Findings of the Cold II SAVE study to revise cold appliance energy labelling and standards in the EU

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1. SYNOPSIS

Findings of a new EU study concerned with making recommendations for a revised energy label and minimum efficiency requirements for domestic refrigeration appliances are reported.

2. ABSTRACT

Cold appliances account for ~17.4% of residential electricity consumption in the EU. Following the introduction of energy labelling in 1995 and minimum energy performance standards in September 1999, the average efficiency of new models improved by ~27%; however, this value is still someway short of the least life-cycle cost potential identified by the GEA study in 1993. In 1998 a new SAVE study, known as Cold II, was launched to investigate technical issues underpinning the revision of the energy label and the establishment of new efficiency thresholds. The current paper presents the findings of that study, particularly those aspects concerning the market trends, technology developments, energy-engineering analyses and labelling structural criteria that were identified within it. The resulting policy recommendations derived from this analysis are also summarised.

3. INTRODUCTION

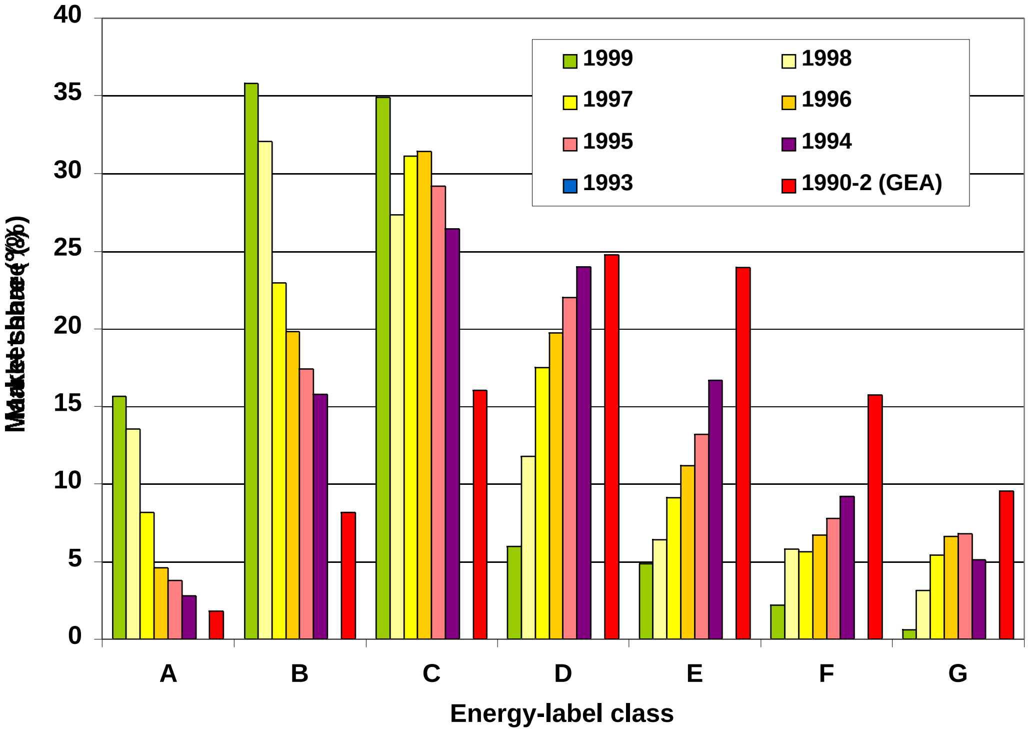
Cold appliances (domestic refrigerators, freezers and their combinations) currently account for ~17.4% of residential electricity consumption in the EU, some 106.7 TWh/year, and give rise to ~52 Mt of annual CO_2 emissions (equivalent to 1.7% of total Community emissions in 1990). In 1995 energy labelling of cold appliances became mandatory throughout the EU,[1] and in September 1999 mandatory minimum energy performance standards (MEPS) were introduced.[2]

Both the energy labelling and MEPS Directives were based upon the technical analyses presented in the 1993 SAVE study by the Group for Efficient Appliances.[3] This paper presents the results of the new Cold II SAVE study[4] that was commissioned to assist the European Commission in the revision of the cold appliance energy labelling and MEPS Directives. The study was conducted by ADEME and NOVEM with co-ordination by PW Consulting and technical support from PW Consulting, Ecole des Mines de Paris, Van Holsteijn en Kemna, ENEA and TNO. Technical and general contributions were supplied by the European and US manufacturers' associations, CECED and AHAM.

The efficiency of the cold appliance market has evolved rapidly in response to EU policy measures such that the share of class A and B appliances on the market increased from only 10% in 1990-92 to ~57% by the end of 1999 (Figure 1). Overall there was an estimated 27% net efficiency improvement for post-MEPS cold appliances on the EU market compared with pre-labelling efficiency levels. The average energy consumption of cold appliances declined from ~450 kWh/year in 1990-92 to an estimated 364 kWh/year immediately post MEPS. It is difficult to be sure what proportion of these improvements was due to labelling, what was due to MEPS and what would have occurred in any case as a result of autonomous energy-efficiency improvements; however, it is likely that the large majority of these improvements would not have occurred without the implementation of the combined EU policy measures.

Despite these significant energy-efficiency improvements cold appliances still have the largest cost-effective energy savings potentials of any of the major residential electricity end-uses. Furthermore, they account for a very significant share of the total cost-effective savings potentials in residential electricity consumption (perhaps 40-50% of the total).

Figure 1. Share of EU cold appliance market by label class from 1990-92 to 1999. (Data for 1999 and 1998, taken from the CECED databases, and the 1990-92 GEA data are not sales-weighted; data for 1994-97, taken from the monitoring evaluation studies for the European Commission,[5,6] are sales-weighted.)



