proposal for revision of volatility classes in EN 228 specification in light of EU fuels directive

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ABSTRACT

CONCAWE has reviewed the current gasoline volatility specifications within EN228 relating to hot weather driveability, i.e. RVP, E70 and Vapour Lock Index (VLI), in anticipation of changes to volatility characteristics after year 2000, due to the impact of the new EU Fuels Directive (98/70/EC).

This study utilises the assessment of the hot weather driveability (or Hot Fuel Handling (HFH) performance of current European vehicles and the trends of current and year 2000 car populations to determine the volatility requirements of individual European markets for year 2000. The generation and interpretation of such data is based upon extensive knowledge in this field accumulated by member companies over many years.

Along with appropriate consideration of future trends in gasoline composition, the study leads to the conclusion that for year 2000 summer volatility classes, a VLI specification is no longer necessary. Data also shows that for other seasons volatility classes (non-summer time), a VLI specification is also generally no longer necessary. Only during the transition periods between summer and winter for four markets, identified as critical, might a VLI be used as an alternative solution to ensure satisfactory driveability.

This report had been made available to CEN / TC19 / WG21 during their review of EN 228 and contains total customer satisfaction curves as a means of allowing the appropriate selection of volatility classes for individual European markets in accordance with their climatic variation and car populations. Further proposals for changes to year 2000 volatility, in addition to VLI removal, are included in this report.

Due to the proposed increase in minimum levels of E70 and E100, in addition to the introduction of an E150 minimum limit, the new version on EN 228 should improve the cold weather driveability performance of gasoline vehicles.

KEYWORDS

Gasoline volatility, volatility classes, Vapour Lock Index, EN 228, gasoline specifications, hot fuel handling, hot weather driveability, EU Fuel Directive, market satisfaction for hot fuel handling

SUMMARY

The European Standardisation Committee (CEN) has the task of harmonising the fuel compositional changes, as defined in the EU Fuels Directive for 2000 (98/70/EC), within a new European Standard for 2000. Accordingly, CEN is revising the year 2000 EN 228 gasoline specifications, which were established for the first time as a European standard in 1993.

CONCAWE has reviewed the volatility specifications related to hot weather driveability, i.e. RVP, E70 and Vapour Lock Index, in anticipation of changes to volatility characteristics after year 2000 due to the impact of the new EU Fuels Directive. In particular, restrictions on maximum content of olefins, aromatics and benzene will require changes in refinery processing and a need for increased use of lower boiling blending components, which would be constrained by the current volatility specifications after year 2000. An example of this is the parameter, E70.

In view of this, CONCAWE has calculated volatility levels which will ensure customer satisfaction of hot weather driveability in individual European countries during their different seasons. By specifying adequate volatility specifications, the occurrence of hot weather driveability will be avoided and satisfactory performance ensured.

CONCAWE's predictions of customer satisfaction for hot fuel handling are based on a database containing many hundreds of vehicles tested over many years representing a wide selection of engine technology (carburetted, multi-point injection (MPI) and single-point injection (SPI). These include an assessment of vehicles' sensitivity to a wide range of fuel volatility at ambient temperatures representative of the European market. Using vehicle population data for individual markets and average monthly maximum temperatures of any individual month of that market (equivalent to around 95%ile highest temperature), technical satisfaction levels are established to calculate lines of total customer satisfaction for year 2000. These total customer satisfaction lines were generated for 14 European markets, for the most relevant months, as a means of allowing the appropriate selection of volatility classes.

The analysis of the hot weather driveability (or Hot Fuel Handling (HFH)) performance of the year 2000 car population of different European markets leads to the conclusion that for year 2000 summer volatility classes, a VLI specification is no longer necessary. Also for other seasons volatility classes (non-summer time) a VLI specification is also generally no longer necessary. However, the transition periods, between summer and winter, of four markets were identified as critical, Finland, France, Greece and Portugal. Here alternative solutions, such as a VLI for those months, are required to also ensure that total customer satisfaction is maintained.

The study also demonstrates that the maximum E70 limit can be raised slightly to 48% v/v for summer classes and to 50% for other seasons, without compromising hot driveability performance. This will ease some constraints of gasoline manufacturing which result from restrictions on year 2000 maximum content of olefins, aromatics and benzene. CONCAWE proposes also to increase the minimum RVP specifications for the revised volatility classes to reflect concerns over fuel tank vapour space flammability during cold spells. An increase in E100 maximum is proposed, reflecting the need to compensate for compositional changes induced by the EU Fuels Directive.

Cold starting and cold weather driveability performance of vehicles were also reviewed in view of the proposed modifications, and were found not to be significantly affected by RVP, but controlled by higher distillation points. It was therefore concluded that cold weather driveability performance should improve in year 2000, due to the increase in E70 and E100, together with the introduction of an E150 minimum limit, in the new version on EN 228.

CONCAWE has made available their proposed volatility classes with detailed technical background documentation to the experts of Working Group 21 of CEN / TC19 to serve as guidelines for the respective revisions of EN 228.

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1. INTRODUCTION

Gasoline volatility specifications in CEN were originally set on the basis of a report CR 262 "Volatility of Petrol" which concluded that limits should be set for RVP min/max., E70 min/max., E100 min/max., E180 min. and FBP max.. It also stated that hot fuel handling performance should be controlled by limits to Vapour Lock Index (VLI) where VLI = RVP(kPa) x 10 + 7 x E70. After long debate, a series of eight volatility classes were agreed for the EN 228 specification with limits for RVP, E70 and VLI, with CEN member countries allowed to choose up to 3 classes to cover their climatic variation.

The new EU Fuels Directive for 2000 (98/70/EC) specifies RVP at a much lower level of 60 kPa max. for the summer period, beginning no later than 1 May and ending not before 30 September. For markets with arctic conditions, RVP will be limited to 70 kPa max. for a summer period beginning no later than 1 June and ending not before 31 August (minimum 3 months). This means that some of the existing volatility classes must be changed to come into line with the new EU limits, and as such, allows an opportunity to re-examine volatility limits for both summer and winter.

While the report focuses on hot fuel handling (or hot weather driveability) performance of European vehicle fleets to propose revised volatility classes in EN 228 specification for year 2000, it also reviews possible effects of such revisions on cold starting and cold weather driveability.

2. BACKGROUND TO HOT FUEL HANDLING (HFH)

If there is a mis-match between the maximum ambient temperature in which a vehicle is expected to operate and the fuel volatility it uses, then Hot Fuel Handling (or hot weather driveability) malfunctions can be experienced. These problems are caused by overheating in the vehicle fuel system leading to vaporisation of the gasoline. This can cause problems with fuel pumps and metering systems (injectors or carburettors) which are designed to handle liquid fuel and cannot cope with vapour. The problems which affect fuel systems can be categorised as:

Carburettor Percolation: Fuel boiling in the float-bowl during a hot-soak forces excess fuel through the jet into engine, which is hard to restart due to an ***over-rich*** mixture.

Carburettor Foaming: Superheated fuel boils as it enters the float-bowl, generating foam in which the float sinks, opening the needle valve and allowing more fuel to enter. Foam blocks the vent causing the float bowl pressure to rise and forcing excess fuel through the jet into the engine. The engine will not run due to an ***over-rich*** mixture.

Fuel Pump/Injector Vapour Lock: Fuel boils in the pump, fuel rail or injectors, forming slugs of vapour which prevent the carburettor or injectors from metering liquid fuel. The engine will not start or misfires due to an ***over-lean*** mixture.

Modern multi-point electronic fuel injection (EFI) engines are much less prone to all HFH problems than carburetted engines. This is mainly because of the higher operating pressure of the fuel system (preventing vaporisation) and re-circulation systems which serve to cool the injectors and dissipate heat energy into the fuel in the tank. Therefore modern vehicles are much more tolerant of hot conditions and high volatility fuels and there are very few cases of HFH problems in the market.

The effect of fuel properties on HFH has been widely studied (see below) and the key parameters are as follows:

$T_{V/L(X)}$ Temperature to give Vapour/Liquid Ratio (x): x can be 10 to 40, but typically 20. This correlates well with HFH, and is used in US ASTM specification. However it is hard to measure, and is generally calculated from a nomogram.

VLI (Vapour Lock Index) or FVI (Flexible Volatility Index) = RVP (kPa) x 10 + 7 x E70 : This index was developed in the 1970s and correlates with $T_{V/L(X)}$. It is generally accepted as the best parameter to describe fuel hot-weather performance of current vehicles (1)[1].

ASVP at 100°C: This has been proposed as an alternative to VLI, but oil industry tests have shown it gives no better correlation with HFH than VLI.

[1] numbers in brackets designate references given in section 9

3. CURRENT FUEL SPECIFICATIONS AND FUTURE DEVELOPMENTS

Current CEN Volatility specifications are shown in **Table 1**.

