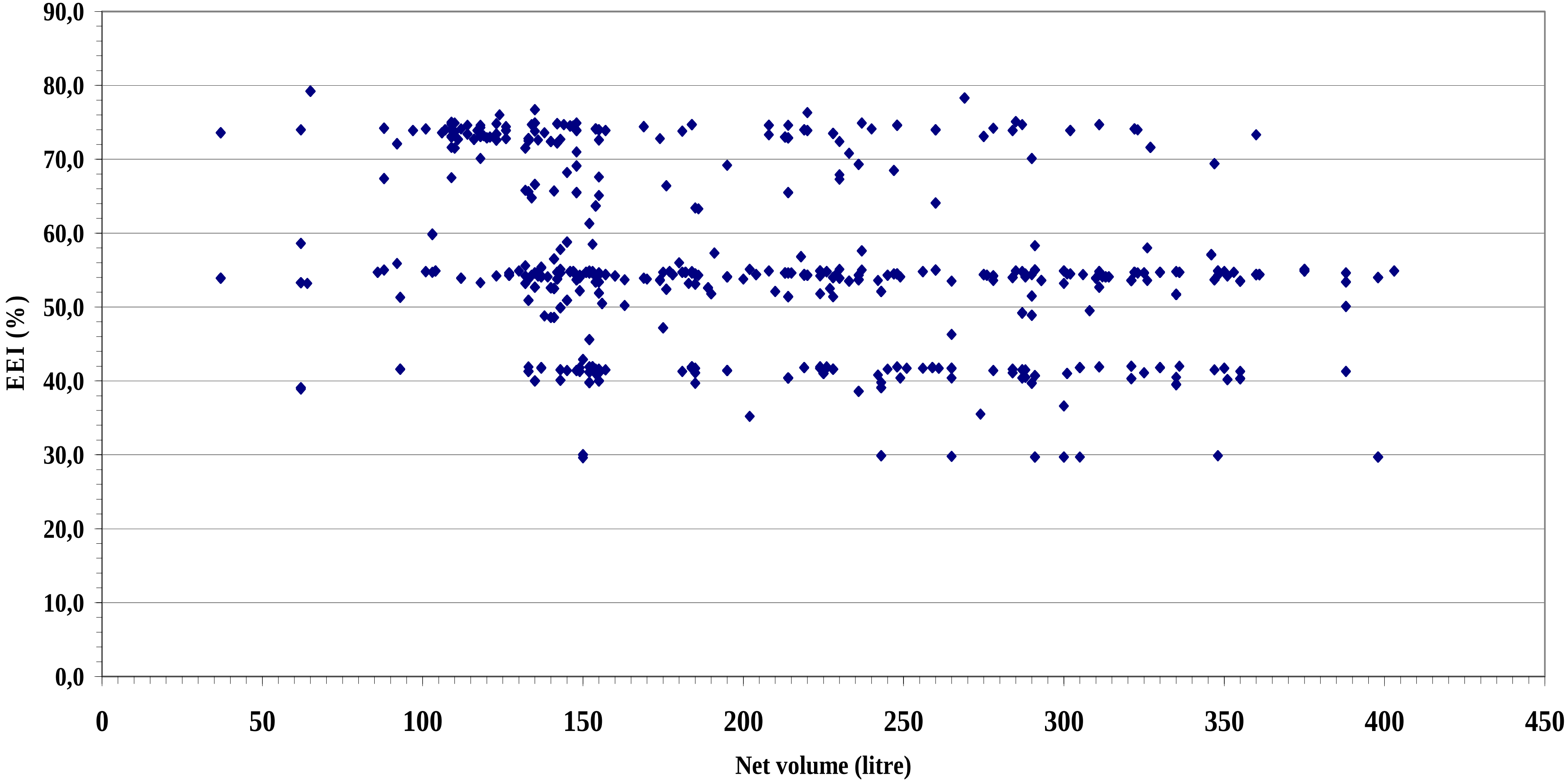


Figure 6.5: Energy Efficiency Index as function of the total net volume for Categories 7&10.7 in the 2005 CECED technical database

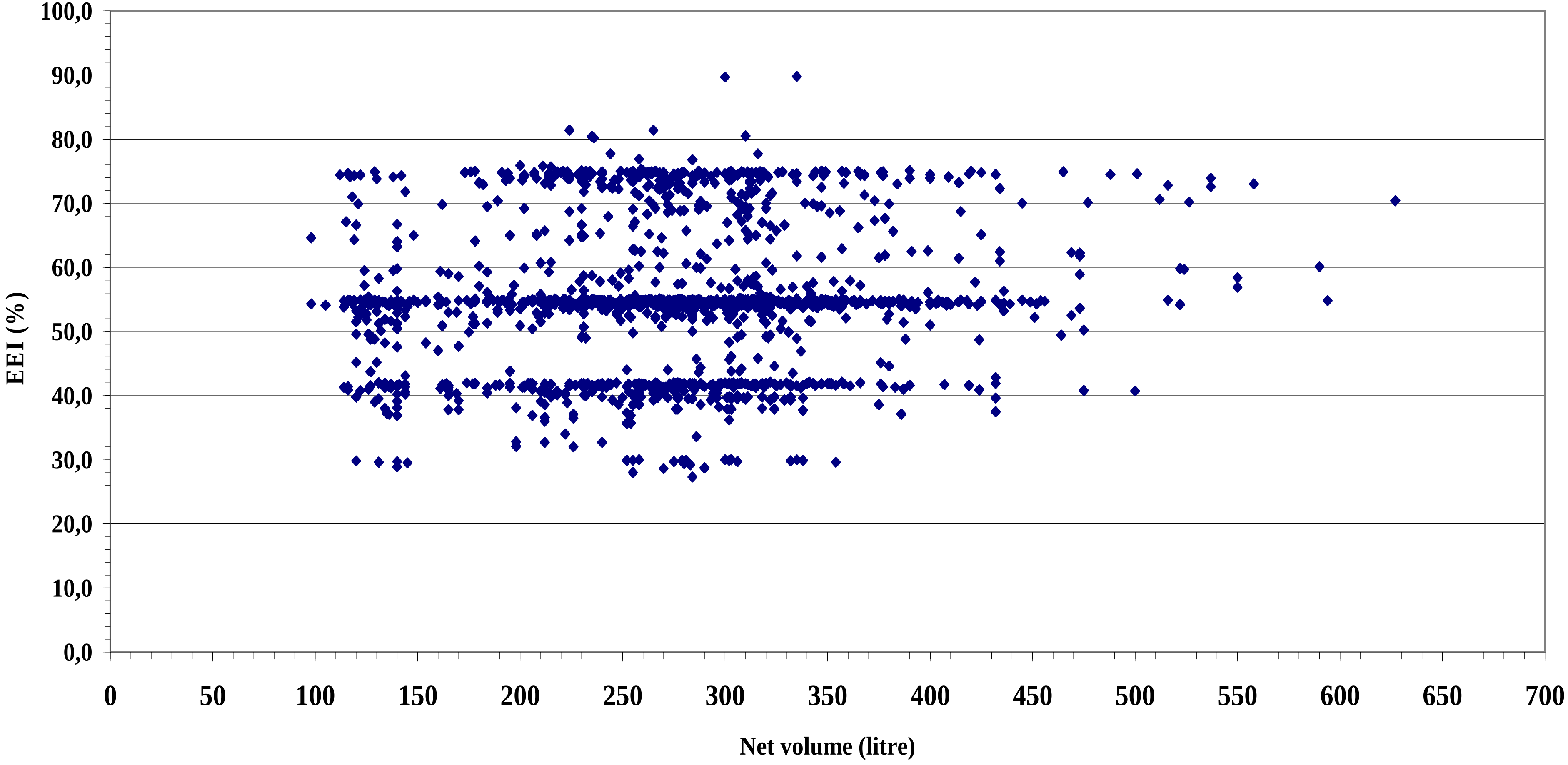


Figure 6.6: Energy Efficiency Index as function of the total net volume for Category 8 in the 2005 CECED technical database

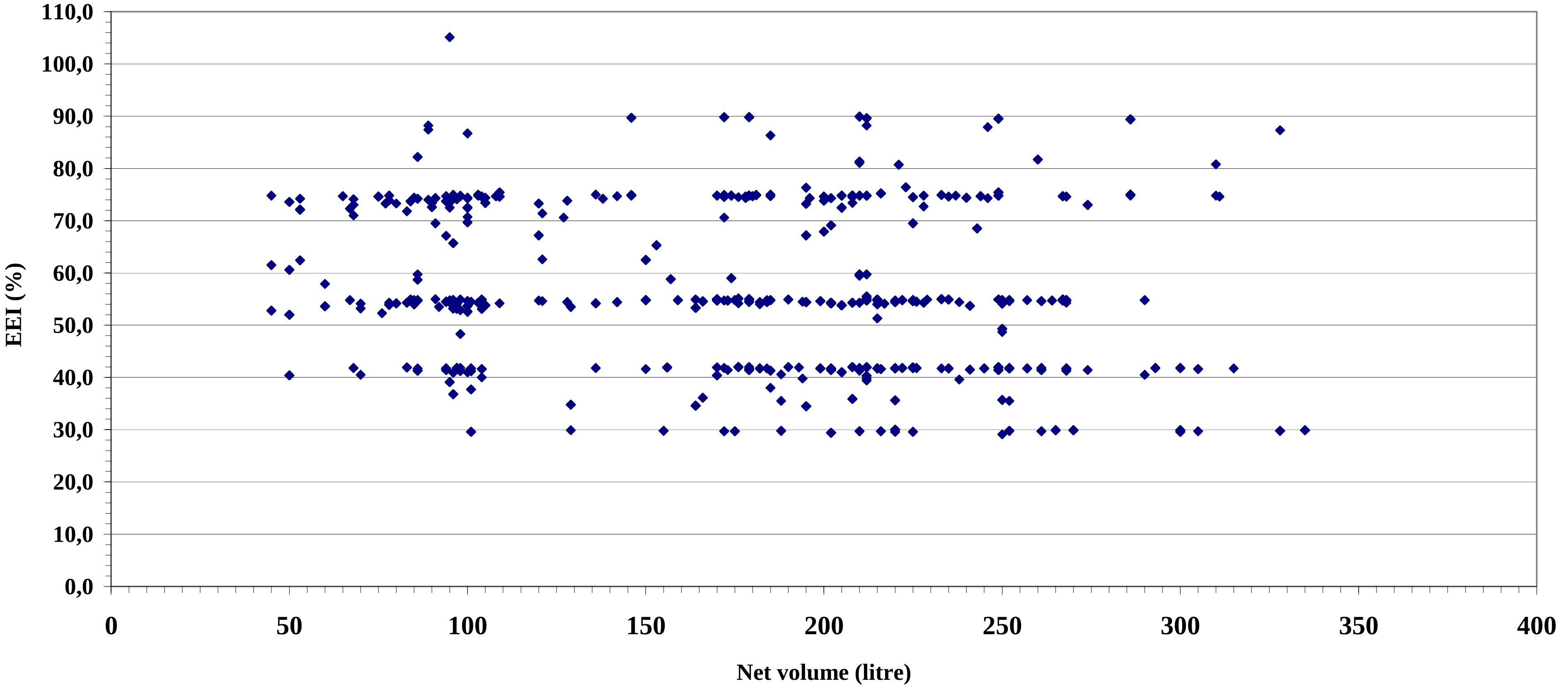
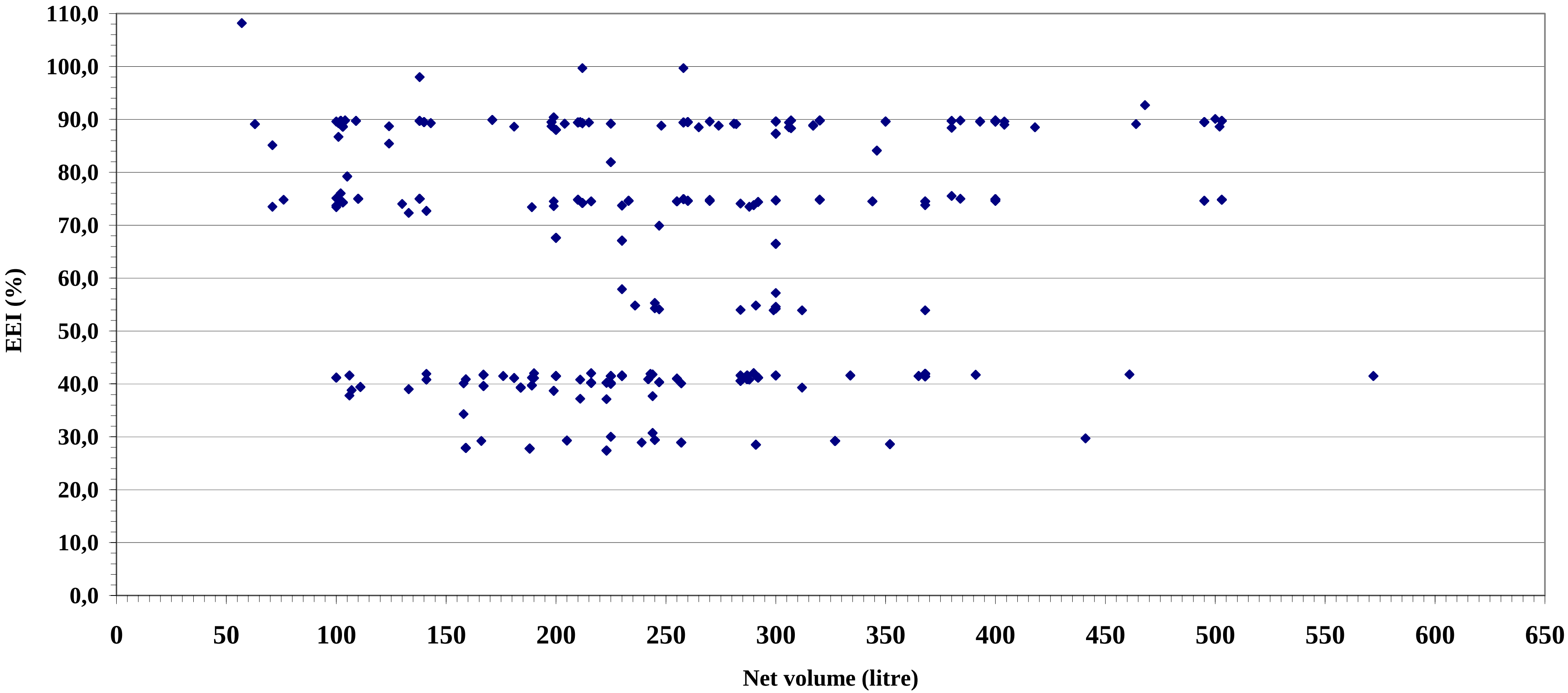


Figure 6.7: Energy Efficiency Index as function of the total net volume for Category 9 in the 2005 CECED technical database



The noise as function of the total net volume is presented in Figures 6.8-6.11 for the four appliances groups: for all groups most or even all of the models present a noise level below 45 dB(A), with the lower values around 35 dB(A), which is a very low noise level (see Task 1, Annex 1).

Figure 6.8: Noise as function of the total net volume for Categories 1-6 in the 2005 CECED technical database

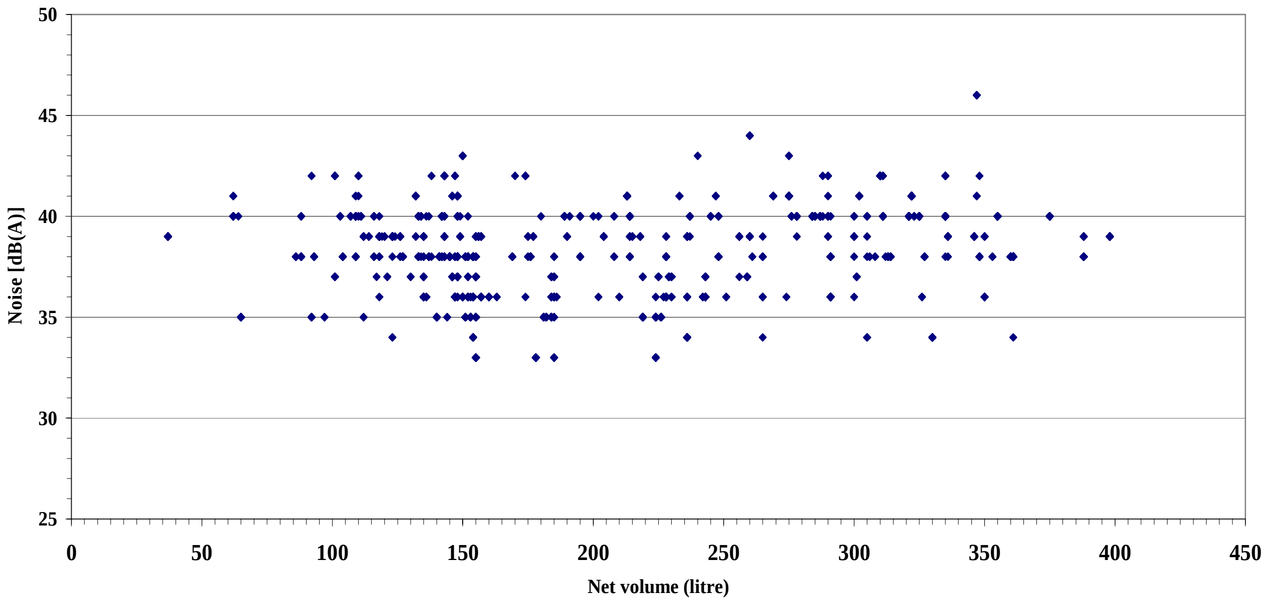


Figure 6.9: Noise as function of the total net volume for Categories 7 & 7.10 in the 2005 CECED technical database

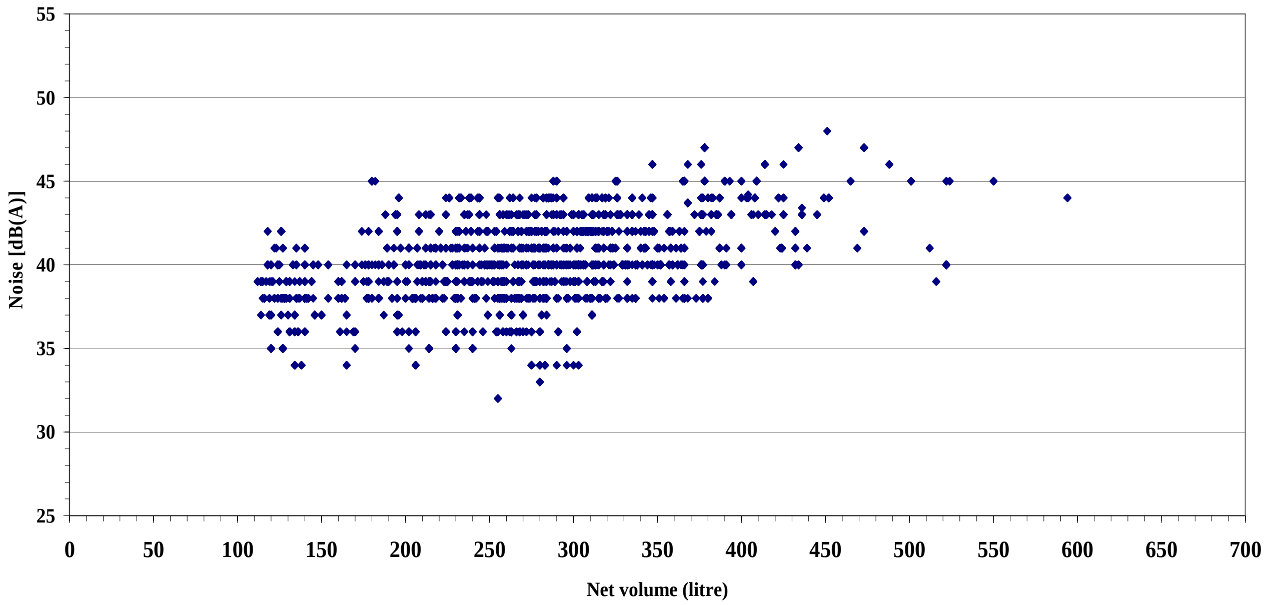


Figure 6.10: Noise as function of the total net volume for Category 8 in the 2005 CECED technical database

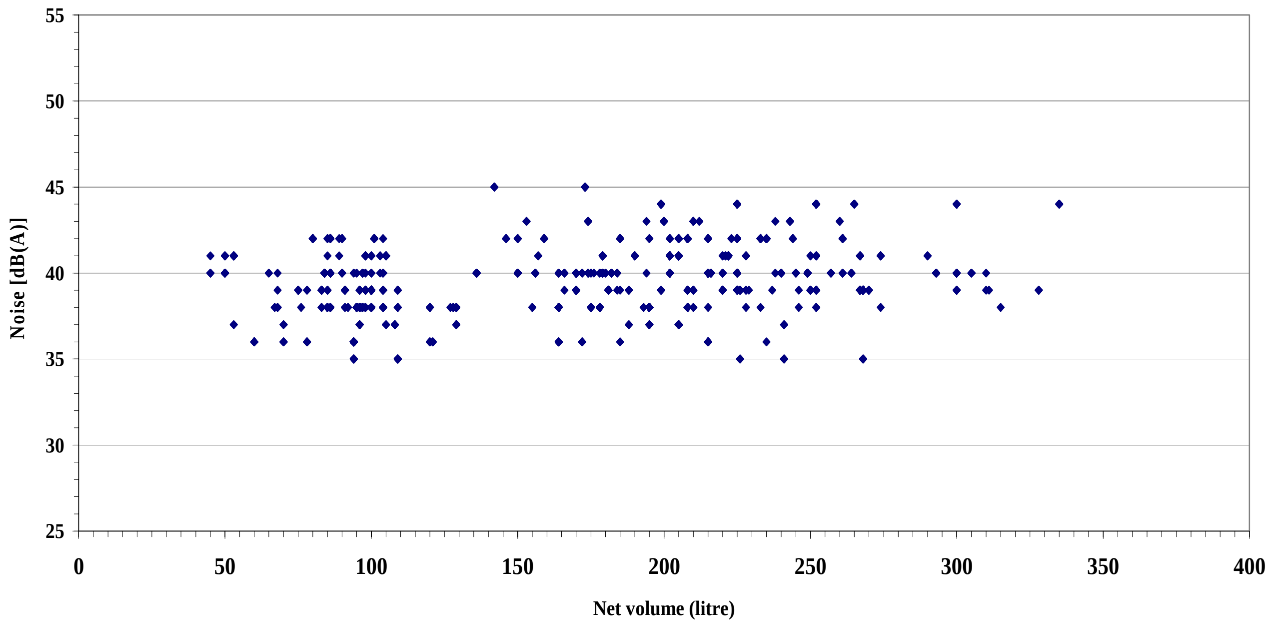
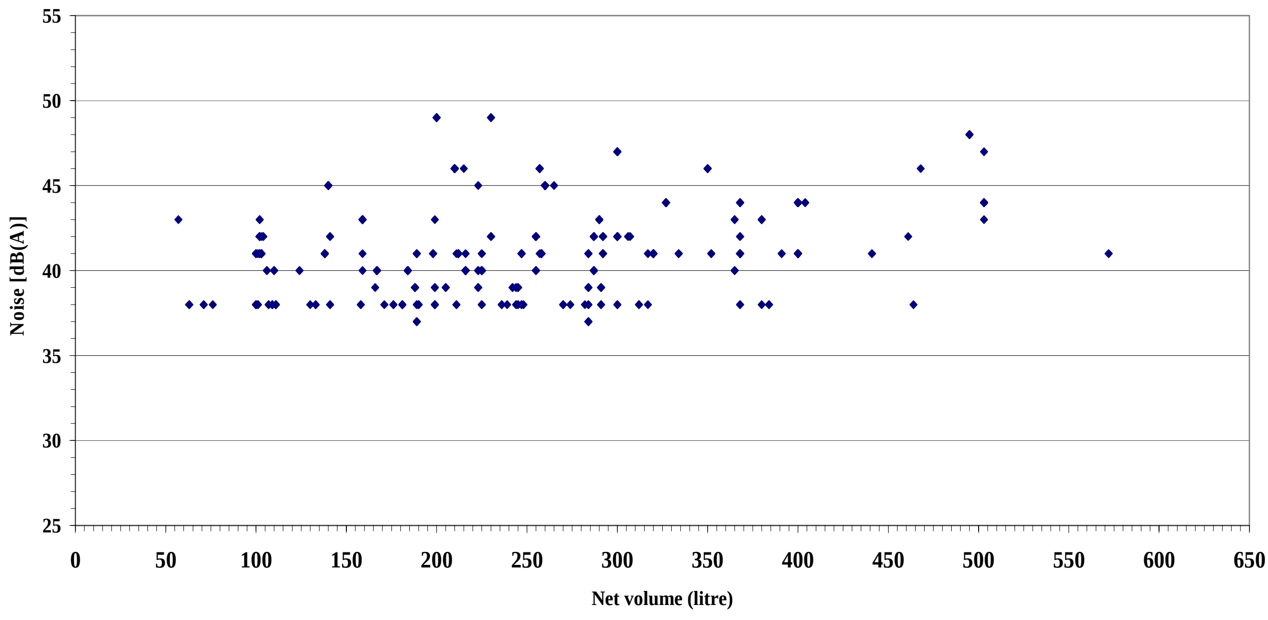


Figure 6.11: Noise as function of the total net volume for Category 9 in the 2005 CECED technical database



6.1.3.2 Main technological trends

The technological trends of cold appliances in 2005 and onwards can be summarised in the introduction of design improvements to guarantee the correct food preservation and "hygiene", practical and comfort in use, maximum flexibility of the inner space and temperatures and integration with other electronic appliances. In particular:

- Compartment temperature control:
  - independent control of the compartment temperature: electronics is fundamental to assure the independent control of the compartment temperature, not only on the refrigerator and freezer compartments, but also in any other compartment. Better temperature control might reduce the energy consumption by decreasing the compressor run time;

- variable temperature compartments: the use temperature can be adjusted by the consumer according to the needs; for example compartment can be converted from refrigerator to freezer. To avoid the increase of the energy consumption in real conditions it would be necessary that this type of compartment is tested at the lowest possible temperature (in the most difficult conditions) declared by the manufacturer, not necessarily the most used by the consumer or the recommended one by the manufacturer. This option can be applied to the *combi* (bottom mounted) refrigerator-freezers where an area of the volume can be converted to have a larger refrigerator or a larger freezer. It is a quite expensive solution, mainly for no-frost appliances;
- Multiple ventilation systems: to achieve homogeneous temperature in the (no-frost) compartments through “flaps” or “orientated ventilation systems” or “air sockets”. The effect of a more homogeneous temperature is better food preservation but has a very low impact on energy consumption.

- New compartments and functions:
  - introduction of “vacuum” (reduced pressure) box(es), evacuated by the use of an external device (provided with the refrigerator by Indesit) or through a pump embedded in the appliance wall, where a special box need to be connected to be evacuated (used by Brandt). Additional energy is needed to run the pump, either external or embedded, but it is estimated to be very low due to the very small volumes (2 litre) of the evacuated box;
  - spread use of the “chill” compartment: named for example “long-fresh, or bio-fresh”, where the temperature is keep constant at 0°C or in the range -1/3°C, with or without adjustable humidity level, for highly perishable foodstuffs. The increase presence of this compartment has been made possible by the increased use of electronics allowing an easier and independent temperature control in compartments and to the “allowance” for this compartment permitted in directive 2003/66/EC which was given due to the longer perishable food conservation achieved in this compartment;
  - inclusion of new *through-the-door* devices: such as ice dispenser, drink dispenser, home pub for draught beer; such devices increase the overall energy consumption because of the energy they consume for the functioning and creating a thermal bridge in the appliance door where they are installed with higher thermal losses. The energy consumption is measured with the device turned “off”, but the difference in the energy consumption of the appliance is 6-7% and also the total net volume is lower, if the device is in. This type of devices is present in about 1% of the models;
  - “drawer” freezer compartments used together with side-by-side refrigerator compartment in three-door refrigerator-freezers (Category 10); the energy loss of a drawer compartment depends on the insulation of the side and bottom walls when opened, which is less thick than in a more traditional door-compartment; on the other side the loss of cold air is limited in a drawer compartment because the cold and heavier air tends to sink inside the compartment. The potential difference in energy consumption is not detectable with EN 153 (because it does not foresee door opening). This feature is applied to 0,01% of the models;
  - creation of new, specialised, compartments such as “soft ice cream” (a drawer in the freezer to store ice cream at the correct temperature for use), or for the rapid cooling of drinks, or compartments at controlled temperature for wine. Most of these (and the previous bullet) new features are added to the large volume side-by-side models and mimic the features already existing in other non-European markets (USA, Australia/New Zealand, Korea);
  - use of LED to light the compartments (instead of the more traditional lamp) or integrated into the shelves (ultra-sound sealed) with an electric contact embedded into the rear cabinet wall. A better internal lighting is achieved without shaded points, the energy savings is probably negligible (the difference between the consumption of a traditional 10-15W bulb and a 3W led when the appliance door is opened) and not detectable by the current standard, but it greatly improves the food lighting due to the lack of shadows and dark spots.

- Hygiene and odour control:
  - introduction of antimicrobial film coatings or silver ions mixed with the coatings of compartments, gaskets and airs flow systems for hygiene purposes (bacteria and moulds proliferation inside the appliance); the same purpose is achieved (by LG) by mixing compounds extracted from the green tea leaves with the filtered air to be blown inside the cabinet. It would be important to evaluate the actual increase (if any) in food preservation caused by such devices;
  - introduction of active carbon filters: filtering the air circulated inside the cabinet against odours. The filters should be changed more or less once per year and can cause a drop in the air circulation. This option and those listed in the previous bullet might have a small influence on the appliance material composition for LCA purpose.
- Options related to the **no-frost systems**: partial no-frost is present in almost all brands/manufacturers and is used in the freezer compartment to avoid periodical manual defrosting; a large part of the manufacturers propose also total no-frost appliances;
  - new R&D elements for the **total "no-frost" technology** are the uniform air circulation and humidity control, achieved through:
    - ✓ "hybrid cooling", where food is indirectly cooled by air flowing from the top, the air is cooled flowing on an aluminium panel in the rear part of the cabinet, continuously and internally cooled at a constant temperature of 0°C. This technology (used for example by Sharp in 4 door-models) avoids stored food dryness and prevents also inner temperature changes and food overcooling;
    - ✓ "pulse air system", using an orientated ventilation system to direct the air flow where necessary, used by Candy together with adaptive defrosting;
    - ✓ "ice beam door cooling": air ducts and small sockets incorporated on the internal wall of the door, plus fans regulated through a series of 8 temperature sensors. A development of this ventilation system is the application of a green tea filter;
    - ✓ "switching modulation power system" (applied by Daewoo): the power system can deliver different tensions and currents in different times to the fans according to the cooling needs; at present three different regulations are available: slow for the night, medium and high speed;
    - ✓ the improved ventilation system is made possible by an electronic control with sensors for the internal (inside the appliance) and external (kitchen) conditions and a micro-processor for data elaboration; in addition, the processor controls the compressor, the evaporator and the defrosting resistance work;
    - ✓ electronic control of the humidity in the refrigerator compartment to avoid food dryness through specific shutters that optimise the internal/external air exchange;
    - ✓ placing the evaporator between the refrigerator and the freezer compartment together with a series of air sockets, allowing an even distribution of the cold air in the two compartment, with a reduction of more than 90% of the humidity claimed by BSH;
  - new features connected to the **partial "no-frost" technology** (in the freezer compartment) are:
    - ✓ "dynamic cooling", where the air re-circulation gives more even temperature distribution in the compartment by use of "flaps";
    - ✓ using two separate evaporators, one for the refrigerator and one for the freezer compartment, for a separate air flows management and a specific control of the relevant temperature/humidity; the separation of the two air flows avoids also the possible odour transmission between the compartments. The system is named "twin cooling" by Samsung and "dual no-frost" by Zoppas and is claimed by the former to save up to 30% of the energy consumption.
- Energy efficiency and efficient components:

- use of highest efficiency conventional compressors: for high-end cooling applications and with the possible use of an electronic PTC (Positive Temperature Coefficient) starting device;
- application of the "inverter" technology (the same applied to air-conditioners), which adapts the compressor run time to the effective cooling needs, through an electronic temperature control system. It is applied to all the variable speed compressors.

- Appliances integration and improved functions: at the 2007 Consumer Electronics Show (CES) the Whirlpool's centralpark™ connector was presented[5] (Figure 6.12). This concept product intends to make the most of the kitchen's inherent efficiency by providing a plug-and-play platform for consumer electronics devices on the refrigerator. The product is claimed to lets consumers use CE devices (such as digital picture frames, DVD players, satellite radios, cell phones, and MP3 players) in the kitchen at eye level, while charging them. Manufacturer claims also that the devices are easily installed or removed, allowing centralpark connector-enabled refrigerators to keep their familiar facade when not in use as an electronics hub. The first of the devices will be available in late 2007, with a large-scale retail rollout planned for spring 2008.

Figure 6.12: Whirlpool's centralpark™ connector presented at the 2007 Consumer Electronics Show

6.1.4 The Technological Option List

6.1.4.1 Technological options for cold appliances in 2005

The technological options for cold appliances previously described in COLD-II study, together with the highlighted new trends are summarised in Table 6.6, along with their general feasibility, the appliance categories where the options can be applied and the percentage of the today market application, if any.

This Table allows to identify which of the options described in 2000 are still available to be applied to improve the energy efficiency of refrigerators and freezers on the coming years, new options entered in the market after 2000 and finally options applicable in the long term or at present still not applicable due to major technical concerns or lack of R&D actions (long term and BNAT),

[5] Source: "On Location at CES: Whirlpool Launches CE Fridge Dock", Appliance Magazine.com, 10 January 2007

Table 6.6: Description and overall applicability of hypothesised technological improvements for cold appliances in 2005

Options		Options feasibility and application to the market in 2005		
No	Description	**Feasibility**	**Applicability** (Category)	**Application to the market**
1	**Options to improve insulation and reduce heat losses**			
1.1	Door gaskets design options	Quality of air-tightness of door gaskets not included in EN 153 (only addressed for safety reasons), therefore it is impossible to fix a value for the gain associated with good gasket design. Gives a very few percent of energy savings and has been already applied to the market	all	already applied to all the market
1.2	Reduction of the edge effect	Important for US models, it is not clear if the issue is so significant for typical European appliances, using natural convective heat transfer at the heat exchangers. Already applied to the market	all	already applied to all the market
1.3	Gas-filled panels	No benefits compared to VIPs	all	not applicable
1.4	Vacuum insulated panels	In 2005 it is used in few models to reach specific high efficiency levels, however, the costs are still too high and there is still concern of VIPs reliability in during a 15 year lifetime. VIPs can be applied to the front door or to the cabinet wall or both (considering a panel thickness of 50%). 6-12% improvement in energy consumption is possible	all	very few models, option still possibly applicable
1.5	Fully vacuum insulated panels	Not available technology because there is no way to make vacuum with the present foam/appliances manufacturing system. Need strong cabinet and sealed walls.	not applicable at present	to be considered for BNAT options
1.6	Increase of additional 10-20 mm in insulation thickness	To be applied to door and cabinet walls by increasing the external dimensions or decreasing the internal net volume; the latter creates a different final model with a reduced net volume and a different market value (cold appliances are sold by their net volume)	all	option still applicable to 80-90% of the market
2	**Accessories and defrost system**	The base case in Lot 13 does not consider no-frost, however the technological options for improvement have been addressed.		
2.1	optimal positioning and design of electric anti-sweat heaters of freezers door	in 2005 considered an old technology not applied today	all	old technology
2.2	electronic control of the hot gas discharge tube embedded around the freezer door frame	Applicable to freezer compartments, for high humidity ambient conditions, but needing at least a valve for the new circuit to bypass the main appliance circuit, with extra costs considered too high compared to the benefits	freezer compartments only	not applicable due to high extra costs and low benefits

Table 6.6: Description and overall applicability of hypothesised technological improvements for cold appliances in 2005 (continued)

Options		Options feasibility and application to the market in 2005		
No	Description	**Feasibility**	**Applicability** (Category)	**Application to the market**
2.3	High efficiency, low energy consumption fans:	To be used for **no-frost** and other cold appliances using **forced air circulation**. A 6-10W fan is already used in A class models. Low consumption 5W fans already used in refrigerator compartments for air circulation.	Cat. 1 (10% of the models), Cat. 7 (high level models), Cat. 8 only no-frost	
2.3.1	4 W AC fans (low wattage brushless fan motor)	Available in 2005. To be used for no-frost appliances/ compartments and models with air circulation. Benefits to be evaluated taking into consideration the decrease in power from 6-10W to 3-4 W, and the running of about 50% in the 24h for no-frost action	only no-frost models in Cat. 7 and Cat. 8	Cat. 7 (5% of the models) Cat. 8 (0% of the models)
2.3.2	12 V DC, 1W fan (low wattage fan)	common in Japanese appliances and found in some European products in 2000. No such fan available in 2005 in Europe with a sufficient mass flow rate for a no-frost appliance. Only for forced air circulation compartments/ appliances to improve temperature gradient on top-of-range or tall models. Energy benefits to be evaluated taking into consideration the decrease in power and the running time with very low or no energy savings	Cat. 1 only, fitted to improve temperature gradient on top-of-range or tall models.	In Cat.1 for forced air circulation compartments/ appliances
2.4	High-efficiency defrost system and control for no-frost and forced air applications	to improve the efficiency of the evaporator defrosting process **for no-frost** appliances.		
2.4.1	adaptive (or modified) defrost with electronic control	Still uncertainty about the energy savings arising from the use of adaptive defrosting. Estimation more complicated by a lack of good field measurements and the enormous array of potential adaptive-defrost systems. New EN 153:2005 accounts for adaptive defrost.	For Cat 1 only to auto-defrost models, not applicable to Cat.4&5; For Cat. 7and Cat. 8 only to no-frost models	Cat.1 <1% Cat.7 <5% Cat.8 <20%
2.4.2	adaptive defrost working at night		No additional benefit over option 2.4.1 from nigh-time defrost	
2.4.3	adaptive-defrost systems using fuzzy logic to train the control system		to be considered together with option 2.4.1	
2.5	High-efficiency defrost system and control for natural convection applications	there is scope to optimise these systems beyond the average arrangement, but the scale of savings that might be expected cannot be easily generalised		

Table 6.6: Description and overall applicability of hypothesised technological improvements for cold appliances in 2005 (continued)

Options		**Options feasibility and application to the market in 2005**		
No	Description	**Feasibility**	**Applicability** (Category)	**Application to the market**
3	**High-efficiency heat exchangers**	Natural convection exchanger technology is the most common in Europe.		
3.1	increasing the surface area of evaporators (10-20%) and condensers (5-10%)	Increased condenser surface: already used to achieve T and ST climatic class for A+/A++ models, this option does not necessary lead to a decrease in energy consumption, but increases the thermal performance. Condenser surface is already mostly optimized, if increased the expected benefit is low:1-2% Larger evaporators can not be used in some of the appliances, it is a product specific option.	All categories, but for Cat. 7 to be considered against the net volume decrease and the achieved balance of the existing evaporators for the refrigerator and freezer compartments	Larger conden-ser already applied to >80% of the models in all categories; Larger evapora-tors the same, but only to 50% of Cat.9
3.2	sophisticated heat exchange surface designs for finned heat exchangers	Finned evaporators only for no-frost, not applicable to natural convection appliances in Cat 7 e 8	No further technological improvement known for domestic-sized finned evaporators.	
3.3	use of phase-change materials integrated into the heat-exchanger to increase the effective thermal capacity	Phase change materials can be integrated into evaporator/ condenser to have energy savings (if not used to temperature rise time). Options 3.3 and 3.4 to be considered together since phase change materials are applied with system optimisation. For the latter, the use of electronics is needed.	All categories	Already applied to less than 5% of the models in each category
3.4	phase-change materials + optimisation of the compressor on/off cycling			
4	**High-efficiency compressors/motors**	Single-speed reciprocating compressors were the most common compressor technology used in domestic cold appliances		
4.1	highest efficiency conventional (reciprocating) compressors (will almost certainly include the use of a run capacitor)	In 2005, iso-butane compressor have been already improved to reach 1,3 COP (ASHRAE) for A class appliances and 1,5 COP for A+ models. Available from most major compressor suppliers.	All categories	Already applied to: Cat.1: 35% Cat.7, 8, 9: 40%
4.2 4.3	Two-speed compressor and Variable-speed compressor (to be considered together)	FSD compressor is a two speed compressor for cold appliances, produced by an Italian company; it is easy to have and the control is included in the compressor. In 2005 it is confirmed that variable speed compressor it is more costly and slightly more efficient than two speed one, the control should be studied for each application. Produced in some counties. Control system described in Option 5.3 included.	All categories	Already applied to: Cat.1: <1% Cat.7, 8, 9: <5%
4.3.2	Direct suction	Used for reciprocating compressors (semi-direct suction), direct suction not applied	All categories	already applied to the market

Table 6.6: Description and overall applicability of hypothesised technological improvements for cold appliances in 2005 (continued)

Options		Options feasibility and application to the market in 2005		
No	Description	**Feasibility**	**Applicability** (Category)	**Application to the market**
4.3.3	Limitation of clearance volume	Majority of compressors are already optimised	All categories	application is already close to the maximum
4.3.4	Limitation of mechanical and pressure losses	Majority of compressors are already optimised	All categories	application is already close to the maximum
4.4	Alternative technologies to reciprocating compressors			
4.5	High efficiency new compressors	COP close to the max possible, this new compressor may include the use of electronic PTC (Positive Temperature Coefficient) starting device	All categories	Already applied to: Cat.1: <1% Cat.7, 8, 9: <5%
4.4.1	Rotary compressors	Not applicable for non-CFC refrigerants, not used in Europe	--	not applicable
4.4.2	Linear free-piston compressors using gas bearings	Claimed to be used by LG, is another solution for variable speed, controlling the stroke is a major problem. Used for high efficiency models, is a totally new technology with high costs. Assumed to have the same benefit as variable-speed compressor	All categories	to be considered for long term options (BNAT)
5	**Improvements to the control system**	for refrigerator-freezers with two compartments, in particular those equipped with fans.		
5.1	Temperature control through electronic thermostats	Not to be used alone for energy savings purposes in thermo-mechanical appliances, but to be applied to models already using electronics for other purposes. Electronics themselves increase energy consumption. Category 1: appliances use most thermo-mechanical thermostats. For other categories it's a mixture. Category 7: A class appliances use all mechanical thermostats. Category 8: appliances: about 50% use electronics Category 9: appliances: 20-30% use electronics	To be used together with option 2.4.1	Already applied to almost all no-frost models; For other models: Cat.1: 20%, Cat 7:15%, Cat.8: 20%, Cat.9: 20%
5.2	Improved of air distribution and control	For full no-frost appliances, the electronic damper gives a better air distribution. Most of the models already optimised	total no-frost only	application is already close to the maximum
5.3	Improved electronic controls with variable-speed compressors	provides new opportunities to adapt the refrigerant mass flow rate to the thermal loads of the refrigerator and freezer	Already included in Option 4.2 & 4.3	
6	**Design options for two-compartment refrigerator-freezers**		Cat.7 &10 only	

Table 6.6: Description and overall applicability of hypothesised technological improvements for cold appliances in 2005 (continued)

Options		Options feasibility and application to the market in 2005		
No	Description	**Feasibility**	**Applicability** (Category)	**Application to the market**
6.1	Use of one-compressor	For the majority of refrigerator-freezers, with or without the diverter valve, a one compressor is used. The single compressor is used in (i) a simple refrigeration circuit optimised for control with a single control device and (ii) a refrigeration circuit with a diverter valve, electronic controls and sensors in each compartment with a conventional reciprocating or a variable speed compressor		Already applied
6.1.1	Bistable solenoid valve (diverter valve)	Applicable to large combi-models with large freezer capacity. No (or very low) energy consumption for the valve. To be used for high energy efficiency models. Maintains correct storage temperatures on appliances suitable for wide ambient range (e.g. SN to T climate class)		Already applied to 30% of Cat. 7 & 10.
6.1.2	Other technical options	the independent operation of fans and evaporators alternatively on the refrigerator and the freezer is covered by other patents		--
6.2	**Use of two-compressors**			
6.2.1	Use of a rated-speed compressor for the refrigerator and a normal high-efficiency compressor for the freezer	One variable speed used today		not applicable
6.2.2	Use of two compressors arranged in series	No advantages compared to the variable speed	not applicable	
7	**Alternative cooling cycles**			
7.1	Non-azeotropic refrigerant mixtures (Lorenz-Meutzner cycle)	In Cat. 7 appliances a 10% reduction (compared a one-compressor) has been reported in literature, but not confirmed by tests at company level.	Cat. 7	not applicable
7.2	Thermo-acoustic, pulse tube and Stirling cycles	no clear advantage exists in favour of these technologies regarding their use in domestic refrigerators and freezers. test results of prototype domestic refrigerators using each of the three technologies indicate that, at best, the system COPs obtained are in the same range as those using standard vapour-compression technologies. major technical problems with gas cycles is that the cooling capacity is produced on a very limited heat-exchange area. This requires new heat exchangers to be designed to be able to transfer the cooling capacity into the refrigerator or freezer volume	Niche and prototype products	not applicable
7.3	Thermoelectric cooling	Very low efficiency, use for the refrigerator compartment only	for campers and similar application	not applicable

Excluding those options already applied and those not technically feasible - even in a long term perspective - a list of possible technological innovations has been drafted, to be considered as the Technological Option List for cold appliances. This list includes:

- **Option a.1** (Option 1.4): Vacuum insulated panels in the model door (assumed panel area 70%, thickness 50%)
- **Option a.2** (Option 1.4): Vacuum insulated panels, in the cabinet walls (50% of the volume)
- **Option a.3** (Option 1.6): Increase in insulation thickness in the cabinet door & walls (10-20mm, outside) which increases the external dimensions of the model
- **Option b** (Option 2.3.1): low wattage brushless fan motor (4W AC fans)
- **Option c** (Options 2.4.1 & 2.4.3): modified/adaptive defrost with electronic temperature control and fuzzy logic (to be used together with Option g)
- **Option d.1** (Option 3.1): increasing 10-20% the surface area of the evaporator
- **Option d.2** (Option 3.1): increasing 5-10% the surface area of the condenser
- **Option e** (Options 3.3 & 3.4): use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation (requires electronic of Option g to be applied)
- **Option f.1**(Option 4.1): higher efficiency reciprocating compressor (from most suppliers)
- **Option f.2** (Option 4.5): highest efficiency reciprocating compressor on the market (from one supplier)
- **Option f.3** (Options 4.2 & 4.3): multi-speed and variable-speed compressor
- **Option g** (Option 5.1): Temperature control through electronic thermostats, to be used together with Option c
- **Option h** (Option 6.1.1): bistable solenoid valve (diverter valve), to be used together with Option c.

Although the standard base case are non no-frost models, technological options applicable only to no-frost appliances (Options b + c) have been described and cost/savings data will be collected[6]. It should be noted that Options f.1, f.2 and f.3 dealing with increase compressor efficiency are alternatives, the technical/economic potential for their application will be evaluated during analysis

Two long term BNAT options were also identified:

- **Option BNAT 1** (Option 4.4.2): linear free-piston compressor using gas bearings
- **Option BNAT 2** (Option 1.5): fully vacuum insulated panels.

which will be analysed together with other similar options in Subtask 6.3.

6.1.4.2 Costs and impacts for cold appliance technological options

Not all the listed option are applicable to the four standard base cases. The selected technological options are shown in Table 6.7 for the refrigerators (Cat. 1-6), in Table 6.8 for the refrigerator-freezers (Cat. 7&10), in Table 6.9 for the upright freezers (Cat. 8) and in Table 6.10 for chest freezers, along with the improvement in manufacturing cost/price and consumer price and the associated energy savings.

An initial data collection has been run with manufacturers to gather basic information about costs and savings for each option, along with percentage of the application of the option to the standard base cases and a qualitative estimation of the time-to market (defined as: Short <1 year, Medium 1-3 years, Long >3 years, Very Long >5 years). The selected technological options and costs/savings

[6] Although not included in previous standard base-case definitions, the introduction of additional no-frost base cases is under evaluation. The no-frost standard base case(s), if any, will be the same as the relevant non no-frost, but with an energy class "B" (EEI~70), instead of "A".

data have been reviewed by university experts, the project team and stakeholders. The costs and savings for long term technologies (known technologies but whose application to the market is considered to happen in the long term) will be hypothesised through experts consultation.

The cost and price parameters shown in Table 6.7 are:

- **Unit production costs** (manufacturing costs): directly related to production including materials, energy, components, labour, any allocated overhead costs and annual investment cost per unit. Annual investment cost per unit is equal to the total investment cost for the technological improvement divided by 10 (years of depreciation) divided by the capacity or units produced annually. The reference capacity is one million units/year. Unit costs directly related to production of that unit/technical option are: materials, components, energy, labour, R&D related to the development of that unit/technical option, overhead costs that can be allocated to that unit/technical option, investment that can be related to that unit/technical option.
  For example, if total investment cost is 5 million Euro, the capacity is 1 000 000 units/year with 10 years depreciation, the annual investment cost per unit is 0,50 Euro. This is summed with the other unit costs of materials, energy, component, labour and any allocated overhead costs.
- **Unit production price** (manufacturing price): unit production costs plus all other costs that are not directly related to that unit/technical option: sales and marketing, general and administrative costs, general R&D expenses, profit before taxes, any other general overhead cost. In the past, the product price at the factory was approximately 1,3 times the unit production cost.
- **Consumer price**: is the price paid by the consumer at the retailing place including transport costs, profit of retailer, advertising of product from retailer, etc. Consumer price was estimated by the product price at the factory plus the mark-up. A mark-up value of 2,9 was used in COLD-II study.

Starting from collected unit production costs, the manufacturing costs have been calculated by multiplying them by 1,28. Consumer price increase has been calculated using a mark-up value of 2,5. In this way it is assumed that all incremental manufacturing costs are fully passed on to the final purchaser and that manufacturer, distributor and retailer profits are maintained as a fixed percentage of the product cost at each point in the distribution chain. If this assumption is correct then manufacturers and retailers would make more profit, in absolute terms, per higher-efficiency unit sold than the base case products. If manufacturers, retailers and distributors were to lower the mark-up (or in case not all the incremental costs were passed to consumers), then their profit would decrease and contemporarily the point of least life-cycle cost would occur at a higher efficiency level.

The electric energy price is 0,17 €cent/kWh in real terms. An increase would cause again the least life-cycle cost be at a higher efficiency level, while a decrease will make the technological innovations less economically attractive for consumer, and therefore the LLCC will occur at a lower efficiency level. The standard base-case annual energy consumption (from Task 5) and efficiency are:

Standard base case (description)	**EEI** (dir. 94/2/EC)	**Energy consumption** (kWh/year)
refrigerator, Cat.1-6	54,4	163,7
refrigerator-freezer, Cat.7&10	54,3	324,4
upright freezer, Cat. 8	56,3	274,5
chest freezer, Cat. 9	64,4	300,6

The technological *Options f.1*, *f.2* and *f.3* encompassing a better (more efficient) compressor can be

Table 6.7: Technological Option List, improvement in price/costs and energy savings for the refrigerators (Categories 1-6)

Option	Technology	Unit production		Electricity savings		Increase in consumer price	Time to market	Already applied to Category	Notes
		cost	price						
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	15,63	20	6,5	4	50,00	S/M	<1	
a.2	vacuum insulated panels, cabinet walls (50%)	31,25	40	16,4	10	100,00	M/L	0	
a.3	+10-15mm insulation, door & cabinet walls	7,81	10	19,6	12	25,00	M	10	
b*	low wattage brushless fan motor (4W AC fans)								only no-frost models in Cat. 7 and Cat. 8
c	modified defrost with electronic temperature control and fuzzy logic, to be used together with Option g	8,59	11**	4,9	3	27,50	M	<1	only applicable to auto-defrost models, not Cat. 4&5
d.1	increasing 10-20% the surface area of the evaporator	2,34	3	4,9	3	7,50	S	>80	
d.2	increasing 5-10% the surface area of the condenser	1,56	2	1,6	1	5,00	S	>80	
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	7,81	10	4,9	3	25,00	M	<5	

*option for no-frost models
** price includes the control of Option g

Table 6.7: Technological Option List, improvement in price/costs and energy savings for the refrigerators (Categories 1-6) continued

Option (No)	Technology (description)	Unit production cost (€)	Unit production price (€)	Electricity savings (kWh/y)	Electricity savings (%)	Increase in consumer price (€)	Time to market (S, M, L, VL)	Already applied to Category (%)	Notes
f.1**	Higher efficiency reciprocating compressors (COP 1,5)	3,91	5	16,4	10	12,50	S	35	will almost certainly include the use of a run capacitor
f.2**	optimisation of reciprocating compressors (highest efficiency)	9,38	12	21,3	13	17,50	S	<2	may only be available from one supplier at the moment and may include the use of electronic PTC starting device
f.3**	multi-speed and variable-speed compressors	23,44	30	32,7	20	45,00	M	<1	Variable speed more costly and slightly more efficient than two speed one, the control should be studied for each application; for A++ models
g	Temperature control through electronic thermostats, to be used together with Option c	see c	10	see c	see c	see c	S/M	20	Only allows added features and possible change to defrost periods. Electronics them-selves increase energy consumption
h	bistable solenoid valve (diverter valve)								only applies to Cat. 7&10

**alternative options

Table 6.8: Technological Option List, improvement in price/costs and energy savings for the refrigerator-freezers (Category 7&10)

Option	Technology	Unit production cost	Unit production price	Electricity savings	Electricity savings	Increase in consumer price	Time to market	Already applied to Category	Notes
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	27,34	35	16,2	5	87,50	S/M	<1	
a.2	vacuum insulated panels, cabinet walls (50%)	39,06	50	32,4	10	125,00	M/L	0	
a.3	+10-15mm insulation, door & cabinet walls	9,38	12	29,2	9	30,00	M	10	
b*	low wattage brushless fan motor (4W AC fans)	3,91	5	9,7	3	12,50	S	5	only for no-frost models/ compartments. 4% energy improvement if total no-frost combi.
c*	adaptive defrost with electronic temperature control and fuzzy logic, to be used together with Option g		4		2		S/M	<5	only for no-frost
d.1	increasing 10-20% the surface area of the evaporator	3,91	5	9,7	3	12,50	S	90	
d.2	increasing 5-10% the surface area of the condenser	1,56	2	3,2	1	5,00	S	80	
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	7,81	10	9,7	3	25,00	M	<5	

*option for no-frost models.

Table 6.8: Technological Option List, improvement in price/costs and energy savings for the refrigerator-freezers (Category 7&10) continued

Option	Technology	Unit production		Electricity savings		Increase in consumer price	Time to market	Already applied to Category	Notes
		cost	price						
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
f.1**	Higher efficiency recipro-cating compressors (COP 1,5)	3,91	5	32,4	10	12,50	S	40	will include the use of a run capacitor
f.2**	optimisation of reciprocating compressors (highest efficiency)	11,72	15	42,3	13	37,50	S	<5	may only be available from one supplier at the moment and may include the use of electronic PTC starting device
f.3**	multi-speed and variable-speed compressors	23,44	30	48,7	15	75,00	M	<5	Variable speed more costly and slightly more efficient than two speed one, the control should be studied for each applicati-on; for A++ models
g	Temperature control through electronic thermostats, to be used together with Option c or Option h	7,81	10	6,5	2 (see c)	25,00	S/M	15	As standalone option, only allows added features and possible change to defrost periods. Fitted to all no-frost fridge-freezers (15% of Cat.7)
h + g	bistable solenoid valve (diverter valve)	14,06	18[a]	6,5	2 max	45,00	S/M	30	[a]Cost includes electronics (see g) with two or more sensors. Also includes capillary/ evaporator changes. Maintains correct storage temperatu-res on appliances suitable for wide ambient range (SN to T climate class)

**alternative options

Table 6.9: Technological Option List, improvement in price/costs and energy savings for the upright freezers (Category 8)

Option	Technology	Unit production		Electricity savings		Increase in consumer price	Time to market	Already applied to Category	Notes
		cost	price						
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	21,88	28	16,5	6	70,00	S/M	<1	
a.2	Vacuum insulated panels, cabinet walls (50%)	39,06	50	32,9	12	125,00	M/L	0	
a.3	+15-20mm insulation, door& cabinet walls	9,38	12	27,5	10	30,00	M	20	
b*	low wattage brushless fan motor (4W AC fans)	3,91	5	11,0	4	12,5	S	5	only for no-frost models/compartments
c*	adaptive defrost with electronic temperature control and fuzzy logic, to be used together with Option g		4		2		S/M	<20	only for no-frost
d.1	increasing 10-20% the surface area of the evaporator	3,91	5	8,2	3	12,50	S	>80	
d.2	increasing 5-10% the surface area of the condenser	1,56	2	2,7	1	5,00	S	>80	
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	7,81	10	8,2	3	25,00	M	<5	

*option for no-frost models.

Table 6.9: Technological Option List, improvement in price/costs and energy savings for the upright freezers (Category 8) continued

Option	Technology	Unit production		Electricity savings		Increase in consumer price	Time to market	Already applied to Category	Notes
		cost	price						
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
f.1**	Higher efficiency reciprocating compressors (COP 1,5)	3,91	5	27,5	10	12,50	S	40	will almost certainly include the use of a run capacitor
f.2**	optimisation of reciprocating compressors (highest efficiency)	11,72	15	35,7	13	37,50	S	<5	may only be available from one supplier at the moment and may include the use of electronic PTC starting device
f.3**	multi-speed and variable-speed compressors	23,44	30	54,9	20	75,00	M	<5	Variable speed more costly and slightly more efficient than two speed one, the control should be studied for each application; for A++ models
g	Temperature control through electronic thermostats, to be used together with Option c	7,81	10	5,5	see c	25,00	S/M	20	Only allows added features and possible change to defrost periods
h	bistable solenoid valve (diverter valve)								only applies to Cat. 7&10

**alternative options.

Table 6.10: Technological Option List, improvement in price/costs and energy savings for the chest freezers (Category 9)

Option	Technology	Unit production		Electricity savings		Increase in consumer price	Time to market	Already applied to Category	Notes
		cost	price						
(No)	(description)	(€)	(€)	(kWh/y)	(%)	(€)	(S, M, L, VL)	(%)	
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	21,88	28	18,0	6	70,00	S/M	<1	
a.2	Vacuum insulated panels, cabinet walls (50%)	39,06	50	36,1	12	125,00	M/L	0	
a.3	+15-20mm insulation, door& cabinet walls	9,38	12	30,1	10	30,00	M	10	
b*	low wattage brushless fan motor (4W AC fans)								only no-frost models
c*	adaptive defrost with electronic temperature control and fuzzy logic, to be used together with Option g								
d.1	increasing 10-20% the surface area of the evaporator	2,34	3	9,0	3	7,50	S	50	Changing tube pitch rather than exposed surface area on chest freezers
d.2	increasing 5-10% the surface area of the condenser	1,56	2	3,0	1	5,00	S	>80	
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	7,81	10	9,0	3	25,00	M	<5	

*option for no-frost models.

Table 6.10: Technological Option List, improvement in price/costs and energy savings for the chest freezers (Category 9) continued

Option (No)	**Technology** (description)	**Unit production** **cost** (€)	**price** (€)	**Electricity savings** (kWh/y)	(%)	**Increase in consumer price** (€)	**Time to market** (S, M, L, VL)	**Already applied to Category** (%)	**Notes**
f.1**	Higher efficiency reciprocating compressors (COP 1,5)	3,91	5	30,1	10	12,50	S	40	will almost certainly include the use of a run capacitor
f.2**	optimisation of reciprocating compressors (highest efficiency)	11,72	15	39,1	13	37,50	S	<5	may only be available from one supplier at the moment and may include the use of electronic PTC starting device
f.3**	multi-speed and variable-speed compressors	23,44	30	60,1	20	75,00	M	<5	Variable speed more costly and slightly more efficient than two speed one, the control should be studied for each application; for A++ models
g (+c)	Temperature control through electronic thermostats, to be used together with Option c	7,81	10	0	0	25,00	S/M	20	Only allows added features and possible change to defrost periods
h	bistable solenoid valve (diverter valve)								only applies to Cat. 7&10

**alternative options.

applied either as alternatives or one after the other, with different impacts in terms of resulting price and savings. The data shown Tables 6.7-6.10 are relevant to their direct application as single options to the base cases, but when the better compressors are applied as subsequent steps of technological improvement the associated energy savings and the price is the difference between one step and the previous one (i.e. when *Option f.2* is applied after *Option f.1*, the increase in the consumer price in the case of refrigerators is (17,50-12,50=5€) and the electricity savings is (13-10=3%); instead when *Option f.3* is applied after *Option f.2*, the increase in the consumer price in the case of refrigerators is (45,00-17,50=36,50 €) and the electricity savings is (20-13=7%).

6.2 SUBTASK 6.2: ANALYSIS LLCC AND BAT

6.2.1 The NPV/MNPV Approach

As stated in the TREN/D1/40-2005 Call for Tender, the assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the total product life (purchase, running costs, etc.). The distance between the LLCC and the BAT indicates - in a case a LLCC solution is set as a minimum target - the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably more subject to promotion measures than restrictive action. The BNAT (= Best Not yet Available Technologies) indicates long-term possibilities and helps to define the exact scope and nature of possible measures.

The evaluation of the Least Life Cycle Cost and the BAT is achieved applying the Marginal Net Present Value (MNPV) approach: through Net Present Value (NPV) analysis the net benefits of the technological options to consumers are estimated; at this stage, the manufacturing cost increases are assumed to be passed completely to consumers through price increase; manufacturing price increase are calculated according to an agreed amount of mark-up from purchasing price increase. The increase in consumer price will be then compared to the discounted annual economic savings (on the electricity) due to higher machine performance for the presumed lifetime of 15 years, resulting in the Net Present Value.

The NPV and LCC are evaluated first for each (single) technological option referred to the base case models. Then the optimum combination of technological options will be defined. First, the single options are sorted according to the NPV (or the simple payback period) with the higher return options first. Second, the savings are calculated for the combined options. Evidently the potential savings decrease as subsequent technological options are added, since less energy/water is available to be saved due to the impact of the previously added technological option(s). This approach has been already followed in previous studies, for example the GEA study for dishwashers[7].

Net Present Value is then calculated for the combined options. In order to see the impact of adding each subsequent option, the net present value of adding a specific option is calculated. This is known as the **Marginal Net Present Value** of adding a given option. Since the options are added in order of their potential economic contribution, we may add options until their marginal net present value is zero or negative. This determines the optimum design and is also the point in which the

[7] "The saving potential of the combined options can not be found by simply adding the savings of the single options. In the first place with most options savings are not a fixed number but a fixed percentage of the initial consumption. So with a machine that already has a lower energy consumption that the base case savings of most options are lower too. In the second place some options can not be combined at all…." (GEA2 study, page 14.47)

total net present value of the combined options is a maximum (or the LCC is at minimum). The BAT is represented by the latest option combination.

The NPV and Life Cycle Cost methods are equivalent. This is due to the fact that the life cycle cost is a constant value (the base case plus its strictly related costs such as maintenance, repairs, disposal) minus the NPV of the improvements, thus the maximum NPV gives the minimum life cycle cost (LLCC). The output of the NPV analysis is the input in the LCC analysis where the constant values are added.

The main difference between the more traditional Life Cycle Cost analysis developed and reported in previous studies and the Marginal Net Present Value analysis (which both use the same design options input from the technical/economic analysis) lies in the fact that in traditional LCC design option impacts (savings and costs) are calculated one independent from another and then their effects are added, while the MNPV analysis calculates the effects of any option taking into account that a previous option has already been implemented and part of the savings has already been achieved. The other difference is that in the traditional LCC the options sequence is decided by "clustering" the options according to an engineering analysis or their simple pay back time, while in the NPV/MNPV approach the options are applied considering their economic return for consumers (in terms of net present value) after initial engineering considerations about their feasibility and compatibility.

6.2.1.1 The MNPV approach limits

The described method of adding percentage savings is completely correct if all options give a fix percentage of improvement, but in reality some of the identified options could results in a fix absolute savings: for these options, the absolute savings value should be subtracted as fix amount from the residual energy consumption; if not, the saving is systematically underestimated and the introduced error is proportional to the option application sequence, being higher the later the option is used, and the amount of savings.

Compared to the previous studies, a more sophisticated mixed system including percentage and fixed saving has been developed in the case options with fixed absolute savings are identified. The energy-consumption implications of various higher-efficiency design options are evaluated using a simple software - an ad-hoc excel sheet - initially developed for use in the previous SAVE studies for household appliances in which ENEA was partner, but now improved.

6.2.2 The NPV/MNPV Analysis for Cold Appliances

6.2.2.1 The key economic assumptions

The key common economic and financial assumptions (see Task 5) are:

- Product life 15 years
- Discount rate 5%/year (PWF = 10,38)
- Electricity price 0,17 €/kWh
- Maintenance & repairs 5,5 €/year
- Disposal & recycling 61 €/life (at end of life)
- Refrigerators price (Cat.1): 345,1 €
- refrigerator-freezers price: 485,0 €
- upright & chest freezers price: 328,0 €

6.2.2.2 The Simple Payback Time and Net Present Value analysis for the standard base cases

The first step of the analysis is the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant base cases. The results are presented in Table 6.11 for the four appliance categories and the technological Options. NPV is calculated for a lifetime of 15 years. Options for the no-frost models are shown although no standard base case has the no-frost technology.

The same data are ordered in Table 6.12 by simple payback time for each appliance category: in general there is a good agreement between the SPB and the NPV values, where the former increases the latter decreases. But this does not happen for some options, such as the *Option f.3* (multi-speed and variable-speed compressors) for refrigerators: although the payback time is lower than the accepted appliance lifetime the net present value (i.e. the economic benefit for the consumer) is negative over the same time horizon. This depends from the fact that refrigerators have a lower energy consumption, compared to other cold appliance categories, and therefore the economic benefit of a further savings compared to the increase purchasing price becomes negative when discounted.

In general the NPV is positive for SPB values below 10 years and becomes negative for a longer time period. In general, the improvement in compressor efficiency have a positive results for the consumers, as well as the improvement in the insulation thickness, while for the VIPs the results of the COLD-II study are confirmed: the payback time is always significantly higher that the expected appliance lifetime for all categories. The increasing of the evaporator area has still a role to play (even if small) while the increase of the condenser area starts to be non profitable for the consumers, with NPV slightly positive or negative depending from the appliance category.

6.2.2.3 The Marginal Net Present Value and the aggregated option LCC analysis

To evaluate the improvement potential of the single base case, the aggregated option analysis is developed. Whilst two aggregated analysis pathways were performed for each of the base-case appliances in COLD-II study (the first including the option of increasing PU foam thickness while the second only allowing the option of using VIPs to improve the insulation) only one technological path was developed in the present LCC analysis, including the addition of both the remaining possibility to increase insulation thickness and VIPs options.

The LCC analysis was run for the average standard base-case appliances and for the standard base case models. The former represent the average of the reference year and takes into consideration the percentage of application of each technological option on the market, or better the percentage of each option still available for application on the market. For the latter a technological level is specified for the base cases and then all the available technological options are applied.

In the first case the possible average improvement of the overall appliance category are predicted. The second analysis allows to predict the best available technology models an can be also considered a sort of inner validation of the previous scenario and more in general of the overall calculation model: if the calculation can predict in a technically and economically sound way the development from the base case model to the to the best available models on the market in 2005, then the overall simulation is coherent with the reality.

Table 6.11: Simple payback time (SPB) and net present value (NPV) at 15 years for the identified technological options applied to cold appliances standard base cases

Appliance categories		Refrigerators		Refrigerator-freezers		Upright freezers		Chest freezers	
Options (n)	**Technology** (description)	SPB (years)	NPV (€)	SPB (years)	NPV (€)	SPB (years)	NPV (€)	SPB (years)	NPV (€)
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	44,9	*-38,45*	31,7	*-58,88*	25,0	*-40,94*	22,8	*-38,17*
a.2	vacuum insulated panels, cabinet walls (50%)	35,9	*-71,11*	22,7	*-67,76*	22,3	*-66,88*	20,4	*-61,35*
a.3	+10-15mm insulation, door & cabinet walls	7,5	*9,66*	6,0	*21,52*	6,4	*18,44*	5,9	*23,04*
b*	low wattage brushless fan motor (4W AC fans)			7,6	*4,67*	6,7	*6,88*		
c (+ g)	modified defrost with electronic temperature control and fuzzy logic, to be used together with Option g	32,9	*-18,83*						
d.1	increasing 10-20% the surface area of the evaporator	9,0	*1,17*	7,6	*4,67*	8,9	*2,03*	4,9	*8,41*
d.2	increasing 5-10% the surface area of the condenser	18,0	*-2,11*	9,1	*0,72*	10,7	*-0,16*	9,8	*0,30*
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	29,9	*-16,33*	15,1	*-7,83*	17,9	*-10,47*	16,3	*-9,09*
f.1**	Higher efficiency reciprocating compressors (COP 1,5)	4,5	*16,39*	2,3	*44,74*	2,7	*35,94*	2,4	*40,54*
f.2**	optimisation of reciprocating compressors (highest efficiency of one producer)	8,3	*7,55*	5,2	*36,91*	6,2	*25,47*	5,6	*31,45*
f.3**	multi-speed and variable-speed compressors	13,5	*-17,23*	9,1	*10,86*	8,0	*21,87*	7,3	*31,08*
g (+ c*)	Temperature control through electronic thermostats, to be used together with Option c for no-frost models			22,7	*-13,55*	26,8	*-15,31*		
h (+g)	bistable solenoid valve (diverter valve) including electronic control			40,8	*-33,55*				

*options for no-frost models
**possible alternative options

Table 6.12: Technological options ordered by simple payback time (SPB) and net present value (NPV) at 15 years for cold appliances standard base cases

Options	Refrigerators		Options	Refrigerator-freezers		Options	Upright freezers		Options	Chest freezers	
	SPB	NPV		SPB	NPV		SPB	NPV		SPB	NPV
(n)	(years)	(€)	(n)	(years)	(€)	(n)	(years)	(€)	(n)	(years)	(€)
f.1**	4,5	16,39	**f.1****	2,3	44,74	**f.1****	2,7	35,94	**f.1****	2,4	40,54
a.3	7,5	9,66	**f.2****	5,2	36,91	**f.2****	6,2	25,47	**d.1**	4,9	8,41
f.2**	8,3	7,55	**a.3**	6,0	21,52	**a.3**	6,4	18,44	**f.2****	5,6	31,45
d.1	9,0	1,17	**b***	7,6	4,67	**b***	6,7	6,88	**a.3**	5,9	23,04
f.3**	13,5	-17,23	**d.1**	7,6	4,67	**f.3****	8,0	21,87	**f.3****	7,3	31,08
d.2	18,0	-2,11	**d.2**	9,1	0,72	**d.1**	8,9	2,03	**d.2**	9,8	0,3
e	29,9	-16,33	**f.3****	9,1	10,86	**d.2**	10,7	-0,16	**e**	16,3	-9,09
c (+ g)	32,9	-18,83	**e**	15,1	-7,83	**e**	17,9	-10,47	**a.2**	20,4	-61,35
a.2	35,9	-71,11	**a.2**	22,7	-67,76	**a.2**	22,3	-66,88	**a.1**	22,8	-38,17
a.1	44,9	-38,45	**g (+ c*)**	22,7	-13,55	**a.1**	25,0	-40,94	**b***		
b*			**a.1**	31,7	-58,88	**g (+ c*)**	26,8	-15,31	**c (+ g)**		
g (+ c*)			**h (+g)**	40,8	-33,55	**h (+g)**			**g (+ c*)**		
h (+g)			**c (+ g)**			**c (+ g)**			**h (+g)**		

*options for no-frost models
**possible alternative options

In Table 6.13 the applied options, with the order of application, the marginal net present value (MNPV) and the corresponding marginal payback time (MPB) for a 15 year lifetime are presented for the standard base cases and the standard base case models. To evaluate the optimum options combinations at the LLCC negative MNPVs up to -1 Euro were accepted. The reasons for the selection of the specific technological pathways (out of the Technological Option List) and the detailed Life Cycle Cost results and calculations for each base case are presented in Annex A.

The optimum option combination varies with the base case and whether the LCC analysis was run for the average standard base-case appliances or for the standard base case models. Nevertheless some common elements can be drawn from the data presented in Table 6.13 (which reports data of Table A.11 of Annex A for the average standard base cases):

- increasing the compressor efficiency was usually cost-effective, at least for some degree;
- increasing the condenser/evaporator surface area was usually a cost-effective design option for the average standard base cases;
- increasing the door and cabinet insulation thickness (with an increase of the appliance external dimensions) was always cost-effective and the best or second choice option in all cases;
- the use of VIPs in door and cabinet was always a non cost-effective options;
- the use of a combination of 'phase-change materials integrated into the heat-exchanger with a compressor cycling optimisation' was always the first of the non cost-effective options, followed sometimes by high efficiency compressors.

a) The results for the average standard base case

The resulting energy consumption and purchase price for Base Case and average LLCC ($LLCC_{av}$) case for the four standard base cases are presented in Table 6.14, along with the marginal payback time (MPB). The energy efficiency index (EEI) is also shown, calculated according to the specifications and algorithms of directives 94/2/EC and 2003/66/EC, whose differences have been described in Task 1. The average EEI at $LLCC_{av}$ are in the range 43,4-45,4 percent, with the exception of chest freezers which reach 50,1 percent. The EEI at $LLCC_{av}$ is lower when calculated according to directive 2003/66/EC, in the range 37,5-44,6 percent; the MPB in the range 6,7-8,2 years.

The improvement, considering only the algorithms of directive 94/2/EC is 9,0% for refrigerators, 10,9% for refrigerator-freezers, 12,7% for upright freezers and 29,2% for chest freezers. The forecast increase in purchase price is respectively 9,6% for refrigerators, 20,7% for refrigerator-freezers, 30,1% for upright freezers and 31,4% for chest freezers. The ratio between the predicted increase in purchase price and the efficiency improvement is:

Appliance	Ratio	Appliance	Ratio
Cat. 1-6	1,04	Cat. 8	2,37
Cat. 7&10	1,90	Cat. 9	1,08

The energy consumption of the average Best Available Technology (BAT_{av}) is presented in Table 6.15, again along with the marginal payback time, which is in the range 12,8-22,8 years. The LCC is also presented in Figures 6.13 and 6.14 for the four average standard base cases.

The differences in the energy consumption from one appliance category to another (Figure 6.14) make the comparison among categories somehow difficult. A further issue arise from the changes in the algorithms and reference lines between directive 94/2/EC and directive 2003/66/EC. When the Life Cycle Cost (lifetime = 15 years) is shown as a function of the Energy Efficiency Index (EEI) in the two directives the curves in Figure 15 result. The least life cycle costs occurs clearly for

Table 6.13: Technological options, marginal net present value (MNPV) and marginal payback time (MPB) at a lifetime of 15 years for the aggregated option analysis for cold appliances average standard base cases and standard base case models

Refrigerators						**Refrigerator-freezers**					
Average standard base case			Standard base case model			Average standard base case			Standard base case model		
Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)
+f.1	10,16	4,49	**+f.1**	16,39	4,49	**+a.3**	19,37	6,04	**+a.3**	21,52	6,04
+a.3	8,70	7,49	**+a.3**	9,66	7,49	**+f.3**	10,32	9,07	**+f.3**	10,86	9,07
+d.1	-0,06	10,82	**+f.2**	-8,83	20,96	**+d.1**	0,08	9,73	**+e**	-11,95	19,88
+d.2	-0,52	21,78	**+e**	-18,50	39,93	**+d.2**	-0,11	11,71	**+(h+g)**	-36,56	55,34
+f.2	-8,57	20,96	**+(g+c)**	-21,20	45,28	**+e**	-11,15	19,56	**+a.1**	-58,88	31,73
+(g+c)	-16,49	41,47	**+f.3**	-24,78	23,10	**+(h+g)**	-25,48	54,36	**+a.2**	-67,76	22,67
+e	-17,37	38,63	**+a.1**	-38,45	44,92	**+a.1**	-58,29	31,73			
+f.3	-24,53	23,10	**+a.2**	-71,11	35,93	**+a.2**	-67,76	22,67			
+a.1	-38,06	44,92									
+a.2	-71,11	35,93									
Upright freezers						**Chest freezers**					
Average standard base case			Standard base case model			Average standard base case			Standard base case model		
Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)
+f.3	20,78	8,04	**+f.3**	21,87	8,04	**+f.3**	29,53	7,34	**+f.3**	31,08	7,34
+a.3	7,39	7,94	**+a.3**	18,44	6,43	**+a.3**	20,74	5,87	**+a.3**	23,04	5,87
+d.2	-0,47	19,70	**+e**	-14,83	25,51	**+d.1**	1,98	6,79	**+d.1**	3,64	6,99
+d.1	-0,92	16,47	**+a.1**	-40,94	25,00	**+d.2**	-0,25	13,80	**+e**	-14,20	24,02
+e	-16,34	33,29	**+a.2**	-66,88	22,32	**+e**	-13,05	23,04	**+a.1**	-38,17	22,83
+a.1	-48,42	34,46				**+a.1**	-37,79	22,83	**+a.2**	-61,35	20,38
+a.2	-85,33	32,71				**+a.2**	-61,35	20,38			

Table 6.14: Marginal payback time, energy efficiency index (EEI), energy consumption and incremental purchase price for cold appliance Base Case and LLCCav for average standard base cases

Standard base case	Energy consumption			EEI (%)				Purchase price			LCC (15y)	
	Base case (kWh/year)	$LLCC_{av}$ (kWh/year)	MPB (years)	Base case (94/2/EC)	$LLCC_{av}$ (94/2/EC)	difference (%)	$LLCC_{av}$ (2003/66/EC)	Base case (Euro)	$LLCC_{av}$ (Euro)	increase (%)	Base case (€)	$LLCC_{av}$ (€)
Refrigerators	163,7	134,8	6,7	54,4	45,4	9,0	44,6	345,1	378,2	9,6	720	702
Refrigerator-freezers	324,4	250,6	8,0	54,3	43,4	10,9	41,4	485,0	585,5	20,7	1.144	1.171
Upright freezers	274,5	203,4	8,2	56,3	43,6	12,7	37,5	328,0	426,8	30,1	899	872
Chest freezers	300,6	212,8	6,9	70,8	50,1	29,2	37,4	328,0	431,0	31,4	945	893

Note: EEI is calculated according to the specifications and algorithms of directive 94/2/EC and 2003/66/EC, although the latter apply only for EEI lower than 42 (the A/A+ threshold). Reference lines for upright and chest freezers have been modified in directive 2003/66/EC, therefore any comparison of the resulting EEI values at LLCC should be carefully made.

Table 6.15: Marginal payback time, energy efficiency index (EEI), energy consumption and incremental purchase price for cold appliance Base Case and average BAT for average standard base cases

Standard base case	Energy consumption			EEI (%)				Purchase price			LCC (15y)	
	Base case (kWh/year)	BAT_{av} (kWh/year)	MPB (years)	Base case (94/2/EC)	BAT_{av} (94/2/EC)	difference (%)	BAT_{av} (2003/66/EC)	Base case (Euro)	BAT_{av} (Euro)	increase (%)	Base case (€)	BAT_{av} (€)
Refrigerators	163,7	89,1	22,8	54,4	30,0	24,4	29,5	345,1	635,2	84,6	720	878
Refrigerator-freezers	324,4	191,6	16,3	54,3	33,2	21,1	31,7	485,0	852,4	75,7	1.144	1.277
Upright freezers	274,5	164,9	17,0	56,3	35,3	21,0	30,4	328,0	644,8	96,6	899	1.022
Chest freezers	300,6	152,8	12,8	70,8	36,0	49,2	26,8	328,0	649,1	97,9	945	1.005

Note: EEI is calculated according to the specifications and algorithms of directive 94/2/EC and 2003/66/EC, although the latter apply only for EEI lower than 42 (the A/A+ threshold). Reference lines for upright and chest freezers have been modified in directive 2003/66/EC, therefore any comparison of the resulting EEI values at LLCC should be carefully made.

Figure 6.13: Life Cycle Cost (lifetime = 15 years) as a function of the applied technological options for each of the cold appliance standard base cases.

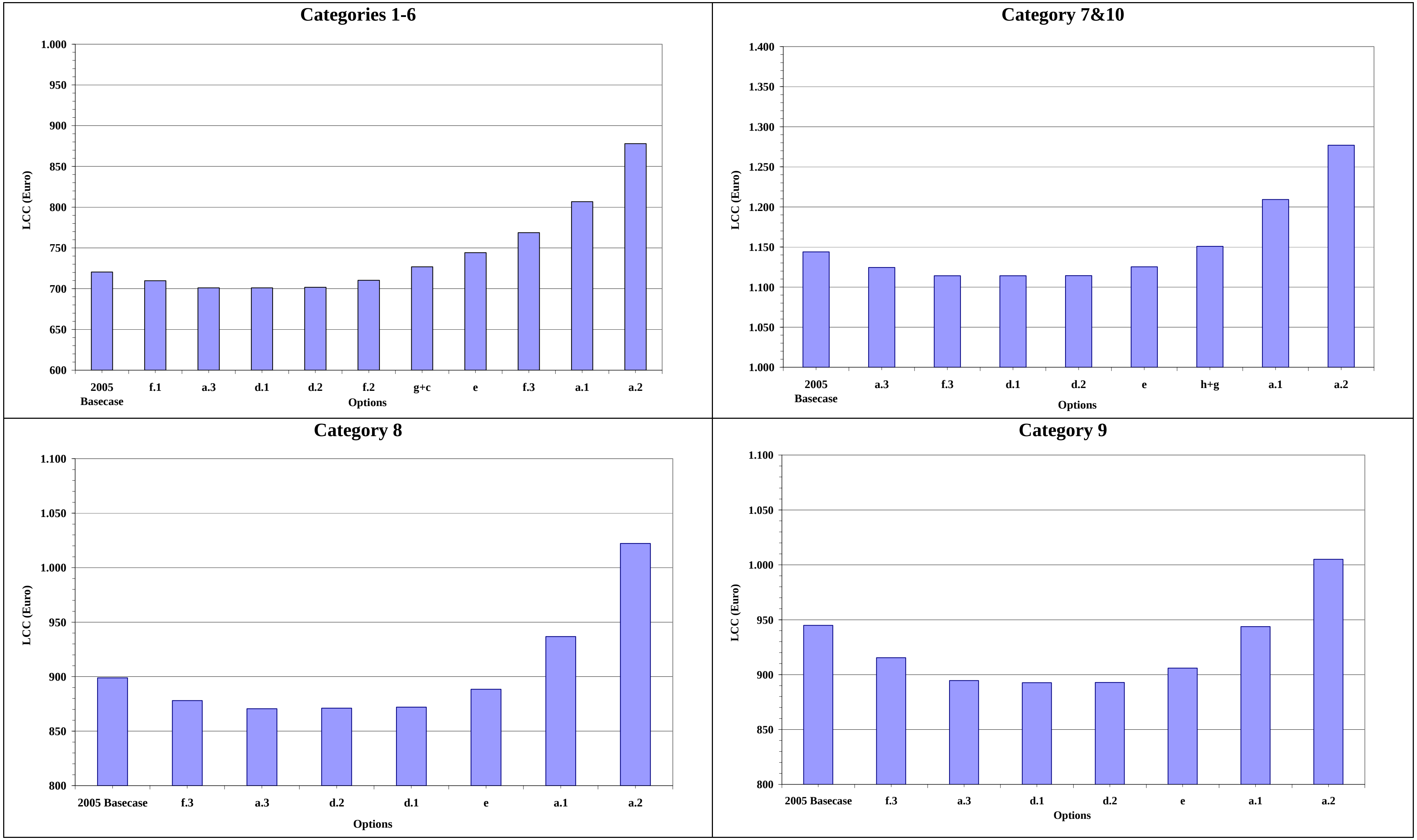


Figure 6.14: Life Cycle Cost (lifetime = 15 years) as a function of the energy consumption for each of the cold appliance standard base cases. The average standard base case is the first point on each curve. Appliance base cases are identified by their category number

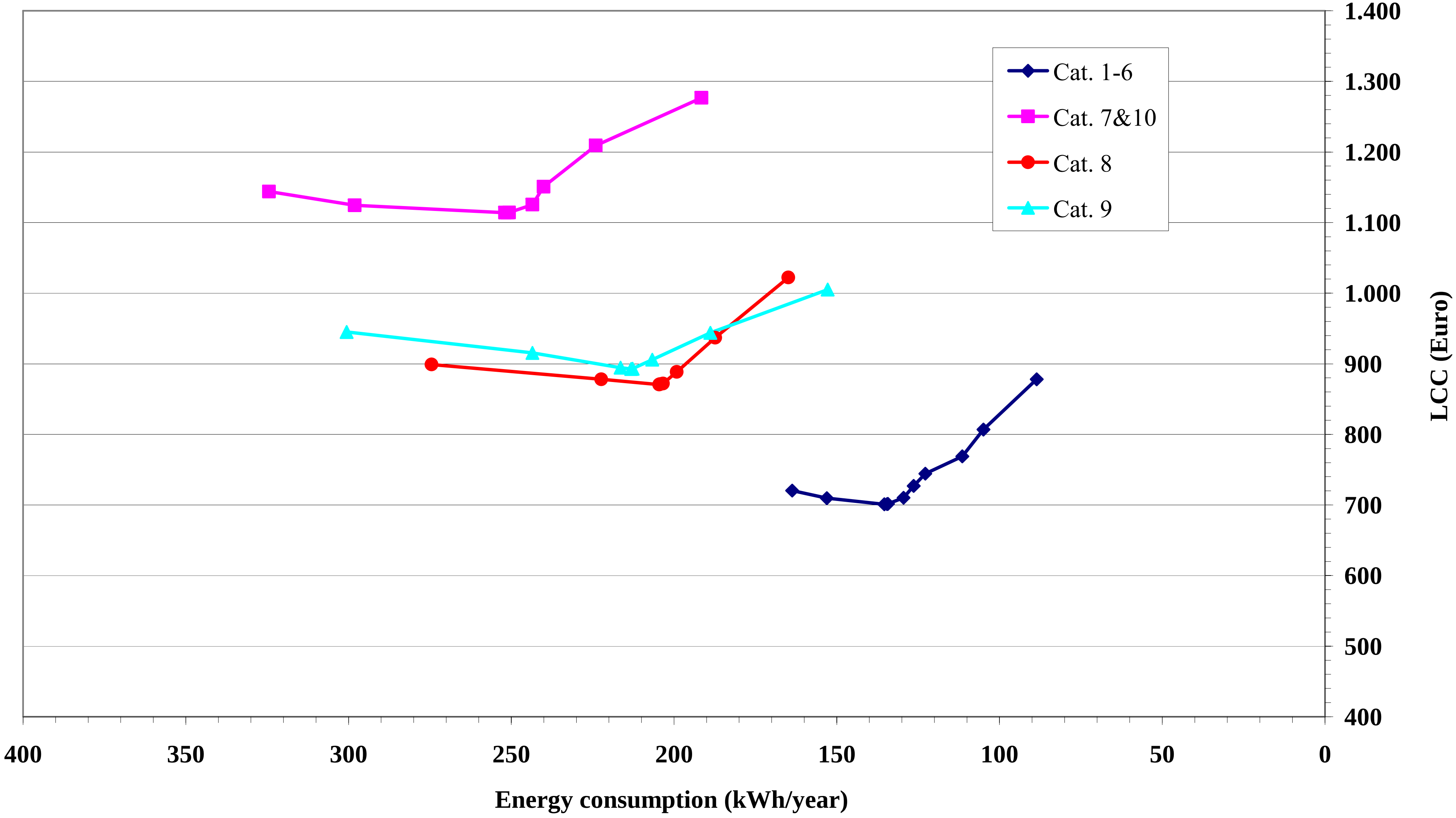
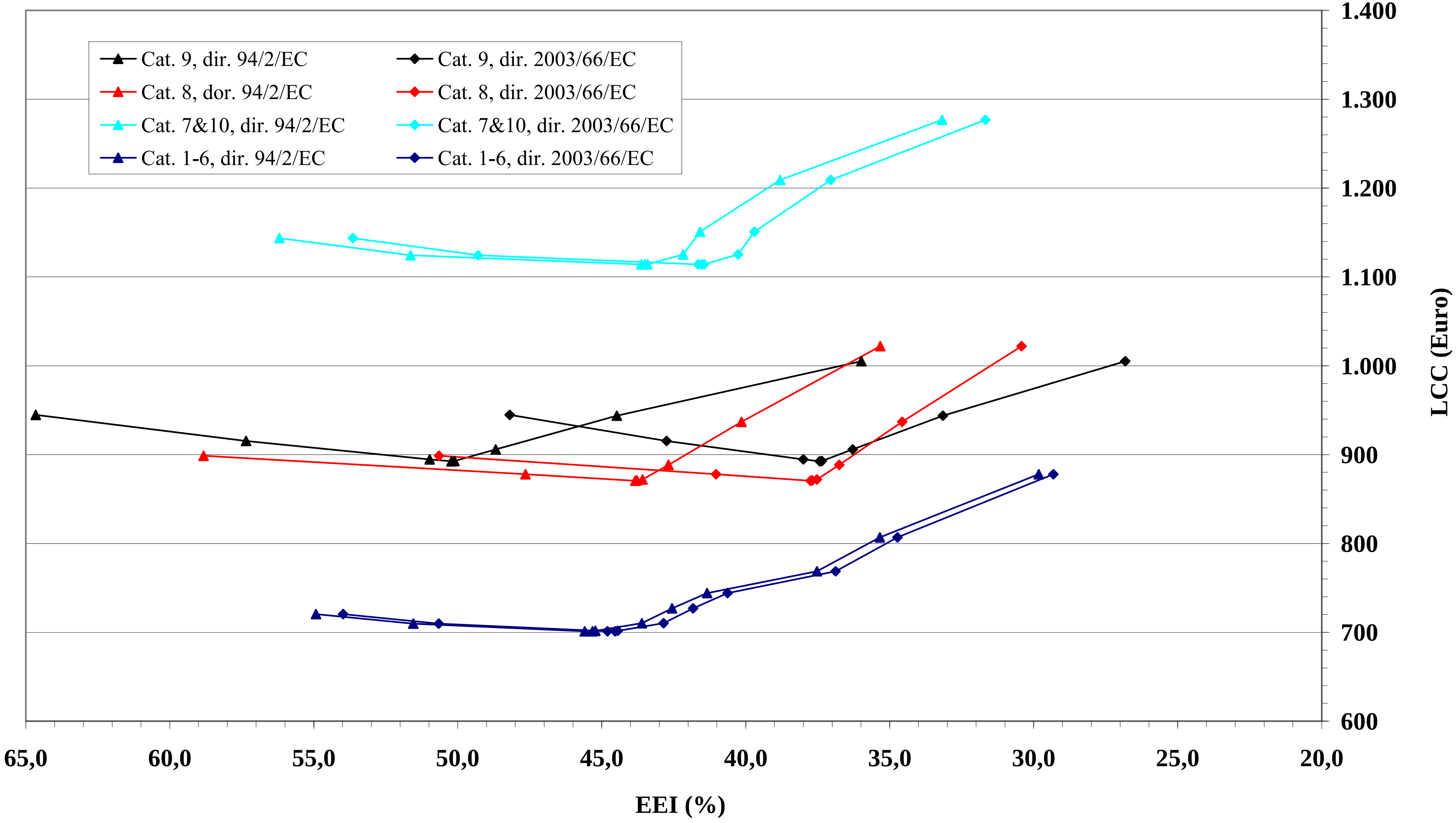


Figure 6.15: Life Cycle Cost (lifetime = 15 years) as a function of the Energy Efficiency Index (EEI) in directives 94/2/EC and 2003/66/EC for each of the cold appliance standard base cases. The average standard base case is the first point on each curve. Appliance base cases are identified by their category number



different EEIs when the different algorithms are used, the major difference occurring for freezers.

b) The results for the standard base case model

When the LCC analysis is to the standard base case models, the technological options already 100% applied to the base cases, and those 100% available for application are identified among those included in the Technological Option List. The LCC analysis is then run. The resulting predicted improvement in energy efficiency and purchasing price is presented in Table 6.16 for each base case model. The marginal payback time is also given.

The average EEI of the LLCC product models (as calculated in directive 94/2/EC) are lower than when for the average standard base cases (dealt in previous paragraph) and in the range 41,2-43,0 percent, with the exception of chest freezers which reach 48,1. The MPB is in the range 6,1 years for refrigerators to 7,9 years for refrigerator-freezers. When calculated according to directive 2003/66/EC the EEI is lower and in the range 35,4-42,3 percent. The improvement, considering only the calculations of directive 94/2/EC is higher that in the previous simulation: 14,4% for refrigerators, 11,6% for refrigerator-freezers, 15,1% for upright freezers and 32,1% for chest freezers; the increase in purchase price is also higher: 10,9% for refrigerators, 21,6% for refrigerator-freezers, 32,0% for upright freezers and 34,3% for chest freezers. The ratio between the predicted increase in purchase price and the efficiency improvement becomes slightly better than in the previous case:

Appliance	Ratio	Appliance	Ratio
Cat. 1-6	0,76	Cat. 8	2,12
Cat. 7&10	1,86	Cat. 9	1,07

The lowest predicted energy consumption for the Best Available Technology (BAT) is presented in Table 6.17 along with the relevant marginal payback time (MPB), which ranges from 12,5 years for chest freezers to 21,6 years for the refrigerators.

The LCC (lifetime = 15 years) is also presented in Figures 6.16 as function of the technological options for the four product categories; in Figure 6.17 the LCC is shown as function of the models energy consumption per year; when the LCC is shown as a function of the Energy Efficiency Index (EEI) in directives 94/2/EC and 2003/66/EC the curves in Figure 18 result: the difference due to the applied algorithms is clearly visible, especially for freezers.

A close agreement can be seen between the results of the LCC analysis in Table 6.17 and the COLD-II study LCC analysis, reported in Table 3 of paragraph 1.3.2.9. Especially the EEI and the purchase price of the improved models at LLCC are surprisingly similar, with the exception of the upright freezers where the LLCC had a predicted EEI of 55 in 1998 and a new index of about 48 in the present simulation, while the price of the improved models is about the same. A further close agreement can be found between the predicted BAT energy consumption and EEI and the actual values of the very best cold appliance models in the 2005 CECED technical database (see Task 5):

Category	Minimum energy consumption (kWh/year)		Minimum EEI (dir. 2003/66/EC)	
	CECED db	LCC - BAT	CECED db	LCC - BAT
Categories 1-6:	83,0	81,1	29,6	26,9
Category 7&10*	190,0	185,7	27,3	30,7
Category 8	135,0	137,0	29,1	25,3
Category 9	134,0	143,4	27,4	25,3

*minimum values in CECED 2005 technical database belong to models in Category 10

Table 6.16: Marginal payback time, energy efficiency index (EEI), energy consumption and incremental purchase price for cold appliance Base Case and LLCC for standard base case models

Standard base case model	Energy consumption			EEI (%)				Purchase price			LCC (15y)	
	Base case (kWh/year)	LLCC (kWh/year)	MPB (years)	Base case (94/2/EC)	for LLCC (94/2/EC)	difference (%)	for LLCC (2003/66/EC)	Base case (Euro)	LLCC (Euro)	Increase (%)	Base case (€)	LLCC (€)
Refrigerator	163,7	127,7	6,1	54,4	43,0	14,4	42,3	345,1	382,6	10,9	720	694
Refrigerator-freezer	324,4	246,5	7,9	54,3	42,7	11,6	40,8	485,0	590,0	21,6	1.144	1.114
Upright freezer	274,5	192,2	7,5	56,3	41,2	15,1	35,5	328,0	433,0	32,0	899	858
Chest freezer	300,6	204,1	6,9	70,8	48,1	32,1	35,8	328,0	440,5	34,3	945	887

Note: EEI is calculated according to the specifications and algorithms of directive 94/2/EC and 2003/66/EC, although the latter apply only for EEI lower than 42 (the A/A+ threshold). Reference lines for upright and chest freezers have been modified in directive 2003/66/EC, therefore any comparison of the resulting EEI values at LLCC should be carefully made.

Table 6.17: Marginal payback time, energy efficiency index (EEI), energy consumption and incremental purchase price for cold appliance Base Case and BAT for standard base case models

Standard base case	Energy consumption			EEI (%)				Purchase price			LCC (15y)	
	Base case (kWh/year)	BAT (kWh/year)	MPB (years)	Base case (94/2/EC)	BAT (94/2/EC)	difference (%)	BAT (2003/66/EC)	Base case (Euro)	BAT (Euro)	Increase (%)	Base case (€)	BAT (€)
Refrigerators	163,7	81,1	21,6	54,4	27,3	27,1	26,9	345,1	647,6	87,7	720	877
Refrigerator-freezers	324,4	185,7	16,4	54,3	32,2	22,1	30,7	485,0	872,5	79,9	1.144	1.287
Upright freezers	274,5	137,0	13,9	56,3	29,4	26,9	25,3	328,0	653,0	99,1	899	981
Chest freezers	300,6	143,4	12,5	70,8	33,9	52,1	25,3	328,0	660,5	101,4	945	1.001

Note: EEI is calculated according to the specifications and algorithms of directive 94/2/EC and 2003/66/EC, although the latter apply only for EEI lower than 42 (the A/A+ threshold). Reference lines for upright and chest freezers have been modified in directive 2003/66/EC, therefore any comparison of the resulting EEI values at LLCC should be carefully made.