4. STUDY ACTIVITIES AND METHODOLOGY

As the successor to the GEA analysis the Cold II study sought not only to update the earlier analysis to take account of market and technological developments but also to improve the technical basis of the analysis in order to raise confidence in the recommendations. The study comprised the following main elements:

- an updated market assessment using both detailed cold appliance sales databases assembled through other SAVE contracts and technical databases supplied by the European industry association, CECED;
- a thorough investigation of energy-saving technologies applicable to cold appliances through an extensive patent search and technical review;
- reinvestigation of the underlying technical basis of the efficiency definitions used in the current labelling and MEPS Directives using a physically based model;
- an extensive energy-engineering analysis linked to an appraisal of the relationship between product efficiency and life-cycle costs (LCCs);
- an energy-engineering analysis to determine the maximum realistically conceivable energy-efficiency limits in the medium to long term;
- the conduct of a new set of cold appliance energy consumption, cost and CO_2 emission projections in response to various policy scenarios;
- a survey of consumer attitudes with regard to improvements in cold appliance energy efficiency and the corresponding anticipated increase in purchase costs and reduction in operating costs;
- a thorough appraisal of the impact of potential policy measures on industry;
- a review of international cold appliance energy-efficiency programmes.

To facilitate these analyses the following methodological advances and checks and balances were introduced:

- new, dynamic cold appliance energy simulation software was developed by the Centre d’Energétique of the Ecole des Mines de Paris;
- some 20 cold appliances were acquired, tested and subjected to detailed technical investigation through a subcontract funded by ADEME. Comparison of energy simulation results with the test data from these appliances showed that the average difference between the Ecole des Mines dynamic simulation model

projections and the test data was _2.4%, which is well within the accepted margin of error of the EN 153 energy test procedure;

- a subset of these appliances were selected for use as base-case models for the energy-engineering analyses;
- the accuracy of the simulation tools was verified against the tested models and also examined for some specific design changes;
- industry was fully engaged in the study and provided valuable data, expertise and peer review of the findings, in addition to some complementary analyses;
- detailed manufacturing cost data were independently assembled but were critiqued by industry and consensus values were derived.

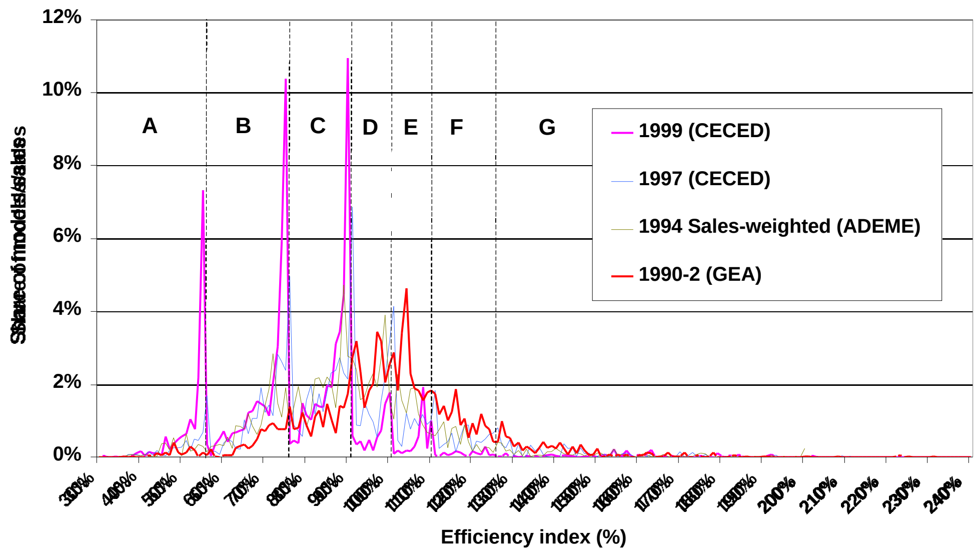
5. PRINCIPAL FINDINGS

Impacts of EU legislation to date

The average energy-efficiency index (EEI) of cold appliances on the market in 1990–92 is estimated to have been 102.2%, while the average of the models in the CECED 1999 database that satisfied the September MEPS was 74.8%. This represents a 27% improvement in efficiency in relative terms over the same period. It is speculative to say exactly how much, if any, of this improvement might have occurred had the EU energy labelling and MEPS Directives not been enacted, but most probably the bulk of the improvement would not have occurred without them. It is clear from the statistical analysis of the cold appliance databases that almost all new products are designed to meet a specific energy-label class threshold, usually with a margin of just one or two units of EEI, and that none of the manufacturers are disinterested in the label (Figure 2).

If the rate of autonomous energy-efficiency improvement would have been 1% per year from 1993 to 2000 then the combined impact of the energy labelling and MEPS Directives would have been to improve cold appliance efficiency by 21% by 2000, which is equivalent to reducing the average energy consumption of new cold appliances by 95 kWh/year.

Figure 2. Distribution of cold appliances for sale in the EU, by energy-efficiency index.



Some of the other developments are as follows:

- surveys of consumer attitudes have indicated that the label has a significant bearing on the way in which products are perceived and may have an important influence on purchasing decisions;
- the number and type of cold appliance models on the EU market has increased, although there have been reductions in the number of Category 6 models (refrigerators with a 3-star frozen-food compartment) and the number of no-frost models. Sales of the former have been supplanted by sales for single-door refrigerator-freezers (Category 7), while sales for the latter have continued to increase slightly, reaching 5.1% in 1998, despite the fall in the number of models;

- the average sales-weighted price of cold appliances declined by 2.9% in real terms from 1994 to 1998 even though both the average adjusted volume and the average efficiency increased;
- sales of cold appliances increased from 16.9 million units in 1994 to 18.7 million units in 1999;
- despite some initial scepticism manufacturers have reported that the energy label is a useful tool as it provides objective differentiation between products, which helps to add value;
- manufacturer profitability, at least for the major producers, has also increased from its nadir of almost 0% in 1996 to levels of 7-8% in 2000.