Table 1 Current CEN EN 288 Volatility Specifications

CLASS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RVP hPa	350-700	350-700	450-800	450-800	550-900	550-900	600-950	650-1000
E70 %v/v	15-45	15-45	15-45	15-45	15-47	15-47	15-47	20-50
VLI max.	900	950	1000	1050	1100	1150	1200	1250
E100 %v/v	40-65	40-65	40-65	40-65	43-70	43-70	43-70	43-70
E180 %v/v min	85	85	85	85	85	85	85	85
FBP °C max.	215	215	215	215	215	215	215	215
Residue %v/v	2	2	2	2	2	2	2	2

Volatility characteristics will change after year 2000 due to the impact of the new EU Fuels Directive. In particular, restrictions on maximum content of olefins (18% v/v), aromatics (42 %v/v) and benzene (1 %v/v) will require changes in refinery processing. There will need to be increased use of lower boiling blending components, such as isomerate and MTBE. CONCAWE studies show that because of these changes to gasoline production, the current limit on maximum E70 (45 - 47% v/v) will be constraining after year 2000. Therefore the needs of the European car parcs have been analysed for year 2000, for individual countries. The parc response to fuel volatility has been determined to predict whether the current E70 and VLI limits are still necessary to maintain problem-free hot fuel handling performance and to assess if there is scope for relaxation.

4. SUMMER VOLATILITY SPECIFICATIONS

4.1. BACKGROUND INVESTIGATION

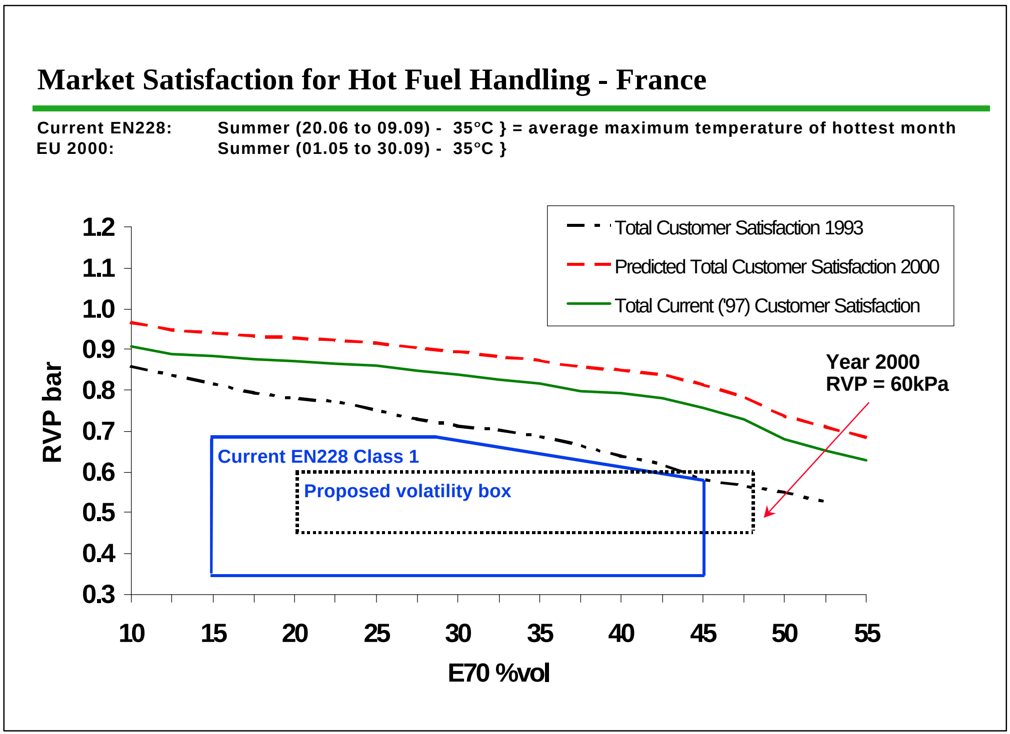
In order to fully understand where the current volatility classes within EN 228 are in relation to driveability satisfaction levels, and to determine future volatility requirements, a detailed investigation was carried out at one of CONCAWE's member companies. The company operates a technical facility that can determine the level of driveability satisfaction of any western European market, for any fuel volatility, based on vehicle performance and vehicle population data for that market.

Vehicle performance data are generated through participation in an inter-industry working group, whose purpose is to generate both hot and cold weather driveability data on a selection of vehicle technologies representative of the European market at different ambient temperatures. These vehicles are assessed for their sensitivity to a wide range of fuels of different volatility. The company's in-house database contains many hundreds of vehicles tested over many years. These performance data when linked, on a market weighted basis, with the vehicle population data and an accurate ambient temperature profile of a region, allow hot weather driveability technical satisfaction levels to be generated for any combination of ambient temperature and volatility. In this analysis, the average monthly maximum temperature at the hottest location in a market is used to define either the hottest month in the season under review, e.g., as shown for the summer below, or for individual months, as specified for other seasons (Figure 2 and Appendix 1). These technical satisfaction levels are then used to determine levels of market satisfaction as explained in further detail in Appendix 2.

4.2. ANALYSIS

This exercise was carried out for 14 European markets: Austria, Benelux, Denmark, Finland, France, Germany, Greece, Italy, Norway, Portugal, Spain, Sweden, Switzerland and UK. For each of these markets, the current EN 228 summer volatility classes were superimposed on the driveability satisfaction plot, at the highest summer season average monthly maximum temperature. This was carried out for 1993, "current" 1997 and a projected year 2000 vehicle fleet which is based on changes in vehicle fleet hot driveability performance extrapolated from current trends as explained in Appendix 2. An example of a single market, France, is shown below in Figure 1.

Figure 1 France - Summer Market Satisfaction for Hot Fuel Handling

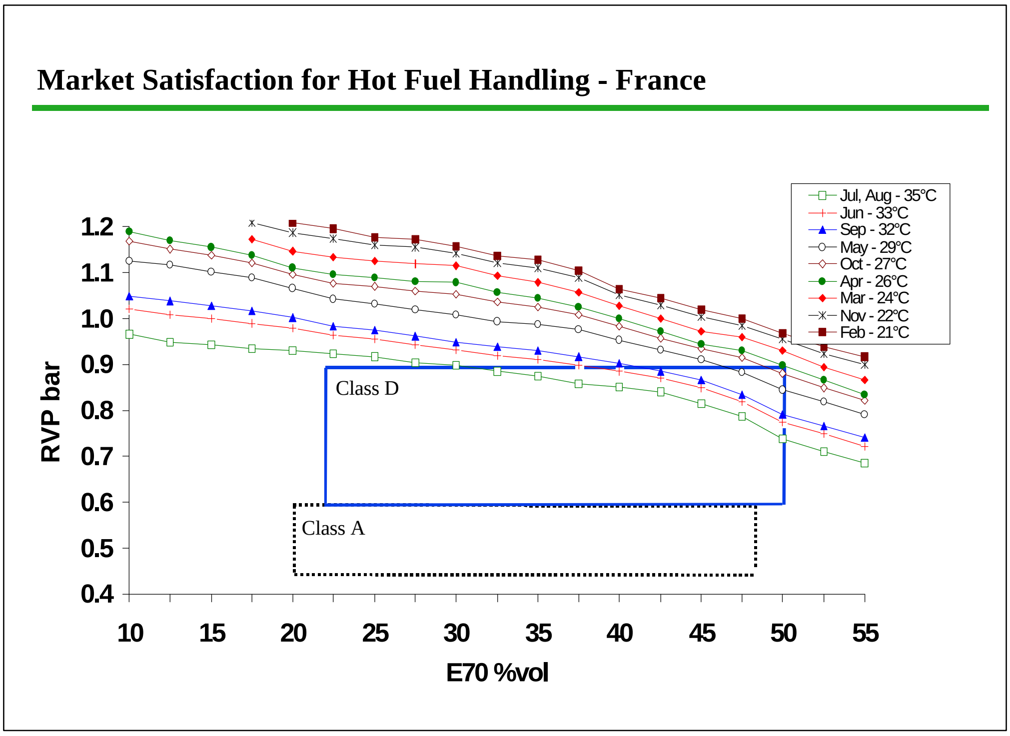


The French car parc contains a significant number of older vehicles which are fitted with carburetted fuel systems and in combination with high summer temperatures are more likely to exhibit hot driveability malfunctions referred to above. Figure 1 clearly shows that the volatility class chosen in 1993, Class 1, was closely aligned with the vehicle requirements, and was thus suitable for the French car parc at that time. This demonstrates the validity of the customer satisfaction analysis, as further described in Appendix 2. However as discussed below vehicle hot driveability performance has improved substantially in recent years due to the progressive replacement of carburetted vehicles by those fitted with EFI, as clearly shown by the satisfaction lines for current (1997) and projected year 2000 vehicle fleets. Thus when RVP is reduced to 60kPa max. in year 2000, the predicted "Total Customer Satisfaction 2000" line shows that separate limits on VLI will be unnecessary and there is technical justification to allow an increase in maximum E70 to 48% v/v.

5. OTHER SEASONS VOLATILITY SPECIFICATIONS

To investigate the volatility requirements for other seasons, similar calculations have been carried out for 14 European markets. These calculations are based on hot driveability performance of the predicted year 2000 vehicle fleet for individual markets (details are given in Appendix 2). They show predicted year 2000 customer satisfaction levels for average monthly maximum temperatures in individual months, covering the critical transition months between winter and summer. On these charts have been superimposed the summer volatility limits and a suggested class to cover the other seasons, based on current maximum RVP levels. An example of a critical market, France, is shown in Figure 2, and a full set of these diagrams for all countries is included in Appendix 1. The proposed volatility classes are given in Tables 2 and 3.