Figure 6.16: Life Cycle Cost (lifetime = 15 years) as a function of the applied technological options for each of the cold appliance base case models.

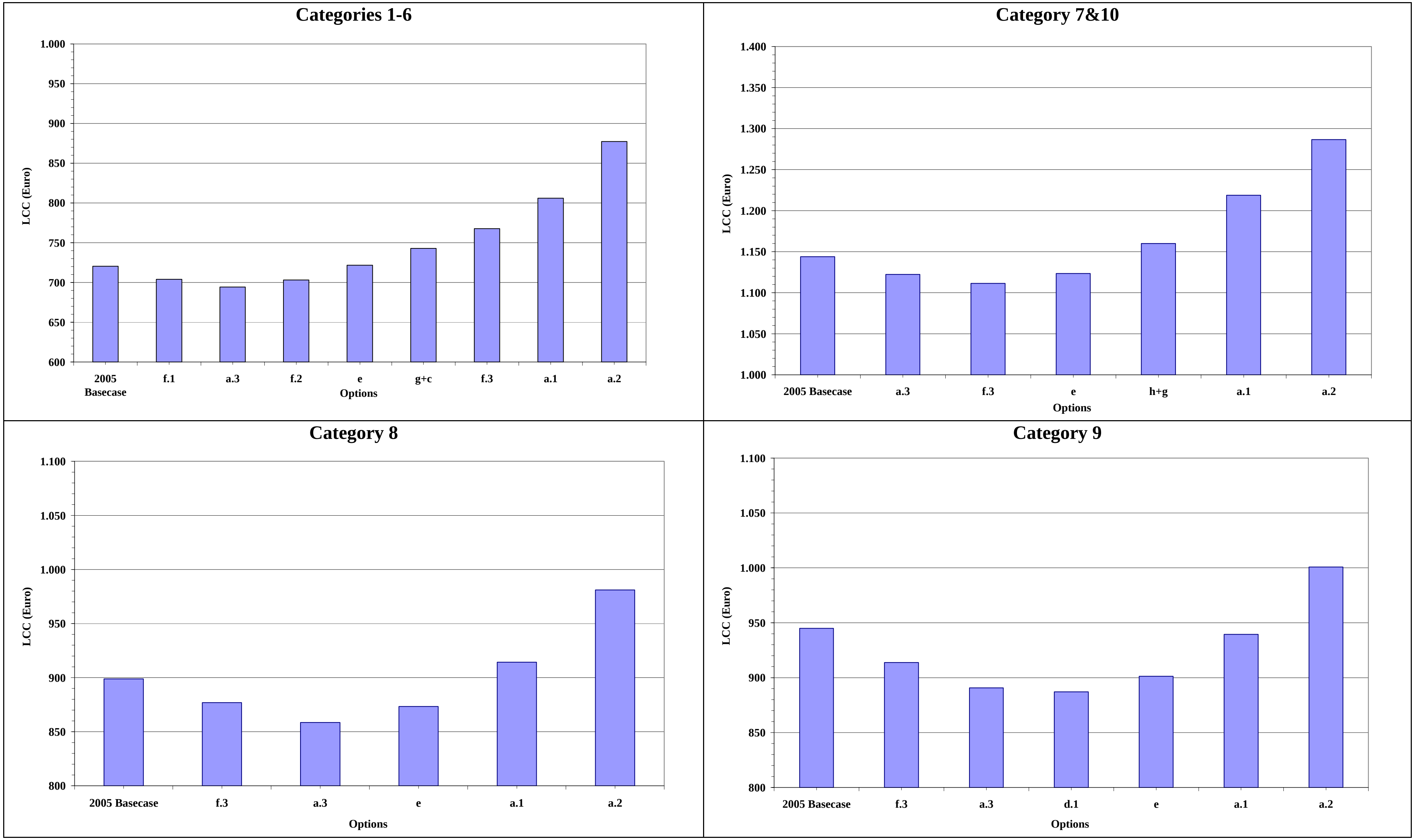


Figure 6.17: Life Cycle Cost (lifetime = 15 years) as a function of the energy consumption for each of the cold appliance standard base case model. The standard base case model is the first point on each curve, the Best Available Technology (BAT) in the reference year (2005) is the last point on each curve. Appliance base cases are identified by their category number

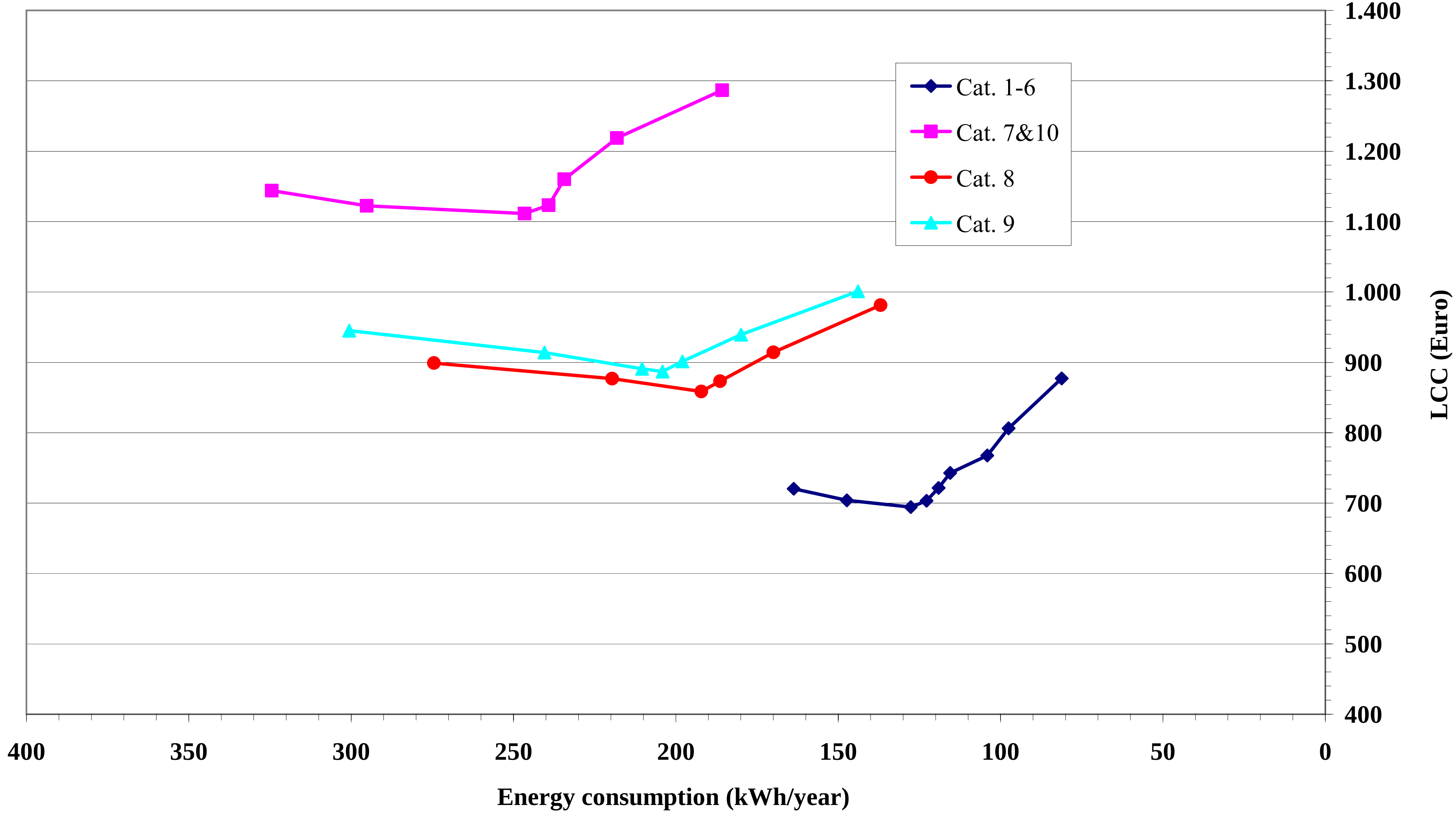
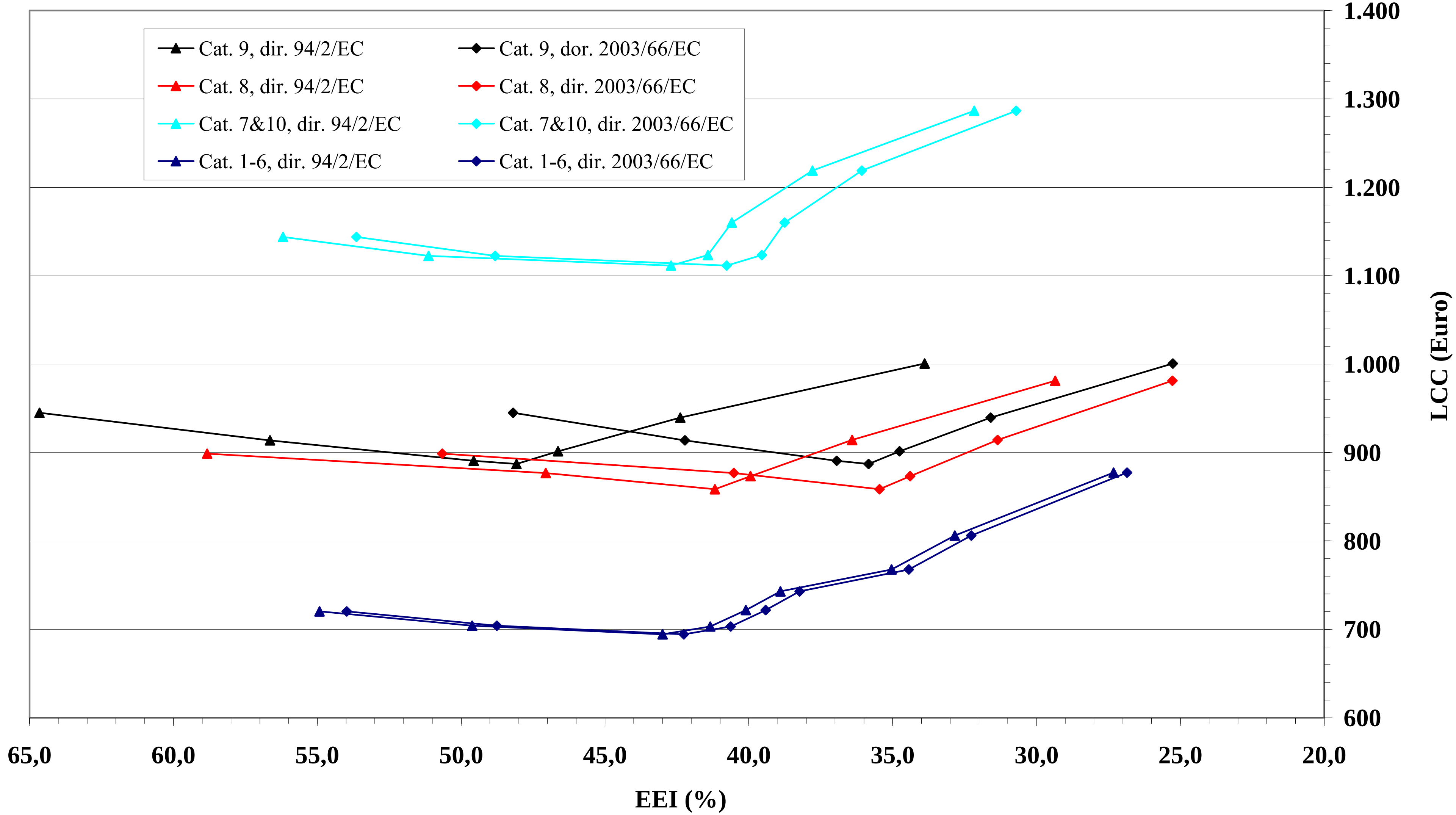


Figure 6.18: Life Cycle Cost (lifetime = 15 years) as a function of the Energy Efficiency Index (EEI) in directives 94/2/EC and 2003/66/EC for each of the cold appliance base case models. The average standard base case is the first point on each curve. Appliance base cases are identified by their category number



This means that the LCC analysis applied to the standard base case models is able to predict the best available technology on the market in 2005 in terms of minimum energy efficiency index and energy consumption.

6.2.2.4 Conclusions from the LCC analysis

The LCC is a means of expressing the overall cost of the appliance from the owner's perspective. It includes both the initial purchase price, the operating expenses for electricity consumption and the other costs (maintenance, repairs, disposal) amortised to the present. In this approach, the net present value of the operating expenses and other costs decrease from one year to the next due to discounting of their current value. The LCC analysis results for the base-case appliances show that:

- due to the time and budget constraints of the present study, and supported by the analysis of the last available technical database of the cold appliance models produced or imported in the EU market in 2005, only free-standing base cases were simulated;
- for the same reasons also no-frost models were not simulated;
- for the standard base cases the least life-cycle cost occurs for appliances that are rated close to class A+ with the exception of chest freezers where the $LLCC_{av}$ occurs for class A;
- the estimated sales-weighted average EEI for all cold appliances at the point of least life-cycle cost in 2005 is 44,1% for the average standard base case and 42,8% for the standard base case models when the algorithm of directive 94/2/EC are used; the EEI becomes respectively 41,1% or 39,9% when the algorithms and reference lines of directive 2003/66/EC are considered. Estimated sales-weighted cold appliance market-average values are computed by assuming the following cold appliance market shares (see Task 5): Category 1=14,1%; Category 2=0,62%; Category 3=0,68%; Category 4 = 0,29%; Category 5 = 0,5%; Category 6 = 0,15%; Category 7 & 10 =62,46%; Category 8 = 15,6%; Category 9 = 5,62%;
- the Marginal Payback Time for the average standard base cases varies with the appliance Category, but is between 6,7 years (refrigerators) and 8,2 years (upright freezers) for the $LLCC_{av}$ and between 12,8 years (chest freezers) and 22,8 years (refrigerators) for the BAT_{av};
- the Marginal Payback time for the standard base case models varies again with the appliance category, and is between 6,1 years (refrigerators) and 7,9 (refrigerator-freezers) years for the LLCC and between 12,5 years (chest freezers) and 21,6 years (refrigerators) for the BAT.

6.2.3 Sensitivity Analysis

The life-cycle cost analysis presented in previous paragraph assumed EU average values for cold appliance prices, lifetime, electricity tariffs and discount rates. As all of these parameters will vary at the Member State level, a sensitivity analysis was performed to determine if the efficiency level associated with the least life-cycle cost might occur at a different level depending on the Member State concerned.

The key national parameters used in the sensitivity analysis are:

- Lifetime: 10y, 12y and 17y (average 15y)
- Electricity price: 0,25 €/kWh and 0,10 €/kWh (average 17 €/kWh)
- Discount rate: 4% and 6%, (average 5%)
- Disposal and recycling costs: 10€ in addition to the 61€ (at the end of life).
- Refrigerators price (Cat.1): 348,8 € in West EU and 251,1 € in East EU (average 345,1 €)
- Refrigerator-freezers price: 509,7 € in West EU and 342,0 € in East EU (average 485,0 €)
- Upright & chest freezers price: 330,4 € in West EU and 281,4 in East EU (average 328,0 €).

The Life Cycle Cost sensitivity analysis for cold appliances has been developed only for the four average standard base cases. The technical and financial assumptions defined in Task 5 were modified, one at time, to evaluate the impact on the LCC output values. It is worth highlighting that in the sensitivity analysis the application order of the technological options is that resulting as the most profitable for the consumers according to the MNPV analysis for the average standard base case and the basic technical and financial assumptions. The variation of parameters such as the energy price and the lifetime might have an influence on the optimum technological option combination (corresponding to the LLCC) and more in general to the options application order, but this more sophisticated sensitivity analysis was not compatible with the time and budget constraints of the study.

6.2.3.1 The sensitivity analysis for refrigerators

In Table 6.18 the LCC analyses of the **refrigerators** are presented for the four values of the lifetime: 10, 12 15 and 17 years. The most important result is that in practice the LLCC point occurs at different technological option combination for the variation of the investigated parameters. For example, when electricity price is considered 0,10 €/kWh (or 58% of the initial value of 0,17 €/kWh) the LLCC occurs after the application of the first option (*Option f.1*) at all lifetimes; when on the contrary the electricity price is considered 0,25 €/kWh (or 147% of the initial value) the LLCC occurs after the application of the fourth option (*Option d.2*) for all lifetimes but 10 years, when it occurs after the application of the third option (*Option d.1*), however the difference in LCC between the options close to the LLCC point is some cases very small. For almost all the other parameters variation the LLCC point occurs at the application of *Options d.1* or *d.2*. The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the LCC over a lifetime of 10 years and an electricity price of 0,10 €/kWh is 457 €; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 846 €, with a difference of 381 €. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61 € to 10 €.
The same data are presented in Figures 6.19-6.22, respectively for 10, 12, 15 and 17 years, using the same scale for the LCC to allow an immediate comparison of the differences due to the lifetime duration. In Figure 6.23 the LCC for refrigerators is presented for the four lifetime values and the basic technical and financial parameters.

6.2.3.2 The sensitivity analysis for refrigerator-freezers

In Table 6.19 the LCC analyses of the **refrigerator-freezers** are presented for the four values of the lifetime: 10, 12 15 and 17 years. The most important result is that the Least Life Cycle Cost point occurs mainly at two different technological option combinations depending on the lifetime: when lifetime is ≤12 years the optimum options combination is the application of *Option a.3*, when lifetime is longer than 12 years the optimum options combination is (a.3+f.3+d.1+d.2). Again, when electricity price is considered 0,10 €/kWh the LLCC occurs after the addition of the first option for a lifetime of 15 or 17 years, while at lower values the base case show the lowest life cycle cost value. When on the contrary the electricity price is considered 0,25 €/kWh the LLCC occurs always after the application of the fourth option. Also in this case there is no effect on the overall LCC results when the disposal and recycling costs are decreased from 61 € to 10 €. The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.2* is applied, the life cycle cost is 851 € over a lifetime of 10 years and with the appliance price at 324 €; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.380 €, with a difference of 529 €. The same data are presented in Figures 6.24-6.27, respectively for 10, 12, 15 and 17 years, using the same scale for the LCC to allow an immediate comparison of the differences due to the lifetime duration. In Figure 6.28 the LCC is presented for the four lifetime

Table 6.18: Sensitivity analysis results for the LCC of refrigerayors (Cat. 1-6) average standard base case. LLCC is highlighted in light blue

Technological options				+f.1	+a.3	+d.1	+d.2	+f.2	+g+c	+e	+f.3	+a.1	+a.2
Lifetime	Investigated parameters and variations		**2005 base case**	optimisation of reciprocating compressors (high efficiency of major suppliers)	+10-15mm insulation, door & cabinet walls	increasing 10-20% the surface area of the evaporator	increasing 5-10% the surface area of the condenser	highest efficiency reciprocating compressors (max COP, available from one supplier)	Temperature control with electronic thermostats + modified defrost with electronic temperature control and fuzzy logic	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	highest efficiency reciprocating compressors (max COP, available from one supplier)	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, door (area 70%, thickness 50%)
years	Annual consumption	kWh/year	163,7	153,6	135,9	135,1	134,8	130,0	126,9	123,3	111,9	105,5	89,1
10	average values		640	634	634	634	635	645	663	682	712	753	831
10	electricity price	€ 0,25	741	729	717	717	718	726	742	758	781	818	886
10	electricity price	€ 0,10	551	551	560	561	562	575	595	616	651	696	783
10	discount rate	4%	657	650	649	649	650	660	678	696	725	766	843
10	discount rate	6%	624	620	620	620	621	632	650	669	700	741	821
10	appliance price	€ 348,8	644	638	637	638	638	649	667	686	716	757	835
10	appliance price	€ 251,1	546	540	540	540	541	551	569	588	618	659	737
10	Disposal&recycling	€ 10	609	603	602	603	603	614	632	651	681	722	800
12	average values		674	667	663	663	664	673	691	709	736	776	852
12	electricity price	€ 0,25	790	776	759	759	759	766	781	796	816	851	915
12	electricity price	€ 0,10	573	572	578	579	580	593	612	633	667	711	796
12	discount rate	4%	696	688	682	682	683	692	709	727	753	793	866
12	discount rate	6%	655	648	645	646	646	657	674	693	721	761	838
12	appliance price	€ 348,8	678	671	666	667	667	677	694	713	740	780	855
12	appliance price	€ 251,1	580	573	569	569	570	579	597	615	642	682	758
12	disposal&recycling	€ 10	646	638	634	635	635	645	662	681	708	748	823
15	average values		**720**	**710**	**702**	**702**	**702**	**711**	**727**	**745**	**769**	**807**	**878**
15	electricity price	€ 0,25	856	838	814	814	814	819	833	847	862	895	952
15	electricity price	€ 0,10	601	599	603	603	604	616	635	655	688	731	814
15	discount rate	4%	750	738	727	727	728	736	752	769	792	829	898
15	discount rate	6%	694	685	679	679	679	688	705	723	749	788	861
15	appliance price	€ 348,8	724	714	705	705	706	714	731	748	773	811	882
15	appliance price	€ 251,1	626	616	608	608	608	617	633	651	675	713	784
15	disposal&recycling	€ 10	696	686	677	677	678	686	703	720	745	783	854
17	average values		747	736	724	724	725	733	749	765	788	825	894
17	electricity price	€ 0,25	895	874	847	**846**	846	850	863	877	889	920	974

Technological options				+f.1	+a.3	+d.1	+d.2	+f.2	+g+c	+e	+f.3	+a.1	+a.2
Lifetime	Investigated parameters and variations		**2005 base case**	optimisation of reciprocating compressors (high efficiency of major suppliers)	+10-15mm insulation, door & cabinet walls	increasing 10-20% the surface area of the evaporator	increasing 5-10% the surface area of the condenser	highest efficiency reciprocating compressors (max COP, available from one supplier)	Temperature control with electronic thermostats + modified defrost with electronic temperature control and fuzzy logic	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	highest efficiency reciprocating compressors (max COP, available from one supplier)	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, door (area 70%, thickness 50%)
years	Annual consumption	kWh/year	163,7	153,6	135,9	135,1	134,8	130,0	126,9	123,3	111,9	105,5	89,1
17	electricity price	€ 0,10	618	615	617	618	618	630	648	668	700	742	824
17	discount rate	4%	782	769	755	754	755	762	778	794	815	851	917
17	discount rate	6%	717	707	698	698	698	707	723	740	765	803	874
17	appliance price	€ 348,8	751	739	728	728	728	736	752	769	792	829	898
17	appliance price	€ 251,1	653	642	630	630	631	639	655	671	694	731	800
17	disposal&recycling	€ 10	725	713	702	702	702	710	726	743	766	803	872

Figure 6.19: Life Cycle Cost (lifetime = 10 years) as function of the technological options for refrigerators sensitivity analysis. Parameters variation is indicated for each curve

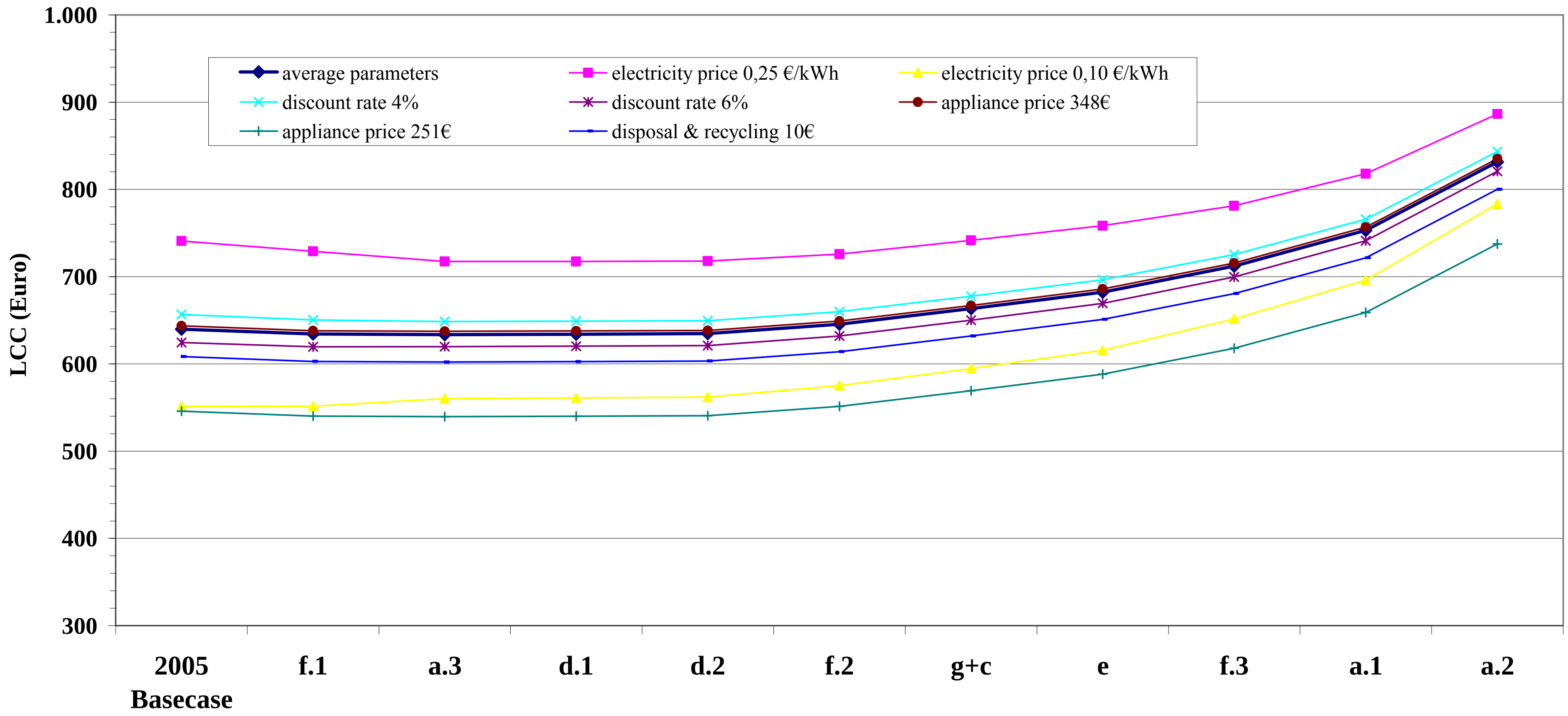


Figure 6.20: Life Cycle Cost (lifetime = 12 years) as function of the technological options for refrigerators sensitivity analysis. Parameters variation is indicated for each curve

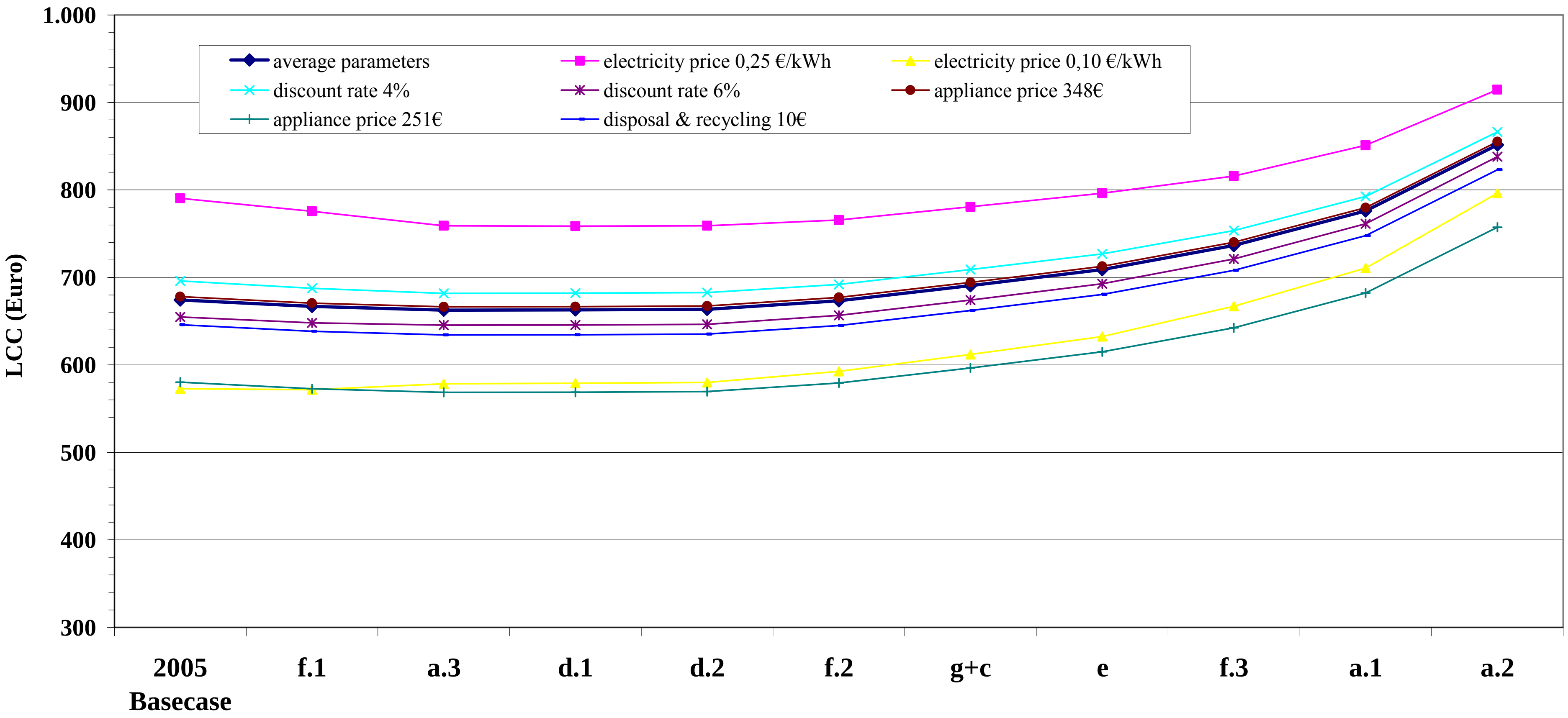


Figure 6.21: Life Cycle Cost (lifetime = 15 years) as function of the technological options for refrigerators sensitivity analysis. Parameters variation is indicated for each curve

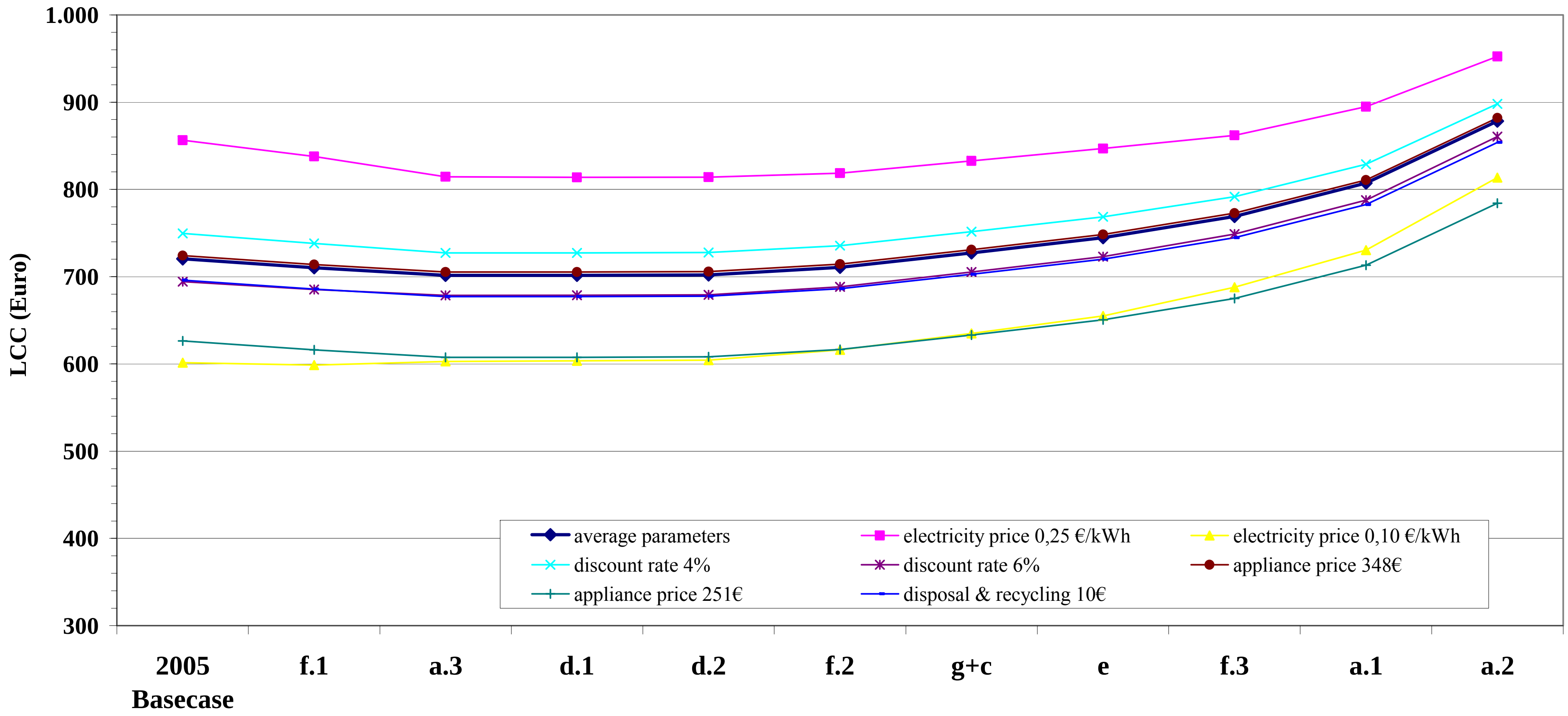


Figure 6.22: Life Cycle Cost (lifetime = 17 years) as function of the technological options for refrigerators sensitivity analysis. Parameters variation is indicated for each curve

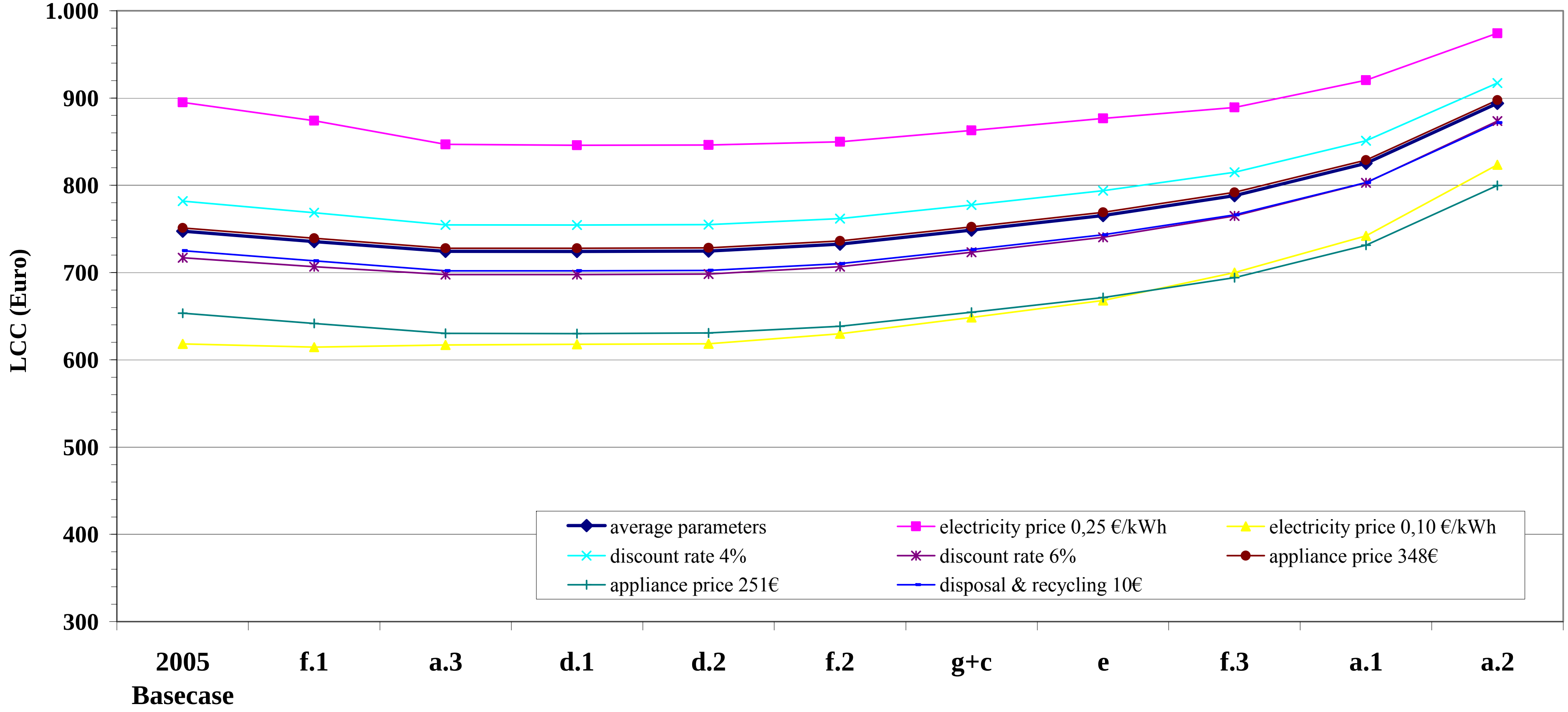


Figure 6.23: Life Cycle Cost as function of the technological options for refrigerators for different values of the lifetime and average technical and financial parameters

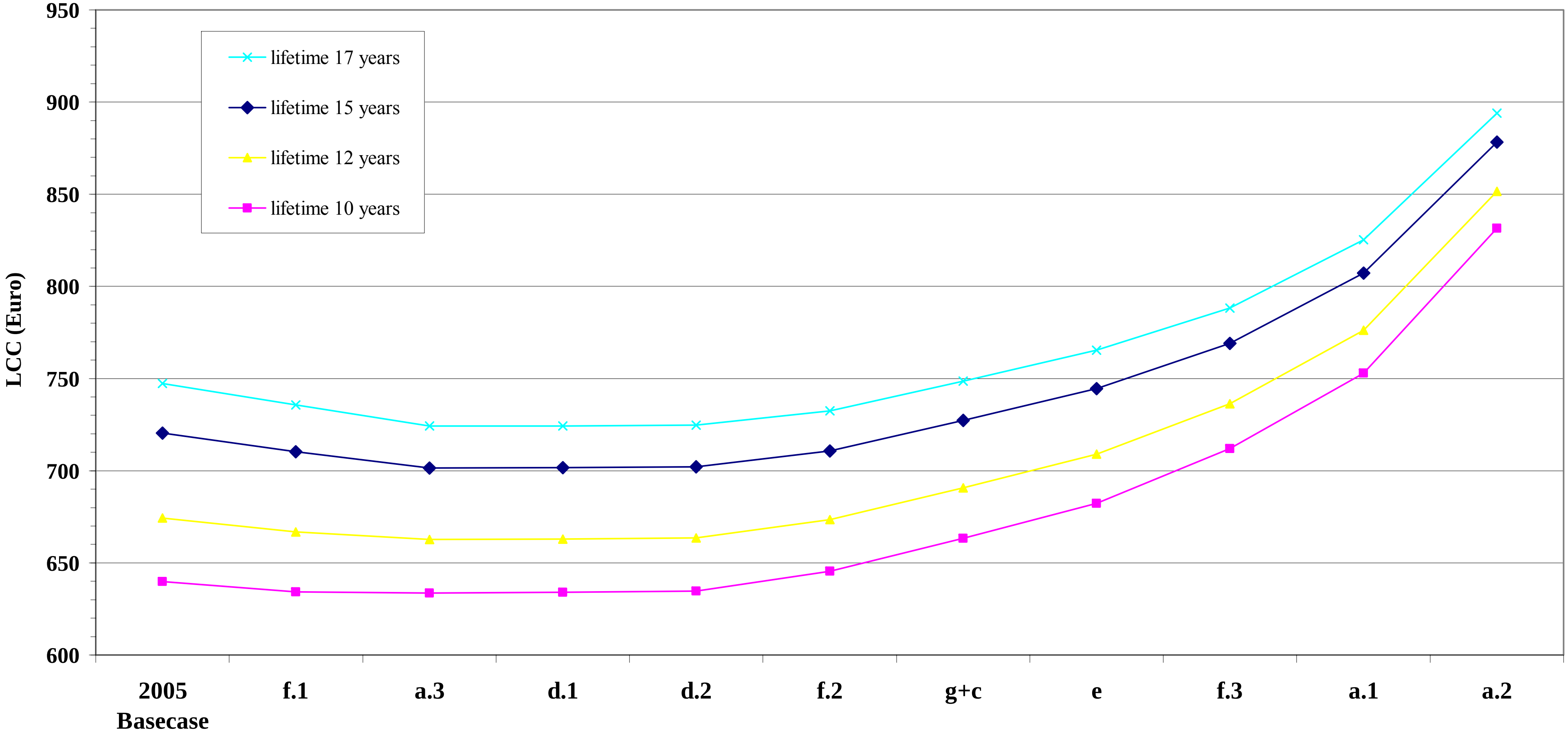


Table 6.19: Sensitivity analysis results for the LCC of refrigerator-freezers (Cat. 7&10) average standard base case. LLCC is highlighted in light blue

Technological options				+a.3	+f.3	+d.1	+d.2	+e	+h+g	+a.1	+a.2
Lifetime	Investigated parameters and variations		**2005 base case**	+10-15mm insulation, door & cabinet walls	highest efficiency reciprocating compressors (max COP, available from one supplier	increasing 10-20% the surface area of the evaporator	increasing 5-10% the surface area of the condenser	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	bistable solenoid valve (diverter valve)	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, door (area 70%, thickness 50%)
years	Annual consumption	kWh/year	324,4	298,1	251,9	251,1	250,6	243,5	240,1	224,0	191,6
10	average values		991	983	994	994	994	1.009	1.036	1.101	1.184
10	electricity price	€ 0,25	1.191	1.167	1.149	1.149	1.149	1.159	1.184	1.240	1.302
10	electricity price	€ 0,10	815	822	858	858	859	877	906	980	1.080
10	discount rate	4%	1.018	1.009	1.016	1.017	1.017	1.031	1.058	1.122	1.202
10	discount rate	6%	965	960	973	973	974	988	1.016	1.082	1.167
10	appliance price	€ 509,7	1.015	1.008	1.018	1.019	1.019	1.033	1.060	1.126	1.208
10	appliance price	€ 324,0	848	840	851	851	**851**	866	893	958	1.041
10	disposal&recycling	€ 10	959	952	962	963	963	977	1.004	1.070	1.152
12	average values		1.056	1.044	1.045	1.045	1.046	1.059	1.085	1.148	1.224
12	electricity price	€ 0,25	1.286	1.255	1.224	1.223	1.223	1.231	1.255	1.306	1.359
12	electricity price	€ 0,10	855	859	889	890	890	908	936	1.009	1.105
12	discount rate	4%	1.092	1.077	1.075	1.075	1.075	1.087	1.114	1.175	1.248
12	discount rate	6%	1.024	1.013	1.019	1.019	1.019	1.033	1.059	1.123	1.202
12	appliance price	€ 509,7	1.081	1.068	1.070	1.070	1.070	1.083	1.110	1.172	1.248
12	appliance price	€ 324,0	913	901	902	902	903	916	942	1.005	1.081
12	disposal&recycling	€ 10	1.028	1.015	1.017	1.017	1.017	1.030	1.057	1.119	1.195
15	average values		**1.144**	**1.125**	**1.114**	**1.114**	**1.114**	**1.125**	**1.151**	**1.209**	**1.277**
15	electricity price	€ 0,25	1.413	1.372	1.323	1.323	1.322	1.328	1.350	1.395	1.436
15	electricity price	€ 0,10	908	908	931	932	932	948	976	1.046	1.138
15	discount rate	4%	1.193	1.171	1.154	1.154	1.154	1.165	1.190	1.246	1.310
15	discount rate	6%	1.099	1.083	1.078	1.078	1.078	1.090	1.116	1.176	1.248
15	appliance price	€ 509,7	1.169	1.149	1.139	1.139	1.139	1.150	1.176	1.234	1.302
15	appliance price	€ 324,0	1.001	982	971	971	971	982	1.008	1.066	1.134
15	disposal&recycling	€ 10	1.119	1.100	1.090	1.090	1.090	1.101	1.126	1.185	1.252
17	average values		1.195	1.172	1.154	1.154	1.154	1.164	1.189	1.245	1.308
17	electricity price	€ 0,25	1.488	1.441	1.382	1.381	**1.380**	1.384	1.406	1.447	1.481
17	electricity price	€ 0,10	939	937	956	956	957	972	1.000	1.068	1.157
17	discount rate	4%	1.254	1.227	1.202	1.202	1.202	1.211	1.236	1.289	1.347

Technological options			2005 base case	+a.3 +10-15mm insulation, door & cabinet walls	+f.3 highest efficiency reciprocating compressors (max COP, available from one supplier	+d.1 increasing 10-20% the surface area of the evaporator	+d.2 increasing 5-10% the surface area of the condenser	+e use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	+h+g bistable solenoid valve (diverter valve)	+a.1 vacuum insulated panels, door (area 70%, thickness 50%)	+a.2 vacuum insulated panels, door (area 70%, thickness 50%)
Lifetime	Investigated parameters and variations										
years	Annual consumption	kWh/year	324,4	298,1	251,9	251,1	250,6	243,5	240,1	224,0	191,6
17	discount rate	6%	1.143	1.123	1.112	1.112	1.112	1.123	1.149	1.207	1.274
17	appliance price	€ 509,7	1.220	1.196	1.179	1.179	1.179	1.189	1.214	1.270	1.333
17	appliance price	€ 324,0	1.052	1.029	1.011	1.011	1.011	1.021	1.046	1.102	1.165
17	disposal&recycling	€ 10	1.173	1.150	1.132	1.132	1.132	1.142	1.167	1.223	1.286

Figure 6.24: Life Cycle Cost (lifetime = 10 years) as function of the technological options for refrigerator-freezers sensitivity analysis. Parameters variation is indicated for each curve

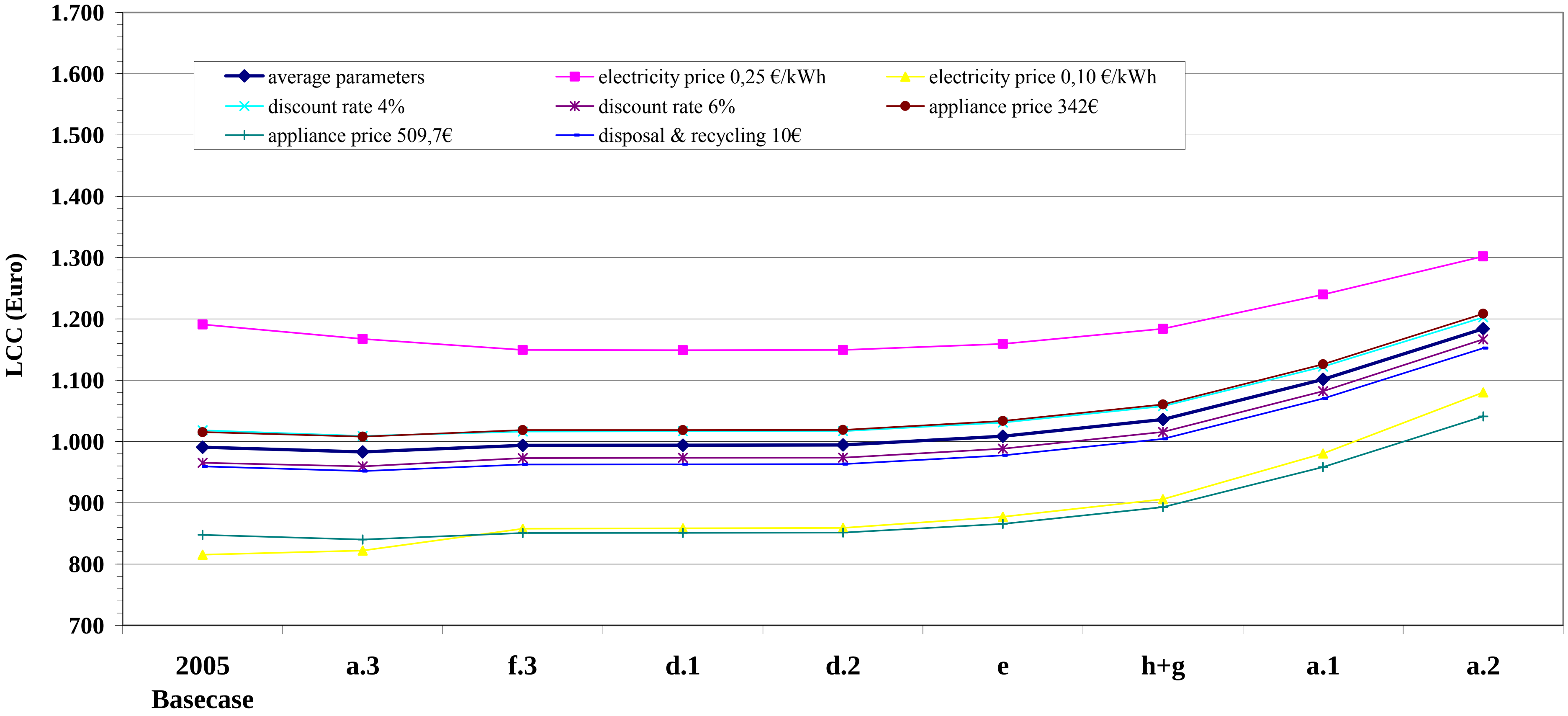


Figure 6.25: Life Cycle Cost (lifetime = 12 years) as function of the technological options for refrigerator-freezers sensitivity analysis. Parameters variation is indicated for each curve

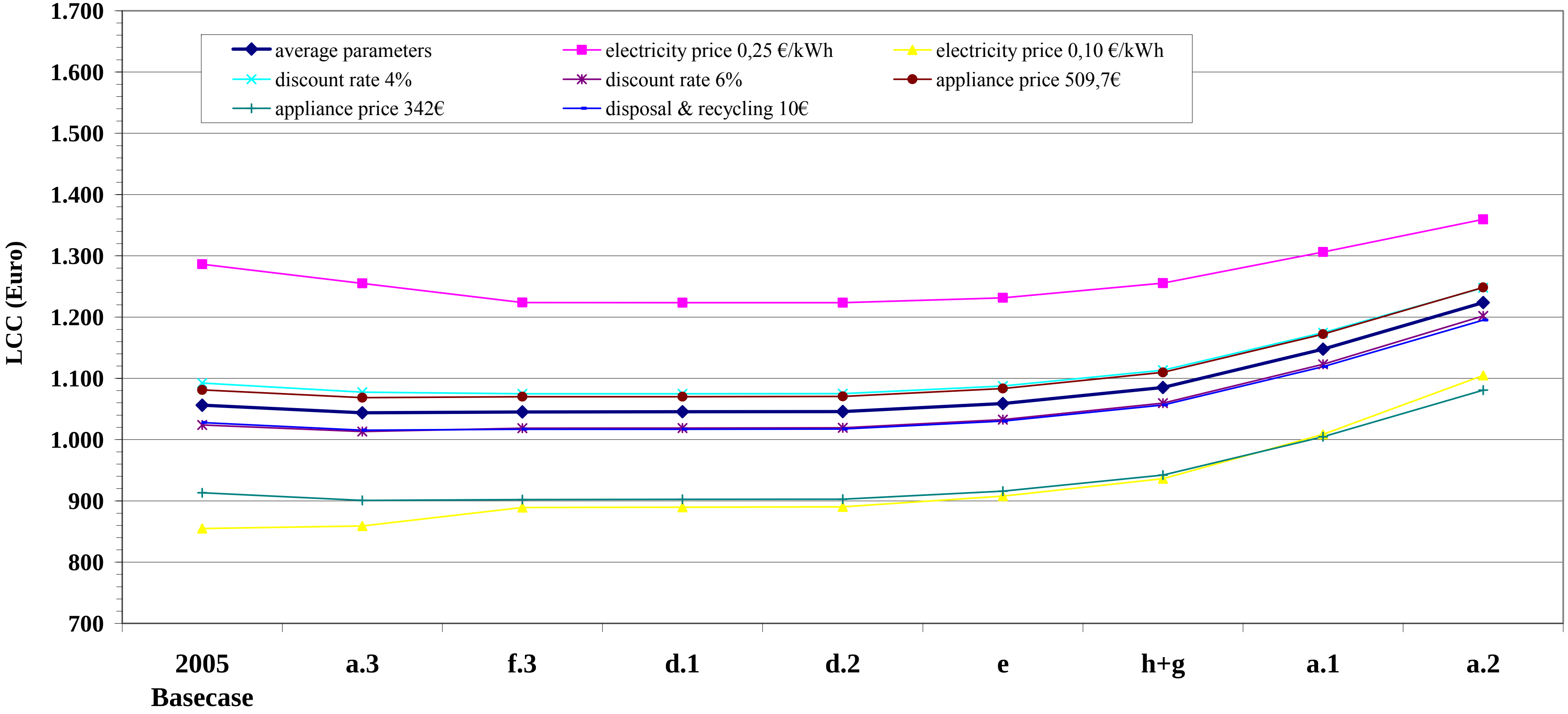


Figure 6.26: Life Cycle Cost (lifetime = 15 years) as function of the technological options for refrigerator-freezers sensitivity analysis. Parameters variation is indicated for each curve

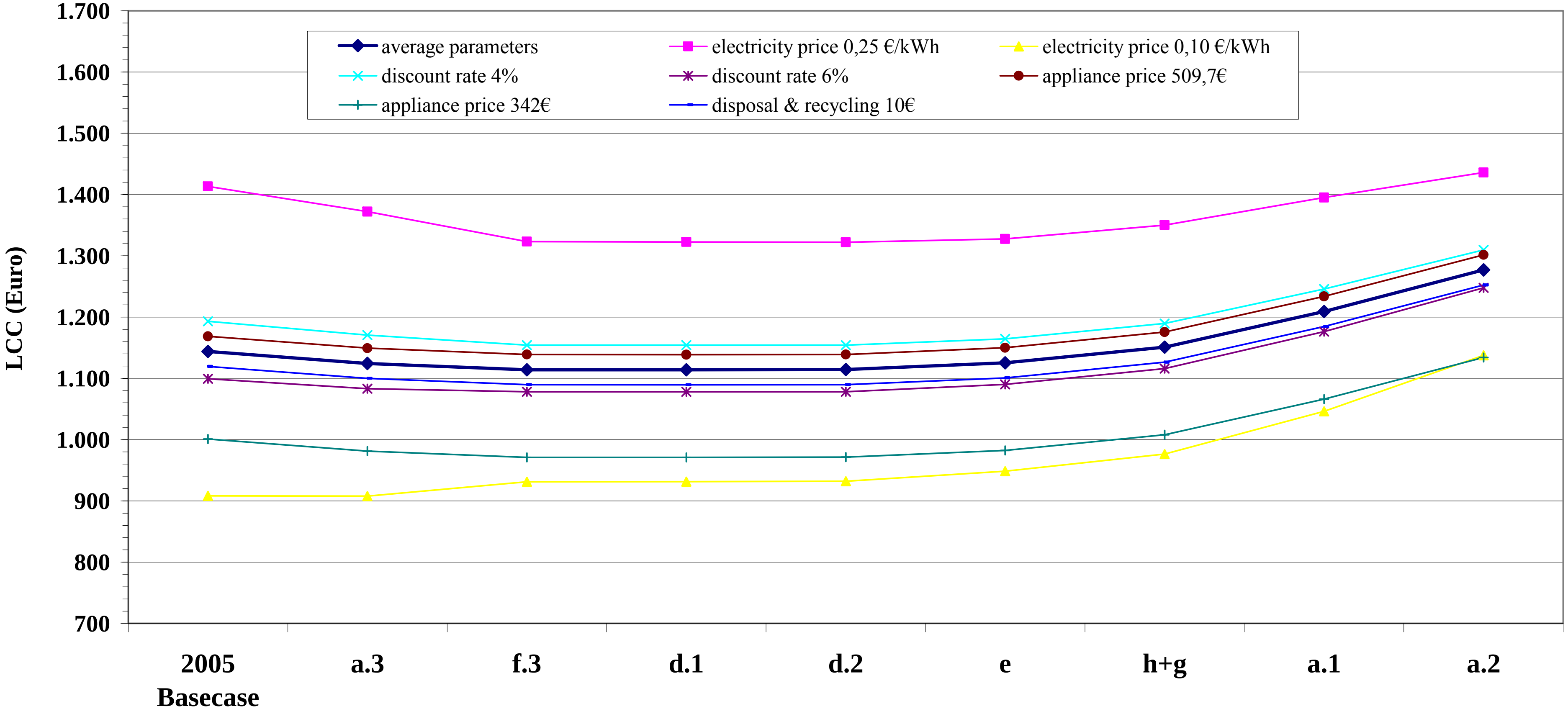


Figure 6.27: Life Cycle Cost (lifetime = 17 years) as function of the technological options for refrigerator-freezers sensitivity analysis. Parameters variation is indicated for each curve

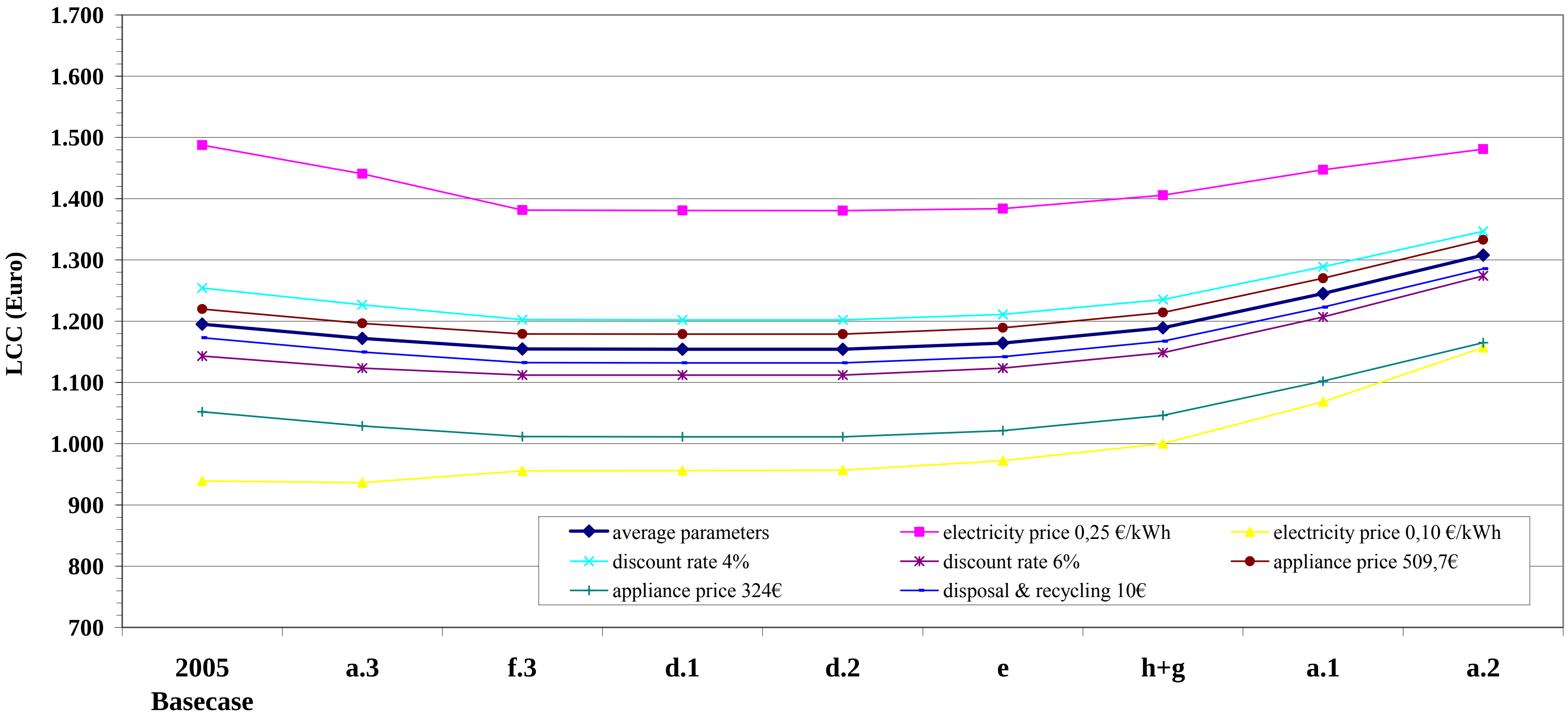
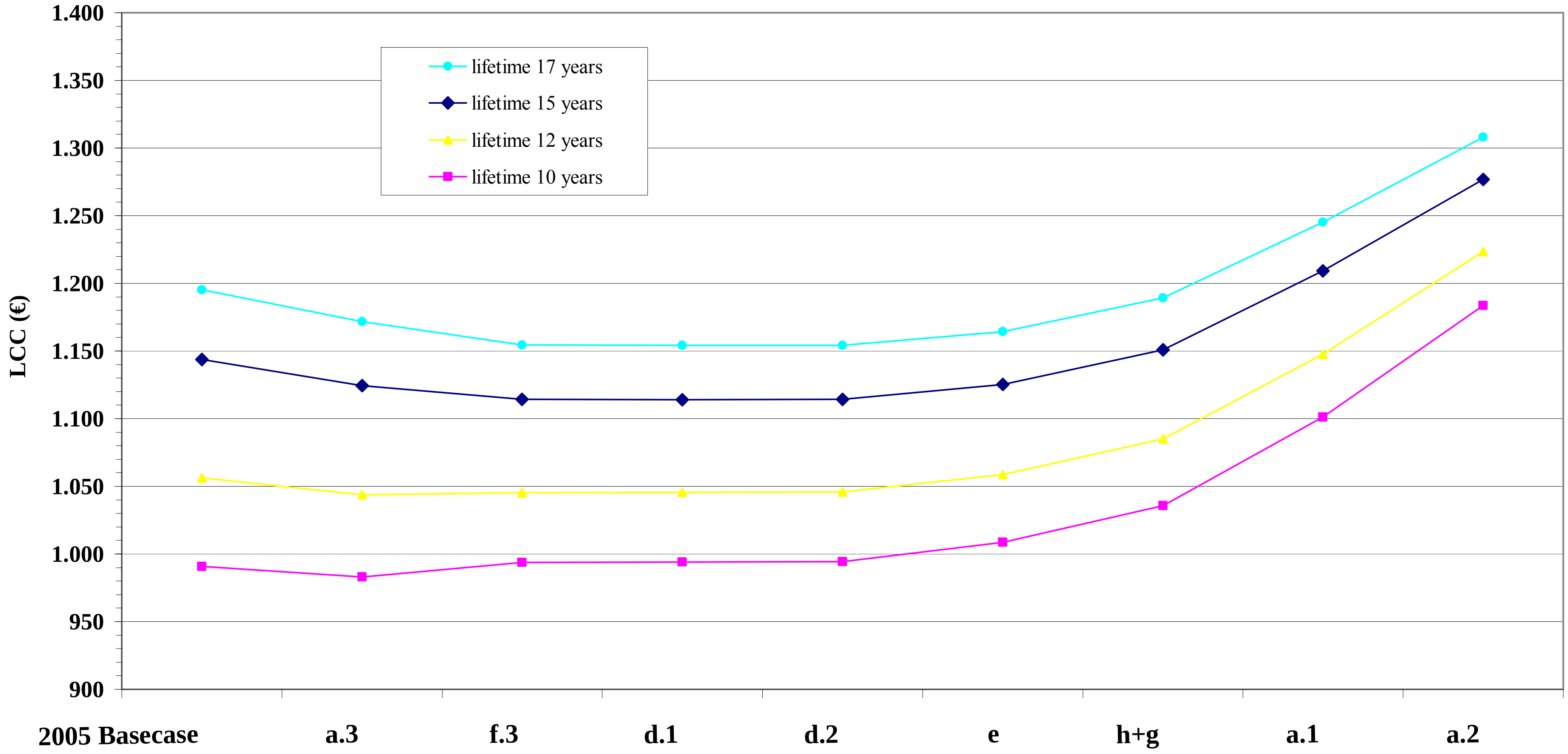


Figure 6.28: Life Cycle Cost as function of the technological options for refrigerator-freezers for different values of the lifetime and average technical and financial parameters



values and the basic technical and financial parameters.

6.2.3.3 The sensitivity analysis for upright freezers

In Table 6.20 the LCC analyses of the **upright freezers** are presented for the four values of the lifetime: 10, 12 15 and 17 years. For upright freezers the most important result is that the Least Life Cycle Cost point occurs at different technological options combinations depending on the lifetime: when lifetime is 10 years the optimum option combination is the *Base case* for all parameters variation a part from when the electricity price is 0,25,e/kWh or when the discount rate is 4%; this happens also when the electricity price is 0,10 €/kWh at all lifetimes. When lifetime is 12 years, the optimum options combination is (f.3+a.3) for most of the parameters. When lifetime is 15 years, the optimum options combination shifts towards (f.3+a.3+d.2) in half of the cases and for the use of the average parameters value. Finally, when lifetime is 17 years the LLCC occurs also for options combinations (f.3+a.3+d.2+d.1) the LLCC in some cases. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61€ to 10€.

The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the life cycle cost is 664 Euro over a lifetime of 10 years; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.088 Euro, with a difference of 424 Euro.

The same data are presented in Figures 6.29-6.32, respectively for 10, 12, 15 and 17 years, using the same scale for the LCC to allow an immediate comparison of the differences due to the lifetime duration. In Figure 6.33 the LCC is presented for the four lifetime values and the average technical and financial parameters.

6.2.3.4 The sensitivity analysis for chest freezers

In Table 6.21 the LCC analyses of the **chest freezers** are presented for the four values of the lifetime: 10, 12 15 and 17 years. For this freezer type the most important result is that the Least Life Cycle Cost point occurs in most of the cases at the technological options combinations (f.3+a.3+d.1+d.2) a part from when electricity price is considered 0,10 €/kWh and the LLCC occurs at the *Base case* level at all lifetimes. For almost all the other parameters variation the LLCC point occurs at the application of *Options d.1* or *d.2* but the difference in LCC between the two option combinations is very small. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61 € to 10 €.

The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the life cycle cost is 675 Euro over a lifetime of 10 years; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.119 Euro, with a difference of 444 Euro. The same data are presented in Figures 6.33-6.36, respectively for 10, 12, 15 and 17 years, using the same scale for the LCC to allow an immediate comparison of the differences due to the lifetime duration.

In Figure 6.37 the LCC is presented for the four lifetime values and the average technical and financial parameters.

Table 6.20: Sensitivity analysis results for the LCC of upright freezers average standard base case. LLCC is highlighted in light blue

Technological options				+f.3	+a.3	+d.2	+d.1	+e	+a.1	+a.2
Lifetime	Investigated parameters and variations		**2005 base case**	multi-speed and variable-speed compressors	+10-15mm insulation, door & cabinet walls	increasing 5-10% the surface area of the condenser	increasing 10-20% the surface area of the evaporator	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, cabinet walls (50%)
years	Annual consumption	kWh/year	274,5	222,3	204,6	204,3	203,4	199,2	187,3	164,9
10	average values		768	771	772	772	774	792	846	941
10	electricity price	€ 0,25	938	908	898	898	899	915	961	1.043
10	electricity price	€ 0,10	620	651	661	662	**664**	684	744	852
10	discount rate	4%	792	792	791	792	793	811	864	958
10	discount rate	6%	746	752	754	754	756	774	829	926
10	appliance price	€ 330,4	771	773	774	775	776	794	848	943
10	appliance price	€ 281,4	722	724	725	726	727	745	799	894
10	disposal&recycling	€ 10	737	740	740	741	742	760	814	910
12	average values		824	817	814	815	816	833	885	976
12	electricity price	€ 0,25	1.019	974	959	959	960	974	1.017	1.093
12	electricity price	€ 0,10	654	679	687	688	690	710	768	874
12	discount rate	4%	856	844	839	840	841	858	908	998
12	discount rate	6%	796	793	791	792	793	811	863	956
12	appliance price	€ 330,4	827	819	816	817	818	836	887	978
12	appliance price	€ 281,4	778	770	767	768	769	787	838	929
	disposal&recycling	€ 10	824	817	814	815	816	833	885	976
15	average values		**899**	**878**	**871**	**871**	**872**	**888**	**937**	**1.022**
15	electricity price	€ 0,25	1.127	1.063	1.041	1.041	1.041	1.054	1.092	1.159
15	electricity price	€ 0,10	699	716	722	723	724	744	801	902
15	discount rate	4%	942	915	905	905	906	922	969	1.051
15	discount rate	6%	860	845	840	840	841	858	908	996
15	appliance price	€ 330,4	901	880	873	874	874	891	939	1.025
15	appliance price	€ 281,4	852	831	824	825	825	842	890	976
15	disposal&recycling	€ 10	874	854	846	847	848	864	912	998
17	average values		943	914	904	904	905	921	967	1.049
17	electricity price	€ 0,25	1.190	1.114	1.088	1.088	**1.088**	1.100	1.136	1.198
17	electricity price	€ 0,10	726	738	742	743	745	764	820	919
17	discount rate	4%	994	957	945	945	946	961	1.005	1.084

Technological options				+f.3	+a.3	+d.2	+d.1	+e	+a.1	+a.2
Lifetime	Investigated parameters and variations		2005 base case	multi-speed and variable-speed compressors	+10-15mm insulation, door & cabinet walls	increasing 5-10% the surface area of the condenser	increasing 10-20% the surface area of the evaporator	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, cabinet walls (50%)
years	Annual consumption	kWh/year	274,5	222,3	204,6	204,3	203,4	199,2	187,3	164,9
17	discount rate	6%	897	876	868	868	869	886	934	1.019
17	appliance price	€ 330,4	945	916	906	907	907	923	970	1.052
17	appliance price	€ 281,4	896	867	857	858	858	874	921	1.003
17	disposal&recycling	€ 10	920	892	882	882	883	898	945	1.027

Figure 6.29: Life Cycle Cost (lifetime = 10 years) as function of the technological options for upright freezers sensitivity analysis. Parameters variation is indicated for each curve

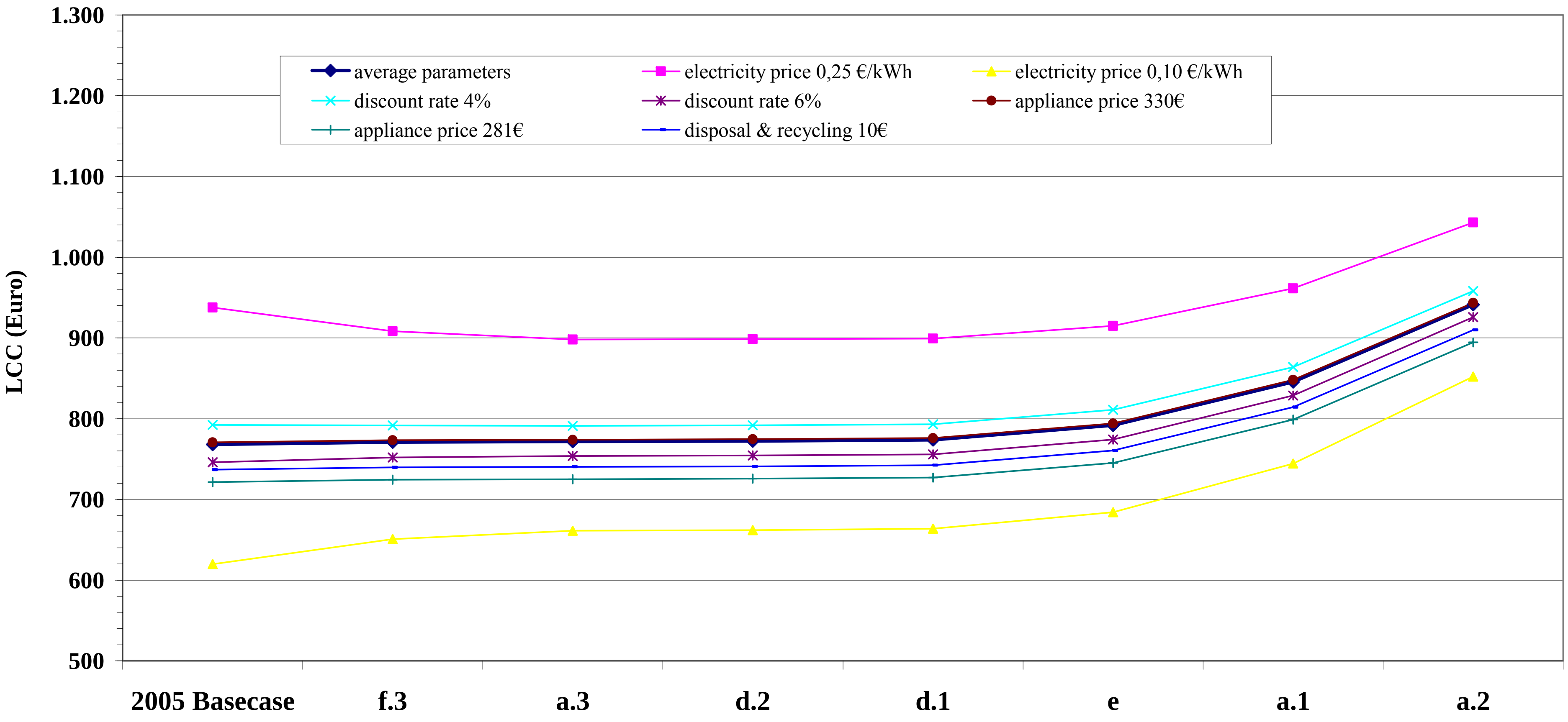


Figure 6.30: Life Cycle Cost (lifetime = 12 years) as function of the technological options for upright freezers sensitivity analysis. Parameters variation is indicated for each curve

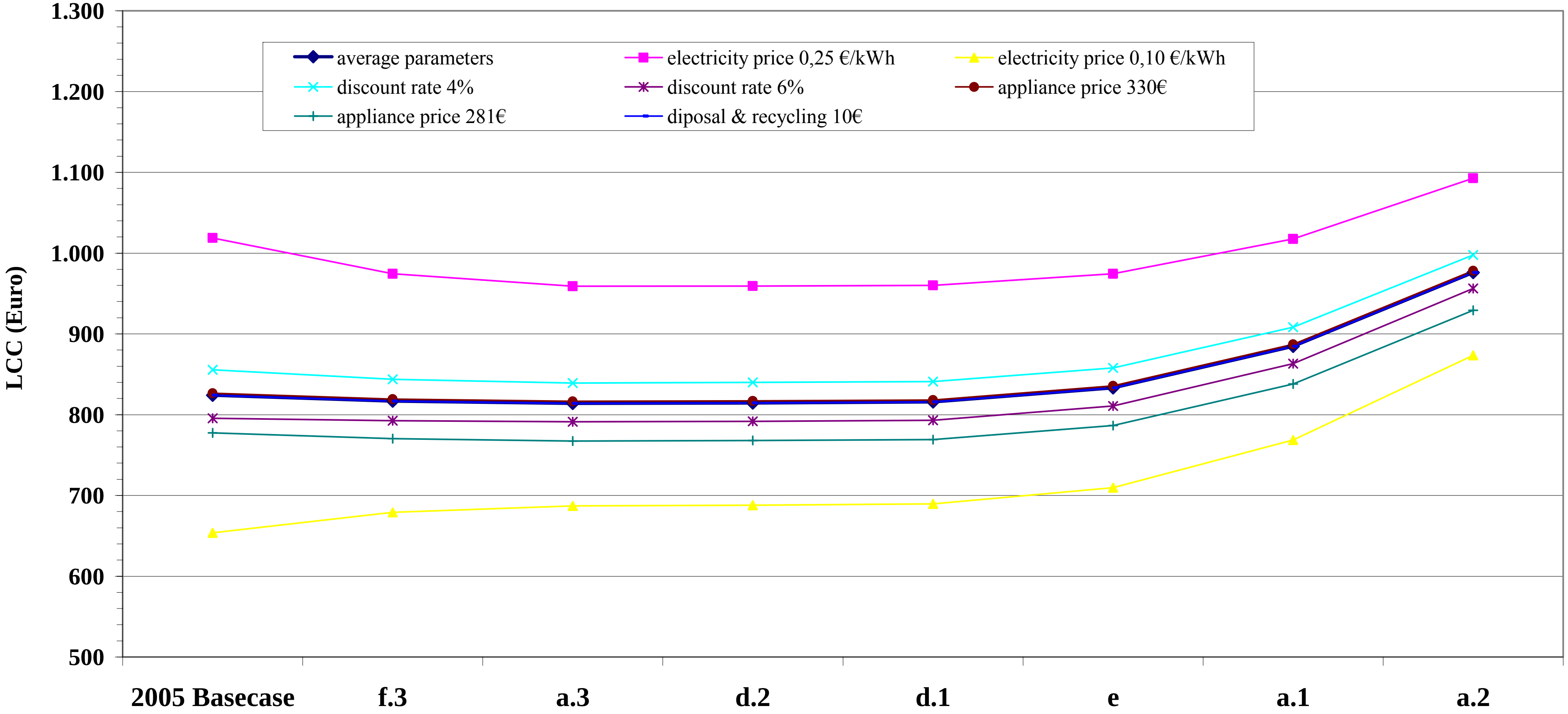


Figure 6.31: Life Cycle Cost (lifetime = 15 years) as function of the technological options for upright freezers sensitivity analysis. Parameters variation is indicated for each curve

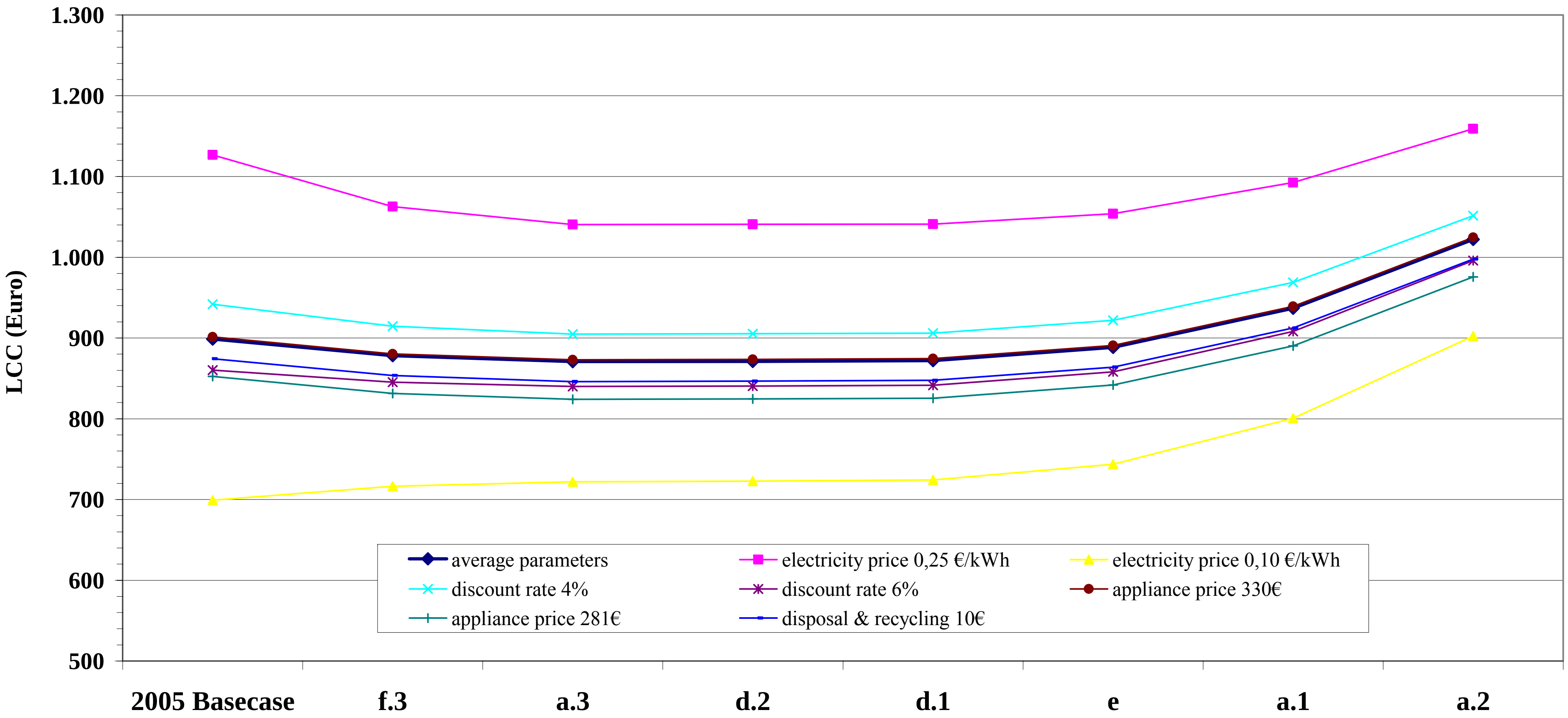


Figure 6.32: Life Cycle Cost (lifetime = 17 years) as function of the technological options for upright freezers sensitivity analysis. Parameters variation is indicated for each curve

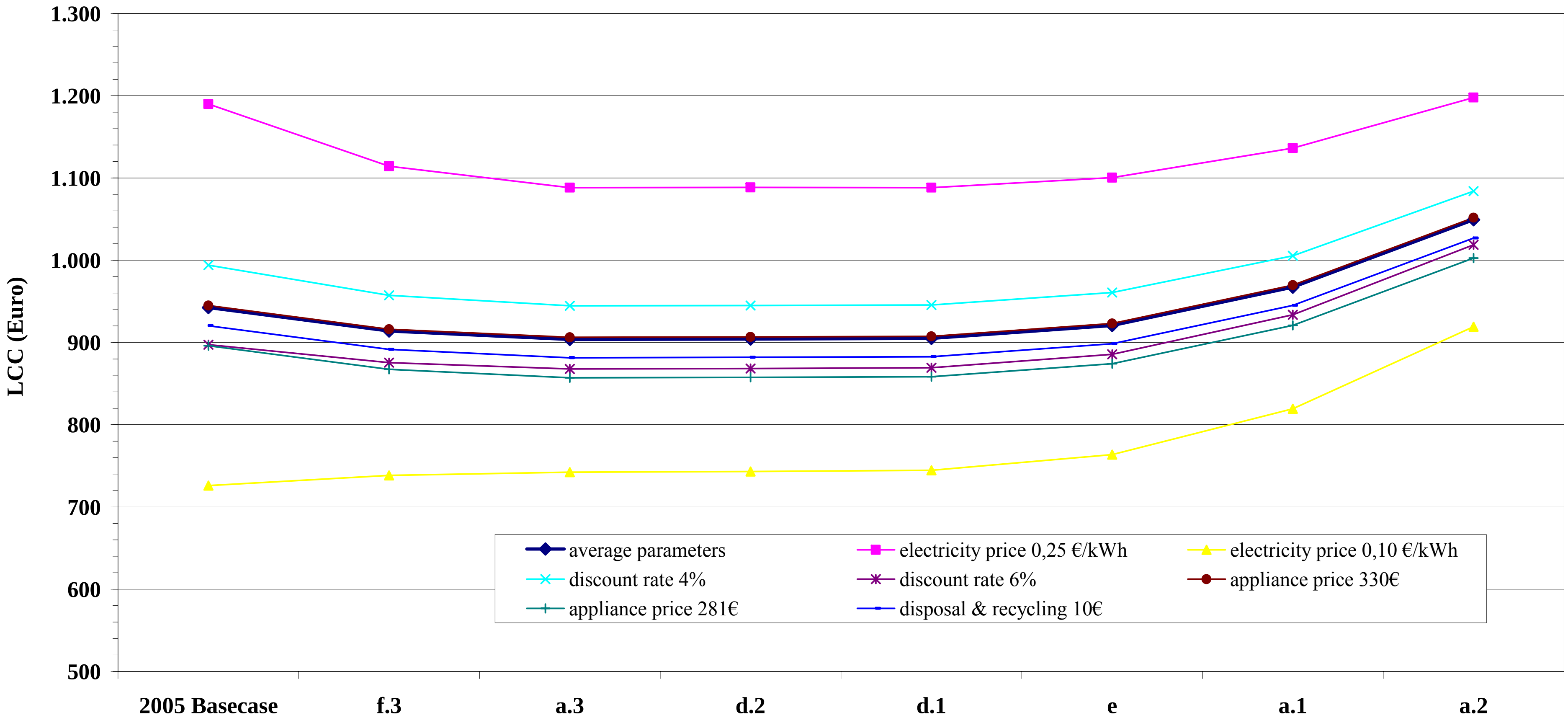


Figure 6.33: Life Cycle Cost as function of the technological options for upright freezers for different values of the lifetime and average technical and financial parameters

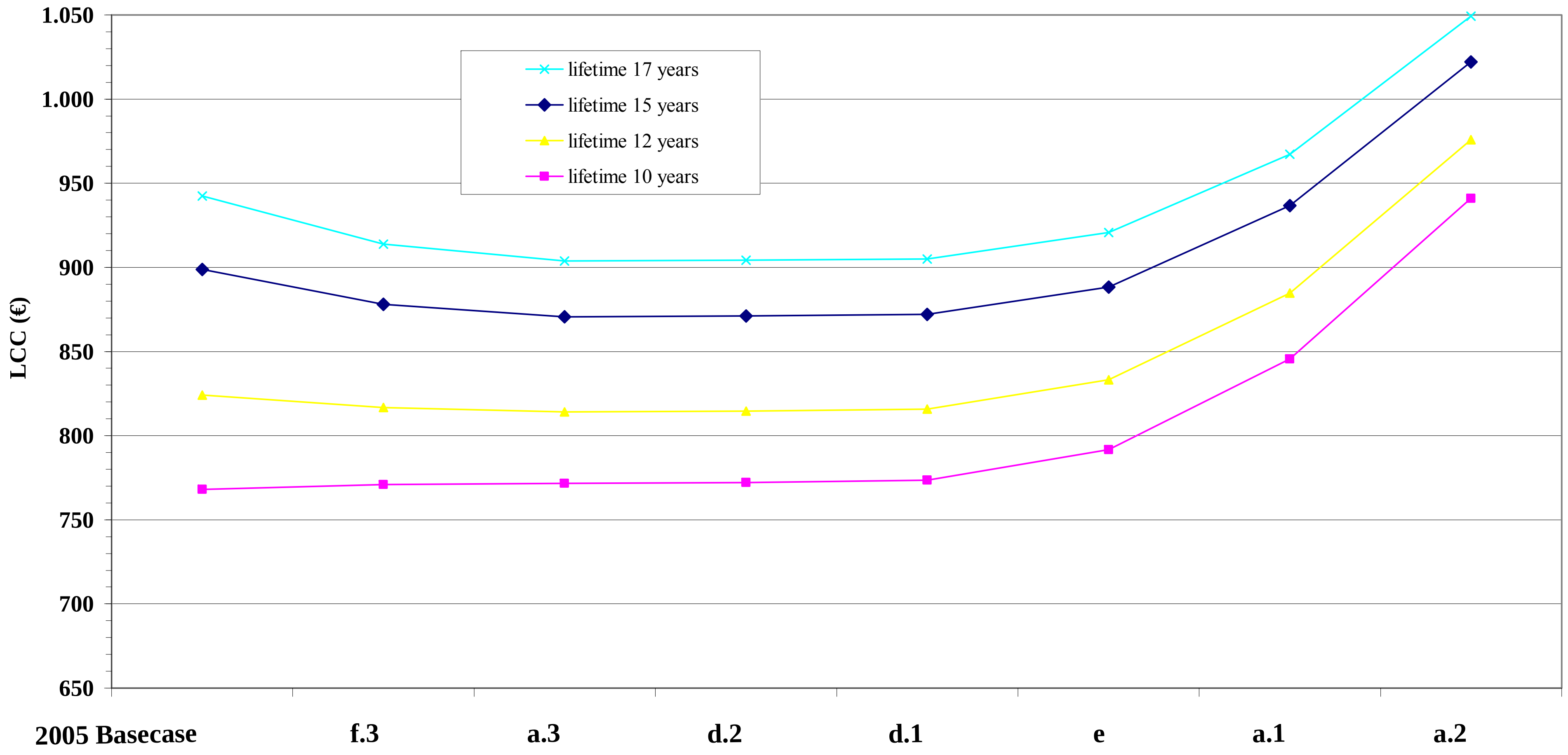


Table 6.21: Sensitivity analysis results for the LCC of chest freezers average standard base case. LLCC is highlighted in light blue

Technological options			2005 base case	+f.3	+a.3	+d.2	+d.1	+e	+a.1	+a.2
Lifetime	Investigated parameters and variations			multi-speed and variable-speed compressors	+10-15mm insulation, door & cabinet walls	increasing 5-10% the surface area of the condenser	increasing 10-20% the surface area of the evaporator	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	vacuum insulated panels, door (area 70%, thickness 50%)	vacuum insulated panels, cabinet walls (50%)
years	Annual consumption	kWh/year	300,6	243,5	216,4	213,2	212,8	206,7	188,8	152,8
10	average values		802	799	790	790	790	806	852	929
10	electricity price	€ 0,25	988	949	924	921	922	934	968	1.024
10	electricity price	€ 0,10	640	667	673	674	**675**	694	750	847
10	discount rate	4%	828	821	810	810	810	826	870	946
10	discount rate	6%	779	778	772	771	772	788	835	915
10	appliance price	€ 330,4	805	801	793	792	793	808	854	932
10	appliance price	€ 281,4	756	752	744	743	744	759	805	883
10	disposal&recycling	€ 10	771	767	759	758	759	775	820	898
12	average values		863	849	835	834	834	849	891	962
12	electricity price	€ 0,25	1.077	1.021	988	985	985	995	1.025	1.070
12	electricity price	€ 0,10	677	698	701	702	702	721	774	867
12	discount rate	4%	897	877	861	860	860	874	915	983
12	discount rate	6%	833	823	811	810	811	826	870	943
12	appliance price	€ 330,4	866	851	837	836	837	851	894	964
12	appliance price	€ 281,4	817	802	788	787	788	802	845	915
12	disposal&recycling	€ 10	835	820	807	805	806	820	863	933
15	average values		**945**	**915**	**895**	**893**	**893**	**906**	**944**	**1.005**
15	electricity price	€ 0,25	1.194	1.118	1.074	1.070	1.070	1.078	1.101	1.132
15	electricity price	€ 0,10	726	738	737	738	738	756	806	894
15	discount rate	4%	991	954	930	928	928	940	976	1.033
15	discount rate	6%	903	880	862	861	861	875	915	980
15	appliance price	€ 330,4	947	918	897	895	895	908	946	1.007
15	appliance price	€ 281,4	898	869	848	846	846	859	897	958
12	disposal&recycling	€ 10	920	891	870	868	868	881	919	981
17	average values		993	954	930	927	927	939	974	1.030
17	electricity price	€ 0,25	1.264	1.174	1.125	1.119	**1.119**	1.126	1.145	1.168
17	electricity price	€ 0,10	755	762	759	759	759	776	825	910
17	discount rate	4%	1.048	1.001	972	969	969	980	1.013	1.063

Technological options			2005 base case	+f.3 multi-speed and variable-speed compressors	+a.3 +10-15mm insulation, door & cabinet walls	+d.2 increasing 5-10% the surface area of the condenser	+d.1 increasing 10-20% the surface area of the evaporator	+e use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	+a.1 vacuum insulated panels, door (area 70%, thickness 50%)	+a.2 vacuum insulated panels, cabinet walls (50%)
Lifetime	Investigated parameters and variations									
years	Annual consumption	kWh/year	300,6	243,5	216,4	213,2	212,8	206,7	188,8	152,8
17	discount rate	6%	944	913	892	890	890	903	941	1.001
17	appliance price	€ 330,4	995	957	932	929	930	942	977	1.033
17	appliance price	€ 281,4	946	908	883	880	881	893	928	984
17	disposal&recycling	€ 10	970	932	907	905	905	917	952	1.008

Figure 6.34: Life Cycle Cost (lifetime = 10 years) as function of the technological options for chest freezers sensitivity analysis. Parameters variation is indicated for each curve

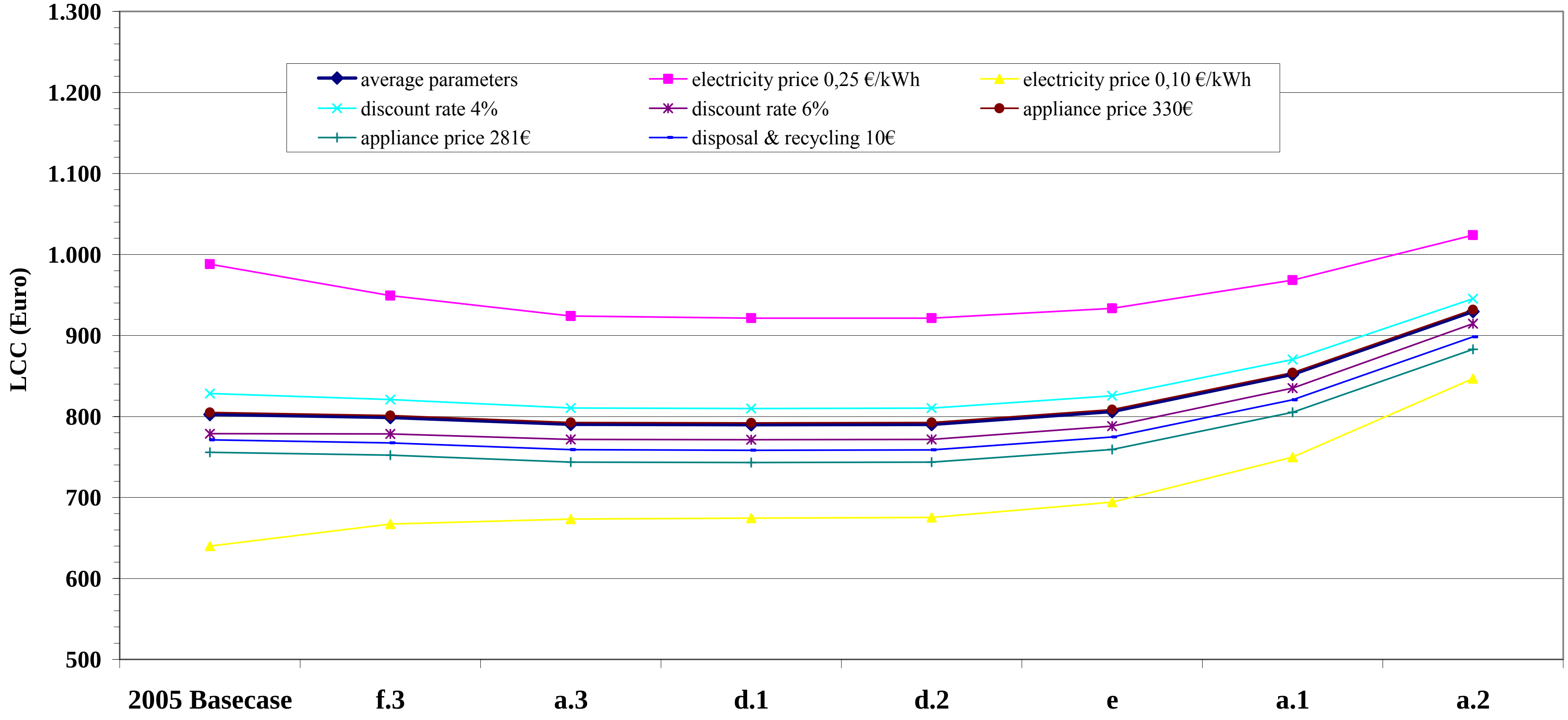


Figure 6.35: Life Cycle Cost (lifetime = 12 years) as function of the technological options for chest freezers sensitivity analysis. Parameters variation is indicated for each curve

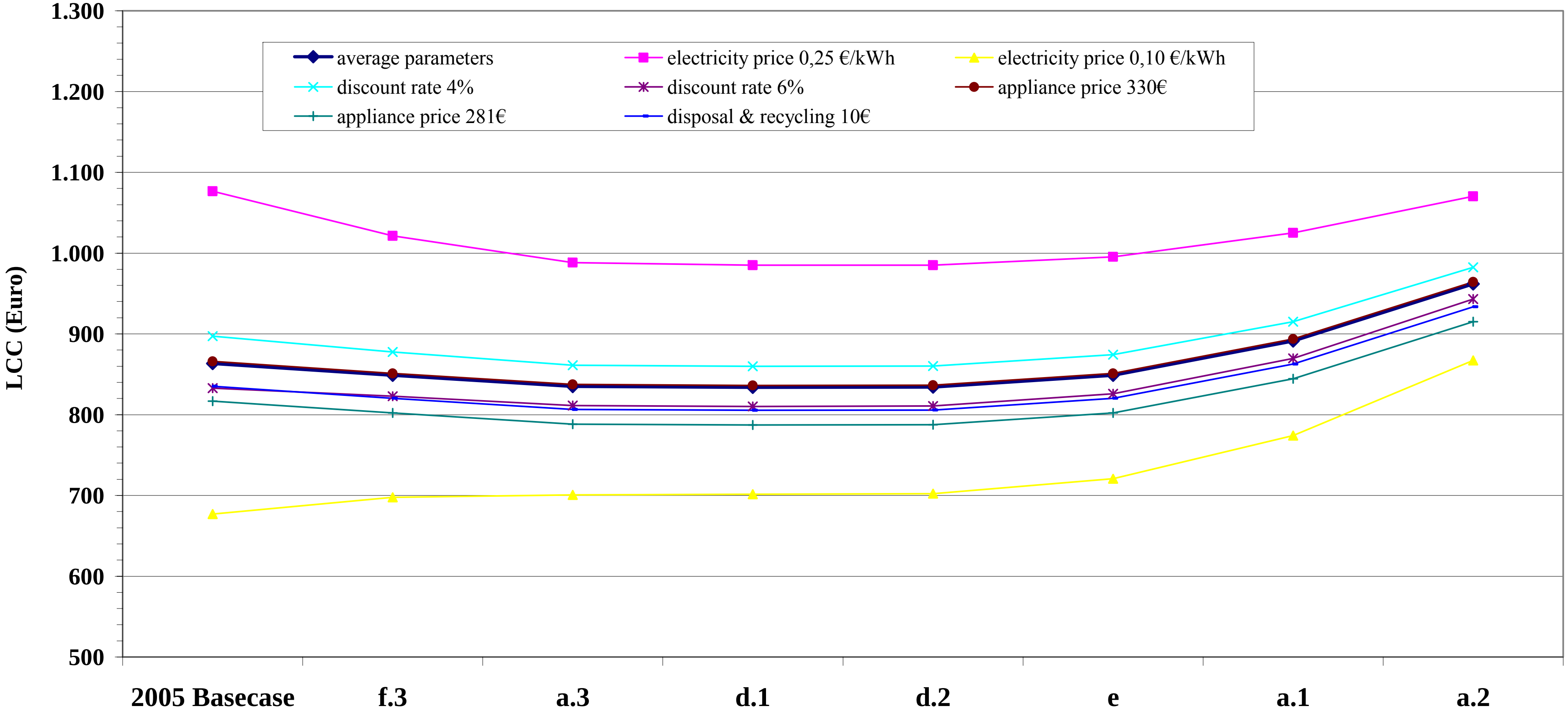


Figure 6.36: Life Cycle Cost (lifetime = 15 years) as function of the technological options for chest freezers sensitivity analysis. Parameters variation is indicated for each curve

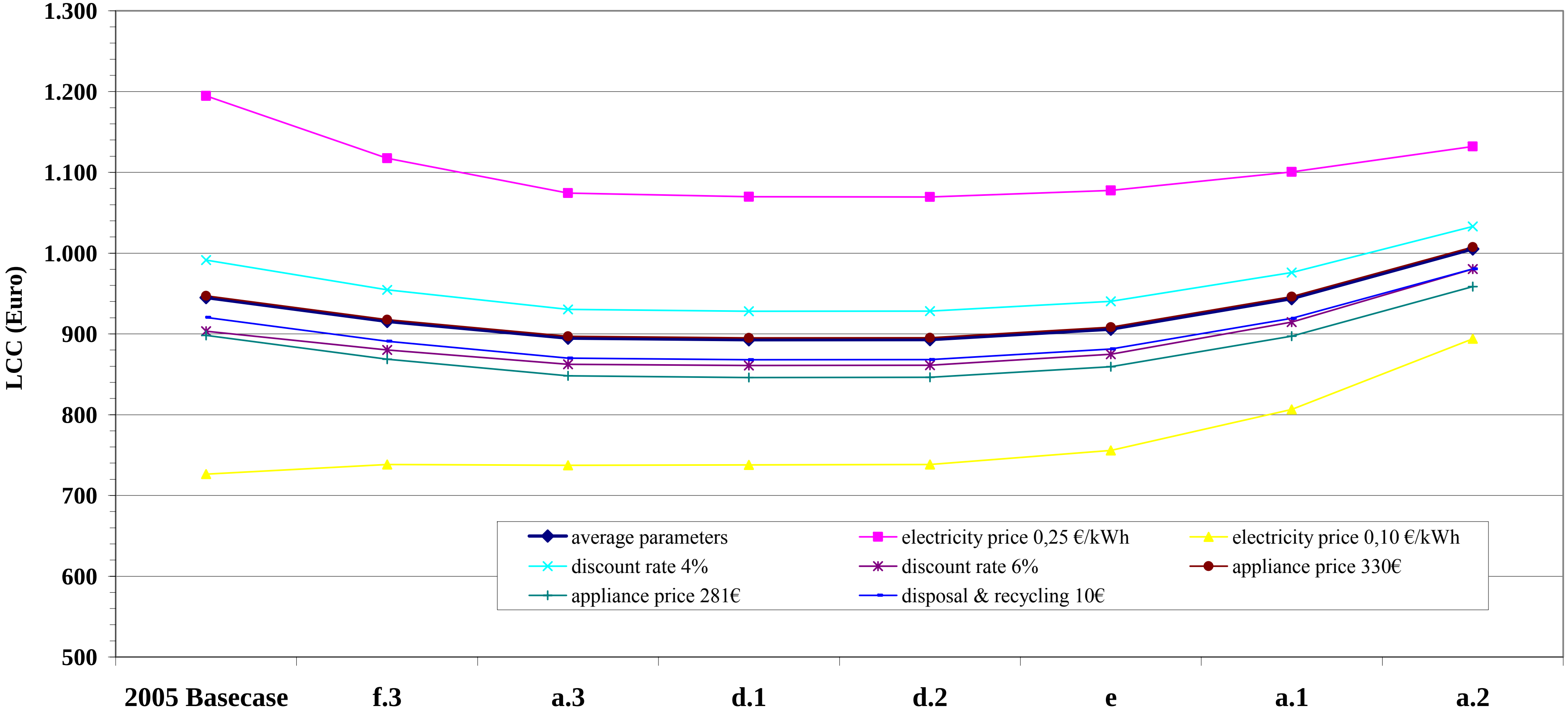


Figure 6.37: Life Cycle Cost (lifetime = 17 years) as function of the technological options for chest freezers sensitivity analysis. Parameters variation is indicated for each curve

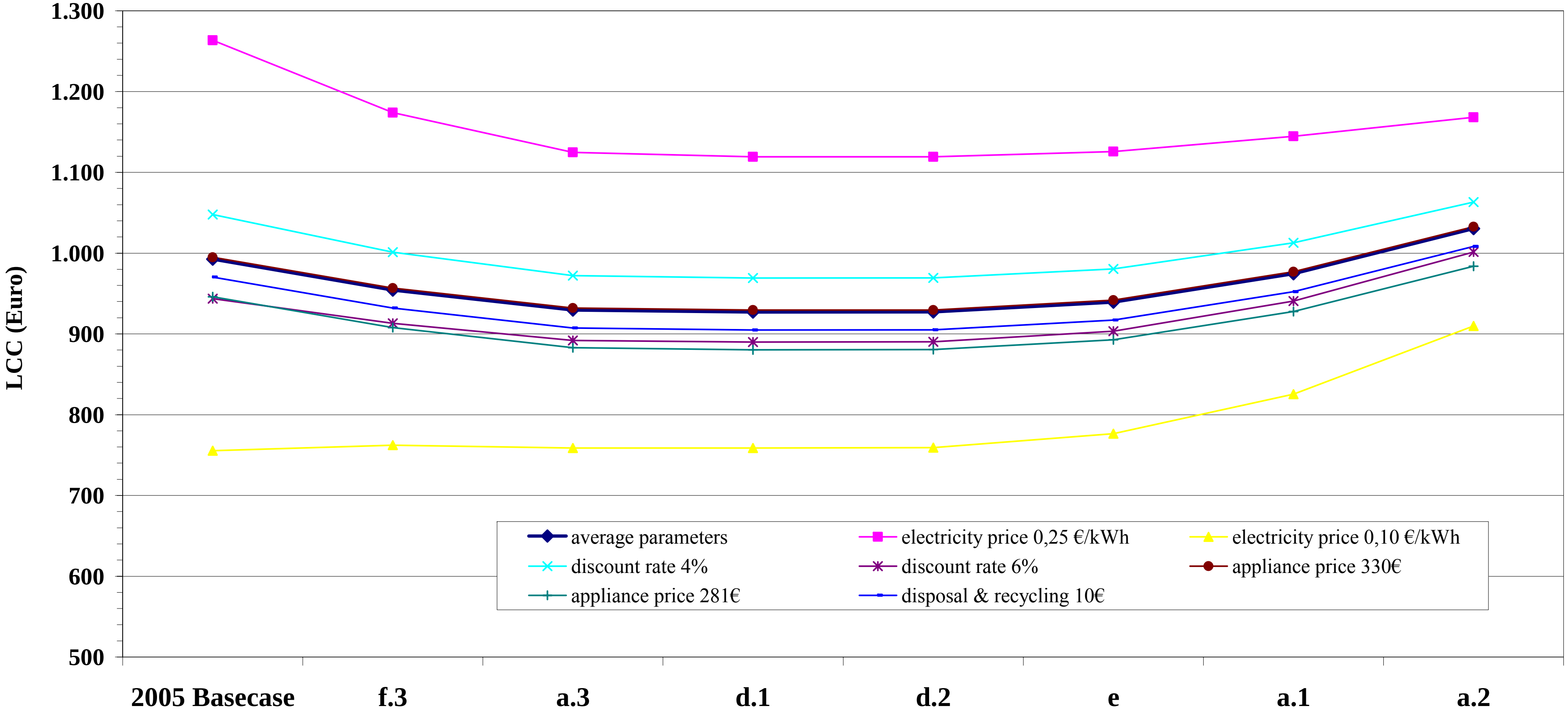
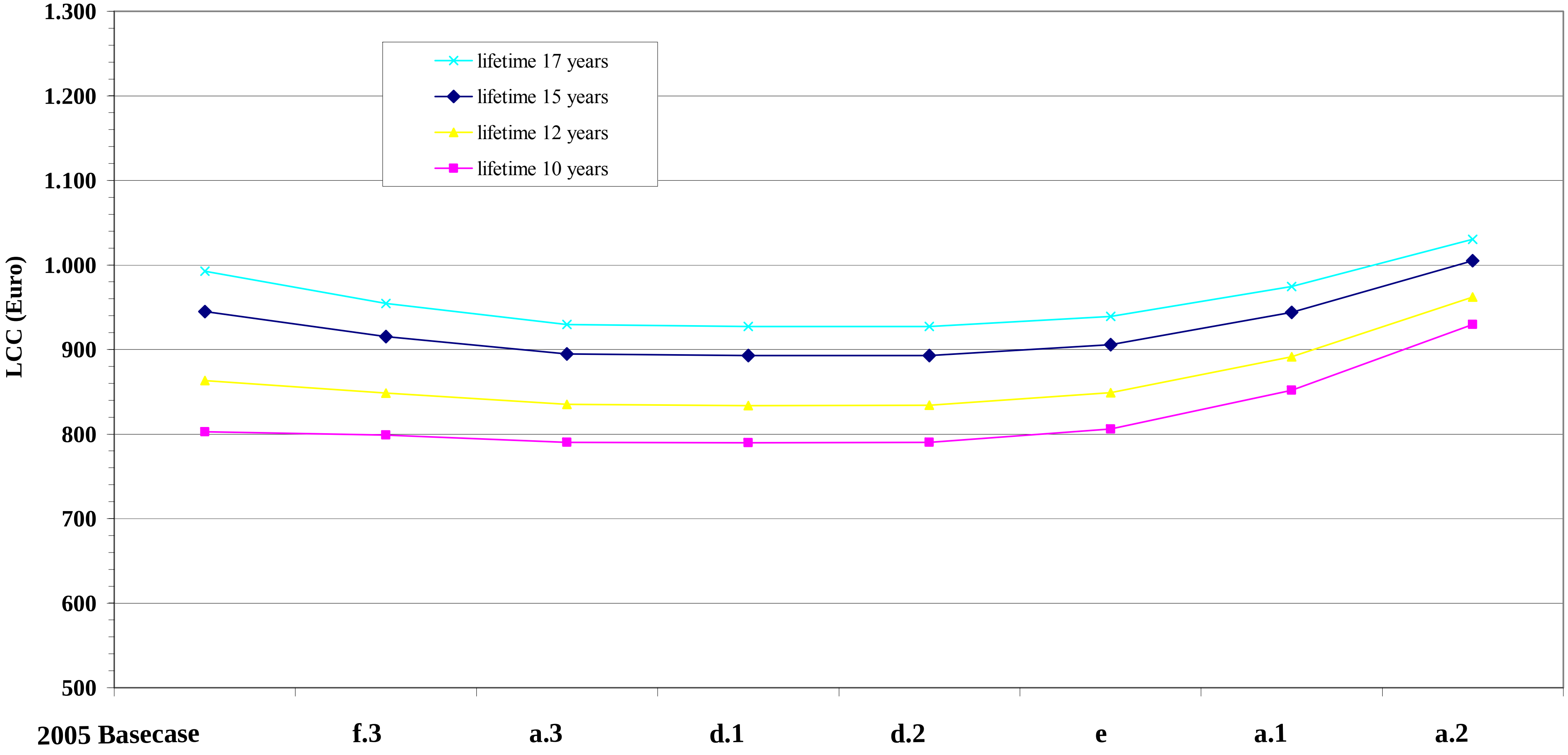


Figure 6.38: Life Cycle Cost as function of the technological options for chest freezers for different values of the lifetime and average technical and financial parameters



6.2.3.5 LCC outcome comparison

To allow a better understanding of the overall LCC analysis an sensitivity results, a comparison of the outcome for the average standard base case, $LLCC_{av}$ and BAT_{av} for different lifetime and electricity price values is presented in Table 6.22. It should be reminded that the optimum technological option pathway around which all the sensitivity analysis was developed has been identified for a lifetime = 15years, discount rate 5% and electricity price of 0,17 €/kWh.