The implication of these results is that both consumers and the environment have benefited from a substantial increase in cold appliance efficiency without any overt (i.e. apparent) adverse impacts on manufacturing or the cold appliance market. The fact that overall real-term cold appliance prices have not increased over this period suggests that consumers have received the benefits of increased average product efficiency almost for free. Any incremental costs that were incurred have presumably been absorbed through productivity increases in the supply of components and materials, and in the manufacturing, distribution and retail sectors.

The technical basis of the EEI and non-linear equal-effort energy-consumption reference lines

In the current energy labelling Directive the EEI is computed by determining the energy consumption of a reference cold appliance of the same type, adjusted volume and features as the appliance to be rated and then expressing the rated appliance's efficiency as the ratio of its energy consumption and the reference appliance's energy consumption. The energy consumption of the reference appliance is calculated using a linear formula of energy as a function of adjusted volume that was determined in the GEA study by linear regression on a limited database of cold appliance technical characteristics. It is likely that this method has introduced some biases due to the nature of the database and the reliance upon a statistical, rather than a physical, approach. New statistical regressions were produced in the Cold II study using far more extensive cold appliance databases that have since been assembled by the European industry association, CECED; however, it was clear from inspection of the results that the new market databases have been strongly influenced by the energy label and hence by the GEA's original regressions. Furthermore, due to the non-linear response of compressor COP with cooling capacity and the change in surface area to volume ratios as a function of appliance dimensions, there are good theoretical grounds for thinking that the expression of cold appliance energy consumption as a linear function of adjusted volume is a crude simplification of the real engineering constraints.

Given the potential for bias inherent in adopting new statistically based energy-consumption regression lines or in continuing to use the old ones in the revised labelling structure, it was considered important to explore the physical basis of these lines and to try to establish their implications for product design. A simple, physically based model was derived and used to develop lines of reference energy consumption as a function of net volume by applying the equal-effort concept. The term 'equal effort' assumes:

- insulation performance for conventional cold appliances is simply a function of the average thickness;
- as the material cost of insulation is cheap, equal insulation effort can be expressed by a constant 'foam ratio' - the share of the total external volume of the appliance minus the volume needed for the cooling system, which is taken up by insulation;
- equal cooling system COP can be expressed as a ratio of the actual COP to the Ideal COP and will follow the same functional form with load as average compressor COP does with cooling capacity.

Expressions of equal-effort load and COP were derived in terms of the internal operating temperature(s) of the appliance and the net volume of the compartment(s). Similar equal-effort expressions of auxiliary energy consumption, i.e. heaters, fans, electronics, etc., were determined as a function of net volume.

Figure 3. Linear and non-linear energy-consumption reference lines for upright freezers

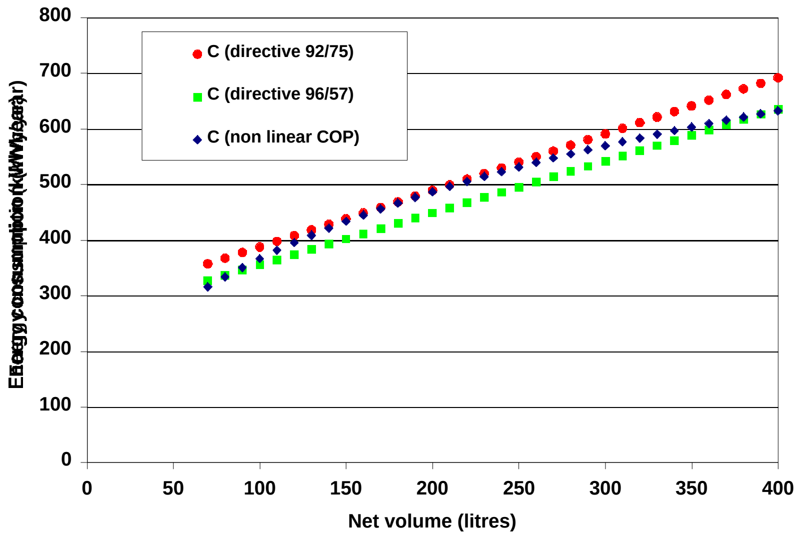


Figure 3 shows the energy consumption against net volume reference lines for an EEI of 100%, defined according to the current labelling Directive, the current minimum efficiency standard line (EEI = 91.7%) and a non-linear line of equal effort for class D products on the European market in 1999 defined using the physically based equal-effort equation. The physically based equal-effort non-linear reference line is curved and therefore indicates that the current use of a linear regression for the energy-label reference line is not technically optimised. To use a straight-line regression is to favour small- and large-volume upright freezers at the expense of the mid-volume freezers, which comprise the majority of sales. Simple refrigerators exhibit an even stronger curvature.

In theory these non-linear equal-effort equations could be used to derive physically based and unbiased expressions of cold appliance energy reference lines for use in new labelling and MEPS regulations. However, despite making initial estimates of the shapes of these lines a definitive quantification was not produced, because it would require a vast quantity of detailed data to be gathered for consensus to be attained and this was not practical within the confines of the Cold II study. Furthermore, there is a considerable institutional momentum behind the basic current approach to defining cold appliance efficiency that is well understood and accepted by industry, commerce and government and which would only render radical changes worthwhile were a very major problem identified. Nonetheless, the equal-effort formulae provide a useful tool for analysing any set of statistically derived reference lines and for proposing modifications when serious faults are found. Within the Cold II study they enabled the physical basis behind the product categorisation to be fully established, largely confirming the validity of the categorisation used in the current energy labelling and MEPS Directives.

Higher-efficiency design options

The GEA study considered the following design options to raise product energy 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). Despite the net aggregate improvements in efficiency since the time of the GEA study, all of these design options are still applicable today; however, a wider range of options is now possible, including: higher-quality insulation (vacuum insulation panels (VIPs)), 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.