Figure 2 France - Year 2000 Market Satisfaction for Hot Fuel Handling in different months

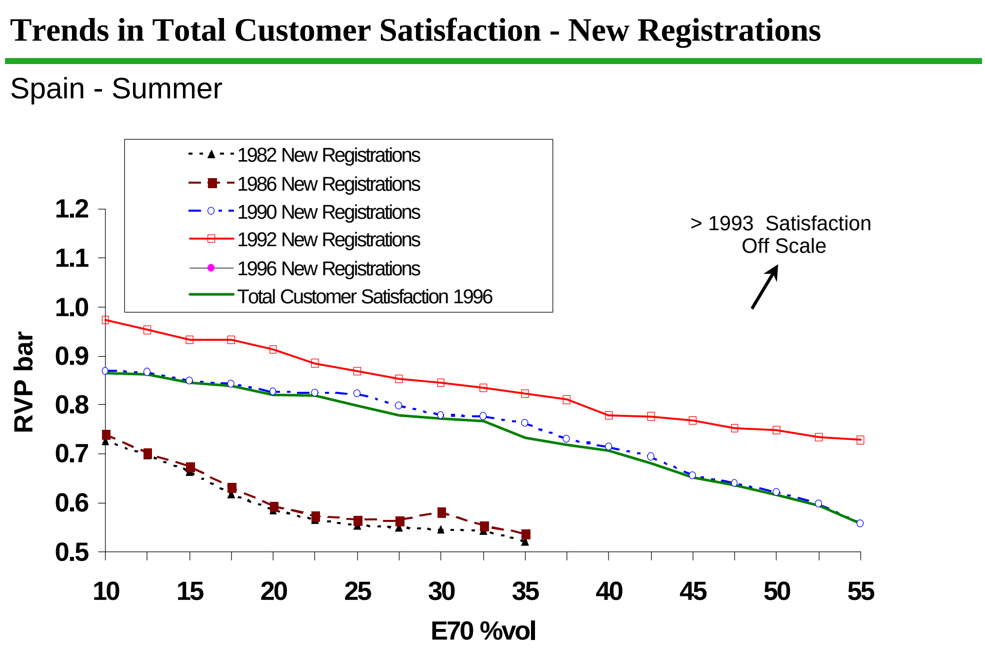


It can be seen that for France, the proposed volatility Class D would give adequate customer satisfaction for months March and November (and all colder months) but would be marginal in April and October. As the new EU summer period from year 2000 covers May to September for non-arctic countries, there is a possibility that driveability could be a concern in April and October. This could be overcome either by retaining an intermediate grade, as is currently the case, or by extending the summer period slightly. A more detailed study of temperature data during April and October is needed to determine the best option. If this approach is taken, it is clear that even for this critical market there is no need for separate VLI limits and an increase of E70 up to 50% v/v is possible without compromising hot driveability performance. Appendix 1 shows that this is the case for all markets, and only in Finland, France, Greece and Portugal is there need for extra control of volatility levels during transition periods between summer and other seasons.

6. TRENDS IN HOT WEATHER DRIVEABILITY PERFORMANCE

As mentioned earlier in this document, modern multi-point electronic fuel injection (EFI) engines are much less prone to HFH problems than carburetted engines and are much more tolerant of hot conditions and high volatility fuels. In order to quantify this impact relative to the overall driveability performance of a market, 2 examples were selected to represent critical and non-critical markets, namely Spain and Germany, respectively, as shown in Appendix 3. The same hot weather driveability satisfaction analysis was again applied, but to vehicles registered in a particular year. By doing this, a driveability performance trend over several years can be established, as shown below in Figure 3 for the Spanish market.

Figure 3 Spain - New Registration Trends for Hot Weather Driveability



Between 1982-1986, approx. 90-95 % of vehicles sold from new were fitted with carburetted fuel systems (see Appendix 3) and this is reflected in the relatively poor driveability performance of the vehicles registered during this period. A major improvement in vehicle performance is seen by 1990-1992 (which coincides with a drop from 70 to 50% penetration of newly registered carburetted vehicles in the market) and by 1993, the improvement becomes so dramatic that the total customer satisfaction line is off scale in Figure 3. This coincides with the mandatory introduction of 3-way catalyst vehicles which were predominantly equipped with fuel injection systems as a technical requirement for greater control of engine stoichiometry. Clearly carburetted vehicle fleets have poorer driveability satisfaction. This is confirmed when comparing the 'Total Customer Satisfaction 1996' line which is based on the total 1996 car parc, to the 1990 'New Registration' line. The two lines are virtually identical and indeed the number of fuel injected vehicles on the road in Spain in 1996 was ca. 30% which compares to the ca. 30% of vehicles registered in 1990 with fuel injection.

The data shown suggests that as carburetted fuel systems are replaced with fuel injection, (EU carburetted population estimated to be ≤ 25% for 2000), markets within Europe will become even less sensitive to fuel volatility. This change will be most evident in critical markets which have currently a high proportion of carburetted vehicles. By way of illustration, the Italian market had been marginal in customer satisfaction in October using the 1996 car parc data (2). By including the 1997 car parc data and revised predictions, the Italian market has become less sensitive to fuel volatility for year 2000 and would not require extra control of volatility levels during transition any more with the proposed winter classification. Details of the change in hot weather driveability performance for the Italian market are discussed in Appendix 2.

7. EFFECTS OF REVISED VOLATILITY CLASSES ON COLD STARTING AND DRIVEABILITY PERFORMANCE

When summer RVP levels were reduced in USA some problems of poor starting and driveability were reported during the transition periods before and after summer. It is therefore important to ensure that this will not happen when the revised volatility classes are introduced in Europe as this could lead to an increase in exhaust emissions and impairing customer satisfaction. However, for the reasons given below, such problems are unlikely to emerge in Europe.

In Europe, only RVP will be reduced in the summer period, and hence potentially during critical transition periods, whereas both E70 and E100 minimum limits will be increased in ALL countries and ALL months. In practice, minimum (and maximum) RVP levels will only be reduced in six countries during transition periods, generally in October, but also in some countries in April or May. The problems in USA were not due directly to a reduction in RVP, but to reduction in other mid-range and front-end volatility properties which was consequent on the change in RVP.

Cold starting performance of vehicles is not significantly affected by RVP, but is controlled by higher distillation points. Early fundamental work (3) showed that time to start is dependent on air/fuel vapour ratio which can be calculated from distillation properties. This showed that E70 was the controlling property which was confirmed in earlier (1970) CONCAWE member company work for carburettor vehicles (4). This work showed that at -18 °C cold starting correlated best with T10E or E70, while at -7 °C the best correlation was with E100 or E120. More recent work on fuel injected vehicles (5) has confirmed that for temperatures between 0 and 16 ºC (more typical of transition periods) the fuel property which correlated best with starting was E100 or T50, giving significantly better correlation than E70. The cold start performance of modern vehicles is very good, such that in this recent work, cold start times greater than 2 seconds were only seen for fuels well outside proposed specification limits.

Similarly Cold Weather Driveability is not affected by RVP but is correlated with mid-range volatility i.e. E100 or T50E, as discussed in a recent CONCAWE document (6). Where driveability has been correlated with other distillation properties, as in the US Driveability Index, front-end volatility (T10 or E70) has only shown a relatively weak effect. Recent CRC work (7) suggested that an Index based on E100 and E150 gives the best correlation, which is supported by another recent SAE paper (8). Analysis by a CONCAWE company of driveability performance of modern European cars showed that less than 10% of cars tested showed RVP to have a significant positive effect. This compared with 50% for E100 and 47% for E70. Thus CWD performance should be significantly improved by the increase in E100, in addition to the introduction of an E150 minimum limit, as defined in the year 2000 fuel specification.

There is undoubtedly a correlation between exhaust emissions and driveability, as driveability malfunctions are a manifestation of engine misfires which will increase HC and CO emissions. This was clearly shown in the EPEFE programme where significant increases in emissions together with reported driveability problems were seen on several of the gasoline vehicle fleet on 2 fuels (EPGA2 and EPGA3), both of which were significantly below the proposed future minimum E100 limit. Work by GM (9) has also demonstrated a clear correlation between HC emissions and driveability. A CONCAWE programme (10) also showed that fuel volatility did affect exhaust emissions, but the effects were relatively small. It is clear that emissions only increase significantly at very low levels of mid-range volatility, well below the year 2000 European standard.