Table 6.23 presents the derived annual energy savings and difference in life cycle costs over the average standard base case for energy prices of 0,10, 0,17 and 0,25 €/kWh.

The energy savings for the $LLCC_{av}$ for cold appliances are in the range 3-22 €/year against an increase in purchase price of 33-103 Euro. In particular, the savings are in the range 2,9-7,2 €/year with a purchase price increase of 33 Euro for refrigerators, depending on the electricity price; for refrigerator-freezers the savings are 7,4-18,5 €/year with a purchase price increase of more than 100 Euro; upright freezers show a saving in the range 7,1-17,8 €/year against an increase in purchase price of 99 Euro and chest freezers have a saving of 8,8-22 €/year with an increase of 103 Euro in the purchasing price.

The energy savings going from the average standard base case to the BAT_{av} are in the range 7,5-59,9 €/year against an increase in purchase price of 290-321 Euro, with some differences among product categories. Refrigerators show the lowest savings with 7,5-18,7 €/year and a purchase price increase of 290 Euro, depending on the electricity price; for refrigerator-freezers the savings are 13,3-33,2 €/year with a purchase price increase of 367 Euro; upright freezers show a saving in the range 11-27,4 €/year against an increase in purchase price of 317 Euro and chest freezers have the highest savings with 14,8-59,9 €/year and 321 Euro price increase.

The LCC difference between the $LLCC_{av}$ and the average standard base case is positive (the LCC is lower than for the standard base case) for all cold appliance categories when the electricity price is 0,17 €/year or higher; when on the contrary the electricity price is 0,10 €/kWh the difference is always negative (with the exception of upright freezers and for refrigerator-freezers for a 10 year lifetime and electricity price = 0,17 €/year).

The LCC difference between the BAT_{av} and the average standard base case is negative (the LCC is higher than for the standard base case) for all cold appliance categories, with the exception of chest freezers for a lifetime ≥ 12 years and for refrigerator-freezers for a 17 year lifetime and electricity price = 0,25 €/year.

Table 6.22: Comparison of the Life Cycle Costs for cold appliances at different lifetimes and electricity prices

Electricity price (€/kWh)	Average standard Base Case (description)	Consumer price (€)	Energy consumption (kWh/year)	Annual energy costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
Average standard base case								
0,17	Refrigerators	345	163,7	27,83	640	674	720	747
0,17	Refrigerator-freezers	485	324,4	55,15	991	1.057	1.144	1.195
0,17	Upright freezers	328	274,5	46,67	768	824	899	943
0,17	Chest freezers	328	300,6	51,10	803	864	945	993
$LLCC_{av}$								
0,17	Refrigerators	377,9	134,8	22,92	635	664	702	725
0,17	Refrigerator-freezers	585,5	250,6	42,60	994	1.045	1.114	1.154
0,17	Upright freezers	426,8	203,4	34,58	774	816	872	905
0,17	Chest freezers	431,0	212,8	36,18	790	834	893	927
BAT_{av}								
0,17	Refrigerators	634,6	89,1	15,15	831	852	878	894
0,17	Refrigerator-freezers	852,4	191,6	32,57	1.184	1.224	1.277	1.308
0,17	Upright freezers	644,8	164,9	28,03	941	976	1022	1049
0,17	Chest freezers	649,1	152,8	25,98	930	962	1005	1031
Average standard base case								
0,10	Refrigerators	345	163,7	16,37	551	573	601	618
0,10	Refrigerator-freezers	485	324,4	32,44	815	855	908	939
0,10	Upright freezers	328	274,5	27,45	620	654	699	726
0,10	Chest freezers	328	300,6	30,06	640	677	726	756
$LLCC_{av}$								
0,10	Refrigerators	377,9	134,8	13,48	562	580	604	618
0,10	Refrigerator-freezers	585,5	250,6	25,06	859	890	932	957
0,10	Upright freezers	426,8	203,4	20,34	664	690	724	745
0,10	Chest freezers	431,0	212,8	21,28	675	702	738	760
BAT_{av}								
0,10	Refrigerators	634,6	89,1	8,91	783	796	814	824
0,10	Refrigerator-freezers	852,4	191,6	19,16	1.080	1.105	1.138	1.157
0,10	Upright freezers	644,8	164,9	16,49	852	874	902	919
0,10	Chest freezers	649,1	152,8	15,28	847	867	894	910

Table 6.22: Comparison of the Life Cycle Costs for cold appliances at different lifetimes and electricity prices (continued)

Electricity price (€/kWh)	Average standard Base Case (description)	Consumer price (€)	Energy consumption (kWh/year)	Annual energy costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
Average standard base case								
0,25	Refrigerators	345	163,7	40,93	741	791	856	895
0,25	Refrigerator-freezers	485	324,4	81,10	1.191	1.287	1.413	1.488
0,25	Upright freezers	328	274,5	68,63	938	1.019	1.127	1.190
0,25	Chest freezers	328	300,6	75,15	988	1.077	1.194	1.264
$LLCC_{av}$								
0,25	Refrigerators	377,9	134,8	33,70	718	759	814	846
0,25	Refrigerator-freezers	585,5	250,6	62,65	1.149	1.223	1.322	1.380
0,25	Upright freezers	426,8	203,4	50,85	899	960	1.041	1.089
0,25	Chest freezers	431,0	212,8	53,20	922	985	1.070	1.119
BAT_{av}								
0,25	Refrigerators	634,6	89,1	22,28	887	915	952	974
0,25	Refrigerator-freezers	852,4	191,6	47,90	1.302	1.360	1.436	1.481
0,25	Upright freezers	644,8	164,9	41,23	1.043	1.093	1.159	1.198
0,25	Chest freezers	649,1	152,8	15,28	1.024	1.070	1.132	1.168

Table 6.23: Savings to the average standard base case for cold appliances at different lifetimes and electricity prices

Electricity price (€/kWh)	Product (description)	Consumer price difference (€)	Annual energy savings (kWh/year)	Annual energy savings (€/year)	Δ_{LCC} at 10 years (€)	Δ_{LCC} at 12 years (€)	Δ_{LCC} at 15 years (€)	Δ_{LCC} at 17 years (€)
$LLCC_{av}$								
0,17	Refrigerators	-32,9	28,9	4,91	5	10	18	22
0,17	Refrigerator-freezers	-100,5	73,8	12,55	-3	12	30	41
0,17	Upright freezers	-98,8	71,1	12,09	-6	8	27	38
0,17	Chest freezers	-103,0	87,8	14,92	13	30	52	66
BAT_{av}								
0,17	Refrigerators	-289,6	74,6	12,68	-191	-178	-158	-147
0,17	Refrigerator-freezers	-367,4	132,8	22,58	-193	-167	-133	-113
0,17	Upright freezers	-316,8	109,6	18,64	-173	-152	-123	-106
0,17	Chest freezers	-321,1	147,8	25,12	-127	-98	-60	-38
$LLCC_{av}$								
0,10	Refrigerators	-32,9	28,9	2,89	-11	-7	-3	0
0,10	Refrigerator-freezers	-100,5	73,8	7,38	-44	-35	-24	-18
0,10	Upright freezers	-98,8	71,1	7,11	-44	-36	-25	-19
0,10	Chest freezers	-103,0	87,8	8,78	-35	-25	-12	-4
BAT_{av}								
0,10	Refrigerators	-289,6	74,6	7,46	-232	-223	-213	-206
0,10	Refrigerator-freezers	-367,4	132,8	13,28	-265	-250	-230	-218
0,10	Upright freezers	-316,8	109,6	10,96	-232	-220	-203	-193
0,10	Chest freezers	-321,1	147,8	14,78	-207	-190	-168	-154
$LLCC_{av}$								
0,25	Refrigerators	-32,9	28,9	7,23	23	32	42	49
0,25	Refrigerator-freezers	-100,5	73,8	18,45	42	64	91	108
0,25	Upright freezers	-98,8	71,1	17,78	39	59	86	101
0,25	Chest freezers	-103,0	87,8	21,95	66	92	124	145
BAT_{av}								
0,25	Refrigerators	-289,6	74,6	18,65	-146	-124	-96	-79
0,25	Refrigerator-freezers	-367,4	132,8	33,2	-111	-73	-23	7
0,25	Upright freezers	-316,8	109,6	27,4	-105	-74	-32	-8
0,25	Chest freezers	-321,1	147,8	59,87	-37	7	62	96

6.3 SUBTASK 6.3: LONG TERM TARGETS (BNAT)

The analysis presented in sections 6.1 to 6.4 focused on the life-cycle cost implications of energy-saving design options applied using fully commercialised technology that is already proven in today's market. However, technology is undergoing constant development and improvement and so it is also useful to consider what improvements are likely in the medium to longer term and to consider the absolute limits to cold appliance energy efficiency. This section presents an analysis of the leading longer-term technologies and the overall energy-savings potentials.

6.3.1 Long Term scenarios in COLD-II study

According to the COLD-II study, the technical options that are likely to become available to improve upon the 1998 LLCC values can be divided into those that concern improvement of the cabinet thermal insulation and those concerned with raising the energy efficiency of the refrigerating system. A description of the technical options was given and then simulations of the medium- to long-term high-efficiency refrigeration systems were developed.

6.3.1.1 Cabinet thermal insulation

Not forgetting the importance of edge effects and gasket performance, the key to limiting the thermal loads of the cabinet is the conductivity and thickness of the insulation materials used in the walls. The analysis showed that a large coverage of VIPs was not in the consumer's economic interests in 1998 but that they constituted an energy-efficient and potentially environmentally justified option. In the simulations it was assumed that the equivalent conductivity of a 50% VIP/50% PU foam wall was 16 mW/m K and imagined that cabinets using standard-cost VIPs would have equivalent conductivities of between 13 and 10 mW/m K in future.

A dramatic reduction in thermal loads requires a simultaneous improvement in the efficiency of low cooling capacity compressors if it is to be converted into comparable cold appliance energy savings. The development of rated-, variable- or 2-speed compressors has enabled this to happen.

6.3.1.2 Energy-efficiency improvements to vapour-compression cycles

a) Alternative refrigeration cycles

Alternative cycles and technologies (Stirling cycle, thermoacoustic cooling, Peltier effect) offer no intrinsic advantages in terms of energy efficiency compared to the usual vapour-compression cycle. The vapour-compression cycle, known as the Perkins–Evans or sometimes inaccurately as the Inverse Rankine cycle continues to have a great efficiency improvement potential, especially for cooling cycles where the difference in temperatures between source and sink are in the range of 30–60K, i.e. the operating range of refrigerators and freezers. Over the medium to long term the vapour-compression cycle is likely to continue to be the most efficient cycle for domestic refrigeration systems.

b) Refrigerant and energy efficiency

The thermodynamic properties of HFC-134a and isobutane imply a different optimisation of the liquid–vapour heat exchangers, compressors and other components in the refrigeration system, but high-efficiency systems can be found. The key means for improving the energy efficiency of the refrigeration system are thus dependent not on the choice of refrigerant but on:

- limitation of the difference between the refrigerant condensation temperature and the room ambient temperature
- limitation of the difference between the refrigerant evaporation temperature and the internal temperature of the cold appliance
- improvement in efficiency of the compressor (both the volumetric and the global values)
- the reduction of irreversibilities during the expansion process.

6.3.1.3 Heat-exchanger efficiency improvement

As can be seen from the Carnot coefficient of performance formula:

$$COP_{Carnot} = \frac{T_{evap}}{T_{cond} - T_{evap}}$$

where: T_{evap} is the evaporating temperature and T_{cond} is the condensing temperature

the smaller the difference between condensing and evaporating temperatures, the higher the energy efficiency; the higher the evaporating temperature, the higher the energy efficiency. Raising the evaporating temperature implies higher efficiency gains than lowering the condensing temperature.

High-efficiency forced-air heat exchangers can lead to refrigerant-to-air temperature differences of only 5–7 K with an appropriate design. However, in 1998 most electric fans used in forced-air systems had a very low energy efficiency (10–15%), which resulted in the efficiency gain derived from forced convection being nullified by the high energy consumption of the fans. However, high-efficiency DC fans with a power demand in the range of 2W (compared to the 8–15 W standard) started to be available.

Pure refrigerators, especially those that include a 1-, 2-, 3- or 4-star compartment, typically have evaporating temperatures in the region of –20°C just to maintain an average temperature of 5°C. The temperature difference between the refrigerant and air is 25 K, which incurs a very high energy penalty. Calculations were made of the change in Carnot COP for four refrigeration cycles with different condensing and evaporating temperatures, indicating the potential energy gains from high-efficiency heat-exchanger design for both refrigerators and freezers:

- the energy penalty of the typically large air-to-refrigerant temperature differences for both heat exchangers is greater than 57% for natural convection refrigerators compared to optimised forced-air designs; reducing the temperature difference at the evaporator alone would produce a 38% energy saving;
- the energy penalty of the typical air-to-refrigerant temperature differences for both heat exchangers is greater than 35% for natural-convection freezers compared to optimised forced-air designs; reducing the temperature difference at the evaporator alone would produce a 23% energy saving.

These values demonstrate the energy-saving potential from using forced-air convection to attain high heat-exchange coefficients. The potential energy gains for freezers are smaller than for refrigerators because the actual differences in refrigerant-to-air temperatures are much higher for refrigerators and so the potential reduction is greater.

In summary, important energy gains can be achieved using forced-convection heat exchangers. The development of high-efficiency, low energy consumption fans enables significant overall energy savings to be realised by adopting forced convection. It should be however reminded that higher cabinet heat losses are expected due to higher air velocities and energy is consumed by the fan and the defrost system.

6.3.1.4 Defrosting system

The rate of frost formation on the evaporator depends on the frequency of door openings, the average humidity and the type of food stored. For natural-convection appliances, defrosting does not require electric heating as it is manually activated every so many months for the freezer and uses passive automatic defrosting at each compressor 'off' cycle for the refrigerator. For forced-air appliances an electric defrosting system is required because the evaporator accumulates all the frost on its surface, which would substantially lower the overall cooling system efficiency if left without defrosting. For a forced-air refrigerator compartment, defrosting can be performed by electric ventilation of the evaporator every time the compressor stops, which accelerates the passive defrost process. The same method cannot be applied in the frozen-food compartment because the air temperature is permanently below zero.

6.3.1.5 Future compressor-efficiency levels

The efficiency of the compressor is another key determinant of the overall cooling system efficiency. The compressor's global efficiency is the most useful expression of its overall efficiency and can be used to simulate the electrical consumption of the compressor under standard cold appliance energy test conditions. ASHRAE COPs in the range of 1,9–2,1 were considered in 1998 to be achievable objectives over the next 5–10 years. These values correspond to global energy efficiencies of 0,70–0,77.

6.3.1.6 Summary of the results

Detailed energy-engineering simulations were conducted (through the ENEREFF and CYCLEREF models) for the six main cold appliance-type base-case models to examine the individual and aggregated impact of the following high-efficiency design options:
- high-performance insulation
- high-efficiency heat exchangers with small air-to-refrigerant temperatures differences
- high-efficiency compressor.

In addition, for 4 of those appliances, smart defrosting (adaptive defrosting) is used for low temperature ventilated evaporators.

Simulation assumptions were:
- two sets of values for air-to-refrigerant temperature differences, ΔT, are assumed:
  - $\Delta T = 7$ K for evaporator and condenser, and an additional load of 1.2 W for the fan; the heat generated by the evaporator fan is added as an additional heat load when the fan is running;
  - $\Delta T = 5$ K; the same assumptions are made but the electrical power required by the fan is assumed to be 1,5 W due to the higher fan output power needed to attain the lower ΔT values;
- compressor global energy efficiencies of 0,70 and 0,75 were chosen as affordable future values. The simulations use evaporation and condensation temperature-dependent formulae to predict the electrical power consumption of the compressor;
- both wall conductivity values of 13 and 10 mW/m K for the main cold appliance types.

A lower and higher value for each long-term technical option was chosen in order to evaluate the potential range of medium- to long-term maximum efficiency level (or the achievable minimum efficiency index) values. Table 6.24 summarises the results of those simulations and compares them to the results of the least life-cycle cost estimates previously produced for the same appliances. The principal findings are as follows:

- for all the simulated appliances, the minimum efficiency index is insensitive to ±10% variation in the efficiency assumption made for the three main technical options;
- depending on the type of cold appliance, the medium- to long-term minimum efficiency index is estimated to be between 17% and 26%
- the lowest values are attained for refrigerators and refrigerator-freezers, while the highest values are for freezers; this reflects the smaller potential savings from reducing the difference in air-to-refrigerant temperatures for freezers
- the additional energy consumption of accessories may have a significant impact on energy consumption of the ultra-high-efficiency systems: the energy used for automatic defrosting is equivalent to a 10% energy penalty for appliances at the minimum efficiency index.

Table 6.24: Estimated minimum efficiency index values for the six main cold appliance types over the medium to long term (COLD-II study)

Cat.	Cold appliance type	Standard base cases (1998)			EEI (94/2/EC)		Lowest potential	
		Model	Energy consumption	Volume	STBC	LLCC	Energy consumption	EEI
(no)	(description)	(description)	(kWh/year)	(litre)	(%)	(%)	(kWh/year)	(%)
1	Simple refrigerator	Bosch KTR 1430	252,7	142	90,2	40,3	59,4<C<64,1	16,6< I <18,1
7	1-door, 4-star	Art. Martin AR7334	313,33	212	60,5	44,3	97,0<C<104	20,0< I <21,5
7	2-door, 4-star, BM	Whirlpool ART868G	603,41	295	89,3	46,5	125<C<142	20,2< I <22,8
7	2-door, 4-star, TM (NF)	Candy CF 400 FF	643,0	379	89,5	51,9	125<C<135,5	18,8< I[a]<20,5
8	Upright freezer	Bosch GSD 1343	371,6	92	95,2	55,0	95,7<C<97,9	25,2< I <25,8
9	Chest freezer	Thomson S20	271,4	179	76,6	51,5	76,5<C<22,2	21,6< I <22,2

BM = bottom-mounted; NF = no-frost; TM = top-mounted.

[a] Calculated without including the no-frost (NF) correction factor.

6.3.1.7 Stakeholder comments to the COLD-II long term scenarios

CECED comments to the COLD-II study were included as Annex to the study Final Report[8]. In particular the European manufacturer Association made the following comments about the long-term scenarios:

The SAVE COLD II report contains a fairly-documented list of technology option which are in principle available to reduce energy consumption of cold appliances (Chapter 4). The report further contains an analysis of expected future efficiency limits (if costs would be no constraint, Chapter 5). However, here not enough importance has been paid on the cross-relationships between the three

[8] CECED Annex to the Cold II study, pag. 237.

fundamental technology options (insulation increase, compressor efficiency improvement, heat exchanger improvement). In other words, once the heat load has substantially reduced by increased performance of the insulation and the heat exchangers have been enlarged, the resulting compressor capacity required will be so low that the global efficiency targets assumed for the compressor (e.g. 0,75) become very unrealistic. Such targets may be realistic for larger capacity systems but become very problematic if compressor input is reduced down to e.g. 25W.

In summary this means that CECED is of the opinion that the calculated future efficiency index levels achievable (from 16 to 25 depending on the appliance category) are not realistic.

This effectively means that the new proposed labelling schemes with a threshold index at 30 for the A class [Note of the author: at present EEI = 30 is the threshold for the A++ class] can not be considered as intermediate schemes but are indeed very final. EEI numbers at very low levels give somewhat false impression when the impact of technology changes is considered. A reduction in index of only 5 points may appear a minor issue. However, on an index level of 35 this constitutes 14,3%. Since energy savings are typically obtained by relative improvements such reduction requires a major technology step. E.g. it will require significant wall coverage with vacuum panels to get an already very efficient appliance with index 35 under the level of 30.

6.3.2 BNATs for cold appliances in 2005

In addition to the two previously identified BNATs:

- **BNAT 1 - linear free-piston compressor using gas bearings** (Option 4.4.2): the costs and benefits are assumed to be similar to those of variable speed compressors;
- **BNAT 2 - fully vacuum insulated panels** (Option 1.5): very difficult to cost accurately without full design details: the manufacturing price has been estimated in 200-400 Euro. Need strong cabinet and sealed walls. The estimated energy savings is at maximum 20%;

other best not available technologies for cold appliances could be:

- **BNAT 3 - CO_2 compressor**: challenges of working with CO_2 compressors include very high pressures (above 100 bar) and the need for transcritical cycle. The critical temperature of CO_2 is 31°C, which means that no condensation is possible above that temperature. In addition the CO_2 cycle is more sensitive to suction temperatures than HC and HFC cycles, and discharge temperatures can also be high. Because CO_2 volumetric capacity is very high in comparison with HCs and HFCs, displacements are much smaller. The high pressure differences between compressor discharge and suction make necessary the use of two-stage compression for low back pressure appliances and imaginative mechanical solutions. CO_2 compressors were field tested in 2005 by the US manufacturer Tecumseh and by the Italian ACC Compressors[9] and were claimed to be commercially available in 2006. The European project PRO-COOL[10] mentioned a prototype commercial refrigerator (EasyReach-CO_2 an open refrigerated display cabinet for the food and beverage trade, produced by the Greek manufacturer Frigoglass and winner of the ProCool competition) with CO_2 compressor, but clearly stated also that this new technology, although promising for commercial applications, is still at an early stage.
  This technology has not been yet considered for household applications.

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[9] Source: “Compressors: meeting environmental demands”, Appliance-European Edition, May 2006, pp.16-17.
[10] Source: ProCool - *Efficient Refrigeration Appliances for Commerce and Trade* project, financed by the EC Life Programme, project leader the Austrian Energy Agency.

- **BNAT 4 - Oil-free compressor**: the development of oil-free compressors offers another important opportunity: oil-free technology simplifies the system chemistry and eliminates the need for oil research and testing. The elimination of oil has the potential to significantly improve heat exchanger performance.
- **BNAT 5 - New refrigerants for new compressors**[11]: due to the high performance (90%) already reached especially by the large compressors and motors a further improvement is limited in quantity and will only be available at high costs. One possible different approach is changing the compression process from an almost adiabatic to a more isothermal one. This requires extensive compressor cooling and comes with significant design challenges, but the final outcome could be quite high especially with refrigerants of small molecular weight, which usually have a high discharge temperature.
- **BNAT 6 - Aerogels as insulating materials**[12]: first created in 1931, aerogel materials have only recently entered the market. It is an extremely low-density material, often called "frozen smoke", but the ratio of gas to solid and the very small scale by which the gas becomes entrapped make aerogels excellent thermal insulating materials. Aerogels are made by taking a gel, then removing the liquids by a process called supercritical drying, to live something similar to a sponge with pores sized on the nano-scale size. Currently available densities are in the range 0,10-0,12 g/cm^3, surface area in the range 400-1 000 m^2/g.

  Silica aerogels integrated into a matrix of non-woven fabric have been produced by the society Aspen Aerogels, claimed to have both thermal and acoustic insulation properties from 2 to 8 times greater than competing insulating materials; the thermal conductivity is 0,011-0,013 W/m-K at 38°C (for polyurethane foam it is 0,021-0,024 W/m-K); the temperature resistance permits aerogels to be used for both hot and cold applications. Aerogels can be also chemically treated at the molecular level to repeal water. The low thermal conductivity of aerogel materials allows to achieve higher insulation values with less space for insulation. This gives designer the option of maintaining current insulation values while reducing the insulating cavity or maintaining current insulating cavity and increasing the insulating values. This could be used to increase interior dimensions of a refrigerator or to meet increased efficiency requirements with the same insulation thickness.

  Although the prices for the material vary by thickness and composition, and are significantly higher than conventional materials such as fibreglass and foams, they are expect to fall in future with increased production. The goal is to make aerogel blankets price-competitive with polyurethane foam and fibreglass. Developments of Aspen aerogels materials are under way for household appliances including refrigerators and freezers, where the material will help appliance makers to meet the energy efficiency requirements and to achieve the US Energy Star ratings more easily. The materials can also save on production costs, because they are easily installed and easy to handle, not requiring complex equipment associated with blown polyurethane foam systems.

  However the mechanical strength of the new aerogel insulation material should be compared to that of the traditional polyurethane foam, which at present is responsible of about 90% of the cold appliances cabinet rigidity.
- **BNAT 7 - Integration of alternative cooling technologies** with traditional vapour compression, for example: thermoelectric system for sub cooling the refrigerant in a vapour compression system, leading to an improvement in both capacity and efficiency.

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[11] Source: "Researching beyond refrigerants", Appliance, September 2006.

[12] Source: R. Babyak, Aerogels arrive – frozen smoke finds warm reception, Appliance Design, pp. 24-26, downloadable from. www.appliancedesign.com.

- **BNAT 8 - Touch screens**[13]: an approach some refrigerator companies are considering is consolidating controls into one location. At present, a refrigerator might have separate controls and displays for freezer temperature, refrigerator temperature, water and ice settings, etc. All controls could be consolidate and displayed into one touch screen location; by doing so costs are saved and the touch control can be used as a design element. Further down, common kitchen placement of touch screens, perhaps on refrigerator doors (see paragraph 1.3.3.2 for an early and simple example) or on a counter. The touch screens are easy to use and durable, and they play into the home automation trend.

A part from the introduction of touch screens, the long term high-efficiency design options deal with:
- higher performance insulation (aerogels, fully vacuum insulated panels)
- higher efficiency heat exchange (integration of alternative cooling technologies with traditional vapour compression, more isothermal compression process)
- higher efficiency compressor and compression process (linear free-piston compressor, oil-free compressor, CO_2 compressor,)

A part from the fully vacuum insulated panels, where a possible energy savings of maximum 20% over the standard base case were estimated, no information are available for the other BNATs about the effect on appliances energy efficiency. With a claimed thermal conductivity of 0,011-0,013 W/m-K at 38°C, the aerogels - should they become price competitive and technically applicable for cold appliances - are an alternative insulation system to polyurethane foam, VIPs of fully vacuum insulated panels. For other Options no actual or simulated data on their effect on the appliance energy efficiency do exist to confirm or modify the outcome of the COLD-II study long term simulation. It should be also highlighted that EEI calculation algorithms in directive 2003/66/EC are somehow different from those in directive 94/2/EC in force in 1998.

6.4 ENVIRONMENTAL ASSESSMENT OF THE TECHNOLOGICAL IMPROVEMENTS

In this paragraph the environmental impact assessment of the LCC and BAT cases analysed in Subtask 6.2 is carried out and the results are compared to the results achieved for the Base Case in Task 5.

The identified technological improvements do not change in sensible way the bill of material, at least as far as environments impact of the Production and End of Life phases are concerned. Therefore, the environmental analysis has been focused only on the Use phase.

The analysis was developed for Category 7 – refrigerator-freezers using the EuP Ecoreport

The Base case, LCC and BAT energy consumption data that taken into consideration in this analysis are:

Energy consumption (kWh/year)	
BASE CASE	324,4
LLCC	250,6
BAT	191,6

[13] Source: "Interfacing with the Consumer - Control Panels and Displays", Appliance – European Edition, January 2007.

According to this input the output presented in Table 6.25, as energy consumption and air and water emissions, has been calculated for all the life of the cold appliances (all other parameters, as materials used, transport and end of life have been considered to be the same in the three cases).

Table 6.25: COLD 7 (Refrigerator – Freezer) – Output of EuP-Ecoreport LCA for BASE CASE, LLCC and BAT cases

CASE	Resources Use and Emissions	UNIT	PRODUCTION	DISTRIBUTION	USE	END-OF-LIFE	TOTAL
01 - BASE CASE	Total Energy (GER)	MJ	4669	1115	51185	-459	56510
02 - LLCC	Total Energy (GER)	MJ	4669	1115	39562	-459	44886
03 - BAT	Total Energy (GER)	MJ	4669	1115	30269	-459	35594
01 - BASE CASE	of which, electricity (in primary MJ)	MJ	1209	2	51105	-61	52256
02 - LLCC	of which, electricity (in primary MJ)	MJ	1209	2	39482	-61	40632
03 - BAT	of which, electricity (in primary MJ)	MJ	1209	2	30189	-61	31340
01 - BASE CASE	Water (process)	ltr	1298	0	3419	-40	4677
02 - LLCC	Water (process)	ltr	1298	0	2644	-40	3902
03 - BAT	Water (process)	ltr	1298	0	2025	-40	3282
01 - BASE CASE	Water (cooling)	ltr	4685	0	136295	-337	140643
02 - LLCC	Water (cooling)	ltr	4685	0	105299	-337	109647
03 - BAT	Water (cooling)	ltr	4685	0	80519	-337	84867
01 - BASE CASE	Waste, non-haz./ landfill	g	84942	564	60089	3599	149194
02 - LLCC	Waste, non-haz./ landfill	g	84942	564	46612	3599	135718
03 - BAT	Waste, non-haz./ landfill	g	84942	564	35838	3599	124943
01 - BASE CASE	Waste, hazardous/ incinerated	g	463	11	1182	2378	4034
02 - LLCC	Waste, hazardous/ incinerated	g	463	11	914	2378	3767
03 - BAT	Waste, hazardous/ incinerated	g	463	11	700	2378	3552
01 - BASE CASE	Greenhouse Gases in GWP100	kg CO2 eq.	257	67	2236	10	2570
02 - LLCC	Greenhouse Gases in GWP100	kg CO2 eq.	257	67	1729	10	2063
03 - BAT	Greenhouse Gases in GWP100	kg CO2 eq.	257	67	1323	10	1657
01 - BASE CASE	Ozone Depletion, emissions	mg R-11 eq.					
02 - LLCC	Ozone Depletion, emissions	mg R-11 eq.					
03 - BAT	Ozone Depletion, emissions	mg R-11 eq.					
01 - BASE CASE	Acidification, emissions	g SO2 eq.	2034	206	13180	31	15450
02 - LLCC	Acidification, emissions	g SO2 eq.	2034	206	10187	31	12457

CASE	**Resources Use and Emissions**	UNIT	**PRODUCTION**	**DISTRIBUTION**	**USE**	**END-OF-LIFE**	**TOTAL**
03 - BAT	Acidification, emissions	g SO2 eq.	2034	206	7794	31	10064
01 - BASE CASE	Volatile Organic Compounds (VOC)	g	6	16	20	3	46
02 - LLCC	Volatile Organic Compounds (VOC)	g	6	16	16	3	41
03 - BAT	Volatile Organic Compounds (VOC)	g	6	16	12	3	38
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq	408	3	339	26	777
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq	408	3	263	26	701
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq	408	3	202	26	640
01 - BASE CASE	Heavy Metals	mg Ni eq.	1069	29	897	129	2124
02 - LLCC	Heavy Metals	mg Ni eq.	1069	29	698	129	1924
03 - BAT	Heavy Metals	mg Ni eq.	1069	29	538	129	1765
01 - BASE CASE	PAHs	mg Ni eq.	1414	37	125	-3	1573
02 - LLCC	PAHs	mg Ni eq.	1414	37	102	-3	1550
03 - BAT	PAHs	mg Ni eq.	1414	37	83	-3	1532
01 - BASE CASE	Particulate Matter (PM, dust)	g	456	2679	453	976	4564
02 - LLCC	Particulate Matter (PM, dust)	g	456	2679	389	976	4500
03 - BAT	Particulate Matter (PM, dust)	g	456	2679	337	976	4449
01 - BASE CASE	Heavy Metals	mg Hg/20	988	1	339	31	1359
02 - LLCC	Heavy Metals	mg Hg/20	988	1	264	31	1285
03 - BAT	Heavy Metals	mg Hg/20	988	1	204	31	1225
01 - BASE CASE	Eutrophication	g PO4	61	0	2	0	63
02 - LLCC	Eutrophication	g PO4	61	0	2	0	63
03 - BAT	Eutrophication	g PO4	61	0	2	0	63
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq					
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq					
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq					

Table 6.26 shows the decrease in percentage of the LLCC and BAT main environmental indicators with respect the Base case. For some environmental impact indicators (such as ozone depletion and POP) no value have been reported because, according to EuP Ecoreport, these impacts are negligible.

Table 6.26: COLD 7 (Refrigerator-Freezers), percentage decrease of LCA's outputs from Base case vs LLCC and BAT cases

CASE	**Resources Use and Emissions**	**UNIT**	**USE PHASE**	**TOTAL**
01 - BASE CASE	Total Energy (GER)	MJ		
02 - LLCC	Total Energy (GER)	MJ	-23%	-21%
03 - BAT	Total Energy (GER)	MJ	-41%	-37%

CASE	Resources Use and Emissions	UNIT	USE PHASE	TOTAL
01 - BASE CASE	of which, electricity (in primary MJ)	MJ		
02 - LLCC	of which, electricity (in primary MJ)	MJ	-23%	-22%
03 - BAT	of which, electricity (in primary MJ)	MJ	-41%	-40%
01 - BASE CASE	Water (process)	ltr		
02 - LLCC	Water (process)	ltr	-23%	-17%
03 - BAT	Water (process)	ltr	-41%	-30%
01 - BASE CASE	Water (cooling)	ltr		
02 - LLCC	Water (cooling)	ltr	-23%	-22%
03 - BAT	Water (cooling)	ltr	-41%	-40%
01 - BASE CASE	Waste, non-haz./ landfill	g		
02 - LLCC	Waste, non-haz./ landfill	g	-22%	-9%
03 - BAT	Waste, non-haz./ landfill	g	-40%	-16%
01 - BASE CASE	Waste, hazardous/ incinerated	g		
02 - LLCC	Waste, hazardous/ incinerated	g	-23%	-7%
03 - BAT	Waste, hazardous/ incinerated	g	-41%	-12%
01 - BASE CASE	Greenhouse Gases in GWP100	kg CO2 eq.		
02 - LLCC	Greenhouse Gases in GWP100	kg CO2 eq.	-23%	-20%
03 - BAT	Greenhouse Gases in GWP100	kg CO2 eq.	-41%	-36%
01 - BASE CASE	Ozone Depletion, emissions	mg R-11 eq.		
02 - LLCC	Ozone Depletion, emissions	mg R-11 eq.		
03 - BAT	Ozone Depletion, emissions	mg R-11 eq.		
01 - BASE CASE	Acidification, emissions	g SO2 eq.		
02 - LLCC	Acidification, emissions	g SO2 eq.	-23%	-19%
03 - BAT	Acidification, emissions	g SO2 eq.	-41%	-35%
01 - BASE CASE	Volatile Organic Compounds (VOC)	g		
02 - LLCC	Volatile Organic Compounds (VOC)	g	-22%	-10%
03 - BAT	Volatile Organic Compounds (VOC)	g	-39%	-17%
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq		
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq	-22%	-10%
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq	-40%	-18%
01 - BASE CASE	Heavy Metals	mg Ni eq.		
02 - LLCC	Heavy Metals	mg Ni eq.	-22%	-9%
03 - BAT	Heavy Metals	mg Ni eq.	-40%	-17%
01 - BASE CASE	PAHs	mg Ni eq.		
02 - LLCC	PAHs	mg Ni eq.	-18%	-1%
03 - BAT	PAHs	mg Ni eq.	-33%	-3%

CASE	Resources Use and Emissions	UNIT	USE PHASE	TOTAL
01 - BASE CASE	Particulate Matter (PM, dust)	g		
02 - LLCC	Particulate Matter (PM, dust)	g	-14%	-1%
03 - BAT	Particulate Matter (PM, dust)	g	-25%	-3%
01 - BASE CASE	Heavy Metals	mg Hg/20		
02 - LLCC	Heavy Metals	mg Hg/20	-22%	-6%
03 - BAT	Heavy Metals	mg Hg/20	-40%	-10%
01 - BASE CASE	Eutrophication	g PO4		
02 - LLCC	Eutrophication	g PO4	-16%	-1%
03 - BAT	Eutrophication	g PO4	-30%	-1%
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq		
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq		
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq		

6.5 ANNEX A: DETAILED MNPV/LCC ANALYSIS FOR COLD APPLIANCE BASE CASES

In this Annex the reasons for the selection of the specific technological pathways (out of the Technological Option List) chosen in paragraph 1.4.2 for each cold appliance category and the relevant detailed Life Cycle Cost results and calculations for each base case are presented.

6.5.1 The MNPV analysis goals

The main goal of the marginal net present value analysis and the following LCC analysis was to define the technological pathway, among those made possible by the combination of some Options listed in the Technological Option List, which:

(i) is technologically feasible: taking into account alternative options, excluding technically incompatible options and following an engineering justifiable design improvement. The discussion about these elements has been developed in paragraphs 1.3.2 and 1.3.3, where the single Options are described in detail;

(ii) is economically acceptable: leading to a high economic return for the consumer (a high MNPV), with an acceptable payback time;

(iii) results in the highest energy efficiency improvement (or in the lowest energy consumption reached) for the technologically improved appliance for the LLCC and BAT levels;

(iv) results should be coherent with the reality of the market in the reference year (2005), i.e. the resulting LLCC and BAT should be at the (energy efficiency) level of existing appliances.

6.5.2 The SPB and NPV analysis for the technological options

The Simple Payback Time and Net Present Value analysis for the single technological options developed in Subtask 6.2 is here briefly reported for an easier comprehension of the overall analysis.

The first step of the analysis is the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant base case. The results are presented in Tables A.1-A.2 for the four appliance categories and the technological Options: NPV is calculated for a lifetime of 15 years; options for the no-frost models are shown although no standard base case has the no-frost technology. In Table A.2, Options are ordered by SPB and NPV for each appliance category: in general there is a good agreement between the SPB and the NPV values, where the former increases the latter decreases. In general, the NPV is positive for SPB values below 10 years and becomes negative for a longer time period. In general, the improvement in compressor efficiency have a positive results for the consumers, as well as the improvement in the insulation thickness, while for the VIPs the results of the COLD-II study are confirmed: the payback time is always significantly higher that the expected appliance lifetime for all categories. The increasing of the evaporator area has still a role to play (even if small) while the increase of the condenser area starts to be non profitable for the consumers, with NPV slightly positive or negative depending from the appliance category.

6.5.3 The MNPV and the aggregated option LCC analysis

To evaluate the improvement potential of the single base case, the aggregated option analysis was developed for each of the possible technological option combinations, to evaluate which specific combination could better satisfy the four above mentioned criteria.

Table A.1: Simple payback time (SPB) and net present value (NPV) at 15 years for the identified technological options applied to cold appliances standard base cases

Appliance categories		Refrigerators		Refrigerator-freezers		Upright freezers		Chest freezers	
Options (n)	**Technology** (description)	SPB (years)	NPV (€)	SPB (years)	NPV (€)	SPB (years)	NPV (€)	SPB (years)	NPV (€)
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	44,9	*-38,45*	31,7	*-58,88*	25,0	*-40,94*	22,8	*-38,17*
a.2	vacuum insulated panels, cabinet walls (50%)	35,9	*-71,11*	22,7	*-67,76*	22,3	*-66,88*	20,4	*-61,35*
a.3	+10-15mm insulation, door & cabinet walls	7,5	*9,66*	6,0	*21,52*	6,4	*18,44*	5,9	*23,04*
b*	low wattage brushless fan motor (4W AC fans)			7,6	*4,67*	6,7	*6,88*		
c (+ g)	modified defrost with electronic temperature control and fuzzy logic, to be used together with Option g	32,9	*-18,83*						
d.1	increasing 10-20% the surface area of the evaporator	9,0	*1,17*	7,6	*4,67*	8,9	*2,03*	4,9	*8,41*
d.2	increasing 5-10% the surface area of the condenser	18,0	*-2,11*	9,1	*0,72*	10,7	*-0,16*	9,8	*0,30*
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	29,9	*-16,33*	15,1	*-7,83*	17,9	*-10,47*	16,3	*-9,09*
f.1**	Higher efficiency reciprocating compressors (COP 1,5)	4,5	*16,39*	2,3	*44,74*	2,7	*35,94*	2,4	*40,54*
f.2**	optimisation of reciprocating compressors (highest efficiency of one producer)	8,3	*7,55*	5,2	*36,91*	6,2	*25,47*	5,6	*31,45*
f.3**	multi-speed and variable-speed compressors	13,5	*-17,23*	9,1	*10,86*	8,0	*21,87*	7,3	*31,08*
g (+ c*)	Temperature control through electronic thermostats, to be used together with Option c for no-frost models			22,7	*-13,55*	26,8	*-15,31*		
h (+g)	bistable solenoid valve (diverter valve) including electronic control			40,8	*-33,55*				

*options for no-frost models
**possible alternative options

Table A.2: Technological options ordered by simple payback time (SPB) and net present value (NPV) at 15 years for cold appliances standard base cases

Options	Refrigerators		Options	Refrigerator-freezers		Options	Upright freezers		Options	Chest freezers	
	SPB	NPV		SPB	NPV		SPB	NPV		SPB	NPV
(n)	(years)	(€)	(n)	(years)	(€)	(n)	(years)	(€)	(n)	(years)	(€)
f.1**	4,5	16,39	**f.1****	2,3	44,74	**f.1****	2,7	35,94	**f.1****	2,4	40,54
a.3	7,5	9,66	**f.2****	5,2	36,91	**f.2****	6,2	25,47	**d.1**	4,9	8,41
f.2**	8,3	7,55	**a.3**	6,0	21,52	**a.3**	6,4	18,44	**f.2****	5,6	31,45
d.1	9,0	1,17	**b***	7,6	4,67	**b***	6,7	6,88	**a.3**	5,9	23,04
f.3**	13,5	-17,23	**d.1**	7,6	4,67	**f.3****	8,0	21,87	**f.3****	7,3	31,08
d.2	18,0	-2,11	**d.2**	9,1	0,72	**d.1**	8,9	2,03	**d.2**	9,8	0,3
e	29,9	-16,33	**f.3****	9,1	10,86	**d.2**	10,7	-0,16	**e**	16,3	-9,09
c (+ g)	32,9	-18,83	**e**	15,1	-7,83	**e**	17,9	-10,47	**a.2**	20,4	-61,35
a.2	35,9	-71,11	**a.2**	22,7	-67,76	**a.2**	22,3	-66,88	**a.1**	22,8	-38,17
a.1	44,9	-38,45	**g (+ c*)**	22,7	-13,55	**a.1**	25,0	-40,94	**b***		
b*			**a.1**	31,7	-58,88	**g (+ c*)**	26,8	-15,31	**c (+ g)**		
g (+ c*)			**h (+g)**	40,8	-33,55	**h (+g)**			**g (+ c*)**		
h (+g)			**c (+ g)**			**c (+ g)**			**h (+g)**		

*options for no-frost models
**possible alternative options

The LCC analysis was run for the average standard base case appliances and for the standard base case models. The former represent the average of the reference year and takes into consideration the percentage of application of each technological option on the market, or better the percentage of each option still available for application on the market. For the latter a technological level is specified for the base cases and then all the available technological options are applied. In the first case the possible average improvement of the overall appliance category are predicted. The second analysis allows to predict the best available technology models an can be also considered a sort of inner validation of the previous scenario and more in general of the overall calculation model: if the calculation can predict in a technically and economically sound way the development from the base case model to the to the best available models on the market in 2005, then the overall simulation is coherent with the reality.

The technological *Options f.1*, *f.2* and *f.3* encompassing a better (more efficient) compressor can be applied either as alternatives or one after the other, with different impacts in terms of resulting price and savings. The data shown in previous Tables 7-10 are relevant to their direct application as single options to the base cases. When the compressors are applied as subsequent steps of technological improvement the associated energy savings and the price should be considered as the difference between one step and the other (i.e. when *Option f.2* is applied after *Option f.1*, the increase in the consumer price in the case of refrigerators is (17,50-12,50=5€) and the electricity savings is (13-10=3%); instead when *Option f.3* is applied after *Option f.2*, the increase in the consumer price in the case of refrigerators is (45,00-17,50=36,50 €) and the electricity savings is (20-13=7%).

The combination of the more efficient compressors leads to four technological pathways that manufacturers could follow to improve cold appliances from the Base Cases to the BATs on the market in 2005:

- technological pathway 1: use of Options f.1+f.2+f.3, the three more efficient compressors are applied in three steps one after the other, from the least to the most efficient one. All the other Options shown in Table A.2 are also applied;
- technological pathway 2: use of option combination (f.2 + f.3): as pathway 1, but here the first compressor to be applied is *Option f.2*, followed by *Option f.3*. All the other Options shown in Table A.2 are also applied;
- technological pathway 3: use of Option f.2 only, the intermediate compressor (the highest efficiency reciprocating compressors, with max COP, available from one supplier) is only applied. All the other Options shown in Table A.2 are also applied;
- technological pathway 4: use of Option f.3 only, the most efficient, variable-speed type compressor is directly applied. All the other Options shown in Table A.2 are also applied.

Which of the identified technological pathway is more suitable for each base case depends on the base case characteristics (mainly its energy consumption) and the cost & energy saving of the technological options. The four pathways will be analysed for the cold appliance base case to evaluate the one(s) better fulfilling the four criteria described in paragraph 6.7.1. In addition, it is worth noting that *Options f.1-f.3* and *Options a.1-a.3* (dealing with the insulation properties of the cabinet door and walls) give an absolute energy savings and not a percentage one.

6.5.3.1 The analysis for the average standard base cases

Tables A.3-A.6 present the technological options, marginal net present value (for a lifetime of 15 years), marginal payback time, annual energy consumption and energy efficiency index (according to directives 94/2/EC and 2003/66/EC) resulting from the application of the four technological pathways respectively to refrigerators (Table A.3), refrigerator-freezers (Table A.4), upright

Table A.3: Technological options, marginal net present value (MNPV), marginal payback time (MPB), annual energy consumption and energy efficiency index (EEI) according to directives 94/2/EC and 2003/66/EC, at a lifetime of 15 years, for the aggregated option analysis of refrigerators standard base cases for different technological pathways

Refrigerators											
Technological pathway 1: use of option combination (f.1+f.2+f.3)						***Technological pathway 2: use of option combination (f.2 + f.3)***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	163,7	0,549	0,540	**Base case**	--	--	163,7	0,549	0,540
+f.1	10,16	4,49	153,6	0,517	0,508	**+a.3**	8,70	7,49	146,0	0,492	0,483
+a.3	8,70	7,49	135,9	0,458	0,450	**+f.2**	7,32	8,29	125,4	0,422	0,415
+d.1	-0,06	10,82	135,1	0,455	0,447	**+d.1**	-0,17	11,73	124,6	0,420	0,412
+d.2	**-0,52**	**21,78**	**134,8**	**0,454**	**0,446**	**+d.2**	**-0,56**	**23,60**	**124,4**	**0,419**	**0,412**
+f.2	-8,57	20,96	130,0	0,438	0,430	**+g+c**	-16,73	43,35	121,4	0,409	0,402
+(g+c)	-16,49	41,47	126,9	0,427	0,420	**+e**	-17,65	40,38	117,9	0,397	0,390
+e	-17,37	38,63	123,3	0,415	0,408	**+f.3**	-24,53	23,10	106,6	0,359	0,353
+f.3	-24,53	23,10	111,9	0,377	0,370	**+a.1**	-38,06	44,92	100,1	0,337	0,331
+a.1	-38,06	44,92	105,5	0,355	0,349	**+a.2**	-71,11	35,93	83,7	0,282	0,277
+a.2	-71,11	35,93	89,1	0,300	0,295						
Technological pathway 3: use of option f.2						***Technological pathway 4: use of option f.3***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	163,7	0,549	0,540	**Base case**	--	--	163,7	0,549	0,540
+a.3	8,70	7,49	146,0	0,492	0,483	**+a.3**	8,70	7,49	146,0	0,492	0,483
+f.2	7,32	8,29	125,4	0,422	0,415	**+d.1**	0,05	10,07	145,1	0,489	0,480
+d.1	-0,17	11,73	124,6	0,420	0,412	**+d.2**	**-0,49**	**20,26**	**144,9**	**0,488**	**0,479**
+d.2	**-0,56**	**23,60**	**124,4**	**0,419**	**0,412**	**+(g+c)**	-15,87	37,22	141,4	0,476	0,468
+(g+c)	-16,73	43,35	121,4	0,409	0,402	**+e**	-16,64	34,67	137,3	0,463	0,455
+e	-17,65	40,38	117,9	0,397	0,390	**+f.3**	-17,06	13,48	104,9	0,353	0,347
+a.1	-38,06	44,92	111,4	0,375	0,369	**+a.1**	-38,06	44,92	98,5	0,332	0,326
+a.2	-71,11	35,93	95,1	0,320	0,315	**+a.2**	-71,11	35,93	82,1	0,276	0,272

Table A.4: Technological options, marginal net present value (MNPV), marginal payback time (MPB), annual energy consumption and energy efficiency index (EEI) according to directives 94/2/EC and 2003/66/EC, at a lifetime of 15 years, for the aggregated option analysis of refrigerator-freezers standard base cases for different technological pathways

Refrigerator-freezers											
Technological pathway 1: use of option combination (f.1+f.2+f.3)						***Technological pathway 2: use of option combination (f.2 + f.3)***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	324,4	0,562	0,536	**Base case**	--	--	324,4	0,562	0,536
+f.1	22,37	2,27	308,2	0,534	0,510	**+f.2**	33,22	5,23	286,4	0,496	0,474
+a.3	19,37	6,04	281,9	0,488	0,466	**+a.3**	19,37	6,04	260,2	0,451	0,430
+d.1	0,24	8,69	281,1	0,487	0,465	**+d.1**	0,13	9,42	259,4	0,449	0,429
+d.2	**-0,01**	**10,46**	**280,5**	**0,486**	**0,464**	**+d.2**	**-0,08**	**11,34**	**258,9**	**0,448**	**0,428**
+f.2	-7,04	15,11	271,7	0,471	0,449	**+e**	-10,73	18,94	251,5	0,436	0,416
+e	-9,64	17,48	263,7	0,457	0,436	**+f.3**	-23,49	40,80	247,0	0,428	0,408
+f.3	-24,75	34,00	257,6	0,446	0,426	**+(h+g)**	-27,35	44,66	242,3	0,420	0,401
+(h+g)	-26,99	42,82	252,7	0,438	0,418	**+a.1**	-58,29	31,73	226,2	0,392	0,374
+a.1	-58,29	31,73	236,6	0,410	0,391	**+a.2**	-67,76	22,67	193,8	0,336	0,320
+a.2	-67,76	22,67	204,2	0,354	0,338						
Technological pathway 3: use of option f.2						***Technological pathway 4: use of option f.3***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	324,4	0,562	0,536	**Base case**	--	--	324,4	0,562	0,536
+f.2	33,22	5,23	286,4	0,496	0,474	**+a.3**	19,37	6,04	298,1	0,516	0,493
+a.3	19,37	6,04	260,2	0,451	0,430	**+f.3**	10,32	9,07	251,9	0,436	0,417
+d.1	0,13	9,42	259,4	0,449	0,429	**+d.1**	0,08	9,73	251,1	0,435	0,415
+d.2	**-0,08**	**11,34**	**258,9**	**0,448**	**0,428**	**+d.2**	**-0,11**	**11,71**	**250,6**	**0,434**	**0,414**
+e	-10,73	18,94	251,5	0,436	0,416	**+e**	-11,15	19,56	243,5	0,422	0,403
+(h+g)	-25,29	52,63	248,0	0,430	0,410	**+(h+g)**	-25,48	54,36	240,1	0,416	0,397
+a.1	-58,29	31,73	231,9	0,402	0,383	**+a.1**	-58,29	31,73	224,0	0,388	0,370
+a.2	-67,76	22,67	199,5	0,346	0,330	**+a.2**	-67,76	22,67	191,6	0,332	0,317

Table A.5: Technological options, marginal net present value (MNPV), marginal payback time (MPB), annual energy consumption and energy efficiency index (EEI) according to directives 94/2/EC and 2003/66/EC, at a lifetime of 15 years, for the aggregated option analysis of upright freezers standard base cases for different technological pathways

Upright freezers											
Technological pathway 1: use of option combination (f.1+f.2+f.3)						***Technological pathway 2: use of option combination (f.2 + f.3)***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	274,5	0,588	0,507	**Base case**	--	--	274,5	0,588	0,507
+f.1	17,97	2,68	260,8	0,559	0,481	**+f.2**	6,18	6,18	242,4	0,519	0,447
+a.3	14,75	6,43	238,8	0,512	0,441	**+a.3**	6,43	6,43	220,4	0,472	0,407
+d.1	0,03	10,26	237,4	0,509	0,438	**+d.1**	11,12	11,12	219,1	0,470	0,404
+d.2	**-0,16**	**12,39**	**236,9**	**0,508**	**0,437**	**+d.2**	**13,42**	**13,42**	**218,7**	**0,469**	**0,404**
+f.2	-9,42	17,86	229,5	0,492	0,423	**+f.3**	11,48	22,42	200,4	0,429	0,370
+f.3	-3,41	11,48	211,2	0,453	0,390	**+e**	24,46	11,48	194,7	0,417	0,359
+e	-13,13	23,21	205,2	0,440	0,379	**+a.1**	25,00	25,00	178,4	0,382	0,329
+a.1	-40,53	25,00	194,9	0,418	0,360	**+a.2**	22,32	22,32	145,5	0,312	0,268
+a.2	-66,88	22,32	162,0	0,347	0,299						
Technological pathway 3: use of option f.2						***Technological pathway 4: use of option f.3***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	274,5	0,588	0,507	**Base case**	--	--	274,5	0,588	0,507
+f.2	22,92	6,18	242,4	0,519	0,447	**+f.3**	20,78	8,04	222,3	0,476	0,410
+a.3	14,75	6,43	220,4	0,472	0,407	**+a.3**	7,39	7,94	204,6	0,438	0,3775
+d.2	-0,22	13,34	220,0	0,471	0,406	**+d.2**	-0,47	19,70	204,3	0,438	0,3769
+d.1	**-0,17**	**11,14**	**218,7**	**0,469**	**0,404**	**+d.1**	**-0,92**	**16,47**	**203,4**	**0,436**	**0,375**
+e	-12,75	22,42	212,4	0,455	0,392	**+e**	-16,34	33,29	199,2	0,427	0,368
+a.1	-40,53	25,00	196,1	0,420	0,362	**+a.1**	-48,42	34,46	187,3	0,401	0,346
+a.2	-66,88	22,32	163,2	0,350	0,301	**+a.2**	-85,33	32,71	164,9	0,353	0,304

Table A.6: Technological options, marginal net present value (MNPV), marginal payback time (MPB), annual energy consumption and energy efficiency index (EEI) according to directives 94/2/EC and 2003/66/EC, at a lifetime of 15 years, for the aggregated option analysis of chest freezers standard base cases for different technological pathways

Chest freezers											
Technological pathway 1: use of option combination (f.1+f.2+f.3)						***Technological pathway 2: use of option combination (f.2 + f.3)***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	300,6	0,708	0,528	**Base case**	--	--	300,6	0,708	0,528
+f.1	20,27	2,45	285,6	0,673	0,501	**+f.2**	28,31	5,64	265,4	0,625	0,466
+a.3	20,74	5,87	258,5	0,609	0,454	**+a.3**	20,74	5,87	238,4	0,561	0,419
+d.1	3,09	5,69	254,6	0,600	0,447	**+d.1**	2,56	6,17	234,8	0,553	0,412
+d.2	**-0,10**	**11,55**	**254,1**	**0,599**	**0,446**	**+d.2**	**-0,17**	**12,53**	**234,3**	**0,552**	**0,411**
+f.2	-8,18	16,31	246,0	0,579	0,432	**+f.3**	-8,98	12,23	205,8	0,485	0,361
+f.3	-0,35	10,48	226,0	0,532	0,397	**+e**	-13,40	23,82	199,9	0,471	0,351
+e	-12,38	21,69	239,6	0,564	0,421	**+a.1**	-37,79	22,83	182,1	0,429	0,320
+a.1	-37,79	22,83	221,7	0,522	0,389	**+a.2**	-61,35	20,38	146,0	0,344	0,256
+a.2	-61,35	20,38	185,6	0,437	0,326						
Technological pathway 3: use of option f.2						***Technological pathway 4: use of option f.3***					
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	EEI 94/2/EC	EEI 2003/66/EC
Base case	--	--	300,6	0,708	0,528	**Base case**	--	--	300,6	0,708	0,528
+f.2	28,31	5,64	265,4	0,625	0,466	**+f.3**	29,53	7,34	243,5	0,574	0,428
+a.3	20,74	5,87	238,4	0,561	0,419	**+a.3**	20,74	5,87	216,4	0,510	0,380
+d.2	2,56	6,17	234,8	0,553	0,412	**+d.1**	1,98	6,79	213,2	0,502	0,374
+d.1	**-0,17**	**12,53**	**234,3**	**0,552**	**0,411**	**+d.2**	**-0,25**	**13,80**	**212,8**	**0,501**	**0,374**
+e	-11,97	20,92	227,7	0,536	0,400	**+e**	-13,05	23,04	206,7	0,487	0,363
+a.1	-37,79	22,83	209,8	0,494	0,368	**+a.1**	-37,79	22,83	188,8	0,445	0,332
+a.2	-61,35	20,38	173,7	0,409	0,305	**+a.2**	-61,35	20,38	152,8	0,360	0,268

freezers (Table A.5) and chest freezers (Table A.6).

For **refrigerators**, technological pathway 1 results in the best combination of MNPV for the LLCC and the achieved energy savings at both LLCC and BAT levels (Table A7), followed by technological pathway 2.

Table A.7: Summary of the MNPV analysis for the four technological pathways for refrigerator average standard base cases (lifetime 15years, electric energy price 0,17€/kWh)

Technological pathway 1				*Technological pathway 2*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	163,7	**Base case**	--	--	163,7
LLCC	18,3	6,7	134,8	**LLCC**	15,3	8,1	124,4
BAT	-157,9	22,8	89,1	**BAT**	-152,8	21,6	83,7
Technological pathway 3				*Technological pathway 4*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	163,7	**Base case**	--	--	163,7
LLCC	15,3	8,1	124,4	**LLCC**	8,3	12,4	144,9
BAT	-128,27	21,4	95,1	**BAT**	-150,48	21,2	82,1

For **refrigerator-freezers**, technological pathway 4 results in the lowest LLCC/BAT energy consumption and in a good MNPV for the LLCC (Table A8), even if the marginal payback time is higher al LLCC.

Table A.8: Summary of the MNPV analysis for the four technological pathways for refrigerator-freezer average standard base cases (lifetime 15years, electric energy price 0,17€/kWh)

Technological pathway 1				*Technological pathway 2*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	324,4	**Base case**	--	--	324,4
LLCC	42,0	4,8	280,5	**LLCC**	52,6	5,7	258,9
BAT	-152,5	17,8	204,2	**BAT**	-135,0	16,5	193,8
Technological pathway 3				*Technological pathway 4*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	324,4	**Base case**	--	--	324,4
LLCC	52,6	5,7	258,9	**LLCC**	29,7	8,0	250,6
BAT	-109,4	15,5	199,5	**BAT**	-133,0	16,3	191,6

For **upright freezers**, again technological pathway 4 results in the lowest LLCC energy consumption and in a good MNPV for the LLCC (Table A9), even if the marginal payback time is higher at LLCC, followed by technological pathway 2, which has the lowest BAT energy consumption but a higher LLCC energy consumption.

For **chest freezers**, again technological pathway 4 results in the lowest LLCC energy consumption and in a good MNPV for the LLCC (Table A10), even if the marginal payback time is higher at LLCC, followed by technological pathway 2, which has the lowest BAT energy consumption but a higher LLCC energy consumption.

Table A.9: Summary of the MNPV analysis for the four technological pathways for upright freezer average standard base cases (lifetime 15years, electric energy price 0,17€/kWh)

Technological pathway 1				*Technological pathway 2*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	274,5	**Base case**	--	--	274,5
LLCC	32,6	5,3	236,9	**LLCC**	37,3	6,5	218,7
BAT	-100,8	15,4	162,0	**BAT**	-87,2	14,4	145,5
Technological pathway 3				*Technological pathway 4*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	274,5	**Base case**	--	--	274,5
LLCC	6,5	37,3	218,7	**LLCC**	26,8	8,2	203,4
BAT	14,8	-82,9	163,2	**BAT**	-123,3	17,0	164,9

Table A.10: Summary of the MNPV analysis for the four technological pathways for chest freezer average standard base cases (lifetime 15years, electric energy price 0,17€/kWh)

Technological pathway 1				*Technological pathway 2*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	300,6	**Base case**	--	--	300,6
LLCC	44	4,8	254,1	**LLCC**	51,4	5,8	234,3
BAT	-76,1	13,7	185,6	**BAT**	-70,1	13,0	146,0
Technological pathway 3				*Technological pathway 4*			
Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)	Options (n)	$MNPV_{av}$ (€)	MPB (years)	En. cons. (kWh/y)
Base case	--	--	300,6	**Base case**	--	--	300,6
LLCC	51,4	5,8	234,3	**LLCC**	52,0	6,9	212,8
BAT	-59,7	13,1	173,7	**BAT**	-60,2	12,8	152,8

6.5.3.2 Conclusions for the average standard base case analysis

The main goal of the marginal net present value analysis and the following LCC analysis was to define the technological pathway, among those made possible by the combination of some Options listed in the Technological Option List, which is (i) technologically feasible, (ii) economically acceptable, (iii) results in the highest energy efficiency improvement and (iv) is coherent with the actual market development in 2005.

To evaluate the improvement potential of the cold appliance base case, the aggregated option analysis was developed for each of the possible technological option combinations, to evaluate which specific combination could better satisfy the four criteria.

In fact, *Options f.1-f.3*, dealing with more efficient compressors, can be applied either as alternatives or one after the other, with different impacts in terms of resulting price and savings. Four technological pathways were identified, that manufacturers could follow to improve cold appliances from the Base Cases to the BATs on the market in 2005, named technological pathway 1, 2 3 and 4.

Table A.11: Technological options, marginal net present value (MNPV) and marginal payback time (MPB) at a lifetime of 15 years for the aggregated option analysis for cold appliances average standard base cases

Refrigerators			**Refrigerator-freezers**		
Average standard base case			Average standard base case		
Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)
+f.1	10,16	4,49	**+a.3**	19,37	6,04
+a.3	8,70	7,49	**+f.3**	10,32	9,07
+d.1	-0,06	10,82	**+d.1**	0,08	9,73
+d.2	-0,52	21,78	**+d.2**	-0,11	11,71
+f.2	-8,57	20,96	**+e**	-11,15	19,56
+(g+c)	-16,49	41,47	**+(h+g)**	-25,48	54,36
+e	-17,37	38,63	**+a.1**	-58,29	31,73
+f.3	-24,53	23,10	**+a.2**	-67,76	22,67
+a.1	-38,06	44,92			
+a.2	-71,11	35,93			
Upright freezers			**Chest frezers**		
Average standard base case			Standard base case model		
Options (n)	$MNPV_{av}$ (€)	MPB (years)	Options (n)	MNPV (€)	MPB (years)
+f.3	20,78	8,04	**+f.3**	29,53	7,34
+a.3	7,39	7,94	**+a.3**	20,74	5,87
+d.2	-0,47	19,70	**+d.1**	1,98	6,79
+d.1	-0,92	16,47	**+d.2**	-0,25	13,80
+e	-16,34	33,29	**+e**	-13,05	23,04
+a.1	-48,42	34,46	**+a.1**	-37,79	22,83
+a.2	-85,33	32,71	**+a.2**	-61,35	20,38

The marginal net present value analysis was developed for the cold appliances average standard base cases and each technological pathway, resulting in technological pathway 1, including the use of Options f.1+f.2+f.3, as the first choice for refrigerators and technological pathway 4 including the use of Option f.3 alone, as the first choice for refrigerator-freezers, upright and chest freezers. The chosen technological pathway for the specific base case results in MNPV and energy consumption more in line with the first three criteria out of the above mentioned four. The coherence of the LCC analysis results for the selected technological pathways with the reality of the market in the reference year (2005) has been studied in paragraph 6.4.2.3.

6.5.3.3 The analysis for the standard base case models

The analysis for the standard base case models will use the same technological pathways identified for the average standard base case analysis and has been developed in paragraph 6.4.2.3.

7 Task 7: Scenario, Policy, Impact and Sensitivity Analysis

7.1 Subtask 7.1: Worldwide Scenarios for Cold Appliances

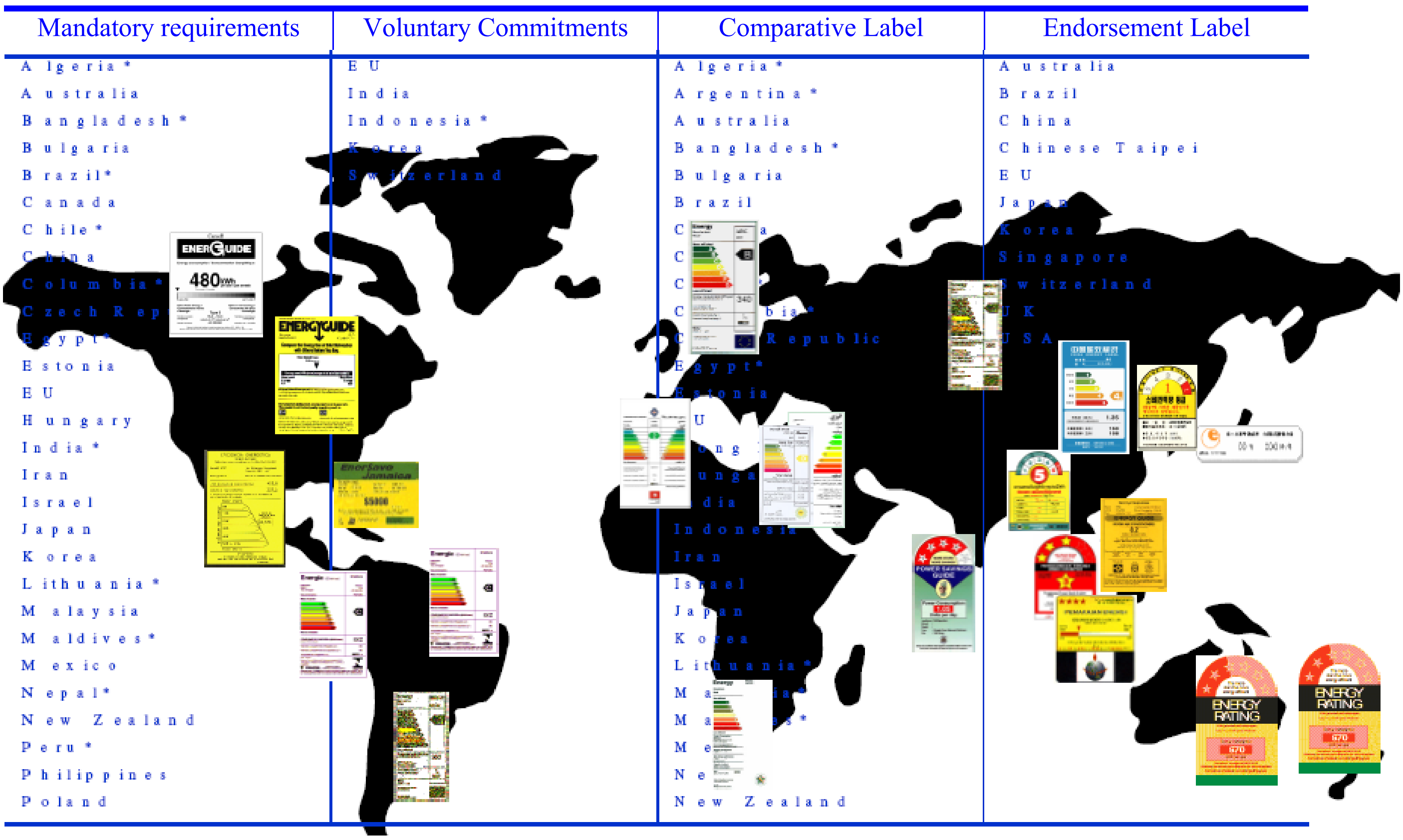
In this Subtask the main policy measures existing and planned worldwide for cold appliances will be summarised and tentatively compared with those of the EU to evaluate the European position in the international context.

7.1.1 Comparison of the worldwide policy measures

As described in Task 1, cold appliances policy measures (labelling schemes and efficiency requirements) are in force in most industrialised economies and many industrialising economies worldwide, starting in late '70s in Canada.

The number of nations adopting energy efficiency requirements and labels for EUPs is growing rapidly, from 9 in 1984 to 36 in 1994 to over 54 in 2006 (Figure 1). The number of regulations worldwide on individual appliances and equipment is growing even more rapidly, increasing from 543 to 878 between 2000 and 2004[14].

Figure 7.1: ***International use of mandatory and voluntary policy measures in 2006***[15]



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[14] Source: APEC," A Strategic Vision for International Cooperation on Energy Standards and Labelling", June 2006.
[15] Source: P. Wade, EEDAL End of Term Report, EEDAL 06, London, June 2006.

The most common policies and measure for cold appliances are labelling (efficiency or other type) and efficiency requirements, implemented in many countries, as described in Table 1. In addition to these countries, other non-EU European countries have either implemented EU cold appliance

Table 7.1: Labelling schemes and energy requirements for refrigerators and freezers around the world[16]

Country	Refrigerators and refrigerator-freezers			Freezers		
	Min. eff. requirements	labelling		Min. eff. requirements	labelling	
		comparative	endorsement		comparative	endorsement
Algeria	**M**[1]	**M**[1]	--	**M**[1]	**M**[1]	--
Argentina	UC	**M**[1,2]	--	UC	**M**[1,2]	--
Australia	**M**[5]	**M**[5]	V	**M**[5]	**M**[5]	V
Bolivia	UC	UC	--		UC	UC
Brazil	UC	V[3]	V	UC	V[3]	V
Bulgaria	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]
Canada	**M**[4]	**M**[4]	V[4]	**M**[4]	**M**[4]	V[4]
Chile	UC	UC	UC	UC	UC	UC
China	**M**[3]	**M**[3]	V	**M**[3]	**M**[3]	V
Columbia	**M**[1]	**M**[3]	--	**M**[1]	**M**[3]	--
Costa Rica	V	**M**	--	V	**M**	--
Croatia	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]
Ecuador	UC	UC	--	UC	UC	--
Egypt	UC	UC[3]	--	UC	UC[3]	--
EU-25/27	**M**	**M**	V	**M**	**M**	V
Ghana	UC	UC[2]	--	UC	UC[2]	--
Hong Kong (CN)	UC	V	V	UC	--	V
Iceland	**M**[2]	**M**[2]	V[2]	**M**[2]	**M**[2]	V[2]
India	**M**	(V)	V	--	--	--
Indonesia	UC	V	V	--	--	--
Iran	**M**	**M**[3]	--	--	--	--
Israel	**M**	**M**[3]	--	**M**	**M**[3]	--
Jamaica	--	**M**	--	--	**M**	--
Japan	**M**[6]	**M**	--	**M/V**[6]	**M**	--
Korea	**M**	**M**	--	**M**	**M**	--
Lichtenstein	**M**[2]	**M**[2]	V[2]	**M**[2]	**M**[2]	V[2]
Malaysia		(M)	--	--	(M)	--
Mexico	**M**[4]	**M**[4]	V	**M**[4]	**M**[4]	V
New Zealand	**M**[5]	**M**[5]	--	**M**[5]	**M**[5]	--
Norway	**M**[2]	**M**[2]	V	**M**[2]	**M**[2]	V
Peru	UC	UC	--	UC	UC	--
Philippines	UC	**M**	--	UC	**M**	--
Romania	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]	UC[2]
Russia	**M**	M[2]	--	**M**	M[2]	--
Singapore	--	--	V	--	--	V
South Africa	UC	M[2]	--	UC	M[2]	--
Switzerland	--	V[2]	V	--	V[2]	V
Chinese Taipei	**M**	--	V	--	--	V
Thailand	M	M	V	--	--	--
Tunisia	**M**[3]	**M**[3]	--	**M**[3]	**M**[3]	--
Turkey	UC[2]	**M**[2]	UC[2]	UC[2]	**M**[2]	UC[2]
United States	**M**	**M**	V	**M**	**M**	V
Uruguay	UC	UC	--	UC	UC	--
Venezuela	V[4]	**M**[4]	--	V[4]	**M**[4]	--
Vietnam	UC	UC	--	UC	UC	--

M = Mandatory, V = voluntary, UC = under consideration
[1] Framework legislation is passed but the implementing legislation is believed to still be under consideration.
[2] Harmonised with EU; [3]Partially harmonised with EU; [4] Partially or fully harmonised with USA
[5] Harmonised between Australia and New Zealand; [6] Japan requires the sales-weighted average efficiency of any suppliers' appliances to exceed a prescribed efficiency threshold. These requirements are mandatory but fines for non-compliance are very low and therefore they are sometimes described as voluntary targets. Nonetheless, being named and shamed for non-compliance is likely to have severe consequences in the Japanese marketplace and hence is thought to be an adequate deterrent by Japanese regulators.

[16] Source: "Can Energy-Efficient Electrical Appliances be considered "Environmental Goods"?, OECD Trade and Environment, Working Paper No. 2006-04.

energy-efficiency regulations for refrigerators and freezers or are likely to do so in the near future: Russia, Ukraine, Belarus, and Turkey.

The comparison of the different efficiency requirements for cold appliances around the world with those applied in the EU could be an interesting exercise in order to see if there are any major differences in performance. However, often the standard used to measure the energy consumption and the other parameters included in various labelling scheme and/or efficiency requirements are based on different measurement methods as is applied in Europe, which makes comparison difficult o even impossible. In particular, summarising the results of Task1:

- The NAFTA economies use a test procedure that has a 32,2 °C ambient test temperature and different internal operating temperatures than required in the EU.
  Australia and New Zealand also test at an ambient temperature of 32 °C and have a number of other differences compared to the ISO and European test conditions. Unfortunately, with the advent of “smart” electronics, it seems some suppliers can use control strategies to reduce the apparent energy used in an energy tests (by modifying or eliminating functions that are otherwise operational in normal use such as anti-sweat heaters) to obtain a favourable label in comparison with competitor products. Therefore in 2007 part of the standard was revised to address many loopholes and inadequacies in the previous edition. In addition, should products appear in the marketplace that meet the letter but not the intent of this Standard, then this standard will be amended accordingly.
- Korea and Taiwan both apply an ambient temperature of 30 °C.
- Japan now uses a test procedure and conditions very similar to EN 153 except that door openings are included, with an estimated increase in the energy consumption between 1-2% to 10% for average appliances. The standard will be changed in 2010 so that testing conditions more closely resemble actual use conditions and it would be possible to avoid the effect of control programmes embedded in the appliances which minimizes the operation of heaters under the standardised stable conditions, while under real conditions the operation of heaters, causing an increase in the electricity consumption.
- Most of the other countries mentioned use the ISO test procedures, which are identical to EN 153 except that the former allows tropical climate-class models to have their energy consumption tested at 32 °C, while under EN 153:2005 all appliances have their energy tested at 25 °C regardless of their climate class.

In this respect, COLD-II study concluded that although it would be of interest to compare the US efficiency requirements with the EU regulations using a theoretical conversion system; however, that was not possible within the confines of this study. Nonetheless, some anecdotal evidence was claimed to be available from a New Zealand-based manufacturer which sells its products in markets that use the AS/NZS test procedure as well as those using the ISO test procedures; this manufacturer reported that the improvement in energy efficiency required to convert its top-mounted refrigerator-freezers to meet the 2004 Australian efficiency requirements, which were (roughly) equivalent to the US efficiency requirements - is approximately the same as that needed to attain a class A rating under the EN 153/ISO test procedure and EU labelling in 2000.

A part from any anecdotal and unverifiable claim, according to AS/NZS 4474.1:2007 *Performance of household electrical appliances - Refrigerating appliances, Part 1: Energy consumption and performance*, published on 15 August 2007, because of the many significant differences between test conditions in the Australia Standard and those of ISO or North America, direct comparison of results obtained under any two of the test regimes are generally not possible.

7.1.1.1 Comparison of the Chinese, the Japanese and the EU efficiency requirements

Since China and Japan use the ISO standards for testing cold appliances as the basis for their national policy measures for cold appliances, the comparison of their efficiency requirement schemes with the EU one is meaningful.

a) Japan

Japan Top-runner sets a maximum level for the **weighted average of the energy efficiency (annual energy consumption) by the volume of shipments** that each manufacturer/importer shall not exceed per appliance category by a given year - usually four to ten years after the target has been announced. Those companies not achieving the target, risk being singled out in public announcements and possibly fined.
Japan announced its first target average energy-efficiency requirements for refrigerators, refrigerator-freezers in 1979, then updated from 1 April 2004. These targets were set to the level of the most energy-efficient model in each product category on the market as of 1999 - hence the name “Top Runner”. In 2010 the scheme will be revised according to already set specifications including the modification of the reference lines and the appliance classification (shown in Table 7.2 for comparison with the current criteria).

Table 7.2: Japanese ‘Top Runners’ cold appliance energy efficiency requirements for 2004-2009 and from 2010

Categories		**Type of appliance**	**Energy efficiency requirements**	
2004	2010		2004-2009, under JIS C9801:1999[1]	from 2010, under JIS C9801:2006[2]
Refrigerators				
a	A	natural convection air circulation	E = 0,427*Veq +178	E =0,844*Veq + 155
b		forced-air air circulation	E = 0,427*Veq +178	
	B	forced-air air circulation ≤ 300 litre		E = 0,774*Veq +220
	C	forced-air air circulation >300 litre, one door		E = 0,302*Veq +343
	D	forced-air air circulation >300 litre, 2 or more doors		E = 0,296*Veq +374
Refrigerator-freezers				
c	A	natural convection circulation	E = 0,433*Veq +320	E = 0,844*Veq +155
d		forced-air air circulation with special feature[3]	E = 0,507*Veq +147	
e		forced-air air circulation	E = 0,433*Veq +320	
	B	forced-air air circulation ≤ 300 litre		E = 0,774*Veq +220
	C	forced-air air circulation >300 litre, one door		E = 0,302*Veq +343
	D	forced-air air circulation >300 litre, 2 or more doors		E = 0,296*Veq +374
Freezers[4]				
a	A	natural convection air circulation	E = 0,281*Veq +353	E = 0,844*Veq +155
b		forced-air circulation	E = 0,281*Veq +353	
	B	forced-air circulation ≤ 300 litre		E = 0,774*Veq +220
	C	forced-air circulation >300 litre		E = 0,302*Veq +343

Notes:
[1]JIS C9801:1999 is almost identical to ISO and EN 153 standard a part form door opening.
[2]JIS C 9801:2006 has been modified to take into consideration testing conditions more close to actual use conditions especially for the so called highly functional refrigerators to reduce the difference between energy consumption values under current standard conditions and actual energy consumption
[3]‘Special features’ are defined as vacuum insulated panels and/or variable-speed compressors.

[4]The Japanese efficiency requirements make no distinction between upright and chest freezers.
Veq = equivalent volume (litres). The equivalent volume is calculated:

- for refrigerators and refrigerator-freezers: by multiplying rated internal volume of freezing compartment by 2,15 for three-star type, 1,85 for two-star type, 1,55 for one-star type (these factors are increased from 2010 to respectively 2,20, 1,87, 1,54) and then by adding the result to the rated internal storage volume excluding the freezing compartment;
- for freezers: by multiplying rated internal volume of freezing compartment by 2,15 for three-star type, 1,85 for two-star type, 1,55 for one-star type; these factors are increased from 2010 to respectively 2,20, 1,87, 1,54;
- the factors are modified since they are calculated according to a 22,4°C reference temperature that is the average of 15°C (winter temperature) and 30°C (summer temperature), found in a survey in 23 households of 8 prefectures in Japan.

E = energy consumption in kWh/year.
For a refrigerator-freezer whose freezing compartment can be switched to a chiller, the energy consumption is the larger of the values measured in respective modes.
Until 2009 manufacturers/importers that manufacture/import less than 2 000 units (300 units for freezers) in total are exempted. However, the display obligations must be met regardless of the number of units shipped.

The same target will be applied to all natural convection appliances (without any distinction between refrigerators, refrigerator-freezers and freezers), while for the forced air circulation a new classification will be introduced based on appliance volume (below or grater that 300 litre) and number of doors (one door or two and more). The new value of annual electricity consumption is labelled on products manufactured after 1st May 2006 and new energy efficiency requirements for refrigerators and freezers will be in place from 2010.

The 2010 Top-runner scheme will use a revised standard JIS C9801:2006, where test conditions were modified due to the increasing differences between the results of measurements of energy consumption of cold appliances under real life conditions and those based on current JIS C9801:1999. Differences are especially large for highly-functional refrigerators, with 3 to 5 doors, which as example may include (Figure 7.2) a top-mounted double door (side-by-side) refrigerator compartment at 4°C, a bottom mounted drawer freezer a7 -18°C on top on which a vegetable compartment at 5°C stands; an small ice box compartment and a multi-purpose compartment complete the appliance. Some heaters are installed in this product (to prevent the freezing in vegetable compartment and the frost formation in the door joints and the freezing of the ice-maker water supply hose) along with other energy consuming devices that makes the appliance energy consumption being much higher than when measured under current standard conditions.

Figure 7.2: ***Example of the so-called highly functional refrigerator-freezer in Japan***

It is interesting to note that the Japanese 2004-2009 requirements foresee a fixed energy-consumption bonus of 20 kWh/year for no-frost appliances compared to natural-convection appliances, whereas the EU scheme applies a variable factor that increases with equivalent volume. In addition, current Japanese efficiency requirements scheme applies much tougher levels for appliances using so-called 'special technologies' (VIPs and/or variable-speed compressors); in this case a typical no-frost refrigerator-freezer with an equivalent volume of 350 litres can only use two-thirds of the energy of the same appliance which does not use VIPs or variable-speed compressors.

Top-runner requirements for 2004-2009 for refrigerators and for freezers appear to be less demanding than the 1999 EU requirements (Figures 7.3 and 7.4). This may reflect the significantly smaller market share of these appliances in Japan and hence a lower importance attached to their improvement. For refrigerator-freezers, more dominant in the Japanese market than in the EU and among these no-frost models with the largest market share, Japanese Top Runner requirements were estimated to be about 22% more stringent for no-frost models and about 18% tougher for natural-convection models (if no account is taken of door openings these values are 12% and 8%, respectively) than the 1999 EU requirements (Figure 7.5). However, cold appliances on the EU market in 2005 complying with the CECED voluntary agreement were fully comparable with the Japanese Top Runner 2004-2009 fleet requirements when refrigerator-freezers are considered and more efficient in the case of refrigerators and freezers (Figures 7.3-7.4).

The comparison of the Top-runner efficiency requirements (maximum annual energy consumption) for refrigerators and refrigerator-freezers in 2004-2009 and from 2010 is shown in Figure 7.6 for refrigerator and refrigerator-freezers and in Figure 7.6 for freezers. In Figure 7.6 the vertical line at 480 litre of equivalent volume corresponds to a net volume of 300 litre for a refrigerator-freezer with 150 litre of refrigerator compartment and 150 litre of freezer compartment; in Figure 7.7 The vertical line at 660 litre of equivalent volume corresponds to a freezer with a net volume of 300 litres. Since testing temperature has been modified from 25°C to 15°C and 30°C, the absolute levels of the threshold sets for 2004 and 2010 cannot be easily compared. In addition, natural convection appliances are tested without door openings in the new standard.