In addition there are several design options that apply solely to cold appliances with a refrigerator compartment and a frozen-food storage compartment (Categories 4, 5, 6, 7 and 10). These comprise: 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; two-way refrigerant control valves with a twin evaporator system. For no-frost appliances and appliances using automatic defrosting, lower-wattage fans and intelligent adaptive defrosting also apply. There are also many minor design options that could cumulatively lead to a few percent in energy savings; e.g. optimised chimney effect for static condensers, optimised positioning of the anti-sweat liquid line around the door edges, and optimised internal airflows to reduce thermal bridging.

Least life-cycle cost and future savings potentials

Energy-engineering technical and economic analysis is an accepted technique for evaluating the costs and benefits of adopting potential higher-efficiency designs. The GEA study used energy-engineering analysis to estimate the LCCs and energy-consumption levels associated with different efficiency design options and on the basis of the findings made policy recommendations regarding minimum energy-efficiency standards. The same approach is also used to aid the evaluation of similar policy measures in many countries, most notably the USA.

In the Cold II study the energy-consumption implications of various higher-efficiency design options were evaluated using a suite of dynamic cold appliance simulation software that was specifically developed for the purpose. 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 were used to convert incremental manufacturing costs associated with higher-efficiency design options into incremental final consumer prices. In general it was assumed that there is a difference of a factor of 2.9 between the manufacturing cost and the final purchase price, which viewed from the perspective of appraising the cost-effectiveness of higher-efficiency design options is a conservative assumption and is considerably more so than the comparable assumptions made in the earlier GEA study.

All in all, the LCC analysis did not venture into 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 significant potential energy-saving technologies were not considered because of the complexity of analysing their benefits and generalising from them to all products in the same category (e.g. variable-speed compressors with electronic controls and phase-change materials in the heat exchangers, both of which are thought to have significant energy savings potentials). The approach followed differs in some other key respects from the GEA analysis:

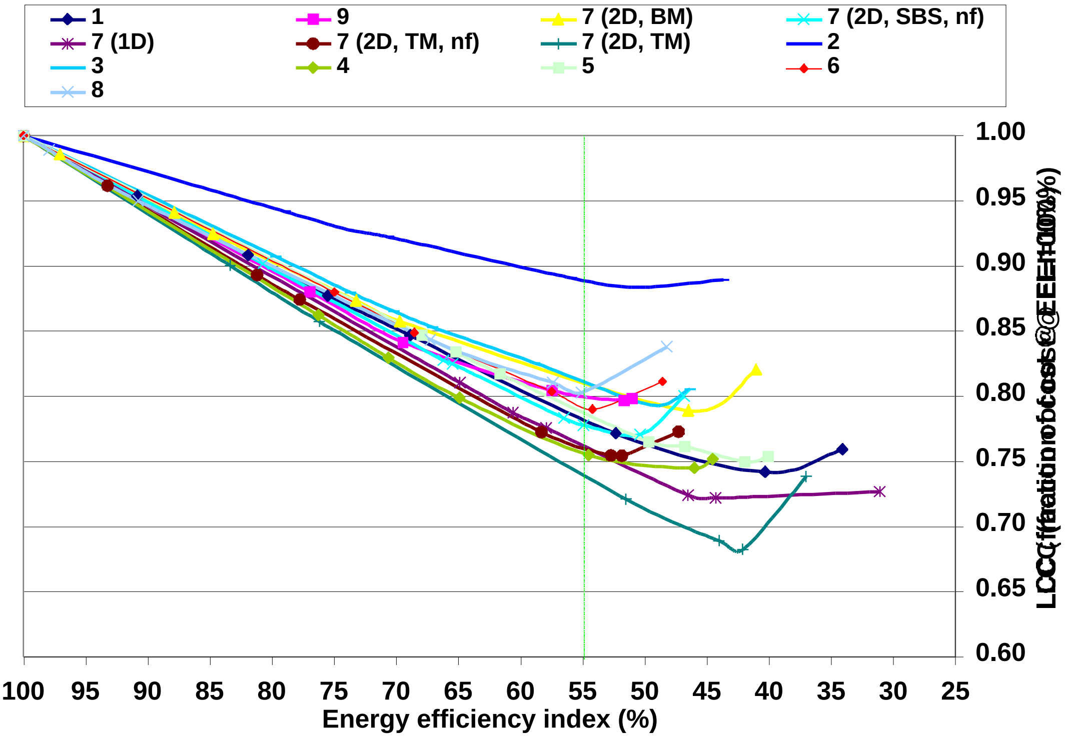
- actual base-case appliances were acquired, measured and tested to gain accurate, detailed data to prime the simulation models prior to the analysis of each higher-efficiency design option;
- the simulation tools were extensively validated against detailed test results from more than 20 cold appliances 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 wider variety of design options were considered;
- a much larger variety of appliance types were investigated;
- design-option costs were systematically critiqued and included estimates of amortised retooling, higher transportation, and labour and burden costs in addition to the standard incremental material and component costs.

As a result of this thoroughness there is a high degree of confidence in the robustness of the results, many of which can be confirmed by inspection of higher-efficiency appliances already found on the European market.

Figure 4 shows the normalised LCC as a function of EEI for each of the free-standing models analysed in the energy-engineering analysis. The normalised LCC for a given appliance category is the LCC associated with any given design option divided by the LCC estimated for an EEI of 100%. The first point on each curve is the estimated normalised LCC for an appliance with the same features as the base-case model, which is the second point on the curve, but with an EEI of 100%. It is clear that the least life-cycle cost (LLCC) occurs for an EEI of 55-40% for all the cold appliance categories and subcategories.

Figure 4. Normalised life-cycle cost (LCC) as a function of energy-efficiency index (EEI) for each cold appliance (identified by Category number) in the energy-engineering analysis.