8. CONCLUSIONS AND PROPOSED SPECIFICATIONS

Analysis of the Hot Fuel Handling (HFH) performance of current European vehicles, the volatility requirements and trends of the current and year 2000 car populations, and future trends in gasoline composition, leads to the following conclusions:

- For year 2000 summer volatility classes, a VLI specification is no longer necessary. The RVP maximum limit of 60 / 70 kPa will already ensure total customer satisfaction.
- For year 2000 other season volatility classes a VLI specification is generally no longer necessary. The proposed volatility levels for other seasons (non-summer time) will also be for most countries below the requirement to ensure total customer satisfaction (Appendix 1). Where this is not the case (Finland, France, Greece and Portugal) alternative solutions are required to also ensure total customer satisfaction during transition periods.
- The customer satisfaction analysis demonstrates that the maximum E70 limit can be raised slightly to 48% v/v for summer classes and to 50% for other seasons, without compromising hot driveability performance. This would accommodate the use of lower boiling blending streams to meet lower limits on olefins, aromatics and benzene. A further review is recommended for the EU 2005 revision.
- Minimum RVP specifications have been increased to reflect concerns over fuel tank vapour space flammability during cold spells. This has been discussed in CONCAWE report 97/53.
- E100 and E150 minimum specifications are included to reflect the revisions agreed in the new EU Fuels Directive. An increase in E100 maximum is also proposed, reflecting the need to compensate for compositional changes induced by the EU Fuels Directive. Other volatility specifications are included for completeness.
- Cold starting and cold weather driveability performance of vehicles are not significantly affected by RVP, but are controlled by higher distillation points. Increased minimum levels of E70 and E100, together with the introduction of an E150 minimum, will all be introduced in the new version on EN 228, so cold driveability performance should improve. Emissions only increase significantly at very low levels of mid-range volatility, well below the year 2000 European standard.

Proposed specifications are given in Tables 2 and 3 below.

Table 2 Proposed new Summer CEN Gasoline Volatility Classes.

CLASS	A	B
RVP kPa	45-60	45-70
E70 %v/v	20-48	20-48
E100 %v/v	46-71	46-71
E150 %v/v min.	75	75
FBP °C max.	215	215
Residue %v/v	2	2

Table 3 Proposed new CEN Gasoline Volatility Classes for other Seasons

CLASS	**C**	**D**	**E**	**F**
RVP kPa	50-80	60-90	65-95	70-100
E70 %v/v	22-50	22-50	22-50	22-50
E100 %v/v	46-71	46-71	46-71	46-71
E150 %v/v min.	75	75	75	75
FBP °C max.	215	215	215	215
Residue %v/v	2	2	2	2

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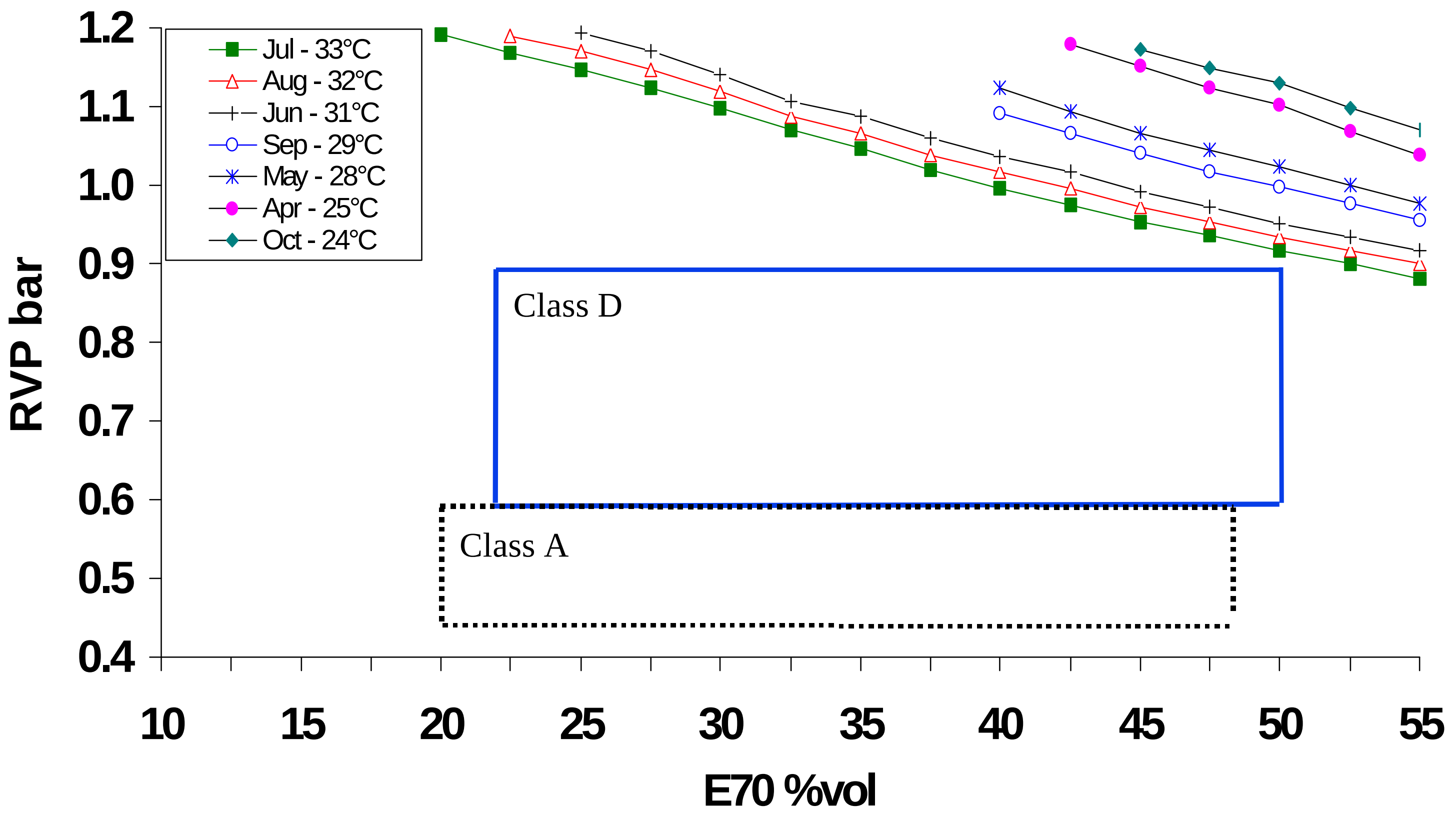
APPENDIX 1

SUMMER AND WINTER MARKET SATISFACTION

FOR KEY MONTHS

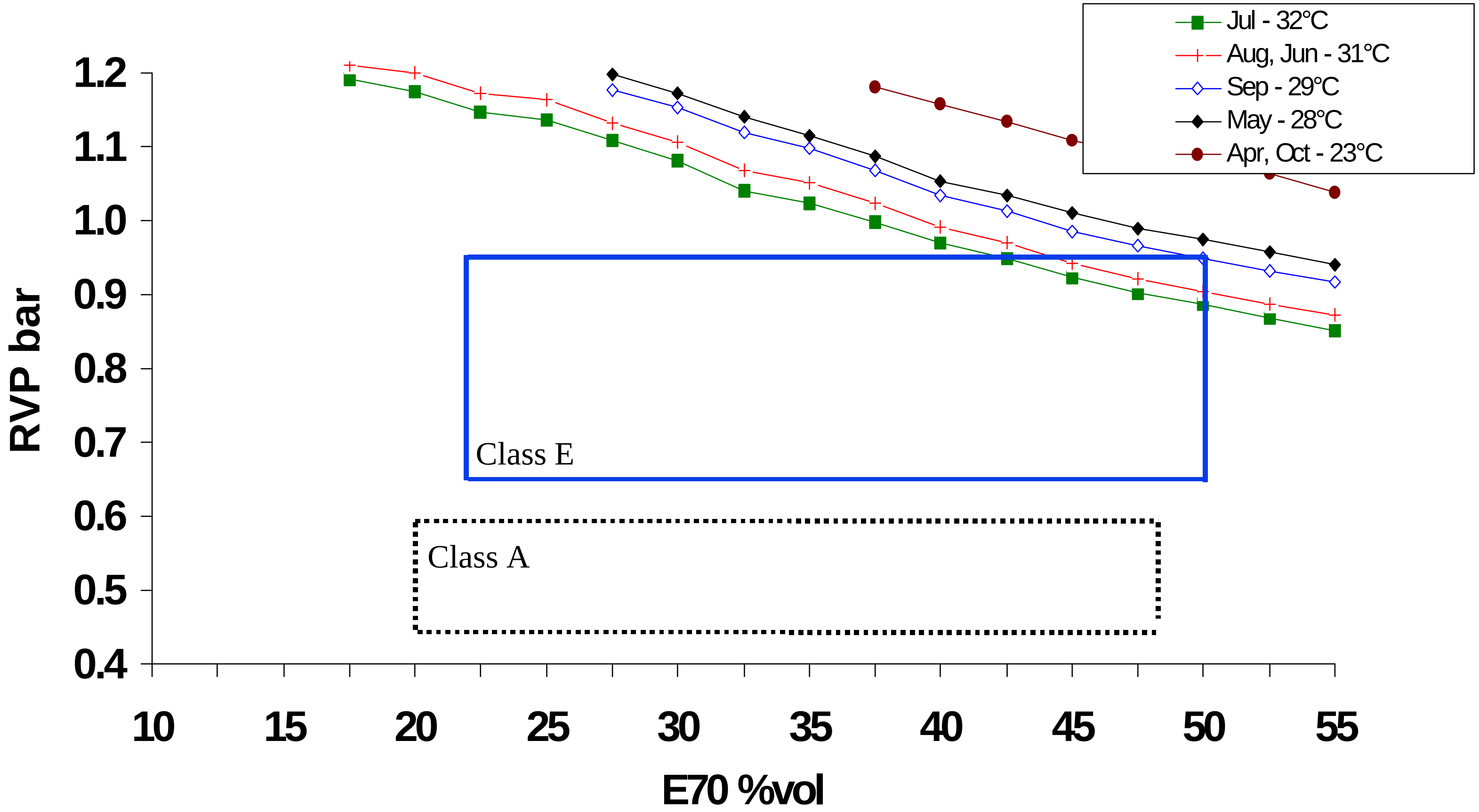
Market Satisfaction for Hot Fuel Handling - Austria