In Figure 7.8[17] the a comparison of the requirements for the different appliance categories are more clearly shown: threshold lines for forced air appliances with a net volume lower than 300 litres are different from threshold lines of models with a higher net volume, irrespective of the appliance category.

Top-runner is not applied to electric refrigerators of absorption type, appliances applying the Peltier method, vehicle-mounted electric refrigerators and freezers and commercial electric refrigerators and freezers.

[17] Source: Final Report by Electric Refrigerator Evaluation Standards Subcommittee, Energy Efficiency Standards Subcommittee of the Advisory Committee for Natural Resources and Energy, June 2006.

Figure 7.3: Comparison of the Japanese 'Top Runner' cold appliance efficiency requirements (maximum annual energy consumption) for refrigerators applicable from 2004, EU 1999 requirements, 2005 results of the Industry Voluntary Commitment and EU energy labelling class A threshold. Japanese corrected energy-consumption values have been adjusted by 10% to take account of the use of door openings in the standard

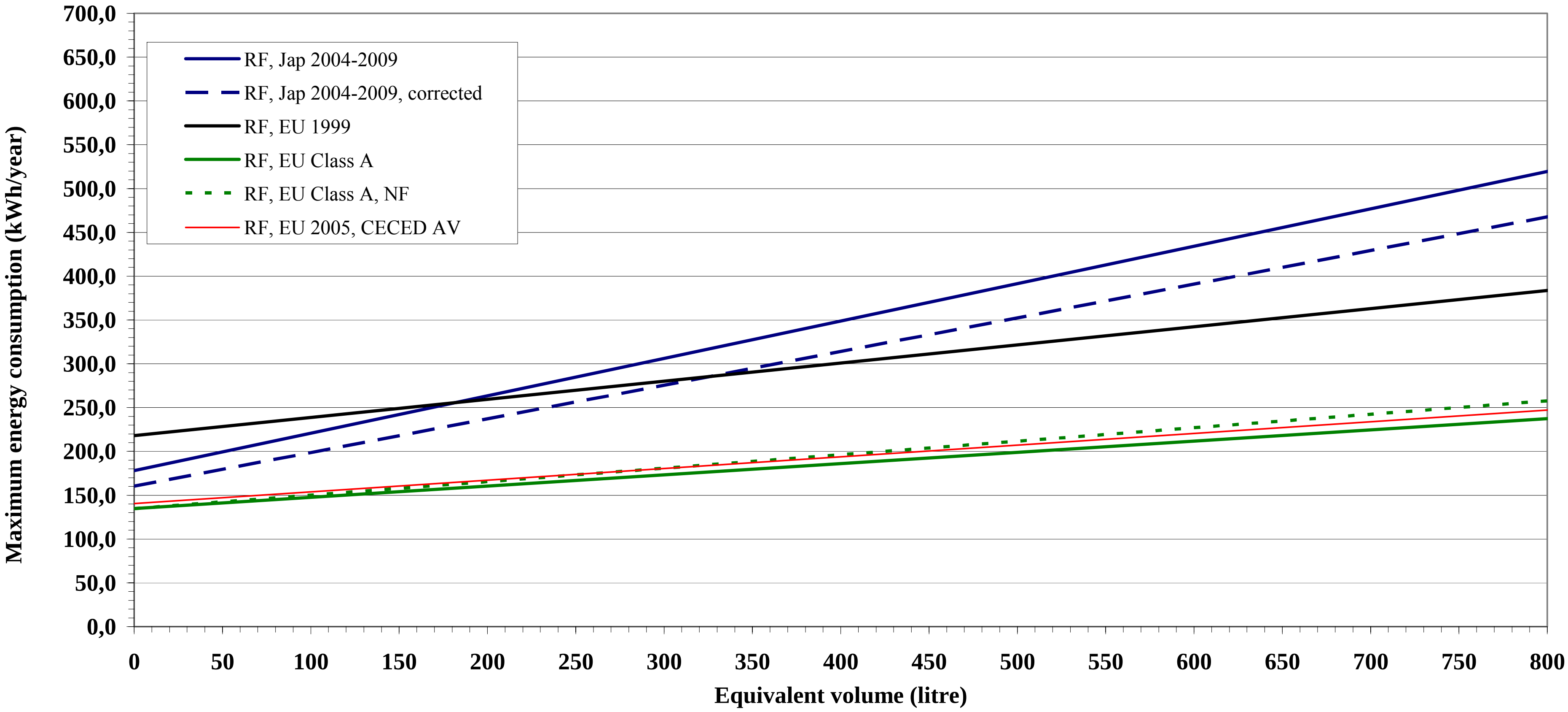


Figure 7.4: Comparison of the Japanese 'Top Runner' cold appliance efficiency requirements (maximum annual energy consumption) for refrigerator-freezers applicable from 2004, EU 1999 requirements, 2005 results of the Industry Voluntary Commitment and EU energy labelling class A threshold. Japanese corrected energy-consumption values have been adjusted by 10% to take account of the use of door openings in the standard

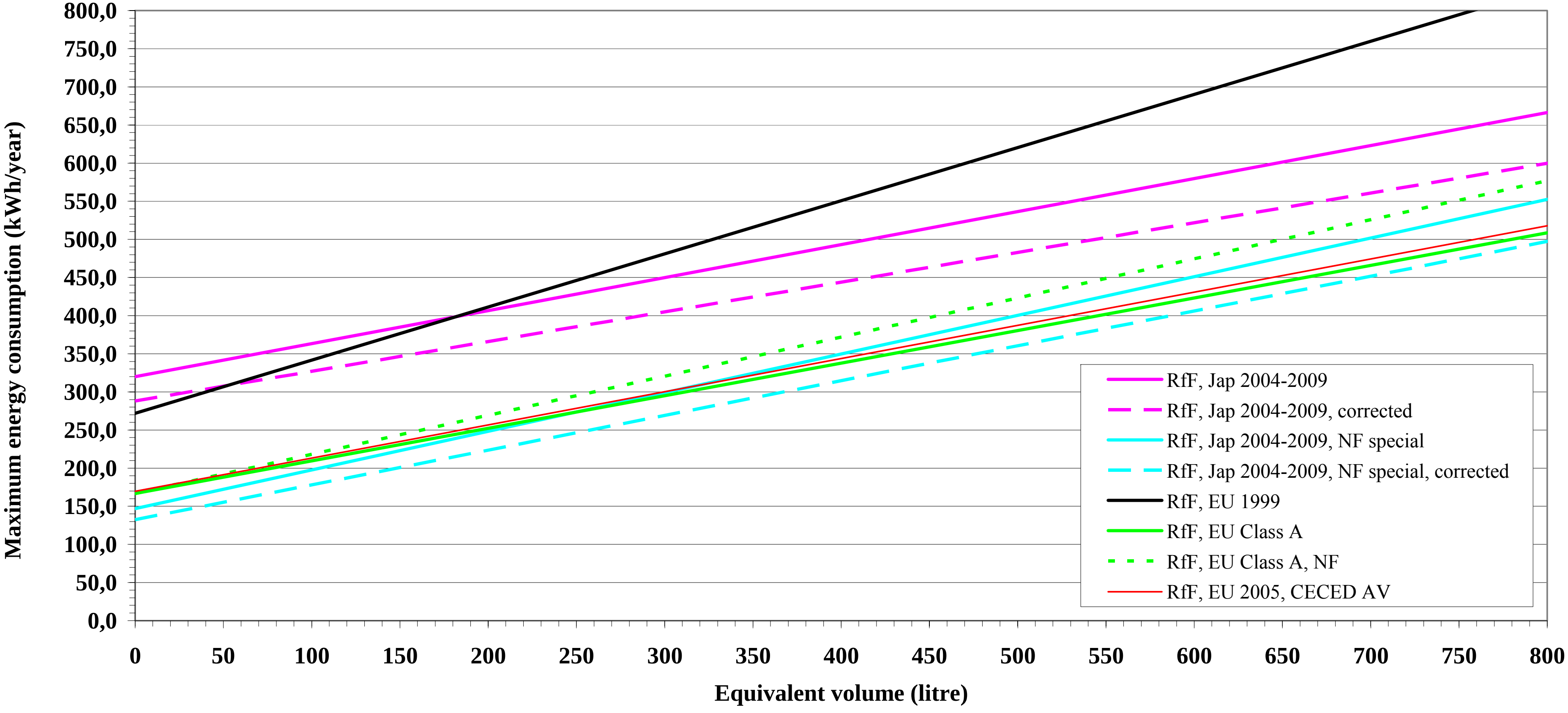


Figure 7.5: Comparison of the Japanese 'Top Runner' cold appliance efficiency requirements (maximum annual energy consumption) for freezers applicable from 2004, EU 1999 requirements, 2005 results of the Industry Voluntary Commitment and EU energy labelling class A threshold. Japanese corrected energy-consumption values have been adjusted by 10% to take account of the use of door openings in the standard

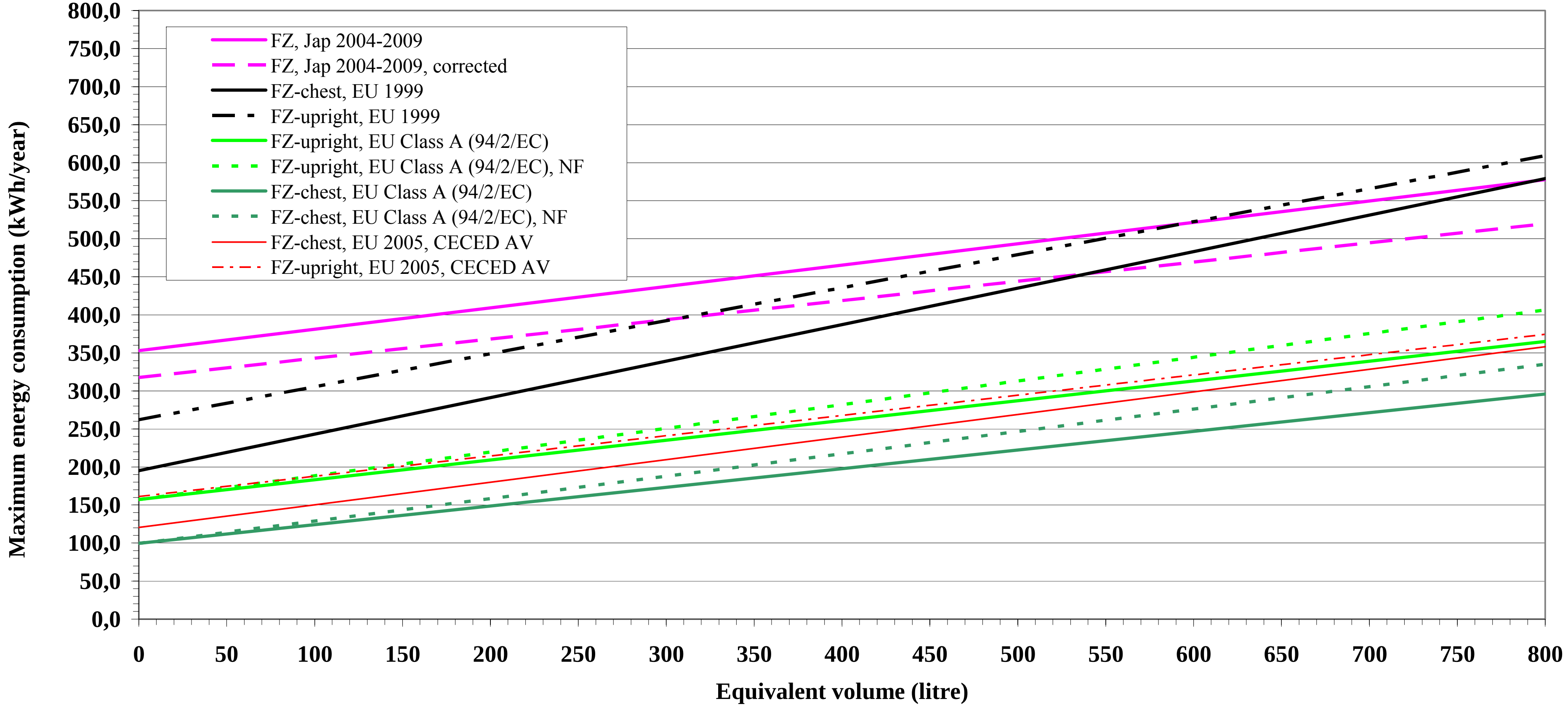


Figure 7.6: Comparison of the Japanese 'Top Runner' cold appliance efficiency requirements (maximum annual energy consumption) for refrigerators and refrigerator-freezers in 2004-2009 and from 2010. Testing temperature has been modified from 25°C to 15°C and 30°C; natural convection appliances are tested without door openings. The vertical line at 480 litre of equivalent volume corresponds to a net volume of 300 litre for a refrigerator-freezer with 150 litre of refrigerator compartment and 150 litre of freezer compartment

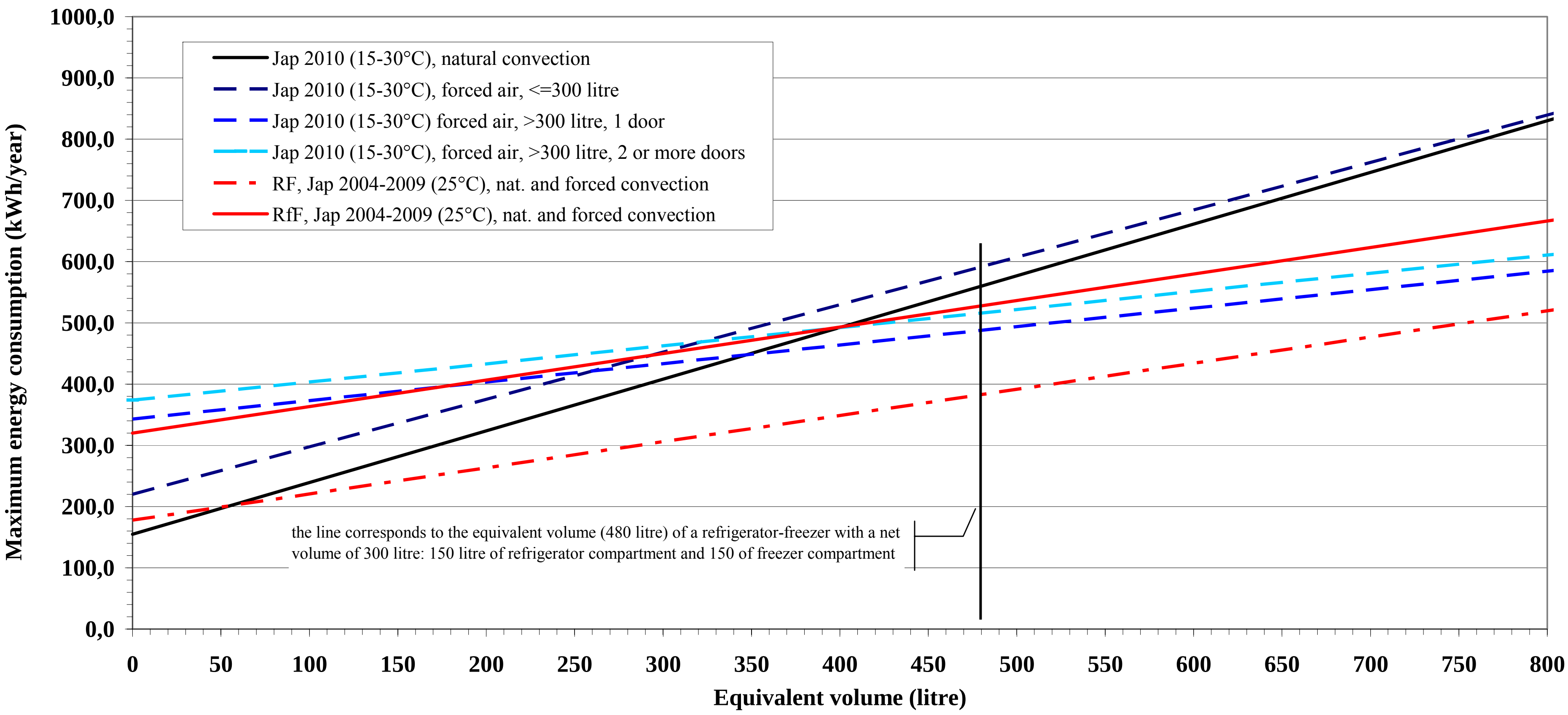


Figure 7.7: Comparison of the Japanese 'Top Runner' cold appliance efficiency requirements (maximum annual energy consumption) for freezers in 2004-2009 and from 2010. Testing temperature has been modified from 25°C to 15°C and 30°C; natural convection appliances are tested without door openings. The vertical line at 660 litre of equivalent volume corresponds to a freezer with a net volume of 300 litres

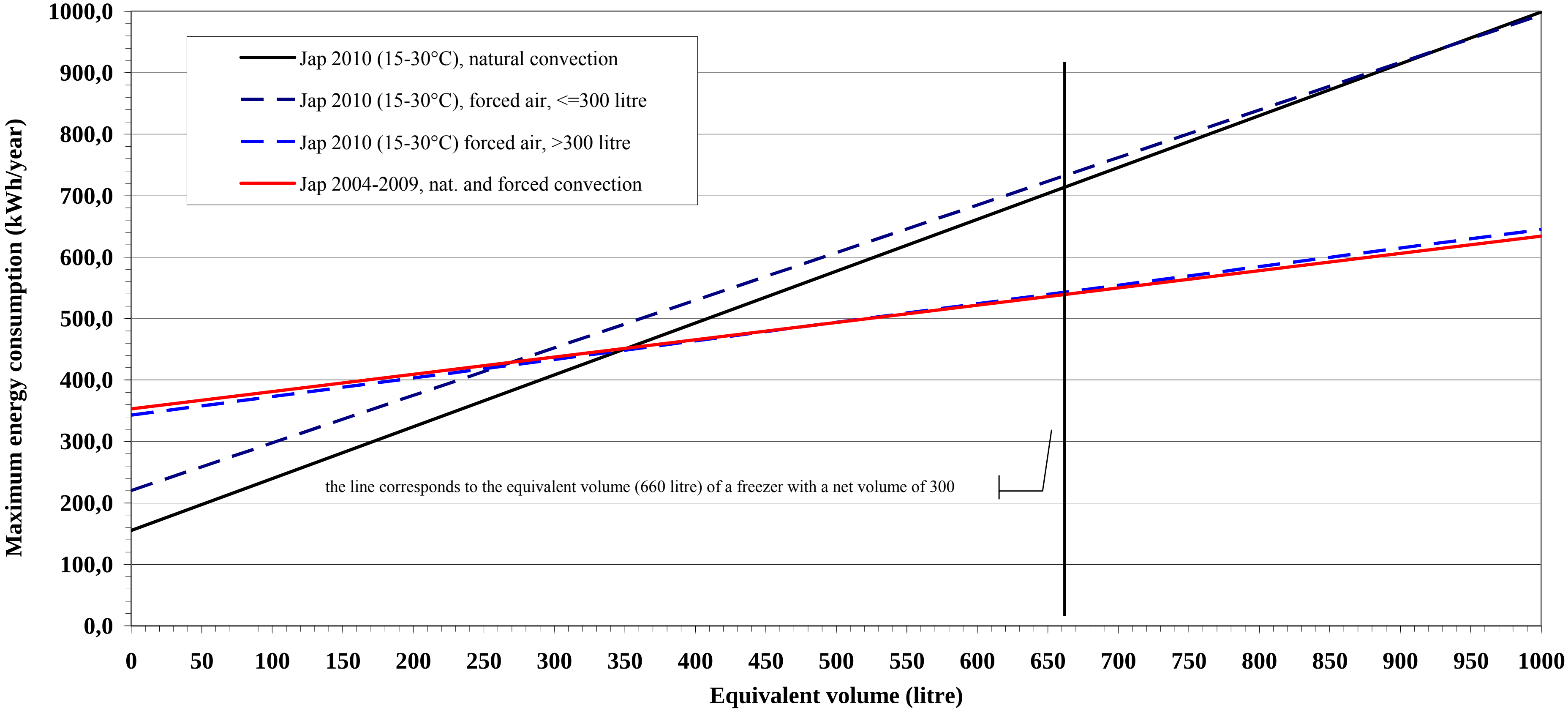
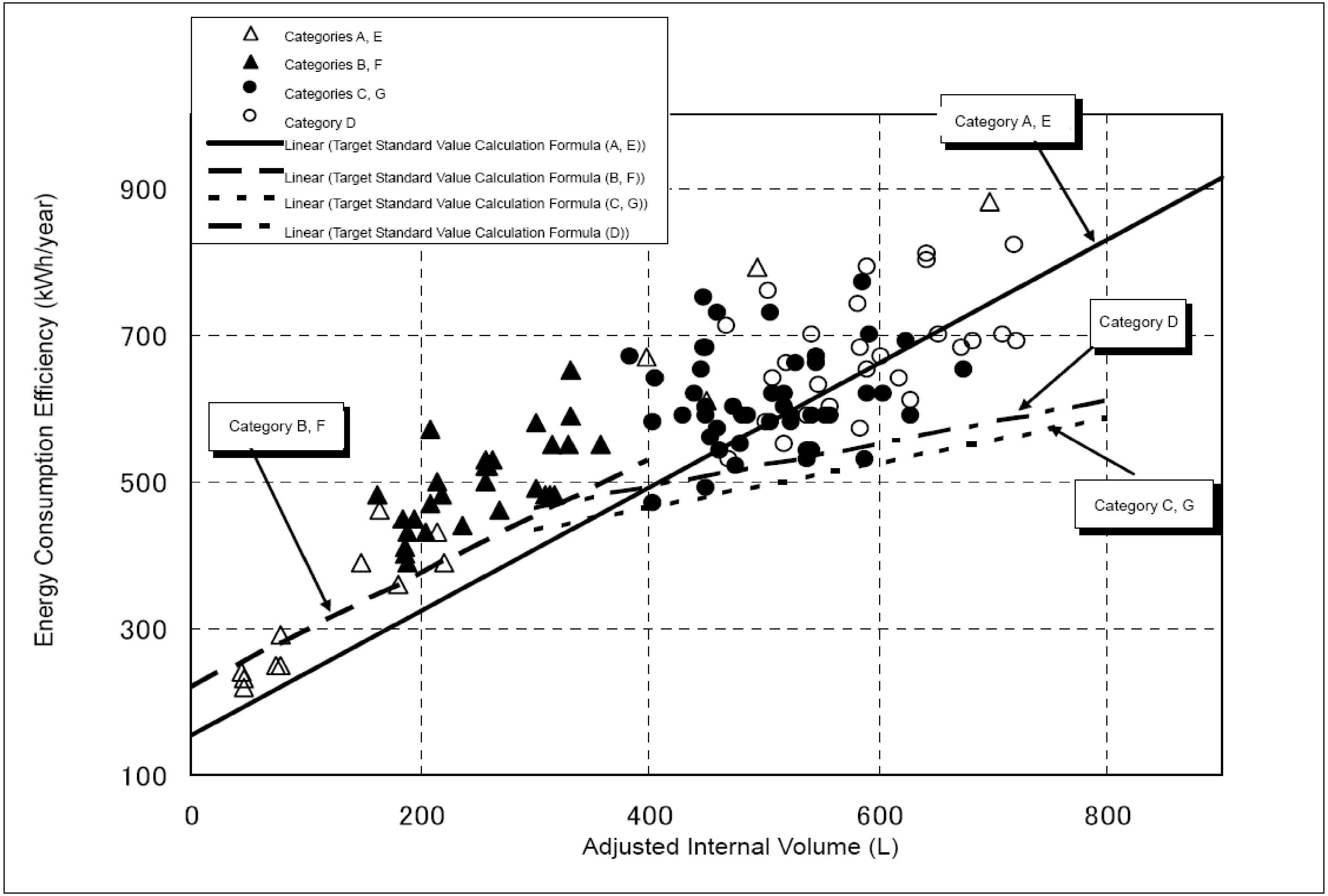


Figure 7.8: Comparison of Japanese Top Runner requirements in 2010 for the different appliance categories; specific threshold lines are set for natural convection appliances



In Table 7.3 the maximum annual energy consumption of the cold appliance standard base cases (for the technical characteristics see Task 5) are calculated under the Japanese Top Runner 2004 and 2010 requirements, and compared with the EU 1999 requirements, the 2005 target for the voluntary industry commitment, the 1999 requirements and the thresholds of energy efficiency classes A and A+ according to directive 2003/77/EC. As already said, the 2010 energy consumption is not comparable with the 2004 requirements.

The energy consumption of the EU standard base cases are: refrigerators 163,7 kWh/years, refrigerator-freezers 324,4 kWh/year, upright freezers 274,5 kWh/kg and chest freezers 300,6 kWh/year. All models have a net volume lower than 300 litres.

Table 7.3: **Maximum annual energy consumption for 2005 standard base cases**

Standard base cases in 2005	Japan Top Runner		EU				
			96/57/EC	94/2/EC	Industry VA		2003/66/EC
	2004	2010*	1999	class A	2005	EEI_{aver}	class A+
(type)	(kWh/year)	(kWh/year)	(kWh/year)	(kWh/year)	(kWh/year)	EEI	(kWh/year)
Refrigerator	273,2	343,2	275,9	163,3	162,7	54,8	126,9
Refrigerator, No-frost	293,2	392,6	287,5	169,0	168,4	54,8	131,7
Refrigerator-freezer, 2 doors	472,9	455,8	530,4	317,5	323,9	56,1	254,0
Refrigerator-freezer, NF, 2d	492,9	495,9	582,1	347,7	354,7	56,1	279,3
- if with special features	306,0	495,9	582,1	347,7	354,7	56,1	279,3
Freezer, upright	460,5	485,5	446,4	256,6	263,2	56,4	227,6
Freezer, upright, No-frost	480,5	523,1	481,3	276,5	295,4	56,4	246,7
Freezer, chest	506,5	626,6	470,2	233,5	282,8	66,6	239,2

*energy consumption is measured with a new standard with modified test conditions

The cold appliance labelling scheme(s) in Japan are very different from the EU one.

b) China

In China the cold appliance categories and coefficients to calculate the threshold lines in 2003 were set at 95% of the EU labelling scheme 1994 reference line (the threshold between class D and E). The comparison of the prescribed maximum daily consumption values as well as the European labelling scheme for refrigerators with a total volume of 220 litre (the most popular refrigerator type in China today) is presented in Table 7.4, along with the EU label value for class A/A+. An additional 10% savings is scheduled to take effect in 2007, to reach an EEI around 85 of the EU labelling scheme or about energy efficiency class C.

The draft plan for management of the Chinese labelling program was completed at the end of 2003[18]. Regulations to create the energy efficiency label were approved in 13 August 2004 and took effect on 1 March 2005. Refrigerators are the first product to use the label (Figure 7.9). This label is similar to the EU energy label, but with a number instead of letter scale and divided into 5 levels. Energy use thresholds for each label category is expressed as a percentage of the maximum energy consumption of the efficiency requirements, which is the maximum threshold for Grade 5.

[18] Source: UN Department of Economic and Social Affairs Division for Sustainable Development, Case Studies of Market Transformation: Energy Efficiency and Renewable Energy, United Nations, New York, 2005.

Table 7.4: **Cold appliance categories and coefficients to calculate the efficiency requirements in 2003 in China**

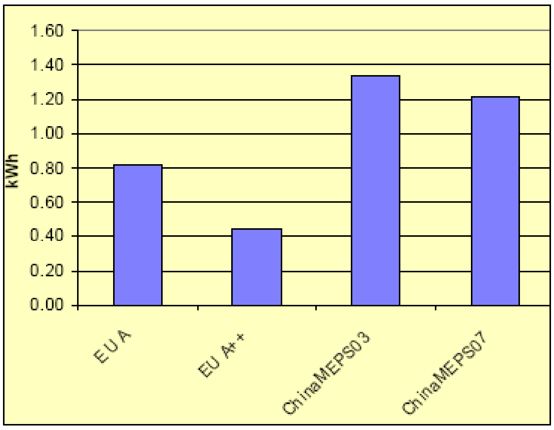
Categories	M	N	Maximum daily energy use comparison (for a 220 litre refrigerator)
Refrigerator, no star compartment	0,221	233	
Refrigerator, 1 star compartment	0,611	181	
Refrigerator, 2 star compartment	0,428	233	
Refrigerator, 3 star compartment	0,624	223	
Refrigerator-freezer	0,697	272	
Frozen food cooler	0,530	190	
Food freezer	0,657	205	

Figure 7.9: China's information label for refrigerators

$\eta \leq 55\%$	1
$55\% < \eta \leq 65\%$	2
$65\% < \eta \leq 80\%$	3
$80\% < \eta \leq 90\%$	4
$90\% < \eta \leq 100\%$	5

For refrigerators and freezers, the noise limits depend to the appliance type and volume as presented in Table 7.5.

Table 7.5: **Noise limits for refrigerators and freezers in China in 2005.**

Volume	Direct-cooled refrigerators	Air-cooled refrigerators	Chest freezers
(litre)	(dBA)	(dBA)	(dBA)
≤ 250	45	47	47
> 250	48	52	55

7.1.2 A worldwide approach to energy efficiency of cold appliances ?

A recently published APEC (ASIA-Pacific Economic Cooperation) monograph sponsored by Australian and co-sponsored by New Zealand and United States[19] presents a vision for international cooperation on energy efficiency requirements and labelling achieved through a series of invited workshops on four continents sponsored by the Australian Greenhouse Office to prompt discussion about a common strategic vision on energy-efficiency requirements and labelling, with the aim to develop a consensus on implementing the best possible scheme in each economy within APEC.

The issue was initiated by the recognition of the management within the Australian Greenhouse Office that the Australian program could benefit from a change to its then-insular approach. Rather than negotiating with resident industry representatives about possible improvements in the energy efficiency of products manufactured in, or imported into Australia, an opportunity existed to shift the focus to examining and matching the product-efficiency targets proposed in the major trading economies in North America, Asia and Europe. The Ministerial Council on Energy accepted recommendations for sweeping changes to the Australian standards and labelling program, allowing any product consuming energy to be considered for inclusion in mandatory or voluntary measures based on equivalent efficiency standards in a major trading partner economy.

The number of nations adopting energy efficiency standards and labels is growing rapidly, from 9 in 1984 to 36 in 1994 to 56 in 2004. The number of regulations worldwide on individual appliances and equipment is growing even more rapidly, increasing from 543 to 878 between 2000 and 2004. There is a need among these countries for harmonized test facilities and protocols, mutual recognition of test results, common comparative energy label content, harmonized endorsement energy labels, harmonized minimum energy requirements for some markets, shared learning of the labelling process, and shared learning of the standard-setting process. Such an approach allows countries, companies, and consumers to avoid the costs of duplicative testing and non-comparable performance information, while benefiting from a reduction in non-tariff trade barriers and access to a wider market of goods. Such an approach reduces the aggregate cost among the world's governments of designing and implementing the energy-efficiency regulations and labels.

Some critical elements and priority list of actions emerged from the mentioned APEC document:

- The primary focus is on standards alignment, as the most useful basis for comparability and a pre-requisite for the benchmarking of product performance and policies. Harmonised (aligned) standards and test facilities is the first step towards mutual recognition of test results. However, when harmonising standards some of the local/regional specificity could be lost.
- Worldwide standardisation bodies IEC/ISO are working towards globally applicable standards, but there also needs to be recognition that there are bilateral treaties, multilateral organizations, such as APEC and several regional trading blocks, and global organizations, such as WTO, who are critical institutions when policy measures are set. This is also the institutional context within which the multi-nationals who deliver energy efficient products also operate to influence policies.
- Shared learning of the labelling and requirements setting process is part of the capacity building in markets and regions only recently starting to address the eco-energy efficiency of end-uses. It

[19] A Strategic Vision for International Cooperation on Energy Standards and Labelling, A monograph with commentary by international experts, June 2006. Prepared as part of the self-funded APEC project, A Vision for Cooperation on Energy Standards and Labelling Programs. Published by Australian Greenhouse Office.

is the basis for the setting of comparative energy label content, harmonized endorsement energy labels, and harmonized energy efficiency requirements (at least for some markets).

- The importance of regional collaborations should not be understated towards international ones. They are crucial to the evolution of the practice of efficiency requirements setting and labelling, and in the long run the interregional activities will likely dominate.
- In the road towards harmonization and alignment, there is a need to recognize that the short- and long-term benefits for different local and global stakeholders may be different. More often than not, even countries in favour of alignment need to provide a time period or temporary incentives to enable the local industry to adjust. The experts working in the field of efficiency requirements and labelling must respect the pace of progress toward harmonization and alignment.
- The critical issue facing efficiency requirements and labelling programs is the need for establishing consistent and cost-effective mechanisms for collection and analysis of end-use data, which can, in turn, provide a baseline and monitored information on savings for the investor. Otherwise, the belief that efficient appliances leads to energy conservation or savings can be challenged.

Finally, it should be reminded that the adoption of the WTO (World Trade Organization) Technical Barriers to Trade Agreement (TBT) places an obligation on IEC to ensure that the International Standards it develops, adopts and publishes are globally relevant. International Standards and other type of Publications are globally relevant when they can be used or implemented as broadly as possible by all stakeholders in markets around the world. According to WTO[20], in order to serve the interests of the WTO membership in facilitating international trade and preventing unnecessary trade barriers, international standards need to be relevant and to effectively respond to regulatory and market needs, as well as scientific and technological developments in various countries. They should not distort the global market, have adverse effects on fair competition, or stifle innovation and technological development. In addition, they should not give preference to the characteristics or requirements of specific countries or regions when different needs or interests exist in other countries or regions. Whenever possible, international standards should be performance based rather than based on design or descriptive characteristics.

7.2 Subtask 7.2: Worldwide Compliance Assessment

Two elements should be taken into consideration in the discussion about the assessment of the compliance of major household appliances to policy measures:

- the measurement certification: the number of units to be tested by suppliers before any declaration or compliance to a criteria claimed is done (and relevant technical documentation reported to regulators) and the way the measured quantities are treated before declaration/compliance
- the enforcement verification of the declared values: either labelling declarations or minimum requirements (threshold values).

7.2.1 The Measurement Declaration

7.2.1.1 Australia

In Australia the registration for energy labelling and minimum energy efficiency requirements is

[20] Source: WTO second triennial review of the operation and implementation of the agreement on Technical Barriers to Trade, Annex 4.

mandatory. To obtain registration of a product, manufacturers are generally required to submit test reports to demonstrate compliance with the requirements of the relevant Australian standard. The veracity of the energy consumption, efficiency and performance values claimed in these reports are usually accepted on initial application without requirement for verification through independent testing.
For household appliances the number of units to be tested are reported in the relevant standard. In particular:

- **washing machines**: for the purpose of determining the CEC (Comparative Energy Consumption) of a model for labelling, 3 separate units of the model shall be tested for energy consumption and standby power. At the supplier's discretion, more than three units may be tested. Each unit shall be subjected to at least one valid test run to obtain values of E_t standby power and Water Extraction Index (WEI) for that unit. Where more than one test run is performed on a unit, the value of E_t and WEI shall be recorded for each run and then averaged and treated as the results for that unit. The measured values for the three units are averaged and declared rounded to the nearest whole kWh/year.
  The minimum performance criteria shall be met by each individual unit tested on the program for energy efficiency labelling;
- **dishwashers**: for the purpose of determining the CEC (Comparative Energy Consumption) of a model for labelling, 3 separate units of the model shall be tested for energy consumption and standby power. At the supplier's discretion, more than three units may be tested. Each unit shall be subjected to at least one valid test run to obtain values of E_t and standby power for that unit. Where more than one test run is performed on a unit, the value of E_t shall be recorded for each run and then averaged and treated as the result for that unit. The measured values for the three units are averaged and declared rounded to the nearest whole kWh/year.
  The minimum performance criteria shall be met by each individual unit tested on the program for energy efficiency labelling,
- **cold appliances**: for the purpose of determining the CEC (Comparative Energy Consumption) of a model for labelling, 3 separate units of the model shall be tested for energy consumption. At the supplier's discretion, more than three units may be tested. Each unit shall be tested with sufficient test runs to enable a valid value of E_t to be determined for that unit. This determination shall be documented in a test report containing the test results for all test runs used to derive E_t (E_t is expressed in Wh per 24 hours and is rounded to the nearest whole number). After testing three or more separate units, the separate values of PAEC (Projected Annual Energy Consumption, in kWh/year to be calculated from E_t) shall be averaged and referred to as $PAEC_{av}$ The average PAEC is rounded to the nearest unit to obtain the minimum allowable value for CEC.
  The minimum performance criteria shall be met by each individual unit tested on the program for energy efficiency labelling.

7.2.1.2 USA

a) Energy and water conservation requirements

The CFR, Title 10: Energy, Part 430 - Energy Conservation Program for Consumer Products, Subpart F - *Certification and Enforcement*, sets forth the procedures to be followed for certification and enforcement testing to determine whether a basic model of a covered product complies with the applicable energy conservation requirements or water conservation requirements (in the case of faucets, showerheads, water closets, and urinals) set forth in Subpart C - *Energy and Water Conservation Standards* of Part 430. Energy conservation requirements and water conservation requirements include minimum levels of efficiency and maximum levels of consumption, and prescriptive energy design requirements.

For certification purposes, each manufacturer or private labeller before distributing in commerce any basic model of a covered product shall certify by means of a compliance statement and a certification report that each basic model(s) meets the applicable energy conservation requirements or water conservation requirements as prescribed in section 325 of the Act. The compliance statement, signed by the company official submitting the statement, and the certification report(s) shall be sent to DOE, Office of Energy Efficiency and Renewable Energy, Office of Codes and Standards.

The above-mentioned Subpart F - *Certification and Enforcement* includes two Appendixes:
- Appendix A: Compliance Statement and Certification Report
- Appendix B: Sampling Plan for Enforcement Testing.

In Appendix A an example of the compliance statement and certification report is given. The compliance statement is signed by a responsible official of the above named company. The basic model(s) listed in certification reports comply with the applicable energy conservation standard or water (in the case of faucets, showerheads, water closets, and urinals) conservation standard. All testing on which the certification reports are based was conducted in conformance with applicable test requirements prescribed in 10 CFR part 430 subpart B. All information reported in the certification report(s) is true, accurate, and complete. The company is aware of the penalties associated with violations of the Act, the regulations thereunder, and is also aware of the provisions, which prohibits knowingly making false statements to the Federal Government.

For purposes of a certification of compliance, the determination that a basic model complies with the applicable energy/water requirements is based upon a defined sampling procedure[21]. The sample to be selected and tested comprises units which are production units, or are representative of production units of the basic model being tested, and shall meet the following applicable criteria:

a) for each basic model of **refrigerators, refrigerator-freezers and freezer**, a sample of sufficient size shall be tested to insure that:
- any represented value of estimated annual operating cost, energy consumption or other measure of energy consumption of a basic model for which consumers would favour lower values shall be no less than the higher of (A) the mean of the sample or (B) the upper 95% confidence limit of the true mean divided by 1,10, and
- any represented value of the energy factor or other measure of energy consumption of a basic model for which consumer would favour higher values shall be no greater than the lower of (A) the mean of the sample or (B) the lower 95% confidence limit of the true mean divided by 0,90;

b) for each basic model of **dishwashers**, a sample of sufficient size shall be tested to insure that:
- any represented value of estimated annual operating cost, energy consumption or other measure of energy consumption of a basic model for which consumers would favour lower values shall be no less than the higher of (A) the mean of the sample or (B) the upper 97,5% confidence limit of the true mean divided by 1,05, and
- any represented value of the energy factor or other measure of energy consumption of a basic model for which consumers would favour higher values shall be no greater than the lower of (A) the mean of the sample or (B) the lower 97,5% confidence limit of the true mean divided by 0,95;

c) for each basic model of **washing machine**, a sample of sufficient size shall be tested to insure

[21] CFR, Title 10: Energy, PART 430 - Energy Conservation Program for Consumer Products, Subpart B - Test Procedures, paragraph 430.24 – Units to be tested.

that:

- any represented value of estimated annual operating cost, energy consumption or other measure of energy consumption of a basic model for which consumers would favour lower values shall be no less than the higher of (A) the mean of the sample or (B) the upper 97,5% confidence limit of the true mean divided by 1,05, and
- any represented value of the energy factor or other measure of energy consumption of a basic model for which consumers would favour higher values shall be no greater than the lower of (A) the mean of the sample or (B) the lower 97,5% confidence limit of the true mean divided by 0,95.

b) Appliance labelling

The CFR, Title 16, Part 305 - *Rule concerning disclosures regarding energy consumption and water use of certain home appliances and other products required under the energy policy and conservation act ("appliance labelling rule")*, establishes requirements for consumer appliance products with respect to energy/water labelling and/or marking the products with information indicating their operating cost (or different useful measure of energy consumption) and related information. It states that the determinations of the estimated annual energy consumption, the estimated annual operating costs, the energy efficiency ratings, and the efficacy factors of refrigerators and refrigerator-freezers, freezers, dishwashers, water heaters, room air conditioners, washing machines, central air conditioners and heat pumps, furnaces, pool heater and fluorescent lamp ballasts, are those located in 10 CFR part 430, subpart B, where the Department of Energy has adopted and published test procedures for measuring energy usage or efficiency, according to the sampling procedures set forth in the same subpart B (except general service fluorescent lamps, medium base compact florescent lamps, and general service incandescent lamps, including incandescent reflector lamps).

Test data shall be kept on file by the manufacturer of a covered product for a period of two years after production of that model has been terminated. Upon notification by the Commission or its designated representative, a manufacturer or private labeller shall provide, within 30 days of the date of such request, the underlying test data from which the water use or energy consumption rate, the energy efficiency rating, the estimated annual cost of using each basic model, or the light output, energy usage and life ratings and, for fluorescent lamps, the colour rendering index, for each basic model or lamp type were derived.

7.2.1.3 The European Union

a) Energy labelling and efficiency requirements

In the EU the veracity of the energy consumption, efficiency and performance values and other information contained in the label and the fiche are accepted without requirement for verification through independent testing. But Member States shall take all necessary measures to ensure that all suppliers and dealers established in their territory fulfil their obligations under the different Directives.

Suppliers (manufacturers and importers) are required to establish technical documentation, sufficient to enable the accuracy of the information contained in the label and the fiche to be assessed. It shall include (i) a general description of the product, (ii) the results of design calculations carried out, where these are relevant, (iii) test reports, where available, including those carried out by relevant notified organizations as defined under other Community legislation, (iv) where values are derived from those obtained for similar models, the same information for these models. The supplier shall make this documentation available for inspection purposes for a period ending five years after the last product has been manufactured.

The information required by the relevant Directives shall be measured according to the harmonised standards, the reference numbers of which have been published in the Official Journal of the European Communities and for which Member States have published the reference numbers of the national standards transposing those harmonized standards.

Both in the energy labelling and efficiency requirement schemes and in the relevant standards there is no specific request to test more than one unit of the model.

b) The eco-label scheme

According to the Annex of Commission Decision (2004/669/EC) of 6 April 2004 establishing the ecological criteria for the award of the Community eco-label to **refrigerators**, and amending Decision 2000/40/EC, for the measurement declaration, the applicant has to provide a copy of the technical documentation referred to under article 2 paragraph 1 of Commission Directive 94/2/EC as amended by Commission Directive 2003/66/EC, including the reports of at least three measurements of energy consumption made according to EN 153 and the test guidelines as detailed in CECED's Operational Code. The arithmetic mean of these measurements shall be less or equal to the energy efficiency ecolabel requirement (energy efficiency class A+ or A++). In addition, the value declared on the energy label shall not be lower than this mean value, and the energy efficiency class indicated on the energy label shall correspond to this mean value.

According to the Annex of Commission Decision (2000/45/EC) of 17 December 1999 establishing the ecological criteria for the award of the Community eco-label to **washing machines** (as amended by Decisions 2003/240/EC of 24.03.2003, and 2005/783/EC, of 14 October 2005), the applicant has to provide a copy of the technical documentation referred to under Article 2(1) of Directive 95/12/EC. This documentation shall include the reports of at least three measurements of energy consumption, the water consumption, the spin extraction and the noise made according to EN 60456:1999, using the same standard 60°C cotton cycle as chosen for Directive 95/12/EC. The arithmetic mean of these measurements shall be less or equal to the above requirement. The value declared on the energy label shall not be lower than this mean value, and the energy efficiency class and the spin-drying efficiency class indicated on the energy label shall correspond to this mean value. The noise value shall appear on the energy label. In case of verification, which is not required on application, competent bodies shall apply the tolerances and control procedures laid down in EN 60456:1999.

For **dishwashers**, according to the Annex of Commission Decision (2001/689/EC) of 28 August 1999 establishing the ecological criteria for the award of the Community eco-label to dishwashers (as amended by Decision 2005/783/EC, of 14 October 2005), the applicant has to provide a copy of the technical documentation referred to under Article 2(1) of Directive 97/17/EC. This documentation shall include the reports of at least three measurements of energy consumption, the water consumption and the noise made according to EN 50242, using the same programme cycle as chosen for Directive 95/12/EC. The arithmetic mean of these measurements shall be less or equal to the above requirement. The value declared on the energy label shall not be lower than this mean value, and the energy efficiency class indicated on the energy label shall correspond to this mean value. The noise value shall appear on the energy label. In case of verification, which is not required on application, competent bodies shall apply the tolerances and control procedures laid down in EN 50242.

7.2.1.4 Comparison of the declaration procedures

In Table 6.6 the described test procedures are compared to highlight the differences and similarities in the procedures.

Table 7.6: **Comparison of the declaration procedures (minimum units to be tested) for household appliances in selected Countries worldwide**

Country	**Product**	**RF** (n)	**FZ** (n)	**WM** (n)	**DW** (n)	Product registration (y/n)
AU/NZ	EE requirements	3	3	3	3	Y
AU/NZ	Labelling	3	3	3	3	Y
USA	EE requirements	sufficient size for 95% confidence limit		sufficient size for 97,5% confidence limit		N
USA	Labelling	sufficient size for 95% confidence limit		sufficient size for 97,5% confidence limit		N
EU	EE requirements	1	1	1	1	N
EU	Labelling	1	1	1	1	N
EU	Ecolabel	3	3	3	3	Y

7.2.2 The verification procedures

7.2.2.1 Australia

National Appliance and Equipment Energy Efficiency Program Administrative Guidelines"[22] have been developed and agreed by all Australian regulators. Although not legally binding, the purpose of the Guidelines is to explain how the national legislative scheme for energy labelling and minimum energy efficiency requirements are intended to be administered, to act as a guide to relevant State and Territory regulatory agencies to facilitate uniform and consistent practice among State and Territory regulatory agencies and to explain to stakeholders the responsibilities of relevant State and Territory regulatory agencies and the responsibilities of industry.

An essential element of the E_3 Program is ensuring that manufacturers' energy efficiency and performance claims accurately reflect the information contained within their original application for registration. This verification process is known as 'check testing' and is effectively the major quality assurance procedure for the energy labelling and minimum energy efficiency requirements schemes in Australia., that ensures that the scheme maintains high levels of credibility both with consumers and manufacturers.

The Guidelines include, *inter alia*, a detailed description of the programme compliance monitoring through laboratory check testing. The E_3 Committee is charged with the ongoing management of these guidelines and conducts since 1991 a national check testing program to provide the community and stakeholders with data on accuracy of the labelling scheme and compliance by suppliers.

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[22] "Administrative Guidelines for the Appliance and Equipment Energy Efficiency Program of Mandatory Labelling and Minimum Energy Performance Standards", Edition 5, June 2005, downloadable from: www.energyrating.gov.au/pubs/admin-guidelines.pdf

a) Check testing programme and principles

Appliances are purchased from retail outlets or obtained anonymously and tested in NATA accredited independent laboratories to verify the claims associated with the energy label and minimum requirements where applicable for six appliance types (air conditioners, ballasts, dryers, washing machines, dishwashers, electric motor, refrigerated display cabinets, refrigerators & freezers and water heaters).

As part of the National Greenhouse Strategy, the E_3 Committee allocates around a quarter of its budget (in excess of 300.000 AU$ in 2002) to conduct check testing in laboratories and related testing used for standards development and round robins, measures compliance on a regular basis and benchmarks against overseas results. From modest beginnings, the national program now tests as many as 100 products per year. Models **are not randomly selected** for check testing, rather **sophisticated selection criteria and market intelligence** are used to target testing towards **models more likely to fail**.

b) Selection criteria

Recommendations for appliance and equipment groups and models to be check tested are to be based on the following criteria, with reference to the listed information sources:

1 Group Selection:

1.1 <u>Plan to cover all product groups</u>: over a two to three year period, there is a strategic plan to ensure that most major categories and types of appliances and equipment are included to ensure a broad and consistent coverage of the entire market. Source of information: check test annual reports.

1.2 <u>Number and turnover of models</u>: regard should be given to the numbers of models and the annual turnover of new models of each appliance group. Appliance groups will be given attention in proportion to such numbers and or turnover; source of information: Energy Labelling Register and Energy Labelling Brochures.

1.3 <u>History of non-compliance in each appliance group</u>: groups with a demonstrated history of high levels of non-compliance should be selected because of the likelihood of a continuation of such historical trends; source of information: check test database.

2 Model Selection (a system of weighting and prioritisation for each the following factors is in use):

2.1 <u>History of testing of specific models</u>: models tested in previous years of the check test program should normally be excluded from any further testing unless specific evidence becomes available to suggest that a re-test is warranted; source of information: check test data base.

2.2 <u>Age of models</u>: newer models should normally be given preference when considering models for check testing because of their potential to remain on the market for a longer period as compared to older models. The exception to this rule is models that have been on the market for a considerable period of time (3 years or more) without being subjected to testing; source of information: Energy Labelling Register and Energy Labelling Brochures.

2.3 <u>Volume of sales of models</u>: models with high volumes of sales should normally be given preference when considering models for check testing because of their greater potential to impact on energy usage as compared to models with low sales volumes; source of information: market survey data (e.g. GFK white goods survey).

2.4 <u>Star rating of models</u>: models with the highest claims for energy efficiency (e.g. high star ratings) should normally be given preference when considering models for check testing because of the market's higher expectations with respect to the performance of these models as compared to models with low ratings. This is an important selection criteria; source of information: Energy Labelling Register and Energy Labelling Brochures, Galaxy award nominations.

2.5 Record of non-compliance by supplier: suppliers with a demonstrated record of check testing non-compliance should be subject to greater scrutiny in the check testing program because of the likelihood of a continuation of such historical trends; source of information: check test data base.

2.6 Third party referrals: complaints as to the accuracy of express (labelling etc) or implied (minimum efficiency and performance requirements) energy use/efficiency claims from third parties such as competitors, consumers, consumer groups or regulatory agencies, will be considered by the Manager of the Check Testing Program, who will be responsible for establishing a complaints handling mechanism that reflects best practice, and will include a 'complaints' report in the Annual Check Testing Report; source of information: manufacturing competitors either directly or via regulators, ACA (Australian Consumer's Association), or other sources.

2.7 New market entrants: a preference will be given to the selection of products that appear as new brands on the market or from suppliers that do not have any check testing track record; source of information: Energy Labelling Register and Energy Labelling Brochures.

c) The check testing process

In general, the check testing includes a two-stage process:

- **Stage I** (also known as the *screen test*)
  Initially, a Stage I check test, which is a full or part test to the relevant Australian and New Zealand standard, is performed on **one sample of the model**. This sample will generally be independently purchased (usually through a retail outlet) and tested by a laboratory accredited for check testing on behalf of the regulatory authorities. In cases of Stage I check test non-compliance, the supplier may choose to request cancellation of the registration for the model in question on the basis of the Stage I check test result or, alternatively, may choose the option of proceeding to Stage II check testing.
  In accordance with the requirements of the relevant standards, prior to test measurements being collected, a laboratory is required to check each sample to ensure that it has no obvious operating defects. A manufacturer/importer who believes that the tested unit is in fact defective will be able to inspect the unit in situ (under supervision of the test laboratory) and report on their findings to the regulator. The onus is on the manufacturer/importer to provide evidence that a defect capable of affecting the test results does exist. Furthermore, it must be demonstrated that the "defect" is peculiar to the test unit alone and not common to other samples of the stock of the appliance. If such evidence is provided and accepted, the original check test will be voided and a new check test will be required to be undertaken at the same laboratory either on the original unit with repairs or on a randomly selected second sample of the stock. The costs associated with inspection and re-testing of defective samples shall be borne by the manufacturer/importer.

- **Stage II**
  Stage II check test procedures require that satisfactory test reports from an accredited check testing laboratory be supplied to the regulator. If the submissions provided by the registration holder are not, in the regulatory agency's opinion, satisfactory, or if the submissions set out details and a timetable for testing which is subsequently not complied with, the regulatory agency may decide to cancel the registration. The actual units to be tested in Stage II will be randomly selected from stock by a representative of the regulatory authority.

For failures which fall into the "supplier declaration" category, three samples are required to be tested in Stage II check testing to establish whether the registration of a model will be maintained (however, the manufacturer or importer can choose to accept the results of check tests undertaken on fewer than three samples if the results of each sample subsequently tested also do not confirm the original claims made by the registration holder in the application for registration); for results which fall into the "energy efficiency/performance requirements" category, regulatory authorities require at least two samples have to be tested in Stage II check testing.

Additional conditions for check testing are:

- **Costs:** Stage I check test costs will generally be met by the regulatory agency. Where the registration holder elects to undertake Stage II check testing, the registration holder will be liable for all Stage II check testing related costs irrespective of the outcome. Where a unit selected for check testing is demonstrated to be defective in manufacture, then the registration holder will be liable for all resulting additional costs incurred for check testing.
- **Screening tests conducted by competitors**: where a product fails a screening test conducted at a NATA accredited laboratory (or one affiliated with an organisation with a mutual recognition agreement with NATA) and the test report is provided by the party that commissioned the test to a regulator or the E_3 Committee, the E_3 Committee will reimburse the (reasonable) costs of conducting the screening tests.
- **Laboratories accredited for Check Testing**: only NATA or other laboratories (not associated with the registration holder) accredited by bodies with a mutual recognition agreement with NATA, and with a registration that permits the laboratory to issue test reports for the test in question, will be accredited to undertake check testing. In circumstances where Stage II check testing can be undertaken at a supplier's own Australian located NATA registered laboratory, regulatory agencies will accept the results provided a NATA appointed witness is present throughout the testing. Costs associated with the provision of a NATA appointed witness will be borne by the supplier.
- **Test requirements**: all testing will be undertaken in accordance with the requirements of the relevant standard.
- **Public reporting on check testing program outcomes**: all State and Territory regulatory agencies, as well as the other members of E_3 will be informed of the identity of product suppliers and retailers whose products fail the check testing program. These agencies and/or the relevant Ministers may publicly report on check testing program outcomes.

The check testing flow chart is presented in Figure 7.10. The validity criteria are described in paragraph e).

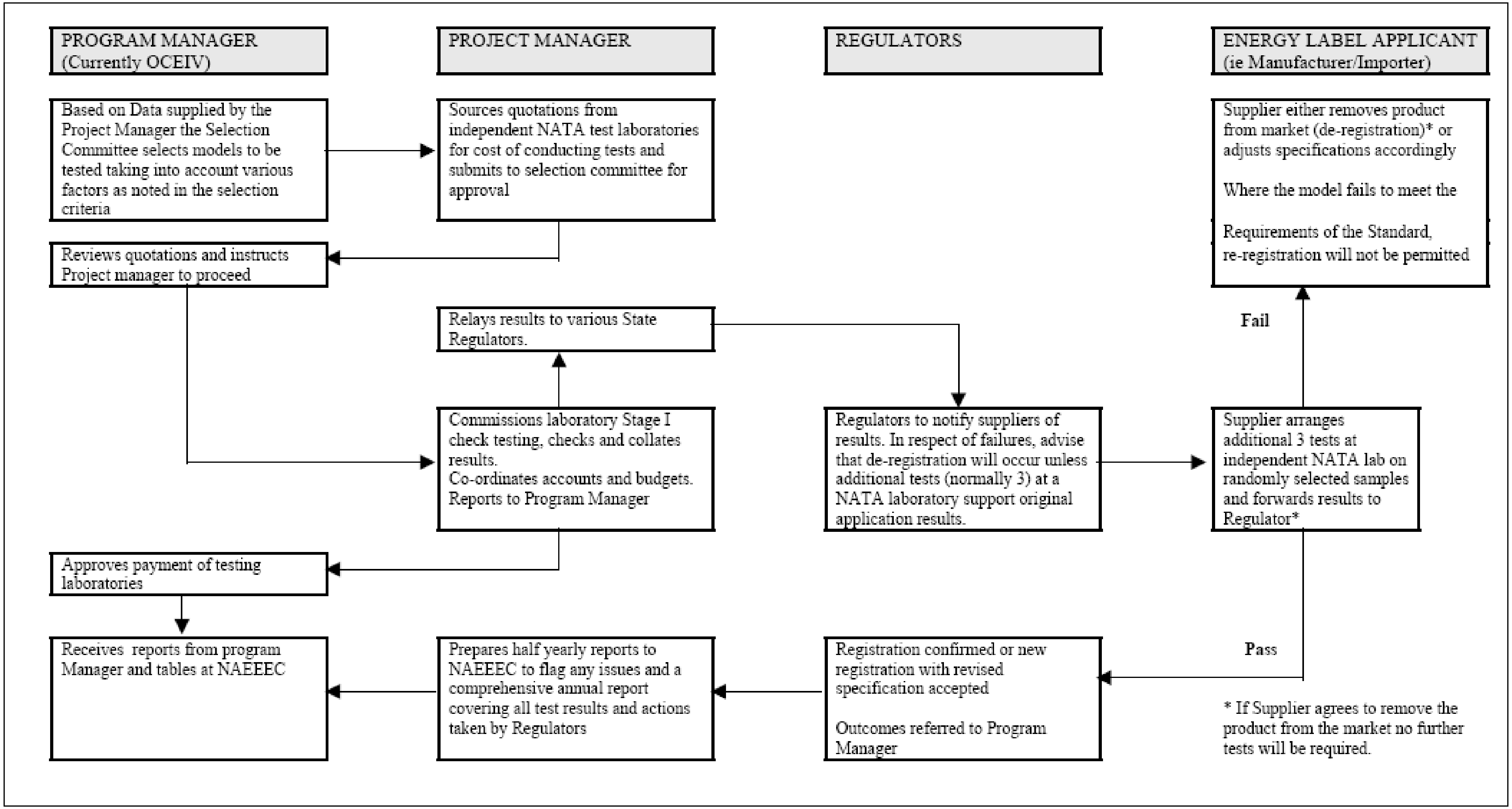
d) The NATA accredited laboratories

The National Association of Testing Authorities (NATA) is Australia's national laboratory accreditation authority[23]. NATA accreditation provides a means of determining, recognising and promoting the competence of facilities to perform specific types of testing, measurement, inspection and calibration.

The latest list of NATA (National Association of Testing Authorities) accredited laboratories has been published on 27 July 2007[24]: 13 laboratories are included, of which 5 are accredited for household refrigerators and freezers (and an additional one is considered capable of doing the test

[23] See: http://www.nata.asn.au .
[24] Downloadable from: http://www.energyrating.gov.au/pubs/nata-laboratorylist.pdf .

Figure 7.10: Australian check testing flow chart



but is yet to be accredited by NATA), 4 laboratories are accredited for both washing machines and dishwashers and only 1 laboratory is accredited for air conditioners (Figure 7.11). The Australian Consumers' Association Test Research is among accredited laboratories. NATA accreditation does not imply that the laboratory in NATA is accredited to do the full range of possible tests covered by the standard.

Figure 7.11: NATA accredited laboratories list description

NATA Accredited Laboratories** – last updated 27 July 2007

**NATA accreditation does not imply that the laboratory is NATA accredited to do the full range of possible tests covered by the Standard. For the most up to date accreditation details of each laboratory, reference should be made to the NATA website at www.nata.asn.au

Notes: ✓ indicates NATA accreditation, * indicates accreditation is imminent, # indicates laboratory may be capable of doing the test but is yet to be accredited by NATA, ® indicates related NATA accreditation. Only laboratories that can test electric products are listed. Some of these labs can also test gas products (marked with §).

Laboratory (in order of NATA accreditation number)	Air-conditioners	Ballasts	Clothes Dryers	Clothes Washers	Dishwashers	Distribution Transformers	Electric Motors	Fluorescent Lamps	Refrigerators/ Freezers - household	Refrigerated Display Cabinets	Storage Water Heaters	Standby	External Power Supplies

e) The statistical approach for check testing: validity criteria

The aim of a verification procedure is to ensure that manufacturers' energy efficiency and other performance claims accurately reflect the information contained within their original application for registration. A failed check test is generally subject to regulatory action so there needs to be a reasonable degree of certainty regarding the results of the test procedure.

The validity criteria should ideally be developed to account for inherent product variability, inter-laboratory variability (reproducibility) and intra-laboratory variability (repeatability) some of which will be attributable to testing apparatus, so that there is a low probability of:

- passing models where the label claims do not reflect the actual values for the entire population of the model in question and which should, therefore, fail check testing; or
- failing models, which should pass.

There are two types of verification that occur during a check test: (i) verification of a supplier's declaration (e.g. energy, volume, capacity etc.) and (ii) verification that an energy efficiency/ performance requirement specified in the standard (i.e. minimum energy efficiency requirements in the case of energy) is achieved by the relevant model.

- **The verification of a supplier declaration**: a supplier declaration is a declaration of energy or performance made either within an energy labelling application or through manufacture information supplied with the product (accompanying literature, user manuals, information affixed to the product such as a rating plate) or at the point of sale (advertising).
  During the verification of a supplier declaration, the focus is on verifying that the average performance level of the model is as claimed by the manufacturer. While some units may have a worse performance level than claimed, these can be balanced by units with a better performance level provided the average performance level of the model is as claimed. The main purpose of a manufacturer declaration is to provide information to the consumer. The general rule for

verification of a supplier's declaration is:

- a single Stage I check test must not be more than 10% worse than the declaration (Stage I);
- if this is found to be the case, a further three units are to be check tested at the supplier's expense (Stage II);
- if the mean of the three additional units check tested for Stage II are found to be more than 10% worse than the declaration, the product fails.

The Australian experts[25] found that for typical measurement errors and variability, the current rule of allowing a 10% variation as the trigger for additional check tests and as the basis of verification of a further 3 units is sound. The probability of deregistration of a model under this rule is extremely small if the supplier's original declaration is in fact accurate (Table 7.7).

***Table 7.7:* Summary of verification limits for supplier declarations in Australia**

Supplier Declarations	Verification Limit Stage I	Stage II Check testing Number of units tested	Criteria for Passing Stage II Check testing
Energy declarations (input: all applicable products *)	1.1 × claim	3	Average < 1.1 × claim
Air conditioner cooling capacity	0.9 × claim	3	Average > 0.9 × claim
Air conditioner heating capacity	0.9 × claim	3	Average > 0.9 × claim
Air conditioner efficiency (EER & COP)	0.9 × claim	3	Average > 0.9 × claim
Clothes washer water extraction index	1.1 × claim	3	Average < 1.1 × claim
Refrigerator compartment volume	0.95 × claim	3	Average > 0.95 × claim
Rated hot water delivery capacity	0.97 × claim	3	Average > 0.97 × claim
Water consumption	1.1 × claim	3	Average < 1.1 × claim

Note *: For some products this limit is not applicable, eg ballasts, where the declaration is the Energy Efficiency Index (EEI) which is based on a total circuit power.

It is important to note that **verification tolerances are not applied** to checks of supplier declarations – the assumed limit of 10% (or the relevant limit for other variables) includes allowances for elements such as **measurement uncertainty**, **systematic and random errors** and **production variability**.

A special case is the **volume declaration for refrigerators and freezers**, where the standard specifies an allowable tolerance of 3% on the measurement (note that the precise rule depends on the compartment volume). Given that the measurement of gross volume by third parties is difficult in some cases (and therefore subject to some uncertainties), the check testing tolerance for refrigerator volume is set at 5% less than the declared value before regulatory action is to be taken (i.e. an allowance of 2% above the tolerance value specified in the standard).

The following supplier declarations are not verified directly (declared value defines test conditions): dryer capacity (0,5 kg steps), washing machine capacity (0,5 kg steps), dishwasher capacity (whole number of place settings), and electric motor output (kW).

[25] During 1999, a statistical consultancy was commissioned to prepare a methodology to determine an approach for verification or rejection of a supplier's claim, based on the testing of up to three units via check tests.

- **The verification that a product meets energy efficiency/performance requirements**: verification of minimum requirements (threshold values) has a different objective. In principle, all units of the model should satisfy the performance limit. In practice, product variability might lead to some units of a model, which operates close to the set limit failing to meet it. This suggests that the verification of the limit(s) should allow for some percentage of failures, say 5% or 10%. The main purpose of a minimum requirement is to provide a degree of consumer protection (consumers are not normally explicitly informed of efficiency/performance minimum requirements).

  For the verification of minimum energy efficiency/performance limits, it is assumed that the actual energy efficiency/performance across individual units of the same model is **normally distributed**. But, under a normal distribution, it is not possible to be assured that all units will be able to pass the set requirements (see also Annex A of this Task).
  For the verification of energy efficiency/performance requirements, a practical requirement would be to allow the worst 10% of units of a particular model to fail the limit(s) (meaning that 90% are required to pass). If it is assumed that the measurement error is equal to the variability of the test measurement, during a check test it would be reasonable to allow about 18% of units to fail the requirement. The practical general application of this rule is:
  - a single initial Stage I check test is conducted and the unit must not fail the specified energy efficiency/performance requirements (**Stage I**);
  - if it does fail, a further two units are to be tested - at the supplier's expense - (**Stage IIa**);
  - if both of the additional units tested for Stage IIa are found to fail the specified energy efficiency/performance requirements, the product fails;
  - if both of the additional units tested for Stage IIa are found to pass the specified energy efficiency/performance requirements, the product shall be deemed to pass;
  - if one of the additional units tested for Stage IIa is found to fail the specified energy efficiency/performance requirements while one passes, one additional unit is tested (**Stage IIb**);
  - if two of the additional three units tested in Stages IIa and IIb are found to fail the specified energy efficiency/performance requirements, the product shall fail;
  - if two of the additional three units tested for Stages IIa and IIb are found to pass the specified energy efficiency/performance requirements, the product shall be deemed to pass.

If 3 units are initially tested in Stage II, then Stages IIa and IIb above are not required. However, 2 of the 3 units tested in Stage II must pass the requirements. For some products, a larger sample may be requested to verify the Stage II check test (e.g. for fluorescent lamps where product variability may be a factor). For some larger products, such as certain models of distribution transformers, a sample of 3 units may not be possible.

Table 7.8 summarises the verification procedures and criteria for the energy efficiency/performance requirements.

- **Verification tolerances**: where there is a known margin of error or uncertainty in the measurement procedure for a particular test, then this value will be used as a verification tolerance by the regulatory agencies on the specified energy efficiency/performance level. Generally, this measurement error is set **at a maximum of 2% of the specified level**, except in cases (see Table 7.9) that are documented to have different measurement errors on the basis of a series of round robin tests conducted for regulatory agencies or on error analysis. Regulatory agencies will also take into account other factors where these are known to impact on the energy efficiency/performance measure, such as the calibration of swatches used to assess washing

Table 7.8: **Summary of verification limits - Minimum requirements in Australia**

Product (name)	**Parameter** (description)	**Requirement in policy measure** (description)	**Stage I verification limit** (description)	**Stage II tested units** (number)	**Stage II passing criteria** (description)
Cold appliances	pull down test	< 6 hours	< 6 hours	2 + 1	2 of the 3 units passes the verification limit*
Cold appliances	maximum annual energy consumption (minimum efficiency requirements)	defined by group in AS/NZS 4474.2	defined by group in AS/NZS 4474.2	3 (additional units may need to be tested to establish the criteria in some circumstances. The procedure to determine efficiency requirements validity for refrigerators and freezers is complex and was released for discussion in June 2005	90% confidence that the mean does not exceed the requirements level and mean energy with verification tolerance <1,03 limits
Washing machines	soil removal	>0,80	>0,80*	2+1	2 of the 3 units passes the verification limit*
	soil removal < 2 × SD	>0,72	>0,72*	2+1	2 of the 3 units passes the verification limit*
	water extraction index	< 1,1	< 1,1*	2+1	2 of the 3 units passes the verification limit*
Dryer	energy efficiency	< 1,36	< 1,36*	2+1	2 of the 3 units passes the verification limit*
Dishwasher	washing performance	>0,90	>0,90*	2+1	2 of the 3 units passes the verification limit*
	drying performance	>0,50	>0,50*	2+1	2 of the 3 units passes the verification limit*

*with a verification tolerance.

performance of washing machines. These tolerances relate only to the verification of the claim associated with energy labelling or minimum requirements.

Table 7.9: **Verification tolerances for specified products exceeding the 2% level**

Product	Parameter	Verification tolerance
Washing machine	wash performance (if $< 2 \times$ SD)	0,03
Dishwasher	wash performance	0,03
	drying performance	0,03
Electric water heater	max. daily heat loss	3% of the limit
Air conditioner	EER minimum requirements	3% of the limit

For cold appliances a different approach is followed. Unlike other products in Australia, domestic refrigerators and freezers follow an approach where the minimum efficiency requirement level (maximum energy consumption) applies to the average of production rather than defining an absolute maximum allowable for every individual product. To verify compliance for this product regulators have to establish the likely average energy for the product and whether this exceeds the set level or not so this product is subject to a different verification procedure.

f) The verification approach for cold appliances

The AS/NZS 4474.2 standard sets also a check testing allowance of 10% for the declared value of the CEC, which appears on the energy label. The basis for a 10% tolerance for the energy labelling is set out in the statistical paper prepared for E_3 Committee[26].

The standard states that the PAECav (average Projected Annual Energy Consumption, which is a proxy for the model average energy consumption) of cold appliances shall not exceed the set maximum level. The principle for verification is that the average energy consumption of the model does not exceed the minimum efficiency requirements level. Therefore for a model to fail minimum efficiency requirements, it's necessary to be confident that the average energy consumption of the model exceeds the minimum efficiency requirements level (is lower than the maximum permitted annual energy consumption). Based on the data collected in the Stage II test, the ***single sided t statistic*** is calculated to determine whether this is true to a specified level of confidence. A maximum allowable mean energy consumption limit (unadjusted) of 5% over the minimum efficiency requirements is also set as a secondary compliance criteria to take into account those cases that may have a larger than normal variability within a particular model and so pass the *t statistic* criteria. In some cases, further units beyond Stage II may have to be tested to provide certainty of the result.

The overall procedure for determining energy efficiency requirements compliance for refrigerators and freezers is set out in the following steps:

1. a screen test (**Stage I**) is conducted on a single randomly selected unit;
2. if the Stage I measured energy consumption exceeds the Stage I screening criteria, then the model will proceed to **Stage II**, where 3 additional randomly selected units are check tested (the supplier may elect to test more than 3 units in the Stage II check test);
3. the results for Stage II are evaluated against the energy efficiency requirements compliance criteria;

[26] Source: Determination of Check testing Validity for Refrigerator MEPS, NAEEEC, May 2005, downloadable from http://www.energyrating.gov.au/pubs/validity-criteria-rf-2005.pdf

4. in specified special cases, the manufacturer may elect to test not less than 5 additional randomly selected units to demonstrate minimum efficiency requirements compliance (**Stage III**). The same general minimum efficiency requirements compliance criteria apply to these additional Stage III units.

Note that for refrigerators and freezers, check testing criteria for minimum efficiency requirements validity and energy labelling validity are applied independently to the test results and failure against either Stage I criteria or Stage II will result in appropriate action.

Stage II compliance verification: the following calculations are required for verification:

- adjust the tested energy values (based on the PAEC which is given in kWh/year) for each of the Stage II units down by 2% (multiply each result by 0,98) which is a **general verification tolerance** for Stage II which represents possible measurement uncertainty and systematic errors in the test results (reproducibility);
- calculate the mean energy consumption ($\overline{X}$), the sample standard deviation (SD) and the sample coefficient of variation CV ($CV = \frac{SD}{\overline{X}}$) of the adjusted Stage 2 units;
- calculate the sample standard error SE ($SE = \frac{SD}{n}$) of the adjusted Stage 2 units, where *n* is the number of units under test;
- calculate the t statistic: $t = \frac{\overline{X} - requirement}{SE}$
- compare the t statistic to the critical t-value for a single sided test, at the 10% level of significance, of the hypothesis that the mean energy consumption of the model exceeds the requirement level (this is equivalent to using a two-sided 80% confidence interval). The t statistic for various sample sizes are given in the table below (single sided 90% confidence level):

Sample size n	Degrees of freedom	t statistic
3	2	1,886
4	3	1,638
5	4	1,533
6	5	1,476
7	6	1,440
8	7	1,415
9	8	1,397
10	9	1,383

  where the t-statistic exceeds the critical t-value, the hypothesis that the mean energy of the model exceeds the requirement level is true at the stated level of significance;
- determine the percentage that the $\overline{X}$ exceeds the relevant requirement level (a negative number indicates that the adjusted sample mean is lower than the requirement level:
  'exceed requirement value' = [($\overline{X}$- requirement) -1]; (expressed as a %)

The Stage II compliance criteria: the model is deemed to have failed if either of the following criteria are true:

- if the value of the t statistic for the Stage II units tested exceeds the value specified in the table, then the model fails;
- if the value of 'exceed requirement value' is greater than +0,029 (+2,9%), then the model fails.

The value of 'exceed requirement value' of +2,9% is equivalent to the unadjusted mean of the sample being 5% greater than the efficiency requirements level.

If the results for Stage II fail only the second of the energy efficiency requirements compliance criteria above (i.e. the value of 'exceed requirement value' is greater than +2,9%) and the Stage II coefficient of variation CV exceeds 5%, the manufacturer may elect to test not less than 5 additional randomly selected units to demonstrate energy efficiency requirements compliance (Stage III). If the manufacturer does not elect to test further units in Stage III, the model is still deemed to fail. The same two compliance criteria apply to these additional Stage III units, except that calculations are based on n = 5 (or the actual number of Stage III units selected for test) and the relevant t-statistic for assessing compliance is 1,533 (in the case of 5 units, or the relevant t-statistic).

As already mentioned in Task 6, with the coming revision of AU/NZS 4474.2 standard it is envisaged that the minimum energy efficiency requirements checking criteria used by government will be changed to make it clear that all the population of a model rather than just the mean of that population must have a lower energy test consumption than the set requirements; minimum requirement values in Part 2 of the standard will be adjusted to compensate for that tightening. However, the relevant discussion with stakeholders has not yet taken place and no discussion document is at present available.

g) Compliance Newsletter and check results

E_3 Newsletters are periodically prepared by the Australian Greenhouse Office (on behalf of the E_3 Committee) and they provide the latest news and information on energy efficient appliances and electrical equipment.

Since October 2006 *Compliance Newsletter* (formerly known as "*Switched-On*") is quarterly published, which shared with stakeholders the latest information about compliance and enforcement activities in Australia and New Zealand. Details of de-registered products and infringement notices (2005-2006) were published in Issue 1[27] (October 2006) of the Newsletter. In fact, the major sanction employed against manufacturers and importers of non-complying equipment is to withdraw the legal right to sell that equipment. Some models have been subsequently reregistered with revised performance claims in line with the results obtained in the verification test.

A total of 46 "check" tests were finalised during the 2005-2006 financial year (Table 7.10), of which 27 (58%) failed at least one of the screen test validity criteria (of particular note is the 87% failure rate of air-conditioners[28] which continues to be a major focus for the check programme). Of the 27 referred failures, 4 suppliers were able to establish to regulators' satisfaction that the equipment range met requirements: 3 of the screen test fail results were subsequently overturned when Stage II check testing failed to confirm the initial finding, and a further screen test fail result was overturned following evidence that the original tested unit (a refrigerated display cabinet) was in fact faulty and the screen test was invalid. At the end of the two-stage process, 23 models or 50% of the 46 initially selected models failed. The nature of failures was also reported:

- electric motors and refrigerated display cabinets typically failed to meet the required minimum efficiency requirements level. One refrigerated display cabinet model failed to meet its claim of

[27] Compliance Newsletter, Issue 1, October 2006, downloadable from: http://www.energyrating.gov.au/newsletters.html
[28] After several instances over some years, energy efficiency regulators complained to the Australian Competition and Consumer Commission about LG and problems with air conditioner efficiency claims. The ACCC and LG subsequently agreed to a $3,1 million package recompensing purchasers for their likely additional energy costs plus a set of additional requirements to be fulfilled by the company.

"High Efficiency";

- a majority of air-conditioners failed due to either over statement of cooling capacity, EER or both. Many of these also failed the validity criteria in heating mode;
- the main reason that refrigerators failed was due to understating energy consumption; 2 units failed to meet the required minimum efficiency requirements level

one washing machine failed the soil removal validity test and one washing machine and one dishwasher failed due to understating the energy consumption.

In addition a further Dishwasher sold in New Zealand that failed its check test was found not to be registered and was therefore banned from further sale.

Table 7.10: **Final outcome of the validating manufacturers' energy rating and or energy efficiency claim in fiscal year 2005/2006**

Appliance type	Screen-test (n)	Passed the screen test (n)	Failed the screen test (n)	Negative results overturned (n)	Confirmed (n)
Air conditioner	15	2	13	1	12
Washing machine	2	0	2	0	2
Dishwasher	8	6	2	0	2
Electric Motor	6	5	1	0	1
Refrigerated display cabinet	10	6	4	1	3
Refrigerator & freezer	5	0	5	2	3
Total	**46**	**19**	**27**	**4**	**23**

In 2007, two Issues of the Compliance Newsletter were published, the February issues dealing with white goods and the May issue dealing with air-conditioners. The planned check tests to be undertaken during the first half of 2007 for white goods include 2 dryers, 2 washing machines, 2 dishwashers and 6 refrigerators & freezers.

The E_3 Committee and its predecessors have undertaken verification testing for some years. Since its inception the program has tested a total of 643 products (in over 10 product categories). The tests target product suspected of being at risk of failing. Detailed in the chart over is a summary of all the check test results conducted since 1991 by product type (Figure 7.12)[29]. Over that time, one third (35%) of these verification tests failed. It should be noted that this high rate of failure reflects a policy of selecting product with a higher risk of failing the test. Risk assessment is based on a number of factors as detailed in the administrative guidelines

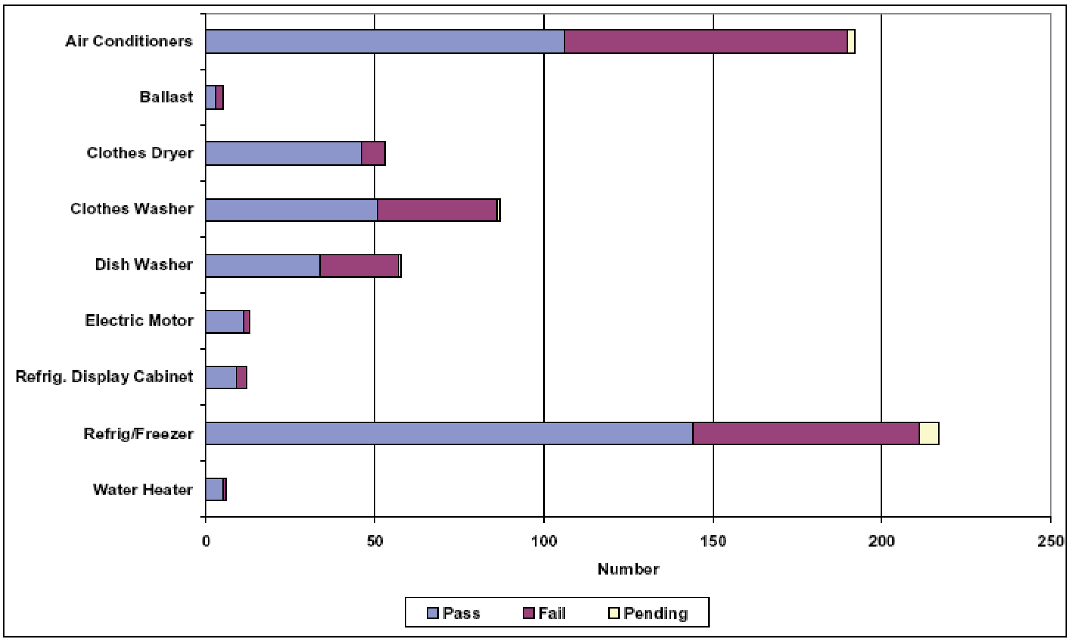
7.2.2.2 USA

a) Energy and water conservation requirements

In the case of performance requirements, upon receiving information in writing concerning the energy/water performance of a particular covered product of a particular manufacturer or private labeller which indicates that the covered product may not be in compliance with the applicable energy/water requirements, the Secretary may conduct testing of that covered product under 10 CFR, 430 Subpart F - *Certification and Enforcement* by means of a test notice addressed to the manufacturer in accordance with the following requirements.

[29] Source: E_3 Compliance Newsletter, AIR CONDITIONER EDITION May 2007.

Figure 7.12: Summary of all the check test results since 1991 by product type in Australia/New Zealand



The test notice will specify the model to be selected for testing, the method of selecting the test sample, the timetable for testing and the facility at which testing will be conducted. The Secretary may require that the manufacturer ships at his expense a reasonable number of units of the specified basic model to a designated testing laboratory. The number of units of a basic model specified in a test notice shall not exceed 20. A DOE inspector will select a batch, a batch sample of up to 20 units randomly selected within the batch, and test units randomly selected from the batch sample

Such a procedure will only be followed after the Secretary or his designated representative has examined the underlying test data provided by the manufacturer and after the manufacturer has been offered the opportunity to meet with DOE to verify compliance with the applicable requirements. A representative designated by the Secretary shall be permitted to observe any re-verification procedures, and to inspect the results of such re-verification.

The Appendix B - *Sampling Plan for Enforcement Testing* of Subpart F includes the sampling plan for enforcement testing. A **Double Sampling** procedure is used, including the following Steps:

Step 1. The first sample size (n_1) must be four or more units.

Step 2. Compute the mean (x_1) of the measured energy/water performance of the n_1 units in the first sample as follows:

$$\bar{x}_1 = \frac{1}{n_1}\left(\sum_{i=1}^{n_1} x_i\right) \qquad (1)$$

where (x_i) is the measured energy efficiency, energy or water consumption of unit *i*.

Step 3. Compute the standard deviation (s_1) of the measured energy or water performance of the (n_1) units in the first sample as follows:

$$s_1 = \sqrt{\frac{\sum_{i=1}^{n_1} (x_i - \bar{x}_1)^2}{n_1 - 1}} \qquad (2)$$

Step 4. Compute the standard error (S_{X1}) of the units in the first sample as follows:

$$s_{\bar{x}_1} = \frac{s_1}{\sqrt{n_1}} \qquad (3)$$

Step 5. Compute the upper control limit (UCL_1) and lower control limit (LCL_1) for the mean of the first sample using the applicable DOE energy or water performance requirements (*EPS*) as the desired mean and a probability level of 95% (two-tailed test) as follows:

$$LCL_1 = EPS - ts_{\bar{x}_1} \qquad (4)$$

$$UCL_1 = EPS + ts_{\bar{x}_1} \qquad (5)$$

where t is a statistic based on a 95% two-tailed probability level and a sample size of n_1.

Step 6(a). For an energy efficiency requirement, compare the mean of the first sample (x_1) with the upper and lower control limits (UCL_1 and LCL_1) to determine one of the following:

1) if the mean of the first sample is below the lower control limit, then the basic model is in non-compliance and testing is at an end;
2) if the mean of the first sample is equal to or greater than the upper control limit, then the basic model is in compliance and testing is at an end;
3) if the sample mean is equal to or greater than the lower control limit, but less than the upper control limit, then no determination of compliance or non-compliance can be made and a second sample size is determined by Step 7(a).

Step 6(b). For an energy or water consumption requirement, compare the mean of the first sample (x_1) with the upper and lower control limits (UCL_1 and LCL_1) to determine one of the following:

1) if the mean of the first sample is above the upper control limit, then the basic model is in non-compliance and testing is at an end;
2) if the mean of the first sample is equal to or less than the lower control limit, then the basic model is in compliance and testing is at an end;
3) if the sample mean is equal to or less than the upper control limit but greater than the lower control limit, then no determination of compliance or non-compliance can be made and a second sample size is determined by Step 7(b).

Step 7(a). For an energy efficiency requirement, determine the second sample size (n_2) as follows:

$$n_2 = \left(\frac{ts_1}{0.05\, EPS} \right)^2 - n_1 \qquad (6a)$$

where s_1 and t have the values used in Steps 4 and 5, respectively. The term '0,05 EPS' is the difference between the applicable energy efficiency requirement and 95% of the requirement, where 95% of the requirement is taken as the lower control limit.

This procedure yields a sufficient combined sample size ($n_1 + n_2$) to give an estimated 97,5% probability of obtaining a determination of compliance when the true mean efficiency is equal to the applicable requirement. Given the solution value of n_2, determine one of the following:

1) if the value of n_2 is ≤0 and if the mean energy efficiency of the first sample (x_1) is either equal to or greater than the lower control limit (LCL_1) or ≥ 95% of the applicable energy efficiency requirement (EES), whichever is greater, i.e., if $n_2 \leq 0$ and $x_1 \geq$ max (LCL_1, 0,95 EES), the basic model is in compliance and testing is at an end;
2) if the value of n_2 is ≤0 l and the mean energy efficiency of the first sample (x_1) is less than the lower control limit (LCL_1) or less than 95% of the applicable energy efficiency requirement (EES), whichever is greater, i.e., if $n_2 \leq 0$ and $x_1 \geq$ max (LCL_1, 0,95 EES), the basic model is in non-compliance and testing is at an end;
3) if the value of $n_2 > 0$, then value of the second sample size is determined to be the smallest integer equal to or greater than the solution value of n_2 for equation (6a). If the value of n_2 so calculated is greater than ($20-n_1$), set n_2 equal to ($20-n_1$)

<u>Step 7(b)</u>. For an energy or water consumption requirement, determine the second sample size (n_2) as follows:

$$n_2 = \left(\frac{ts_1}{0.05\ EPS} \right)^2 - n_1 \qquad (6b)$$

where s_1 and t have the values used in Steps 4 and 5, respectively. The term '0,05 EPS' is the difference between the applicable energy or water consumption requirement and 105% of the requirement, where 105% of the requirement is taken as the upper control limit. This procedure yields a sufficient combined sample size ($n_1 + n_2$) to give an estimated 97,5% probability of obtaining a determination of compliance when the true mean consumption is equal to the applicable requirement. Given the solution value of n_2, determine one of the following:

1) if the value of $n_2 \leq 0$ and if the mean energy or water consumption of the first sample (x_1) is either equal to or less than the upper control limit (UCL_1) or equal to or less than 105% of the applicable energy or water performance requirement (EPS), whichever is less, i.e., if $n_2 \leq 0$ and $x_1 \leq$ min (UCL_1, 1,05 EPS), the basic model is in compliance and testing is at an end;
2) if the value of $n_2 \leq 0$ and the mean energy or water consumption of the first sample (x_1) is greater than the upper control limit (UCL_1) or more than 105% of the applicable energy or water performance requirement (EPS), whichever is less, i.e., if $n_2 \leq 0$ and $x_1 >$ min (UCL_1, 1,05 EPS), the basic model is in non-compliance and testing is at an end;
3) if the value of $n_2 > 0$, then the value of the second sample size is determined to be the smallest integer equal to or greater than the solution value of n_2 for equation (6b). If the value of n_2 so calculated is greater than ($20-n_1$), set n_2 equal to ($20-n_1$).

<u>Step 8</u>. Compute the combined mean (x_2) of the measured energy or water performance of the n_1 and n_2 units of the combined first and second samples as follows :

$$\bar{x}_2 = \frac{1}{n_1 + n_2} \left(\sum_{i=1}^{n_1+n_2} x_i \right) \qquad (7)$$

<u>Step 9</u>. Compute the standard error (S_{x1}) of the measured energy or water performance of the n_1 and n_2 units in the combined first and second samples as follows (s_1 is the value obtained in Step 3):

$$s_{\bar{x}_2} = \frac{s_1}{\sqrt{n_1 + n_2}} \qquad (8)$$

<u>Step 10(a)</u>. For an energy efficiency requirement, compute the lower control limit (LCL_2) for the mean of the combined first and second samples using the DOE energy efficiency requirement (EES)

as the desired mean and a one-tailed probability level of 97,5% (equivalent to the two-tailed probability level of 95% used in Step 5) as follows:

$$LCL_2 = EES - ts_{\bar{x}_2} \qquad (9a)$$

where the t-statistic has the value obtained in Step 5.

Step 10(b). For an energy or water consumption requirement, compute the upper control limit (UCL_2) for the mean of the combined first and second samples using the DOE energy or water performance requirement (*EPS*) as the desired mean and a one-tailed probability level of 102,5% (equivalent to the two-tailed probability level of 95% used in Step 5) as follows:

$$UCL_2 = EPS + ts_{\bar{x}_2} \qquad (9b)$$

where the t-statistic has the value obtained in Step 5.

Step 11(a). For an energy efficiency requirement, compare the combined sample mean (x_2) to the lower control limit (LCL_2) to find one of the following:

1) if the mean of the combined sample (x_2) is less than the lower control limit (LCL_2) or 95% of the applicable energy efficiency requirement (*EES*), whichever is greater, i.e., if $x_2 < \max (LCL_2, 0{,}95\ EES)$, the basic model is in non-compliance and testing is at an end;
2) if the mean of the combined sample (x_2) is equal to or greater than the lower control limit (LCL_2) or 95% of the applicable energy efficiency requirement (*EES*), whichever is greater, i.e., if $x_2 \geq \max (LCL_2, 0{,}95\ EES)$, the basic model is in compliance and testing is at an end;

Step 11(b). For an energy or water consumption requirement, compare the combined sample mean (x_2) to the upper control limit (UCL_2) to find one of the following:

1) if the mean of the combined sample (x_2) is greater than the upper control limit (UCL_2) or 105% of the applicable energy or water performance requirement (*EPS*), whichever is less, i.e., if $x_2 > \min (UCL_2, 1{,}05\ EPS)$, the basic model is in non-compliance and testing is at an end;
2) if the mean of the combined sample (x_2) is equal to or less than the upper control limit (UCL_2) or 105% of the applicable energy or water performance requirement (*EPS*), whichever is less, i.e., if $x_2 \leq \min (UCL_2, 1{,}05\ EPS)$, the basic model is in compliance and testing is at an end.

Manufacturer-Option Testing: if a determination of non-compliance is made in Steps 6, 7 or 11, the manufacturer may request that additional testing be conducted, in accordance with the following procedures:

Step A. The manufacturer requests that an additional number, n_3, of units be tested, with n_3 chosen such that ($n_1+n_2+n_3$) does not exceed 20;
Step B. Compute the mean energy or water performance, standard error, and lower or upper control limit of the new combined sample in accordance with the procedures prescribed in Steps 8, 9, and 10, above;
Step C. Compare the mean performance of the new combined sample to the revised lower or upper control limit to determine one of the following:

- a.1) for an Energy Efficiency Standard, if the new combined sample mean is equal to or greater than the lower control limit or 95% of the applicable energy efficiency standard, whichever is greater, the basic model is in compliance and testing is at an end;
- a.2) for an Energy or Water Consumption Standard, if the new combined sample mean is equal to or less than the upper control limit or 105% of the applicable energy or water consumption standard, whichever is less, the basic model is in compliance and testing is at an end;

- b.1) for an Energy Efficiency Standard, if the new combined sample mean is less than the lower control limit or 95% of the applicable energy efficiency standard, whichever, is greater, and the value of (n_1+n_2+n_3) is less than 20, the manufacturer may request that additional units be tested. The total of all units tested may not exceed 20. Steps A, B, and C are then repeated;
- b.2) for an Energy or Water Consumption Standard, if the new combined sample mean is greater than the upper control limit or 105% of the applicable energy or water consumption standard, whichever is less, and the value of (n_1+n_2+n_3) is less than 20, the manufacturer may request that additional units be tested. The total of all units tested may not exceed 20. Steps A, B, and C are then repeated;
- c) otherwise, the basic model is determined to be in non-compliance.

The manufacturer bears the cost of all testing conducted under this Option.

b) Appliance labelling

The CFR, Title 16, Part 305 - *Rule concerning disclosures regarding energy consumption and water use of certain home appliances and other products required under the energy policy and conservation act ("appliance labelling rule")*, establishes requirements for consumer appliance products with respect to energy/water labelling and/or marking the products with information indicating their operating cost (or different useful measure of energy consumption) and related information.

It states that upon notification by the Federal Trade Commission or its designated representative, a manufacturer of a covered product shall supply, at the manufacturer's expense, no more than two of each model of each product to a laboratory, which will be identified by the Commission or its designated representative in the notice, for the purpose of ascertaining whether the estimated annual energy consumption, the estimated annual operating cost, or the energy efficiency rating, or the light output, energy usage and life ratings or, for general service fluorescent lamps, the colour rendering index, disclosed on the label or fact sheet or in an industry directory, or, as required in a catalogue, or the representation made by the label that the product is in compliance with applicable requirements is accurate.

Such a procedure will only be followed after the Commission or its staff has examined the underlying test data provided by the manufacturer and after the manufacturer has been afforded the opportunity to re-verify test results from which the estimated annual energy consumption, the estimated annual operating cost, or the energy efficiency rating for each basic model was derived, or the light output, energy usage and life ratings or, for general service fluorescent lamps, the colour rendering index, for each basic model or lamp type was derived. A representative designated by the Commission shall be permitted to observe any re-verification procedures required by this part, and to inspect the results of such re-verification.

The Commission will pay the charges for testing by designated laboratories

c) Laboratory accreditation

No accredited laboratories are requested for household appliances, while the testing for general service fluorescent lamps, general service incandescent lamps, incandescent reflector lamps, and medium base compact fluorescent lamps, shall be conducted by test laboratories accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) or by an accrediting organization recognized by NVLAP. NVLAP is a program of the National Institute of Standards and Technology, U.S. Department of Commerce. NVLAP standards for accreditation of laboratories that test for compliance with standards for lamp efficacy and CRI are given in 15 CFR part 285 as supplemented by NVLAP Handbook 150–01, "Energy Efficient Lighting Products, Lamps and Luminaires." A manufacturer's or importer's own laboratory, if accredited, may conduct the applicable testing.

7.2.2.3 The European Union

a) Energy efficiency requirements (for cold appliances)

Although an energy efficiency requirement directive is not in force for wash appliances, the verification procedure of directive 96/57/EC for cold appliances is described for sake of completeness of the description of the EU verification procedures. This directive bases the verification on a two-stage procedure: in **Stage 1** the check is performed on one sample of the model. In case of non-compliance, the **Stage 2** check is developed on three additional samples of the model. The test procedures are described in Annex 1 of the directive "*Method for calculating the maximum allowable electricity consumption of a refrigeration appliance and procedure for checking conformity*" as:

> **Test procedures for checking whether an appliance complies with the electricity consumption requirements of this Directive**
>
> If the electricity consumption of a refrigeration appliance submitted for verification is less than or equal to E_{max} (the maximum allowable electricity consumption value for its category, as defined above), plus 15 %, the appliance is certified as conforming to the electricity consumption requirements of this Directive. If the electricity consumption of the appliance is greater than E_{max} plus 15 %, the electricity consumption of a further three appliances must be measured. If the arithmetic mean of the electricity consumptions of these three appliances is less than or equal to E_{max} plus 10 %, the appliance is certified as conforming to the electricity consumption requirements of this Directive. If the arithmetic mean exceeds E_{max} plus 10 %, the appliance must be judged not to conform to the electricity consumption requirements of this Directive.

b) Energy labelling

The energy labelling schemes for household appliances base the verification on the provisions included in a specific Clause or normative Annex of the relevant standards, which are mentioned in the specific directives. In general, the verification is based on a two-stage procedure: in Stage 1 the check is performed on one sample of the model. In case of non-compliance, the Stage 2 check is developed on three additional samples of the model. Depending on the parameter to be verified, a verification tolerance is applied to both Stages.

For cold appliances, Annex C - Rated characteristics and control procedure of EN 153, states the control procedure for :

1) Volumes and areas
- **Rated gross volume**: the measured value shall not be less than the rated value by more than 3% or 1 litre, whichever is the greater value;
- **Rated storage volume**: the measured value shall not be less than the rated value by more than 3% or 1 litre, whichever is the greater value. Where the volumes of the cellar compartment and fresh-food storage compartment are adjustable relative to one another by the user, this requirement applies when the cellar compartment is adjusted to its minimum volume;
- **Rated storage shelf area**: the measured storage shelf area, including that of any cellar and chill compartment, shall not be less than the rated storage shelf area by more than 3%;
- **Control procedure**: if the previous requirements are not met on a single refrigerating appliance, the measurements shall be made on a further 3, randomly selected, refrigerating appliances. The arithmetical mean of the measured values of these 3 refrigerating appliances shall be in

accordance with the requirements.