The base-case model is the second point on each curve. The first point is the estimated LCC of the given appliance with an EEI of 100% and is derived by linear interpolation. The normalised LCC is the LCC at any given point divided by the LCC estimated for an EEI of 100%. (1D = one door; 2D = two doors; TM = top-mounted frozen-food compartment; BM = bottom-mounted frozen-food compartment; SBS = side-by-side; nf = no-frost)



The results show that:

- the estimated sales-weighted average EEI for all cold appliances at the point of LLCC is 46.8%[1]
- the LLCC occurs for appliances that are rated A class or better for all categories except built-in upright freezer, which have an EEI of 56.2%;
- the most efficient cold appliances on the market in 1999 had EEIs of 31% for refrigerators, 29.6-34.6% for refrigerator-freezers and 39% for freezers; thus the estimated LLCC efficiency level is exceeded by the most efficient models on the market;
- the EEI at the LLCC 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;
- appliances designed to reach the LLCC efficiency level would be expected to cost an average of 23 Euro more to manufacture and 66 Euro (15%) more to purchase (assuming that 100% of the incremental costs are passed on to the consumer and that a multiplicative factor of 2.9 exists between manufacturing cost and retail price) compared to those that just satisfy the 1999 MEPS; however, they would avoid electricity costs worth an average of 24.7 Euro per year or 272 Euro over a typical 15-year product lifetime. The average payback time for the consumer would be 2.7 years assuming a 5% real discount rate;
- the sales-weighted average energy consumption of cold appliances that just satisfy the 1999 MEPS level is ~422 kWh/year, of those at the class A threshold ~255 kWh/year and of those at the LLCC efficiency level ~216 kWh/year;
- over its lifetime a typical cold appliance at the 1999 MEPS level would give rise to 3089 kg of indirect CO_2 emissions, at the class A threshold to 1867 kg and at the LLCC efficiency level to 1581 kg assuming EU average CO_2 emissions per kWh consumed.

It is clear that the LLCC is a moving target, and that as technologies improve and production volumes of high-efficiency components increase the EEI which gives the LLCC for the consumer will decline. An additional energy-engineering analysis was conducted to estimate the expected maximum conceivable medium- to long-term efficiency levels for the main types of cold appliance. It is estimated that the lowest technically achievable EEIs in the medium to long term are 16–18% for refrigerators, 19–23% for refrigerator-freezers and 22-26% for freezers.

6. POLICY CONSIDERATIONS

The need to revise the energy label and current MEPS requirements is clear. The cold appliance energy label was the first energy label to be implemented under the terms of the energy-labelling framework Directive 92/75/EEC and is now well established; however, since the introduction of MEPS the effectiveness of the current label has been compromised as only the top three classes are permissible for the majority of cold appliance types. Despite substantial recent improvements in cold appliance energy efficiency, stimulated by the energy labelling and MEPS Directives, there are very considerable savings potentials which remain unrealised.

The European Commission has indicated that any CO_2 abatement measures that cost less than 50 Euro per tonne of avoided CO_2 are 'viable' measures for inclusion in the Community's CO_2 reduction programme.[7] Policy measures aimed at improving appliance efficiency are some of the few CO_2 abatement measures that can produce substantial CO_2 savings at a lower net cost to consumers and society than would occur if the measures were not implemented, i.e. the net cost of avoiding CO_2 is negative. Consequently, policy measures that accelerate energy savings in this sector are 'win-win' measures and therefore should be vigorously pursued.

Relationship between new policy measures and Kyoto targets

In general it can be said that the EU is not on track to meet its CO_2 reduction commitments under the Kyoto agreement. The European Commission has estimated that 440 Mt of CO_2 emissions will need to be avoided each year from 2000 to 2010 to meet the commitments of an 8% cut compared to 1990 levels by 2010.[8] Eventually, if all new cold appliances were to be at the LLCC efficiency level, 22.6 Mt of CO_2 per year would be saved compared with the average estimated efficiency levels of appliances available for sale in 2000; however, new appliances take time to work their way into the stock. As this turns over at a rate of roughly one-fifteenth every year, even if all new models sold between 2000 and 2010 had an efficiency at the LLCC level it would save only 89 Mt of CO_2 compared with if they were at the estimated average efficiency of the market in 2000. More plausibly, if an LLCC efficiency standard were to be introduced at the earliest imaginable date of 2004, the total savings by 2010 are estimated to be ~44 Mt of CO_2, equivalent to 1% of the required EU total savings over the same period. Thus, new policy measures need to be implemented rapidly and stringently if cold appliances are to make the contribution they are capable of to the Community's CO_2 reduction targets.

Other factors to be considered in policy development

In framing a revised set of policies it is important to evaluate the various impacts and consequences of the measures under consideration and to prioritise them to give a balanced outcome. The policy recommendations delivered in the Cold II study were made after careful consideration of the extent to which they would deliver the energy, CO_2 and cost saving potentials that were identified in the technical, economic and environmental-impact analyses of the study, and the impact that the policies would be likely to have on manufacturers, retailers, consumers and society as a whole. The support that the policy gives to the EU's climate change programme is a paramount concern and so it is important to consider the role that efficient cold appliances can play in reducing total domestic electricity demand.

Nor are the implications of implementing any set of policy measures confined to the current EU. The EU Accession States of Bulgaria, the Czech Republic, Estonia, Hungary, Lithuania, Poland, Romania, Slovakia and Slovenia, comprising a population of more than 100 million, have all enacted or are considering enacting EU efficiency regulations for cold appliances. These states are likely to formally accede to the EU within the coming years and are therefore likely to adopt any new regulations passed within the EU in the interim, thereby greatly expanding the impacts. Furthermore, China has based its new cold appliance MEPS on the EU's energy-efficiency formulations, and some of the Middle Eastern and North African states are considering adoption of the EU regulations. Argentina has drawn up legislation to implement the EU cold appliance energy label and both Brazil and Iran have copied the format of the EU label for their own energy-labelling schemes.