Year 2000 Satisfaction - Forecast Using 1997 Data



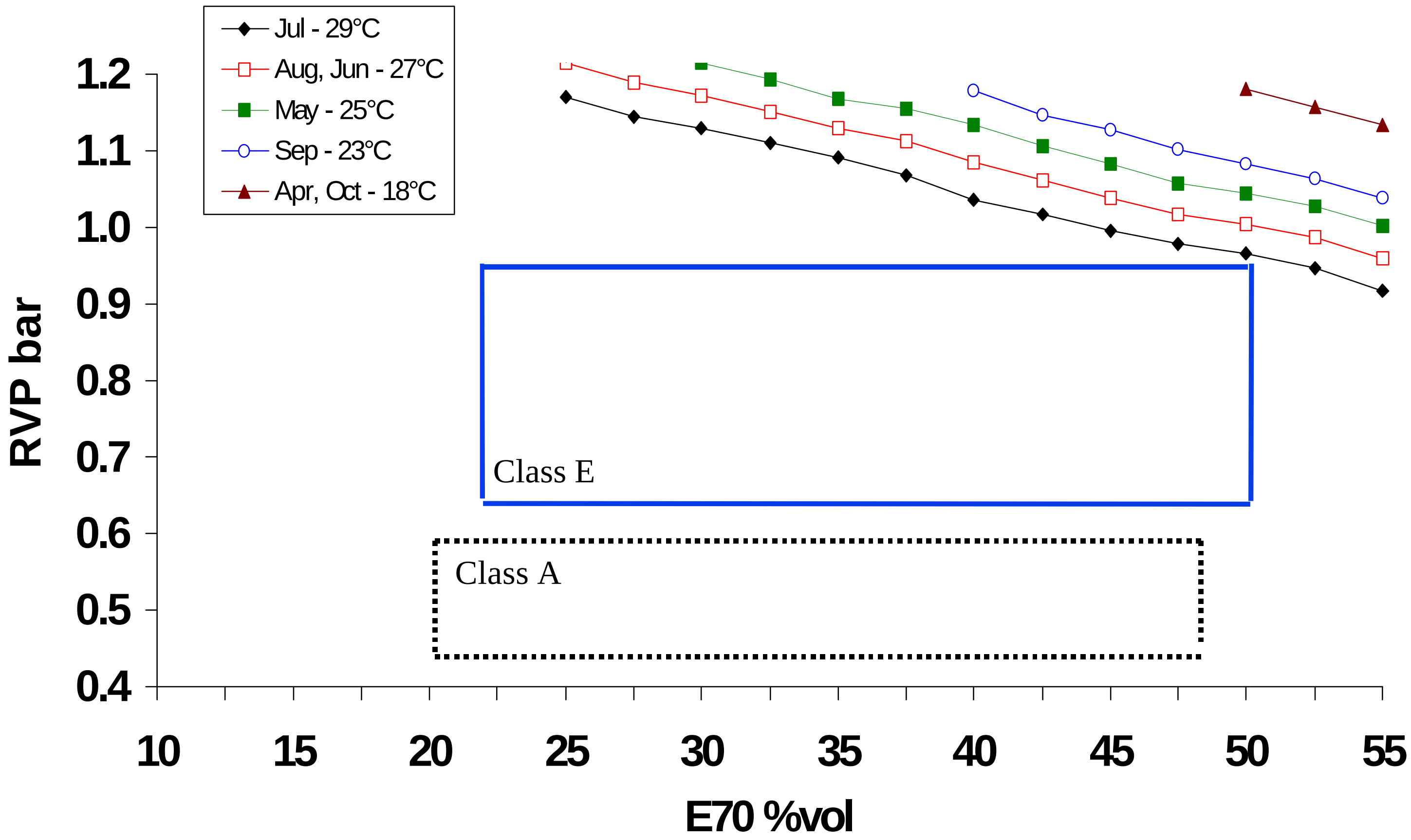
Market Satisfaction for Hot Fuel Handling - Benelux

Year 2000 Satisfaction - Forecast Using 1997 Data



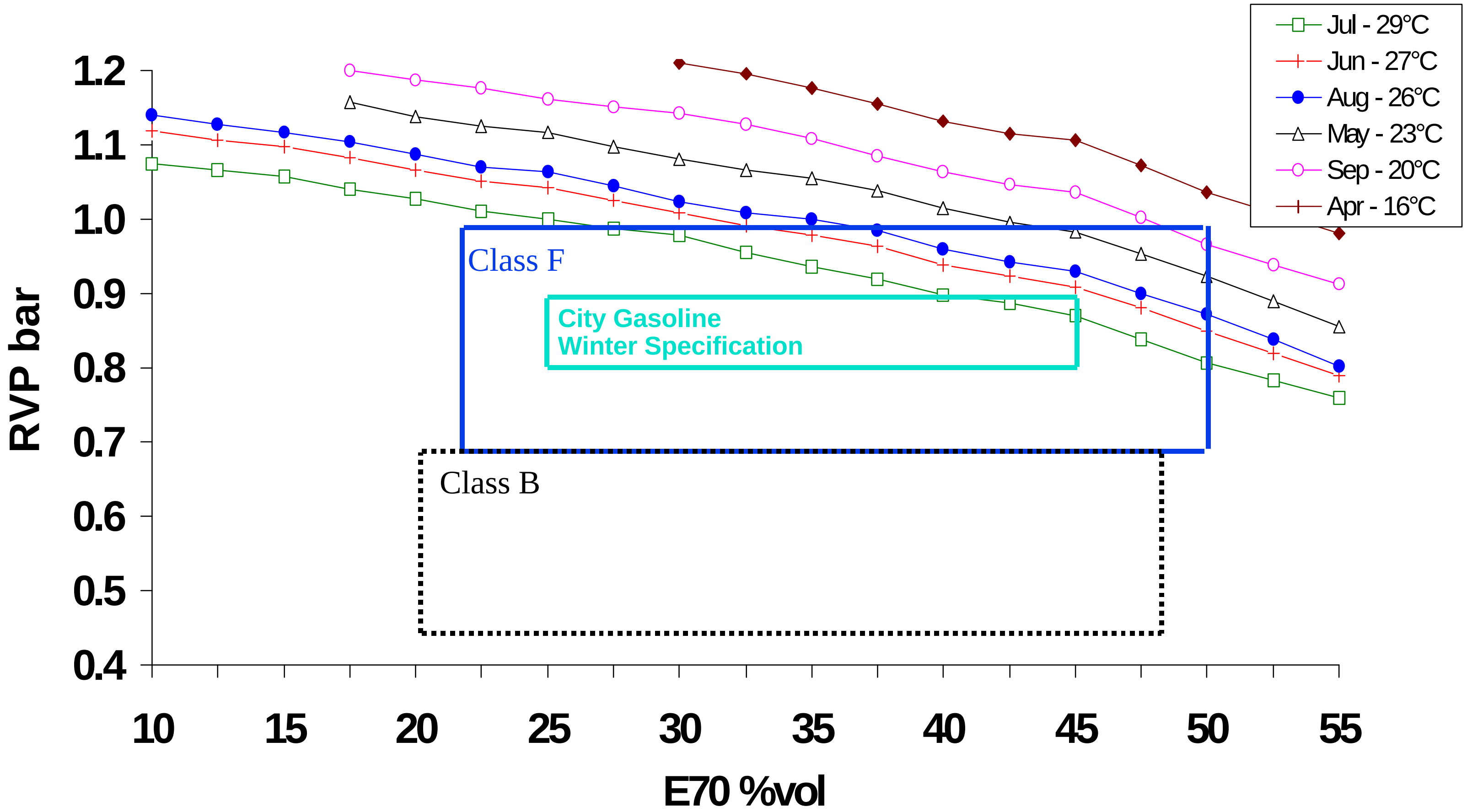
Market Satisfaction for Hot Fuel Handling - Denmark