2) Performance characteristics

- **Storage temperatures**: the values on the first refrigerating appliance tested shall comply with the requirements of the standard. If any result of the test carried out on the first refrigerating appliance is outside the specified values, the test shall be carried out on a further 3, randomly selected, refrigerating appliances. All the values on these 3 refrigerating appliances tested shall comply with requirements given in the standard;
- **Freezing capacity**: the value measured on the first refrigerating appliance tested shall not be less than the rated value by more than 15%. If the result of the test carried out on the first refrigerating appliance is less than the rated value minus 15%, the test shall be carried out on a further 3 randomly selected refrigerating appliances. The arithmetical mean of the values of these 3 refrigerating appliances shall be equal to or greater than the rated value minus 10%.
  The value obtained either on the first refrigerating appliance tested or the arithmetical mean value obtained on a further 3 refrigerating appliances shall be in accordance with the minimum stated values;
- **Energy consumption, Ice making, Temperature rise time**: the value measured shall not be greater than the rated value by more than 15%. If the result of the test carried out on the first refrigerating appliance is greater than the rated value plus 15%, the test shall be carried out on a further 3 randomly selected refrigerating appliances. The arithmetical mean of the values of these 3 refrigerating appliances shall be equal to or less than the rated value plus 10%.

For wash appliances:

1) **Dishwashers**: Clause Z2 - Tolerances and control procedures of EN 50242 Ed.2 and EN 60436, states the control procedure for:

- **Cleaning performance**: the cleaning performance shall not be less than the value declared by the manufacturer minus 6%. If the result of the test carried out on the first appliance is less than the value declared by the manufacturer minus 6% the test shall be carried out on a further 3 appliances. The arithmetic mean of the values of these 3 appliances shall not be less than the declared value minus 4%;
- **Drying performance**: the drying performance shall not be less than the value declared by the manufacturer minus 15%. If the result of the test carried out on the first appliance is less than the value declared by the manufacturer minus 15% the test shall be carried out on a further 3 randomly selected appliances. The arithmetic mean of the values of these 3 appliances shall not be less than the declared value minus 10%;
- **Energy consumption**, **Water consumption**, **Cycle time**: the measured value shall not be greater than the value declared by the manufacturer plus 15%. If the result of the test carried out on the first appliance is greater than the declared value plus 15%, the test shall be carried out on a further 3 randomly selected appliances. The arithmetical mean of the values of these 3 appliances shall not be greater than the declared value plus 10%.

By retesting the further 3 appliances with limited tolerances all values shall be specified (cleaning, drying, energy, water and time).

2) **Washing machines**: Clause Z3 - Tolerances and control procedures of EN 60456, states the control procedure for :

- **Energy consumption**, **Water consumption, Spin extraction**: the measured value shall not be greater than the value declared by the manufacturer plus 15%. If the result of the test carried out on the first appliances is greater than the declared value plus 15% , the test shall be carried out on a further 3 appliances, which shall be randomly selected from the market. The arithmetic mean of the values of these 3 appliances shall not be greater than the declared value plus 10%;

- **Spin speed**: the spin speed shall not be less than the value declared by the manufacturer minus 10% or minus 100 rpm, whichever is the smaller value. If the result of the test carried out on the first appliances is less than the declared value minus 10% or minus 100 rpm (whichever is the smaller value), the test shall be carried out on a further 3 appliances, which shall be randomly selected from the market. The value of each of these 3 appliances shall not be less than the declared value minus 10% or minus 100 rpm, whichever is the smaller value;
- **Washing performance**: the washing performance, shall not be less than the value declared by the manufacturer minus 0,03. If the result of the test carried out on the first appliance is less than the declared value minus 0,03, the test shall be carried out on a further 3 appliances, which shall be randomly selected from the market. The arithmetic mean of the values of these 3 appliances shall not be less than the declared value minus 0,02;
- **Programme duration**: the programme duration shall not be longer than the value declared by the manufacturer plus 15 %. If the result of the test carried out on the first appliances is longer than the declared value plus 15%, the test shall be carried out on a further 3 appliances, which shall be randomly selected from the market. The arithmetic mean of the values of these 3 appliances shall not be longer than the declared value plus 10%.

A summary of the EU verification system for the energy consumption declarations in the energy labelling and energy efficiency requirement schemes is presented in Table 7.11.

Table 7.11: **Summary of the EU verification system for energy consumption in labelling and efficiency requirements**

Appliance	Implementing Directives	Standard	Verification procedure			
			Stage 1		Stage 2	
			Units (n)	Tolerance (%)	Units (n)	Tolerance (%)
Energy labelling scheme						
Refrigerators&freezers	94/2/EC, 2003/66/EC	EN 153	1	15%	3	10%
Washing machines	95/12/EC, 96/89/EC	EN 60456	1	15%	3	10%
Tumble dryers	95/13/EC	EN 61121	1	15%	3	10%
Washer-dryers	96/60/EC	EN 50229	1	15%	3	10%
Dishwashers	97/17/EC, 99/9/EC	EN 50242	1	15%	3	10%
Air conditioning	2002/31/EC	EN 14511	1	15%	3	10%
Ovens	2002/40/EC	EN 50304	1	40Wh+10%	3	10%
Efficiency requirements						
Refrigerators&freezers	96/57/EC	EN 153	1	15%	3	10%

b) The eco-label scheme

In the Annex of Commission Decision (2004/669/EC) of 6 April 2004 establishing the ecological criteria for the award of the Community eco-label to refrigerators, and amending Decision 2000/40/EC, only the procedure for the measurement declaration are described. A brief mention of the verification procedure and criteria was included in previous Decision 2000/40/EC, which reported: “in case of verification, which is not required on application, competent bodies shall apply the tolerances and control procedures laid down in EN 153”.

No verification procedure is described for washing machines and dishwashers in the respective Commission Decisions.

c) Laboratory accreditation

No accreditation is requested in the European Union to laboratories for the verification activity.

7.2.2.4 Conclusions for the verification procedures

A comparison of the test procedures described in the previous paragraphs shows that that there are some common elements:

- the most important outcome is that under the different form of a measurement error considered equal to the variability of the test measurement, or a verification limit taking care of measurement uncertainty, systematic and random errors and production variability, a 'tolerance' is always used in testing, both for the labelling declarations and for the compliance with minimum requirements;
- countries foreseeing accredited laboratories for verification generally use a lower value of 'tolerance', usually set equal to the error of the laboratory (reproducibility of the measurement method); but only accredited laboratories can then run official verification tests;
- a complete and correct verification procedure includes at least 2 Stages (sometimes three), and 4 or more units of the tested models (from 4 up to 20 units in US);
- the verification of the energy consumption for cold appliances is more complex than for other household appliances in Australia and US, while in the EU the same procedure is followed for all household appliances.

7.2.3 The Enforcement and market surveillance

7.2.3.1 The Australian market compliance control

As reported in the Issue 2 of Compliance Newsletter, a registration compliance audit was undertaken in the second half of 2006 into air conditioners on the Australian marketplace. The in store compliance audit consisted of comparing a list of air conditioner unit sales supplied by the marketing firm GfK and of advertising on the internet against the list of models included in the Energy Rating database in order to uncover potentially unregistered product. The search was extended to air conditioners Internet websites and other supply outlets to look for unregistered models.

A number of unregistered models were found and relevant suppliers were contacted. An ongoing dialogue commenced and actions may be taken against suppliers of unregistered stock.

This audit was considered successful by regulators because a number of previously unknown suppliers were contacted and made aware of labelling and energy efficiency requirements. The main sanction used against electrical equipment retailers is infringement notices. During the 2005-2006 financial year, Australian energy regulators concentrated on using educative approaches to retailers explaining their responsibilities in relation to labelled appliances.

A similar audit for white goods targeting dryers, washing machines, dishwashers, refrigerators and freezers is to be undertaken during 2007. A further audit will be conducted in 2007 for air conditioners and at that time sanctions other than discussion and correspondence with regulators will be used where instances of non-compliance are detected.

7.2.3.2 The European Union

The EU market surveillance is based on Article 3 of directive 94/2/EC, Member States shall take all necessary measures to ensure that all suppliers and dealers established in their territory fulfil their obligations under this Directive.

Starting 1996, the European Commission DG TREN promoted under the SAVE programme three monitoring studies to evaluate the impact of the EU legislation on the market transformation of cold appliances and energy consumption under the leadership of the French Agency ADEME- Agence de l'Environnement et le Maîtrise de l'Énergie (ADEME, 1998[30]; ADEME, 2000[31]; ADEME, 2001[32]). No other major studies or reports on the overall implementation of the labelling scheme and the efficiency requirements in the EU have been promoted or prepared. Some more recent projects developed in the framework of the SAVE-II[33] and the Intelligent Energy Europe[34] programmes have addressed the implementation of the energy-labelling scheme in groups of member States.

Single Member States have developed market surveillance activities at national level in a discontinue way over the years. For example, the 2001 document "Evaluating the Implementation of the Energy Consumption Labelling Ordinance", Research Project on behalf of the German Federal Ministry of Economics and Technology[35] states the energy labelling implementation in Germany, or the document "Ten Years of Energy Labelling of Domestic Appliances 1995–2005"[36] of the Swedish Energy Agency stating the conclusion after ten years and showing also the result of appliance testing from one single test: ù

- 101 cold appliances, 15 deviated more than allowed (14,9%).
- 19 ovens, 2 deviated more than allowed (10,5%).
- 28 dishwashers, 13 deviated more than allowed (46,4%).
- 48 washing machines, 20 deviated more than allowed (41,7%).
- 14 tumble dryers, 2 deviated more than allowed (14,3%).

since only the Step 1 of the two-stage verification procedure of the labelling scheme has been completed, it is not possible to draw conclusions about the actual compliance rate.

The CECED Voluntary Commitment on Reducing Energy Consumption of **Household Refrigerators, Freezers and their Combinations** (2002-2010), foresee a monitoring and reporting actions. In particular, the monitoring system of the Commitment supervises both the fulfilment of the conditions and the progress in energy saving resulting from the Commitment itself. The compliance with the targets is based on data, which are declared on the energy label for household refrigerating appliances (according to the energy labelling Directive).

A Notary monitors on an annual basis the results achieved by the Commitment, in terms of an overall production weighted energy consumption figure, calculated on the basis of the complete production/ import range in the EU of all participants. Participants to the Commitment are responsible for the accuracy of the data communicated to the Notary and for this purpose, they commit themselves to have such data validated by an independent (responsible) auditor. Each

[30] ADEME, Monitoring of energy efficiency trends of European domestic refrigeration appliances: final report, PW Consulting for ADEME on behalf of the European Commission, 1998.
[31] ADEME, Monitoring of energy efficiency trends of refrigerators, freezers, washing machines and washer-dryers in the EU, Final Report, PW Consulting for ADEME on behalf of the European Commission, 2000.
[32] ADEME, Monitoring of energy efficiency trends of refrigerators, freezers, washing machines, washer-dryers and household lamps in the EU, Final Report, PW Consulting for ADEME on behalf of the European Commission, 2001.
[33] SAVE project "Energy Labels - Making a Greener Choice", contract 4.1031/Z/01-024/2001, 2004.
[34] IEE project "CEECAP – Implementing EU Appliance Policy in Central and Eastern Europe project", http://www.ceecap.org/cntnt/ceecap/library .
[35] Fraunhofer ISI, "Evaluating the Implementation of the Energy Consumption Labelling Ordinance", Executive Summary, Research Project on behalf of the German Federal Ministry of Economics and Technology, No. 28/00, March 2001.
[36]The Swedish Energy Agency, Ten Years of Energy Labelling of Domestic Appliances 1995–2005, ER 2006:18.

participant remains responsible for the data declared on the label and communicated to CECED, which will ensure that the information is passed consistently in the database.
As far as the reporting is concerned, the Notary collects on a confidential basis from each manufacturer the production weighted energy efficiency index and the total production quantity for each product category and for each energy efficiency class. The Notary will provide CECED with an aggregated summary and anonymous ranking of the participants.

CECED collects a database, which contains technical data of all models of household refrigerating appliances placed on the Community market by all the participants. For each single model the data mandatory on the energy label are given. The database is available to the European Commission, national authorities and, for study purposes, to experts appointed by them. The copyright is owned by CECED.

Based on the data provided, CECED submits each calendar year starting from 01.01.2003 to the European Commission a report including the following information:

- on the base of the Notary summary:
  - the overall production weighted energy efficiency index;
  - a histogram of production weighted energy efficiency index for each efficiency classes and product category;
  - the ranking of the production weighted energy efficiency indexes of the participants in an anonymous way.
- on the base of the CECED technical database:
  - the respective share of each product category
  - some charts showing the trend in the technology

The annual report will be made available to the public free of charge.

A similar procedure is foreseen also for the "Second Voluntary Commitment on Reducing Energy Consumption of Domestic **Washing Machines** (2002-2008)" and the "Voluntary Commitment on Reducing Energy Consumption of Household **Dishwashers** (2000-2004)".

7.3 SUBTASK 7.3: THE BUSINESS AS USUAL SCENARIO

The definition of the Business as Usual (BaU) scenario for the cold appliances is based on qualitative assumptions rather then factual evidences.

It is worth remembering that the notable technological progress and the high energy efficiency gains achieved by this manufacturing sector during the last 10-12 years are entirely due to the effective mandatory and voluntary policies and measures enforced or promoted by the European Commission and the Members States. This does not mean that, without these policies, the sector would have not improved the energy efficiency of its products, but there is no evidence to which extent this could have been achieved and what technological innovation would have resulted. Actually, significant improvements of the energy efficiency were realised during the '80s and the beginning of the '90s (see Table 7.12[37] showing the average annual energy consumption for cold appliances starting from 1950) but at that time the energy efficiency and technological improvement potentials were high and the energy savings relatively easy to obtain. Today any further improvement is more difficult to achieve for the household appliances industry and needs to be justified by the market demand.

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[37] Source: CECED

Table 7.12: Average annual energy consumption of the cold appliances (source CECED)

Year	Average annual energy consumption (kWh/year)
1950-1979	839
1980-1984	586
1985-1990	526
1990-1994	482
1995	425
1996	437
1997	432
1998	411
1999	382
2000	363
2001	334
2002	328
2003	317
2004	308
2005	292

At present, without any new policy measure (the latest action, the CECED industry voluntary commitment, will terminate in 2010), no further penetration of new technologies is expected in the BaU scenario. Indeed, due to the market transformation induced by the EU energy labelling scheme, consumers will continue to purchase class A appliances as average models on the market, and class A+ models as more efficient units, especially in Member States where economic incentives for efficiency have been put in place. Since manufacturers will very likely not decrease the price difference between class A++ and class A+ appliances, A++ models will still remain almost as a niche product for some time in the future. This leads to the following scenario assumptions:

- for refrigerators:
  - efficiency classes A, A+ and A++ will represent the totality of the market in 2009;
  - in this year, class A will account for 70% of the market, class A+ 26% and class A++ the residual 4%;
  - the market share of higher efficiency classes will gradually improve until 2030 when class A+ appliances will dominate the market with 75% of the share, followed by class A++ ones with 25%;

- for freezers:
  - in 2005 there was still a significant presence of class B and C models (together representing more than 50% of the market) and a notable penetration of class A+ units (25%);
  - in this situation, a gradual phase out of class B is expected until 2020, and a parallel significant and steadily penetration of the classes A+ (70% in 2030) and A++ (30% in 2030) appliances.

These scenario assumption are presented in Tables 7.13-7.14 and in Figures 7.13-7.14, showing the market transformation trends for respectively refrigerators and freezers[38].

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[38] The time intervals in the BaU Scenario are not evenly distributed between 2005 and 2025. The first interval is 4 years, the second and the third 5 years, the fourth 6 years. These time intervals have been selected to match with those proposed for the enforcement of policy measures discussed in Subtask 7.6.

Table 7.13: BaU Scenario for refrigerators, energy efficiency classes trends in 2005-2030

Year	A++ (%)	A+ (%)	A (%)	B (%)	C (%)	Tot. (%)
2005	1	18	61	19	1	100
2009	4	26	70	0	0	100
2014	12	43	45	0	0	100
2019	16	64	20	0	0	100
2025	20	80	0	0	0	100
2030	25	75	0	0	0	100
EEI	30	42	55	75	90	--
Energy consumption (kWh/y)	166,0	232,4	291,6	397,7	477,2	--

Table 7.14: BaU Scenario for freezers, energy efficiency classes trends in 2005-2030

Year	A++ (%)	A+ (%)	A (%)	B (%)	C (%)	Tot. (%)
2005	5	25	33	25	12	5
2009	10	35	40	15	0	10
2014	15	52	28	5	0	15
2019	20	63	17	0	0	20
2025	25	75	0	0	0	25
2030	30	70	0	0	0	30
EEI	30	42	55	75	90	--
Energy consumption (kWh/y)	166,1	232,5	251,5	342,9	411,5	--

Figure 7.13: ***BaU Scenario, market transformation in 2005-2030 for refrigerators*** **((percentage of models in each class are shown)**

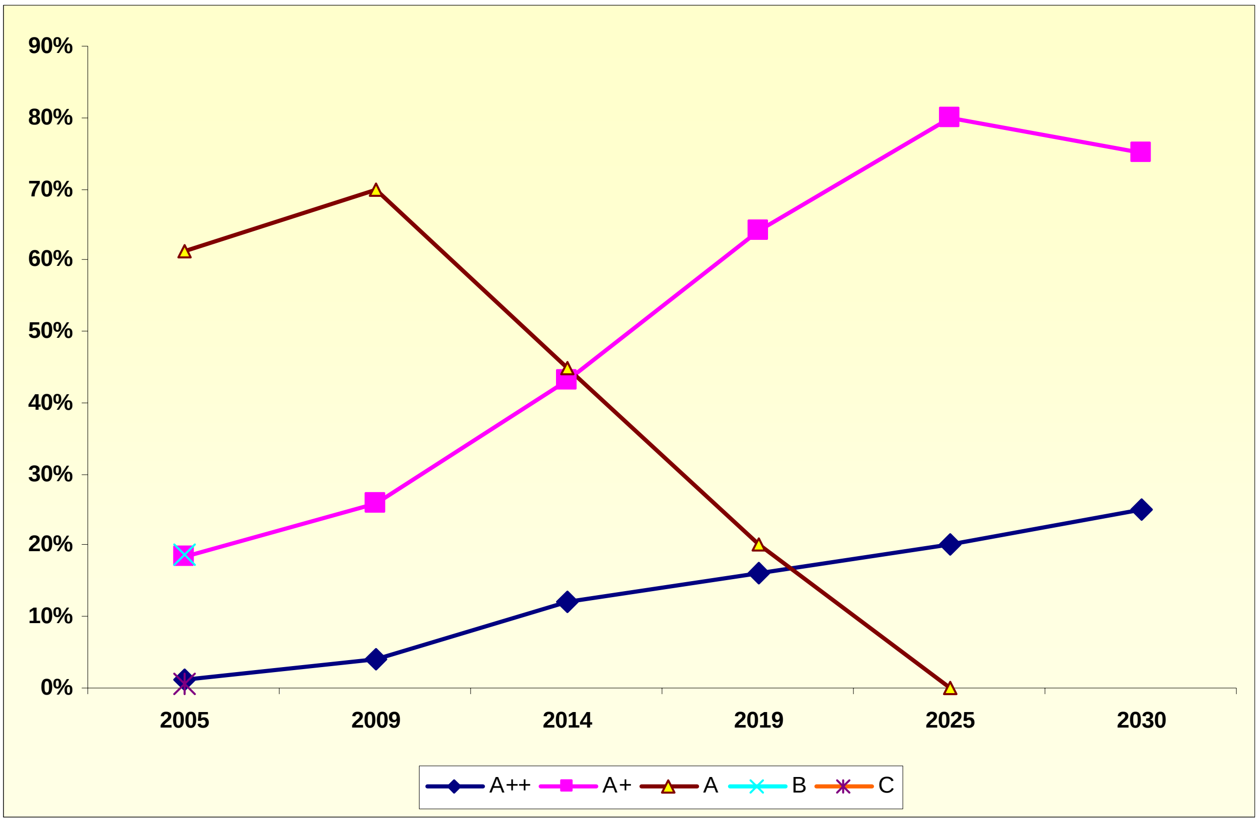
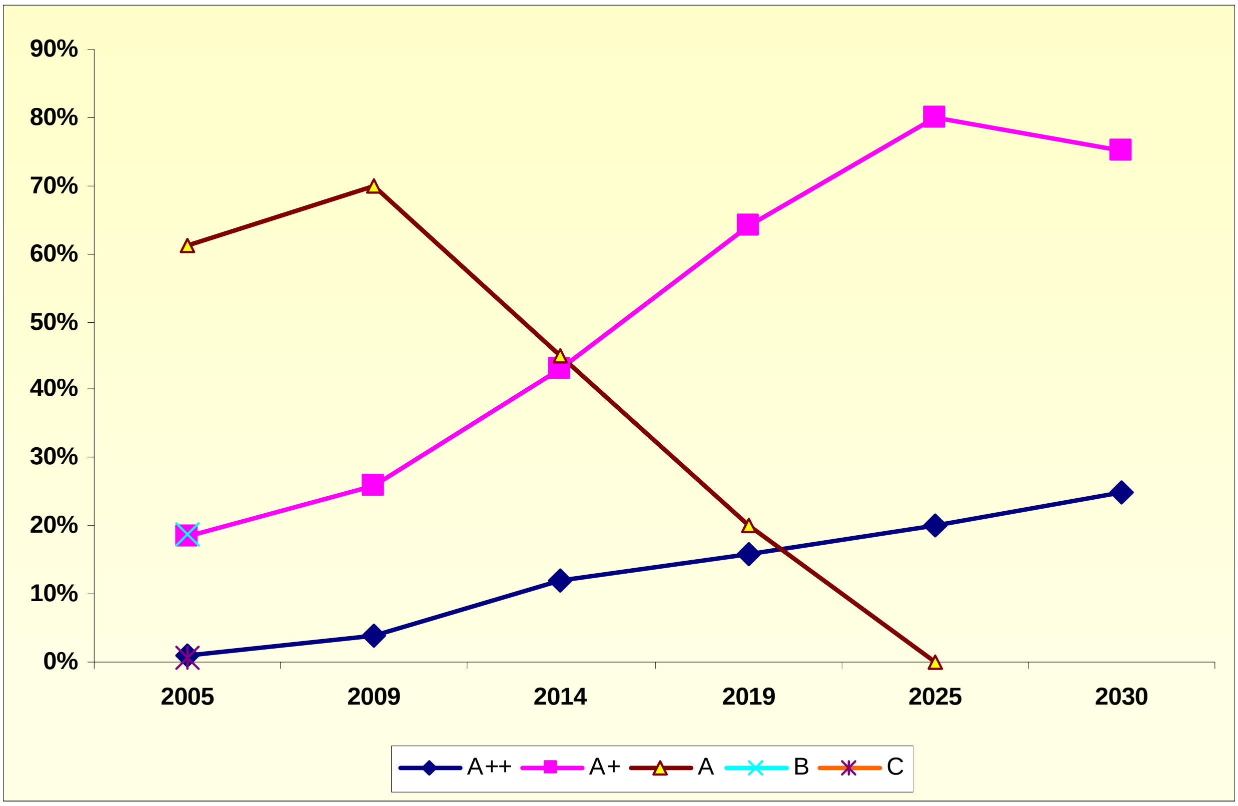


Figure 7.14: ***BaU Scenario, market transformation in 2005-2030 for freezers*** **(percentage of models in each class are shown)**



Tables 7.15-7.17 and Figures 7.15-7.17 for refrigerators and Tables 7.18-7.20 and Figures 7.18-7.20 for freezers, show the trends of the appliance stock (in million of units), the overall stock energy consumption (in GWh/year) and the average energy consumption (in kWh/year) for the years 1990-2020 in accordance with the BaU Scenario assumptions and the stock growth rates resulting from the stock model described in Task 2.

As far as refrigerators are concerned, the stock energy consumption (Figure 7.16) decreases significantly and steadily until 2020. After this year the decreasing rate is supposed to somewhat reduce its trend, being the household growth rate not enough balanced by the energy efficiency improvement. The ownership is considered saturated at 104% around 2020 for EU15 and at 100% in the same year for EU10. This trend, clearly showing the effect of the policy measures implemented during the past decade, is consistent with the trend of the average energy consumption values (Figure 7.17) which are foreseen to decrease at a more slow rate around 2014.

Figures 7.18 and 7.19 show respectively the appliance stock and the stock energy consumption trends for freezers in 1990-2030. For EU15 the ownership rate was assumed to reach a steady value of 50% from 2005; for EU10 the ownership rate was assumed to be about 8% in 1995, 10% in 2005 and 16% in 2020; the EU10 values are derived from an assessment carried out within the SACHA projects[39] during the second half of the '90s and from more recent figures of yearly sales provided by GfK (see Task 2). The overall ownership rate of freezers has been assumed very low at the beginning of the '90s, with a steadily increase in accordance with the above mentioned EU15 trend.

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[39] The SACHA 1 and SACHA 2 projects, developed under the DG TREN SAVE-I programme in 1995-1998, evaluated the refrigerators and washing machines state of the art in seven Central and Eastern European countries, including forme.

The results of the BaU simulation show that despite the sharp increase of the freezers stock due to the combined effect of the households' number growth rate and the increase of the ownership rate, the stock energy consumption decreases steadily, at least until 2015, due to the constant improvement of the energy efficiency of these appliances.

Table 7.15: Refrigerator stock trend in the EU countries in 1990-2030, BaU Scenario (million of units)

Year	**Refrigerator stock (thousand)**		
	EU25	EU15	EU10
1990	151	127	23
1995	164	138	25
2000	174	147	27
2005	182	153	28
2009	191	162	29
2014	203	173	30
2019	213	182	31
2025	225	194	31
2030	236	204	32

Table 7.16: Stock energy consumption trend for refrigerators in EU countries in 1990-2030, BaU Scenario (GWh/year)

Years	**Refrigerator total energy consumption**		
	EU25	EU15	EU10
1990	91 419	76 561	14 858
1995	85 761	71 957	13 804
2000	80 321	67.489	12 832
2005	71 067	59 487	11 595
2009	65 596	54 970	10 626
2014	59 582	50 209	9 373
2019	56 023	47 613	8 410
2025	54 098	46 411	7 687
2030	49 726	42 809	6 917

Table 7.17: Average energy consumption trend for refrigerators in EU countries in 1990-2030, BaU Scenario (kWh/year)

Year	**Refrigerator average energy consumption**		
	EU25	EU15	EU10
1990	606	600	639
1995	524	520	550
2000	461	458	479
2005	391	388	411
2009	343	339	360
2014	294	291	309
2019	263	261	273
2025	240	239	247
2030	211	209	219

Figure 7.15: ***Refrigerator stock trend in the EU countries in 1990-2030, BaU Scenario (million of units)***

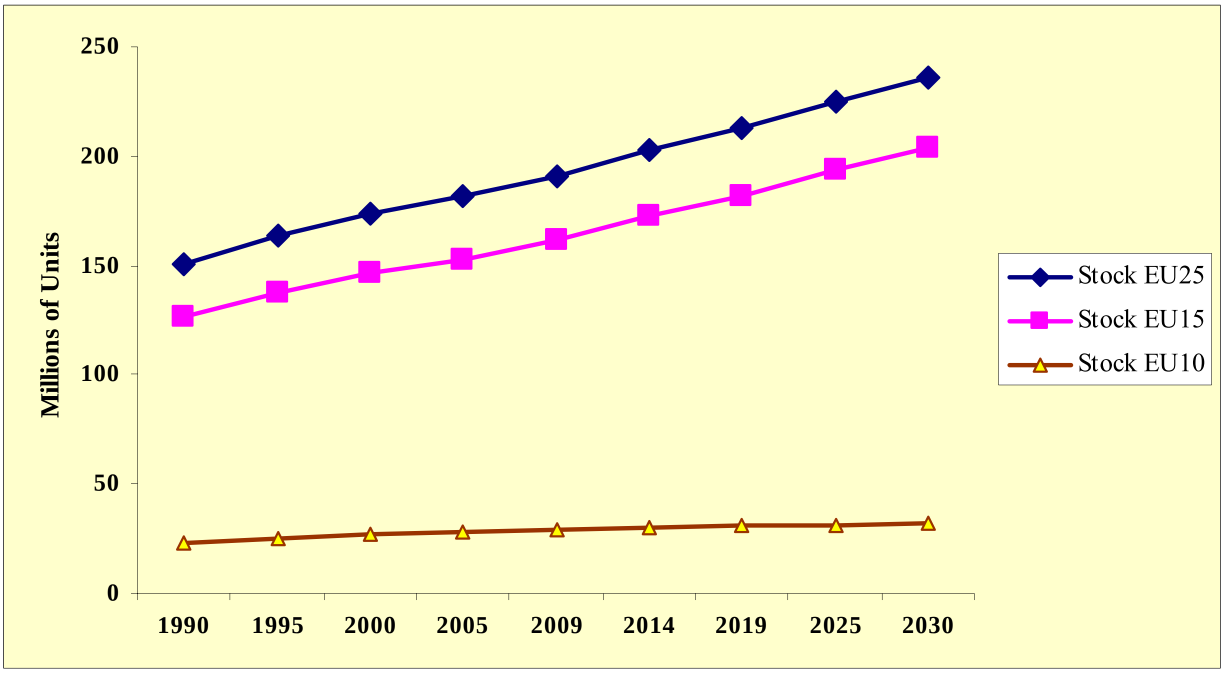


Figure 7.16: ***Stock energy consumption trend for refrigerators in EU countries in 1990-2030, BaU Scenario (GWh/year)***

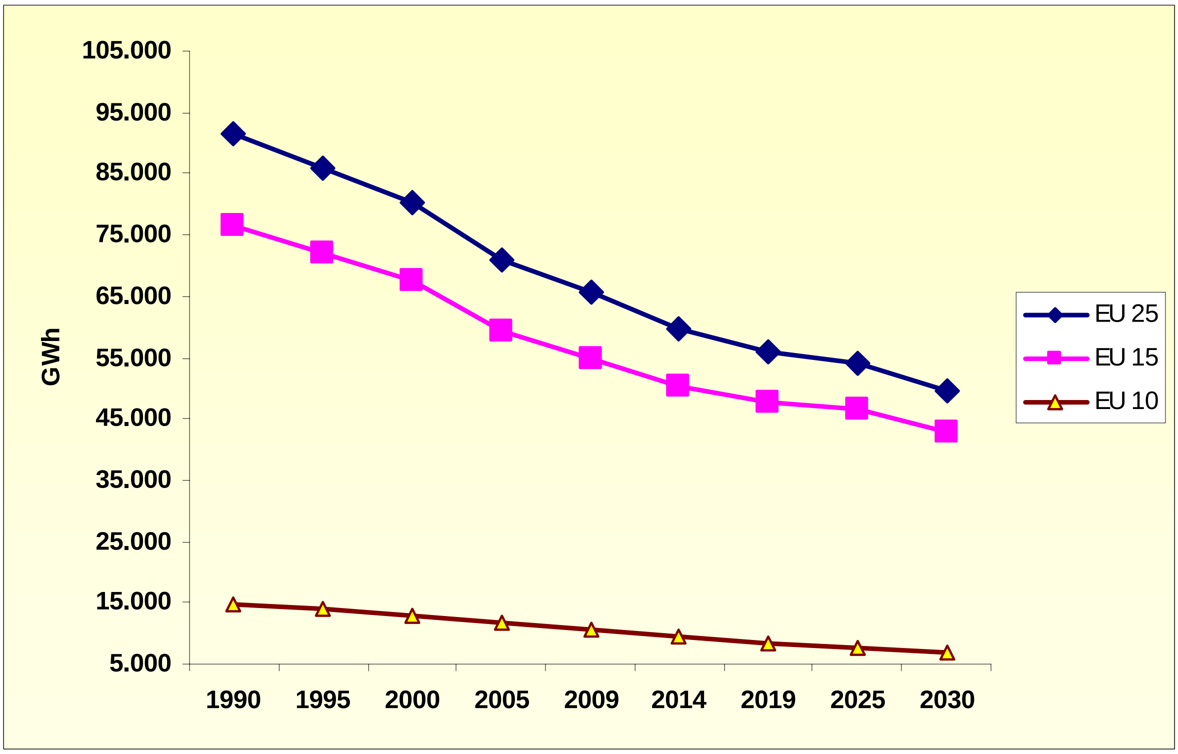


Figure 7.17: ***Average energy consumption trend for refrigerators in EU countries in 1990-2030, BaU Scenario***

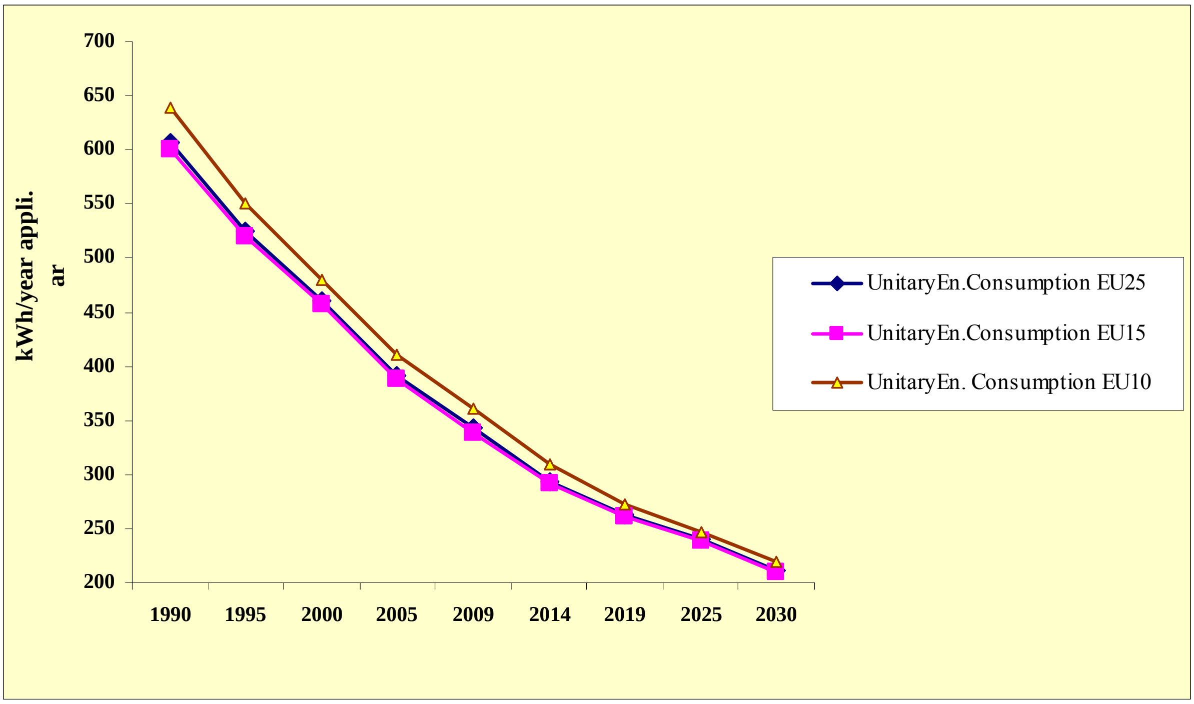


Table 7.18: Freezer stock trend in the EU countries in 1990-2030, BaU Scenario (million of units)

Years	Freezer stock (thousand)		
	EU25	EU15	EU10
1990	54	53	2
1995	67	64	2
2000	77	74	3
2005	81	78	3
2009	85	81	4
2014	88	84	4
2019	92	87	5
2025	97	92	5
2030	103	97	6

Table 7.19: Stock energy consumption trend for freezers in EU countries in 1990-2030, BaU Scenario (GWh/year)

Year	**Freezer total energy consumption**		
	EU25	EU15	EU10
1990	39.337	38.204	1.133
1995	41.315	40.018	1.297
2000	39.810	38.441	1.369
2005	34.986	33.653	1.333
2009	31.074	29.761	1.314
2014	26.651	25.396	1.255
2019	24.129	22.891	1.238
2025	23.036	21.760	1.276
2030	21.745	20.479	1.266

Table 7.20: Average energy consumption trend for freezers in EU countries in 1990-2030, BaU Scenario (kWh/year)

Year	Freezer unitary energy consumption		
	EU25	EU15	EU10
1990	722	723	715
1995	621	622	611
2000	520	521	508
2005	431	432	417
2009	366	367	338
2014	301	302	286
2019	262	262	254
2025	237	237	236
2030	212	211	225

Figure 7.18: ***Freezer stock trend in the EU countries in 1990-2030, BaU Scenario (million of units)***

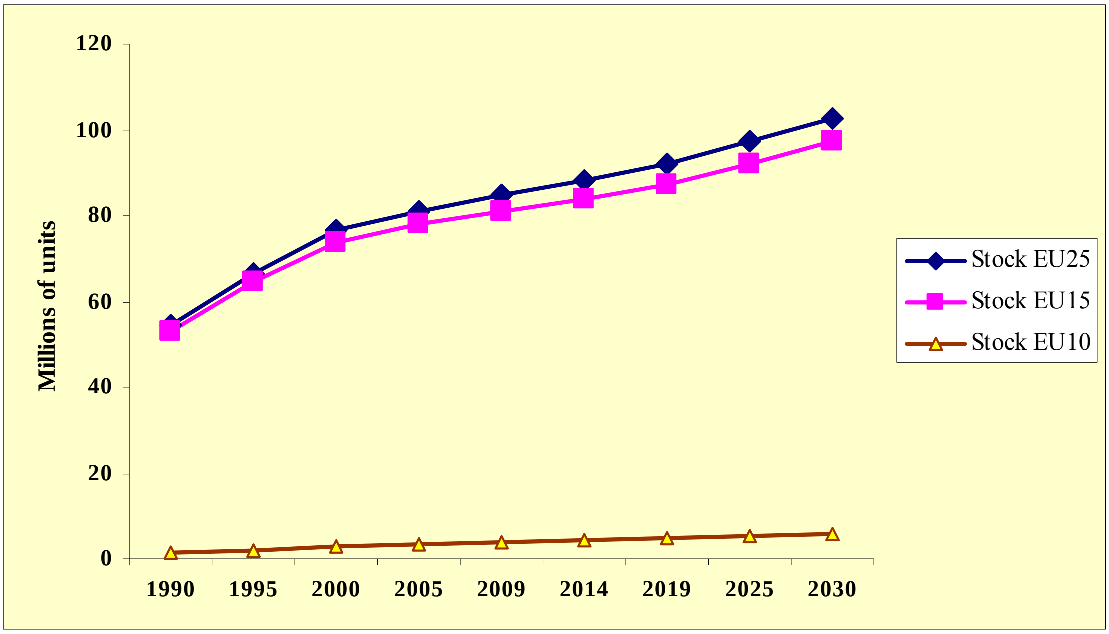


Figure 7.19: ***Stock energy consumption trend for freezers in EU countries in 1990-2030, BaU Scenario (GWh/year)***

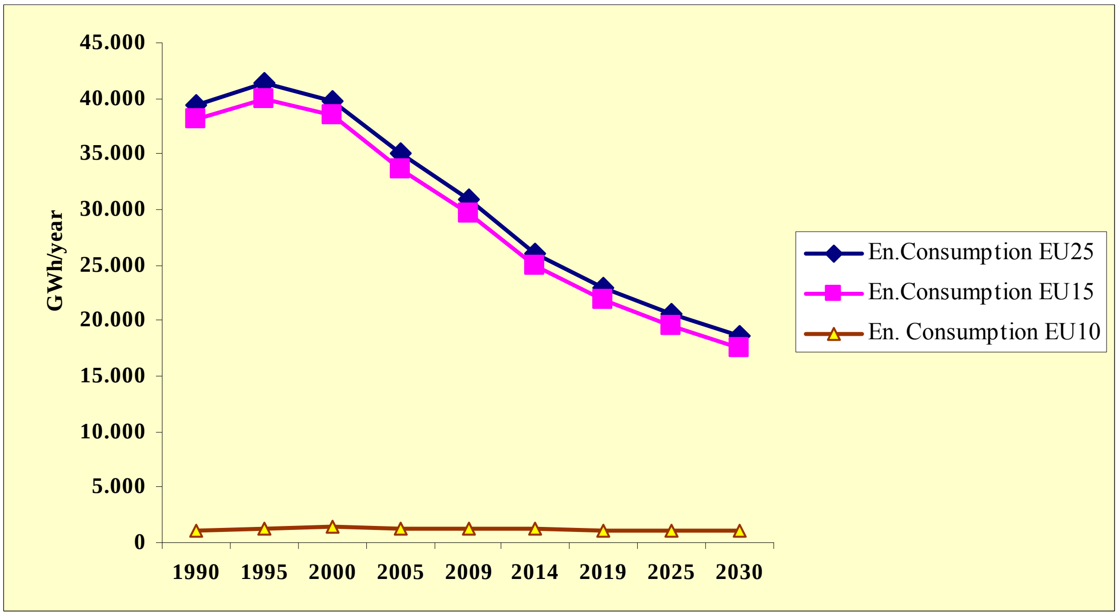
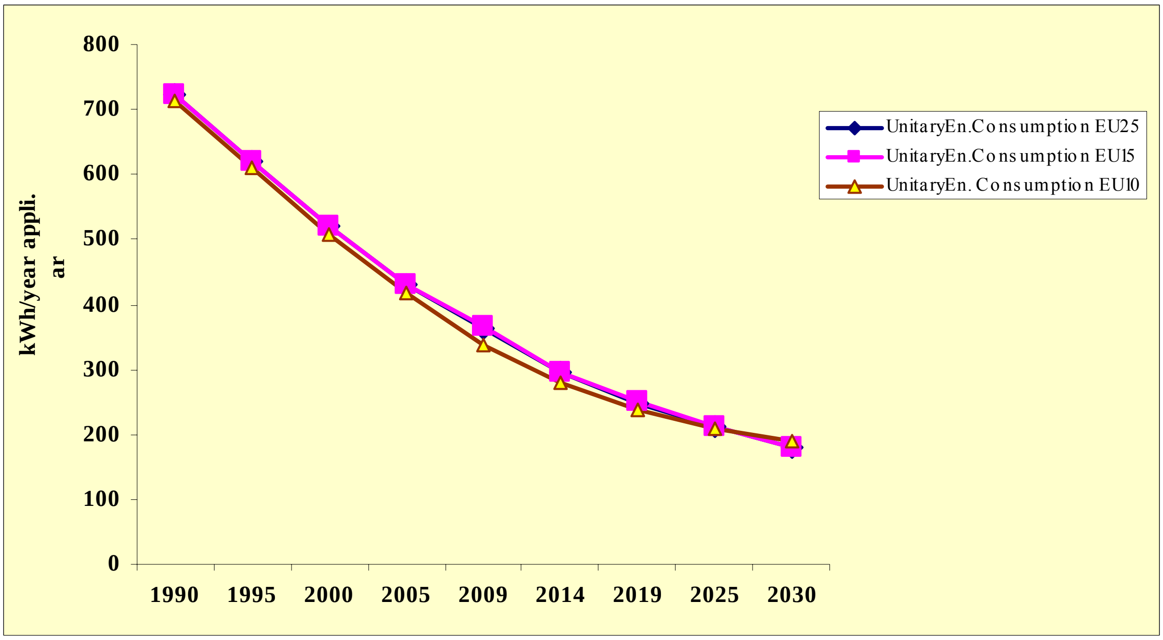


Figure 7.20: ***Average energy consumption trend for freezers in EU countries in 1990-2030, BaU Scenario***



7.4 SUBTASK 7.4: MANUFACTURERS IMPACT ANALYSIS

The impact analysis on manufacturers will be run using the E-GRIM model, developed by ENEA in the framework of previous SAVE projects and already successfully applied in the analysis of the WASH-2 project.

Cost data used in the NPV and Life Cycle Cost methods is further disaggregated and used as input in E-GRIM model. Quantitative market data, industry structure, consumers' habits provided by previous phases of the study or by literature will be used to establish a framework to describe the linkages of the market and the technological improvement. E-GRIM model is expressly designed to allow the analysis of the effects of a single policy measure upon a single product. By combining multiple iterations it is also possible to analyse multiple products with policy measures taking effects over a period of time and/or multiple policy measures on the same product. The program simulates the sales, all main elements of cost and the cash flow, each year for fifteen years and then determines the present value of those cash flows without policy measure – the Base case – and with policy measure – the Policy Measure case. Output consists in the complete cash flow calculations, summary statistics, and graphs of major variables, including net cash flow for industry and for consumers (due to electricity savings), employment, investments required and impact on profits.

Average values to be used as input to E-GRIM model are presented at the sector level in terms of the "typical manufacturer".

7.4.1 The E-GRIM model

The white goods appliance market is essentially one of low growth and substitution among models, favouring higher efficiency categories, the only exception being air conditioners, a relative latecomer to the European market. Overall unit sales growth are usually between one or two percent, whereas new models gain market share relatively rapidly. In this context a new type of E-GRIM (European Government Regulatory Impact Model) was developed incorporating dual production lines: one for the newer, higher share penetration model and a second for the typical model being substituted. For simplicity, both lines are assumed to be within the same facility of one million units nominal capacity. One more unit of sales (and production) of the higher penetration model corresponds to one less unit of sales and production of the typical substituted model. For more complex situations, additional growth rates above the substitution rates can be introduced, relaxing the assumption of constant production capacity, allowing capacity to grow slightly.

The dual production line model of E-GRIM was first introduced in a study for CECED in 2006[40] and subsequently in 2007[41]. It results in more realistic representation of the industrial dynamics because it explicitly considers the losses due to substitution that inevitably occur within industry and normally within the same firm. Only in the situation of a firm rapidly gaining market share in the new models over the other firms can this substitution be partially avoided within the firm. The traditional single-line production model overestimates cash flows and profits in this context, not subtracting the substituted cash flows lost. Fortunately the margin of the newer higher penetration models is greater than that on the older models and after substitution there remain profits. This is

[40] Mebane, William (November 2006) *Final Report on Production Tax Credits*, site: www.ceced.org (see Statements and Press Info)
[41] Mebane, William and Piccino, Emanuele (2007), *New Policy Instruments for Energy Efficient Home Appliances in Europe,* 9th IAEE European Energy Conference, Energy Markets and Sustainability in a Larger Europe, Florence, Italy

consistent with the practice of product life cycles, introducing the newer higher margin product with gradually decreasing price and margins over time.

The original GRIM was developed by Arthur D. Little and subsequently modified by ENEA and William Mebane for a European context[42]. It has been utilized in several studies for industry and the European Commission[43].

The primary purpose of the method is to simulate the impact of changes in policy due to the introduction of new or improved technologies that modify the cost of manufacturing. The impact of these changes are simulated by the model through annual projections of the profit/loss and cash flow statements of a production facility, projected forward in time for fifteen years.. It is this cost structure and along with the evolution of prices that determine the future cash flows. Policies introduce changes in these inputs and the resulting outputs and cash flows can be compared to base case.

Since the energy savings and price savings are known between a base case product and an improved product, the various impacts for consumers can be estimated. Similarly changes in value added, manufacturers' profits and income tax can be calculated for new products. These changes impact on the national government where the production facility is located and these impacts on government revenues may be estimated.

7.4.2 Impact Analysis

The more general aspects of the impact analysis are presented here. Instead the specific data input and results regarding the Base, the LLCC and BAT models for refrigerators and freezers are given successively together with their corresponding scenarios.

7.4.2.1 General Input Data

The most single group of important set of inputs is undoubtedly the structure of the production costs. Unfortunately there are not detailed income statements available for many of the producers and the ones available often involve other products. The cost structure also is not available for different appliances or for different models within the same appliance group. Often this reflects the industrial reality where it is difficult to follow costs at a detailed and rapidly evolving level of production. Therefore over the years we have developed a consensus model of costs, which is retained by industry to fairly accurately represent the cost structure of a large plant of one million units of nominal capacity. The cost assumptions have been reviewed by industry representatives recently as part of this task.

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[42] The original model was developed by Arthur D. Little, Inc. of Cambridge, Massachusetts. It was modified and upgraded by ENEA on March 11, 1997 and subsequently modified by William M. Mebane on July 26, 2006.

[43] E-GRIM has been utilized in the following studies:

- ISIS/ENEA, Study of the Environmental Impact of Dishwashers, promoted by CECED, completed in September 2005.
- Enhancing the Government Regulatory Energy Measures Impact and Diffusion Speed Appraisal Method (E-GRIDS), project number NNE5-2001-00147, contract number ENG1-CT2001-80550, completed in 2002.
- Government Regulatory Energy Measures Impact and Diffusion Speed Appraisal Method (GRIDS), project number NNE5-1999-00657, contract number ENK6-CT-1999-00016, completed in 2001.
- Proposal for the Revision of Energy Labelling and the 2nd Stage of Minimum Energy Efficiency Standards for Domestic Refrigerators and Freezers and their Combinations, contract number XVII/4.1031/Z/98-269, completed in 2000.
- Revision of energy labelling & targets washing machines (clothes), contract number XVII/4.1031/Z/98-091, completed in 2000.

These costs are presented in Table 7.21 and shown on the assumption page of every simulation of the E-GRIM.

Table 7.21: General Cost Assumptions

Income Tax Rate	48%
Working Capital	18% of Revenue
Sales, General and Admin. (SG&A)	10% of Revenue
Research and Development	2,5% of Revenue
Ordinary Depreciation	4,3% of Revenue
Ordinary Capital Expenditures	4,5 % of Revenue
Variable Overhead as % of Total Overhead	60%
Total Unit Manufacturing Cost	about 78% of revenue
Within the Unit Manufacturing Costs:	
Materials and Components	72%
Labour	15%
Overhead (only variable part)	7%
Depreciation	6%
Total	100%

Usually we have a net income of between 2 and 6% of revenue depending on the model and price levels.
For example, applying this structure of costs to LLCC model of the refrigerator-freezer of Category 7&10.7, the outcome of Figure 7.21 results.

Notice that net income is not net cash flow, which is shown for the above example as a percent of sales.

Net Income:	5,94%
Depreciation	4,30%
Change in Working Capital	-3,43%
Total (Cash Flows from Operations)	6,82%

From this we subtract cash used in investments:

Extra Productivity capital expenditure	0
Ordinary Capital Expenditures	-4,50%
Extra Conversion Capital Expenditures (for example, an ad hoc marketing campaign)	0
Total Cash Used In Investment	-4,50%
Net Cash Flow	2,32%

It so happens that the change in working capital is quite strong in the first years so that the margin of net cash flow to revenue at 2,3 % is not representative. The average for the period is 4,0% for the BAU scenario.

As suggested, one of the most important data input is the appliance price trend. These trends have been analyzed over the latest available 8 years and are reported in Table 7.22.

Figure 7.21: Example of Composition of Industry Costs of LLCC Model for the refrigerator-freezer

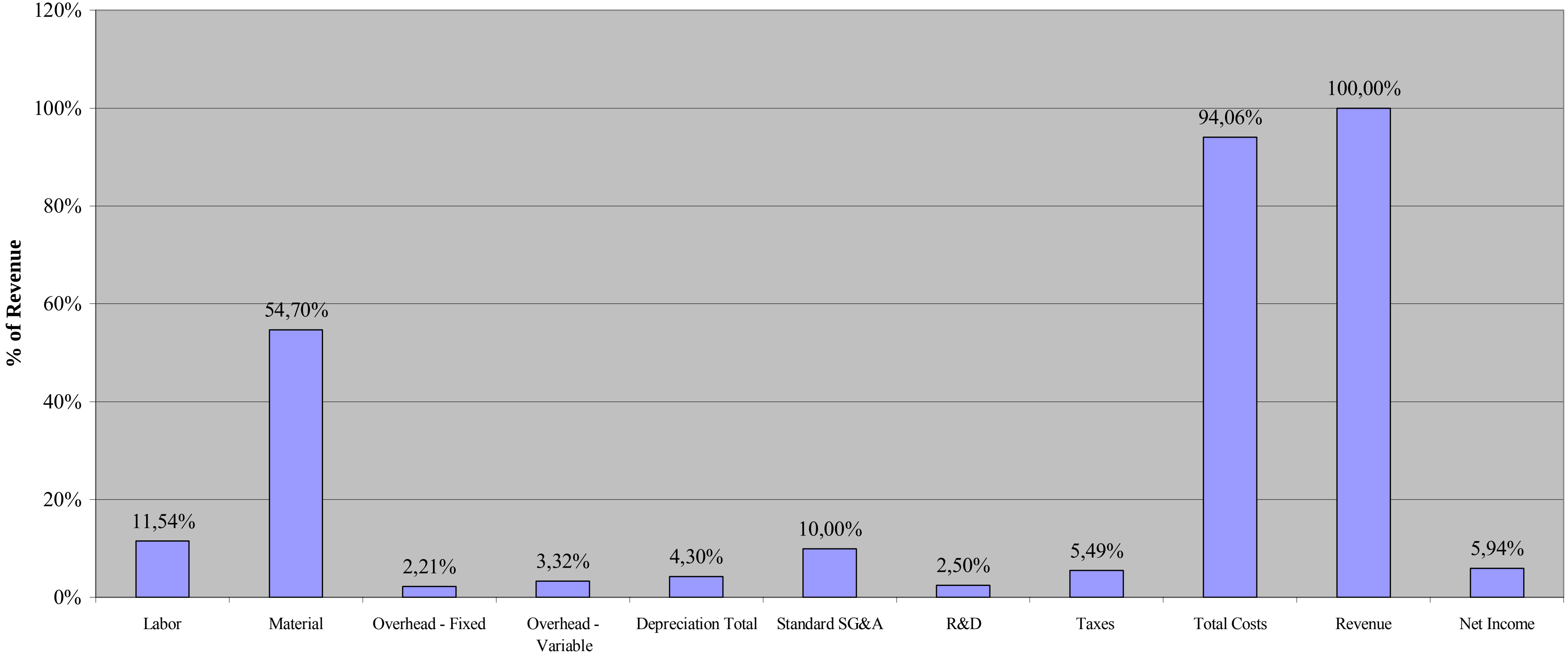


Table 7.22: Real Price Growth of Appliances in Europe

Real Price Growth (1996-2004, Source: GfK)										
Appliance/Data	Country:									
	Austria	Belgium	Germany	Spain	France	Great Britain	Italy	Netherlands	Sweden	
Refrigerators										
Real Price, 1996	532,8338703	566,3930263	526,7301793	570,159144	512,1198398	375,8941111	418,9888412	537,7363588	713,061262	
Sales * 1000, 1996	203	272,9	2559,2	862	1562,4	1761,7	774,4	486,6	115,7	8597,9
	12,5804296	17,97748949	156,783386	57,16246783	93,06179854	77,02027885	37,73769858	30,4333049	9,595504485	492,3523583
Real Price, 2004	460,2620873	491,4491177	436,2766235	519,4741337	495,2822413	505,3400139	456,6635709	400,6570273	622,1368576	
Sales, 2004	219290,2457	314658,9158	2448339,72	1279777,695	2122244,399	2711370,182	1485652,152	494875,7549	197110,8162	11273319,88
	8,953084565	13,71724108	94,75056129	58,97210553	93,23872414	121,5404033	60,18131519	17,5880265	10,87788736	479,819349
									Ratio 2004/1996	0,974544634
								% decrease in 8 years		0,025455366
							Refrigerators Annual Price Growth:			-0,003217931
Washing Machines										
Real Price, 1996	730,679358	765,4887567	772,3900528	449,6679959	575,5683155	494,8901758	428,565729	782,7187546	753,8076198	
Sales * 1000, 1996	187	208,3	1977,5	964,8	1708,4	1817,8	1145,9	401,8	91	8502,5
	16,07021934	18,75346169	179,6414383	51,0249553	115,6484458	105,8055115	57,75871436	36,98869693	8,067802811	589,7592461
Real Price, 2004	552,3884656	594,2049788	506,021695	644,6829427	393,2977434	483,3249826	471,1059306	445,7067093	573,025708	
Sales, 2004	217530,2319	266720,624	2225274,997	1406644,64	2089027,873	2717126,812	1453263,414	507287,988	187303,8784	11070180,46
	10,85449253	14,31654374	101,7180732	81,9173463	74,21829764	118,6299784	61,84551514	20,4243879	9,695409932	493,6200448
									Ratio 2004/1996	0,836985682
								% decrease in 8 years		0,163014318
							Washing Machine Annual Price Growth:			-0,021997976
Freezers										
Real Price, 1996	521,5926494	470,2778461	494,6394751	337,8720853	396,5529733	298,0462183	319,6286303	426,2693687	588,558502	
Sales, 1996	47840	43009	418725	40651	226244	189922	82002	53013	34529	1135935
	21,96691919	17,80575463	182,3325403	12,09121837	78,98139497	49,8316663	23,07366789	19,89358374	17,89040439	423,8671498
Real Price, 2004	394,9810871	434,4190221	350,8892083	322,8991454	404,1354721	378,1123786	271,1807008	308,0327134	339,4571126	
Sales, 2004	96877,17883	136585,3415	898414,7617	137434,8129	618152,8707	970442,922	320555,2355	183951,6251	106197,6127	3468612,361
	11,03168917	17,10634233	90,88477225	12,79404529	72,02231793	105,7876878	25,06143217	16,33596156	10,39307112	361,4173196
									Ratio 2004/1996	0,852666501
								% decrease in 8 years		0,147333499
							Freezers Annual Price Growth:			-0,019726189
							Refr+WM+ Freez. Annual Price Growth:			-0,013288408
								(weighted by sales, GfK data)		
							EU25 Large Appliance Price Index Growth:			-0,008
								(1996-2006, EU official data)		

The consulting firm GfK gathered price data for the latest available years for the above countries. The percent change in the average, weighted by sales, was computed for the period 1996-2004. As shown this results in real price declines of 0,032%/yr, 1,97%, and 2,19% for refrigerators, freezers, and washing machines respectively. As a check the average price decline for these three appliances is calculated weighting again by sales and compared to the EU25 large appliance price index. The three-appliance average is -1,3%/yr percent compared to -0,8%/yr for the EU25 appliance index, which appears reasonable.

7.4.2.2 Other General Assumptions

The base year is 2007, the year of announcement of a policy is 2008 and the first year of the policy implementation is 2009. Including the first year of the policy, 15 years of production are simulated ending in 2023. Since the last appliance sold in year 2023 has a fifteen-year lifetime that produces savings through year 2038, which is the last year simulated for consumers.
As in the original version of E-GRIM, it is assumed that the normal activities of production including the normal level of capital investment, assumed to be 4,5% of sales, produces the historic increase in labour productivity of 1,5% per year. This increase of labour productivity may come through automation or relocation of facilities. It is applied to direct labour and variable overheads in both the BAU and policy scenarios. There is also an option to increase these types of investments.
The real discount rate of 5%t is used. This compares with a real risk free discount rate of 2 to 3% in Europe (for long term government bonds for example) plus a very low risk premium in keeping with the social aspects of public policy
In these preliminary simulations the base case or business as usual scenario (BAU) is defined as a continuation of the affects of present policies through year 2008, then from year 2009 and forward the relative quota of sales and production remain constant. No new policies are introduced and producers keep their quotas constant. Instead the policy scenario, here called 'scenario evolution' represents a possible tendency of the quotas without a well-defined instrument on the part of the governments, European Commission or producers to achieve that new tendency. It is an exploration on the production side to see the implication of achieving such a new tendency without the extra costs in promotion to achieve it, in terms of extra marketing costs, a production tax scheme or EC policy. More detailed policy analysis will be made subsequently in Task 7.

In the dual production model depreciation is treated as a more rapidly changing variable than usual. This is believed to better represent the cost of conversion, which will involve more re-tooling costs with a shorter lifetime (typically 5 years). Essentially depreciation is a lagged amount of capital expenditures for each production line.

7.4.2.3 General Output Data

Starting from the first year, a profit/loss and cash flow statement is projected forward for 15 years based on all the various cost and price assumptions. For each year a complete profit/loss and cash flow statement is available. In the case of the dual production model this applies to each line of production and a summary of the profits, taxes and cash flow for the combination of both lines, that is the entire production facility. Thus for the fifteen year period we have all the key production variables: units shipped, manufacturer's price, revenue, all the major costs, the profit before taxes, the corporate taxes, net profits, depreciation, change in working capital, operating cash flow, capital investments, net (or free) cash flow. These may be displayed in table or graphic form. A key summary variable for the manufacturers' is the net present value (or discounted value) of the net cash flows. This is industry value that has been added over the years and is used as a summary comparison of policies.

The model calculates the various impacts on consumers assuming that all the models produced are sold, assuming zero change in inventories in the long run. Consumers' purchases, and the difference in the price between the newer and the substituted model are calculated. This difference is the investment cost for the relative energy saving between the two models, as hypothesized in the LCC optimization in Task 6. Economic savings, electricity savings and avoided carbon dioxide emissions are calculated as a result of sales and use by the consumer for each year through 2038, after the last product sold has exhausted its average lifespan.

A new feature was introduced in E-GRIM for estimating the changes in cash flows of a government that introduces production tax credits. This is a new type of policy instrument currently being utilized by the US government to promote high efficiency appliances that appears to be more effective than traditional rebates (or reduction in value added tax) and costs less for the government.

7.4.3 Impact Analysis and Results for Freezers

From Task 6, Tables 6.14 and 6.15, we have the key characteristics of the three cases of freezers (Categories 8 and 9), where manufacturers' price is estimated with a 3,0 factor of mark-up (Table 7.23).

Table 7.23: Energy and Price Characteristics of Freezers

	Energy Consumption (kWh/year)			Consumer Purchase Price (€)			Manufacturers' Price (€)		
Product	**Base Case**	**LLCC**	**BAT**	**Base Case**	**LLCC**	**BAT**	**Base Case**	**LLCC**	**BAT**
Upright Freezers	274,5	203,4	164,9	328,0	426,8	644,8	131,2	170,7	257,9
Chest Freezers	300,6	212,8	152,8	328,0	431,0	649,1	131,2	172,4	259,6
Average Freezers	**287,6**	**208,1**	**158,9**	**328,0**	**428,9**	**647,0**	**131,2**	**171,6**	**258,8**

Since there is a small difference in the prices between the two types of freezers, from 0 to 1%, and also the energy consumption is similar, we have taken the average figures for simulation with E-GRIM assuming that the underlying cost structure is also similar.

7.4.3.1 Formulation of Preliminary Scenarios for freezers

At the factory level, two sets of hypotheses are made (Table 7.24): a) one regarding a producer with 80% production of the Base Model and 20% with the LLCC model, in year 2008. In the Business-As-Usual (BAU) Scenario these quotas remain constant in time. Instead in the Evolution Scenario the two quotas go to 50% Base Model and 50% LLCC over the next five years, remaining constant afterwards. This is called the **'Base LLCC Accelerated 50/50 Hypothesis'** and b) regarding a producer with the 95% of his production in the Base model and a small but growing 5% in the BAT model in year 2008. In the Business-As-Usual (BAU) Scenario these quotas remain constant in time. Instead in the Evolution Scenario the two quotas go to 50% Base Model and 50% BAT rapidly over the next five years, remaining constant afterwards. This is called the **'Base BAT Accelerated 50/50 Hypothesis.'**

The factory is simulated with two production lines. Naturally a producer may have other production lines and additional models in production. It was also thought to be more realistic to have a shorter period of evaluation and the simulation is terminated in 2020.

The other dramatic difference is the historic rate of real price decline for freezers, which has been 1,97%/year. In this analysis we use -1,9% per year.

Table 7.24: Production hypotheses for freezers

Hypothesis Set	Model	Factory capacity		
		2008	2020 BAU	2012-2020 Evolution
Base LLCC Accelerated 50/50:	Base	80%	80%	50%
	LLCC	20%	20%	50%
Base BAT Accelerated 50/50:	Base	95%	95%	50%
	BAT	5%	5%	50%

7.4.3.2 'Base Case-LLCC accelerated 50/50' hypothesis for average freezers

The input and assumptions page for the above hypothesis of the LLCC freezer model is shown in Table 7.25. Similarly the assumptions for the Base Model average freezer are presented in Table 7.26.

With the very strong decline in real freezer prices, the initial margin (year 2008) of the LLCC model was raised to 7,0% in the BAU scenario. As can be seen in Table 7.27 in the income statement the *average* margin of net cash flow of the LLCC model for the period was instead only 2,9%.

Slightly higher margins are assumed initially for the new model. The optimization carried out in Task 7.6, assumes average conditions and does not take into consideration these dynamics of the product life cycle, which favours initial higher margins for new model declining gradually in time.

The initial margin for the Base model was 4,65% in year 2008 and the average only 0,9% for the period, as shown above. The average difference in margins between the two models is 2,0%. The higher initial margin for the LLCC model was achieved by a minor increase in price (5 €) and slightly lower initial costs. Even with this hypothesis, with the severe price declines, the discounted cash flows are minimal as will be illustrated.

Examining the cash flows, we have first that of BAU scenario shown in Figure 7.22.

Figure 7.22: BAU Scenario Net Cash Flows for Freezer LLCC (New) Models and Base Case Models

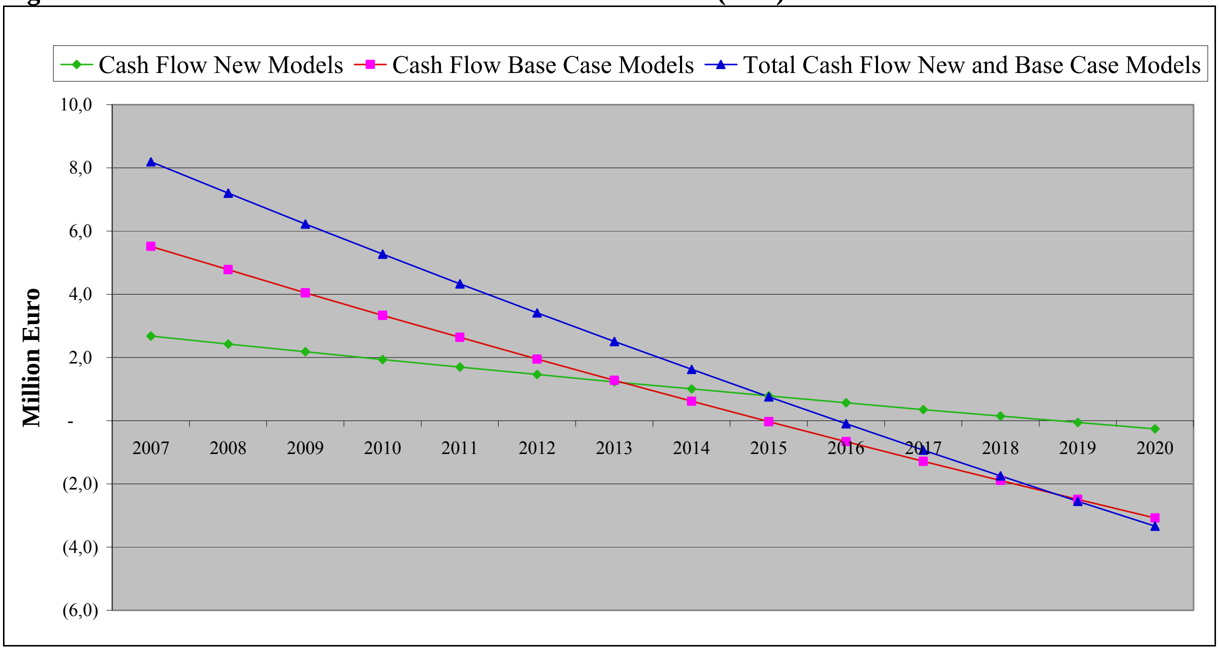


Table 7.25: Assumptions for Average LLCC Freezer

Assumptions Page for				
Situation Studied	Freezers Base & LLCC (LLCC Prod)			
Situation Studied in Base Prod.	Freezers Base & LLCC (Base Prod)			
	Freezers Base & LLCC (Base Prod)			
Base Year	2007			
Announcement Year	2008	*Year in which the announcement is made*		
Policy Measure Year	2009	*Year in which the policy measure takes effect*		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	177,00	*(EURO)*	Price Grow. UPMY	-1,9%
Base Year Unit Sales	0,050	*(million)*	Price Grow. APMY	-1,900%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%		Dist. Mark-up	3,00
			Tax Credit (€)	0
			El. Savings (kWh/yr)	79,5
			Electr.Price (€/kWhr)	0,17
			Water Savings (€/yr)	0
	BAT Case	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	**94,00**	0,00	0%	0%
Labor / Unit	**19,00**	0,00	0%	0%
Overhead / Unit	**9,00**	0,00	0%	0%
Depreciation / Unit	7,61	0,00		
Total/ Unit	129,61	-		
Hypothetical Full Price Increase (Policy Measure Case Only)		0,00		
Percent of H. F. Price Increase Recovered by Manufacturers		100,00%		
Manufacturers' Price Increase		0,00		
Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10		0%	0%
Tooling	5		0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%
	Shipments BAU Scenario	**Shipments Evolution Scenario**		
(Year)	*(%)*	*(%)*		
2007	**20,00%**	**20,00%**		
2008	**20,00%**	**25,00%**		
2009	**20,00%**	**35,00%**		
2010	20,00%	**45,00%**		
2011	20,00%	**50,00%**		
2012	20,00%	**50,00%**		
2013	20,00%	**50,00%**		
2014	20,00%	**50,00%**		
2015	20,00%	**50,00%**		
2016	20,00%	**50,00%**		
2017	20,00%	**50,00%**		
2018	20,00%	**50,00%**		
2019	20,00%	**50,00%**		
2020	20,00%	**50,00%**		

Table 7.26: Assumptions for the Average Base Freezer

Assumptions Page for				
	Freezers Base & LLCC (Base Prod)			
Scenario Description	Base Model			
Base Year	2007	*Beginning year for analytical purposes*		
Announcement Year	2008	*Year in which the announcement is made*		
Policy Measure Year	2009	*Year in which the policy measure takes effect*		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	131,00	*(EURO)*	Price Grow. UPMY	-1,9%
Base Year Unit Sales	0,950	*(million)*	Price Grow. APMY	-1,9%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%			
			Tax Credit (€)	0
			El. Savings (kWh/yr)	79,5
			Electr.Price (€/kWhr)	0,17

	Base Model	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	73,70	0,00	0%	0%
Labor / Unit	15,10	0,00	0%	0%
Overhead / Unit	7,30	0,00	0%	0%
Depreciation / Unit	5,63	0,00		
Total/ Unit	101,73	-		

Hypothetical Full Price Increase (Policy Measure Case Only)	0,00
Percent of H. F. Price Increase Recovered by Manufacturers	100,00%
Manufacturers' Price Increase	0,00

Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10	0	0%	0%
Tooling	5	0	0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%

Table 7.27 Income and Cash Flow Statements BAU Scenario for Base and LLCC Average Freezers

Freezers Base & LLCC (LLCC Prod)															
BASE CASE SCENARIO		Base Year	Announce Year	Policy Year											
New (and Base Case)		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Income Statement															
Price/Unit		177,0	173,6	170,3	167,1	163,9	160,8	157,8	154,8	151,8	148,9	146,1	143,3	140,6	137,9
Unit Sales		0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20
Revenues		35,4	34,7	34,1	33,4	32,8	32,2	31,6	31,0	30,4	29,8	29,2	28,7	28,1	27,6
Cost of Sales															
Labor		3,8	3,7	3,7	3,6	3,6	3,5	3,5	3,4	3,4	3,3	3,3	3,2	3,2	3,1
Material		18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8	18,8
Overhead - Fixed		0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
Overhead - Variable		1,1	1,1	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,9	0,9	0,9	0,9	0,9
Depreciation Productivity Cap. Exp.			-	-	-	-	-	-	-	-	-	-	-	-	-
Depreciation Ordin. & Convers.		1,5	1,5	1,5	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	1,2	1,2	1,2
Depreciation Total		1,5	1,5	1,5	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	1,2	1,2	1,2
Selling, General and Administrative															
Standard SG&A		3,5	3,5	3,4	3,3	3,3	3,2	3,2	3,1	3,0	3,0	2,9	2,9	2,8	2,8
R&D		0,9	0,9	0,9	0,8	0,8	0,8	0,8	0,8	0,8	0,7	0,7	0,7	0,7	0,7
Product Conversion Expense		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Profit Before Tax		5,1	4,6	4,1	3,6	3,2	2,7	2,3	1,8	1,4	1,0	0,6	0,2	(0,2)	(0,6)
% Profit B.T./ Revenue		14,3%	13,15%	12,00%	10,8%	9,6%	8,44%	7,21%	5,95%	4,67%	3,37%	2,04%	0,69%	-0,69%	-2,09%
Taxes		2,4	2,2	2,0	1,7	1,5	1,3	1,1	0,9	0,7	0,5	0,3	0,1	(0,1)	(0,3)
Net Income Before Financing		2,6	2,4	2,1	1,9	1,6	1,4	1,2	1,0	0,7	0,5	0,3	0,1	(0,1)	(0,3)
Cash Flow Statement		**2007**	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Net Income		2,6	2,4	2,1	1,9	1,6	1,4	1,2	1,0	0,7	0,5	0,3	0,1	(0,1)	(0,3)
Depreciation		1,5	1,5	1,5	1,4	1,4	1,4	1,4	1,3	1,3	1,3	1,3	1,2	1,2	1,2
Change in Working Capital		0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Cash Flows from Operations		4,3	4,0	3,7	3,4	3,2	2,9	2,6	2,4	2,1	1,9	1,7	1,4	1,2	1,0
Productivity capital expenditure			-	-	-	-	-	-	-	-	-	-	-	-	-
Ordinary Capital Expenditures		(1,6)	(1,6)	(1,5)	(1,5)	(1,5)	(1,4)	(1,4)	(1,4)	(1,4)	(1,3)	(1,3)	(1,3)	(1,3)	(1,2)
Conversion Capital Expenditures		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cash Used In Investment		(1,6)	(1,6)	(1,5)	(1,5)	(1,5)	(1,4)	(1,4)	(1,4)	(1,4)	(1,3)	(1,3)	(1,3)	(1,3)	(1,2)
Average Base Model Margin	**0,9%**	5,26%	4,65%	4,01%	3,37%	2,71%	2,05%	1,36%	0,67%	-0,03%	-0,75%	-1,49%	-2,23%	-2,99%	-3,77%
Cash Flow New Models		2,7	2,4	2,2	1,9	1,7	1,5	1,2	1,0	0,8	0,6	0,4	0,1	(0,1)	(0,3)
Cash Flow Base Case Models		5,5	4,8	4,0	3,3	2,6	1,9	1,3	0,6	(0,0)	(0,7)	(1,3)	(1,9)	(2,5)	(3,1)
Total Cash Flow New and Base Case Models		8,2	7,2	6,2	5,3	4,3	3,4	2,5	1,6	0,8	(0,1)	(0,9)	(1,7)	(2,6)	(3,3)
Average New Model Margin	**2,9%**	7,56%	6,99%	6,39%	5,78%	5,17%	4,54%	3,90%	3,24%	2,58%	1,90%	1,21%	0,51%	-0,21%	-0,94%
Present Value Factor		1,000	0,952	0,907	0,864	0,823	0,784	0,746	0,711	0,677	0,645	0,614	0,585	0,557	0,530
Discounted Cash Flow		8,2	6,9	5,6	4,5	3,6	2,7	1,9	1,2	0,5	(0,1)	(0,6)	(1,0)	(1,4)	(1,8)
Total Cash Flow as % of Revenue	1,6%	5,8%	5,2%	4,6%	4,0%	3,3%	2,7%	2,0%	1,3%	0,6%	-0,1%	-0,8%	-1,5%	-2,3%	-3,1%
Industry Value (Net Present V.)	**30,2**														

Since in BAU case the production quotas are fixed, we observe the gradual linear decline in net cash flow due to the very strong real price decline of 1,9% per year. After about 9 to 10 years, 2016 to 2017, it is no longer profitable to produce. Turning to the evolution scenario, we see a more complex pattern (Figure 7.23).

Here we have the result of the switch in production quotas, mirrored in the cross over of the cash flows of each model in years 2009-2012.
In fact, in those years there is a slowing of the decline in total cash flow. The year when the total cash flow goes negative is extended slightly to 2018. Not too surprisingly there is not much difference in the total cash flow between the BAU and Evolution scenarios as illustrated in Figure 7.24.

In fact, discounting these two cash flows we have their net present value, which does not differ more than about 10% (Figure 7.25).

The absolute values are 30 million Euro, an average of 2 million Euro/year over the 15 year period, not an excess considering the one-million unit plant. From a strictly profit point of view there is not much incentive, 3,4 million Euro in the conversion to the Evolution scenario. It may be more a question of following the market. The situation improves slightly if in fact the production is closed before the total cash flow goes negative in year 2018. In this case the net present values are 35 and 40 million Euros respectively with a difference of 5 million.

Figure 7.23: Evolution Scenario Net Cash Flows for Freezer LLCC (New) Models and Base Case Models

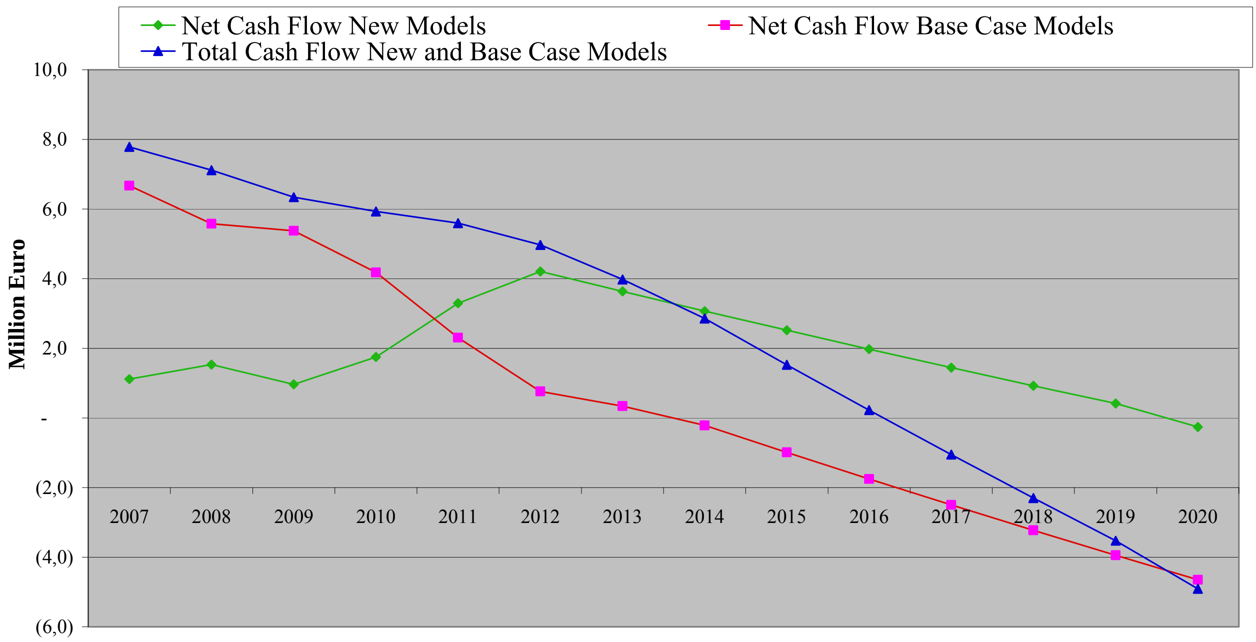


Figure 7.24: Total (both LLCC and Base Freezer Models) Cash Flow in the BAU and Evolution Scenarios (for 'Base LLCC Accelerated 50/50 Hypothesis')

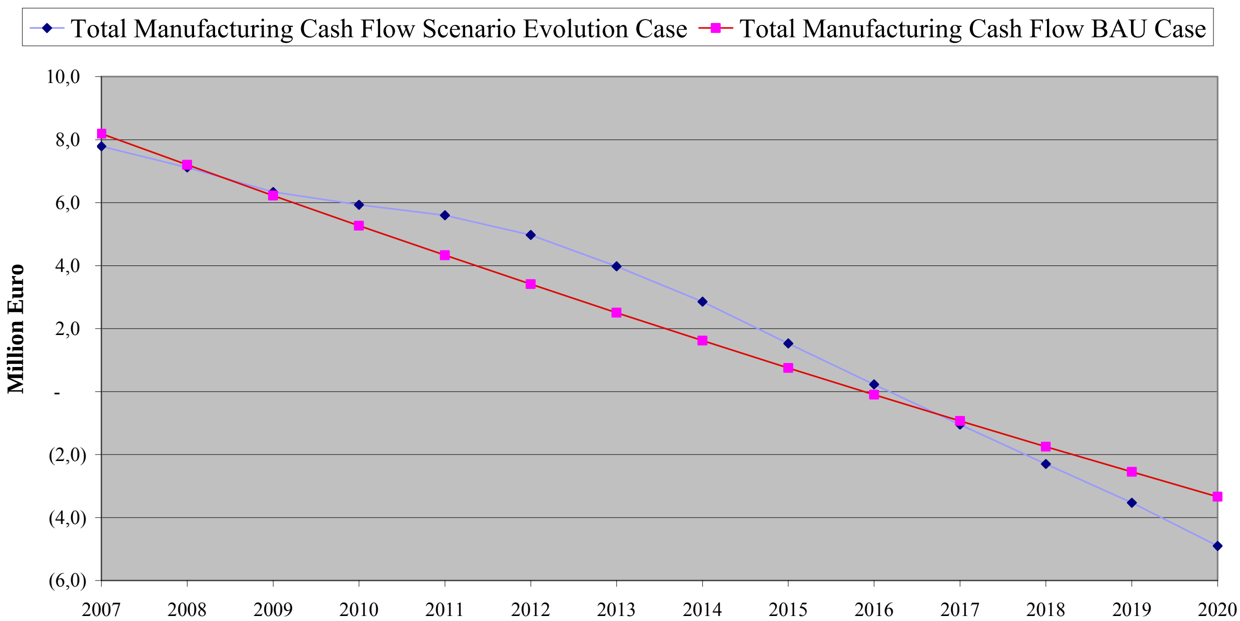
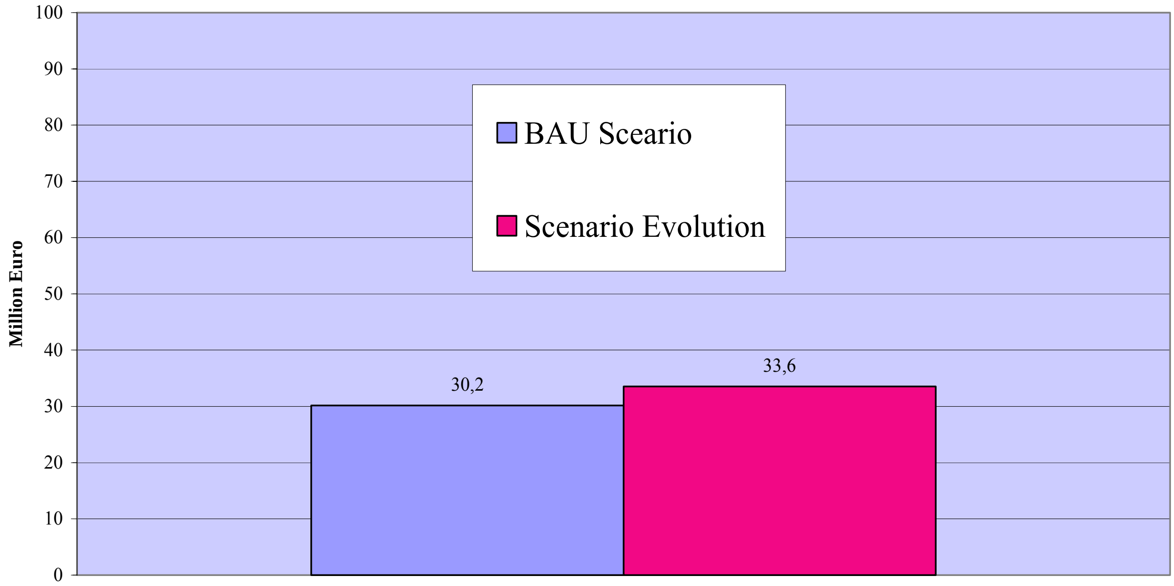


Figure 7.25: Total Discounted Cash Flow in the BAU and Evolution Scenarios (for 'Base LLCC Accelerated 50/50 hypothesis')



7.4.3.3 'Base Case-BAT accelerated 50/50 for average freezers

The input page for the BAT model production is presented in Table 7.28. The initial manufacturing price has been raised slightly above those of Task 6 and the manufacturing costs adjusted a tad lower to result in an initial margin of 7,0% in year 2008 for the BAT model. The average margin for the period is 2,8% for BAT model compared to the 0,9% for the Base Case model in the BAU scenario. The initial situation is very similar to that of the previous hypothesis involving the LLCC freezer model.
The input data for the Base Case model are the same as that previously presented in Table 7.6. Now we may turn to the examination of the cash flows in the two scenarios. The BAU Scenario presents the usual declining linear cash flows due to the fixed production quotas (Figure 7.26).

Figure 7.26: Cash Flows of BAU Scenario (BAT= New Model and Base=Base Case Model)

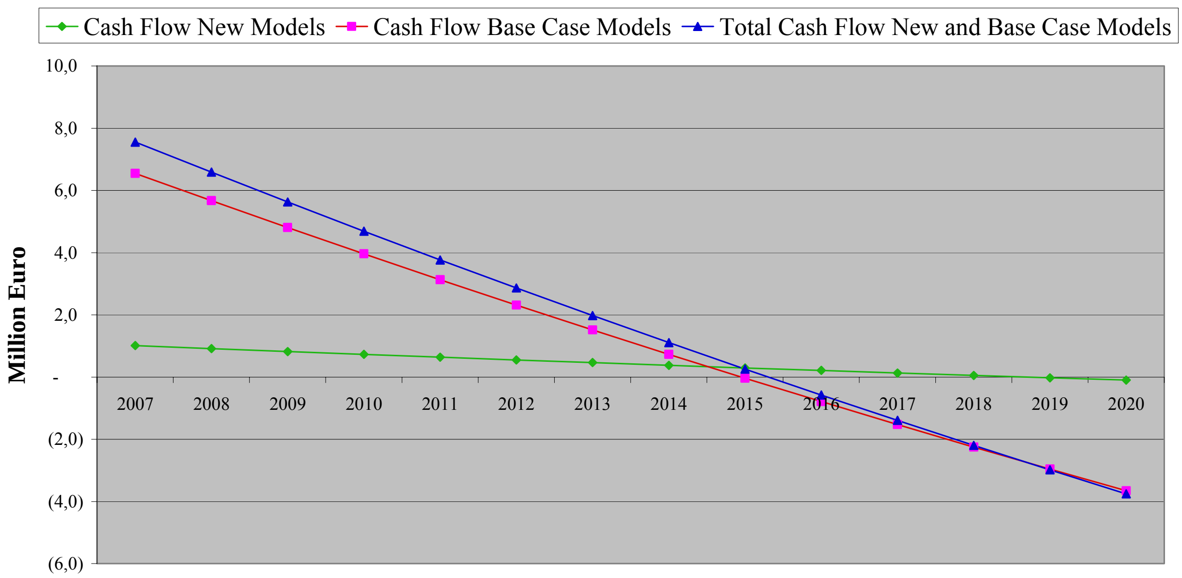
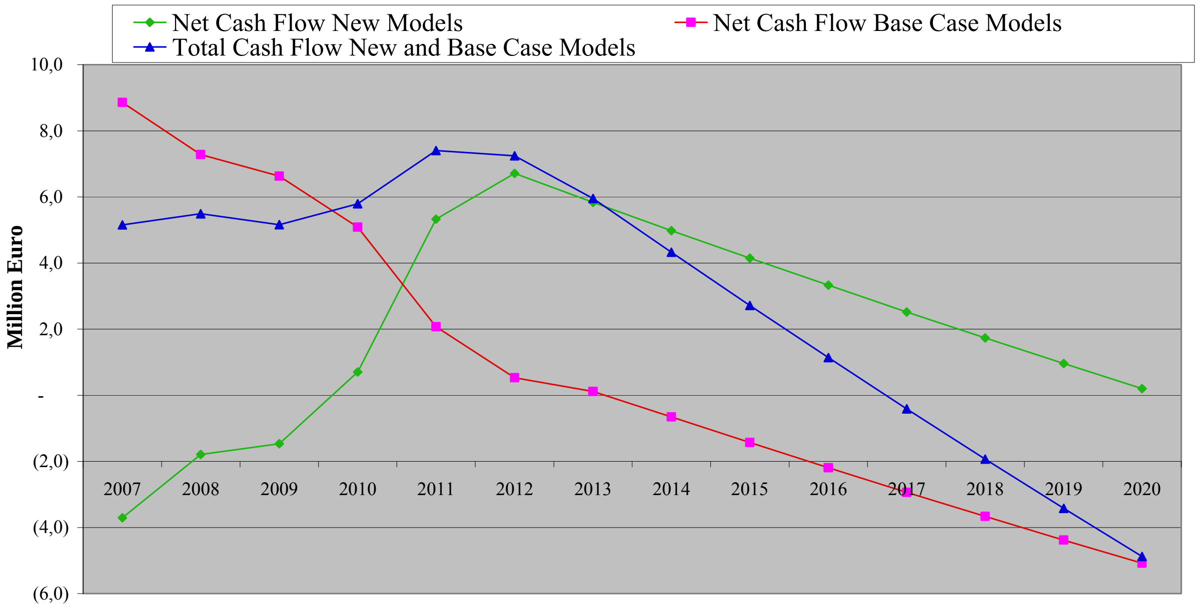


Table 7.28: Data and Assumptions for Average Freezer BAT Model Production

Assumptions Page for				
Situation Studied	**Freezers Base & BAT (BAT Prod)**			
Situation Studied in Base Prod.	**Freezers Base & BAT (Base Prod)**			
	Freezers Base & BAT (Base Prod)			
Base Year	2007			
Announcement Year	2008	*Year in which the announcement is made*		
Policy Measure Year	2009	*Year in which the policy measure takes effect*		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	267,00	*(EURO)*	Price Grow. UPMY	-1,9%
Base Year Unit Sales	0,050	*(million)*	Price Grow. APMY	-1,900%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%		Dist. Mark-up	3,00
			Tax Credit (€)	0
			El. Savings (kWh/yr)	128,7
			Electr.Price (€/kWhr)	0,17
			Water Savings (€/yr)	0
	BAT Case	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	**143,00**	0,00	0%	0%
Labor / Unit	**28,00**	0,00	0%	0%
Overhead / Unit	**13,00**	0,00	0%	0%
Depreciation / Unit	11,48	0,00		
Total/ Unit	195,48	-		
Hypothetical Full Price Increase (Policy Measure Case Only)		0,00		
Percent of H. F. Price Increase Recovered by Manufacturers		100,00%		
Manufacturers' Price Increase		0,00		
Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10		0%	0%
Tooling	5		0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%
	Shipments BAU Scenario	**Shipments Evolution Scenario**		
(Year)	*(%)*	*(%)*		
2007	**5,00%**	**5,00%**		
2008	**5,00%**	**15,00%**		
2009	**5,00%**	**30,00%**		
2010	5,00%	**45,00%**		
2011	5,00%	**50,00%**		
2012	5,00%	**50,00%**		
2013	5,00%	**50,00%**		
2014	5,00%	**50,00%**		
2015	5,00%	**50,00%**		
2016	5,00%	**50,00%**		
2017	5,00%	**50,00%**		
2018	5,00%	**50,00%**		
2019	5,00%	**50,00%**		
2020	5,00%	**50,00%**		

In this scenario the BAT production quota remains at a low 5% and as a result the total cash flows go negative earlier than in that of the previous hypothesis, where the quota for the new model was 20%. The cash flows for the Evolution scenario is shown in Figure 7.27.

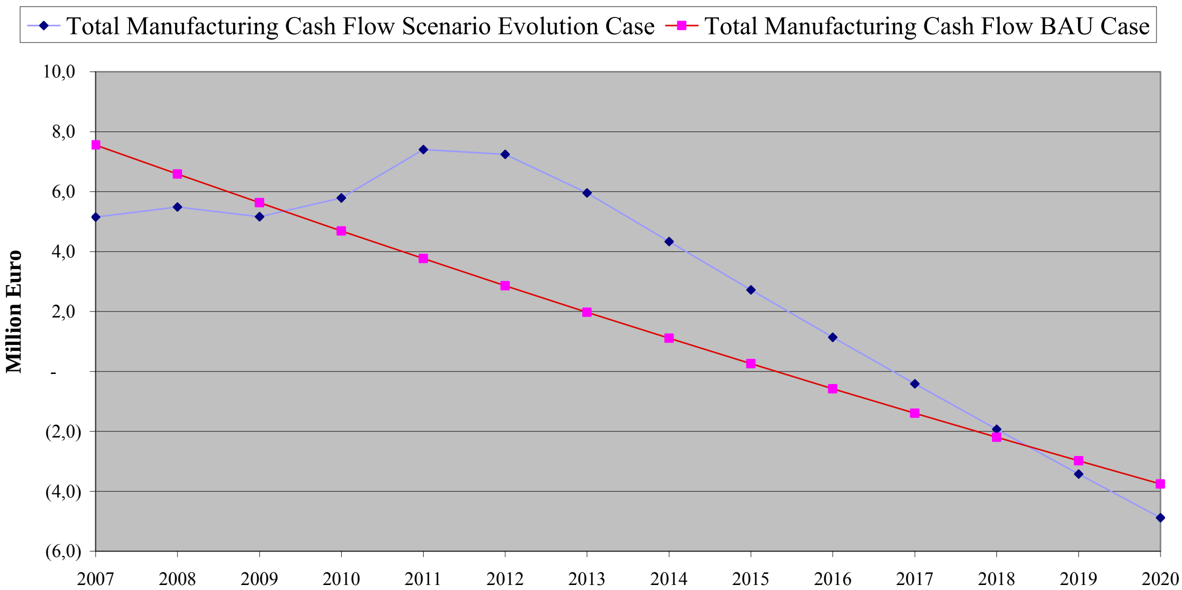
Figure 7.27: Cash Flows of the Evolution Scenario (BAT= New Model and Base=Base Case Model)



Although the margins are approximately equivalent to those of the previous hypothesis concerning the LLCC model, here they are working on the higher priced BAT model and are greater in terms of Euros. In fact, they are sufficient to bring the total net cash flow up for a brief period of years, from 2009 to 2012. Afterwards price dynamics take over.

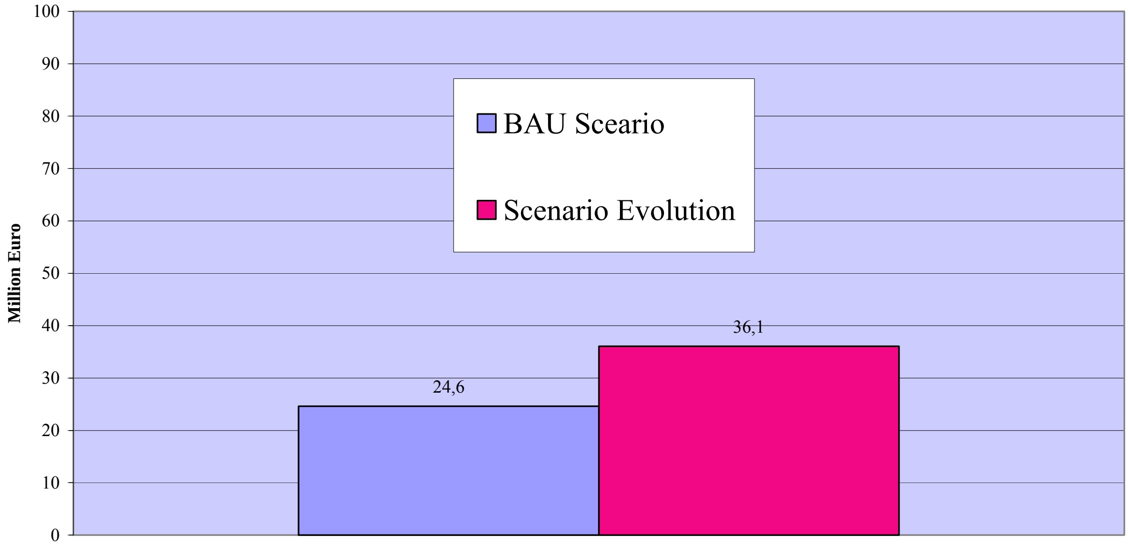
As one might suspect the total cash flows for the Evolution scenario are greater than that of the BAU case as illustrated (Figure 7.28).

Figure 7.28: Comparison of Total Cash Flows between BAU and Evolution Scenarios in the Hypothesis Set of 'Base Case BAT Accelerated 50/50'



Discounted this gives us the industry values or present value of cash flows in the BAU and Evolution scenarios (Figure 7.29).

Figure 7.29: Industry Values in the Hypothesis Set of 'Base Case BAT Accelerated 50/50'



The evolution scenario industry value is 36 million Euro, slightly above that of the previous hypothesis (33 million Euro) and in keeping with the higher value added of the BAT model. The improvement over the BAU is much greater (50% compared to 10%), which is also due to the larger price difference between models and the fact that in this BAU the fixed quota for the newer model is five percent compared to the 20% in the previous hypothesis.