7. POLICY RECOMMENDATIONS

The Cold-II study recommends implementation of the following mix of policy measures:

- the introduction of a new round of mandatory MEPS in 2005 set at the current class A efficiency threshold (i.e. a maximum EEI of 55%);
- the issuance of a revised energy label in 2002 with a fully sales-active A-G scale that has a maximum class A EEI threshold of 30% and a class G threshold of ~80% (two potential structures are equally recommended);
- the negotiation of a voluntary agreement with industry for the fleet-average efficiency of cold appliances to reach the LLCC level by 2005.

Revised energy label

Two appropriate labelling structures have been devised and are equally recommended (Table 1). Both alternatives have 7 active label classes and set the new A and G thresholds, respectively, at an EEI of 30% and ~80%. The main difference between the schemes is that the linear proposal applies a fixed 10% EEI step between adjacent classes, whereas the geometric proposal applies a geometric progression where the relative efficiency improvement is ~18% between adjacent classes.

Table 1. Linear and geometric-progression proposals for a revised energy-label structure using linear energy-efficiency index (EEI) class widths and a relative efficiency improvement of ~18% between label classes, respectively.[1]

Linear proposal			Geometric proposal		
Class	EEI	Relative improvement	Class	EEI	Relative improvement
A	I < 30	B to A = 25%	A	I < 30	B to A = 19%
B	30 _ I < 40	C to B = 20%	B	30 _ I < 37	C to B = 18%
C (A)	40 _ I < 50	D to C = 17%	C	37 _ I < 45	D to C = 17%
D (A + B)	50 _ I < 60	E to D = 14%	D (A)	45 _ I < 54	E to D = 18%
E (B)	60 _ I < 70	F to E = 13%	E (A + B)	54 _ I < 66	F to E = 19%
F (B + C)	70 _ I < 80	MEPS to F ~11%	F (B + C)	66 _ I < 81	MEPS to F ~10%
G (C + D)	80 _ I		G (C + D)	81 _ I	

Abbreviation: MEPS = minimum energy performance standards.

[1] The current label classes are shown in parentheses.

Before comparing the pros and cons of these two proposals it is worth considering why a G threshold of ~80% and an A threshold of 30% are appropriate. The current MEPS levels for N climate-class appliances are set at ~88% for the majority of cold appliance types. Setting the new G at ~80% means there would be some sales-active G-class products in all product classes at the beginning of the new scheme. Furthermore, a 7% gap in EEI between the current MEPS level and the new F level is sufficiently large to require a real design change to reach the next step.

A 30% EEI threshold for the new class A is appropriate because the technical analysis has shown that it is ambitious but certainly possible to attain, which is attested to by the existence of a small number of products with EEIs at or very close to this level. The technical analysis has also shown that significantly higher efficiency levels are conceivable in some years from now, or even today if expense were no object. In fact, determining the most appropriate level for the top efficiency class involves balancing trade-offs between a number of factors. The whole success of the labelling scheme lies in it giving sufficient reward, through product differentiation and marketing value, to manufacturers who make the investment in higher-efficiency products. If a low- or intermediate-ambition labelling scheme is proposed it will have a short useful life as the top labels will quickly saturate and it will therefore need to be revised sooner than a more ambitious scheme; however, this will leave manufacturers with stranded assets as those who have invested in producing A-class products will be left with investments in product platforms that are no longer giving the returns typical for class A products. Thus, opting for a less ambitious but more frequent revision of the labelling scheme will discourage participation. Conversely, opting for an extremely ambitious A is also likely to discourage participation and therefore be self-defeating, because manufacturers will be pessimistic regarding the size of the mass market prepared to buy top-efficiency products at the implied additional costs and will be deterred from making the required investments. Thus, in order to underwrite manufacturer investments, and hence to maximise participation, an ambitious, but not unreasonable, new A class is proposed at a 30% EEI with a minimum of 6 years' duration.

Class A MEPS and a fleet-average voluntary agreement

While a revised energy label should provide market pull for higher-efficiency products it has no guaranteed impacts and does not remove the less efficient products from sale. The certainty of knowing that efficiency savings will be delivered can only be provided by renewing the current mandatory MEPS. The current class A threshold (EEI = 55%) is selected as the best compromise between the desire to reach LLCC, or higher, efficiency levels and the needs of industry for the following reasons:

- the energy-engineering analysis has shown that the LLCC occurs at an EEI of 55% or below for all free-standing products and that the sales-weighted average EEI across all product types is 46.8%. This means that it is strongly in the consumer's own economic interests to buy an appliance with at least A-class efficiency;
- the consumer-investment payback periods are favourable;
- the guaranteed energy, cost and CO_2 savings are significant and complement the other proposed policy measures;
- the impact on manufacturers is uncertain but is unlikely to be strongly negative because:
  - the statistical analysis showed that the current class A is a readily attainable efficiency threshold for all product classes and that a growing share of models with this efficiency level or better are entering the market;
  - all manufacturers are currently making some class A products, some almost exclusively class A, and most will already have plans to extend their range of class A products;
  - the class A target can be reached by all cold appliance types and all manufacturers have the required knowledge base to replace non-compliant products with class A products;
  - there will be ample forewarning to make all necessary investment and production preparations if a quick decision is made to introduce MEPS in 2005;
  - the minimum targets will apply to domestically produced and imported products alike, whereas a voluntary agreement cannot deliver this;
  - setting the MEPS threshold at class A guarantees significant energy savings but will leave manufacturers with a substantially smaller proportion of stranded assets than if the level had been set just a few EEI percentage points lower;
  - setting the MEPS threshold at an EEI of anything between ~70% and 55% makes little difference to the level of manufacturer stranded assets because almost all class B products have an EEI between 75% and 70%; however, it makes a big difference with respect to the level of guaranteed energy savings;
  - increases in component and materials costs are moderate;
  - overall sales volumes are unlikely to be significantly affected;
  - there are reasonable prospects for recovering incremental costs.