Year 2000 Satisfaction - Forecast Using 1997 Data



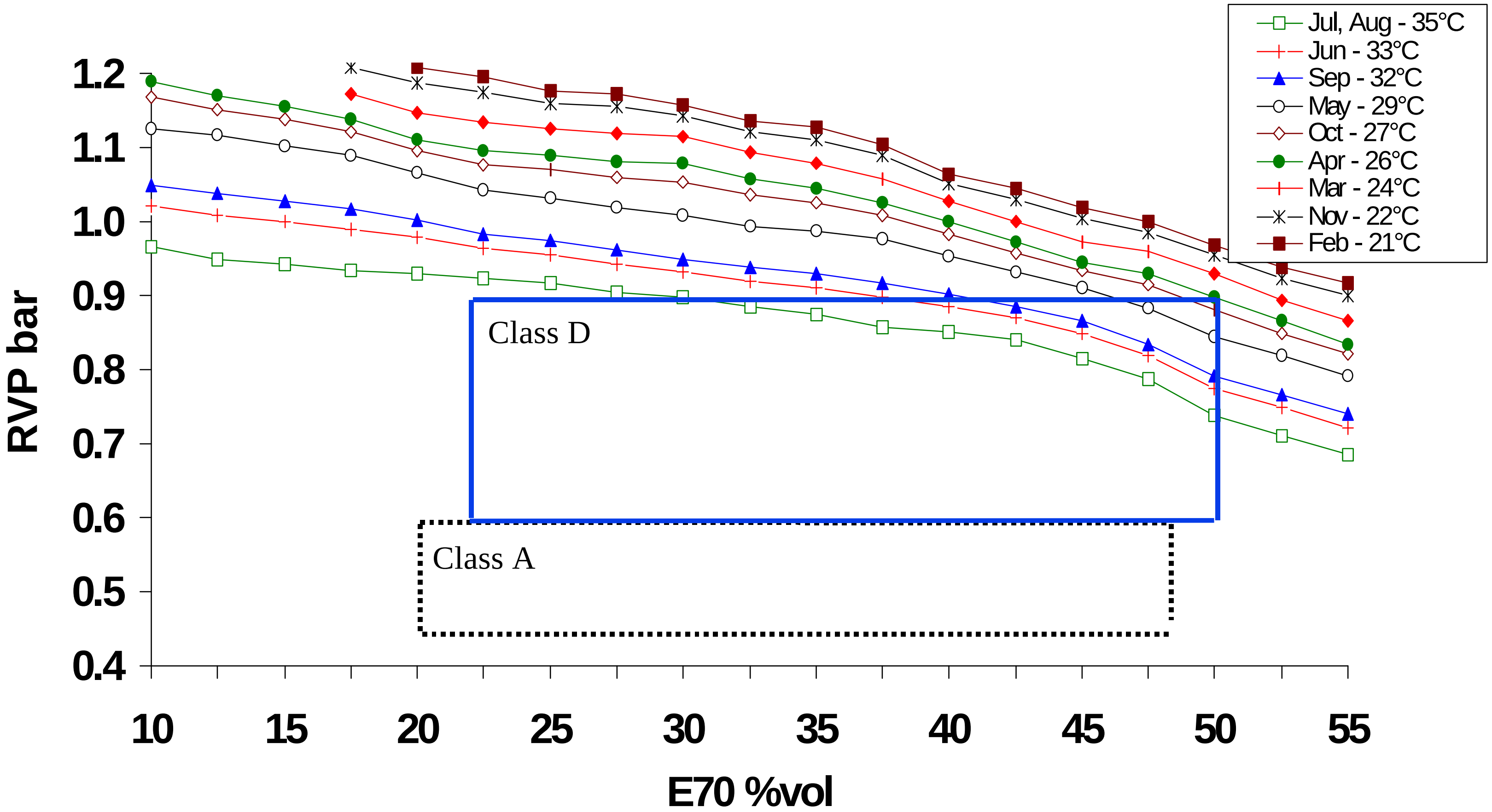
Market Satisfaction for Hot Fuel Handling - Finland

Year 2000 Satisfaction - Forecast Using 1997 Data



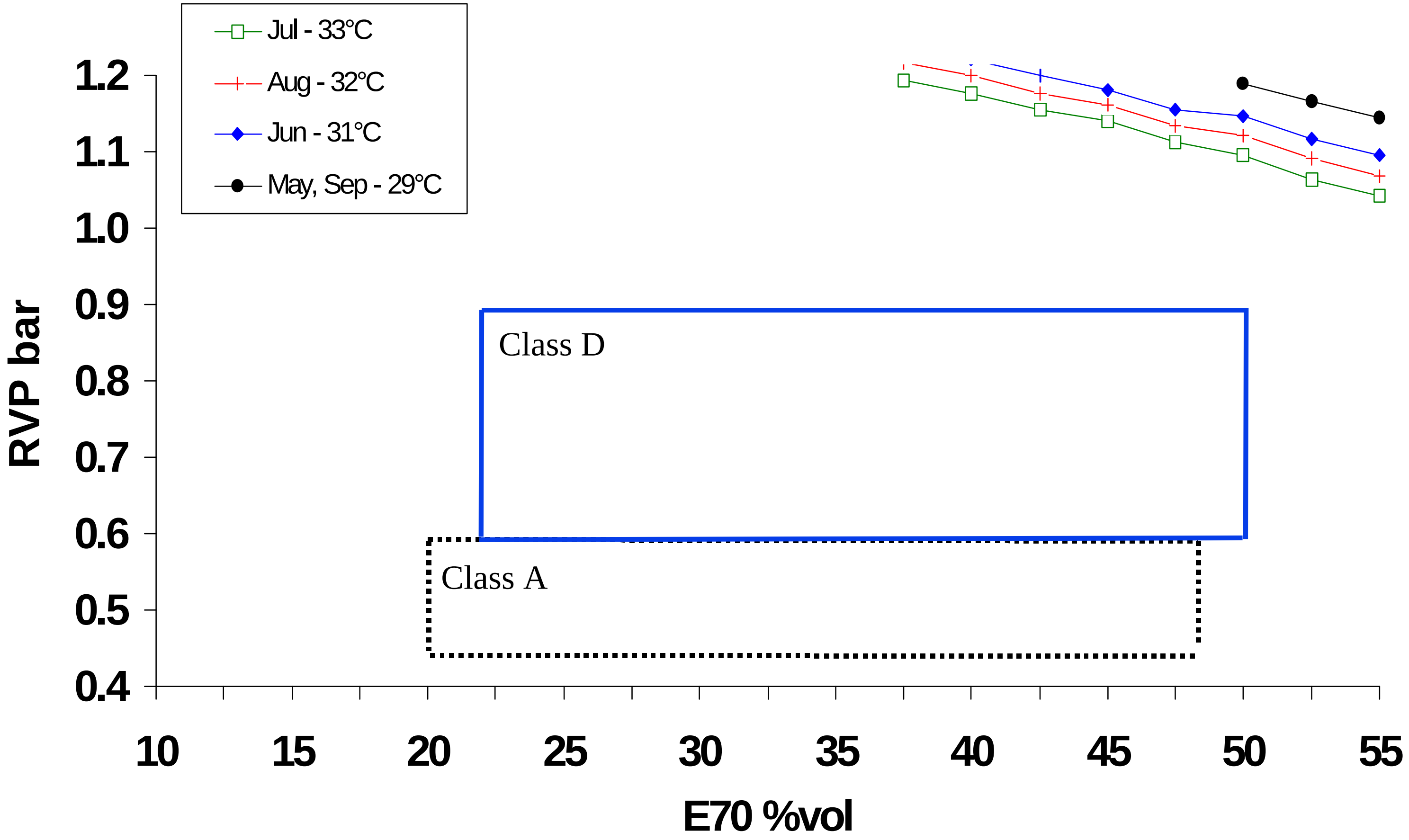
Market Satisfaction for Hot Fuel Handling - France