7.4.3.4 Cost Sensitivity analysis and conclusions for average freezers

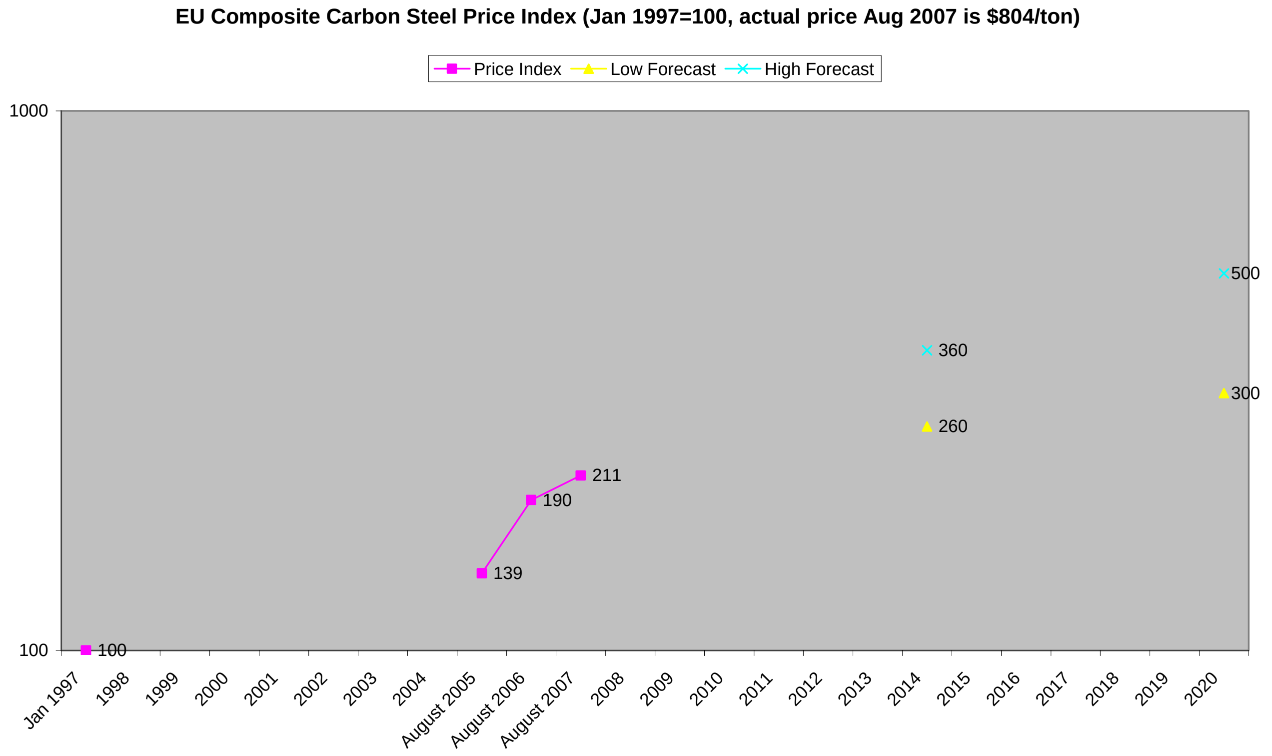
Price sensitivity was seen for the individual models and hypothesis. Here we examine sensitivity to cost changes in the base case and then in some instances the LLCC and BAT cases.

Steel prices have risen dramatically recently as shown in Figure 7.30 for the EU. The index has doubled in the last ten years, suggesting that it will at least do so in the next decade, given the very strong infrastructure demand in the developing world. Using this conservative estimate we have a mid-period index price of 310, which would correspond to 1.181 $ or 844 € per ton. This represents a 270 €/ton increase over today's prices, around year 2014. The ferrous metal composition of the base case freezers is shown in Table 7.29.

Table 7.29: Base Case Average Freezer - Ferrous Metal Composition

Ferrous Metal Composition of Freezers (kg.)			
	Mod 8	Mod 9	**Average**
Iron	0,437	6,538	**3,488**
Steel + Plastic	0,603	0,163	**0,383**
Steel Other	4,270	1,780	**3,025**
Steel Stip	9,729	9,055	**9,392**
Total Steel	13,999	10,835	**12,417**
other Ferrous Metals	9,928	8,554	**9,241**
Tot Ferrous Metals	24,967	26,090	**25,529**

Figure 7.30 EU Steel Price Trend (Source: MPS Co., U.K.)



With 12,4 kg of steel used to make the average freezer, the above represents a materials price increase of 3,45 € per unit or an increase in unit manufacturing cost by the same amount. Using a conservative one-third of the price increase for iron and other ferrous metals adds 1,15 € for a total of 4,60 €/unit.

Electricity consumption during assembly is on the average 22 kWh/unit. Assuming that the price increases is in the order of 0,02 € to 0,04 €/kWh, this represents a 0,44€ to 0,88 €/unit increase. How much might we reasonably gain from extra labour productivity investments?

Let us assume that they still have a reasonable rate of return of between 3 and 5 years of payback time, beginning with three in the early years and ending at five years in the last. Let us assume we can add an *extra* 1,5% reduction in labour cost per year, that is we go from the usual historical 1,5% to its double 3,0%/year. In our case of the LLCC freezer production, the new Evolution Scenario, which contains this new productivity investment, the net present value of cash flow increases from 33,6 to 36,7 million Euro, a 3,1 million Euro increase. This in itself is important and could offer some further financial advantage to manufacturers. The cost of labour can be brought down by automation or other means, but these have capital costs and the overall trade-off leads to these relative modest benefits. With the BAT model hypothesis, the productivity improvement is slightly greater with a 3,6 million Euro increase.

Compared to the potential increase in steel and ferrous metal prices however the labour productivity does not compensate the difference. On an undiscounted basis the 3,1 million Euro in productivity gains becomes about 4,2 million Euro and divided by the roughly 10 million units produced over the period, amounts to 0,42 € savings per unit, compared to possible increase in the cost of steel and ferrous metals from 3,45 € to 4,60 €, not to mention electricity cost increases. For the BAT model the equivalent is 0,49 €.

Could some of the component cost come down? Undoubtedly the largest item is the compressor/motor. The steel in the compressor has already been accounted for, but there might be labour cost savings in the production of compressors or some learning curve phenomenon. Suppose that the compressors cost to the manufacturers is as much as 30 €/unit about one-third of the materials and components total. This would imply cost reductions due to further automation or learning on the part of compressor producers in the order of 4 €/unit, 13% of their price.

This overall cost analysis may be summarised in Table 7.30.

Table 7.30: Sensitivity Analysis of Key Costs for Average Freezers

Source	Estimated impact on average unit cost (€/unit)
Steel price increase	+3,45 to+ 4,60
Electricity price gains	+0,44 to+0,88
Labour productivity	-0.44 to -0,49
Component maker productivity or learning efforts	Not estimated

In general, these simulations for average freezers illustrate that:

1) **There is a high degree of sensitivity in cash flow due to price**. This is because price acts directly on revenues, cash flow is a difference equation (revenue minus costs) and the historic level of profit margin in the household appliance sector is low, from the three to five percent. To not overestimate these effects the fixed costs have been assumed to be a minimum.
2) **In the specific context of severe and continued decline in real prices (-1,9%/year), that have historically characterised the freezer market, rather low levels of industry value are generated in both the BAU and Evolution scenario.** This is true despite an increase in labour productivity of 1,5% per year, which is applied in the simulation. Industry value is slightly greater with the BAT model due to higher value added.
   Evidently there is a lack of pricing power on the part of the appliance producers. Few large distributors in given geographic areas may exert a greater concentration of power, not allowing the household appliance producers much flexibility in pricing. No producer has direct sales through Internet, although some distributors are beginning this.
3) **Also in this context of strong price decline, differences in margins of the products (2% here) have less impact on the improvement in industry values between the BAU and Evolution scenarios**. In the LLCC case, the investment in the conversion to more new product capacity is rewarded with a 10% increase in industry value over the period, which normally would not be considered sufficient to cover the financial risks involved in a new investment. In the BAT case there is a greater improvement, but part was due to the lower initial quota for the BAT case.
4) **The sensitivity analysis of costs reveals the strongest cost increases coming from possible gains in steel prices.** Productivity investments within the freezer plant may help, but are an order of magnitude less than possible impact due to steel prices. Possible reductions in the cost of major components are not estimated but they would have to be substantial to offset other gains. If these steel price gains materialize, the freezer production might be hard pressed to make a profit.
5) **Possible benefits from policy actions, for example production tax credits are yet to be analyzed**. This will be explored in the policy section. Public policy could be aimed at the energy saving products that are the most critical to introduce.

7.4.4 Impact Analysis and Results for Refrigerator-freezers

From Task 6, Tables 6.14 and 6.15, we have the key characteristics of the three refrigerator-freezers cases (Category 7&10.7), where manufacturers' price is estimated with a 2,5 factor of mark-up (Table 7.31).

Table 7.31: Energy and price characteristics of the refrigerator-freezers

Model (type)	Energy consumption (kWh/y)	Consumer Price (€)	Manufacturing Price (€)
BAT	185,7	852,4	341
LLCC	250,6	585,5	234
Base case	324,4	485	194

7.4.4.1 Formulation of Preliminary Scenarios for refrigerator-freezers

At the factory level, two sets of hypotheses (Table 7.32) are made: a) one regarding a producer with 80% production of the Base Model and 20% with the LLCC model, in year 2008. In the Business-As-Usual (BAU) Scenario these quotas remain constant in time. Instead in the Evolution Scenario the two quotas go to 50% Base Model and 50% LLCC gradually over the fifteen years. The producer is following a very slow change in the market. This is called the **'Base LLCC 50/50 Hypothesis'** and b) regarding a producer with the 95% of his production in the Base model and a small but growing 5% in the BAT model in year 2008. In the Business-As-Usual (BAU) Scenario these quotas remain constant in time. Instead in the Evolution Scenario the two quotas go to 50% Base Model and 50% BAT gradually over the fifteen years. This is called the **'Base BAT 50/50 Hypothesis'** the factory is simulated with two production lines. Naturally a producer may have other production lines and additional models in production.

Table 7.32: Production Hypotheses for refrigerator-freezers

Hypothesis set	Model	Factory capacity		
		2008	2023 BAU	2023 Evolution
Base LLCC 50/50:	Base	85%	85%	50%
	LLCC	15%	15%	50%
Base BAT 50/50:	Base	95%	95%	50%
	BAT	5%	5%	50%

The Evolution Scenario is a representation of the producers' wishes without the introduction of specific policy instruments to achieve the desired changes in production. Only the costs of production are included, not even extra costs of a marketing campaign for promoting the desired changes. Policy will be fully studied subsequently.

7.4.4.2 'Base Case-LLCC 50/50' hypothesis for the refrigerator-freezer

The input data for the refrigerator-freezer (Category 7&10) base model are presented in Table 7.33.

Table 7.33: Base Model Inputs and Assumptions

	Combi LLCC & BASE Ver July 07 check			
Scenario Description	**Base Model**			
Base Year	2007	***Beginning year for analytical purposes***		
Announcement Year	2008	***Year in which the announcement is made***		
Policy Measure Year	2009	***Year in which the policy measure takes effect***		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	194,00	*(EURO)*	Price Grow. UPMY	-0,8%
Base Year Unit Sales	0,950	*(million)*	Price Grow. APMY	-0,8%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%			
			Tax Credit (€)	0
			El. Savings (kWh/yr)	73,8
			Electr.Price (€/kWhr)	0,17

	Base Model	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	112,00	0,00	0%	0%
Labor / Unit	23,00	0,00	0%	0%
Overhead / Unit	11,66	0,00	0%	0%
Depreciation / Unit	8,34	0,00		
Total/ Unit	155,00	-		

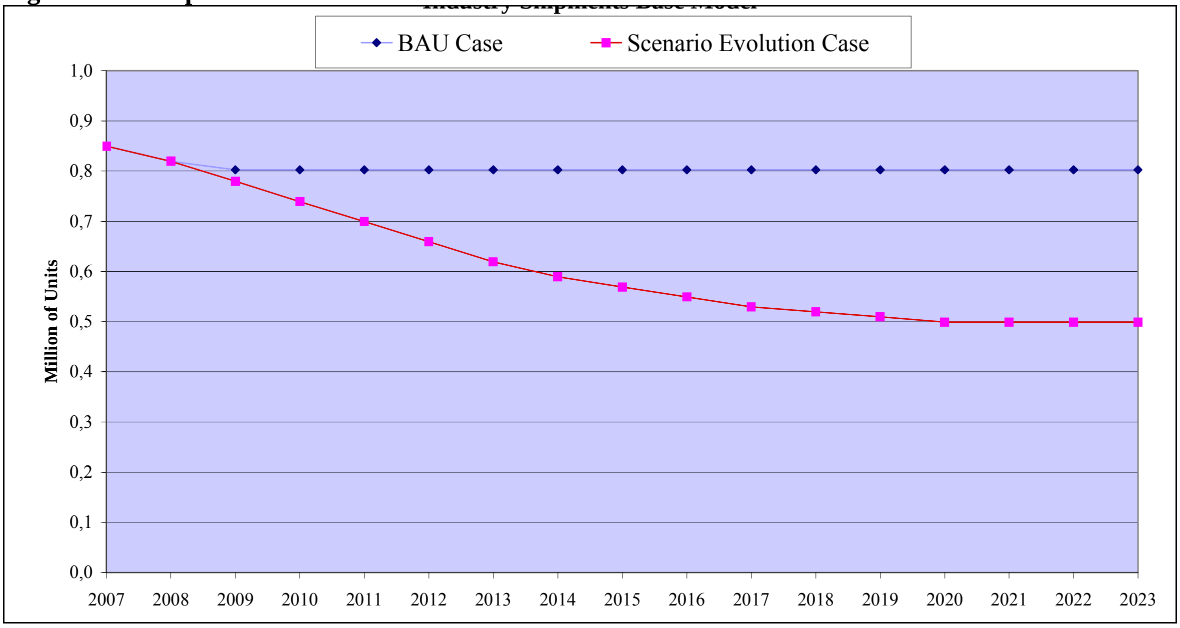
Hypothetical Full Price Increase (Policy Measure Case Only)	0,00
Percent of H. F. Price Increase Recovered by Manufacturers	100,00%
Manufacturers' Price Increase	0,00

Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10	0	0%	0%
Tooling	5	0	0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%

As can be seen the base model has a manufacturer's price of 194€ and thus a consumer price of 485€ as results from Table 7.14, Task 6. The total manufacturing cost is 155 €/unit in keeping with a lower margin for the older base model. The average margin in terms of base model cash flow/base model revenues is 2,3% for the period of simulation in the business as usual (BAU) scenario. Evidently the newer LLCC model should have a slightly higher margin.

The shipments in the BAU and Scenario Evolution for the base model are shown in Figure 7.31.

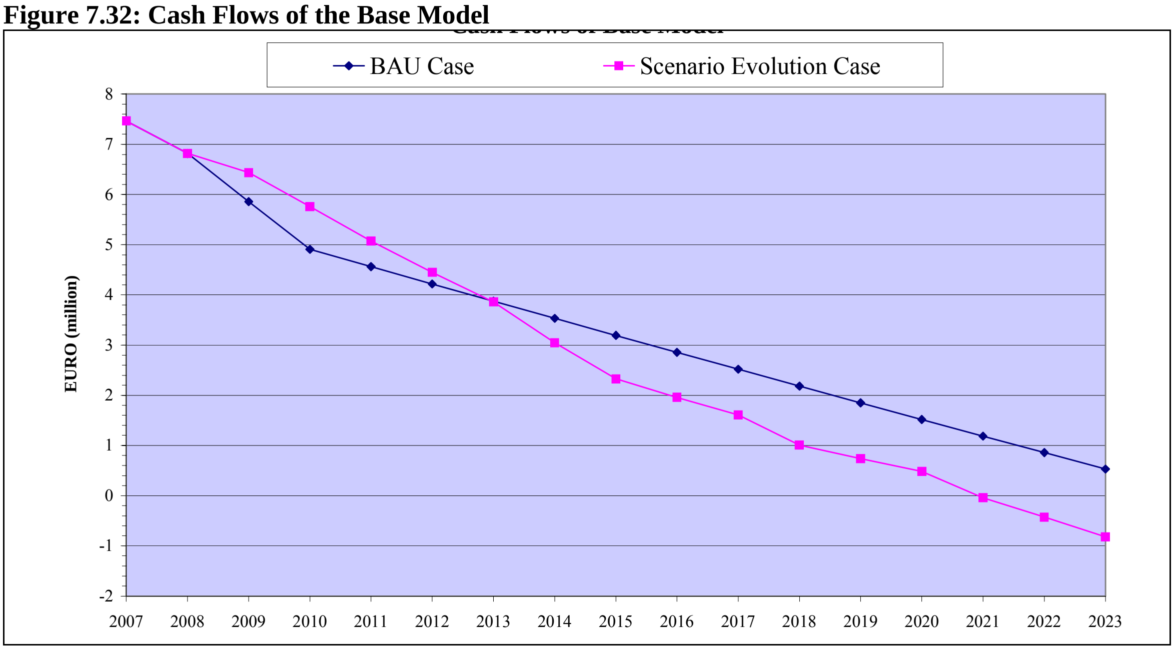
Figure 7.31: Shipments for the Base Model



In the BAU scenario the sales continue to decrease from 2005, the year last available data, through year 2009. In year 2007 there are 850 000 units and after 2009 the quota remains constant at 800 000 units or 80% of the total capacity. In the BAU scenario there is no change in the quotas of the two models beyond year 2009. The sales for the other model, the least life cycle cost (LLCC) model is the difference between full capacity and the base model capacity. Full nominal capacity of one million units is assumed. The LLCC model remains at a 20% quota in the BAU case.

In the Scenario Evolution it is hypothesized that the quota of the LLCC model is goes up to 50% and consequently the fraction of the base model decreases to 50%. It is not specified what motivates type of outcome or the circumstances that accompany this evolution. In the SE we have the quota and naturally the cash flow of the base model falling (Figure 7.32).

Figure 7.32: Cash Flows of the Base Model



The Base Model cash flows are declining in the BAU scenario due to the price decline of 0,8% per year and declining even faster in the SE scenario because of both loss in quota and price. In the first years of the SE the revenue declines free up more working capital, making the SE cash flows a little higher, but eventually these level off and the long-term impact of the lower quota is felt.

Naturally to complete the model description we must include the other half, the inputs concerning the LLCC model (Table 7.34).

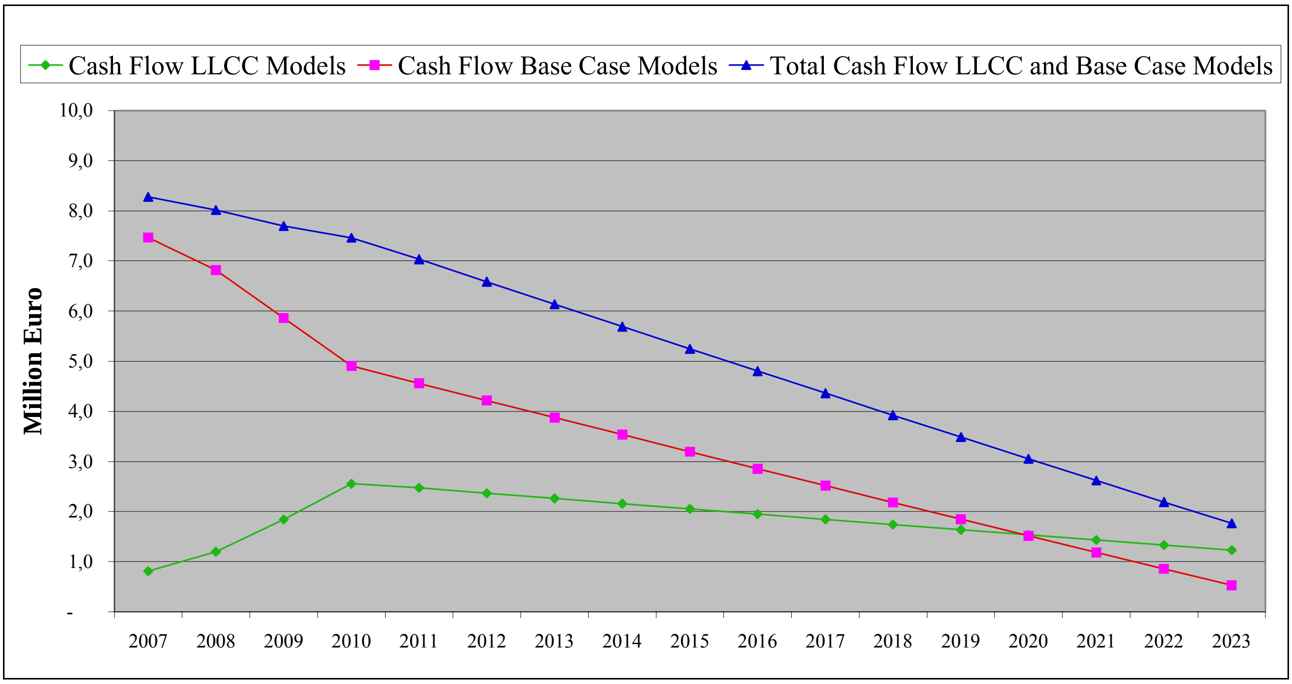
Table 7.34: Input and Assumptions of the LLCC model for refrigerator-freezers (Categories 7&10)

Situation Studied	**Combi LLCC & BASE Ver July 07**			
Situation Studied in Base Prod.	**Combi LLCC & BASE Ver July 07 check**			
	Combi LLCC & BASE Ver July 07 check			
Base Year	2007			
Announcement Year	2008	***Year in which the announcement is made***		
Policy Measure Year	2009	***Year in which the policy measure takes effect***		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	234,00	*(EURO)*	Price Grow. UPMY	-0,8%
Base Year Unit Sales	0,050	*(million)*	Price Grow. APMY	-0,800%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%		Dist. Mark-up	2,50
			Tax Credit (€)	0
			El. Savings (kWh/yr)	73,8
			Electr.Price (€/kWhr)	0,17
			Water Savings (€/yr)	0
	BAT Case	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	**128,00**	0,00	0%	0%
Labor / Unit	**27,00**	0,00	0%	0%
Overhead / Unit	**12,94**	0,00	0%	0%
Depreciation / Unit	10,06	0,00		
Total/ Unit	178,00	-		
Hypothetical Full Price Increase (Policy Measure Case Only)		0,00		
Percent of H. F. Price Increase Recovered by Manufacturers		100,00%		
Manufacturers' Price Increase		0,00		
Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10		0%	0%
Tooling	5		0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%

As seen the manufacturer's and consumers' prices are those resulting from the optimization procedure of Task 6, Table 15, namely 234 € and 585,5 €. (here we see input the difference in consumers' prices between the LLCC and Base Model of 100,5 €). The manufacturing costs are estimated at 178 €, resulting in a higher average cash flow margin of 4,1% for the LLCC model for the period during the BAU scenario. This compares with the average 2,3% cash flow margin of the Base Model, a difference of only 1,8%. The slightly newer model has a moderately higher margin in keeping with the theory of product life cycles.

Now let us turn to the BAU scenario and the behaviour of the cash flows of both models (Figure 7.33).

Figure 7.33: Cash Flow of the LLCC and Base Case Models in BAU Scenario



As one might expect the LLCC cash flows start from a lower level due to their initial smaller quotas of production, rise somewhat, and then gradually decline - less sharply due to the slightly higher margins of the LLCC Model. Both models are subject to the general price decline of 0,8% annually.

As a result, primarily of the price affects, the total cash flow dwindles, from around 8 million Euro in the early years to 2 million Euro in the end. The small increase in labour productivity improving at the rate of 1,5% annually in all scenarios is not enough to offset the price and quota declines. The (5%) discounted total cash flow is positive at 67,3 million Euro in the BAU scenario, which will be compared to that of the SE. First, let us examine the cash flows in the SE (Figure 7.34).

We have the primary impact of the changing quotas that slowly increases the cash flows of the LLCC models and reduces that of the Base Model. The common factor of declining prices and the rather small difference in margin contribute to the general trend of the combined cash flows. And how does this compare to that of BAU (Figure 7.35)?

No surprise in the trend, both are declining and the SE is above BAU. However, notice the scale, only about one million Euro separates the two – the cash flow difference is minimal. Discounting both cash flows we have the net present values, 67 and 76 million Euro respectively (Figure 7.36).

This is the most significant result of this simulation: in going from producing primarily Base models to producing 50% and 50% Base and LLCC models, a relatively small 13% improvement in industry value occurs, when carefully taking into consideration substitution effects of the models, which differ relatively little in price and even less in margins. Also here, no direct policy parameters are taken into consideration, not even an extra marketing campaign on the part of the manufacturer. Some modest growth in the overall unit sales will occur, due to the increase in the number of new families, but this is dominated by the growth in quota of the LLCC, which is going from 15% in 2007 to 50% in later years.

Figure 7.34: Cash Flows in the Scenario Evolution Case

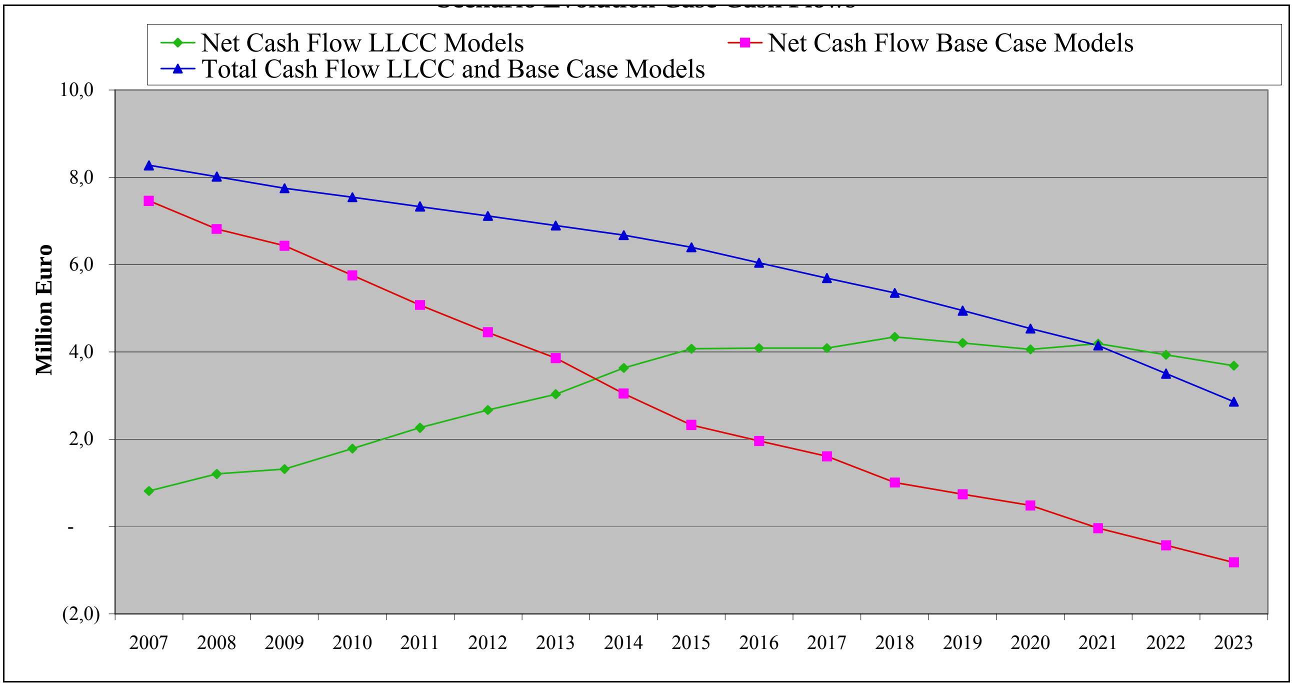


Figure 7.35: Comparison of Combined Cash Flows in the BAU and SE Scenarios

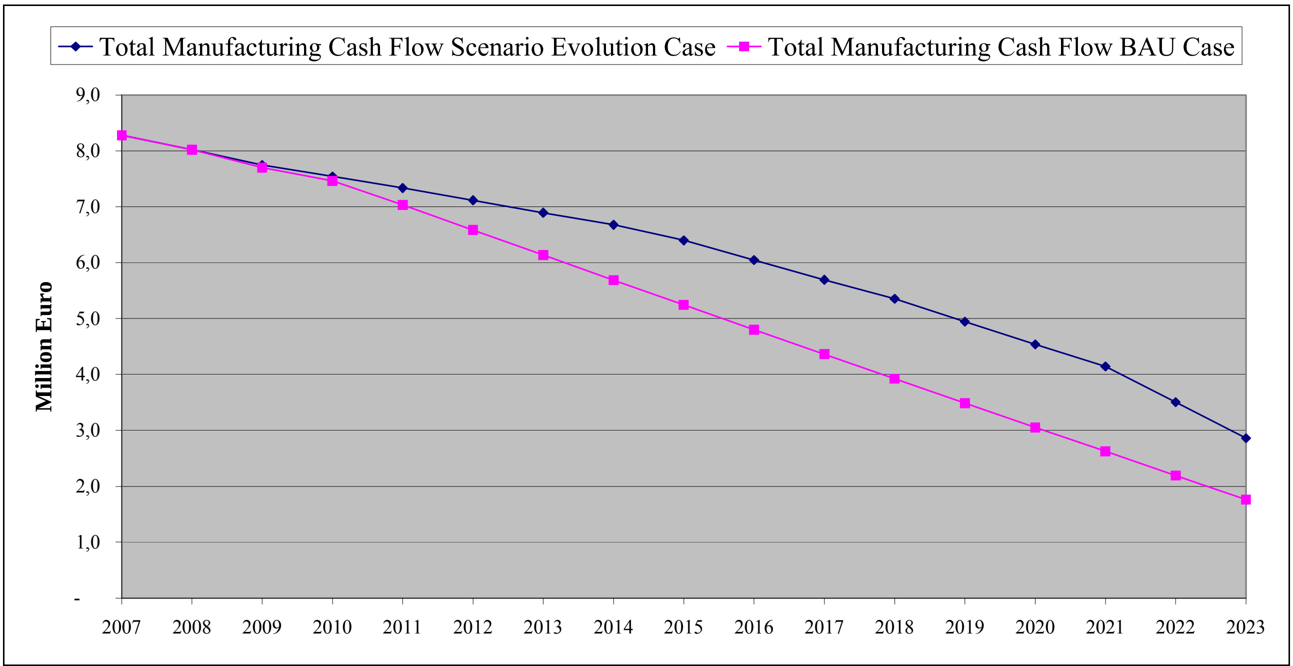
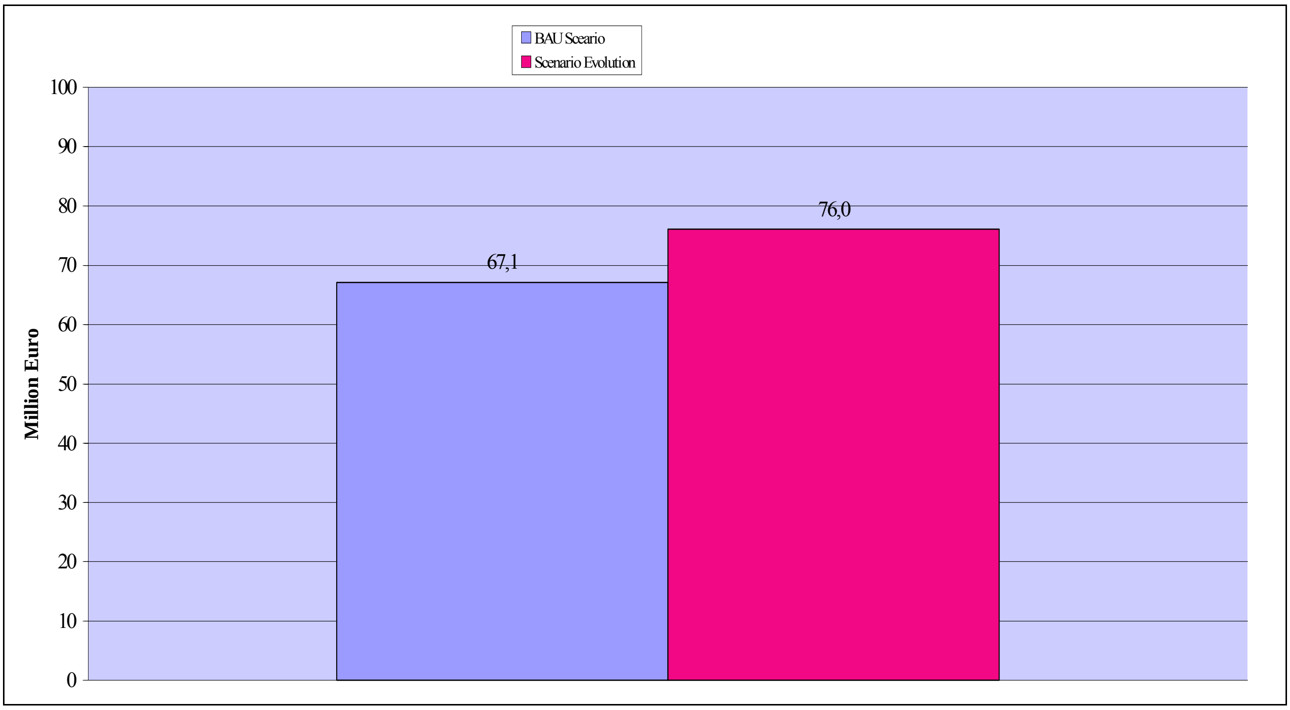
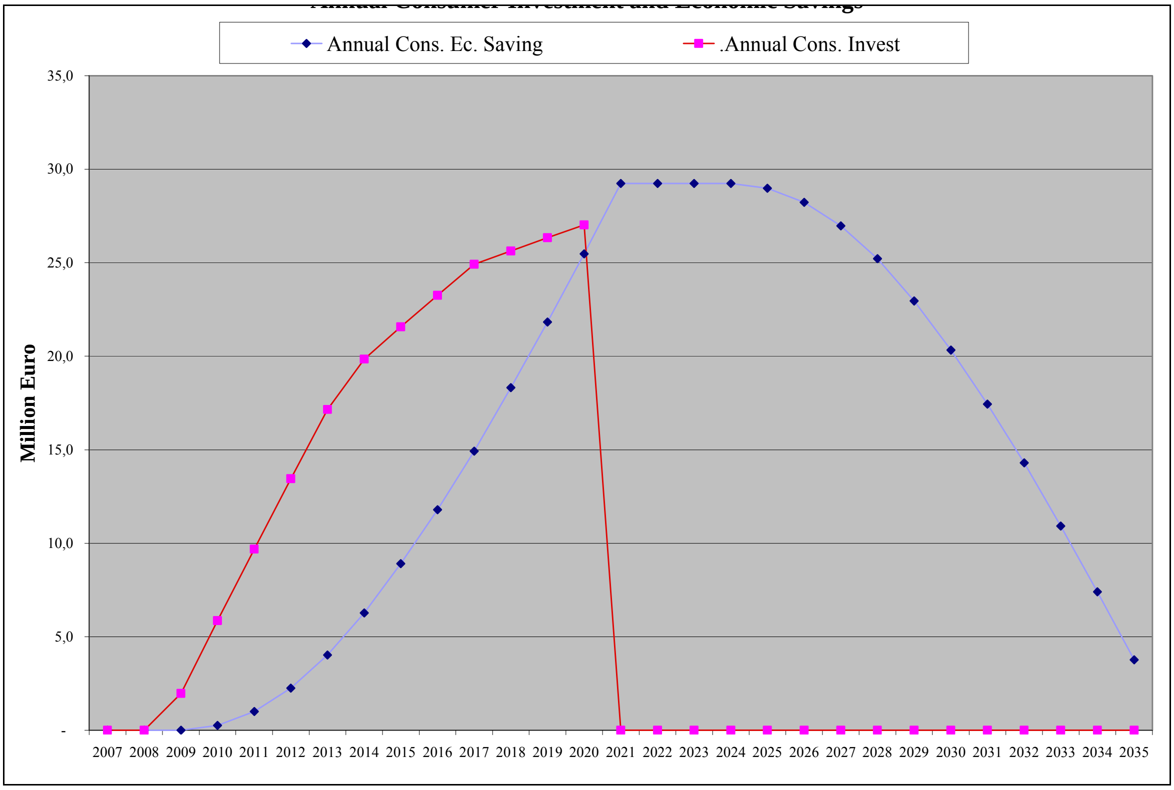


Figure 7.36: Net Present Value (NPV) of the Total Cash Flows in the BAU and SE Scenarios



With regard to consumers, the payback time on purchasing the LLCC model instead of the Base Case one is 8 years. The cost of investment (difference in price) and annual benefits (electricity savings) are shown for the production and purchase from 2008 to 2020 (Figure 7.37).

Figure 7.37: Consumer Investment and Benefits (Hypothesis Base Case LLCC)



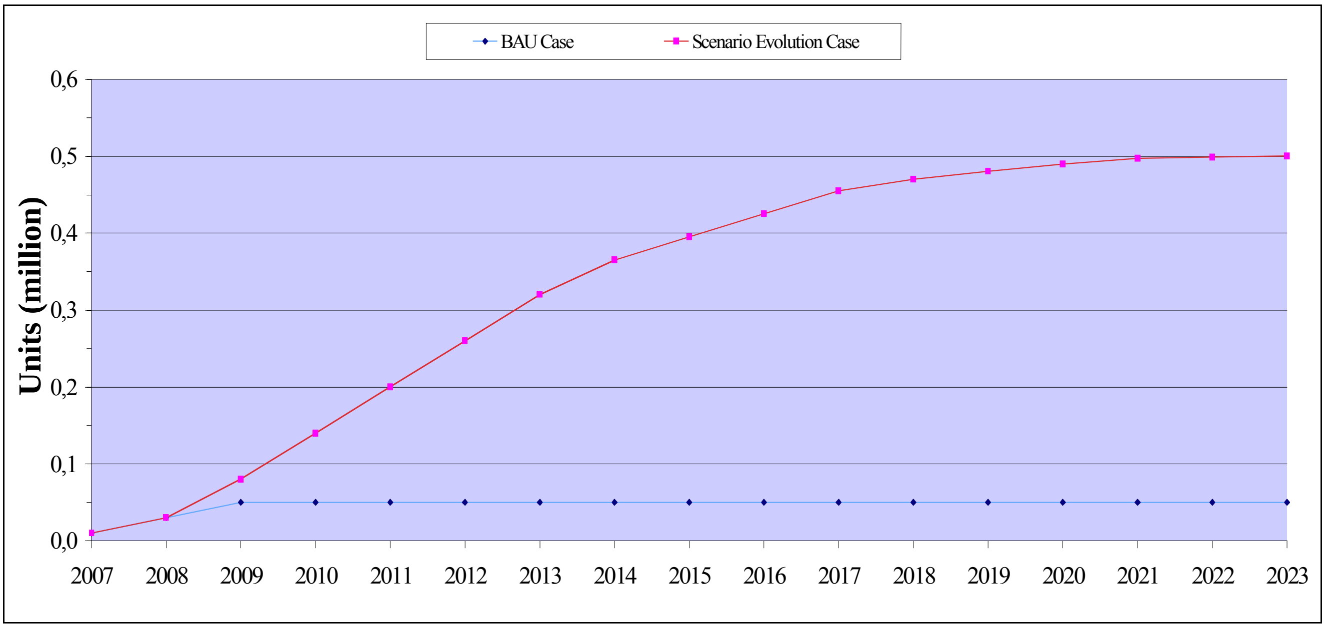
7.4.4.3 ‘Base Case-BAT 50/50’ hypothesis for refrigerator-freezers

Now let us turn to a new situation of a producer with 95% of his production in the base model and a small and growing capacity in the BAT model. The BAU scenario would have the quotas fixed at the 2009 level. Instead in the E scenario both quotas go to 50%. The data input for the BAT model as taken from Task 6 and the previous general assumptions are as presented in Table 7.35.

As shown, the total manufacturing cost is set at 256 €, which results in an average cash flow margin of 5,5% after 2008. This should be in the high range as it refers to the BAT model. The first two years have very strong increases in revenues resulting in abnormally high cost of increase in working capital and were excluded in the margin average.

The quota of shipments in the two scenarios are discussed for the BAT model (Figure 7.38).

Figure 7.38: Shipments of the BAT Model for refrigerator-freezers (Categories 7 and 10)



The shipments of the Base Model are equal to one million units minus the shipments of the BAT model and are not shown here. Likewise, the assumptions and input data of the Base model are those already given in Table 7.34.

Table 7.35: Assumptions for BAT Model (Categories 7 and 10)

	Assumptions Page for			
Situation Studied	**Combi BAT & BASE Ver July 07**			
Situation Studied in Base Prod.	**Combi BAT & BASE Ver July 07 check**			
	Combi BAT & BASE Ver July 07 check			
Base Year	2007			
Announcement Year	2008	*Year in which the announcement is made*		
Policy Measure Year	2009	*Year in which the policy measure takes effect*		
Tax Rate	48,00%			
Discount Rate for NPV	5,0%			
Inflation Rate	0,0%	*per annum*		
Working Capital	18,00%	*of Revenue*		
Base Year Unit price	341,00	*(EURO)*	Price Grow. UPMY	-0,8%
Base Year Unit Sales	0,050	*(million)*	Price Grow. APMY	-0,800%
Unit Sales Growth Rate	0,0%	*per annum*		
Standard SG&A	10,00%	*of Revenue*	Prod. Base Case	0,015
Research and Development	2,50%	*of Revenue*	Prod. Policy Case	0,015
			Reference Prod.	0,015
Ordinary Depreciation	4,30%	*of Revenue*		
Ordinary Capital Expenditures	-4,50%	*of Revenue*	Price elasticity	-0,4
Variable Overhead as % of Total	60,00%			
			Tax Credit (Ū)	0
			El. Savings (kWh/yr)	138,7
			Electr.Price (Ū/kWhr)	0,17

	BAT Case	**Policy Measure Case**		
0	**Year 2007**	**Year 2009**	**Sens. Anal. of Manufacturing Costs**	
Manufacturing Costs	**(Euro)**	**Additional Costs Euro**	**% Below**	**% Above**
Materials / Unit	**185,00**	0,00	0%	0%
Labor / Unit	**38,00**	0,00	0%	0%
Overhead / Unit	**18,34**	0,00	0%	0%
Depreciation / Unit	14,66	0,00		
Total/ Unit	256,00	-		

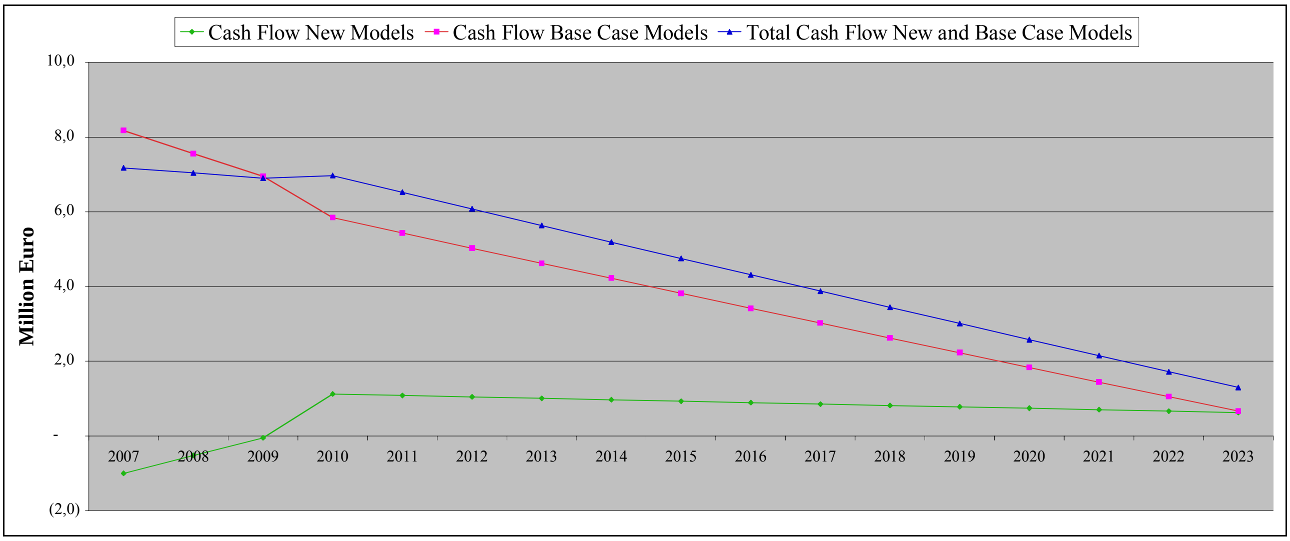
Hypothetical Full Price Increase (Policy Measure Case Only)	0,00
Percent of H. F. Price Increase Recovered by Manufacturers	100,00%
Manufacturers' Price Increase	0,00

Conversion Costs (Policy Case)	**Useful Life**	**Investment Cost**	**Sens. Anal. Of Conversion Costs**	
Capital Expenditures	*(Years)*	*(EURO 10^6)*	**% Below**	**% Above**
Investment	10		0%	0%
Tooling	5		0%	0%
Design & Marketing Expenses		**Total Expenditures**		
R&D		0		
Marketing		0	0%	0%

	Shipments BAU Scenario	Shipments Evolution Scenario
(Year)	*(%)*	*(%)*
2007	**1,00%**	**1,00%**
2008	**3,00%**	**3,00%**
2009	**5,00%**	**8,00%**
2010	5,00%	**14,00%**
2011	5,00%	**20,00%**
2012	5,00%	**26,00%**
2013	5,00%	**32,00%**
2014	5,00%	**36,50%**
2015	5,00%	**39,50%**
2016	5,00%	**42,50%**
2017	5,00%	**45,50%**
2018	5,00%	**47,00%**
2019	5,00%	**48,05%**
2020	5,00%	**48,95%**
2021	5,00%	**49,70%**
2022	5,00%	**49,85%**
2023	5,00%	**50,00%**

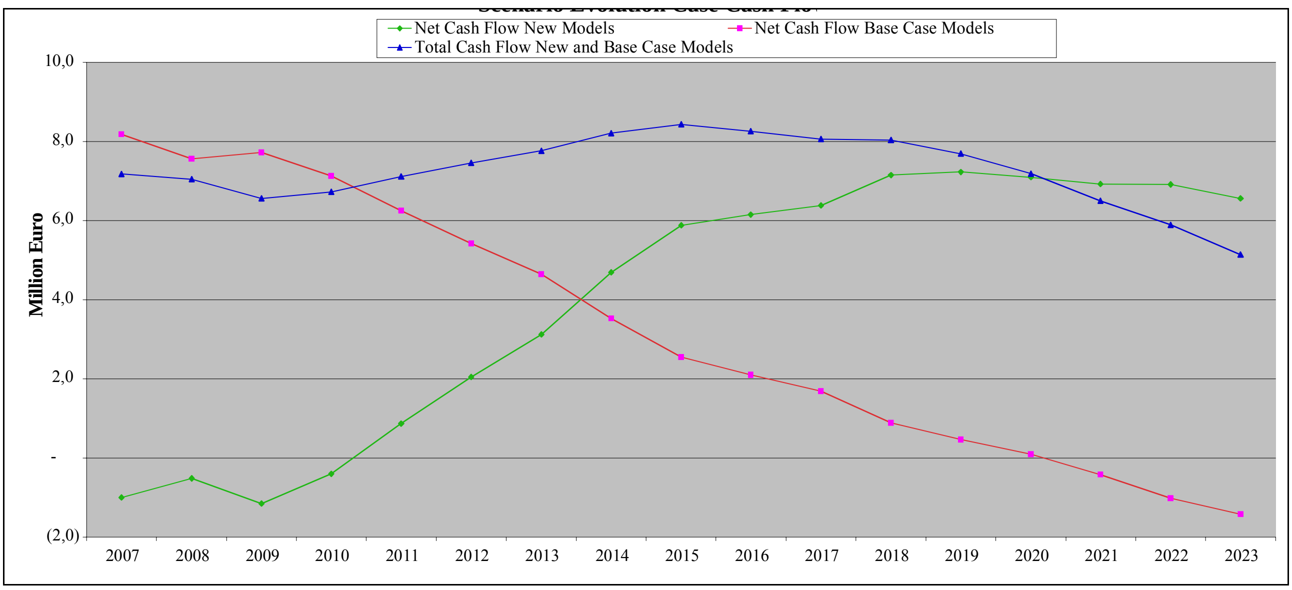
The cash flows in the BAU scenario are declining after the initial gains in quota of the BAT model through 2009 as shown in Figure 7.39.

Figure 7.39: Cash Flows of Business as Usual Scenario



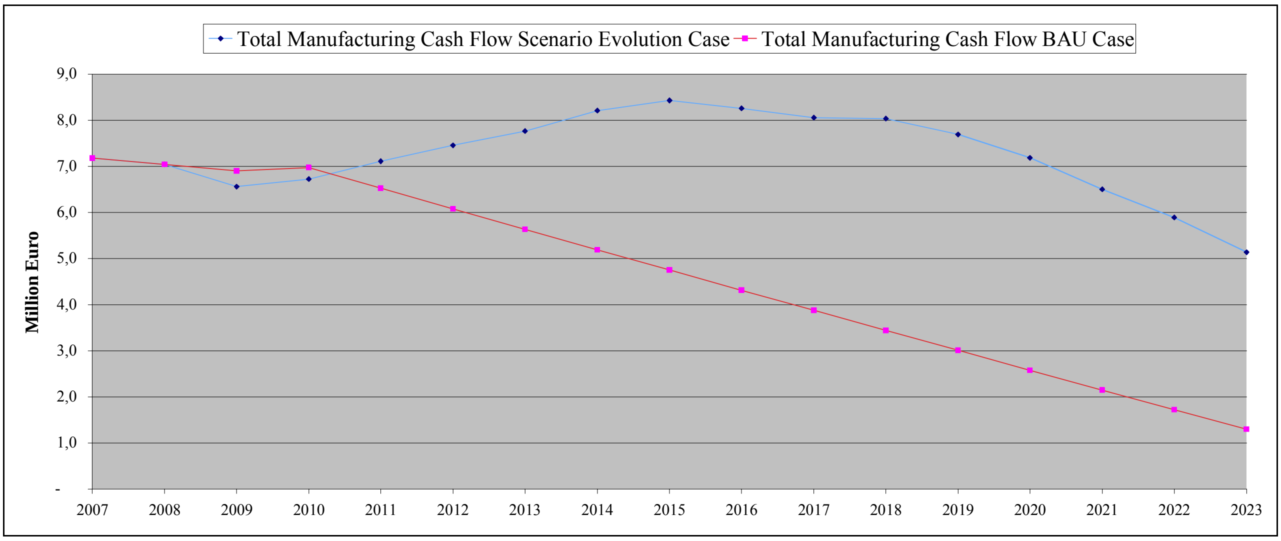
This decline is due to the decrease in prices that impacts directly on the revenue and the limited compensation in labour productivity, which acts only on labour costs, constituting roughly 15% of sales. Instead the cash flows of the Evolution Scenario are dramatically different (Figure 7.40).

Figure 7.40: Cash Flows of Evolution Scenario



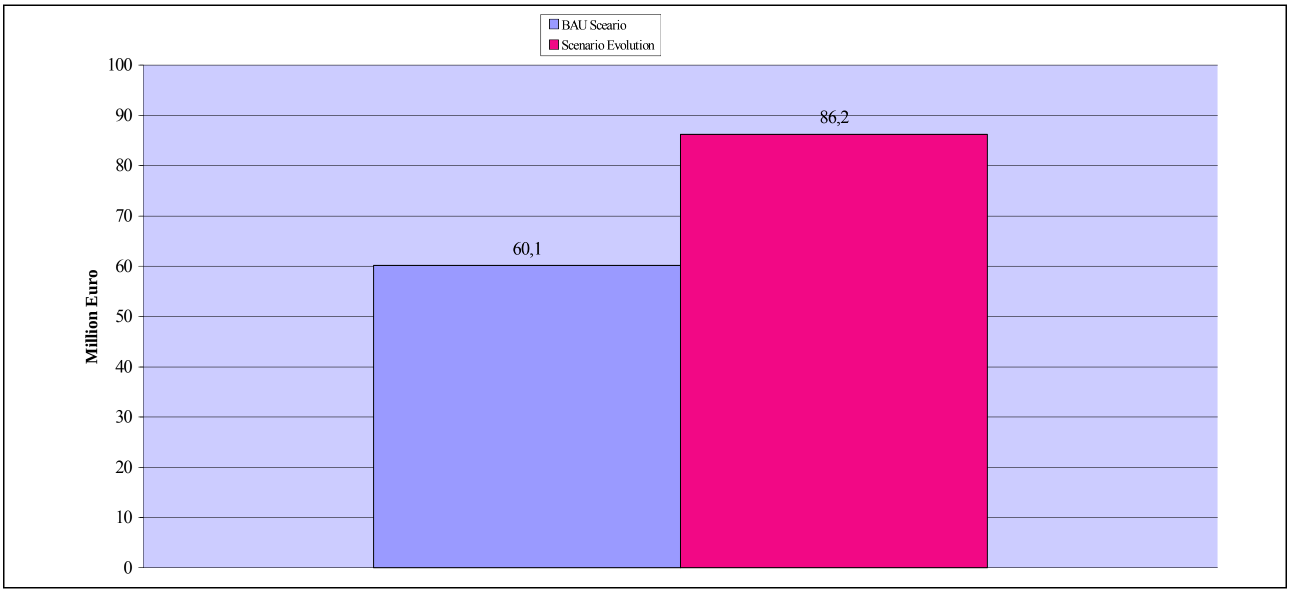
The base model has a net decline both due to share of production and price; whereas the BAT models exhibit a strong increase as the share of production nears 50% around year 2019 and subsequently the price affects begin to prevail. What is noteworthy is the amount of the cash flows, which we see more clearly comparing the total cash flows between the two scenarios (Figure 7.41).

Figure 7.41: Comparison of Total Cash Flows in Scenario Evolution and BAU



As a result the Industrial Values (Figure 7.42) are considerably different.

Figure 7.42: Total Industrial Value in the BAU and SE scenarios

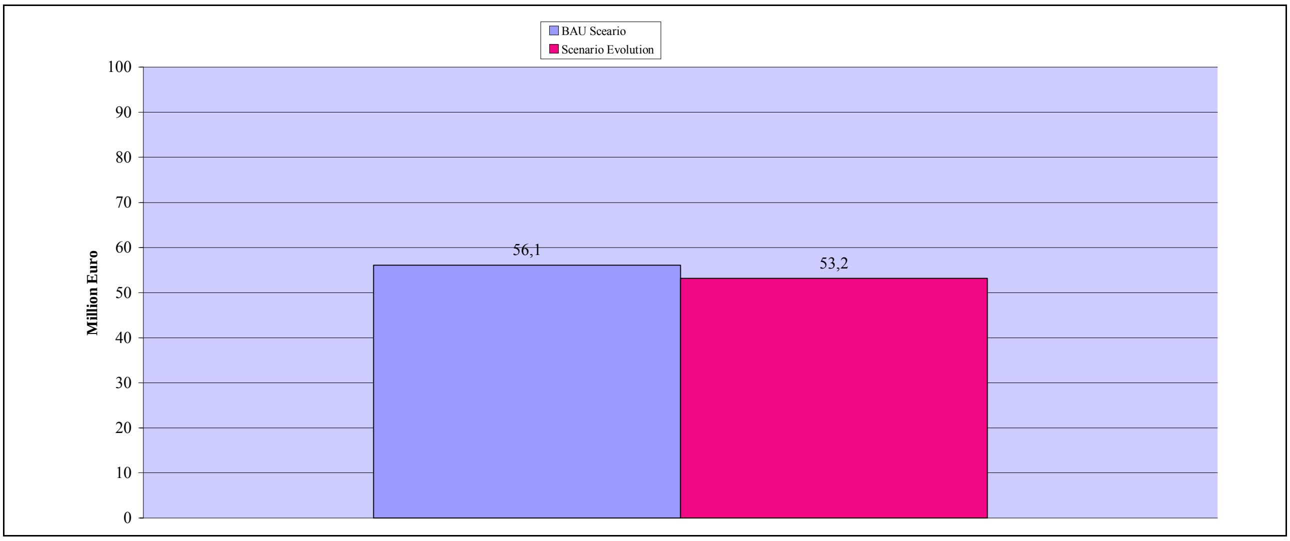


The industry value increases from 60,1 to 86,2 million Euro in the Evolution scenario or 43%, which contrasts sharply with the previous set of scenarios regarding the Base case and LLCC models. The above is certainly an attractive possible outcome; however it does not include any of the policy costs or even extra marketing costs of the firm to get there. It also presupposes that the market and consumer will respond very favourably to the BAT model that is currently some 367 € more expensive than the base model.

The consumer has a payback period of 15 years on this purchase of the BAT model instead of the base one. This payback time doubles with respect to the eight year period of the LLCC purchase with respect Base Case because of the larger increase in price for the BAT model. The difference in price quadruples whereas the savings doubles.

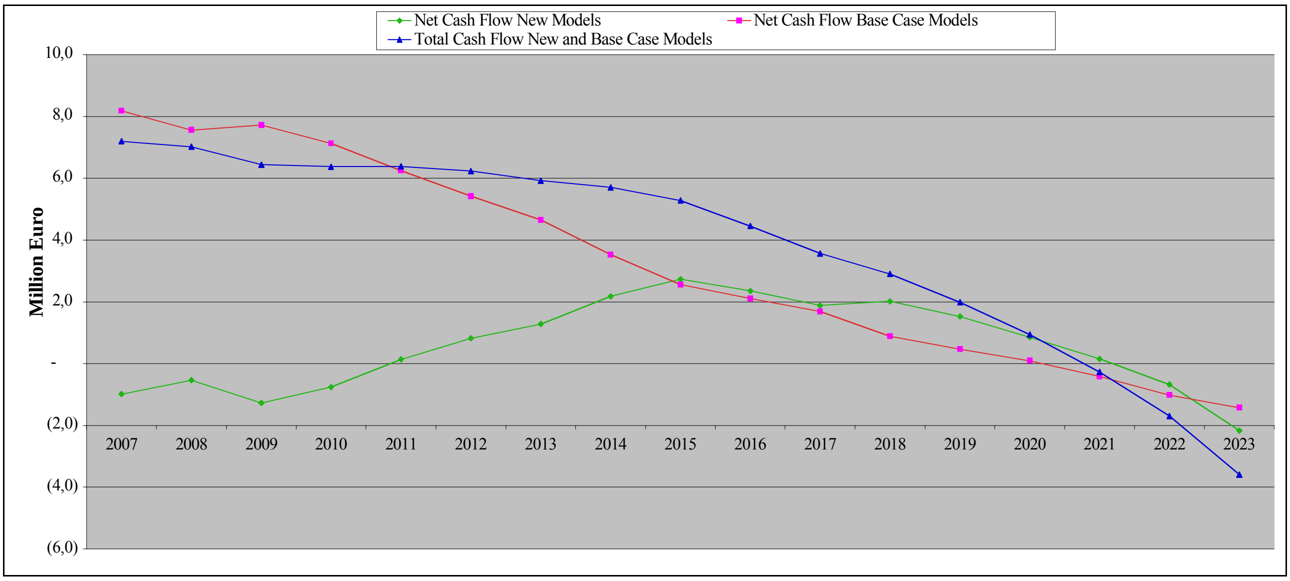
Probably the most likely complication to this simplified scenario would be increased price competition with an acceleration of price declines for the BAT model. If instead of the historic 0,8%/year price decline, we experience a doubling of the historic rate to a 1,6%/year decline from year 2007, then the industry value does not even grow in the new scenario! The BAU value is also slightly lowered (Figure 7.43).

Figure 7.43: Industry Value with Doubling of the Historic Rate of Price Decline



With a relatively low margin of net cash flow to revenue of around five percent in the early years, it does not take many years before this is eroded by the 1,6% decreases every year, even though fixed costs are minimal. Net cash flows even from the BAT model begin to decline 7 to 8 years after initial production, as illustrated in Figure 7.44.

Figure 7.44: Cash Flows with Doubling of the Historic Rate of Price Decline



Doubling the historical price decline, year after year, reduces real industry prices from 341€ to 263€ in year 2023, with consumer prices going from 852€ to €659 € almost a 200 Euro drop.

In this context there may be possibility for a speeding up the lengthy conversion to the newer model that has a higher margin. In fact this is what was done in the case of freezers, which have a steeper decline in prices.

7.4.4.4 Cost sensitivity analysis and conclusions regarding the refrigerator-freezers

The same cost factors that were considered in the case of freezers are analyzed for refrigerator-freezers. The rising cost of steel is also a preoccupation for relative large amount contained in these units (Table 7.36).

Table 7.36: Base Case refrigerator-freezers, Metal Composition

Ferrous Metal Composition of Combi Base Model (kg.)	
Ferrous Metals	15,262
Iron	0,711
Total Iron and Ferrous Metals	**15,973**
Mixed Steel & Plastic	0,007
Stainless Steel	0,860
Steel	3,328
Steel Strip	9,198
Other Steel	1,373
Total Steel	**14,759**
Total	30,739

Using the same hypothesis of increase in the price of steel of 0,27 €/kg., with 14,8 kg. of steel used to make the average refrigerator-freezer, this represents a materials price increase of 4,00€ per unit or an increase in unit manufacturing cost by the same amount. Using a conservative one-third of the price increase for iron and other ferrous metals adds 1,44 € for a total of 5,44 €/unit.

Electricity consumption during assembly is on the average 25 kWh/unit. Assuming that the price increases in the order of 0,02 € to 0,04 €/kWh, this represents a 0,50 € to 1,00 €/unit increase.

Turning to labour costs, let us examine the possible from additional labour productivity investments. Let us assume that they still have a reasonable rate of return of between 3 and 5 years of payback time, beginning with three in the early years and ending at five years in the last years of investment. The improvements occur gradually over the production period. Let us hypothesize that we can add an *extra* 1,5% reduction in labour cost per year, that is we go from the usual historical 1,5% to its double 3,0%/year. This would appear to be a reasonable upper limit.

In the hypothesis of the base case and LLCC refrigerator-freezer in the new Evolution Scenario, which contains this new productivity investment, the net present value of cash flow increases from 70,9 to 73,5 million Euro, a 2,6 million Euro increase. This in itself is important and could offer some further financial advantage to manufacturers. The cost of labour can be brought down by automation or other means, but these have capital costs and the overall trade-off leads to these relative modest benefits. With the BAT model hypothesis, the productivity improvement is slightly greater with a 3,2 million Euro increase.

Compared to the potential increase in steel and ferrous metal prices however the labour productivity does not compensate the difference. On an undiscounted basis the 2,6 million Euro in productivity gains becomes about 3,5 million Euro and divided by the roughly 10 million units produced over the period, amounts to 0,35 € savings per unit, compared to possible increase in the cost of steel and ferrous metals from 4,00 € to 5,40 € not to mention electricity cost increases. For the BAT model the equivalent is 0,44 €.

Could some of the component costs come down? Undoubtedly the largest items are the vacuum panels (in the BAT model) and compressor. The steel has already been accounted for, but there might be labour cost savings in the production of vacuum panels and compressors, or some learning curve phenomenon. Compressors have been produced for many years, but large vacuum panels are relatively new and more learning and cost improvement may be possible here for the BAT model. Unfortunately information on this subject is not readily available and no estimates have been made. This overall cost analysis may be summarised in Table 7.37.

Table 7.37: Sensitivity Analysis of Key Costs for Refrigerator-freezers

Source	Estimated impact on average unit cost (€/unit)
Steel price increase	+4,00 to +5,40
Electricity price gains	+0,50 to +1,00
Labour productivity	-0.35 to -0,44
Component maker productivity or learning efforts	Not estimated

In general, these preliminary simulations for refrigerator-freezers illustrate that:

1) **There is a high degree of sensitivity in cash flow due to price**. This is because price acts directly on revenues, cash flow is a difference equation (revenue minus costs) and the historic level of profit margin in the household appliance sector is low, from the three to five percent. To not overestimate these effects the fixed costs have been assumed to be a minimum.
2) **In the specific context of moderate decline in real prices (-0,8%/year), that have historically characterised the refrigerator-freezer market, substantial levels of industry value are generated in both the BAU and Evolution scenario.**
3) **Also in this context, small differences in margins of the products (0,9 to 1,6%) do produce significant differences in industry values of the BAU and Evolution scenarios**. The average was a 23% increase in industry value. **In a healthy price environment, market incentives to invest in improved LLCC and BAT model do exist.** Obviously the faster the market moves to higher margin products, and the margins are sustained, the better for the producer.
4) **In all cases, including freezers and refrigerator/freezers, greater potential cash flows exist for the higher value added BAT model, which however has the longest payback time for the consumer**. The payback times are coming from Task 6 and are only slightly changed by the price dynamics of the E-GRIM simulations. Sometimes these returns to the consumer do not have a positive net present value at a real discount rate of five percent.
5) **The sensitivity analysis reveals the strongest cost problems coming from possible increases in steel prices.** Productivity investments within the freezer plant may help, but are an order of magnitude less than possible impact due to steel prices. Possible reductions in the cost of major components such as the compressor are not estimated, but they would have to be substantial to offset other gains. If these **steel price gains materialize, the refrigerator-freezer model profit likely will be compressed. A quicker introduction of the higher margin models would help.**
6) **Possible benefits from policy actions, for example production tax credits are yet to be analyzed**. This will be explored in the policy section. Public policy could be aimed at the most critical products, those energy saving products having the most difficulty of introduction. In this case, freezers would have a higher priority than combination refrigerator/freezers.

7.5 SUBTASK 7.5 - SENSITIVITY ANALYSIS

The sensitivity analysis of the main parameters allows to evaluate the robustness of the analysis outcome. The cost sensitivity of the manufacturer impact analysis has been developed in the previous paragraphs. A sensitivity analysis covering the most relevant factors: the price of energy, the production costs and discount rates, was carried out in Task 6 for the four average standard base cases to check if there are significant changes in results and if the overall LCC conclusions, BATs and BNATs are reliable. The main outcome are here reported.

7.5.1.1 The sensitivity analysis for the LCC

In this analysis, the application order of the technological options is that resulting as the most profitable for the consumers according to the MNPV analysis for the average standard base case and the basic technical and financial assumptions. The variation of parameters such as the energy price and the lifetime might have an influence on the optimum technological option combination (corresponding to the LLCC) and more in general to the options application order, but this more sophisticated sensitivity analysis was not compatible with the time and budget constraints of the study.

a) Refrigerators

The most important result for refrigerators is that in practice the LLCC point occurs at different technological option combination for the variation of the investigated parameters. The second most important outcome is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the LCC over a lifetime of 10 years and an electricity price of 0,10 €/kWh is 457 €; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 846 €, with a difference of 381 €. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61 € to 10 €.

b) Refrigerator-freezers

The most important result for refrigerator-freezers is that the Least Life Cycle Cost point occurs mainly at two different technological option combinations depending on the lifetime: when lifetime is ≤12 years the optimum options combination is the application of *Option a.3*, when lifetime is longer than 12 years the optimum options combination is (*a.3+f.3+d.1+d.2*). Again, when electricity price is considered 0,10 €/kWh the LLCC occurs after the addition of the first option for a lifetime of 15 or 17 years, while at lower values the base case show the lowest life cycle cost value. When on the contrary the electricity price is considered 0,25 €/kWh the LLCC occurs always after the application of the fourth option. Also in this case there is no effect on the overall LCC results when the disposal and recycling costs are decreased.

The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.2* is applied, the life cycle cost is 851 € over a lifetime of 10 years and with the appliance price at 324 €; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.380 €, with a difference of 529 €.

c) Upright freezers

For upright freezers the most important result is that the Least Life Cycle Cost point occurs at different technological options combinations depending on the lifetime: when lifetime is 10 years the optimum option combination is the *Base case* for all parameters variation a part from when the electricity price is 0,25 €/kWh or when the discount rate is 4%; this happens also when the electricity price is 0,10 €/kWh at all lifetimes. When lifetime is 12 years, the optimum options combination is (*f.3+a.3*) for most of the parameters. When lifetime is 15 years, the optimum options combination shifts towards (*f.3+a.3+d.2*) in half of the cases and for the use of the average parameters value. Finally, when lifetime is 17 years the LLCC occurs also for options combinations (*f.3+a.3+d.2+d.1*) the LLCC in some cases. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased.

The second most important outcome is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the life cycle cost is 664 Euro over a lifetime of 10 years; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.088 Euro, with a difference of 424 Euro.

d) Chest freezers

For this freezer type the most important result is that the Least Life Cycle Cost point occurs in most of the cases at the technological options combinations (*f.3+a.3+d.1+d.2*) a part from when electricity price is considered 0,10 €/kWh and the LLCC occurs at the *Base case* level at all lifetimes. For almost all the other parameters variation the LLCC point occurs at the application of *Options d.1* or *d.2* but the difference in LCC between the two option combinations is very small. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61 € to 10 €.

The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when *Option d.1* is applied, the life cycle cost is 675 Euro over a lifetime of 10 years; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.119 Euro, with a difference of 444 Euro.

7.6 SUBTASK 7.6: HYPOTHESISED POLICY MEASURES FOR COLD APPLIANCES

7.6.1 The Policy Measures Portfolio

7.6.1.1 The mandatory vs. the voluntary approach in Europe

After the first experience in setting minimum efficiency requirements for products, resulting in the issue of directive 96/57/EC for cold appliances and directive 2000/55/EC ballast for fluorescent lamps, a set of five Industry Voluntary Commitments (described in Task 1) have been discussed and agreed between the household appliance manufacturers' European industry association, CECED, the European Commission and Member States.

However, on 21 March 2007 with a Press Release[44], CECED, called for legislative measures to ensure future energy performance standards as an alternative to continued updating of the voluntary agreements that industry introduced a decade ago.

[44] "Top Executives Discontinue Voluntary Energy Efficiency Agreements for Large Appliances", Embargo: 17.00 hrs, 21 March 2007, downloadable from http://www.ceced.org.

The strategy change was announced after a meeting of the CECED steering committee in Brussels. Patchy government enforcement of the EU's energy labelling scheme, the vehicle whereby energy efficiency information is shared with the public, has undermined industry's ability to go to the next phase of voluntary measures. CECED's voluntary agreements on energy efficiency have delivered major performance improvements estimated to have cut 17 million tons of CO_2 from Europe's emissions tally, equivalent to the carbon output of nine 500 MW thermo-electric power plants.

"European manufacturers are as committed as ever to designing and marketing energy efficient appliances because it is the right thing to do and consumers expect that of us," said CECED President, Magnus Yngen of Electrolux. "But governments must guarantee fair competition by enforcing the law and ensuring that product declarations are genuine–or our investment in high performing products is compromised. The next round of improvements needs to be driven by legislation that applies to all and is enforced on all."

Covering on average 90% of the market for large appliances, CECED's five existing voluntary agreements (for washing machines, refrigerators and freezers, dishwashers and water storage heaters) have been widely recognised as a progressive and a pro-active. These have required an investment by European manufacturers of €10 billion over the past decade.

"Too many governments are not stopping careless or unscrupulous operators from marketing products that claim better energy efficiency than they actually deliver," says Yngen. "Free-riding must be strongly discouraged. Today we have a very worrisome situation where politicians set rules, expect companies to abide by them and then fail to invest the resources needed to stop the lawbreakers."

To show that market surveillance is not working, the top managers also announced that CECED will launch a one-off market testing programme, using independent laboratories to check products sampled from the market against the performance claims stated on their labels. The results will be made public later this year. The exercise will demonstrate that market surveillance is feasible and not prohibitively expensive for governments. Sampling will cover refrigeration appliances in the market, regardless of source.

7.6.1.2 Is the extension of the Energy Star programme to household appliances appropriate?

In 2005 detailed discussions and negotiations were held with the US Environmental Protection Agency and the US Department of Energy. These resulted in an in principle agreement that Australia and New Zealand could set local Energy Star "high efficiency" criteria for products that were sold in the Australasian market (such as white goods where the USA had their own domestic Energy Star criteria), subject to detailed review by EPA and DOE on a product by product basis. On this basis, E3 decided to move towards the use of the Energy Star label as the primary endorsement label for appliances and equipment in Australia and to discontinue TESAW as an endorsement label.

One of the key decisions made at the E3 Stakeholder Working Group meetings in 2005 was that any Energy Star criteria to recognise high efficiency refrigerators and freezers needs to be linked to the star rating system. This is critical as it provides a consistent message with regard to the relative efficiency of products for both program elements (comparative energy label and the Energy Star endorsement label). So in principle, an Energy Star qualification level should be defined in terms of star ratings under the new energy labelling algorithm under preparation by the Australian authorities (see Task 1 for details).

At this stage, no draft Energy Star criteria have been proposed. Further analysis needs to be undertaken to refine the likely criteria and the approval of proposed levels needs to be sought from US authorities prior to their implementation. In fact, setting Energy Star levels that are comparable with or better than US levels (i.e. 10% to 15% better than current 2005 efficiency requirements levels) and also where 20% to 30% of products on the Australia and New Zealand market can attain the criteria would be ideal. But using these criteria together with the new star rating index could create some mismatches and complications that may need to be examined and resolved. Other issues for implementation that require some consideration are frequency of review of qualification levels and whether there should be any tag or identifier on the Energy Star label used for locally developed high efficiency levels to distinguish this from the standard EPA Energy Star label which is used internationally

The Energy Star Program, commenced in the USA in 1992, applies to a vast array of products in that country, including equipment, appliances, materials and even buildings. A large part of the US Energy Star program is set up as a domestic endorsement labelling system that works in conjunction with other domestic programs such as minimum efficiency requirements and energy labelling (the Energy Guide) or as a stand-alone program for selected unregulated products. The use of Energy Star as an endorsement of high efficiency products at this stage is used in North America (USA and Canada) only, but neither the US nor the Canadian energy labels have a star rating system or its equivalent categorical rating system (such as the EU labelling scheme) so this potential information miss-match is not an issue there.

If the criteria of the Energy Star and the categorical labelling scheme are the same, and the Energy Star approach calls for a 20% of the models fulfilling the criteria at the time of enforcement, there is little scope is setting this endorsement label. The justification given by Australia is that Energy Star, as the former TESAW scheme, allows consumer to quickly recognise highly efficient product on the market.

The extension of the Energy Star, or any other similar endorsement label, to cold appliances might derive from an interpretation of the Action Plan for Energy Efficiency of the European Commission (2006), where maximally 10-20% of the models should belong to the highest energy efficiency class in the EU labelling scheme. Whereas the Energy Star programme calls for about 20% of the models being compliant at the moment the criteria are established. But if high efficient refrigerators and freezers, are identified by the present energy efficiency classes A+ and A++, and the label is mandatory on models displayed in shops or offered for sale, high efficient models are immediately recognisable by consumers. An additional Energy Star logo (or any other endorsement label, efficiency mark, etc.) is not only useless, but can also create the impression of a poor quality of the categorical labelling scheme, that needs to be supported by the endorsement label to be sure that 'true' highly efficient appliances are identified.

7.6.1.3 Issues for standardisation

Some elements emerged from the developed analysis that should be addressed and solved at standardisation body level. They are:

- room conditions with temperature below 10-15°C should be addressed, to take care of appliances installed in non-heated rooms. A possible approach could be the definition of an additional Climate Class for room temperature below 10-15°C or an extension of the SN class; however, since the minimum temperature at which the correct functioning of a refrigerating appliance is guaranteed is up to a certain extent model-specific, another possible solution is to define the lower temperature boundary for all cold appliances. In practice, the minimum

external operational temperature will be determined and declared for each model along with the other technical characteristics;
- definition of the so called “0-star” compartment which is considered in the EU energy labelling as having a temperature between 0°C and -6°C; part of this temperature range is now covered by the chill compartment (temperature range -2°C to +3°C), but the temperature range between -2°C and -6°C is still uncovered. Although ISO 15502[45] defines at point 3.3.4 the ice-making compartment as a “*low-temperature compartment intended specifically for the freezing and storage of ice*” the temperature range is not specified. Some manufacturers experts consider that such poorly defined compartment – the 0 star - should disappear from the market, but until it is present a more correct definition is necessary;
- wine cellar: the new standard is under preparation, it should be cover both ‘wine storage cabinets’ and ‘wine coolers’ models; in addition, compartments with a temperature higher than +14°C should be defined and addressed;
- an extension of the refrigerators definition is needed: to cover appliances or compartments designed to cool only drinks (which are not considered fresh food) and which can be used for household or similar purposes;
- ‘static’ appliance with drawers should be tested as sold to the consumer and not with a different ‘optimised combination’ of drawers in and out. This should be preferably addressed at IEC worldwide level during the discussion of the new global standard for cold appliances;
- at present, ‘through the door devices’ are switched off, when possible, during the test. They should be “on” during standard tests or at least in the same setting as when the model is sold to the consumer.
- the evaluation of the energy consumption of the ‘heating device’ to be used in refrigerating appliances to be operated at ambient temperature lower than about 10°C (perhaps 15°C);
- a circumvention clause should be considered: to avoid that some energy consuming “features” are deactivated when the appliance sense that standard test conditions (mainly a constant 25°C external temperature), resulting in a lower energy consumption.

7.6.1.4 A new labelling scheme

a) Elements to be updated in the present labelling scheme

Elements of the present labelling scheme that should be updated in view of a revised scheme be put in place for cold appliances are:
- applicability: included and excluded appliances to be clarified;
- appliance classification: categories definitions to be clarified and where necessary amended;
- Energy Efficiency Index calculation algorithm: to be consolidated;
- Energy Efficiency Classes: existing thresholds to be amended and new thresholds defined; in addition, the rescaling the present A-G scale or the definition of a new categorisation should be investigated;
- information to be disclosed: information in the label and the fiche to be revised and if necessary amended.

b) Labelling scheme applicability

According to Article 1 of directive 94/2/EC (not modified in directive 2003/66/EC), the Directive applies to electric mains operated household refrigerators, frozen food storage cabinets, food

[45] International Standard ISO 15502:2005 and its Corrigendum (2005) have been recently cancelled and replaced by International Standard IEC 62552 Ed. 1, 2007, published under the responsibility of IEC Technical Committee 59: Performance of household and similar electrical appliances.

freezers and their combinations. Appliances that may also use other energy sources, such as batteries, are excluded.

The applicability of a revised labelling scheme could be:

1. Excluded appliances:

- Appliances using other energy sources than 230V electric energy from the mains: battery operated appliances (12V operated appliances), appliances using other fuels than electricity (gas or kerosene operated appliances), dual fuel appliances (electricity and gas or electricity and kerosene operated appliances).
  Battery only and 12V/230V operated appliances are mainly used for picnic or on Recreational Vehicles (RV) campers, boats, etc. and are used for a very limited amount of time during the year; only the models working with both 12/230V DC/AC might be of interest for a EU eco-design measure since they could be used for long periods when connected to the electricity supply. Although they are claimed to be used only for part of the week or occasionally (see later in this report) and no better information about penetration, consumption and actual use are known to evaluate the possible saving or even their energy consumption, the labelling scheme can be applied.
  Dual fuel (absorption) appliances are used in households (or similar applications) where the electric energy supply is discontinue or even missing for some parts of the year. They are generally more energy consuming than traditional electricity operated compressor refrigerators and freezers, but their share, although unknown, is considered very low and expected to reduce in time, with the further improvement of the coverage and the quality of the electricity distribution system.
- (Household) appliances intended for non-household or non-household similar use: appliances for medical application (for example: vaccine refrigerators and freezers). Although medical equipment are included in directive 2005/32/EC, such appliances are aimed at special uses outside Europe. Cold appliances shall comply with specific strict WHO criteria to be declared and sold as ‘vaccine refrigerators and freezers’: the 2000 edition of the PIS (Product Information Sheets produced by the WHO Department of Vaccines and Biologicals in collaboration with the UNICEF) listed a total of 37 refrigerators and freezers. See Task 1 for a complete description of these appliances.
- Appliance specifically designed exclusively for the storage and/or long term maturation of wine: *wine storage cabinets* (both compressor or absorption type). Key characteristics of wine storage cabinets include constant temperature over time (with a very low variation), specific humidity characteristics and low vibrations. They may be designed to have stratified temperature zones. A specific standard is under preparation. These appliances could be added to the new labelling directive as soon as the new standard is ready.
  In the meantime, to avoid any possible product “misuse” (for example, models declared as wine storage cabinets then sold for household refrigeration use just to overcome the specific legislation) these products will be excluded only if declared and advertised for the specific use and not suitable for wine, food or other beverages cooling.

2. Included appliances: any product that can be used for a household or household-related use. In addition:

- Refrigerating appliances for non-fresh food foodstuffs: refrigerators for drinks only (drinks shall be explicitly make equal to fresh food items when), if they can be tested according to EN 153 in terms of reached inner temperature. Although ISO 15502 defines at point 3.3.2 cellar compartment as a “*compartment intended for the storage of particular foods or beverages at a* *temperature warmer than that of the fresh-food storage compartment*" some misunderstanding occurs (see following point c.1 for a detailed discussion). A clarification is therefore urgent;

- Refrigerating appliances that are not specifically designed (advertised and sold) as wine storage cabinets (for the store and/or long term maturation of wine) but that may be nevertheless used for this purpose. Appliances that have a wine storage compartment (again specifically designed for wine storage) combined with any other compartment type defined in EN 153;
- Refrigerating appliances used to have different wines at the correct drinking temperature (*wine coolers*), if they can be tested according to EN 153 in terms of reached inner temperature;
- Non-compressor refrigerating appliances: absorption refrigerators with electricity (from the mains) as the only energy source. They are sold mainly for hotel application, but also for household use (students, drinks coolers) and office (meeting rooms). They are already implicitly covered by the present directive, but it would be better to have them explicitly mentioned, to avoid potential doubts in any stakeholder.

c) The appliance classification

c.1) Other refrigerating appliance types on the market

Some product types are - for different reasons - not covered by the EU legislation, or there is a persisting doubt coverage. For example. the UK Market Transformation Programme[46] classified in 2005 different types of small non-traditional cold appliances available on the national market (and possibly also in other Member States):

- *mini drinks chillers* (Peltier effect type)
- *non-compressor mini refrigerators* (absorption type)
- *mini refrigerator/chillers (sometimes with ice compartment*)
- *wine cellars.*

The main characteristics are presented in Table 7.38. Some of the mentioned products could be considered refrigerators under the definition and storage temperature in the European standard, should some very minor modification be introduced either in the standard (EN 153) or in a revised labelling directive. However most of them are not usually sold with energy labels because manufacturers do not believe that they are covered by the EN 153 and therefore do not qualify as regulated appliances.

A discussions with some UK manufacturers suggested that they do not give energy labels to the appliances they sell as 'drinks refrigerators' because the definition of a household refrigerator given in the reference standard EN ISO 15502[47] requires the appliance to have at least one compartment suitable for the storage of fresh food; thus Category 1 (and Category 10) can not be applied, because drinks are not fresh food. Category 2 (depending on the interpretation of the category definition, see later for a discussion of this issue) refers only to household refrigerator-chillers with a compartment suitable for fresh food and not to a single cellar compartment[48] appliance, which should be considered a Category 10. Category 10 could be used to classify drinks chillers, but the design temperature of a cellar compartment under EN ISO 1550 is in the range 8-14°C (considered

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[46]"Small, non-traditional refrigerated appliances on the UK market", BNC15, version 1.2, 05 October2007, downloadable at: http://www.mtprog.com .

[47] EN ISO 15502, clause 3.1.3: refrigerator = refrigerating appliance intended for the preservation of food, one of whose compartments is suitable for the storage of fresh food.

[48] EN ISO 15502, clause 3.3.2: cellar compartment = compartment intended for the storage of particular foods or beverages at a temperature warmer than that of the fresh-food storage compartment.

Table 7.38: Non-traditional refrigerators in the UK market in 2005

Appliance	Mini drinks chillers	Mini refrigerators	Mini refrigerator/chillers	Wine cellars
Size/volume	typically 6 to 8 cans, volume 2,8 litre	around 75 litre, with 5 or 6 litre freezer (probably 3 star) box. Larger products are available for the wine chiller market	50 - 70 litre	120 litres, 30 or more bottles
Technology	Thermoelectric cooling (Peltier effect)	Absorption	Compression	Compression
Power supply	12/230 V DC/AC	230 V AC	230 V AC	230 V AC
Operating temperature	Not always mentioned, but generally claim that they work up to 20°C below the ambient temperature and are limited by a fixed point thermostat to +5°C. Some also have a heating function of up to 65°C	+5°C to +8°C in refrigerator compartment	Not always explicitly stated, variable between brands and models, but an example is +4°C to +10°C	Usually variable for different types of wine and drinks.
Availability	Mini drinks chillers are widely available in supermarkets, multiple retailers, DIY and catalogue stores	Not widely available	widely available in domestic appliance retailers.	Available in some domestic appliance retailers.
Target market	Products related to cool boxes and picnic boxes that run on 12 V power supplies, but are designed as mini-refrigerators rather than picnic boxes. Some are available in novelty shapes such as a football, others are branded to appeal to pre-teenagers. They look like refrigerators, as opposed to single-can coolers that just cool one can at a time and can be run as and when cooling is needed.	Promoted for in-room use (i.e. in hotels and for students, for wine	Domestic market and promoted as "the answer to overcrowded refrigerator"	Wine connoisseurs and the 'pub at home'. These are generally glass-fronted models
EU Energy labelling	Not required to be supplied with an energy label	These products are required to be supplied with an energy label, but are not subject to the energy efficiency regulations	Not clear	Not clear
Energy consumption	Not typically declared. When tested: 0,60-1,48, average 1,13 kWh/day	An energy consumption of 1,6 kWh/day found on one sample with an annual consumption of 584 kWh. When tested: 1,25-1,53, average 1,30 kWh/day	A declared energy consumption of 0,6 kWh/day found on one sample with an annual consumption of 219 kWh. A variant has an ice compartment; one model claims A+ for a 46 litre refrigerator using 106 kWh/year. When tested: 0,63-1,53, average 1,04 kWh/day	Not known. When tested: 0,25-1,53, average 1,39 kWh/day

sometimes too high for drinks). In addition, chill compartments, which can be present in any models classified in a refrigerator category, have a temperature range of -2°C to +3°C under EN 153 (Table 7.39); they are considered unsuitable for storing drinks, which should be stored at warmer temperatures (in the range +5°C to +8°C).

Table 7.39: Compartment storage temperatures in EN ISO 15502

Fresh-food storage compartment		Food freezer and three-star compartment/ cabinet	Two-star compartment/ section	One-star compartment	Cellar compartment	Chill compartment
t_{1m}, t_{2m}, t_{3m}	t_{ma}	t^{***}	t^{**}	t^{*}	t_{cm}	t_{cc}
$0 \leqslant t_{1m}, t_{2m}, t_{3m} \leqslant 8$	$\leqslant +4$	$\leqslant -18$ [a]	$\leqslant -12$ [a]	$\leqslant -6$	$+8 \leqslant t_{cm} \leqslant +14$	$-2 \leqslant t_{cc} \leqslant +3$

[a] As a result of a defrost cycle, the storage temperatures of frost free and/or adaptive defrost refrigerating appliances are permitted to rise by no more than 3 K during a period not greater than 4 hours or 20 % of the duration of the operating cycle, whichever is the

As conclusion, drinks can be stored in a refrigerator compartment, but since they are not considered fresh food a drink refrigerator can not be – at present – be classified as a refrigerator. The ambiguity could be overcome if drinks are considered as fresh food from the labelling legislation point of view or if the refrigerator compartment definition will include also drinks.

Some appliances were checked in 2005 and found they had user instructions that stated the product should not be used for food; however, others had conflicting advice such as “designed for storing drinks and other small items, not food” in the user instructions and “beer safe, dairy safe, food safe” on the box. Clarity in the purpose of these items is essential not only to inform consumers about the correct appliance use but also to finally decide as to whether these items should be covered by the EU energy label scheme.

In addition, MTP tested a range of 17 these non traditional refrigerators in March 2005 (see Table 7.38) including four mini refrigerator/chillers using traditional compressor technology. The tests were conducted at 230 V in a controlled environment room at ambient conditions of 25°C and 65% relative humidity. Although the standard requires 220 V, this test was considered close enough to standard conditions to give an indication of where the results would be on the energy label scale; the energy efficiency class was calculated on the basis of the measured energy consumption values and the declared net volume; if no volume was declared then the volume was measured.

As far as the potential market for these non traditional refrigerators is concerned, data are still poor. A report in The Independent Electrical Retailer (a UK monthly magazine for electrical retailers) said that the beer and wine cooler sector was growing: the wine cabinet market increased from 15 000 units sold from April 2005 to March 2006 to 31 000 wine cabinets sold in the year from April 2006 to March 2007, with an average price of 215 £. Less detailed information were available about the drink chiller sector where 110 000 units were claimed to be sold in the period October 2006-March 2007 at an average price of 30-40£. It was also claimed that the UK is following the US market where customers have multiple cooler units (e.g. in the conservatory, child’s room, TV room, and garage), but it is worth noting that the UK market is probably more close to the USA market than any other EU Member State. For sake of comparison, in 2004 the total UK market for refrigerators was 1 225 000 units.

To investigate potential user habits a postal survey of the UK-Intertek user panel was undertaken in June 2005. The survey received 200 replies and found 16 owners of mini-refrigerator/chillers and mini-drinks chillers. The mini-refrigerator/chillers owners tended to use them for drinks and sweets (sometimes also medicines such as insulin) and have them running all the time; the mini-drinks chiller owners tended to use them for sweets and other foodstuffs and claimed to use them only for part of the week or occasionally. The results cannot be taken as an estimate of ownership neither to represent ownership because the panel is not, as a whole, demographically representative of the population, but it does include members of different demographic groups.

Also according to other sources a growing market in the domestic refrigeration and cooling sector is the gadget or '*boy's toys*' area[49]. Increasingly in the developed world, well-off individuals are looking for ways of spending their money. In the domestic refrigeration/cooling market, designer gadgets are typically stylish *wine chillers* (Figure 7.45) *icemakers, ice cream makers* and *individual refrigerators for drink cans* (Figure 7.46). Since the market is not price-sensitive, alternative refrigeration systems such as Peltier ones are often used (as shown in previous Figures).

Figure 7.45: Wine chiller with Peltier effect

Figure 7.46: Refrigerator for drink cans with Peltier effect

Finally, a number of new products are starting to be manufactured which are not easily and/or not completely referable to the ten energy labelling categories or to other classification schemes, such as "*convertible appliance*" (where the compartments can be converted from refrigerators to freezers by the users) or "*bottom tilt-out freezers*" (where the bottom mounted freezer compartment is tilting and slide opening, but the food in loaded from the top).

c.2) Wine cellars

Wine storage began in the underground caves of Europe. These caves provided the consistent storing conditions that allowed wine to age at an elegant pace. By convention, these conditions have become the standard for modern wine cellars: The ideal wine aging conditions are:

- Temperature: extreme temperatures and temperature changes are dangerous, a constant

[49] Source: S. James, Developments in domestic refrigeration and consumer attitudes, Bulletin of the IIR, No 5, 2003.

temperature is necessary, ideally in the range 10-14°C, for an optimum wine maturation process;

- Light: light and in particular UV can rapidly degrade wine, mainly due to the tannin irreversible oxidation; wine should be stored in a dark place;

- Natural ventilation: a constant natural ventilation is essential to prevent odours formation and mould growth;

- Humidity: a correct humidity, higher than 50%, but lower than 80%, is important to allow the cork to maintain its airtight characteristics and to prevent mould growth on the cork and the label;

- Vibrations: vibrations disturb the wine maturation, mainly for the most precious wines.

Different names and classifications are commercially used to define refrigerated appliances for wine, wine cellars and wine cabinets are the most used. Two main types of wine cellars are manufactured: models to age and preserve all types of wine at a constant temperature (the **wine storage cabinets**) and those to have all wines at the perfect serving temperature in one single-temperature or multi-temperature cabinet (the **wine coolers**). Also mixed appliances are on the market, which make the exact classification more difficult.

A brief internet survey resulted in the following wine cabinets types available on the market:

- wine cabinets at one temperature:
    - are used to replace a natural cellar, both for commercial or domestic use, and preserve or mature all types of wine. They guarantee a constant temperature between 10°C and 14°C (Figure 7.47); these cabinets are equipped with a double circuit for cooling and heating, to operate with an external temperature between 0°C and 35°C, and can be installed in garages and other non-heated rooms;
    - a single temperature can be adjusted in the range from +3°C to +22°C (Figure 7.48);

- wine cabinets at two temperatures: with two separate zones at different temperatures, one (a wine storage zone/compartment) to store wine at the optimum temperature (between 10°C and 14°C) and the other to cool the wine at the perfect serving temperature (between 6°C and 10°C) or a wine cooler zone/compartment (Figure 7.49). The two zones can also be both with adjustable temperature (Figure7.50);

- wine cabinets at three temperatures: with three separate temperatures: the storage zone in the centre of the appliance, to store wine at the optimum temperature (between 10°C and 14°C), a cooling compartment (between 6°C and 10°C) in the lower part of the cabinet and an upper compartment to temper wines (between 16°C and 20°C) (Figure 7.51). The three zones can have an adjustable temperature (Figure7.52);

- multi-temperature wine cabinets: temperatures are distributed in the range 7°C to 20°C, into up to 10 temperature zones; these cabinets are designed to provide each wine at the perfect serving temperature (champagne, white, red, rosé) (Figure 7.53);

cabinets can be ventilated, with humidity control, with a glass door equipped with UV filter, free-standing or built-in.

Figure 7.47: Wine storage cabinet	**Figure 7.48: One-temperature wine cabinet**
	
Wine storage cabinet, temperature 10-14°C (model EuroCave, V 083T)	Wine cabinet with one constant temperature, adjustable from 5°C to +22°C (model Liebherr, WKes 4177)

Figure 7.49: Two-temperature wine cabinet	**Figure 7.50: Two-temperature compartments wine cabinet**
	
Wine cabinet with 2 temperature zones: the bottom compartment for wine cooling at 6-10°C and the middle compartment to store wine at 10-14°C (model Artevino Ambiance - AG2)	Wine cabinet with 2 separate and adjustable temperature compartments: each compartment temperature can be independently set between +5°C to +18°C (model Liebherr, WTes 1753)

Figure 7.51: Three-temperature wine cabinet

Wine cabinet with 3 temperature zones: the bottom compartment at 6-10°C to cool the wine, the middle compartment to store wine at 10-14°C and the upper compartment to temper the wine at 16-20°C (model EuroCave E283T)

Figure 7.52: Three-temperature adjustable wine cabinet

Wine cabinet with 3 separate and adjustable temperature compartments: each compartment temperature can be independently set between +3°C to +20°C (model Liebherr, WT 4677)

Figure 7.53: Multi-temperature wine cabinet

Wine cabinet with 6 temperature zone: bottom zone +5°C, top zone +18°C (model Liebherr, WTes 4177)

The most recent definition of **wine storage cabinets** has been introduced in the new proposal for Australian/New Zealand standard 4474.1-2007, to clarify the demarcation between cabinets specifically designed for the storage of wine (which are excluded from the standard) and those acting as 'refrigerating appliances' to have all wines at the perfect serving temperature. In fact,

refrigerating appliances that are not specifically designed for wine storage but that may be nevertheless used for this purpose are covered by the AU/NZ standard as well as refrigerating appliances that have a wine storage compartment combined with any other compartment type defined in the standard. On the contrary, separate wine storage cabinets are not within the scope of the standard but may be tested using the described test methods depending on the claimed temperature range.
According to Clause 1.3.18, a wine storage cabinet/compartment is an appliance - or a compartment within an appliance - *which is specifically designed exclusively for the storage and/or long term maturation of wine*. Key characteristics of wine storage cabinets/compartment include constant temperature over time, specific humidity characteristics and low vibration. They may be designed to have stratified temperature zones. Typical characteristics include:
(i) the capability of maintaining continuously a nominated temperature (typically 14°C to 16°C) at an ambient temperature either, above or below the nominated temperature usually with heating as well as cooling;
(ii) the capability of maintaining temperatures within a variation over time of less than 0,5 K;
(iii) control of the compartment humidity; and
(iv) construction to reduce the transmission of vibration to the compartment, whether from the refrigerator compressor or from external source.

Excluding wine storage cabinets, due to their specific service which is far from that of a refrigerator, all other appliances are in principle refrigerating appliances, to be tested according to EN 153 and therefore can be subject to energy labelling and other eco-design implementing measures.

It is suggested that models with one or more adjustable temperature compartments are tested either at the lowest possible temperature and classified accordingly into Category 1 (maximum temperature +8, with the average ≤ +4°C) or at the maximum possible temperature for the cellar compartment (maximum temperature +14°C) and classified accordingly into Category 2. Both conditions present pro and cons:
- +5°C are the worse conditions from the energy consumption point of view, and there is little scope to test a model at such low temperature if it is then used at a (much) higher temperature,
- +14°C are the best conditions from the energy consumption point of view, but if the appliance is then used at a (much) lower temperature the energy consumption is higher.