Although minimum attainment of the current class A will bring significant benefits, these are not sufficient in themselves to bring the market to the efficiency levels associated with the consumer's LCC optimum and even less so to the least societal cost level that is implied by internalising the value of externalities (i.e. through adding the value of avoided CO_2 emissions costs). The revised energy label is likely to provide a strong incentive for manufacturers to produce models with higher efficiencies than the estimated consumer LLCC levels. This is especially likely for those manufacturers who position their products with a green or top-range image. In order to bring maximum benefits the Cold II study recommends that efforts be made to complement the new MEPS and energy-labelling regulations with a negotiated agreement with industry for the fleet-average (sales or production-weighted) efficiency of new cold appliances to reach the levels associated with the consumer LLCC by 2005. A negotiated fleet-average-LLCC agreement underwritten by class A MEPS would allow industry to demonstrate willingness to contribute to Community societal goals but, in conjunction with the revised energy label, would give them more freedom to differentiate their products than if new MEPS were applied at the LLCC level. It would also avoid penalising manufacturers who have already invested in attaining the highest efficiency levels thus far defined by the Community's policies.

Product categories, adjustments in energy-consumption reference lines and feature correction factors

The study also recommends that the same ten categories of cold appliance currently defined in the energy labelling and MEPS Directives continue to be used in the revised schemes but that some adjustments be made to the energy-consumption reference lines and adjusted-volume correction factors to take account of biases and features. The technical analysis of the energy-consumption reference lines used to define the EEI in the current schemes showed that there is a bias against refrigerators with 3-star frozen-food compartments (Category 6) compared to equivalent-sized refrigerator-freezers (Category 7). The two categories are almost technically identical but the former are required to meet much more stringent energy levels to attain the same label rating. Despite the conclusion that linear energy reference line equations were not optimal, as previously alluded, there were insufficient resources available to conduct all the analyses needed to determine the precise shape of the curves and so it was recommended to continue using the current linear regression lines with some modifications:

- the energy consumption as a function of adjusted volume reference line for upright freezers (Category 8) should be raised by 10% to take account of the greater technical difficulty in attaining a low EEI for this appliance compared to the other cold appliance categories;
- the refrigerator-freezer (Category 7) energy-consumption reference line equation should also be applied to refrigerators with 3-star frozen-food compartments (Category 6) to correct the current bias against these appliances.

The study makes the following recommendations regarding adjusted-volume correction factors:

- the no-frost correction factor should be maintained at 1.2 for use in the revised MEPS to respect the range of incremental energy-consumption levels implied by this technology as a function of the different service it provides; however, it should not be applied for energy labelling as it is likely to mislead consumers who wish to compare the energy performance of conventional natural-convection cooling appliances with that of no-frost appliances;
- correction factors for ST and T climate-class appliances are not required and could potentially encourage poor design and the proliferation of appliances with this climate classification being sold in temperate Europe;
- built-in appliances should receive an adjusted-volume correction factor of 1.2 to compensate for the technical limitations some of them have in attaining higher efficiency levels due to space constraints. In this case it makes sense to apply the correction factor in both the energy labelling and MEPS schemes as built-in cold appliances are not in direct competition with free-standing cold appliances.

For each category a single straight line defines the maximum permissible energy-consumption level as a function of the adjusted volume. The formulae defining the recommended MEPS (actually a maximum energy consumption standard) and energy-label reference lines are shown for each of the ten primary categories of cold appliance. The A–G efficiency classes for the recommended new energy label are defined for each cold appliance category in terms of the energy-efficiency index, I, as given in Table 1. I is defined as the electricity consumption of the cold appliance measured according to EN 153 divided by the energy consumption for a unit of the same adjusted volume, as derived from the energy-label reference line given in Table 2, and is expressed as a percentage.

The details of the energy-labelling and MEPS recommendations are summarised in Table 2.

Table 2. Recommended new cold appliance minimum energy performance standards (MEPS) and energy-label reference lines

Product class and description	Category no.	_ (equivalent to W_c)	Maximum allowable energy use (kWh/year)[1] MEPS for 2005	Energy-label reference line[2] for 2002
Freezers				
Chest freezers	9	2.15	0.245AV+99.6	0.446AV+181
Upright freezers	8	2.15	0.285AV+173	0.519AV+314
Refrigerators and refrigerator-freezers				
Refrigerator without FFC[3]	1	1.00	0.128AV+135	0.233AV+245
Refrigerator/chiller[4]	2	0.75	0.128AV+135	0.233AV+245
Refrigerator with 0-star[5] FFC	3	1.25	0.128AV+135	0.233AV+245
Refrigerator with 1-star FFC[6]	4	1.55	0.354AV+105	0.643AV+191
Refrigerator with 2-star FFC[7]	5	1.85	0.248AV+135	0.450AV+245
Refrigerator with 3-star FFC[8]	6	2.15	0.427AV+167	0.777AV+303
Refrigerator with 4-star FFC[9]	7	2.15	0.427AV+167	0.777AV+303
Refrigerators with 3 or more doors and other appliances	10	= (25–T_C)/20	0.128AV+135[10]	0.233AV+245[10]
			0.354AV+105[11]	0.643AV+191[11]
			0.248AV+135[12]	0.450AV+245[12]
			0.427AV+167[13]	0.777AV+303[13]
			0.427AV+167[14]	0.777AV+303[14]

[1] The value given by the formula is to be compared against the measured rating under the test protocol EN 153. AV is the adjusted volume given by AV = _ V_c _ W_c _ F_c _ B_c as summed over all compartments in the appliance, and where:

- V_c = the net volume of a given type of compartment in the appliance;
- W_c = the temperature weighting coefficient for that type of compartment (equal to (25–T_c)/20, where T_c is the compartment design temperature);
- F_c = 1 for all compartments when determining the adjusted volume for use in the revised energy-label ratings. When determining the adjusted volume for the revised MEPS, F_c = 1.2 for no-frost frozen-food storage compartments and for no-frost fresh-food storage compartments that share the same evaporator as a frozen-food compartment in a refrigerator-freezer combination; F_c = 1 for all other compartments;
- B_c = 1.2 for built-in appliances with a width and depth of less than 60 cm (excluding built-under units) and 1 for all other appliances (including built-under units).