Year 2000 Satisfaction - Forecast Using 1997 Data



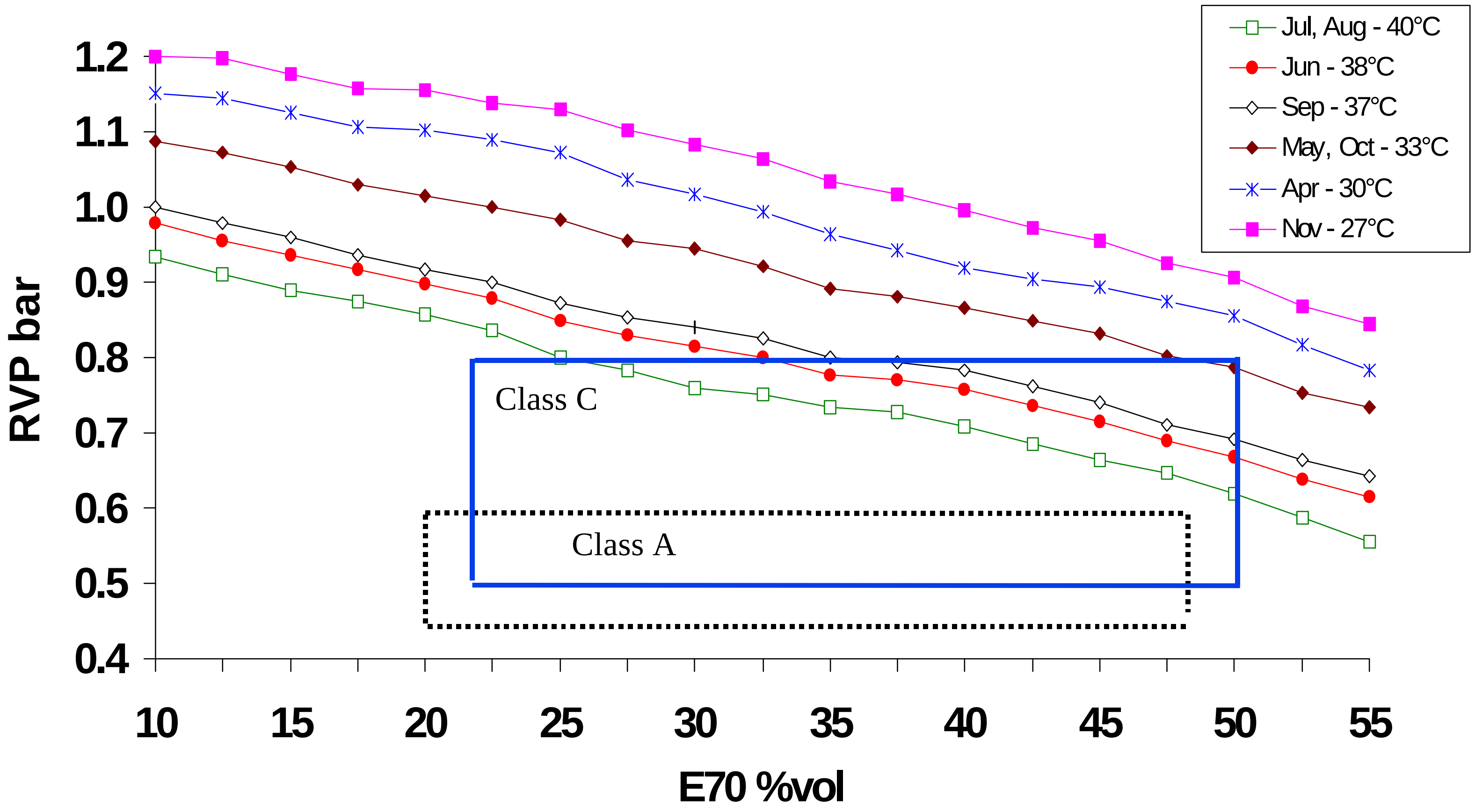
Market Satisfaction for Hot Fuel Handling - Germany

Year 2000 Satisfaction - Forecast Using 1997 Data



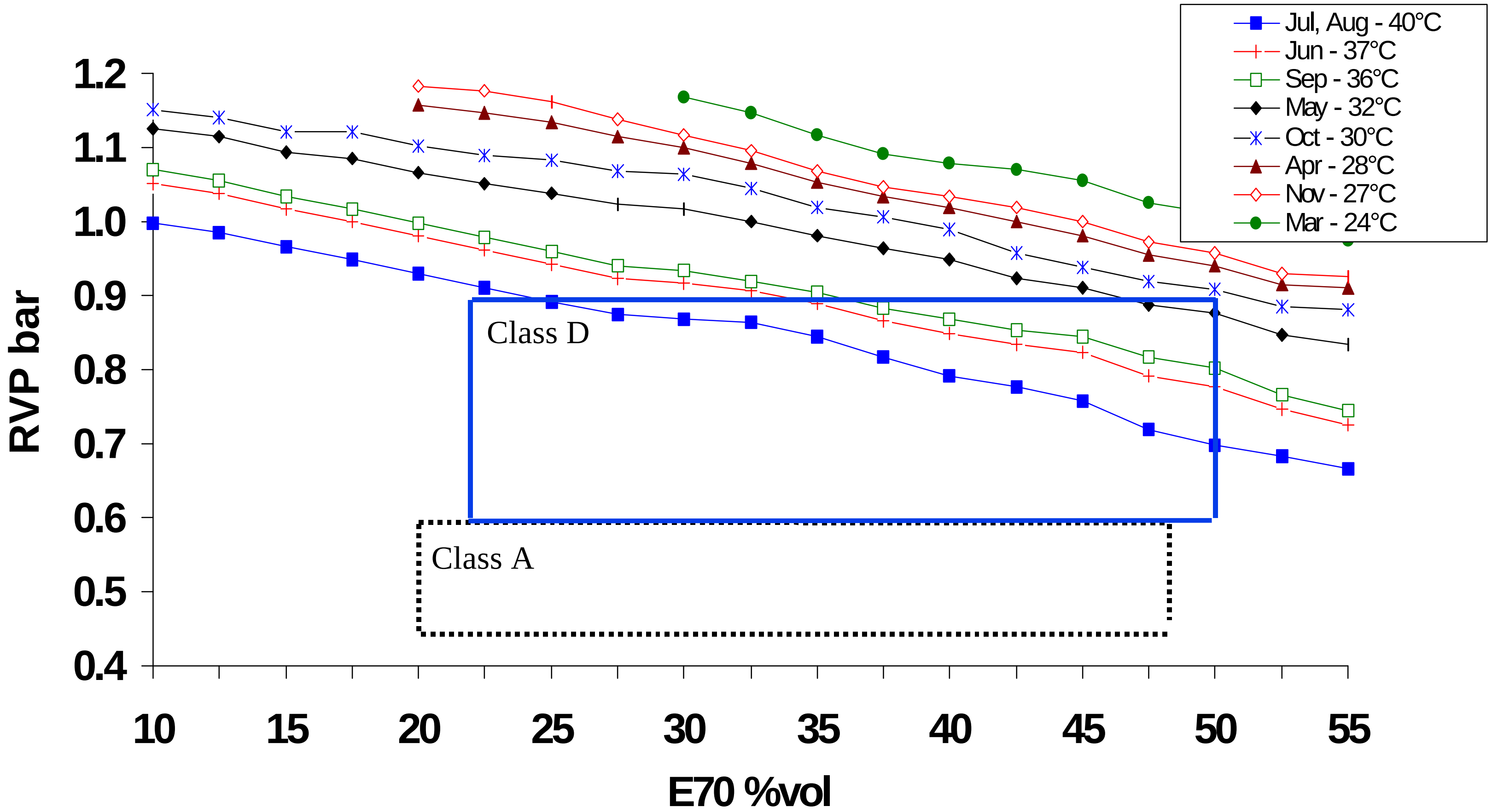
Market Satisfaction for Hot Fuel Handling - Greece

Year 2000 Satisfaction - Forecast Using 1997 Data



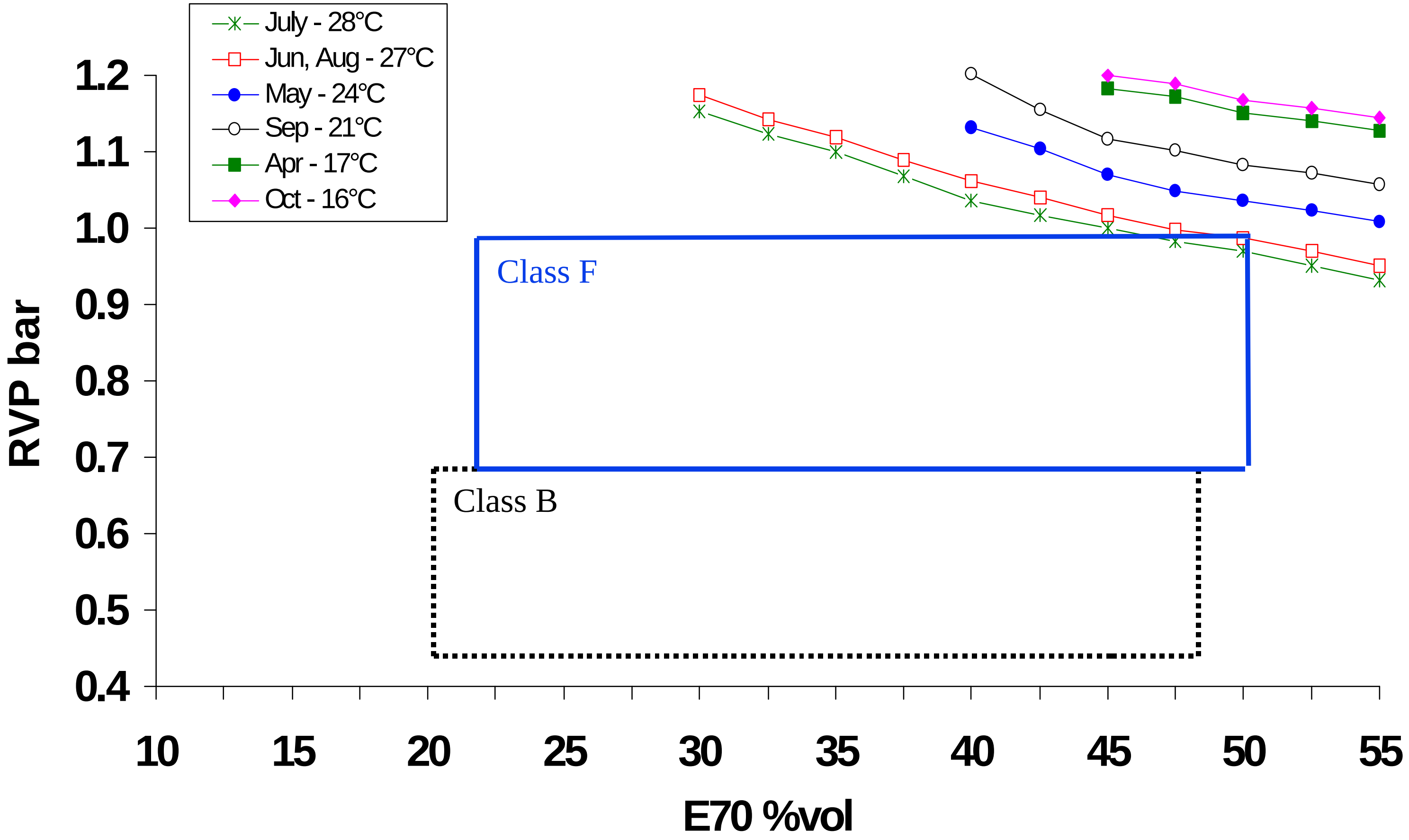
Market Satisfaction for Hot Fuel Handling - Italy