The temperature range between +3°C and +14°C is then covered, but possible models with a temperature range between +15°C and +22°C are not. This temperature range is used by the wine storage cabinets according to the AU/NZS standard, but is on the contrary used in other type of wine cabinet compartments or in mono-temperature adjustable cabinets according to the developed brief internet survey. For these specific appliances Category 10 can be used, where the nominal compartment temperature is considered in the equivalent volume calculation.

Models with multiple temperature zones (up to 20 as said) without separate compartments are more difficult to measure because the temperature stratification is just the contrary effect of a traditional refrigerator, where temperature uniformity is pursued. Although these appliances might be tested under the same condition as traditional refrigerators, the specificity of temperature stratification and stability control will be lost. Hopefully these appliances could be better addressed as soon as the relevant standard is ready and can be excluded for the moment from labelling scheme and any eco-design implementing measure.

Conclusions

Wine cellars or wine cabinets are a complex product group where different appliances are included.

Wine storage cabinets, defined as appliances or compartments *specifically designed exclusively for the storage and/or long term maturation of wine* offer a different service compared to the traditional refrigerating appliances, and – at least for the moment – can be excluded from any labelling scheme or specific eco-design implementing measure, until the new specific standard will be ready. To avoid any possible product "misuse" (for example, models declared as wine storage cabinets then sold for household use just to overcome the specific legislation) these products will be excluded only if declared and advertised for the specific use, and not suitable for wine, food or other beverages cooling.

When **wine storage compartments** are present in more traditional refrigerators, it can be considered a special cellar compartment and the models measured, classified and labelled accordingly.

All the other appliances that are not specifically designed for wine storage but that may be nevertheless used for this purpose and appliances designed for wine cooling (at the perfect serving temperature) are considered as refrigerated appliances, to be measured according to EN 153 and labelled accordingly (with some exclusions):
- single- and multi-compartment adjustable temperature wine cabinets shall be tested at the lowest reachable temperature according to the manufacturers instructions and classified accordingly as Category 1 (average temperature ≤ 4°C) or Category 2 (maximum temperature +14°C) appliances;
- appliances which are not wine storage cabinets and have an adjustable temperature between +15°C and +22°C shall be measured and classified in appliances Category 10, where the nominal compartment temperature is considered in the equivalent volume calculation;
- wine cabinets where a compartment with an adjustable temperature between +15°C and +22°C is present shall be classified in appliances Category 10, where the nominal compartments temperature is considered in the equivalent volume calculation;
- multi-temperature zones wine cabinets without separate compartments are difficult to measure because of temperature stratification; they are therefore excluded for the moment from the labelling scheme and any other specific/generic eco-design implementing measures;

c.3) Absorptions refrigerators

The annual European market for absorption refrigerators (see Task 1) is estimated in 700 000-800 000 units. About 300 000 units (mainly gas appliances) are absorbed by various types of recreation vehicles and boats and the rest by various environments:
- miniBars for hotels and cruise liners (where no noise is required)
- refrigerators (miniCool) for compact living spaces, offices and rooms outside the kitchen
- wine cellars (no vibration from the compressor on/off could "compromise" wine maturation)
- large refrigerators for areas with unreliable power supply
- portable and stationary refrigeration systems for medical applications.

About 250 000 units are sold to hotels, other 125 000 to other professional uses such as medical applications and about 10-20 000 units are estimated for household use. Common volumes for recreation vehicles are 60, 100, 120 and 180 litre, with an energy consumption in the range 2,4-3,2 kWh/24h. Common volumes for hotel and household refrigerators are 30, 40, 60 and 80 litre, where the energy consumption is in the range 0,6-1,2 kWh/24h (or 219-438 kWh/year). Larger appliances for recreational vehicles (RV) can be equipped with a small 3-star freezer. For the other appliances a simple ice box is possible.

It is therefore estimated that the quota of absorption refrigerators that can be addressed by the EU legislation for household-related products is about 260 000-270 000 units per year.

c.4) Appliance Categories definition

The energy labelling Directive 94/2/EC has a prescriptive definition of the Ω_c term as its values are stated directly for each cold appliance category (except Category 7 and Category 10) and thereby removes the freedom to calculate the value depending on the exact design temperature of the compartment. In most cases this does not matter as the prescriptive values agree with the values that would be computed; however, it could be relevant for at least (a) US-made refrigerator-freezers that have not had the freezer compartment converted to 3- or 4-star capability, (b) refrigerator/chillers, (c) cellar compartments.

Some inconsistencies in the scheme set by the directive 94/2/EC were already highlighted in previous COLD-II study:

- the definition given in the labelling Directive for Category 2 (refrigerator/chillers) is a "*household refrigerator/chiller, with compartments at 5 °C and/or 10 °C*". The use of plural 'compartments' gives rise to an interpretation problem: a strict interpretation of the labelling directive would imply that an appliance comprising a single chiller compartment (i.e. a single compartment designed to operate at +10 °C) would be classified not as a "Category 2 - refrigerator/chiller", as it only has one compartment, but as "Category 10 - *multi-door or other appliance*". But Category 10 appliances are the only group where the value of Ω_c is not prescribed but is calculated, so in this case the manufacturer would have the freedom to specify the actual design temperature. If the design temperature is +12°C (as is defined for this compartment type in directive 96/57/EC) then the calculated Ω_c value is 0,65. While Ω_c in the labelling directive is fixed at 0,75 for the +10°C compartment;
- for a 2-compartment refrigerator/chiller appliance, comprising a standard +5 °C refrigerator compartment and a warmer +10 °C compartment, and belonging to Category 2, the value of Ω_c for the warmer +10°C compartment in the labelling directive is fixed at 0,75. For a 3-compartment appliance (comprising a standard +5 °C refrigerator, a -18°C frozen food compartment and a warmer +10°C or +12°C cellar compartment) the Ω_c for the latter can be 0,65 or 0,75 depending on the manufacturer decision about the compartment design temperature. In practice, the difference found when calculating the appliance equivalent volume and the consequent standard energy consumption is minor, but still enough, for an appliance close to the EEI threshold between two energy efficiency classes, to be classified in either one or the other class;
- the name of the compartments is misleading: taking into consideration the previous example, the Category 2 appliance named "*household refrigerator/chiller*" includes (or is made only by) a +10°C compartment which is generally known as "*cellar compartment*", because it mimics the temperature and the conservation properties of a "house cellar". On the other side, one of the possible compartments in a refrigerator is the "*chiller (or chill) compartment*" designed to have a temperature of 0 °C (and an Ω_c= 1,15). The chill compartment is now defined in EN 153 as having a temperature between -2°C and + 3°C;
- the so called "0-star compartment" is not defined in EN 153 standard, but was commonly used in Europe, and designed to operate at $-6\ °C < T_c < 0\ °C$.

An updated cold appliance classification is proposed in Table 7.40. The absorption refrigerators will be included in Category 1 (refrigerators without low temperature compartments or in Category 3 refrigerators with the no-star low temperature compartment if a separate ice-box is present in the appliance.

Table 7.40: Revised appliance classification for a labelling scheme

Description	Category
Household refrigerators, without low temperature compartment	1
Household refrigerator/cellars with or without a refrigerator compartment and/or a chill compartment	2
Household refrigerators, with no-star low temperature compartment	3
Household refrigerators, with a low temperature compartment (*)	4
Household refrigerators, with a low temperature compartment (**)	5
Household refrigerators, with a low temperature compartment (***)	6
Household refrigerator-freezers, with a low temperature compartment *(***)	7
Household food freezers, upright	8
Household food freezers, chest	9
Household refrigerators and freezers with more than two doors, or other appliances not covered above	10

Additional elements to be clarified include:

- *Convertible appliances*: the compartments (or even the overall appliance) can be converted from refrigerators (+5°C) to freezers (-18°C) by the users: to be classified and tested according to the most severe (coldest inner temperature) conditions according to manufacturers instructions. In addition, the appliance or the compartment shall not be declared or advertised to be used for conditions more severe (lower temperature) than the tested ones;
- *Bottom tilt-out freezer*s: the freezer has at least two freezer compartments and the bottom mounted freezer compartment is tilting and slide opening (the upper freezer compartment is of the upright type); since the food is loaded from the top in at least part of the appliance, then the overall unit shall be considered as a top-opening horizontal (chest) freezer in testing and in declaration of the energy efficiency class (including the reference line), which is the worse condition from the energy consumption point of view;
- *Two-star section(s)* in freezers: under certain circumstances freezers are allowed to present two-star sections and/or compartments. These sections shall be considered two-stars also when the equivalent volume of the appliance is calculated, although sometimes this apparently does not happen;
- *Three star freezers*: are appliances suitable for the storage of frozen food under three-star storage conditions (in which the temperature is not warmer than -18 °C). According to the ISO 15502 standard they are already considered together with four-star freezers, but probably this should be better highlighted;
- *Drawer appliances/compartments*: to be classified, tested and declared according to the coldest temperature. If freezer only to be considered as top-opening horizontal (chest) freezers;
- Category 10: although the miscellaneous Category 10 is undoubtedly necessary to take care of appliances not included in previous categories, it might become a sort of loop-hole for some models to achieve a better energy efficiency rating, due to the fact that the Equivalent Volume formula is based on the nominal temperature of the compartment(s) instead of the default one, which may result in a benefit when a new compartment is defined. This is the case of the so called "bio-fresh" refrigerators, where a large chill compartment is included: since no appliance with a refrigerator and a chill compartment was included in the directive 94/2/EC, this models was classified as Category 10 and the nominal (and unknown) temperature of the compartment was used to calculate the equivalent volume and then the EEI. A possible solution is that when a refrigerating appliance is classified as Category 10 the nominal temperatures of the compartments shall be declared.

d) Energy efficiency algorithms

A discussion about the opportunity of amending algorithms and formulae to calculate the Energy Efficiency Index (EEI), the Standard annual energy consumption, the Equivalent Volume (called adjusted net volume in directive 94/2/EC) and other energy efficiency factors and parameters is here developed.

Energy Efficiency Index calculation algorithm: the algorithm for the calculation of the Equivalent Volume and EEI as in directive 2003/66/EC, Part 1. For the calculation of the EEI, the energy consumption of any given appliance is compared to the reference energy consumption of the same category of appliance with an identical equivalent volume in order to calculate its energy label class. In particular:

- Energy Efficiency Index (as a percentage) = annual energy consumption of appliance/standard annual energy consumption of appliance.
- Standard annual energy consumption of an appliance (in kWh/year) is calculated as:

$$SC = V_{eq} \times M + N + CH$$

where the M and N values are reported in Table 7.41 and CH is a correction term (an allowance) equal to 50 kWh/year given to appliances with a chill compartment of at least 15 litres (see also Table 7.43).

Table 7.41: M and N coefficient in directive 2003/66/EC, Part 1

Category	M	N
1	0,233	245
2	0,233	245
3	0,233	245
4	0,643	191
5	0,450	245
6	0,777	303
7	0,777	303
8	0,539	315
9	0,472	286

- Equivalent Volume: for all appliance Categories is calculated through the following equation:

$$V_{eq} = \sum_{c=1}^{c=n} V_c \times \frac{(25 - T_c)}{20} \times FF \times CC \times BI$$

where *n* is the number of compartments, T_c is the design temperature of the compartment in degrees Celsius as proposed in Table 7.40; the term *FF* is a correction term for the presence of a ‘no frost’ function, set to 1,2 for no-frost frozen food compartments and 1 otherwise; *CC* is a correction term for the climate class of the appliance, ranging from 1 to 1,2 depending on the climate class and compartment type and BI is a correction term for built in appliances (Table 7.43)[50].

The main component of the equivalent volume, previously named the Ω_c term, is defined by the temperature difference between the internal design temperature of a compartment and the ambient temperature under standard test conditions (25 °C) expressed as a ratio of the same difference for a pure refrigerator compartment at +5 °C as $\frac{(25-T_c)}{20}$. It had a prescriptive nature in directive 94/2/EC, but has now been made explicit to take care of the actual nominal compartments temperature. To assure a smooth transition between the previous labelling directives and the new scheme it is nevertheless proposed that if the design compartment temperatures defined in Table 7.42 are not used, the actual compartments temperatures are declared by manufacturers.

Table 7.42: Design temperatures for cold appliances

Compartment	Design temperature	(25-T_c/20)
Refrigerator compartment	+5°C	1,00
Cellar compartment	+10°C	0,75
Chill compartment	0 °C	1,25
no-star low temperature compartment	<0 °C	1,25
1-star low temperature compartment (*)	-6 °C	1,55
2-star low temperature compartment (**)	-12 °C	1,85
3-star low temperature compartment (***)	-18 °C	2,15
4-star low temperature compartment (***)*	-18 °C	2,15
Household food freezers, upright	-18 °C	2,15
Household food freezers, chest	-18 °C	2,15

[a] a chill compartment is designed in EN 153 to operate at - 2 °C < T_c < +3 °C
[b] a no-star low temperature compartment is considered to operate at - 6 °C < T_c <0 °C

Table 7.43: Correction factors in directive 2003/66/EC Part 1

Correction factor	Value	Condition
FF (frost-free)	1,2	For "frost-free" (ventilated) frozen food compartments
	1	Otherwise
CC (climate class)	1,2	For "tropical" appliances
	1,1	For "subtropical" appliances
	1	Otherwise
BI (built-in)	1,2	For built-in appliances (¹) of under 58 cm in width.
	1	Otherwise
CH (chill compartment)	50 Kwh/y	For appliances with a chill compartment of at least 15 litres
	0	Otherwise

(¹) An appliance is "built-in" only if it is designed exclusively for installation within a kitchen cavity with a need of furniture finishing, and tested as such.

[50] It has been suggested to complement the correction terms in Part 1 of directive 2003/66/EC with a specific term of 1,2 for the wine coolers with a glass door where the free glass area is ≥ 60% of the access opening of the compartment. The glass door which is typical of most wine coolers and does not allow a good door thermal insulation (for example VIP panels can not be used).

- Allowances:
  - no allowances for the extra 'through the door' features (ice making, cold drink dispenser, etc.). Typical of regions such as USA and Australia, much less present in Europe (with the probable exception of UK). Mainly applied to larger side-by-side models as extra "comfort" features to add value to the appliance. One might argue that in case this feature is not present in the refrigerator, then one (or more) additional small appliance will be purchased to satisfy the "comfort" needs. However, since the main refrigerator is usually located in the kitchen, and the beer/soft drink is mainly consumed when doing other recreational activities in a different room (living room for example) the risk is that the consumer will have this feature in the main refrigerator and one or more additional small refrigerators in the other room(s). For the ice dispenser the same applies, with the exception that if ice is consumer in the kitchen then there is almost no difference for the consumer to have it via a through the door dispenser (which consumes energy), or simply opening the freezer compartment (which also consumes energy, but only when the door is opened and not 24h a day).
  - allowance factor: for the chill compartment as in directive 2003/66/EC Part 1 (Table 7.43).

e) Energy Efficiency Classes: definition and thresholds

It has to be discussed whether a revised A-G scale should be adopted or if a new categorical system is a better approach. In addition, following the discussion a decision should be also taken about the value of the classes thresholds:

- retain the existing ones and create new ones on top, following the same pace;
- redesign the entire threshold systems, taking into consideration that the A+/A++ thresholds were 'interim values' set urgently in 2003 to address a strong market need.

Some elements should be taken into consideration for the discussion and decision:

1. a lack of differentiation by label efficiency class will inevitably reduce the impact of the labelling scheme and therefore there is a clear need to revise the energy label set in directive 2003/66/EC such that there is a restoration of the differentiation in products by their efficiency class;
2. it is important - at least in principle - to maintain a large number of labelling classes as this reinforces the key message to consumers that there remains a significant difference in energy performance between the most and least efficient products, whether this is technically feasible depends on the outcome of this study;
3. in this respect, absorption (and other non-compressor type) refrigerators need at least 2 to 3 separate classes (possibly the latest 2 or 3 of the scale): F (EEI<125), G1 (EEI<150) and G2 (EEI ≥150); if EEI ≥150 is phased out, then the G2 class will not exist, it has been defined only to clarify the phase out level. Some E class model probably exist for absorption products;
4. following from points 2 and 3, compression refrigerators need at least 5 classes under the ambitious scenario: A (EEI<55), A+ (EEI <42), A++ (EEI <30), A3 (EEI <25) and A4 (EEI <20). The values EEI=25 and EEI=20 have been proposed by stakeholders to take into consideration the BAT level coming from Task 6 and a super efficient refrigerator-freezers with EEI=19,8[51] produced for a limited period by the Turkish manufacturer ARCELIK under the Energy+ scheme (promoted by the SAVE-II programme) an probably sold on the German market. Different scenarios and EEI values for EEI are also set in the followings;
5. the penetration of the A+ and A++ classes of the present labelling scheme show that while class A+ in increasing as expected, class A++ is almost stable at a very low percentage. Although the

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[51] Model BLOMBERG CT 1300A Super plus, see Energy+ LISTS March 2004, Participating Organisations and Qualifying Refrigerators & Freezers, FINAL VERSION, 12 March, 2004, downloadable from http://www.energy-plus.org .

thresholds of the two new classes were proposed by manufacturers in 2002, it is now common opinion that the effort to improve products from A+ to A++ efficiency is too large (12 EEI points or almost 29% over A+ threshold) to be covered in one single step; a suggestion came to create an intermediate level to facilitate the products technological development;

6. to avoid the consumers confusing the best absorption refrigerators (now belonging to class F, and few to class E) with the worse compressor models (now belonging to energy efficiency class B or C) it would be better to have an empty class between the two product groups, which can be also considered a buffer for a future improvement of absorption models (if technically feasible);
7. the structure of the labelling scheme should be in place for a reasonably long time so that manufacturers who make the investment needed to attain the higher labelling classes have sufficient time to recoup their investment. If this is not guaranteed the impact of the labelling scheme will be lessened;
8. as a result of previous point and to maximise the long-term impact of the scheme, the top labelling class needs to be ambitious, but technically attainable, as it will remain the means of distinguishing the highest-efficiency products for many years and therefore needs to take full account of expected technological developments;
9. the concern about measurement uncertainty in the test procedure can never be eliminated due to its statistical nature, therefore there will always be products near the efficiency boundaries of two labelling classes that could be interpreted as belonging to either class because of testing uncertainty (unless there has been a deliberate mis-declaration or a test error). It is desirable to maintain efficiency classes at a sufficient width to avoid products that are declared to be in one class being reported after a new test as belonging to two or more classes different from the declared one. It is therefore recommended that the revised labelling classes be no narrower than the narrowest class that currently exists, i.e. an energy efficiency index (EEI) spread of 10% (from E to D, or D to C in directive 94/2/EC), or be sufficiently broad in both relative and absolute EEI terms;
10. to avoid confusion among retail staff and others who need to understand the scheme, the EEI thresholds used to define the labelling classes should be the same across all product Categories.

The distinction between the linear labelling proposal (the more ambitious scenario) and the geometric proposal (the more realistic scenario) in Table 7.42 reflects the above discussion:

- the *geometric label* structure gives a more even-handed progression (of ~20%) in relative efficiency steps in moving from one class to the next and hence will better represent the changes in design effort required. It allows to accommodate an “intermediate step” between the current A+ and A++ classes to make the transition less difficult for manufacturers;
- the gap between the new labelling classes is 5 EEI units in the *linear label* proposal, which is about half of the gap between the A and A++ classes today, but represent a progressively more severe design effort to reach the higher efficiency classes at absolute EEI levels which are very close (or even beyond for some product types) the technological limit.

Other proposals can be derived from the two main scenarios. For example, a *very ambitious static* (and almost unrealistic) scenario is to set an increasing effort to reach the highest possible energy efficiency class at EEI <10, which is probably not achievable by most of the product categories. In addition, the absorption refrigerators will belong to the last energy efficiency class, where EEI ≥ 55, but they have a much higher index, more than the double.

Table 7.44 shows also proposals for cold appliance phase-out, see paragraph 7.8.1.5 for a detailed description of efficiency requirements.

Table 7.44: Linear and geometric proposal for a revised energy label structure using a linear Energy-Efficiency Index class widths or a relative efficiency improvement between labelling classes

EEI Directive 2003/66/EC	Relative improvement (units)	(%)	EEI ambitious scenario	Relative improvement (units)	(%)	EEI realistic scenario	Relative improvement (units)	(%)	EEI very ambitious static scenario	Relative improvement (units)	(%)
			EEI <10	--	--	EEI < 15	--	--			
			EEI <15	5	33	EEI <18	3	17			
			15 ≤ EEI < 20	5	25	18 ≤ EEI < 22	4	18	EEI < 10	--	--
			20 ≤ EEI < 25	5	20	22 ≤ EEI < 28	6	21	10 ≤ EEI < 20	10	50
EEI <30	--	--	25 ≤ EEI < 30	5	17	28 ≤ EEI < 35	7	20	20 ≤ EEI < 30	10	33
30 ≤ EEI < 42	12	29	30 ≤ EEI < 42	12	29	35 ≤ EEI < 44	9	20	30 ≤ EEI < 42	12	29
42 ≤ EEI < 55	13	24	42 ≤ EEI < 55	13	24	44 ≤ EEI < 55	11	20	42 ≤ EEI < 55	13	24
55 ≤ EEI < 75	20	27	55 ≤ EEI < 75	20	27	55 ≤ EEI < 75	20	27	EEI ≥ 55	Phase out of compression refrigerators	
	threshold of class A, EEI<55			Phase out of compression refrigerators			Phase out of compression refrigerators				
75 ≤ EEI < 90	15	17	75 ≤ EEI < 90	15	17	75 ≤ EEI < 90	15	17			
90 ≤ EEI < 100	10	10	90 ≤ EEI < 100	10	10	90 ≤ EEI < 100	10	10			
100 ≤ EEI < 110	10	9	100 ≤ EEI < 110	10	9	100 ≤ EEI < 110	10	9			
110 ≤ EEI < 125	15	12	110 ≤ EEI < 125	15	12	110 ≤ EEI < 125	15	12			
EEI ≥125	--	--	125 ≤ EEI < 150	25	17	125 ≤ EEI < 150	25	17			
			EEI ≥150	Phase out of absorption refrigerators		EEI ≥150	Phase out of absorption refrigerators		EEI ≥150	Phase out of absorption refrigerators	
			Linear progression proposal for a revised energy label structure using a relative efficiency improvement of 5 EEI points or 17-30% between labelling classes			Geometric progression proposal for a revised energy label structure using a relative efficiency improvement of 20% between labelling classes			Linear progression proposal for a revised energy label structure using a relative efficiency improvement of 10 EEI point or of 25-50% between labelling classes		

f) Information to be disclosed

Additional information to be disclosed in the label or the fiche are:

- in the label: addition of the appliance Climatic Class or better the minimum temperature at which the model can be used (the inside temperature is guaranteed);
- in the fiche: addition of the volume(s) and temperature(s) of the compartment(s) for appliances belonging to Category 10 and for all appliances where the design compartment temperatures, set in Table 7.42, are not used.

7.6.1.5 Specific requirements

a) Energy efficiency algorithm

One question when proposing a new round of specific requirements for energy efficiency is whether the directive 96/57/EC should be upgraded or if a different system should be put in place through a complete amendment.

The *energy efficiency requirements* directive classified the products into broadly the same fundamental Categories used in the energy labelling directive. The main difference is that directive 96/57/EC rather than formally defining appliances with more than two doors or other appliances not covered in the preceding nine Categories as a distinct tenth category, relates the applicable limits back to the first 7 Categories according to the temperature of the coldest compartment. "Subcategories" arise under the directive because different equivalent-volume coefficients apply to no-frost, subtropical and tropical climate-class appliances, which are different from both the first labelling directive 94/2/EC and the updated 2003/66/EC one. Category 10 is a catch-all category containing at least 5 primary subcategories based on the lowest operating temperature of any compartment in the appliance and has the usual subcategories depending on climate class and the presence of a no-frost function.

Other inconsistencies with the labelling scheme provisions are the temperature of the "chiller" compartment (+12°C instead of +10°C) which in reality mimics a cellar.

For each product Category, a single straight line defines the maximum permissible energy consumption level per 24h as a function of the equivalent volume (named adjusted volume in the directive), with defined values for the slope and the intercept. Since the slope and intercept were derived broadly (but not completely overlapping) from the existing labelling scheme (directive 94/2/EC) the calculated annual energy consumption had to be divided by 365 to find the maximum daily energy consumption for each cold appliance model. In addition, since the slope and the intercept are fixed (and were set without taking into consideration ST and T Climatic Classes) the threshold straight line does not overlap with any of the energy labelling threshold lines for the same model. At the time directive 96/57/EC was enforced this not perfect matching with the other main cold appliance policy measure created some discomfort in stakeholders.

To avoid any potential confusion, it is therefore proposed that the new energy efficiency requirements are set in terms of maximum Energy Efficiency Index value, which indirectly defines a maximum annual energy consumption. This approach allows:

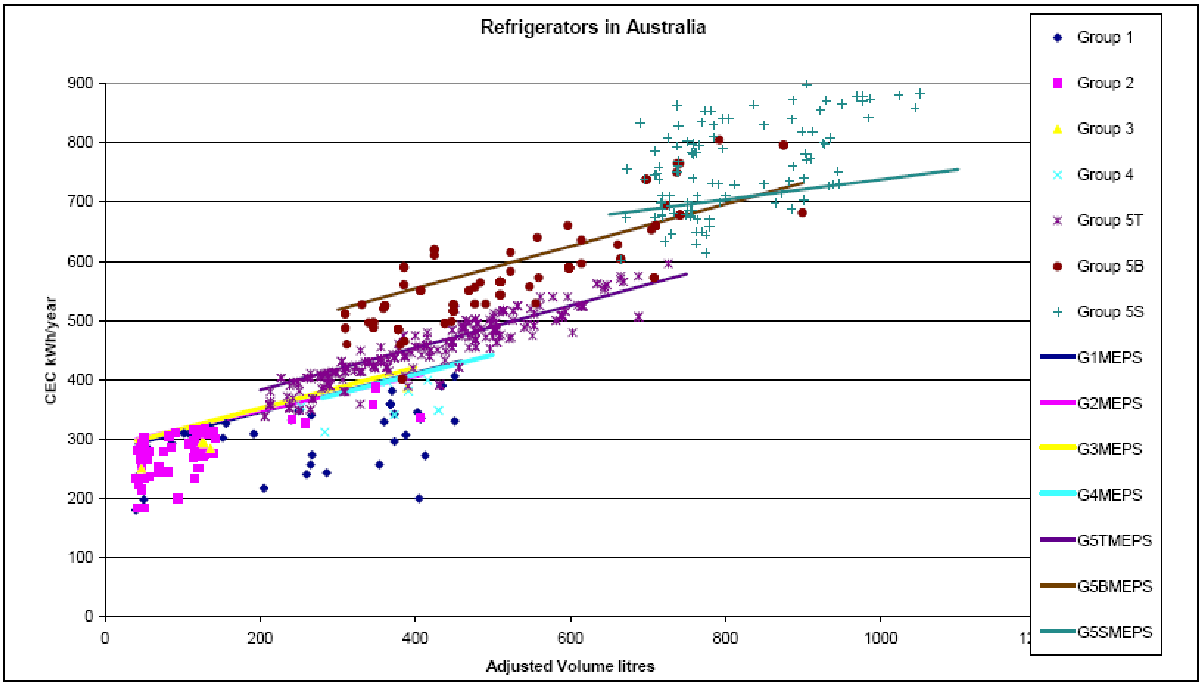
1. to set an univocal energy index and corresponding consumption value for a given model,
2. to phase out an energy efficiency class when setting a minimum efficiency requirement (should the phase-out EEI value corresponding to a labelling class threshold, which is a recommended

choice); the market control will be facilitated because no residual models in a labelling class will remain on the market (as happened in 1999),

3. to put in place a 'dynamic' approach for the phase-out of less efficient products, implicitly given by the sequence of the labelling energy efficiency classes, and
4. to reinforce the synergy – and therefore the effectiveness – between the labelling system and the eco-design energy efficiency/consumption requirements.

The main elements of a specific requirement are that the product classification and the energy efficiency calculation algorithms are the same as the new labelling scheme. No allowance factors for through-the-door devices (ice making, drink dispenser, etc.) are foreseen. The risk is to have the effect shown in Figure 7.54 for Australia[52]: some products (mainly within refrigerator-freezer groups 5T, 5B and 5S) appear to lie above the relevant maximum annual energy consumption lines because they have one or more specified features for which they are permitted an energy allowance with respect to the threshold value (these allowances are for adaptive defrost, additional doors and/or through the door icemakers). For example a side-by-side refrigerator-freezer (group 5S) allowed to consume no more than 700 kWh/year has an actual annual energy consumption of more than 850 kWh (or +21%) due to the allowances.

Figure 7.54: 2005 minimum efficiency requirements and refrigerator energy consumption in Australia



Another effect signalled in Australia is that there is a range of energy efficiency for most groups except Group 5T. Group 5T (refrigerator-freezers top mounted), making up about 50% of all refrigerator and freezer sales in Australia in 2006 and just under 30% of sales in New Zealand in 2006, are clustered on a relatively narrow band around the threshold line which indicates that manufacturers have designed to just meet the regulator requirements and do not care much about the achievable labelling class (the number of 'stars' in Australia). And this despite the long existing and very well known national labelling system (star rating scheme). The same problem can be also seen for group 5S, where most of the models are beyond the maximum energy consumption due to

[52] Source: Equipment Energy Efficiency Committee, Refrigerator Star Rating Algorithms in Australia and New Zealand – Revised Proposal, Discussion draft for stakeholder comment issued under the auspices of the Ministerial Council on Energy, September 2007, downloadable from: http://www.energyrating.gov.au .

the allowances, and therefore have a star rating equal to zero, and only for lower equivalent volumes some models are spreading below the threshold line.

A possible explanation of the phenomenon is that when the efficiency requirements reach a certain level there is no scope in manufacturing better products, that the labelling scheme is not (sufficiently) able to promote to the consumers. At this point, product diversification is no more entrusted to the national label (and therefore to energy efficiency, which just complies with the allowed minimum) but on other elements such as price, through-the-door devices, design, etc.
This might be also due to the continue categorical labelling rescaling developed in Australia, which time to time sets back to a low star rating scale the products, with a reduced pulling effect in the long term: there is little scope for manufacturers to produce - and for consumers to buy - products with a 3-4 stars label (although such products have an energy efficiency double than the 3-4 stars models of 5 years before); it is more a psychological effect, but might have its relevance.
Another explanation is that in the Anglo-Saxon world (USA, Australia, New Zealand) the technological development and the energy efficiency improvement are traditionally more entrusted on mandatory minimum requirements (imposed through legislation by the central/national government) than on consumers informed choice (a labelling system, although set through legislation). Therefore, there is a general lack of interest in setting a powerful and effective labelling system.

Product categories and Energy Efficiency Index algorithms, allowances and factors as set in the revised labelling scheme.

b) Requirements for compressor refrigerators

Appliances to be excluded from the specific requirements are the same excluded from the labelling scheme (models which can be powered by batteries, by energy sources different from electricity, and dual fuel appliances, wine storage cabinets and multi-temperature wine coolers, vaccine refrigerators).

Specific criteria are based on a minimum EEI level, equal for all product Categories, with a timely (dynamic) approach. Three possible scenarios are hypothesised:

- ambitious scenario:
  - Step 1: from 01.01.2009: phase out of models with EEI ≥ 55 (present energy efficiency classes C and B)
  - Step 2: from 01.01.2014: phase out of models with EEI ≥ 42 (present energy efficiency class A)
  - Step 3: from 01.01.2019: phase out of models with EEI ≥ 30 (present energy efficiency class A+)

under this scenario by beginning 2020 only models belonging to the present A++ class will be on the market; this scenario will complement and be run in parallel with the “ambitious scenario” previously described for labelling;

- realistic scenario:
  - Step 1: from 01.01.2009: phase out of models with EEI ≥ 55 (~ present energy efficiency classes C and B)
  - Step 2: from 01.01.2014: phase out of models with EEI ≥ 44 (~ present energy efficiency class A).

A further step:

- Step 3: from 01.01.2019: phase out of models with EEI ≥ 35 (~ present energy efficiency class A+)

can be hypothesised under this scenario, but it should be enforced provided a new eco-design study is developed to evaluate on one side its economical feasibility and on the other side the real need of such step in the light of the achieved market transformation under the new round of EU policy measures. This scenario will complement and be run in parallel with the "realistic scenario" previously described for labelling;

- very ambitious static scenario: under the labelling very ambitious static scenario, after the phase out of models with EEI ≥ 55 no additional requirements will be necessary, the very demanding labelling scheme will entirely drive the market.

c) Absorption refrigerators

The major positive effect of the absorption is the lack of noise and vibrations, but the electric energy consumption of the models is higher than a traditional compressor refrigerator of the same volume.

Appliances to be excluded from the specific requirements are:

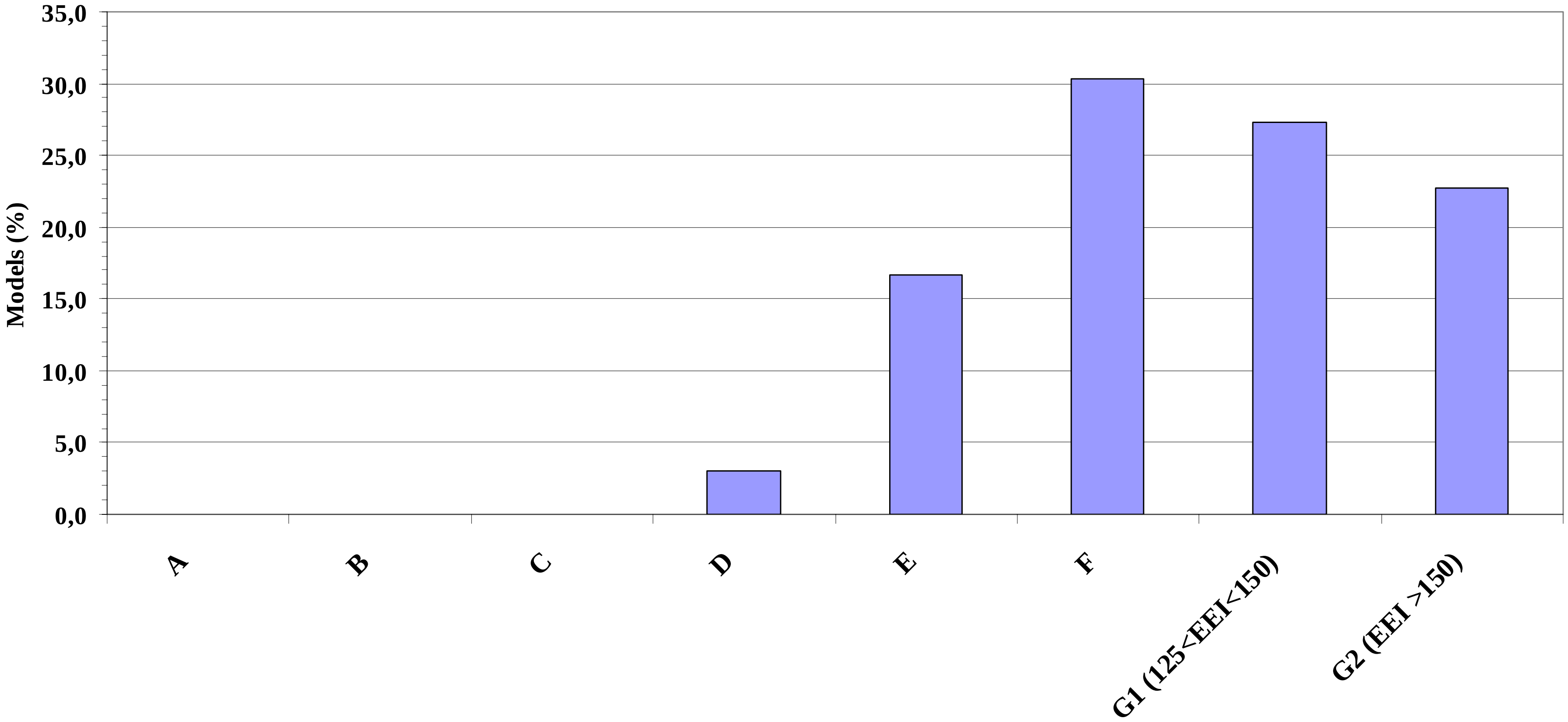
- vaccine refrigerators (for their specific use see Task 1), RV appliances (for vans, boats, etc), appliances which can be powered by batteries (only if RV appliances) or by energy sources different from electricity (gas/kerosene) alone or as alternative to electricity (models to be used where electricity is lacking or the supply is discontinue);
- wine storage cabinets, since there is the need to avoid vibration that can disturb the wine maturation process. If deleted from the market consumer without a traditional cellar home will not be able to have their own wine properly aged (with a consequent lack of a service). Exempted appliances shall be classified as wine storage cabinets and not be advertised or sold for a different purpose;
- electric powered household or similar appliances belonging to Categories from 4 to 7 and freezers. Although the energy consumption can be very high, the number of models is very low; the pulling effect of the labelling scheme is considered sufficient to improve the overall efficiency (if technologically feasible).

Proposed specific energy efficiency criteria are:

- Step 1: from 01.01.2009: phase out of models with EEI ≥ 150 (present the very inefficient models in the lowest part of class G)
- Step 2: from 01.01.2014: phase out of models with EEI ≥ 125 (phase out of present energy efficiency class G).
- Step 3: from 01.01.2019: phase out of models with EEI ≥ 110 (phase out of present energy efficiency class F). The technical and economic feasibility of this step to be evaluated in a new study.

In Figure 7.55 the results of a brief (and not fully representative) internet survey over the absorption models in the EU is presented; 66 models belonging to Categories 1 to 3 were collected were collected, plus 16 models of dual fuel (gas/electric or kerosene/electric) operated appliances, and 4 models of electric operated appliances belonging to Categories 4-6. Only the refrigerator models are presented in the Figure. G class has been split in G1 (125 ≤ EEI <150) and G2 (EEI ≥ 150) to highlight the effect of the proposed efficiency requirements. The (very few) highest energy efficiency models belong today to class D, but the vast majority of the models are in classes F and G, with some models having EEI values down to about 250.

Figure 7.55: Disaggregation of the absorption refrigerator models in modified Energy Efficiency classes (classification according directive 2003/66/EC)



7.6.1.6 The dynamic approach in labelling and specific energy efficiency requirements

A dynamic approach, means a labelling classes rescaling or introduction of a new highest class/classes after some time, for example when the present highest class includes more that ~20% of the models (or of the sales) or after a certain number of years.

To be more effective, the threshold lines or values for the new classes should be known in advance, to allow on one side manufacturers to take them into consideration in the appliance redesign cycle and a better planning of the investments and on the other side policy makers to plan future policy measures or incentive schemes and to make more accurate energy savings forecasts.

A dynamic approach implies also some consideration about the structure of the labelling scheme and its evolution with time: is the A-G rescaling appropriate, and under which conditions?; or would it be preferable to define a new classification system with more than 7 classes and with new "names"?

The three labelling scenarios hypothesised in previous paragraphs:
- the very ambitious static scenario
- the ambitious scenario
- the realistic scenario

present substantial differences which make the dynamic approach differently applicable.

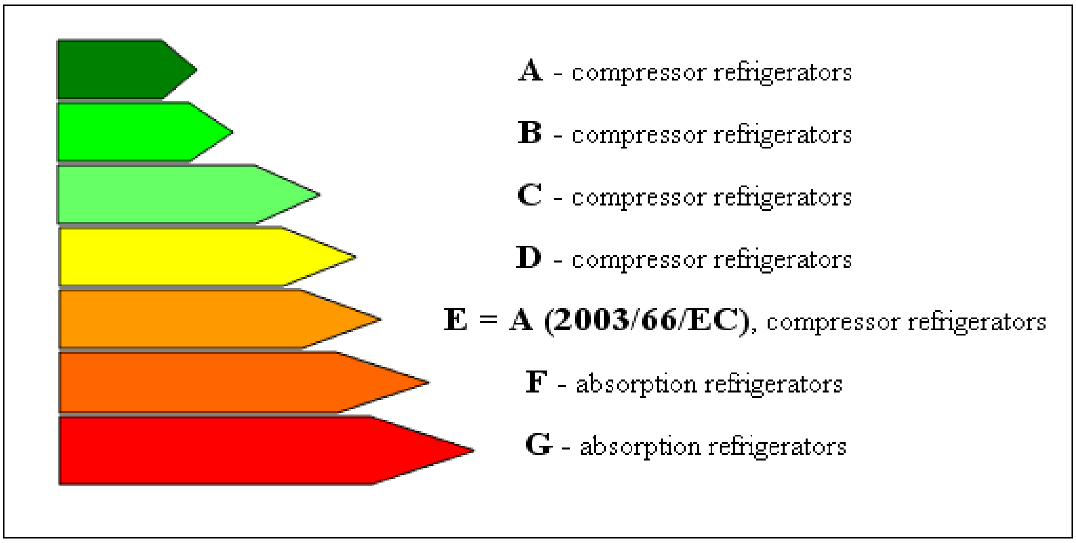
a) The very ambitious static scenario

Under this scenario (Table 7.45) there will be only one rescaling of the present labelling scheme (therefore the name 'static') to be enforced in 01.01.2009. A new A to G scale will be set, with the new class A with EEI <10 and the new class G with EEI ≥125. After the initial phase out of compressor refrigerators with EEI ≥ 55 (as per 01.01.2009 through a specific requirement setting) only models belonging to classes A to E will remain while classes F and G will take care of the absorption refrigerators after the initial phase out of models with EEI ≥150 through a specific requirement enforced at 01.01.2009 (Figure 7.56).

Table 7.45: Comparison of the EEIs of directive 2003/66/EC and Very Ambitious Static Scenario

Directive 2003/66/EC			Very ambitious static scenario		
EEI	improvement (units)	improvement (%)	EEI	improvement (units)	improvement (%)
			EEI < 10	--	--
			10 ≤ EEI < 20	10	50
EEI <30	--	--	20 ≤ EEI < 30	10	33
30 ≤ EEI < 42	12	29	30 ≤ EEI < 42	12	29
42 ≤ EEI < 55	13	24	42 ≤ EEI < 55	13	24
55 ≤ EEI < 75	20	27	55 ≤ EEI < 125	Phase out of compressor refrigerators	
75 ≤ EEI < 90	15	17	EEI ≥ 125	Phase out of absorption refrigerators at EEI ≥ 150	
90 ≤ EEI < 100	10	10			
100 ≤ EEI < 110	10	9			
110 ≤ EEI < 125	15	12			
EEI ≥125	--	--			

Figure 7.56: Energy efficiency classes for the revised labelling scheme under the 'Very Ambitious Static Scenario'



Under this scenario, the new class A is empty and will probably remain for a long time, since an EEI below 10 is almost theoretical and achievable only in the very long term (or even never) being far beyond the long term technological development foreseen for the BNATs. This will be the last labelling scheme for refrigerators. A part from the initial phase out of compressor refrigerators with EEI ≥55 and for absorption refrigerators with EEI ≥150, no other specific energy efficiency requirements are foreseen, since the pulling effect of such an ambitious labelling will drive the market. Absorption refrigerators will be definitively confined in class F since no models will ever achieve an EEI better than 55. Compressor refrigerator of present class A will be relabelled as E, present class A+ as new class D and present class A++ as new class C. Under this classification, compressor models in classes below new A and new B will either compete on price (which is positive for consumers, who will have a present A++ model at the price of a new C model) or be improved to reach a new and challenging EEI of at least 20 (new class B), which is again positive if only the consumers are considered.
On the contrary the effect for European manufacturers could be very strong or even dramatic: in the competition for price they will be very likely overcome by suppliers of imported products (from countries with a very low labour cost), therefore the only way to survive will be to work for technological development to reach the highest energy efficiency, which requires substantial R&D investments.
Under this scenario a very strong and long-lasting commitment of the European and national Authorities is critical and essential to assure sufficient R&D funding, incentive programmes and any other measure to support the technological effort of the European manufacturing industry.

b) The realistic scenario

Under this scenario a more realistic modulation of the EEI improvement is expected (Table 7.46) with almost even pace and technological effort between the classes. After the phase out of the absorption refrigerators with EEI ≥150 and of the compressor refrigerators with EEI ≥55 (as per 01.01.2009 through a specific requirement setting), 12 (or even 13) energy efficiency classes will be possible, from F (EEI ≥125) to A5 (EEI <18) or even A6 (EEI <15). With such a large number of classes different (re-)scaling systems may be hypothesised and applied.

The most important element of this scenario is that all the new energy efficiency classes (their name and EEI thresholds) will be set at the beginning of the revised scheme, thus eliminating the never-ending discussion on how a new labelling scheme needs to be revised.

Table 7.46: Comparison of the EEIs of directive 2003/66/EC and Realistic Scenario

Directive 2003/66/EC			Realistic scenario		
EEI	improvement (units)	improvement (%)	EEI	improvement (units)	improvement (%)
			EEI < 15	--	--
			EEI <18	3	17
			18 ≤ EEI < 22	4	18
			22 ≤ EEI < 28	6	21
EEI <30	--	--	28 ≤ EEI < 35	7	20
30 ≤ EEI < 42	12	29	35 ≤ EEI < 44	9	20
42 ≤ EEI < 55	13	24	44 ≤ EEI < 55	11	20
55 ≤ EEI < 75	20	27	55 ≤ EEI < 75	20 Phase out of compressor refrigerators	27
75 ≤ EEI < 90	15	17	75 ≤ EEI < 90	15	17
90 ≤ EEI < 100	10	10	90 ≤ EEI < 100	10	10
100 ≤ EEI < 110	10	9	100 ≤ EEI < 110	10	9
110 ≤ EEI < 125	15	12	110 ≤ EEI < 125	15	12
EEI ≥125	--	--	125 ≤ EEI < 150	15	17
			EEI ≥150	Phase out of absorption refrigerators	

The second innovative element of this scenario is that the rating system is turned upside down, with the higher energy efficiency classes still on top but named with an increasing number or a letter/number combination. This will make the EU labelling system more attuned with the other worldwide categorical labelling schemes using an increasing number of stars, such as the Australia/New Zealand system (see Figure 7.1).

The name of the new classes, either with a combination of letter and numbers (from class G to class A5 or A6) or only with numbers (from class 1 to class 12 or 13) will remain constant and the coloured arrows will either be set at the beginning (Pattern 1) or will move across the scheme with the dynamic phase-in of new classes at the top (and the phase out of classes at the bottom) as described in Patterns 2 and 3a & 3b.

Given these basic elements, some different implementing patterns are possible:

Pattern 1: the advantage of Pattern 1 (Figure 7.57) is that the energy efficiency classes are set at the beginning of the labelling exercise and the market will then be transformed by the combined pulling effect of the set high efficiency classes and the phase-out of the less efficient ones (through the energy efficiency specific requirements). This pattern will require a redesign of the label as it is presently known, but the essential elements (such as the A-G classes structure and the coloured red-to-green arrows) are retained; also the consumer awareness built in more that 10 years of national and European campaigns will not be lost. The blue colours chosen for classes beyond A together with the increasing number (from A to A5 or A6) represent the improvement above class A. The pattern will allow national policies to be implemented in more ‘virtuous’ countries because all the energy efficiency thresholds will be disclosed since the new directive enforcement, thus multiplying the pulling effect of the labelling. Under this hypothesis, absorption refrigerators will be confined in lower classes, from G to D, while compressor refrigerators will be included in the upper classes, from A to A5 (or A6), thus excluding any overlapping or confusion among technologies (class B will remain empty at least in the medium-long term). As phase out is implemented (through specific energy efficiency requirements) some classes will become empty, but the overall scheme will remain unchanged over the years.

Figure 7.57: Energy efficiency classes for the revised labelling scheme under the 'Realistic Scenario', Patterns 1 and 2

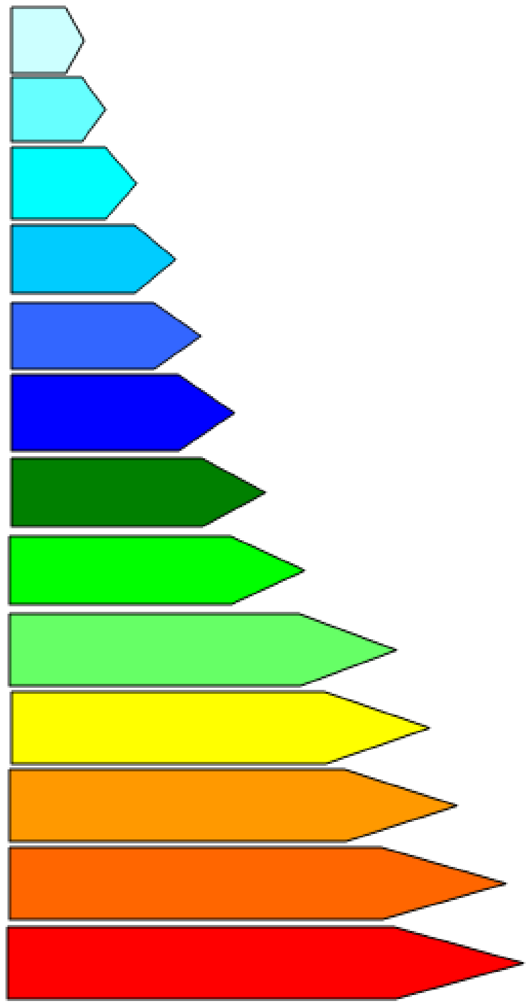
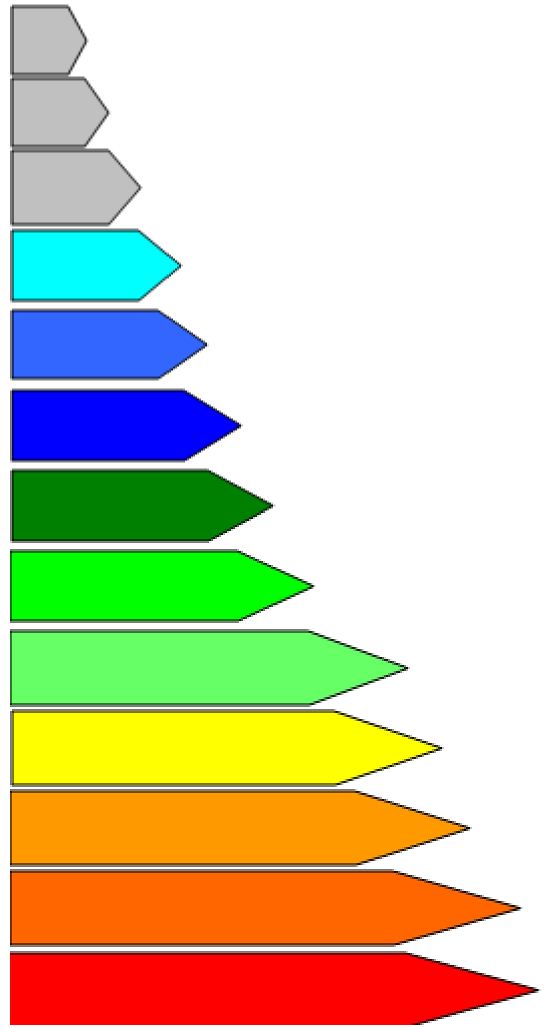
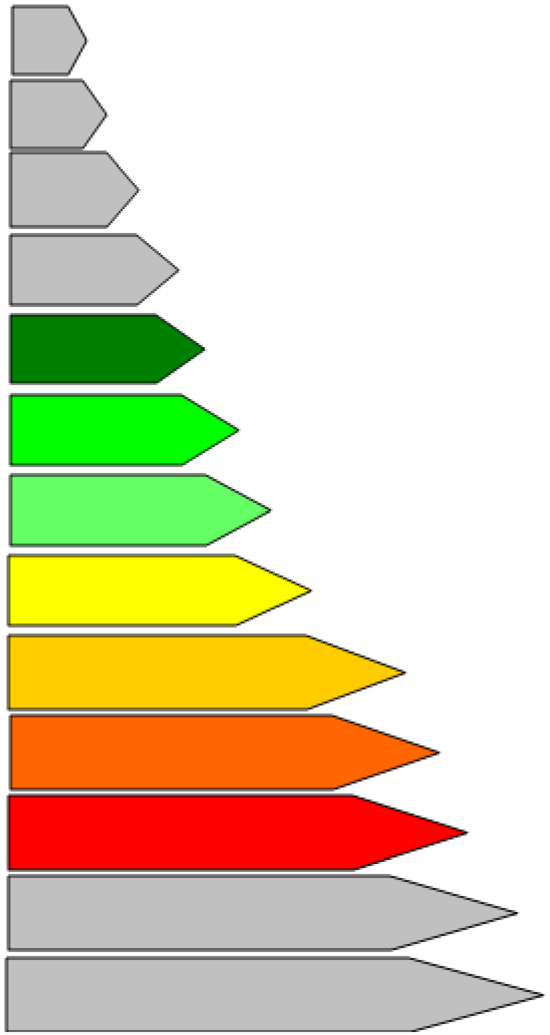
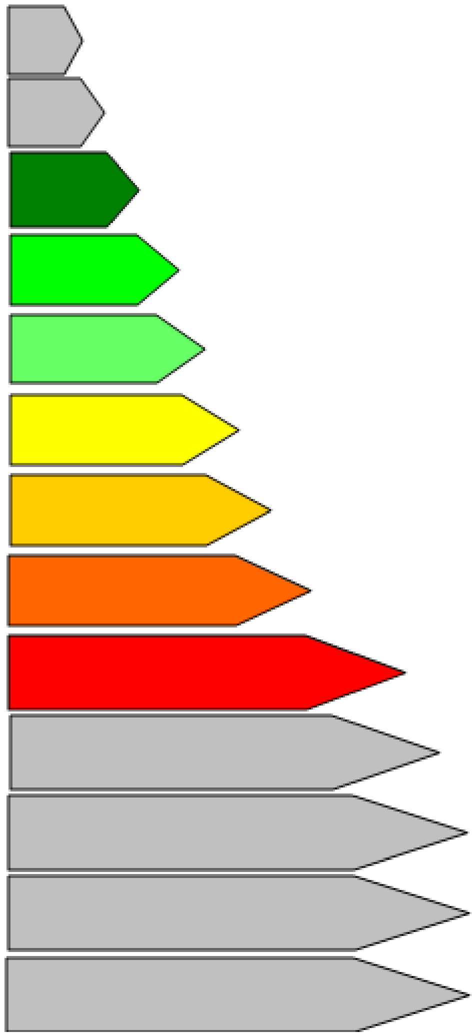
Class name	EEI	Class name	Pattern 1: all classes implemented at the beginning of the new labelling scheme	Pattern 2: dynamic approach with 10 initially set classes, the other coming after some time
(A6	EEI < 15	13)		
A5	EEI < 18	12		
A4	18 ≤ EEI < 22	11		
A3	22 ≤ EEI < 28	10		
A2	28 ≤ EEI < 35	9		
A1	35 ≤ EEI < 44	8		
A	44 ≤ EEI < 55	7		
B	55 ≤ EEI < 75	6		
C	75 ≤ EEI < 90	5		
D	90 ≤ EEI < 100	4		
E	100 ≤ EEI < 110	3		
F	110 ≤ EEI < 125	2		
G	EEI ≥ 125	1		

Figure 7.58: Energy efficiency classes for the revised labelling scheme under the 'Realistic Scenario', Pattern 3

Class name	EEI	Class name	Pattern 3a: dynamic with 7 moving classes, at the beginning	Pattern 3b: the same as before, after some years
(A6	EEI < 15	13)		
A5	EEI < 18	12		
A4	18 ≤ EEI < 22	11		
A3	22 ≤ EEI < 28	10		
A2	28 ≤ EEI < 35	9		
A1	35 ≤ EEI < 44	8		
A	44 ≤ EEI < 55	7		
B	55 ≤ EEI < 75	6		
C	75 ≤ EEI < 90	5		
D	90 ≤ EEI < 100	4		
E	100 ≤ EEI < 110	3		
F	110 ≤ EEI < 125	2		
G	EEI ≥ 125	1		

- **Pattern 2**: this Pattern (Figure 7.58) is a modification of the previous one in which the dynamic approach is more clearly envisaged. All the 12 or 13 classes will be set in terms of expected EEI thresholds at the beginning of the new scheme, but only a certain number will be implemented at the enforcement date and then a new class will be added only when the actual highest has reached a certain amount of models or sales (for example ~20%) or when the front-runner manufacturers will put on the market innovative more efficient models. The advantage is that stakeholders will know since the beginning the new efficiency classes thresholds, only the implementing date will be 'tuned' according to the production (manufacturers) and market (consumers) answer to policy measures.
  Before the scheme is implemented also the criteria for phasing-in a new class should be defined. Different approaches are possible: (i) a sales weighted EU market share, or (ii) a sales weighted market share in the majority of the Member States, or (iii) a sales weighted market share in at least one Member State, or (iv) the percentage of the models at EU level, etc. Each system presents pros and cons that should be evaluated before the final decision is taken, to avoid penalising more energy efficient or less energy efficient markets.
  The classes colour will go from the old red (the very inefficient class G) to a lighter blue above class A passing through the green colour for the class A. This pattern will allow national energy efficiency policies to be implemented in more 'virtuous' countries even if the corresponding (higher) class in still not implemented at EU level, because its energy efficiency threshold is known and will be applied within a certain time period. In addition, less efficient (and less rich) markets will not be penalised by the introduction of higher efficiency classes, since the less efficient ones will remain in force. But this might somehow decrease the efficiency improvement speed in these countries although contemporarily protect local consumers from a parallel import of second-hand cheap and inefficient products or from the extension of the installed units lifetime.
  Under this hypothesis, absorption refrigerators will be confined in lower classes, from G to D, while compressor refrigerators will be included in the upper classes, from A to A5 (or A6), thus excluding any overlapping or confusion among technologies (class B will remain empty at least in the medium term). As phase out is implemented (through specific energy efficiency requirements) some classes will become empty, but the overall scheme will remain unchanged over the years.
- **Pattern 3a/3b**: this Pattern is more similar to the present labelling scheme, although embedding all the innovations of previous patterns. Again all the 12 or 13 classes will be set in terms of expected EEI threshold at the beginning of the new scheme, but a new class will be implemented only when the actual highest has reached a certain amount of sales (for example ~20% of the sales or of the models) or when the front-runner manufacturers will put on the market innovative more efficient models; contemporarily an inefficient class will be phased-out. Only the known 7 classes will be enforced at any time.
  This pattern needs an optimum synchronisation with both the market transformation (for the phase-in of the new classes) and the enforcing of the specific energy efficiency requirements phasing-out the older classes, which might be difficult to achieve especially for the phase out of the absorption refrigerators at the bottom of the scale.
  The classes' colour will go from the old red (the very inefficient class G) to the green (for the highest efficiency) as in the present scheme. Some additional "reddish" colour might be also hypothesised for the less efficient classes if no phase out is considered possible.
  This pattern will allow national energy efficiency policies to be implemented in more 'virtuous' countries even if the corresponding (higher) class in still not implemented at EU level, because its energy efficiency threshold is known, but less efficient (and rich) markets might be penalised by the phasing-out of less efficient models, which will no more be in force The lack of less efficient models might somehow increase the efficiency improvement speed in these countries although at a high economic impact on consumers and the risk of a parallel market of cheap and

inefficient second-hand product might be created. Nevertheless since the name and the thresholds of the phased-out classes will be retained, a system of derogation for countries or for specific technologies (such as the absorption appliances) can be hypothesised.

c) The ambitious scenario

For the ambitious scenario the same three-pattern approach can be applied, as presented in Figures 7.59 and 7.60. Also the elements discussed for the three Patterns are still valid. The most critical aspect of this scenario, is the creation of the last class (class A6 or 13) which is even far beyond the long term technological development foreseen for the BNATs.
The overall effect of this scenario is a more rapid improvement of the energy efficiency but, more than the economical sustainability, its technical feasibility is questionable.

7.6.1.7 Generic requirements

a) Fast freezing button in freezers and freezer compartments

For freezers and freezer compartment of refrigerator-freezers: when fast freezing button is present, a reversion to normal operation after 24 or 48h shall be assured. Probably a period of 48h would be better, to allow a complete food freezing in case the consumer tend to overload the appliance/compartment above its declared freezing capacity (indicated in the instruction booklet).

b) External temperature sensor for refrigerator-freezers with 1 compressor and 1 thermostat

Refrigerator-freezers with 1 thermostat 1 compressor to be used in unheated spaces below 10-15°C shall have an external temperature sensor connected to the 'heating device' to revert it when not needed. This requirement will apply only for SN class models, since model belonging to other Climate Classes are not suitable (shall not be used) in non heated climates.
A hard switch (to be operated by the consumer only to turn all system 'on' in winter or when ambient temperature is too low) or an automatic system (driven by the external temperature and by definition always 'active') can be used.

c) The use of drawers in appliance testing

The current standard allows domestic cold appliances to be tested with or without the drawers inserted, and models are often tested without drawers in place. 'Static' appliances may perform better with drawers in place but the volume of the freezer is larger without the drawers. This larger volume affects the EEI and possibly the resulting energy efficiency class under the energy labelling scheme. Some appliances are even tested with an 'optimised combination' of drawers in and out.

To avoid this loop-hole, any appliance shall be tested as sold to the consumer, with a clear indication that the specific drawers combination gives the better energy performance and should possibly not be modified. When energy label values have been declared from tests without drawers and then the appliance is sold with drawers, it could be argued that miss-selling has taken place.

d) Wine storage cabinets

Wine storage cabinets, defined as *specifically designed exclusively for the storage and/or long term maturation of wine* shall be advertised and sold only for the storage and maturation of wine. This

Figure 7.59: Energy efficiency classes for the revised labelling scheme under the 'Ambitious Scenario', Patterns 1 and 2

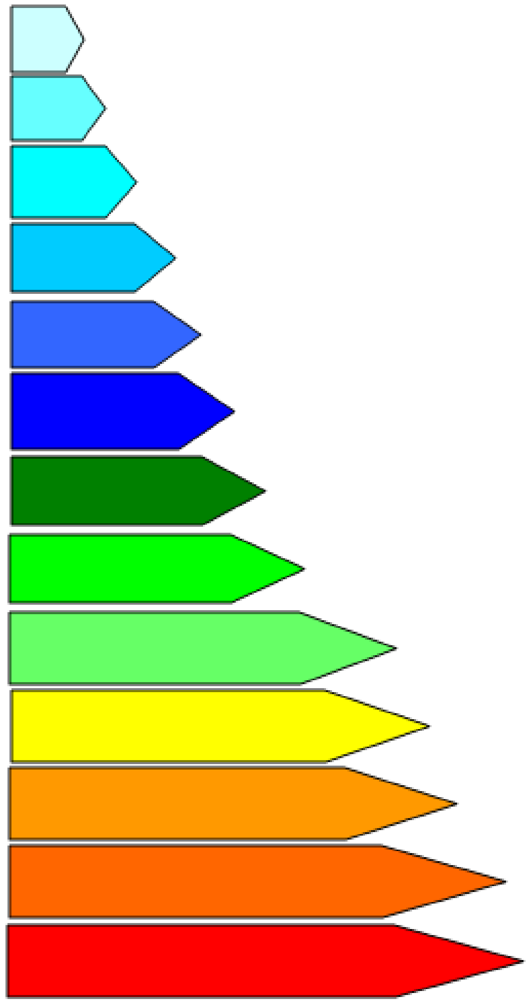
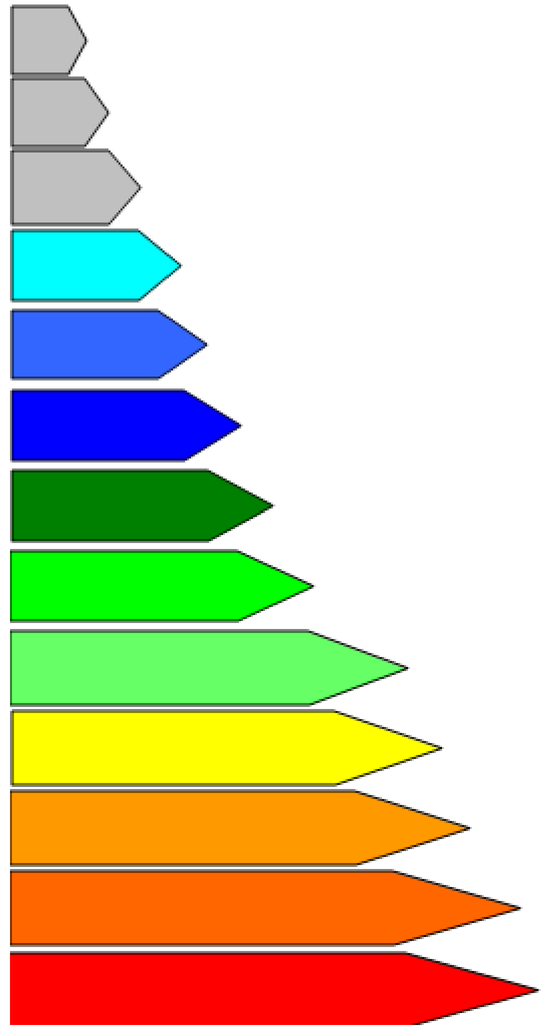
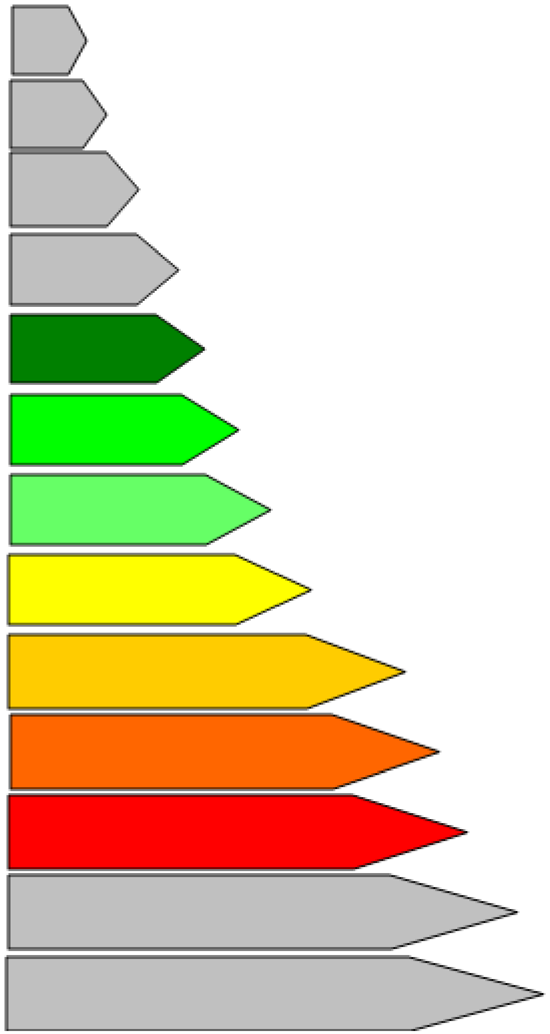
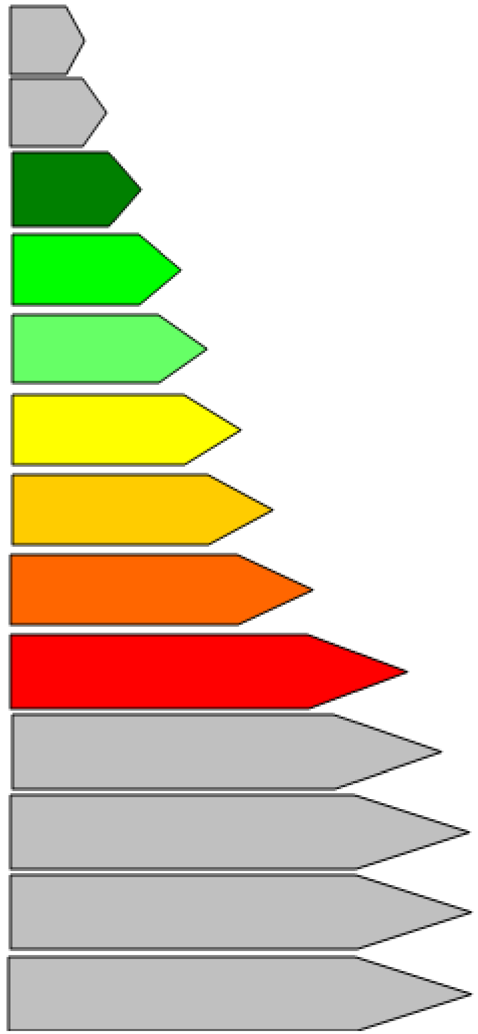
Class name	EEI	Class name	Pattern 1: all classes implemented at the beginning of the new labelling scheme	Pattern 2: dynamic approach with 10 initially set classes, the other coming after some time
(A6	EEI < 10	13)		
A5	EEI < 15	12		
A4	15 ≤ EEI < 20	11		
A3	20 ≤ EEI < 25	10		
A2	25 ≤ EEI < 30	9		
A1	30 ≤ EEI < 42	8		
A	42 ≤ EEI < 55	7		
B	55 ≤ EEI < 75	6		
C	75 ≤ EEI < 90	5		
D	90 ≤ EEI < 100	4		
E	100 ≤ EEI < 110	3		
F	110 ≤ EEI < 125	2		
G	EEI ≥ 125	1		

Figure 7.60: Energy efficiency classes for the revised labelling scheme under the 'Ambitious Scenario', Pattern 3

Class name	EEI	Class name	Pattern 3a: dynamic with 7 moving classes, at the beginning	Pattern 3b: the same as before, after some years
(A6	EEI < 10	13)		
A5	EEI < 15	12		
A4	15 ≤ EEI < 20	11		
A3	20 ≤ EEI < 25	10		
A2	25 ≤ EEI < 30	9		
A1	30 ≤ EEI < 42	8		
A	42 ≤ EEI < 55	7		
B	55 ≤ EEI < 75	6		
C	75 ≤ EEI < 90	5		
D	90 ≤ EEI < 100	4		
E	100 ≤ EEI < 110	3		
F	110 ≤ EEI < 125	2		
G	EEI ≥ 125	1		

information should be also included in the booklet of instruction, explaining that the model is not intended for wine cooling and/or other food storage and refrigeration.

e) AC/DC powered appliances

To be excluded from the specific requirements, appliances that can be powered by 230V and 12V - both compressor and absorption type - shall be advertised and sold as RV products.

7.6.1.8 Compliance assessment and verification procedures

a) The possible sources of appliance non compliance

According to a recently pamphlet by Alan Maier, Senior Executive Editor, and published by the US Home Energy Magazine Online[53], several unrelated matters related to compliance with energy efficiency regulations. These incidents illustrate that compliance - or failure to comply - with a regulation is not always objective. Indeed, one could say that there is a spectrum of "compliance." An insidious, new form of non-compliance has recently emerged. Thanks to microprocessor controls, some appliances now recognize when they are being tested and switch into a low-energy mode. According to Consumer Reports, this appears to be the case with a new refrigerator from a large Asian manufacturer, which inexplicably switches-off some operations when the ambient temperature approaches the testing temperature and when doors haven't been opened for a while. These measures cut enough electricity use to qualify the unit for Energy Star endorsement and sales-enhancing utility rebate programs. But it is not alone; other refrigerator manufacturers became so adept at circumventing the test that actual electricity use of refrigerators in a country was typically twice as high as the labels claimed; the government changed the test procedure to make it harder to circumvent. Many appliance manufacturers (and importers) might poised to adopt the same approach. The competent Authorities should be on the alert.
A more subtle form of non-compliance occurs when manufacturers misrepresent the capacity of their products and efficiency, which is described in terms of energy use per unit of capacity, might thus overstated.
Finally, there are cases where the energy-saving claims are partly true for example, under certain conditions. The motor controllers did save electricity when motors were oversized or the voltage delivered was unnecessarily high. Here the problem is agreeing on appropriate test conditions. Reasonable people may disagree on these conditions, so compliance is less clear-cut.

These stories show that compliance is not a simple yes-no decision. It begins with clear regulations. But it must be followed by vigilance, intelligence, and, occasionally, Solomon-like decisions.

b) The verification limits and verification tolerance

In a recently published MTP document[54], it is stated that when tested, an individual cold appliance sample is permitted by the standard to be 15% worse on energy consumption, while the eco-labelling directive, which adopts the same EN 153 standard as the energy labelling directive in fact does not permit any 15% tolerance.

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[53] Source: Alan Meier, http://www.homeenergy.org/blog.php?id=18&blog_title=January/February_2007_Editorial-Compliance:_Following_the_Letter_(and_the_Spirit)_of_the_Law. The document has been adapted to better 'comply' with the spirit of this EuP study by omitting manufacturers and Countries names.
[54] Source: BNC07: Domestic cold appliance EC Energy Label revision, Version 1.5, 05 October 2007, downloadable from http://www.mtprog.org .

This is the most common misunderstanding that has originated the never ending discussion about a (too large) permitted tolerance in the EU legislation. In fact, a general confusion has always been made between the compliance of the declared values of a model with the regulation(s) criteria (in general threshold values or lines) and the compliance assessment in the verification procedure.

A clarification is needed. The EU legislation about household appliances (both energy labelling schemes and efficiency requirements, where existing) **does not permit any declaration tolerance; i.e. all units of a same model shall comply with the set criteria**. An example of 'declaration tolerance' can be found for example in the Australian standard for cold appliances, which specifies an allowable tolerance of 3% on the measurement of the volume (note that the precise rule depends on the compartment volume).

The EU legislation is more stringent than for example the mentioned Australian regulations, since for cold appliance minimum requirements the latter requires, at 90% confidence, that the mean (of all the units of a same model) does not exceed the requirements level and mean energy.

A different issue is the **verification tolerance** or **verification limit**, that is the maximum permitted variation between the supplier's declared value and the measured value resulting from a test developed in a Laboratory under a verification procedure. This 'verification tolerance or verification limit' should not be interpreted as an allowed tolerance on the original declaration used to support the compliance with a regulation. More in detail:

- a '**verification limit**' (usually larger than a verification tolerance) includes allowances for elements such as production variability, measurement accuracy and uncertainties;
- a '**verification tolerance**' is intended to take care only of the known margin of error or uncertainty in the measurement procedure for a particular test method (no production variability is considered).

Only when Government certified/accredited laboratories are used for the compliance assessment both the verification limit and the verification tolerance can be kept at a real minimum (2-3% for the latter, but higher in the specific case of the energy consumption of cold appliances) because the laboratory error is known and under control.

Following the above definitions, in the EU legislation a verification limit (which includes production variability) of 15% is assumed on a single sample and a 10% on a sample of 3 units of the same model.

The application of verification limits or verification tolerance means that the models a consumer buys is not necessarily as the declared one, but at a lower extent when a lower verification tolerance is used. The solution proposed by the before mentioned MTP document that, the laboratories' own measurement tolerance aside, a 'zero tolerance' (in our discussion a zero production variability) Energy Label is possible, but the claimed benefit for consumers as the Energy Label scheme that a B-energy consuming appliances would be B-declared is unfortunately unattainable, since there will be always "border line" appliances that will comply with a different (worse) energy efficiency class when tested.

The benefit of adopting a lower verification tolerance is that the difference of between the declared and the measured energy consumption will be at maximum as great as the verification tolerance. But on the other side a lower verification tolerance can be applied only under the condition that the margin of error or uncertainty in the measurement procedure (the reproducibility of the measurement method including the laboratory error) for the testing Laboratories is kept under strict control. This is possible only under if a system of certified/accredited Laboratories is put in place.

As far as the claim that the EU eco-label does not permit any 15% tolerance, again a major misunderstanding occurred. The eco-label Decisions related to household appliances describe only the procedure for the declaration of the measured values: the reports of at least three measurements of energy consumption made according to EN 153 and the test guidelines as detailed in CECED's Operational Code shall be presented; the arithmetic mean of these measurements shall be less or equal to the energy efficiency ecolabel requirement; the value declared on the energy label shall not be lower than this mean value, and the energy efficiency class indicated on the energy label shall correspond to this mean value. In simpler words this means that 3 units of a same models are tested, and the average of the three measured values is declared on the energy label, while at present the energy labelling schemes foreseen that only one unit of a model is tested.

The before mentioned MTP document stated also that “when challenged by the Trading Standards Office, manufacturers will sometime declare a fault on the appliance ‘that one is not functioning as designed’ or state that model is no longer available”. Although a fault of a model may always happen, the misuse of this loop-hole can be avoided by imposing (as already in force in Australia) that the onus is on the manufacturer/importer to provide evidence that a defect capable of affecting the test results does exist; furthermore, it must be demonstrated that the "defect" is peculiar to the test unit alone and not common to other samples of the stock of the appliance. But this has nothing to share with the setting of a larger/stricter verification limits or verification tolerance.

c) The verification error sources

Very little information is generally available on the different factors that impact on the verification process. In addition, the way of explaining the differences in test results may also somehow differ.

According to the latest Australian experience[55], typically, differences in the test results represent the outcome of several different types of factors that can be classified into two general categories: (i) random errors, and (ii) systematic errors:

- **Random Errors**: random errors are the kinds of errors that are caused by natural variations in materials, human factors, fluctuations in power input etc. Such errors may cause measurements of appliance energy consumption or performance to deviate from the true or “design” level. A key feature of random errors is that they are just as likely to be positive as they are to be negative and over many measurements they average out to be zero. The main sources of random error in the verification process are:
  - Production Variability: all production processes are subject to random fluctuations as a result of manufacturing tolerances, variations in input materials, power fluctuations, human factors etc. These variations in the production process may cause different units of the same model to have slightly different average energy consumption or performance levels. This random error describes the differences in the average energy consumption and/or performance values of different units of the same model due to production variability;
  - Performance Variability: in addition, the same individual unit may perform differently on different occasions under test; e.g. a pressure switch may terminate fill volume to a different amount each time, even under identical test conditions. Performance variability is often related to the quality of components used in an appliance but it can also be a reflection of the complexity of the process being tested and of the test assessment (e.g. hand soiling of dishes and the subsequent visual assessment of washing performance of a dishwasher). This type of

[55] Source: NAEEEC, Statistical Basis for the Determination of Check testing Validity Criteria, Report prepared by: Professor R. Bartels, University of Sydney, L. Harrington, Energy Efficient Strategies, original Report: January 1999, updated and corrected: February 2004, downloadable from http://www.energyrating.gov.au .

error affects a test's repeatability.
  - Random Measurement Error: if the performance of a single unit is tested twice, in the same laboratory, and using exactly the same equipment and the same staff, then, in addition to the performance variability, there will be some variability in the test results due to random variations in testing equipment, measurement procedure, human factors, etc. This type of error also affects a test's repeatability.

It is difficult to separate out the error due to performance variability from the random measurement error. Hence the joint impact of these two errors (out of the three identified random errors) is referred to as the '***test repeatability error***'. In conclusion it can be affirmed that the random error is given by the sum of 'production variability' and 'test repeatability error'.

- **Systematic Errors (measurement errors)**: systematic errors are not completely random. These errors may have some pattern in them: for example, a bias in a series of measurements leading to an overstatement (or understatement) of the true measure. Such errors can be caused by differences in measuring equipment, calibration errors, differences in procedures between laboratories etc. For the verification process purposes, the sources of systematic error can be classified into two categories:
  - Calibration Errors: equipment which is not properly calibrated can lead to systematic errors in the measurement of energy consumption or performance levels. Calibration errors cannot be detected in the verification testing procedure since they are confounded with laboratory-specific factors, such as types of metering equipment, different operating procedures etc. For the verification procedure purposes it can be assumed that calibration errors are adequately addressed by a laboratory Accreditation Procedure. For electrical energy consumption, the calibration error is usually less than 2% (typically 1% or better). However, for products such as washing machines, much of the energy is embodied in hot water drawn into the machine, which means that calibration errors in water temperature measurement and water volume will also contribute to energy errors. For other products such as refrigerators and air conditioners, calibration errors in air temperature measurement can have a large effect on the measurement of energy consumption and performance actually delivered;
  - Inter-Laboratory Variability: performance measurements taken in one laboratory can differ systematically from those taken in another laboratory due to differences in equipment, operating procedures and staff. An estimate of the size of the errors introduced due to inter-laboratory variability can be obtained through a program of Round Robin Tests in which two or more laboratories all carry out tests on the same unit. Estimates of inter-laboratory variability, if established through round robin tests, will include any calibration errors present.

A summary of the different errors occurring during a verification procedure according to the Australian experience is shown in Figure 7.61.

Only limited information is available on the relative sizes of the errors introduced in the verification measurements due to production variability or test repeatability. More data are available on the combined variability caused by production variability and test repeatability. Table 7.47 summarises some of the available information in relation to the energy consumption of a number of products in the energy labelling program in Australia and New Zealand. These data have been derived from energy labelling applications where 3 different units of the same model are tested in the same laboratory.

A somehow different description on how to express uncertainty in standardisation is presented in Annex A.

Figure 7.61: Possible errors affecting the verification procedure of energy consumption and performance values

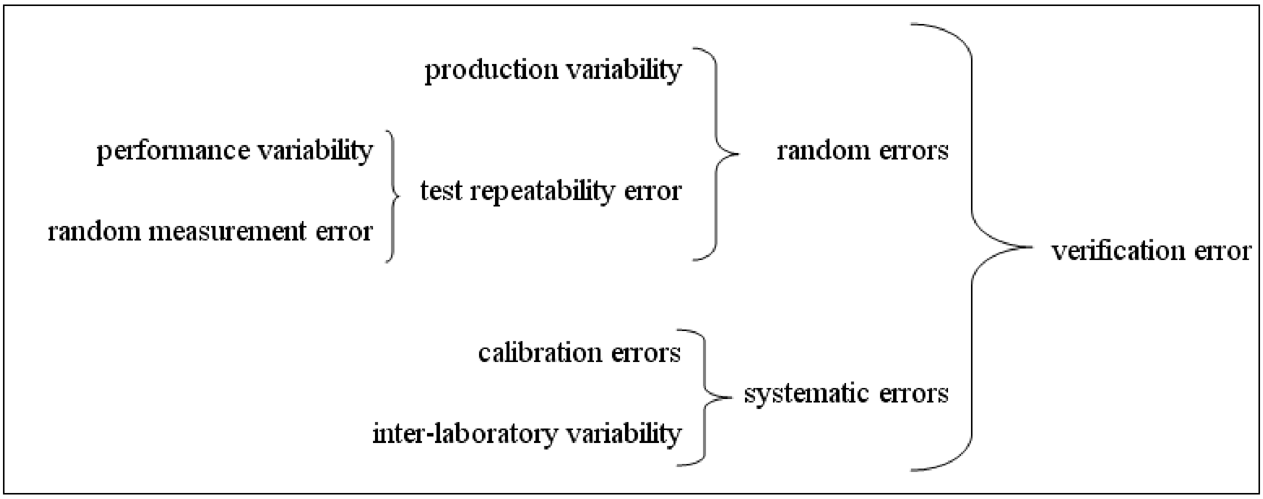

Table 7.47: Variability in the measurement of the energy consumption for selected household appliances in Australia

Product	*Average Standard Deviation*[1]	*Maximum Difference from Average*[2]	*Number of Models*
Refrigerator	25 kWh (3.2%)	125 kWh (18%)	1006
Air conditioning (cooling EER)	0.028 (1.0%)	0.25 (9.2%)	2188
Air conditioning (heating COP)	0.033 (1.1%)	0.39 (12.8%)	1469
Clothes Washer (warm wash)	18.9 kWh (4.5%)	102 kWh (23%)	490
Clothes Washer (cold wash)	3.4 kWh (2.9%)	41 kWh (24%)	232
Clothes Dryer	6.1 kWh (1.5%)	40 kWh (6.9%)	114
Dishwasher (cold connect)	8.7 kWh (2.1%)	51 kWh (9.1%)	369

Notes:
1. sample standard deviation of 3 units is used to calculate this value. The standard deviations are also measured as a percentage of the sample mean. This is also known as the 'coefficient of variation'. Measuring standard deviations as percentages allows to make comparisons across different models and different appliance types. The numbers shown are the average of these absolute and relative sample standard deviations across the different models for which 3 measurements were available for 3 different units of the same model.
2. The maximum difference is calculated as the absolute difference between the most extreme unit in the sample of 3 from the mean of the 3. In most of these cases (which are generally very unrepresentative) it appears that 3 very different units were tested (or in some cases 1 unit was very different from the other 2). Specific investigations would be required to ascertain why such large variations were produced in these isolated cases. The minimum difference between all 3 units was zero for all products.

d) A possible verification procedure for cold appliances

In Table 7.48 the measurement errors identified in the previous paragraph are listed according to their source. Taking into consideration the pragmatic Australian experience, although the test methods followed in the country are sometimes non comparable with the European standards, the measurement variability can be divided into three components:

- variability due to the production, which is in charge of the manufacturers and can be controlled and possibly reduced adopting better manufacturing processes, quality control systems, etc;
- variability of the test method, which can not be modified once the standard in defined, but that might be reduced through the improvement of the test method by the standardisation bodies;
- variability due to the testing Laboratories errors, which can be controlled and kept to the minimum in qualified laboratories.

Table 7.48: Verification errors and relevant sources

error source error type	MANUFACTURERS	TEST METHOD	TESTING LABORATORIES
production variability	**X**		
performance variability		**X**	
random measurement error		**X**	
calibration error			**X**
inter-laboratory variability			**X**

The 15% tolerance allowed in the EU verification procedure for the energy consumption can be therefore broadly divided into three 5% components: 5% due to the manufacturing process, 5% due to the test method and finally another 5% due to the Laboratory errors.

Manufacturers have the full control of the first 5% only, but not on the other two, which represent the reproducibility of the measurement method and the variability of the testing laboratories.

The quality of the production process, which in turn is reflected in a more stable – or less variable – performance characteristics (including the energy consumption) of the produced units of the same model, should be considered part of the overall appliance ‘performance’ and should be taken into consideration when setting policy measures. While the measurement method reproducibility and Laboratory error should be included in the verification tolerance.

Taking into consideration the discussed allocation of verification errors, a double approach is proposed, according to whether the verification involves a qualified or in a non-qualified testing Laboratory: As example of this new approach, for the energy consumption it is proposed that:

- when the verification in done **in a non-qualified laboratory**: the value measured on one randomly selected wash appliance shall not be greater than the rated value by more than 10%. If the result of the test carried out on the first refrigerating appliance is greater than the rated value plus 10% the test shall be carried out on a further three randomly selected refrigerating appliances. The arithmetic mean of the three refrigerating appliances shall be equal to or less than the rated value plus 10%
- when the verification in done **in a qualified laboratory**: the tolerance value can be different (lower) than the value for non-qualified laboratories provided that technical evidence is given on the laboratory ability to reduce such value.

The verification tolerance values for the other measured parameters should be modified following the same approach.

This approach (i) internalises in any case the appliances production variability in the measured energy/water consumption and (ii) sets a different value for the verification tolerance depending if the appliances are tested in qualified or non-qualified laboratories.

No different specific verification scheme is deemed necessary for the verification of the specific requirements compared to the labelling scheme declarations.
It is recommended that the verification tolerances are verified and if necessary modified according to the results of specific Round Robin Test(s) that the Commission should promote and fund either within the existing EU programmes or through the delivering of mandates to the relevant standardisation bodies.

In addition, a system of qualified laboratories should be put in place by the Commission, taking into account the experience achieved at European and other countries level, such as the Australian one. It is also suggested that a further mandate is given to the standardisation bodies to define the criteria and the procedure for the laboratories qualification since this is a critical issue to assure that the lowest possible verification tolerance is pursued.

For the selection criteria for the verification of appliance models two approaches are possible:

- the ‘random type selection’: a certain number of appliances are randomly selected from the market and tested. The resulting failure rate gives the almost exact picture of the investigated market, but the resources to be used are maximised;
- the ‘maximum failure selection’: the selection criteria are set as to maximise the failure rate (i.e. the non complying models). The outcome is not representative of the market situation, but the use of the available resources is optimised.

e) The 2001 Round Robin Test for cold appliances

The only Round Robin Test at EU level for cold appliances was developed in 1999-2001 in the framework of the SAVE programme. TNO was the project leader. Figures 7.62-7.64 present the results of the measurements in percentage difference from the TNO value. The blue lines in the Figures represent σ, 2σ and 3σ values of the overall RRT result for each product group.

The Figures highlights a spread of the values measured in the participating laboratories, which was alos the main conclusion of the ring test participants: a number of causes of differences between different test lab procedures and differences of interpretation of the standard EN153:1995 and relevant ISO standards were at that time identified. A proposal came to minimise differences by clarifying specific test conditions in a common set of guidelines. Test methods guidelines were detailed in CECED's Operational Code published in 2000, which are mentioned also in Commission Decision 2004/669/EC establishing revised the eco-label criteria for refrigerators. The declared purpose of this code[56] is “to arrive at a commonly accepted practice for cold appliance testing between manufacturers organised in CECED. Furthermore, the operational code is offered as the CECED standpoint to the SAVE “Ringtest group”. Finally the operational code is used as input to the discussions within the relevant ISO committee for the revision of the present standards”. Some of the proposed modifications/clarifications are now included in the new standard EN ISO 15502:2005 (see before).

7.6.1.9 Main effects of the proposed policy measures on cold appliances in 2005

The effect of the combined effect of proposed new energy labelling and specific requirements is presented in Table 7.49 for the ‘realistic scenario’ applied to the 2005 CECED technical database. Only the first step of the specific efficiency requirements is considered. The first step of specific requirements could phase-out 22% (or about 3 500) of the models, of which about 19% of refrigerators and about 32% of freezers, where in particular chest freezers will face the phase out of more than 45% of the models and contemporarily will present about 3% of the model in new class A3.

In Table 7.50 the same is presented but under the hypothesis that the 5% reduction in verification tolerance will lead to a 5% net increase in the appliance energy consumption compared to the data declared in the 2005 database. This is more a theoretical worse-case scenario that the reality. But

[56] CECED, “Operational Code for Appliance Testing for refrigerators and freezers”, final version, 6 December 2000,

Figure 7.62: 2001 RRT– comparison of the difference (%) of the Laboratories results form the TNO measurement with the σ value for refrigerators

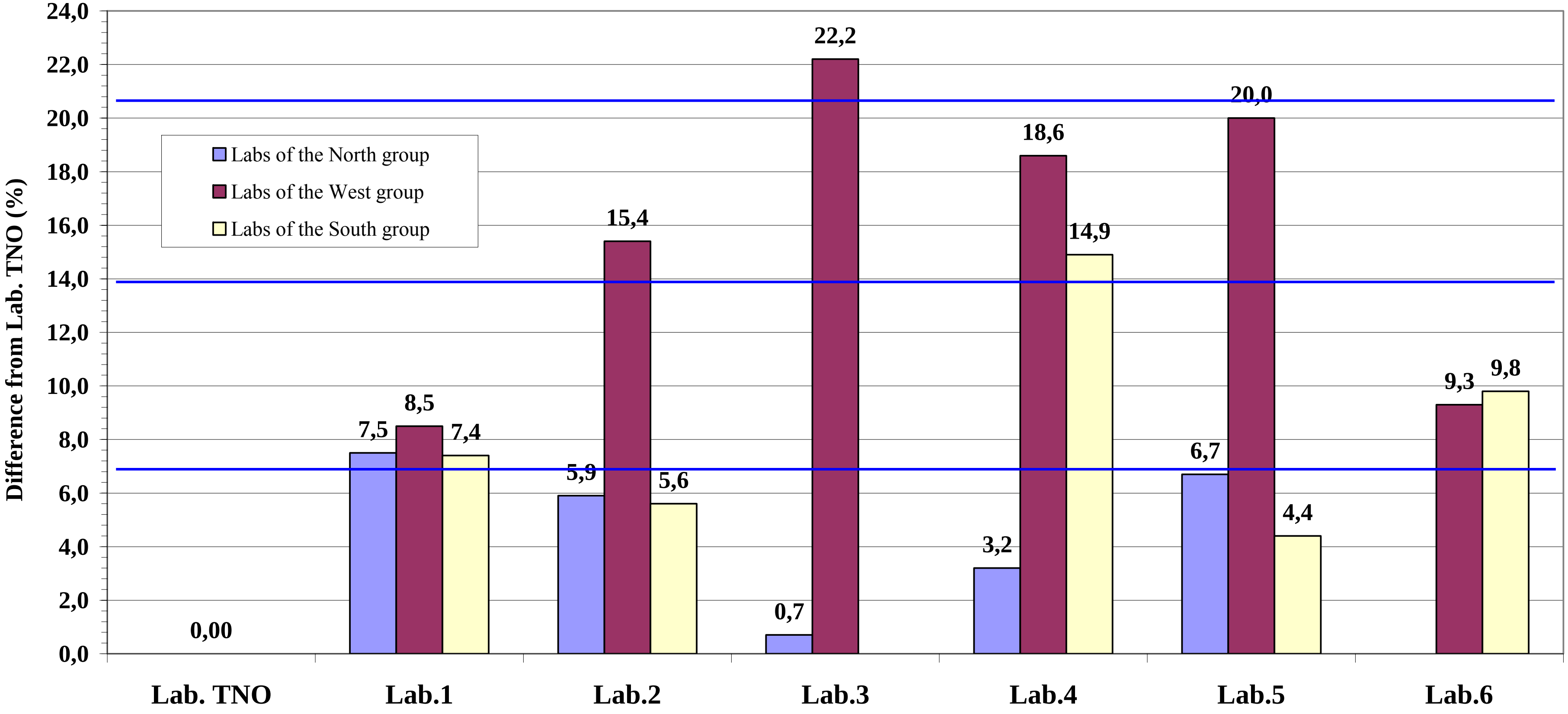

Figure 7.63: 2001 RRT– comparison of the difference (%) of the Laboratories results form the TNO measurement with the σ value for refrigerator-freezers

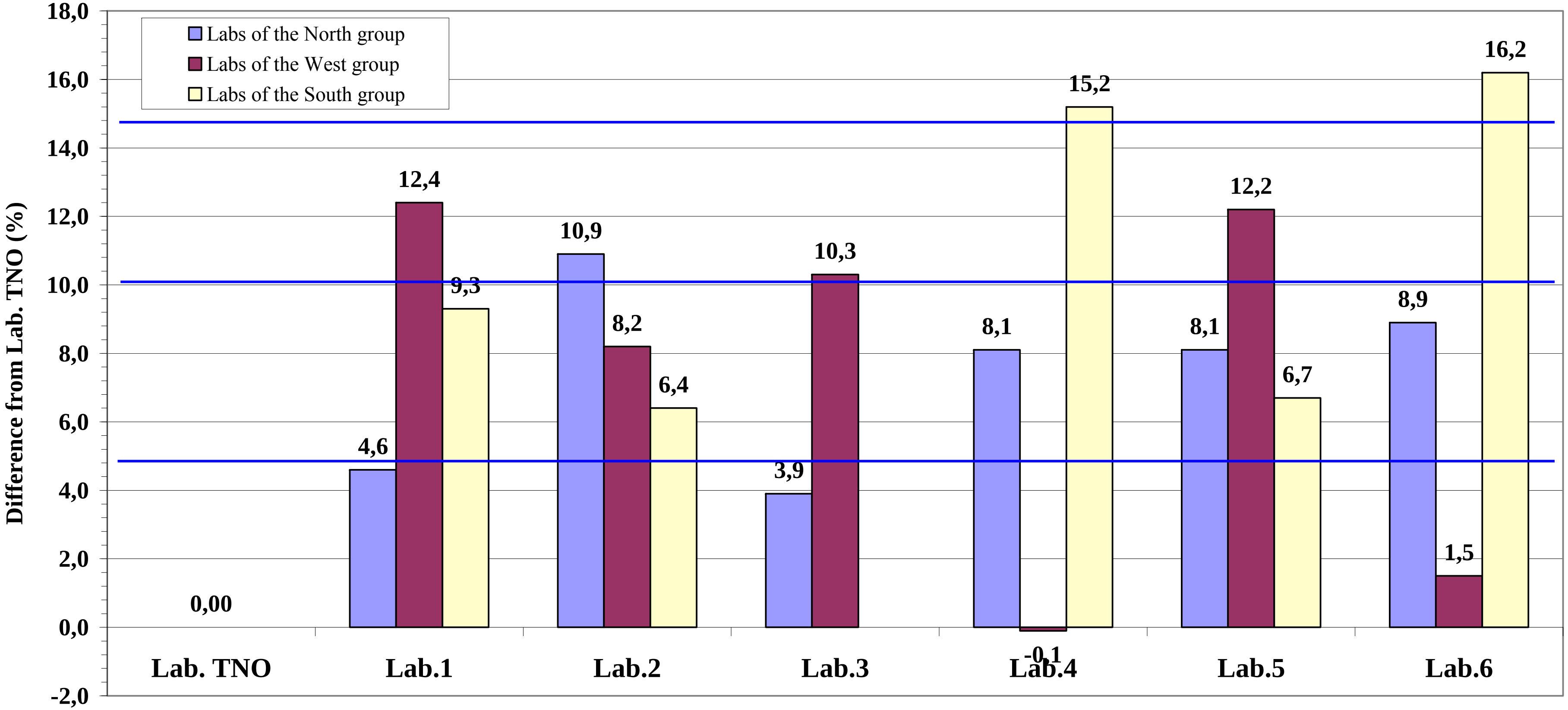

Figure 7.64: 2001 RRT– comparison of the difference (%) of the Laboratories results form the TNO measurement with the σ value for freezers

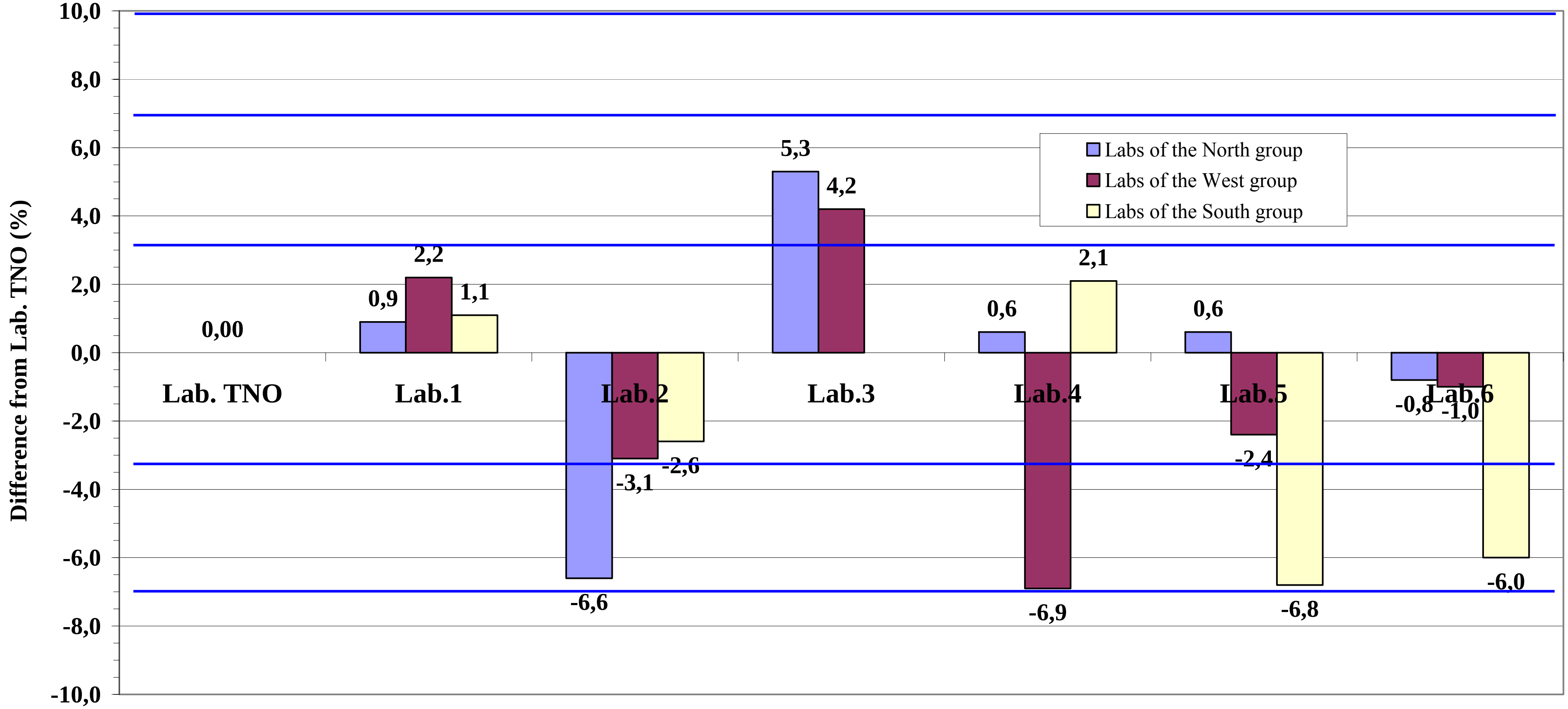

Table 7.49: Effects of combined policy measures (new labelling scheme and Step 1 of specific requirements) on cold appliance in 2005

Realistic scenario		Cold appliances		Refrigerators		Freezers		Cat. 1-6		Cat.7&10		Cat.8		Cat.9	
ENERGY LABELLING SCHEME															
EEI	Classes	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
(15)	(A6)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	A5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	A4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	A3	30	0,19	5	0,04	25	0,75	0	0	5	0,05	0	0	25	2,8
35	A2	323	2,1	142	1,15	181	5,45	33	1,29	109	1,1	139	5,69	42	4,8
44	A1	3.185	20,4	2.360	19,2	825	24,8	535	20,9	1.825	18,7	522	21,4	303	34,5
55	A	8.660	55,4	7.445	60,4	1.215	36,6	1.467	57,4	5.978	61,2	1.107	45,4	108	12,3
75	B	3.290	21,0	2.287	18,6	1.003	30,2	498	19,5	1.789	18,3	602	24,7	401	45,6
>75	C	151	1,0	80	0,6	71	2,1	22	0,9	58	0,6	71	2,9	0	0
Total		15.639	100	12.319	100	3.320	100	2.555	100	9.764	100	2.441	100	879	100
SPECIFIC REQUIREMENTS															
Step 1 (2009)		3.441	22,0	2.367	19,2	1.074	32,3	520	20,4	1.847	18,9	673	27,6	401	45,6

Table 7.50: Effects of combined policy measures (new labelling scheme and Step 1 of specific requirements) on cold appliance in 2005 (with a 5% reduced verification tolerance)

Realistic scenario		Cold appliances		Refrigerators		Freezers		Cat. 1-6		Cat.7&10		Cat.8		Cat.9	
ENERGY LABELLING SCHEME															
EEI	Classes	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
(15)	(A6)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	A5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	A4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	A3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	A2	302	1,93	143	1,16	159	4,79	33	1,3	110	1,1	93	3,8	66	7,5
44	A1	2.738	17,5	1.985	16,1	753	22,7	510	20,0	1.475	15,1	489	20,0	264	30,0
55	A	5.447	34,8	4.226	34,3	1.221	36,8	473	18,5	3.753	38,4	1.146	46,9	75	8,5
75	B	6.210	39,7	5.170	42,0	1.040	31,3	1.247	48,8	3.923	40,2	623	25,5	417	47,4
>75	C	942	6,0	795	6,5	147	4,4	292	11,4	503	5,2	90	3,7	57	6,5
Total		15.639	100	12.319	100	3.320	100	2.555	100	9.764	100	2.441	100	879	100
SPECIFIC REQUIREMENTS															
Step 1 (2009)		7.152	45,7	5.965	48,4	1.187	35,8	1.539	60,2	4.426	45,3	713	29,2	474	53,9

under this hypothesis the number of phased-out models will increase to 45,7% or more than 7 000.