[2] The line defining an energy-efficiency index of 100%.
[3] FFC = frozen-food compartment, referring to any compartment operating at less than 0_ C. Normal refrigerator compartments are designed to operate at 5_ C.
[4] Refrigerator/chillers have a compartment designed to operate at internal temperatures of 12 _ C; they may or may not include a 5_ C refrigerator compartment.
[5] 0-star compartments are designed to operate at –6_ C < Tc < 0_ C.
[6] 1-star compartments are designed to operate at Tc _ –6_ C.
[7] 2-star compartments are designed to operate at Tc _ –12_ C.
[8] 3-star compartments are designed to operate at Tc _ –18_ C.
[9] 4-star compartments are designed to operate at Tc _ –18_ C and to freeze >4.5 kg of food per 100 litres of storage capacity from 25_ C to -18_ C within 24 hours.
[10] For multi-door models where the temperature of the coldest compartment is _–12_ C.
[11] For multi-door models where the temperature of the coldest compartment is >–6_ C.
[12] For multi-door models where the temperature of the coldest compartment is _–18_ C.
[13] For multi-door models where the temperature of the coldest compartment is _–6_ C.
[14] For multi-door models where the temperature of the coldest compartment is _–18_ C and the compartment can freeze > 4.5 kg of food from 25 _ C to –18_ C within 24 hours.

Impacts of recommended policies

The policy scenario analysis conducted in the Cold II study shows that if the average efficiency of new appliances sold in the EU were to move to the LLCC by 2005, the eventual CO_2 savings from the new appliances sold up to 2020 would be 419 Mt compared with what would occur if the average efficiency were to remain at the year 2000 level. This is equivalent to removing 140 million cars from Europe's roads for 1 year, or 7 million over the entire 20-year scenario period. However, far from incurring costs to society of 21 billion Euro (i.e. those equivalent to 50 Euro per tonne of avoided CO_2), the net present value cost to society from this change is negative to the value of 83.7 billion Euro. This is equivalent to saving each household in the EU ~533 Euro over the period, or some 27 Euro per year. This calculation does not include the positive value of any avoided externality costs such as avoided pollution costs but is simply based upon offsetting the discounted net present value of the avoided electricity costs by the increment in cold appliance purchase prices.

In fact it is unlikely that cold appliance energy efficiency would remain static after 2000 if no new policy measures are introduced. Ongoing technological progress will reduce the cost of making efficient appliances and raise manufacturer design options, while older, less efficient product lines will be retired at the end of their normal commercial life and most likely be replaced by platforms designed for the production of A- or B-class products, as has already happened to a considerable degree. If savings from moving the average efficiency of new cold appliances to LLCC levels by 2005 are compared with this 'business as usual' case it is forecast that the eventual CO_2 savings from cold appliances sold up to 2020 would be 255 Mt. Net present value LCC savings of 47.8 billion Euro are projected from sales made in the 2000–20 period.

The impact on manufacturers is not so simple to assess because there is difficulty in appraising real cost structures and, particularly, in assessing dynamic market responses. A key factor is the degree to which incremental production costs can be passed on to retailers and eventually the consumer. In the longer term higher efficiency requirements may assist in raising the general competitiveness of the European industry and may encourage a greater share of the employment within it to be in highly skilled positions, which could help its long-term future.

8. CONCLUSIONS

The Cold II study found that despite the significant improvements in average cold appliance efficiency which have been stimulated by the current energy labelling and MEPS regulations, there remains a very significant potential for further improvements. A mixture of a revised energy label, new underpinning MEPS and a negotiated voluntary agreement with industry are proposed as the policy mix best able to bring the market to LLCC efficiency levels in a timely and relatively painless way. The benefits from enacting these measures include CO_2 cuts equivalent to permanently removing 4.3-7.0 million cars from European roads and giving consumers net present value savings of 48–84 billion Euro over the period 2000-20.

9. REFERENCES

[1] Commission Directive 94/2/EC of 21.1.94 implementing Council Directive 92/75/EEC with regard to energy labelling of household electric refrigerators, freezers and their combinations.

[2] Parliament and Council Directive 96/57/EC of 3.9.96 efficiency requirements for household electric refrigerators, freezers and their combinations.

[3] *Study on energy efficiency standards for domestic refrigeration appliances*, Group for Efficient Appliances for DG-XVII of the European Commission, March, 1993.

[4] *Cold II: The revision of energy labelling and minimum energy performance standards for domestic refrigeration appliances*, PW Consulting on behalf of ADEME, with Novem, Ecole des Mines de Paris, VHK, ENEA and TNO and assistance from CECED and AHAM for DG-TREN of the European Commission, SAVE contract No. XVII/4.1031/Z/98-269, December 2000.

[5] *Monitoring of energy-efficiency trends of European domestic refrigeration appliances: final report*, PW Consulting and ADEME for DG-XVII of the European Commission, SAVE contract No. XVII/4.1031/D/97-021, 1998.

[6] *Monitoring of energy efficiency trends of refrigerators, freezers, washing machines and washer-dryers sold in the EU*, PW Consulting and ADEME for DG-TREN of the European Commission, SAVE contract No. XVII/4.1031/Z/98-251, 2000.

[7] Communication from the Commission to the Council and the European Parliament on EU policies and measures to reduce greenhouse gas emissions: Towards a European Climate Change Programme, 2000.

[8] Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions. Action Plan to Improve Energy Efficiency in the European Community, COM(2000) 247 final, Office for Official Publications of the European Communities, Brussels, 26 April 2000.

10. END NOTES

[1] 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.