The outcome of the two Tables can be considered as the minimum and maximum boundaries of the actual effect of the realistic scenario application.

Finally it should be highlighted that with the introduction of a new and more global standard, which is under discussion and planning at IEC level, it is expected that in about 5 years new test conditions and performance characteristics will be requested for cold appliances. The new measurement method will probably have a deep influence on the appliances classification, storage temperatures, and other aspect which might deeply affect the models energy efficiency. This will also have a profound impact on the new EuP implementing measures, requirements and labelling system.

7.6.2 The Effect of Other Measures

The effect of other measures: early replacement, subsidies and incentives to manufacturers, studied or run in EU and non-European countries are briefly summarised to evaluate the possible benefits for a EU-wide application within the eco-design framework.

7.6.2.1 Early replacement

It has been proved that replacement of old appliances with new efficient ones would represent a good answer to the efforts of the EU towards reducing CO_2 emissions. Therefore, CECED invites authorities to set up policies encouraging earlier and better replacement of our appliances, to promote the penetration of existing energy efficiency appliances.

Today's products have very low running costs compared to old generation ones, and consumers could make significant saving by replacing a ten year old appliance with a state-of-the-art one. Yet, despite this and despite our efforts as an industry to promote this message, the transformation is not taking place, and consumers are not accelerating the replacement of the old products. Some 188 million obsolete and energy inefficient appliances are still used in European households. 22 millions tonnes of CO_2 emissions could be avoided by replacing them with new efficient products. Therefore, there is need that governments push for the early replacement of inefficient appliances and educate consumer to buy only most efficient ones. Initiatives in this direction can provide more significant results than chasing the residual energy efficiency improvement.

In 2005 the German Öko-Institut[57] analysed the environmental and economic impact of the accelerated replacement of domestic appliances. The goal of the study, commissioned by CECED, was to compare the impact of the substitution of installed appliances of different age with the purchase (and use) of new models on the market in 2005, considering both environmental and economic aspects from the point of view of the involved German households. For each product category six alternatives were compared: the use of installed appliances from 1980, 1985, 1990, 1995 and 2000 without substitution and the purchase of a new model of 2005 belonging to the energy efficiency class A+ (with a sensitivity analysis considering the replacement with a new A class or A++ class appliance).

[57] I. Rüdenauer, C. Gensch, "Environmental and economic evaluation of the accelerated replacement of domestic appliances, Case study refrigerators and freezers". Commissioned by European Committee of Manufacturers of Domestic Equipment (CECED), Öko-Institut e.V., Freiburg, June 30, 2005.

The following results were achieved:

- LCA and LCC for a new model of the four product categories
- the environmental impacts and the connected costs according to the manufacturing year of appliances:
  - in the use phase (specific electricity demand)
  - through recycling since the presence of different refrigerants and foaming agents according to the manufacturing year might result in different environmental impacts
- calculation on annual basis from 2005 to 2025 for the following six alternatives:
  - for the four cold appliance categories,
  - for the four environmental indicators and the costs and
  - for the three replacement actions (A+ over base case, A and A++ as sensitivity analyses).

The lifetime of the appliances was 14 years for refrigerators and 2-door refrigerator-freezers and 17 years for upright and chest freezers. For the evaluation of the accelerated replacement, the environmental impacts and costs are calculated on an annual basis for the years from 2005 to 2025 or 21 years.

Cross-comparing the results between the refrigerators, refrigerator-freezers and upright freezers, the environmental payback time is quite similar: mostly <1 year or between 1 and 3 years; only when replacing the newest installed appliances with an A class model the payback time raises up to 6 years. In the case of chest freezers the payback is longer than for the other three appliance categories: between <1 year and about 15 years.

The payback time for the costs is longer than for the environmental impact. However due to the variability of the purchase prices and the uncertainty of the dependency of the energy consumption costs on the energy efficiency class, the results are more uncertain than in the case of the environmental impacts.

The payback time for the primary energy demand (CED) is between <1 and 5 years for all appliance categories, all appliances in stock to be replaced and all energy efficiency classes of the new appliances. The exception is the replacement of a chest freezer manufactured in 2000 with a new chest freezer with an energy efficiency class ‘A’: the payback period is about 9 years)

The payback time for the GWP has a similar magnitude than for the total environmental burden (that is, depending on the category and installed appliance age, between some 2 and 12 years) and is longer than for CED. When replacing refrigerators, refrigerator-freezers and upright freezers with models belonging to A++ class, the payback time is less than 5 years for all considered old appliances. In the case of the chest freezers, the payback time is longer than 5 years and in the case of replacing a quite new installed model even more than 20 years.

The results for the ODP are not meaningful since they only represent the very high impacts through recycling – which occurs anyway at any time. The methodological issue of impact allocation has a strong impact on the results.

The main question if it is “worth” to further use an existing cold appliance or to substitute it and use a newer model cannot be answered absolutely. The answer depends on the individual evaluation of a time period which is acceptable for the environmental and economic payback period. When a 5 year period is considered, as in the German study, the substitution is justified in almost all cases.

7.6.2.2 Subsidies

Economic incentives in the form of rebate schemes or tax deduction have been enforced in The Netherlands[58,59]. From the beginning the energy label in the Netherlands had a strong relation with the following energy policy instruments: the MAP (Environmental Action Plan from 1991 to 2000) and the EPR (Energy Premium Regulation from 2000 to 2003). Only a MAP or EPR subsidy could be received when the appliance had an A class label. The EPR started in 2000 and aimed to stimulate households to take energy saving measures and to buy energy efficient appliances. Until October 2003, consumers could get an EPR subsidy for appliances with an energy efficiency class A. For some appliances additional conditions where set to receive the subsidy.

The introduction of the EPR has led to an enormous growth of the supply of A labelled appliances The market share of A class washing machines grew from 40 to 71% over the 1999-2000 period and 26% to 55% for refrigerators (see Task 1). This increase is most likely due to the EPR and has led to a situation where retailers very often advice their customers to buy an A class appliance as the best on offer.

More recently, the Italian experience of incentives to consumers (a tax deduction worth 20% of purchase, transport, disposal costs, up to 200 €) resulted in an ongoing success in 2007: sales of A+ and A++ models more than doubled on 2006 to reach 23% of the market at the end of July 2007. Sales are accelerating fast in the final months, positioning Italy as the most "virtuous" market in Europe[60].

A further example of subsidy scheme comes from, UK. In the UK the more efficient white goods products - cold appliances, washing machines and dishwashers - have been subsidised by power supply firms which are required to promote energy efficient products to consumers by the Energy Efficiency Commitment (EEC) as part of a range of activities to reduce energy consumption. The promotion of products has taken several forms, including subsidising products at point of sale to consumers and replacing old products in some low income homes. The scheme is administered by Ofgem[61], but is a Defra[62] initiative. The EEC scheme has run in two phases - 2002 to 2005 and 2005 to 2008. In 2008 it will be replaced by the Carbon Emissions Reduction Target, but it likely to continue to promote some white goods.

7.6.2.3 Tax incentives to manufacturers

Direct manufacturer subsidies to cover the incremental costs of producing more-efficient appliances have not been tried in Europe to date, but they are implemented in the USA (see Task 1).
Were it possible to introduce a similar tax subsidy in the EU, it could produce substantial positive improvements in the average efficiency of new appliances and far higher efficiency levels could reasonably be requested without any fear of serious negative impacts for industry or consumers. The existence of a mark-up factor between manufacturing cost and final price suggests it is more

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[58] Source: Maxim Luttmer, Evaluation of Labelling of Appliances in the Netherlands, Case Study executed within the framework of the AID-EE project, FINAL DRAFT, contract number EIE-2003-114, April 2006.
[59] Source: "Evaluation of the Netherlands energy efficiency subsidy scheme EPR", Tax Office/Centre for process- and product development, 21 June 2002. English summary by VHK, René Kemna, 8 October 2002. Original title "Rapportage van Onderzoeksbevindingen in Het Kader van de Evaluatie van de Energiepremieregeling, Belastingdienst/Centrum voor proces- en productont-wikkeling, 21 juni 2002
[60] Source:"2007-10-30_Large_Appliances_Manufacturers_in_Italy_ask_for_incentives_to_transform_the_market_in_2008.pdf, downloadable from: http://www.ceced.eu .
[61] For information see: http://www.ofgem.gov.uk/Sustainability/Environmnt/EnergyEff/Pages/EnergyEff.aspx .
[62] For information see: http://www.defra.gov.uk/environment/climatechange/uk/household/eec/index.htm

cost-effective to deliver subsidies directly to manufacturers (assemblers and component suppliers alike) than to deliver them in the form of rebates; however, there are some complications:

- the legality of direct tax credits has to be established as they contravene state aid regulations. Unfortunately the recent guidelines on state aid for the environment makes it clear that investments for products (as opposed to processes) that bring about energy and environmental benefits in their use, are still not included in state aid[63]. This rules out manufacturing tax credit for the time being;
- production of cold appliances in the EU occurs mainly in some countries and yet the products are consumed throughout the EU and beyond. Unless the main producer Member States were to offer unilateral subsidies for the production of higher-efficiency products, an agreement between net producer and net importer Member States may be needed regarding an equitable funding mechanism. The benefits of production tax grants, which may include price reductions or increased marketing go to all the consumer Member States; however, any increase in profits would come home to the producing companies in the producer Member States.

A recent study promoted by CECED addressed the issue[64]. This study showed how it was necessary to consider all of the three major players involved: producers, consumers and Member State governments in analyzing public incentive policy. The situation examined is that of a consumer who decides to purchase a class A++ combination refrigerator-freezer instead of a class A model as the result of the marketing campaign associated with production tax credits. In order to capture the substitution effects, a dual production facility (for both class A++ and class A production) is modelled using the E-GRIM method, utilized in several studies for CECED and the European Commission.

Compared to the business as usual base case, the production tax credit resulted in increased discounted cash flows for the manufacturer, zero or neutral cash flows for the government and positive discounted cash flows for the consumer. Surprisingly, for the government, even including the loss in electricity taxes due to energy savings, the cost of the tax credits were almost fully compensated by increased value added taxes and increased corporate income taxes, due the production shift to the more costly and profitable class A++ model. Thus, the production tax credit can result in essentially positive cash flows for all three major stakeholders.

A comparison was made with the traditional policy of rebate. Under assumptions quite favourable to rebates, it was found that government cash flows are significantly negative and consumer benefits disproportionately high, due to the fact that rebate schemes cannot identify and eliminate free riders, those who would have purchased in any case the higher efficiency model.

In general production tax credits are more cost effective for governments with respect to rebates and lower value added taxes. The production tax credits are based upon tax credits for *only those units produced above an established historic level of production and sales*, which is the level associated with those that would have purchased the improved model anyway. Thus it eliminates free riders, which is very important for promoting a product that already has an initial market share. Also if the government is not successful in the incentive policy it pays nothing. Instead in the rebate scheme, it pays everyone even though the historic sales may not have been reached.

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[63] Source: “State aid: guidelines on state aid for the environment– frequently asked questions”, Europe Press Releases, MEMO/08/31, 23/01/2008.

[64] Also see, “New Policy Instruments for Energy Efficient Home Appliances In Europe: Production Tax Credits”, 9th IAEE European Energy Conference: Energy Markets and Sustainability in a Larger Europe, June 12, 2007, Florence, Italy

The second reason tax grants can be more effective is that if the grant is used to lower prices at the production stage this has a greater impact on retail prices because of the high distributor/retailer mark-up, typical of the household goods sector. One hundred Euro less in terms of production prices implies two to three hundred Euro less at consumer prices.

The entire program of Energy Using Products is hindered if the EU financial policy can only address energy process improvement. Other major trading nations such as the United States do not suffer such limitations.

7.7 SUBTASK 7.7: EU POLICY SCENARIOS AND TARGETS

An attempt to model the policy measures (a mix of specific requirements and a revised energy labelling scheme) described in Subtask 7.6 is here developed, aimed at evaluating the overall energy impact at EU level[65]. To this end, the analysis of the possible market penetration trends of the energy efficiency classes in the Business as Usual (BaU) scenario developed in Subtask 7.3 is used as reference. The new energy efficiency classes hypothesised for the revised labelling scheme are evaluated and the resulting energy efficiency potential when compared to the BaU scenario are discussed.

7.7.1 Summary of the Policy Scenarios

In Subtask 7.6 a set of policy measures to ensure the penetration of the current best available and the future energy efficient technologies in the market have been hypothesized and discussed. Three different policy scenarios, encompassing a mix of a new labelling scheme and the enforcement of specific requirements, were outlined:

- Very Ambitious (VA) Static Scenario: a single rescaling of the present labelling scheme (therefore the name 'static') is suggested. A new A to G scale (to be enforced from 01.01.2009) is proposed in which the threshold of new class A will set to an EEI < 10 and that of the new class G to an EEI ≥ 125 (see Table 7.45).
- Realistic Scenario: under the second and dynamic scenario a more realistic modulation of the EEI improvement is expected (Table 7.46) with an almost even pace and technological effort between the efficiency classes. Two new classes have been added with respect the VA Static Scenario and the upper threshold has been reduced to EEI < 15 (instead of EEI <10);
- Ambitious Scenario: this dynamic scenario has the same number of classes of the Realistic Scenario but tighter thresholds and again an upper level having the same challenging limit of the VA static one with EEI <10.

It is worth noting that in the revised labelling scheme hypothesised under the Realistic and Ambitious Scenarios, the new energy efficiency classes could be named either through letters (from G to A6) or numbers (from 1 to 13). Just for sake of a better comparison with the current situation, energy efficiency classes will be indicated only with letters in the followings. This should not be interpreted as preference or commitment towards this specific option. The final layout of a possible revised labelling scheme will be defined by the Regulatory Committee managing the EU energy labelling scheme.

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[65] In this modelling exercise the absorption refrigerators are not taken into account.

In all Scenarios the current C, and B energy efficiency classes are phased out beginning 2009 while the current A class is phased out in 2014. In the Realistic Scenario models with an EEI ≥ 35 will be phased out in 2019 (after a new eco-design study is developed to evaluate its economical feasibility and need) while under the Ambitious Scenario models with an EEI ≥ 30 will be phased out in the same year. The most critical aspect of all the Scenarios is the creation of the upper efficiency class (class A, A6 or 13) which is far beyond the long term technological development foreseen for the BNATs.

Tables 7.51-7.53 and Figures 7.65-7.67 show the market share of the new energy efficiency classes for refrigerators. Tables 7.54-7.56 and Figures 7.68-7.60 show the same information for freezers. In the lower rows of each Table the Energy Efficiency Index and the average annual energy consumption for each class are given.

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A part from the phase out of the mentioned energy efficiency classes in the years 2009-2014 and even 2019 (under the Realistic and Ambitious Scenarios), the introduction in the market of appliances having EEI<20-22 is not foreseen before the years 2014-2019. It is also worth underlying that by the years 2019-2030 and in the Realistic and the Ambitious Scenarios, the energy efficiency classes with EEI<28-35 dominate the market with an overall penetration of about 70-80%. The VA Static Scenario is apparently more ambitious, envisaging the introduction of appliances with EEI around 20 from 2014, nonetheless, in the period 2014-2019 models belonging to class C (EEI < 30) and – at a lower extent - class D (EEI<42) are still dominant. This latter class is no more on the market after 2025.

Table 7.51: Energy efficiency class trend in the VA Static Scenario for refrigerators (percentage of models in each class are shown)

New labelling classes	A	B	C	D	E	F	G	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	1	18	61	19	1	100
2009	--	--	5	40	55	0	0	100
2014	--	1	24	75	0	0	0	100
2019	1	15	54	30	0	0	0	100
2025	5	30	55	10	0	0	0	100
2030	10	50	40	0	0	0	0	100
EEI	<10	<20	<30	<42	<55	<75	<90	--
Energy consumption (kWh/y)	55,3	110,7	166,0	232,4	291,6	397,7	477,2	--

Table 7.52: Energy efficiency class trend in the Realistic Scenario for refrigerators (percentage of models in each class are shown)

New labelling classes	A6	A5	A4	A3	A2	A1	A	B	C	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	--	--	1	18	61	19	1	100
2009	--	--	--	--	5	40	55	0	0	100
2014	--	--	--	1	24	75	0	0	0	100
2019		1	5	14	80	0	0	0	0	100
2025	1	4	10	20	65	0	0	0	0	100
2030	4	6	20	30	40	0	0	0	0	100
EEI	<15	<18	<22	<28	<35	<44	<55	<75	<90	--
Energy consumption (kWh/y)	83,0	99,6	121,8	155,0	193,7	243,5	291,6	397,7	477,2	--

Table 7.53: Energy efficiency class trend in the Ambitious Scenario for refrigerators (percentage of models in each class are shown)

New labelling classes	A6	A5	A4	A3	A2	A1	A	B	C	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	--	--	1	18	61	19	1	100
2009	--	--	--	--	5	40	55	0	0	100
2014	--	--	--	1	24	75	0	0	0	100
2019	--	1	5	14	80	0	0	0	0	100
2025	1	4%	10	20	65	0	0	0	0	100
2030	4	6	20	30	40	0	0	0	0	100
EEI	<10	<15	<20	<25	<30	<42	<55	<75	<90	--
Energy consumption (kWh/y)	55,3	83,0	110,7	138,4	166,0	232,4	291,6	397,7	477,2	--

Table 7.54: Energy efficiency class trends in the VA Static Scenario for freezers (percentage of models in each class are shown)

New labelling classes	A	B	C	D	E	F	G	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	5	25	33	25	12	100
2009	--	--	25	50	25	0	0	100
2014	--	1	52	47	0	0	0	100
2019	1	15	54	30	0	0	0	100
2025	5	30	55	10	0	0	0	100
2030	10	50	40	0	0	0	0	100
EEI	<10	<20	<30	<42	<55	<75	<90	--
Energy consumption (kWh/y)	55,4	110,7	166,1	232,5	251,5	342,9	411,5	--

Table 7.55: Energy efficiency class trends in the Realistic Scenario for freezers (percentage of models in each class are shown)

New labelling classes	A6	A5	A4	A3	A2	A1	A	B	C	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	--	--	5	25	33	25	12	100
2009	--	--	--	--	25	50	25	0	0	100
2014	--	--	--	1	52	47	0	0	0	100
2019	--	--	5	15	80	0	0	0	0	100
2025	1	4	10	20	65	0	0	0	0	100
2030	5	10	20	25	40	0	0	0	0	100
EEI	<15	<18	<22	<28	<35	<44	<55	<75	<90	--
Energy consumption (kWh/y)	83,0	99,6	121,8	155,0	193,7	243,6	251,5	342,9	411,5	--

Table 7.56: Energy efficiency class trends in the Ambitious Scenario for freezers (percentage of models in each class are shown)

New labelling classes	A6	A5	A4	A3	A2	A1	A	B	C	Tot.
Year	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2005	--	--	--	--	5	25	33	25	12	100
2009	--	--	--	--	25	50	25	0	0	100
2014	--	--	--	1	52	47	0	0	0	100
2019	--	--	5	15	80	0	0	0	0	100
2025	1	4	10	20	65	0	0	0	0	100
2030	5	10	20	25	40	0	0	0	0	100
EEI	<10	<15	<20	<25	<30	<42	<55	<75	<90	--
Energy consumption (kWh/y)	55,4	83,0	110,7	138,4	166,1	232,5	251,5	342,9	411,5	--

Figure 7.65: Energy efficiency class trend in the VA Static Scenario for refrigerators (percentage of models in each class are shown)

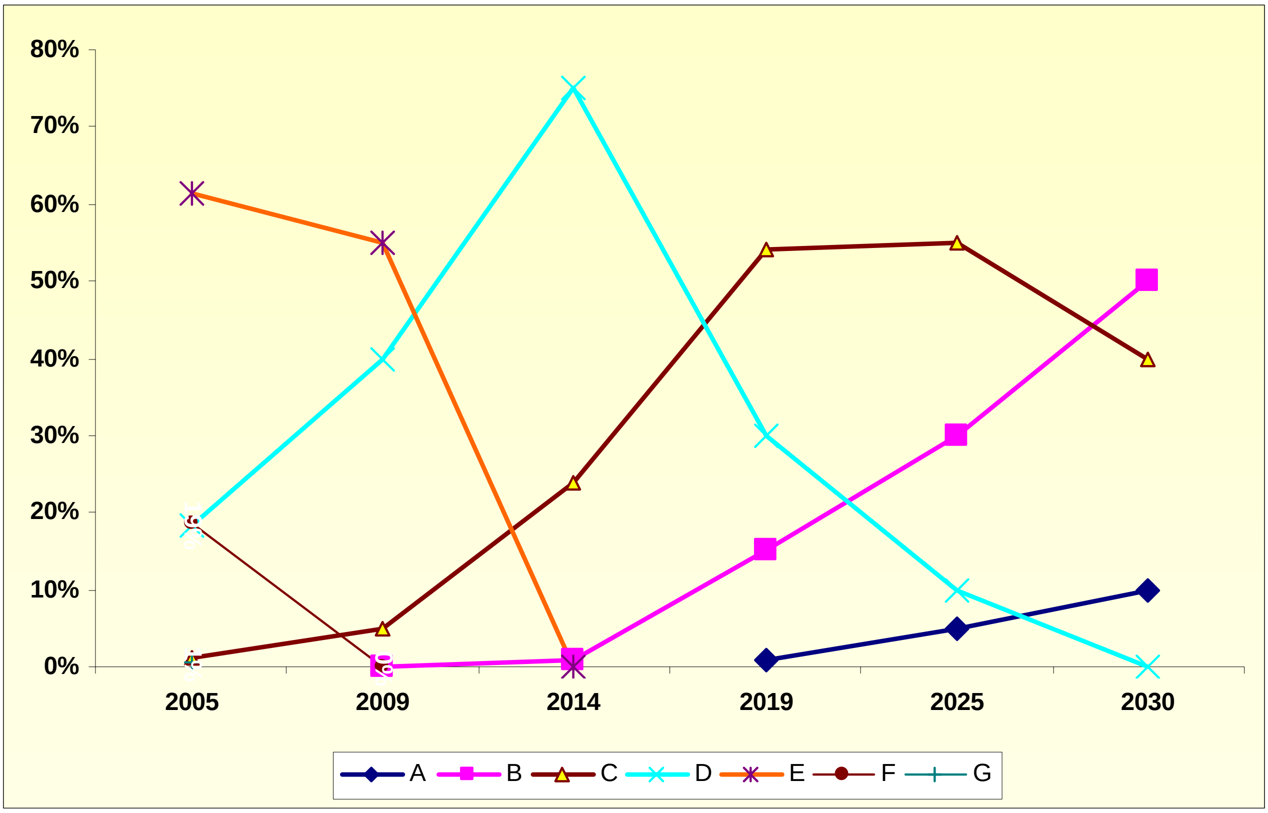


Figure 7.66: Energy efficiency class trend in the Realistic Scenario for refrigerators (percentage of models in each class are shown)

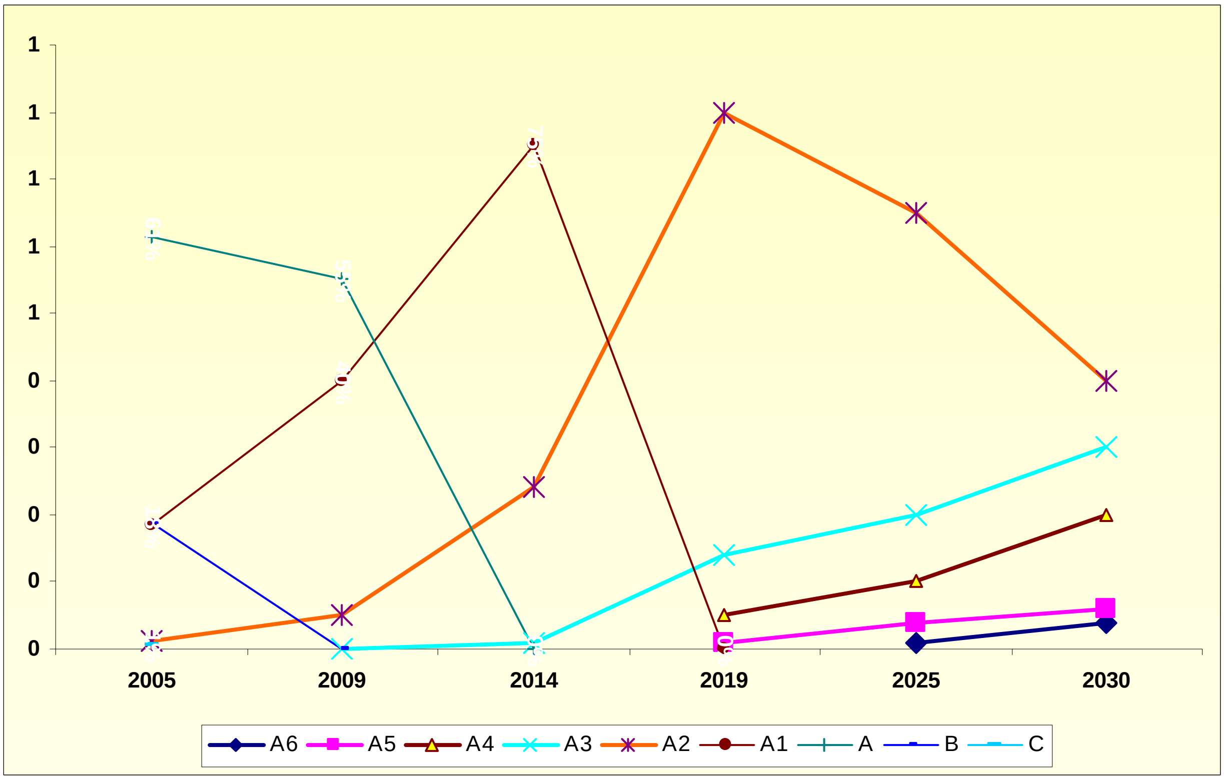


Figure 7.67: Energy efficiency class trend in the Ambitious Scenario for refrigerators (percentage of models in each class are shown)

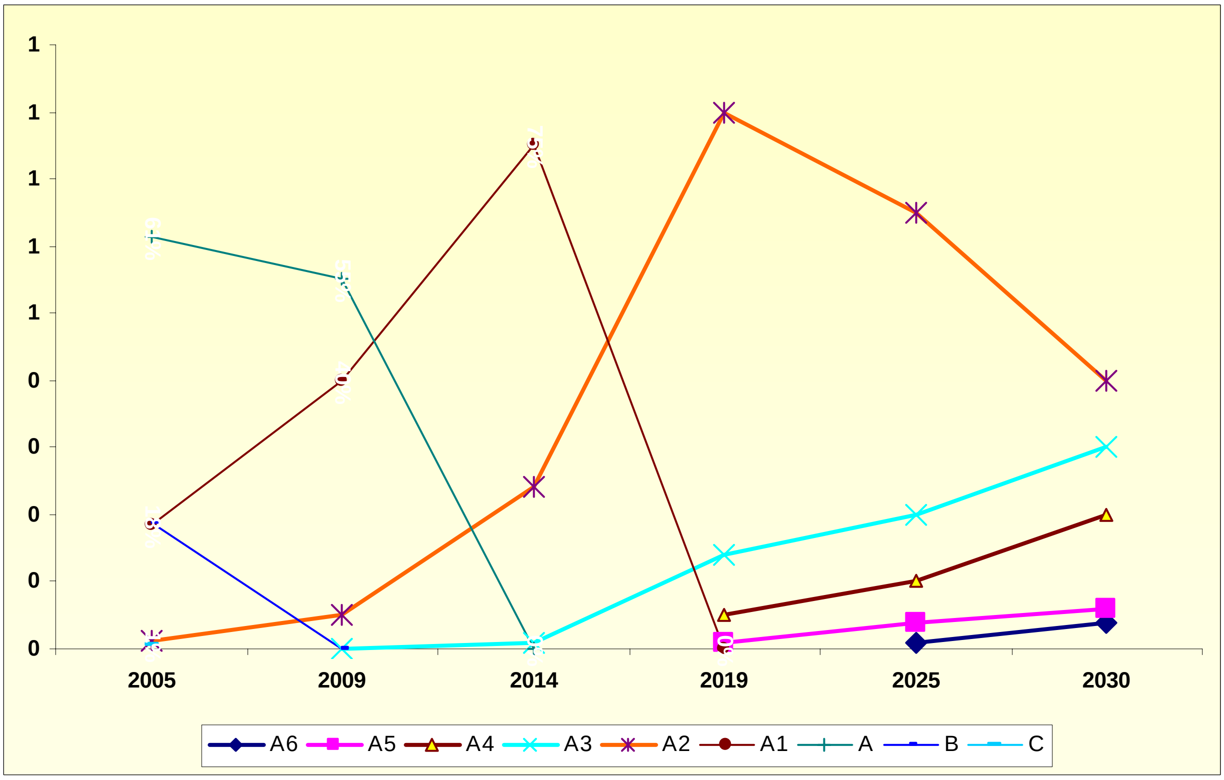


Figure 7.68: Energy efficiency class trends in the VA Static Scenario for freezers (percentage of models in each class are shown)

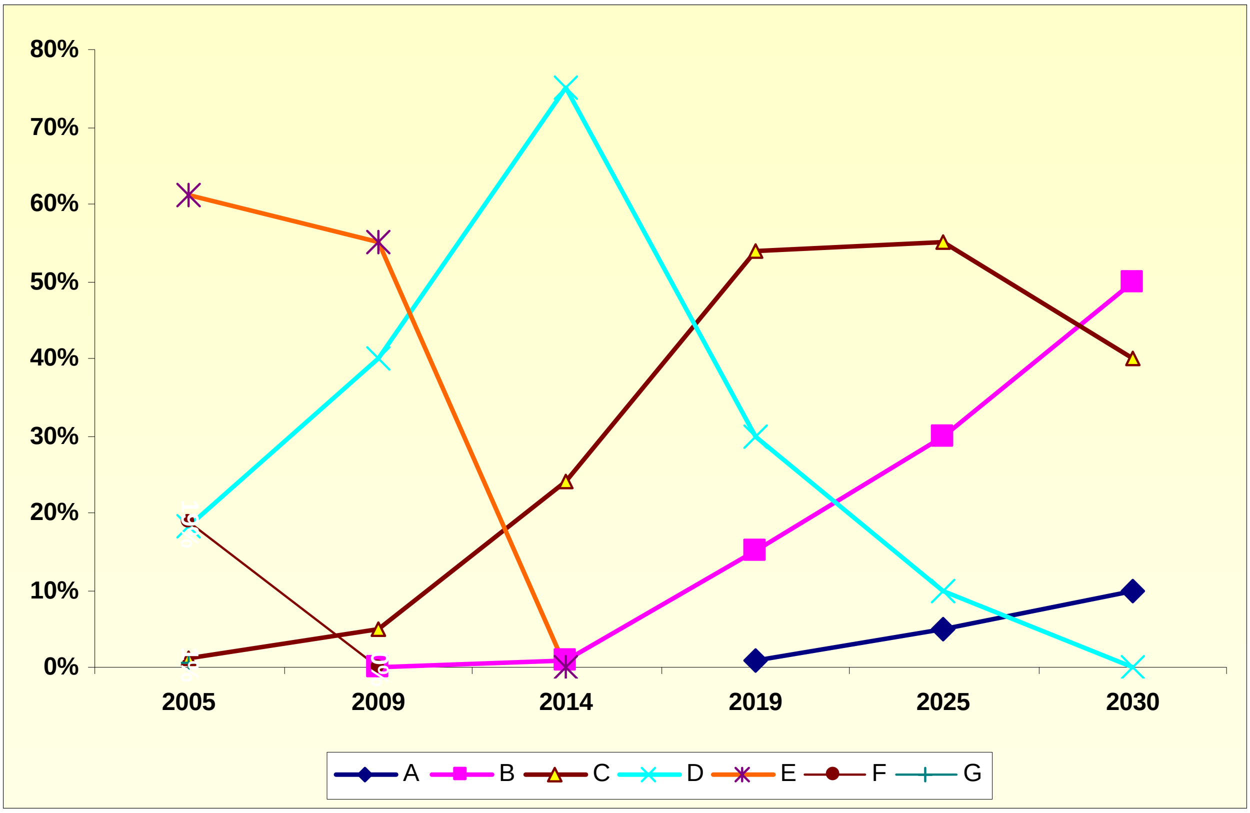


Figure 7.69: Energy efficiency class trends in the Realistic Scenario for freezers (percentage of models in each class are shown)

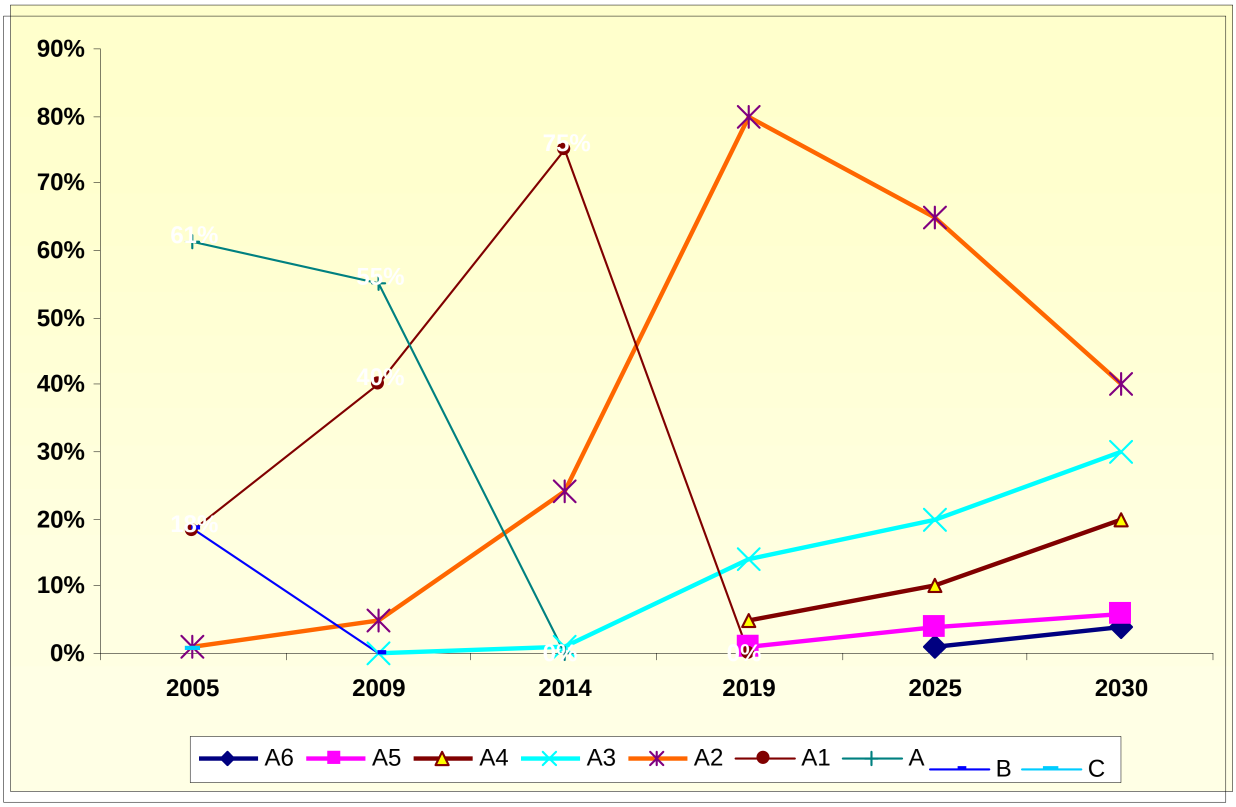
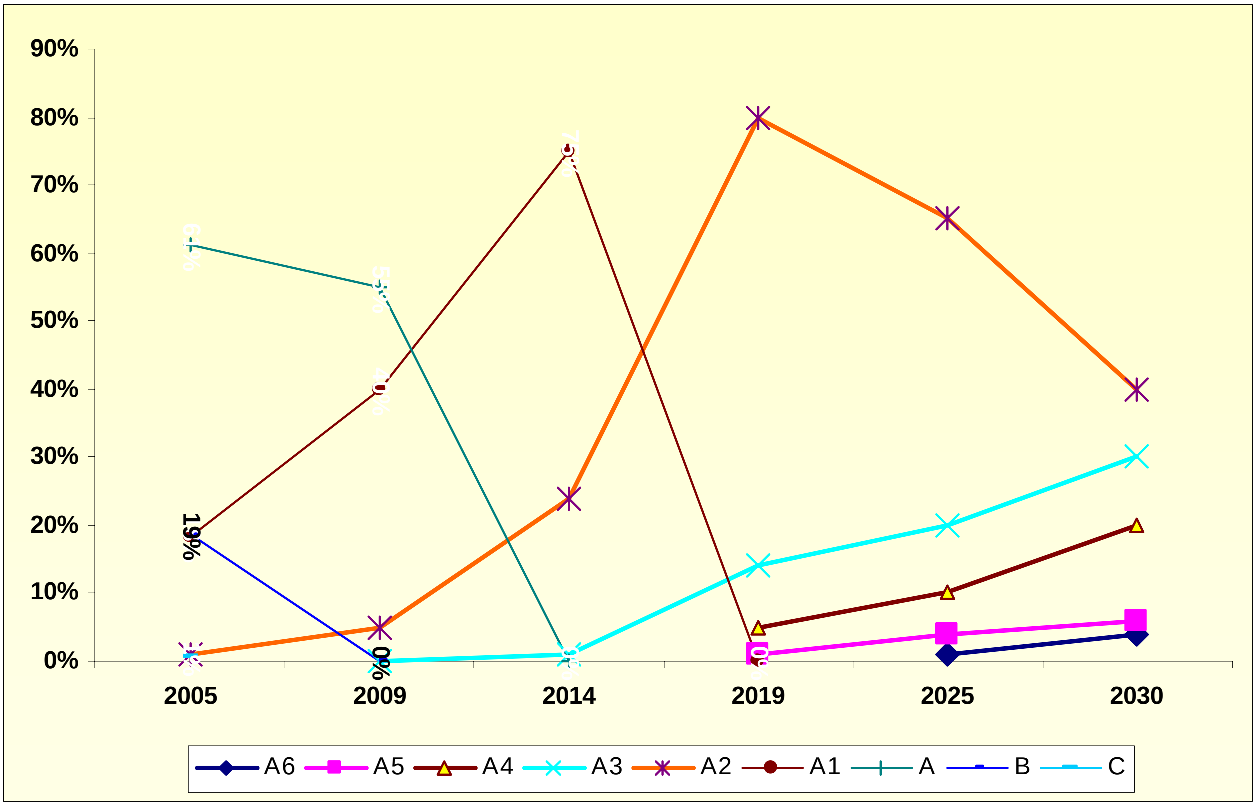


Figure 7.70: Energy efficiency class trends in the Ambitious Scenario for freezers (percentage of models in each class are shown)



7.7.2 The impact of the Policy Scenarios on the EU energy consumption of cold appliances

Tables 7.57-7.59 and Figures 7.71-7.73 show the energy consumption forecast for the refrigerators in the EU25, EU15 and EU10 countries under the three policy Scenarios described in the previous paragraph and the BaU Scenario described in Subtask 7.3. Tables 7.60-7.62 and Figures 7.74-7.76 show the same results for freezers. In all the cases it is possible to see that:

- the impact of the Policy Scenarios compared to the reference BaU becomes more evident after 2014 and increases steadily to the selected time horizon (2030). This is due to the foreseen introduction on the market of the more performing cold appliance models;
- the difference between the effects of the Policy Scenarios is practically negligible. Actually the scenarios mainly differ in the way the efficient products (described through the relevant energy efficiency classes under a revised labelling scheme) are introduced on the market;
- for freezers, the energy consumption trend in EU10 countries is different from EU15 countries (see Figure 7.76) due to the different ownership rate of these appliances in the considered countries.

The impact of the Policy Scenarios compared to the reference BaU and among each other is better highlighted in terms of energy savings potential in Tables 7.63-7.64 and in Figures 7.77-7.78 for refrigerators and freezers respectively. For refrigerators, the maximum energy savings is achieved for the Ambitious Scenario with about 4 770 GWh in 2019 and about 13 900 ten years later (EU25 countries); in the Realistic Scenario about 3 900 and 12 300 GWh are saved in the same years, while for the VA Static the savings are about 2 700 GWh in 2019 and 9 100 GWh in 2030. For the freezers, smaller savings are expected due to their lower ownership, going from 2 200 GWh and 5300 GWh of the Ambitious Scenario to 1 200 GWh and 3 200 GWh of the VA Static Scenario again in 2019 and 2030. In terms of expected energy savings percentage (compared to the BaU Scenario), refrigerators and freezers are quite similar, as shown in Tables 7.65 and 7.66. It is worth adding that the significant difference between the savings potential foreseen for 2019 and 2030 (the savings are more than doubled) is due to the strong spreading in the market of the models having EEI <20-25

Finally Table 7.67 and Figure 7.79 for refrigerators and Table 7.68 and Figure 7.80 for freezers show the trend of the average annual energy consumption per unit in the EU25 countries. The average consumption starts in 2005 with a value close to the current B class (391 kWh/year for refrigerators) to arrive in 2019 at a value between the current A and A+ classes (251–247 kWh/year depending on the scenarios, while in 2030 an average energy consumption value lower than the current A++ class (161-154 kWh/year.) is foreseen. In practice the hypothesised energy policies are expected to improve the stock average annual consumption of one efficiency class (from B to A) in a time frame (2005-2019) equivalent to the average life of cold appliances, and of more than two efficiency classes in a 25 year period.

Table 7.57: Comparison of the stock energy consumption for refrigerators in the BaU and Policy Scenarios for the EU25 countries

Year	**Stock energy consumption** (GWh/y)			
	BaU	Realistic	Static	Ambitious
2005	71.082	71.082	71.082	71.082
2009	65.759	65.701	65.739	65.609
2014	60.504	59.884	59.832	59.188
2019	57.365	54.628	53.447	52.592
2025	55.260	47.886	45.800	43.715
2030	50.339	41.228	38.017	36.401

Table 7.58: Comparison of the stock energy consumption for refrigerators in the BaU and Policy Scenarios for the EU15 countries

Year	**Stock energy consumption** (GWh/y)			
	BaU	**Realistic**	**Static**	**Ambitious**
2005	59.487	59.487	59.487	59.487
2009	55.113	55.062	55.096	54.981
2014	51.024	50.475	50.428	49.859
2019	48.792	46.365	45.308	44.562
2025	47.405	40.876	39.027	37.199
2030	43.312	35.312	32.490	31.091

Table 7.59: Comparison of the stock energy consumption for refrigerators in the BaU and Policy Scenarios for the EU10 countries

Year	Stock energy consumption (GWh/y)			
	BaU	Realistic	Static	Ambitious
2005	11.595	11.595	11.595	11.595
2009	10.645	10.639	10.643	10.628
2014	9.480	9.409	9.404	9.329
2019	8.572	8.263	8.139	8.030
2025	7.855	7.010	6.773	6.516
2030	7.028	5.916	5.527	5.310

Figure 7.71: Stock energy consumption trends by Scenario for refrigerators in EU25 countries (GWh/year)

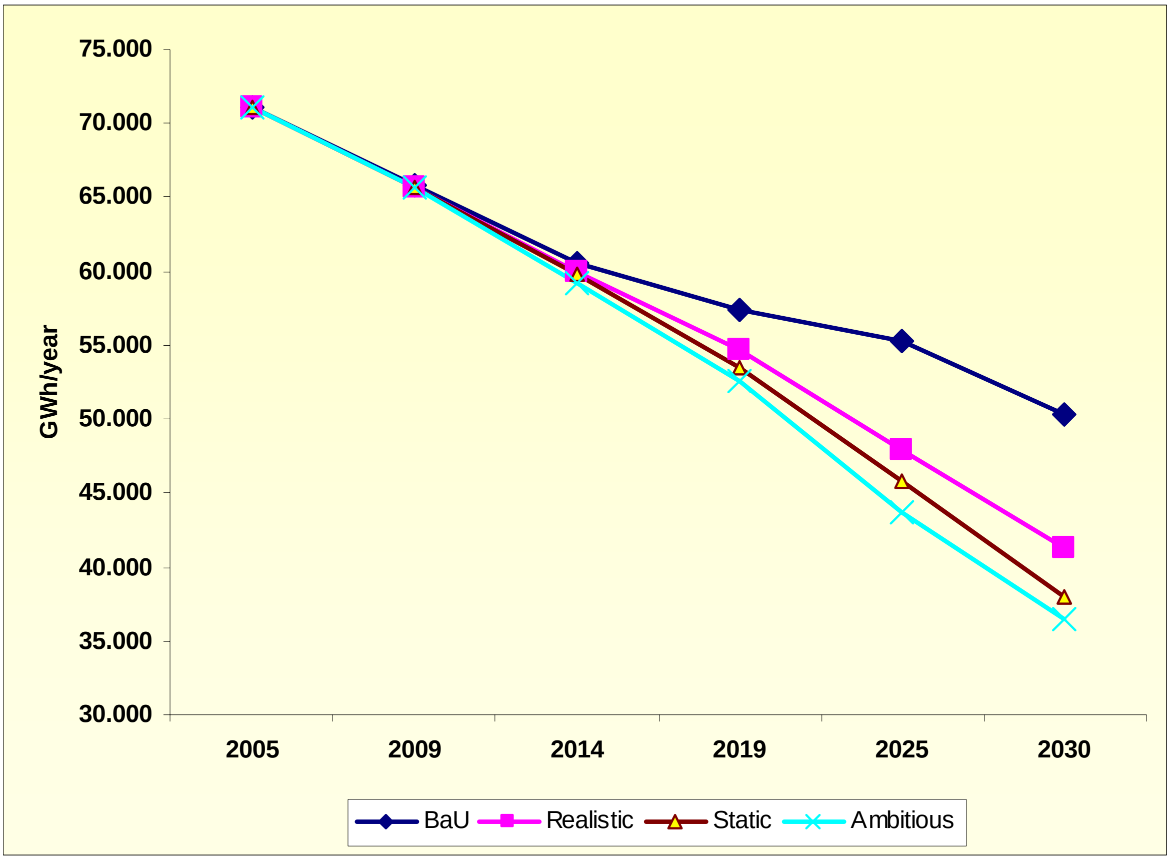


Figure 7.72: Stock energy consumption trends by Scenario for refrigerators in EU15 countries (GWh/year)

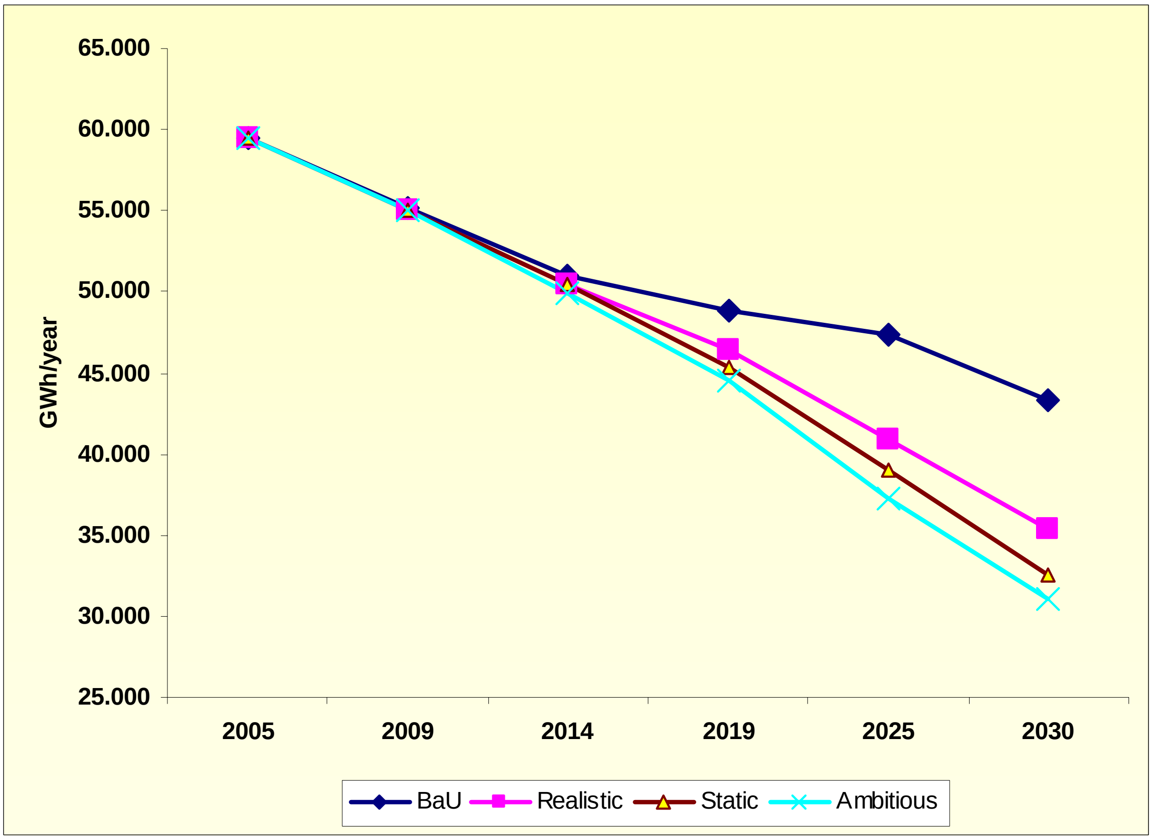


Figure 7-73: Stock energy consumption trends by Scenario for refrigerators in EU10 countries (GWh/year)

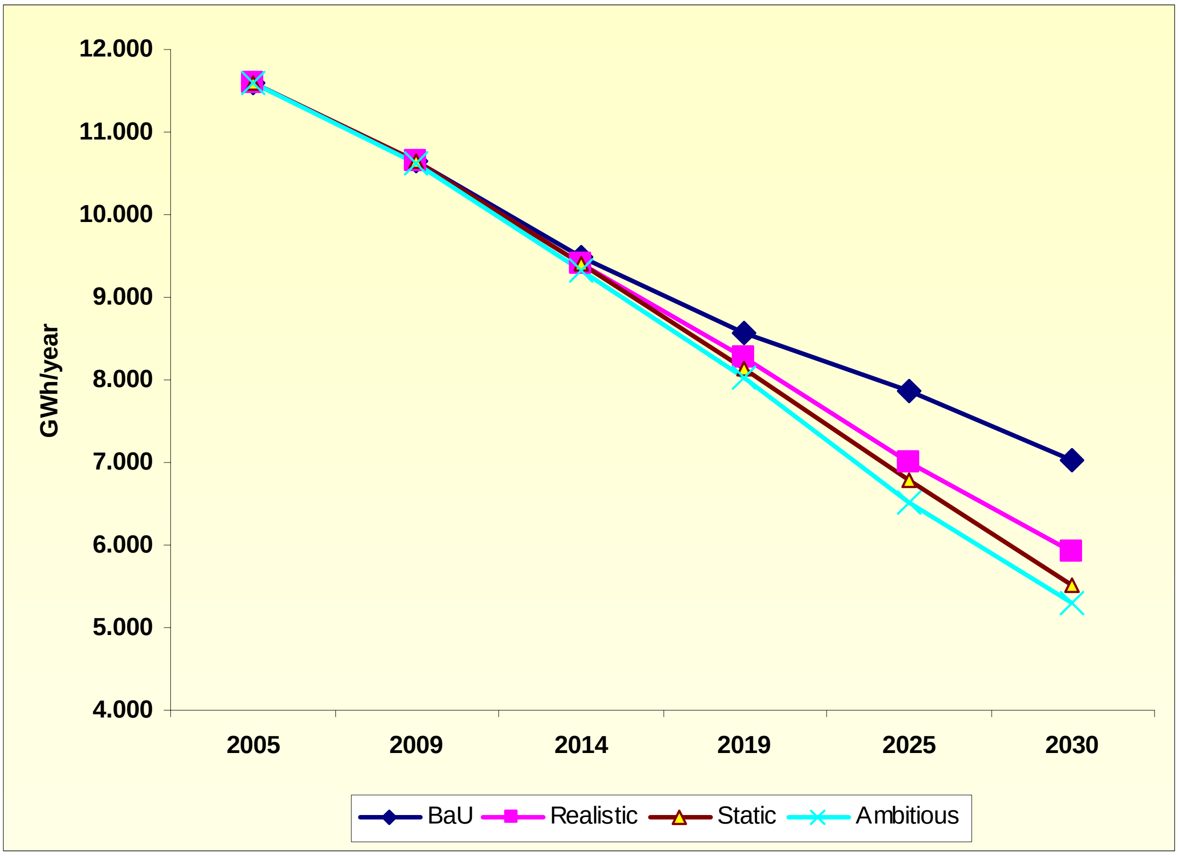


Table 7.60: Comparison of the stock energy consumption for freezers in the BaU and Policy Scenarios for the EU25 countries

Year	**Stock energy consumption** (GWh/y)			
	BaU	**Realistic**	**Static**	**Ambitious**
2005	34 986	34 986	34 986	34 986
2009	31 074	30 973	30 901	30 901
2014	26 651	26 071	25 607	25 609
2019	24 129	22 949	21 942	21 892
2025	23 036	20 621	19 117	18 790
2030	21 745	18 586	16 772	16 456

Table 7.61: Comparison of the stock energy consumption for freezers in the BaU and Policy Scenarios for the EU15 countries

Year	**Stock energy consumption** (GWh/y)			
	BaU	**Realistic**	**Static**	**Ambitious**
2005	33 653	33 653	33 653	33 653
2009	29 761	29 670	29 604	29 604
2014	25 396	24 851	24 417	24 418
2019	22 891	21 786	20 836	20 792
2025	21 760	19 483	18 064	17 756
2030	20 479	17 514	15 808	15 508

Table 7.62: Comparison of the stock energy consumption for freezers in the BaU and Policy Scenarios for the EU10 countries

Year	**Stock energy consumption** (GWh/y)			
	BaU	**Realistic**	**Static**	**Ambitious**
2005	1 333	1 333	1 333	1 333
2009	1 314	1 304	1 296	1 296
2014	1 255	1 220	1 191	1 191
2019	1 238	1 164	1 106	1 100
2025	1 276	1 138	1 054	1 034
2030	1 266	1 072	965	948

Figure 7.74: Stock energy consumption trends by Scenario for freezers in EU25 countries (GWh/year)

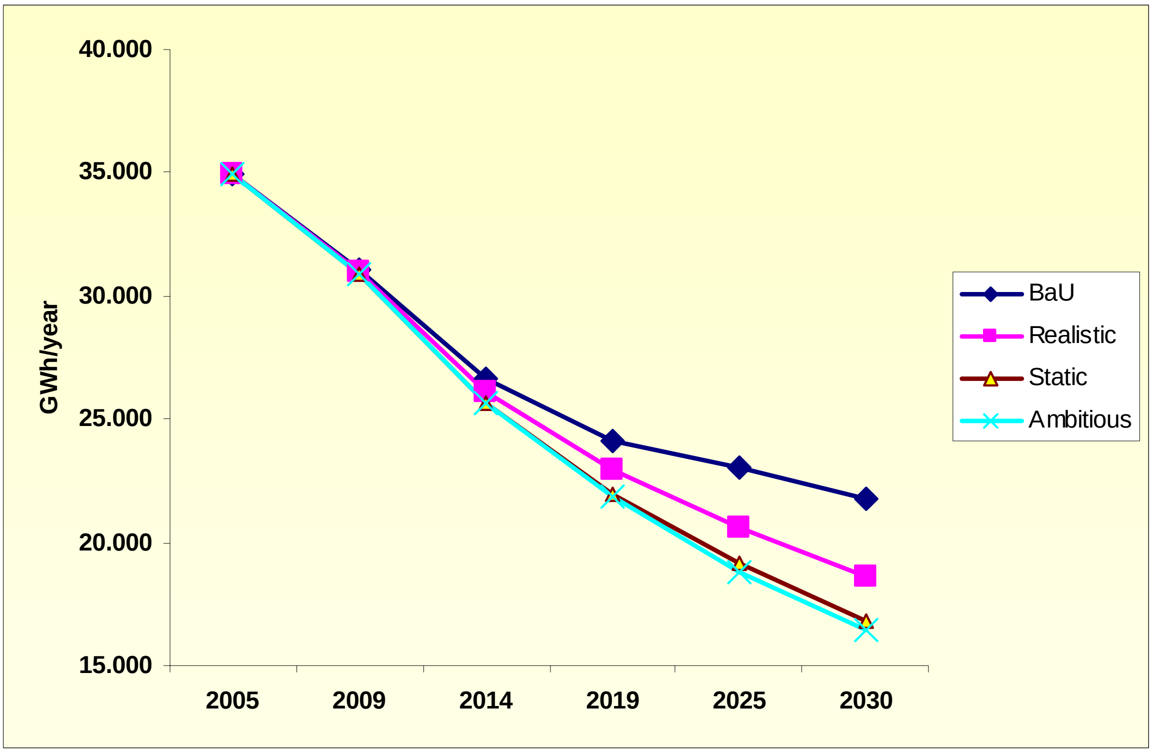


Figure 7.75: Stock energy consumption trends by Scenario for freezers in EU15 countries (GWh/year)

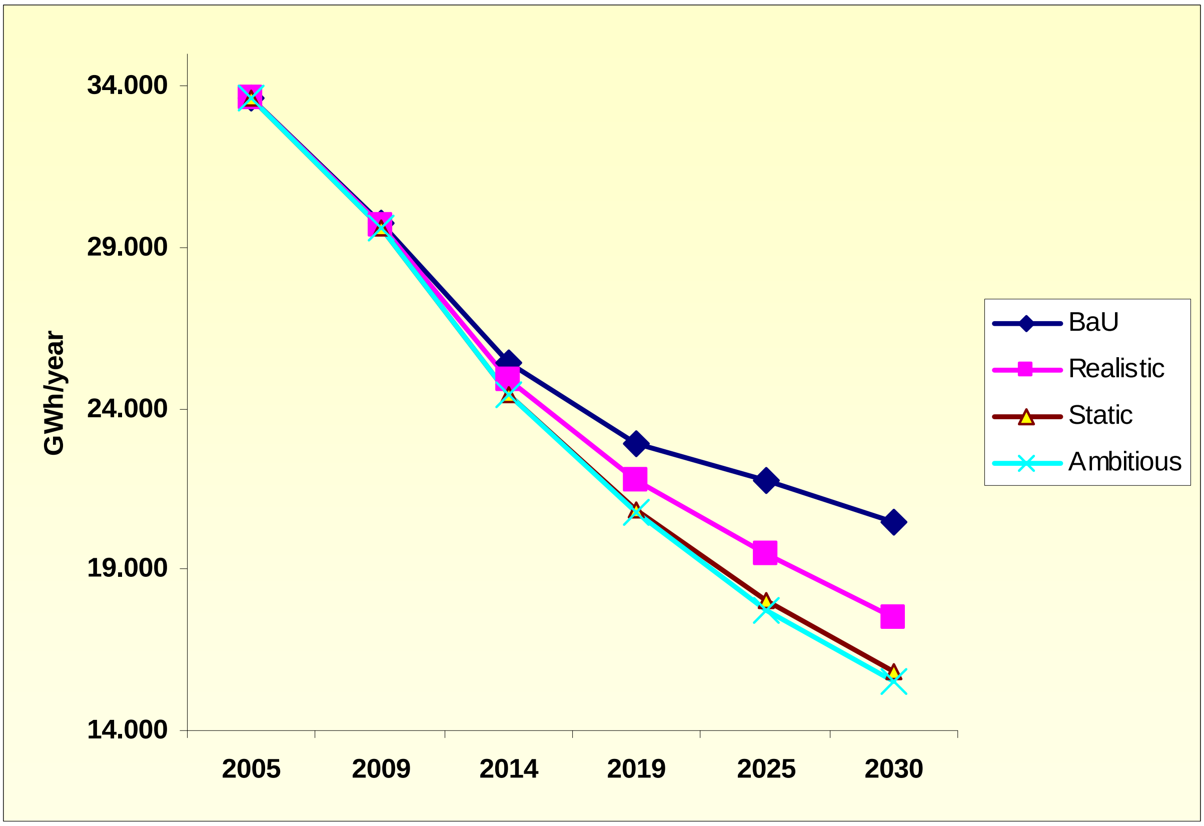


Figure 7.76: Stock energy consumption trends by Scenario for freezers in EU10 countries (GWh/year)

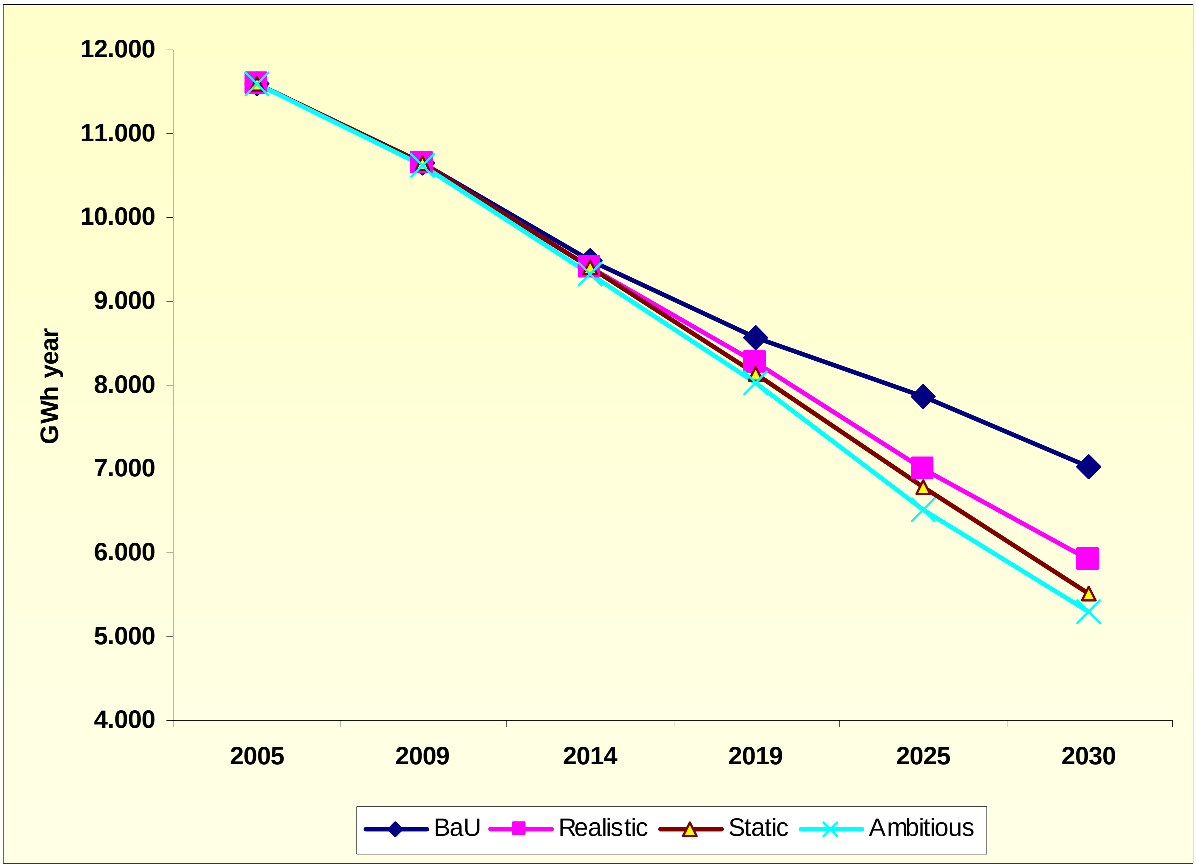


Table 7.63: Energy savings potential of the Policy Scenarios for refrigerators in EU25 countries

Year	**Total energy savings** (GWh)		
	Static	**Realistic**	**Ambitious**
2005	0	0	0
2009	58	20	150
2014	620	672	1.316
2019	2.737	3.918	4.773
2025	7.374	9.460	11.545
2030	9.111	12.322	13.938

Table 7.64: Energy savings potential of the Policy Scenarios for freezers in EU25 countries

Year	Total energy savings (GWh)		
	Static	Realistic	Ambitious
2005	0	0	0
2009	101	174	174
2014	580	1.044	1.042
2019	1.179	2.186	2.237
2025	2.416	3.919	4.246
2030	3.159	4.973	5.290

Figure 7.77: Energy savings potential of the Policy Scenarios for refrigerators in EU25 countries

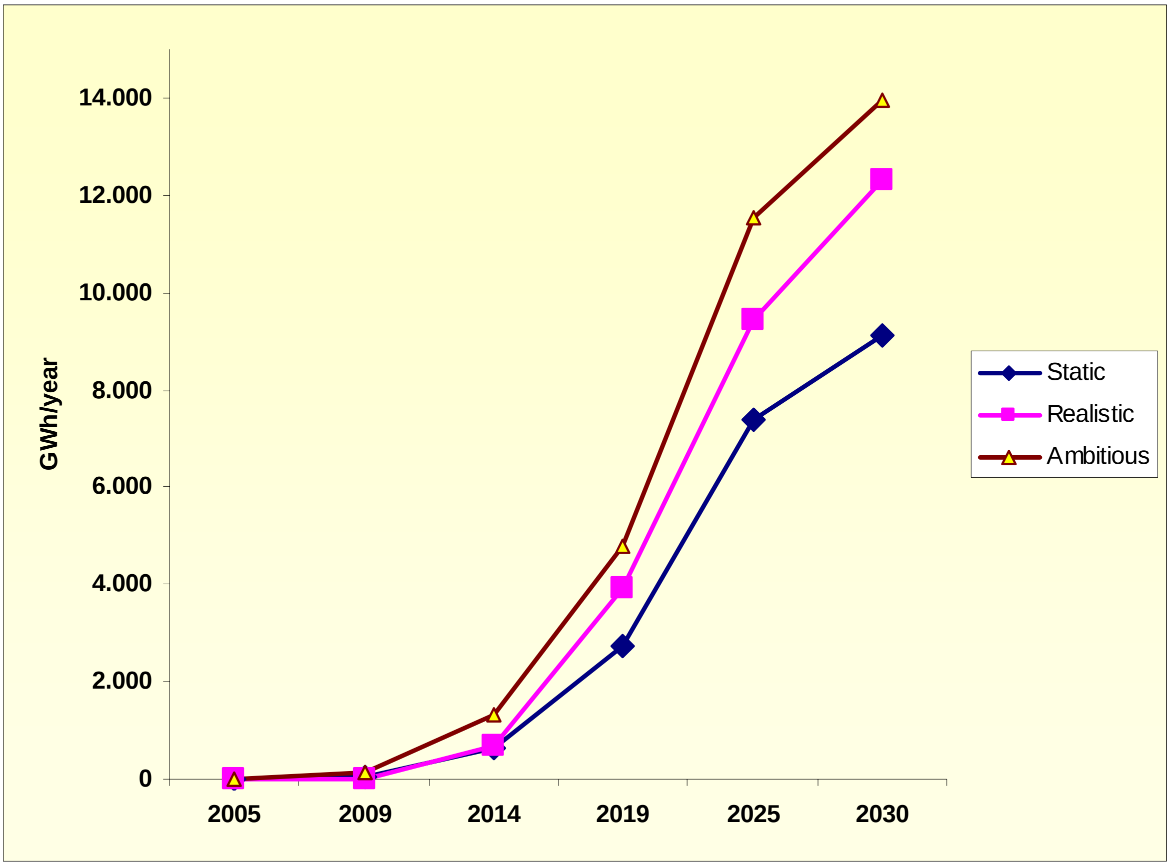


Figure 7.78: Energy savings potential of the Policy Scenarios for freezers in EU25 countries

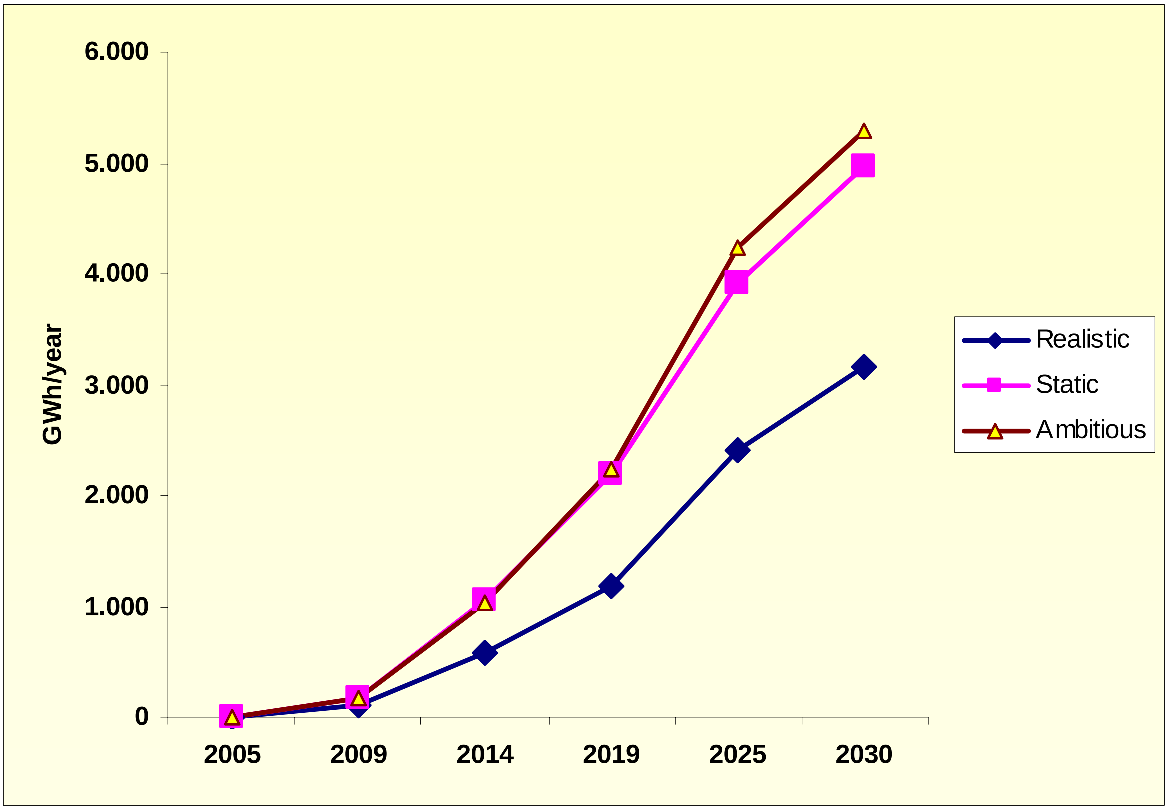


Table 7.65: Energy savings potential of the Policy Scenarios for refrigerators in EU25 countries

Year	Total energy savings (%)		
	Static	Realistic	Ambitious
2005	0	0	0
2009	0,1	0,0	0,2
2014	1,0	1,1	2,2
2019	4,8	6,8	8,3
2025	13,3	17,1	20,9
2030	18,1	24,5	27,7

Table 7.66: Energy savings potential of the Policy Scenarios for freezers in EU25 countries

Year	Total energy savings (%)		
	Static	Realistic	Ambitious
2005	0	0	0
2009	0,33	0,56	0,56
2014	2,18	3,92	3,91
2019	4,89	9,06	9,27
2025	10,49	17,01	18,43
2030	14,53	22,87	24,32

Table 7.67: Average annual unitary energy consumption by Policy Scenarios for refrigerators in EU25 countries

Year	Average annual energy consumption (kWh/year unit)			
	BaU	Static	Realistic	Ambitious
2005	391	391	391	391
2009	343	344	344	344
2014	294	295	295	292
2019	263	251	256	247
2025	240	204	213	194
2030	211	161	175	154

Table 7-68: Average annual unitary energy consumption by Policy Scenarios for freezers in EU25 countries

Year	Average annual energy consumption (kWh/year unit)			
	BaU	Static	Realistic	Ambitious
2005	431	431	431	431
2009	366	364	365	364
2014	301	290	295	290
2019	262	238	249	237
2025	237	196	212	193
2030	212	163	181	160

Figure 7-79: Average unitary annual energy consumption by policy scenarios for refrigerators in EU25 countries

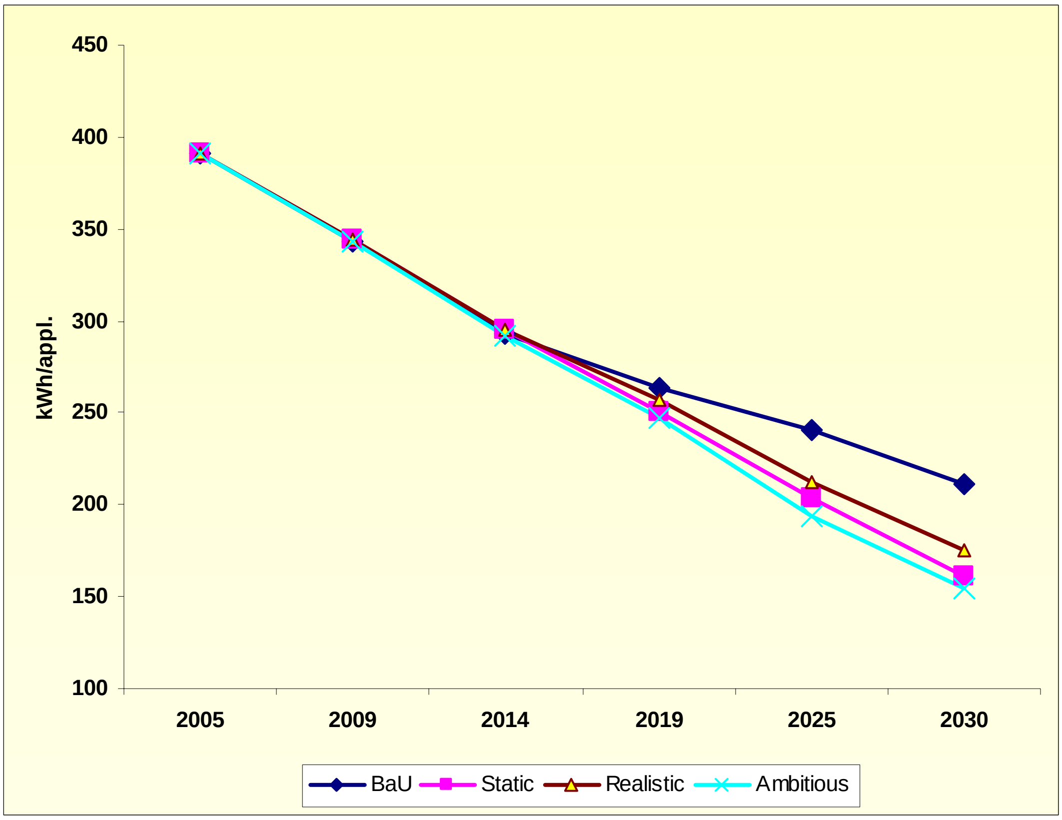
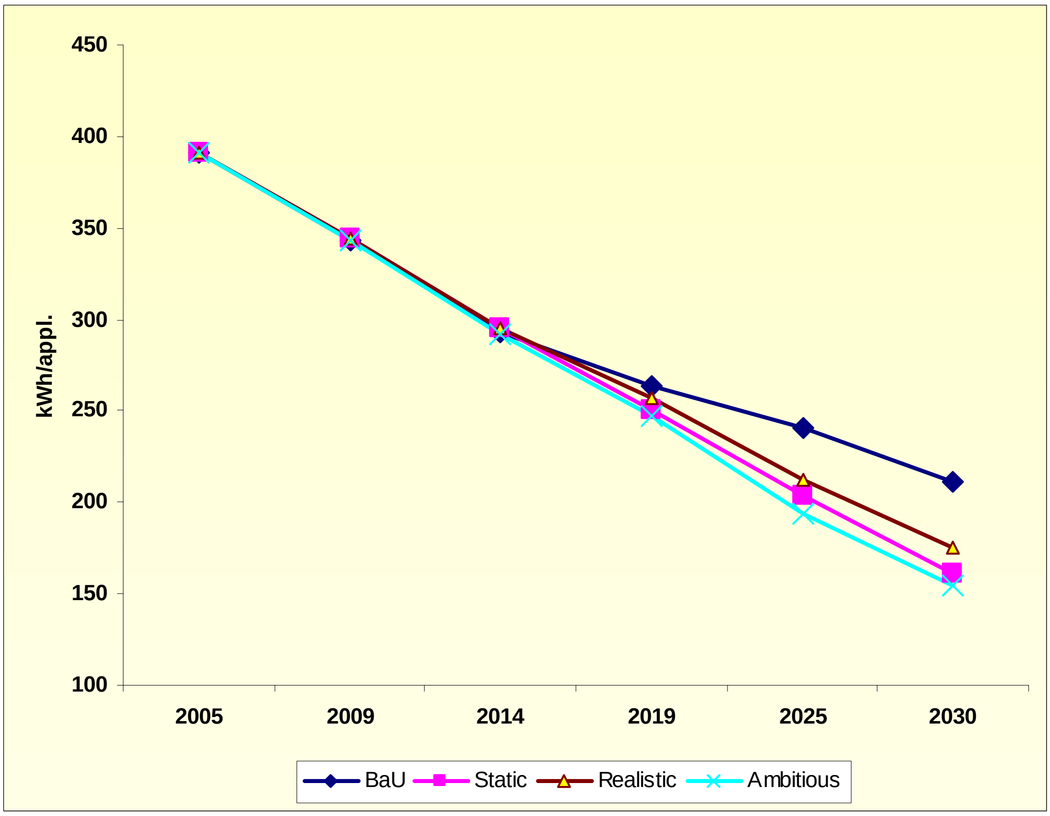


Figure 7.80: Average annual unitary energy consumption by policy scenarios for freezers in EU25 countries



7.8 ANNEX A: UNCERTAINTY IN STANDARDISATION

7.8.1 The uncertainty in measurements

Uncertainty reporting is essential to ensure measured data are interpreted in a correct way. Especially when data of measurements are to be compared between laboratories or when normative requirements are set up, it is necessary to know the uncertainty with which data can be measured.

The current international view of how to express uncertainty in measurement is the "Guide to the Expression of Uncertainty in Measurement" (called in short GUM), Ed.1, prepared by BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML in 1995.

In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement, that is, the *measurand*, and thus the result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty of the result of a measurement generally consists of several components which, may be grouped into two categories according to the method used to estimate their numerical values:

A. those which are evaluated by statistical methods,
B. those which are evaluated by other means.

There is not always a simple correspondence between the classification of uncertainty components into categories A and B and the commonly used classification of uncertainty components as "random" and "systematic" (described in Subtask 7.6). The nature of an uncertainty component is conditioned by the use made of the corresponding quantity, that is, on how that quantity appears in the mathematical model that describes the measurement process. When the corresponding quantity is used in a different way, a "random" component may become a "systematic" component and vice-versa. Thus the terms "random uncertainty" and "systematic uncertainty" can be misleading when generally applied. An alternative nomenclature that might be used is:

1) component of uncertainty arising from a random effect
2) component of uncertainty arising from a systematic effect,

where a random effect is one that gives rise to a possible random error in the current measurement process and a systematic effect is one that gives rise to a possible systematic error in the current measurement process. In principle, an uncertainty component arising from a systematic effect may in some cases be evaluated by 'method A' while in other cases by 'method B', as may be an uncertainty component arising from a random effect.

The difference between *error* and *uncertainty* should always be borne in mind. For example, the result of a measurement after correction can unknowably be very close to the unknown value of the measurand, and thus have negligible error, even though it may have a large uncertainty.

Basic to the GUM approach is representing each component of uncertainty that contributes to the uncertainty of a measurement result by an estimated standard deviation, termed **standard uncertainty** with suggested symbol u_i, and equal to the positive square root of the estimated variance u^2_i.

It follows that an uncertainty component in 'category A' is represented by a statistically estimated standard deviation s_i , equal to the positive square root of the statistically estimated variance s^2_i, and the associated number of degrees of freedom n_i. For such a component the standard uncertainty is $u_i=s_i$. The evaluation of uncertainty by the statistical analysis of series of observations is termed a **Type A evaluation (of uncertainty)**.

In a similar manner, an uncertainty component in ‘category B’ is represented by a quantity u_j, which may be considered an approximation to the corresponding standard deviation; it is equal to the positive square root of u^2_j, which may be considered an approximation to the corresponding variance and which is obtained from an assumed probability distribution based on all the available information. Since the quantity u^2_j is treated like a variance and u_j like a standard deviation, for such a component the standard uncertainty is simply u_j.
The evaluation of uncertainty by means other than the statistical analysis of series of observations is termed a **Type B evaluation (of uncertainty)**.

A Type A evaluation of standard uncertainty may be based on any valid statistical method for treating data; a Type B evaluation of standard uncertainty is usually based on scientific judgment using all the relevant information available, which may include: previous measurement data, experience with, or general knowledge of, the behaviour and property of relevant materials and instruments, manufacturer’s specifications, data provided in calibration and other reports, and uncertainties assigned to reference data taken from handbooks.

Convert a quoted uncertainty that is a stated multiple of an estimated standard deviation to a standard uncertainty by dividing the quoted uncertainty by the multiplier. Convert a quoted uncertainty that defines a “confidence interval” having a stated level of confidence (such as 95% or 99%) to a standard uncertainty by treating the quoted uncertainty as if a normal distribution had been used to calculate it and dividing it by the appropriate factor for such a distribution. These factors are 1,960 and 2,576 for the two levels of confidence given.

If the quantity in question is modelled by a normal distribution there are no finite limits that will contain 100% of its possible values. However, ±3 standard deviations about the mean of a normal distribution corresponds to 99,73% limits. Thus, if the limits a_- and a_+ of a normally distributed quantity with mean = $(a_+ + a_-)/2$ are considered to contain “almost all” of the possible values of the quantity, that is, approximately 99,73% of them, then $u_j = a/3$, where $a = (a_+ - a_-)/2$.

7.8.2 The combined standard uncertainty

The *combined standard uncertainty* of a measurement result, u_c, is taken to represent the estimated standard deviation of the result. It is obtained by combining the individual standard uncertainties u_i, whether arising from a Type A evaluation or a Type B evaluation, using the law of propagation of uncertainty (also known as “root-sum-of-squares” method) for combining standard deviations. It is assumed that a correction (or correction factor) is applied to compensate for each recognized systematic effect that significantly influences the measurement result and that every effort has been made to identify such effects.

In many practical measurement situations, the probability distribution characterized by the measurement result y and its combined standard uncertainty $u_c(y)$ is approximately normal (Gaussian). When this is the case and $u_c(y)$ itself has negligible uncertainty, $u_c(y)$ defines an interval $y - u_c(y)$ to $y + u_c(y)$ about the measurement result y within which the value of the measurand Y estimated by y is believed to lie with a level of confidence of approximately 68%. That is, it is believed with an approximate level of confidence of 68% that $y - u_c(y) \leq Y \leq y+u_c(y)$, which is commonly written as $Y = y \pm u_c(y)$.

The term "confidence interval" has a specific definition in statistics and is only applicable to intervals based on u_c when certain conditions are met, including that all components of uncertainty that contribute to u_c be obtained from Type A evaluations. Thus, an interval based on u_c is viewed as encompassing a fraction *p* of the probability distribution characterized by the measurement result and its combined standard uncertainty, and *p* is the coverage probability or level of confidence of the interval.

Although the combined standard uncertainty u_c is used to express the uncertainty of many measurement results, for some commercial, industrial, and regulatory applications of such results, what is often required is a measure of uncertainty that defines an interval about the measurement result *y* within which the value of the measurand *Y* is confidently believed to lie. The measure of uncertainty intended to meet this requirement is termed **expanded uncertainty**, U, and is obtained by multiplying $u_c(y)$ by a **coverage factor** *k*. Thus $U = ku_c(y)$ and it is confidently believed that $y - U \leq Y \leq y + U$, which is commonly written as: $Y = y \pm U$.

In general, the value of the coverage factor *k* is chosen on the basis of the desired level of confidence to be associated with the interval defined by $U = ku_c$. Typically, *k* is in the range 2 to 3. When the normal distribution applies and u_c has negligible uncertainty, $U = 2u_c$ (i.e., *k*=2) defines an interval having a level of confidence of approximately 95% and $U = 3u_c$ (i.e., *k*=3) defines an interval having a level of confidence greater than 99%.

For a quantity *z* described by a normal distribution with expectation μ_z and standard deviation *s*, the interval $\mu_z \pm ks$ encompasses 68,27%, 90%, 95,45%, 99% and 99,73% of the distribution for *k*=1, *k*=1,645, *k*=2, *k*=2,576, and *k*=3, respectively.

Ideally, one would like to be able to choose a specific value of *k* that produces an interval corresponding to a well defined level of confidence *p*, such as 95% or 99%; equivalently, for a given value of *k*, one would like to be able to state unequivocally the level of confidence associated with that interval. This is difficult to do in practice because it requires knowing in considerable detail the probability distribution of each quantity upon which the measurand depends and combining those distributions to obtain the distribution of the measurand.

The GUM gives an approximate solution to the problem of how the relation between *k* and *p* is to be established. Use expanded uncertainty *U* to report the results of all measurements other than those for which u_c has traditionally been employed. To be consistent with current international practice, the value of *k* to be used for calculating U is, by convention, $k = 2$. Values of *k* other than 2 are only to be used for specific applications dictated by established and documented requirements.

An example of the use of a value of *k* other than 2 is taking *k* equal to a t-factor obtained from the t-distribution when u_c has low degrees of freedom in order to meet the dictated requirement of providing a value of $U = ku_c$ that defines an interval having a level of confidence close to 95%.

7.8.3 Accuracy of a measurement method

The current international method for assessing the accuracy of a measurement method is the standard ISO 5725: *Accuracy (trueness and precision) of measurement methods and results*, Part 1-6, issued in issued 1994 – 1998.

Methods for measuring declared values for energy and other resources consumption must be of sufficient ***accuracy*** to provide confidence to governments, consumers and manufacturers. The term accuracy imply the total displacement of a result from a reference value due to random as well as systematic effects. The accuracy of a test method is expressed in terms of *trueness* and *precision*:

- ***trueness*** refers to the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference values. Trueness assess the various components of bias;
- ***precision*** refers to the closeness of the agreement between test results. Precision is the general term for variability between repeated measurement. The need to consider precision arises because tests performed on presumably identical materials or products in presumably identical circumstances do not, in general, yield identical results. This is attributed to unavoidable random errors inherent in every measurement procedure; the factors that influence the outcome of a measurement cannot all be completely controlled. For instance, the difference between a test result and some specified value may be within the scope of unavoidable random errors, in which case a real deviation from such a specified value has not been established

Accuracy data can be used in various practical situation:
- giving a standard method of calculating the repeatability limit, the reproducibility limit and other limits to be used in examining the test results obtained by a standard measurement method
- providing a way of checking the acceptability of test results obtained under repeatability or reproducibility conditions
- describing how to assess the stability of results within a laboratory over a period of time, and thus providing a method of "quality control" of the operations within a laboratory
- describing how to assess whether a given laboratory is able to use a given standard measurement method in a satisfactory way
- describing how to compare alternative measurement methods.

Two conditions of precision: ***repeatability*** and ***reproducibility*** have been found necessary and useful for describing the variability of a measurement method, where:
- *repeatability*: is precision under repeatability conditions, where independent test results are obtained with the same method, on identical test items, in the same laboratory, by the same operator, using the same equipment, within short intervals of time;
- *reproducibility*: is precision under reproducibility conditions, where test results are obtained with the same method, on identical test items, in different laboratories, with different operators, using different equipment.

The *repeatability* of a test method must be sufficiently accurate for comparative testing, while *reproducibility* must be sufficiently accurate for the determination of values which are declared and for checking the declared values.

Many different factors may contribute to the variability of results from a measurement method, including:
- the operator
- the equipment (instrumentation) used
- the calibration of the equipment
- the environmental conditions (temperature, humidity, etc.)
- the time elapsed between measurements.

The variability between measurements performed by different operators and/or different equipment will usually be greater than the variability between measurements carried out within a short interval of time by a single operator using the same equipment. Under repeatability conditions the listed factors are considered constant and do not contribute to the variability, while under reproducibility conditions they vary and do contribute to the variability of test results. Thus *repeatability* and *reproducibility* are the two extremes of precision, the first describing the minimum and the second the maximum variability in results.

The measure of precision usually is expressed in terms of "*imprecision*" and is computed as a standard deviation σ of the test results. Less precision is reflected by a larger standard deviation. However, in statistical practice, where the true value of a standard deviation is not known, it is replaced by an estimate based upon a sample, then the symbol σ is replaced by "s" to denote that it is an estimate. The square of the standard deviation is called the *variance* "S". According to ISO 5725:

- S_L^2 = *between-laboratory variance*; it includes the between operator and between equipment variability
- S_W^2 = *within-laboratory variance*, under repeatability conditions. **Note**: under IEC 61923:1997, within-laboratory variance is the square of the within-laboratory standard deviation indicated as $S_{L,i}$
- S_r^2 = *repeatability variance*; it is the arithmetic mean of the within laboratory variances S_W^2; this arithmetic mean is taken over all those laboratories taking part in the accuracy experiment which remain after outliers have been excluded
- $S_R^2 = (S_L^2 + S_r^2)$ = *reproducibility variance*

From variance values "S" the repeatability (s_r) and the reproducibility (s_R) of the measurement method are derived:

- s_r = repeatability of the test method, is the square root of the *repeatability variance*;
- s_R = reproducibility of the test method, is the square root of the *reproducibility variance*

The 'trueness' of a measurement method is of interest when it is possible to conceive a true value for the property being measured. Although for some measurement methods the true value cannot be known exactly, it may be possible to have an accepted reference value for the property being measured. The trueness of a measurement method can be investigated by comparing the accepted reference value with the level of the results given by the measurement method.

Trueness is normally expressed in term of *bias*. Bias is the difference between the expectation of test results and an accepted reference value. Bias is the total systematic error as contrasted to random error. There may be one or more systematic error components contributing to the bias:

- ***laboratory bias***: the difference between the expectation of the test results from a particular laboratory and an accepted reference value
- ***bias of the measurement method***: the difference between the expectation of test results obtained from all laboratories using that method and an accepted reference value
- ***laboratory component of bias***: the difference between the laboratory bias and the bias of the measurement method.

An accepted reference value is a value that serves as an agreed-upon reference for comparison, and which is derived as:

a) theoretical or established value, based on scientific principles
b) an assigned or certified value, based on experimental work of some national or international organisation
c) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group
d) when a), b) and c) are not available, the expectation of the (measurable) quantity, i.e. the mean of a specified population or measurements.