Year 2000 Satisfaction - Forecast Using 1997 Data



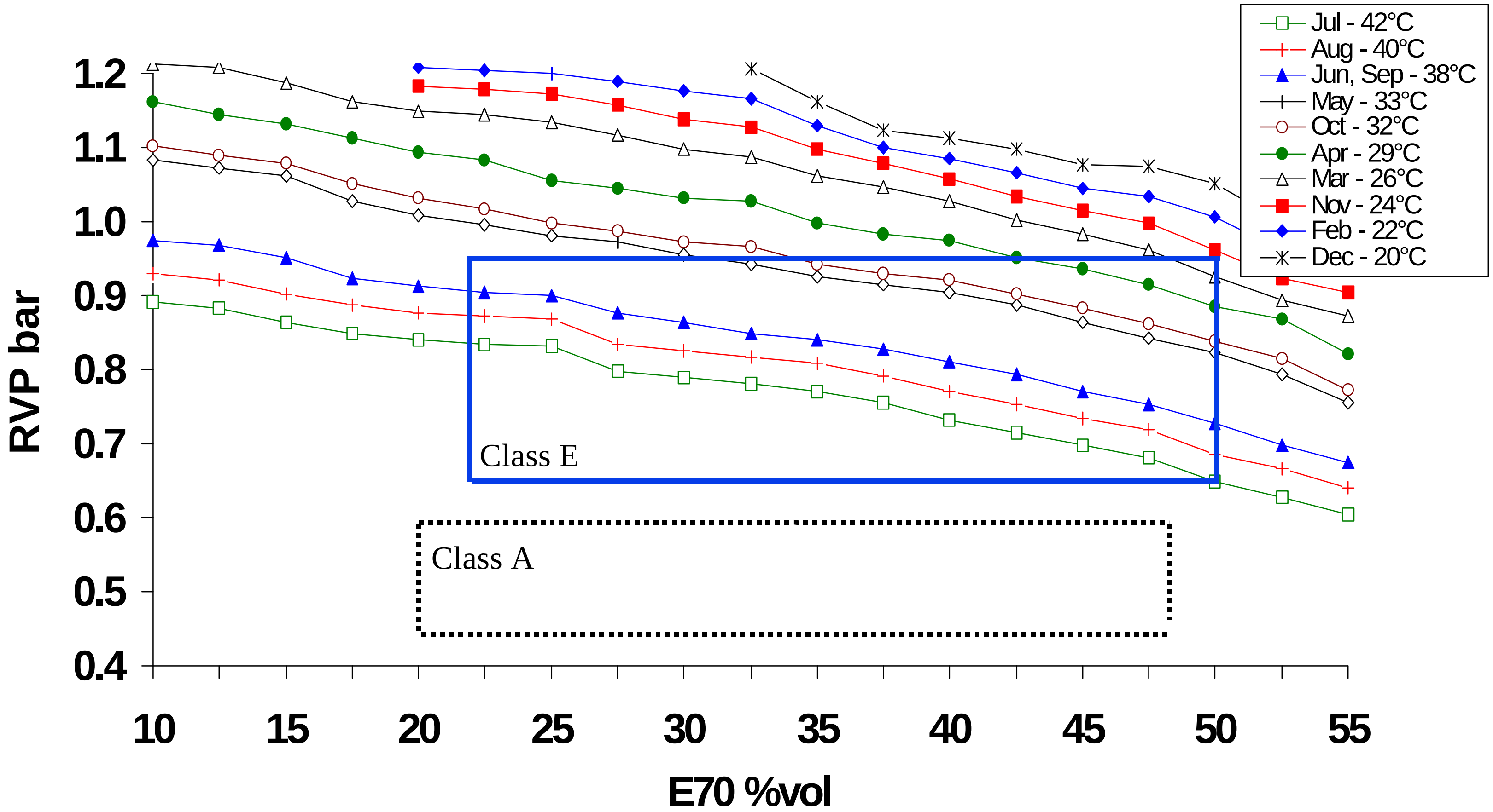
Market Satisfaction for Hot Fuel Handling - Norway

Year 2000 Satisfaction - Forecast Using 1997 Data



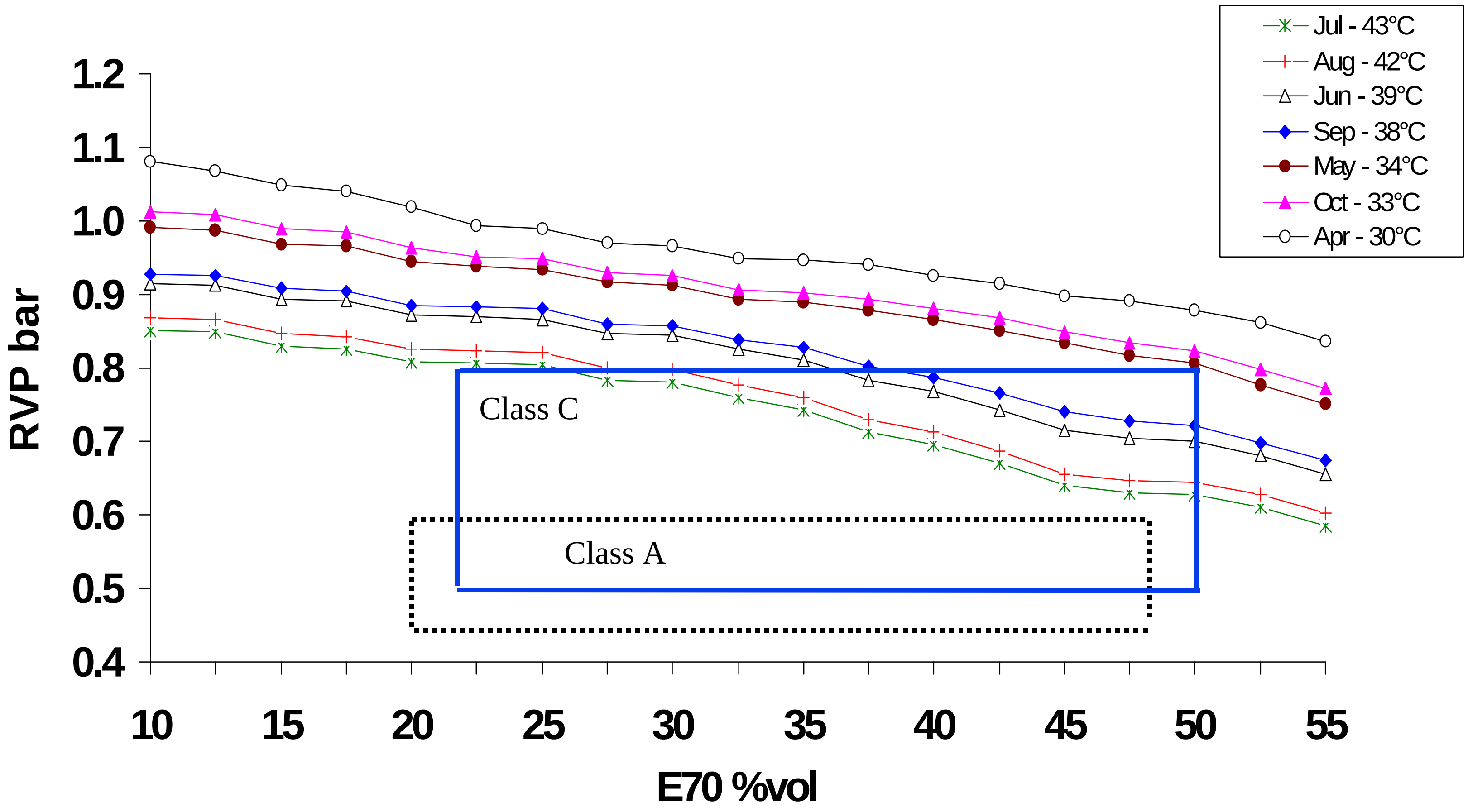
Market Satisfaction for Hot Fuel Handling - Portugal

Year 2000 Satisfaction - Forecast Using 1997 Data



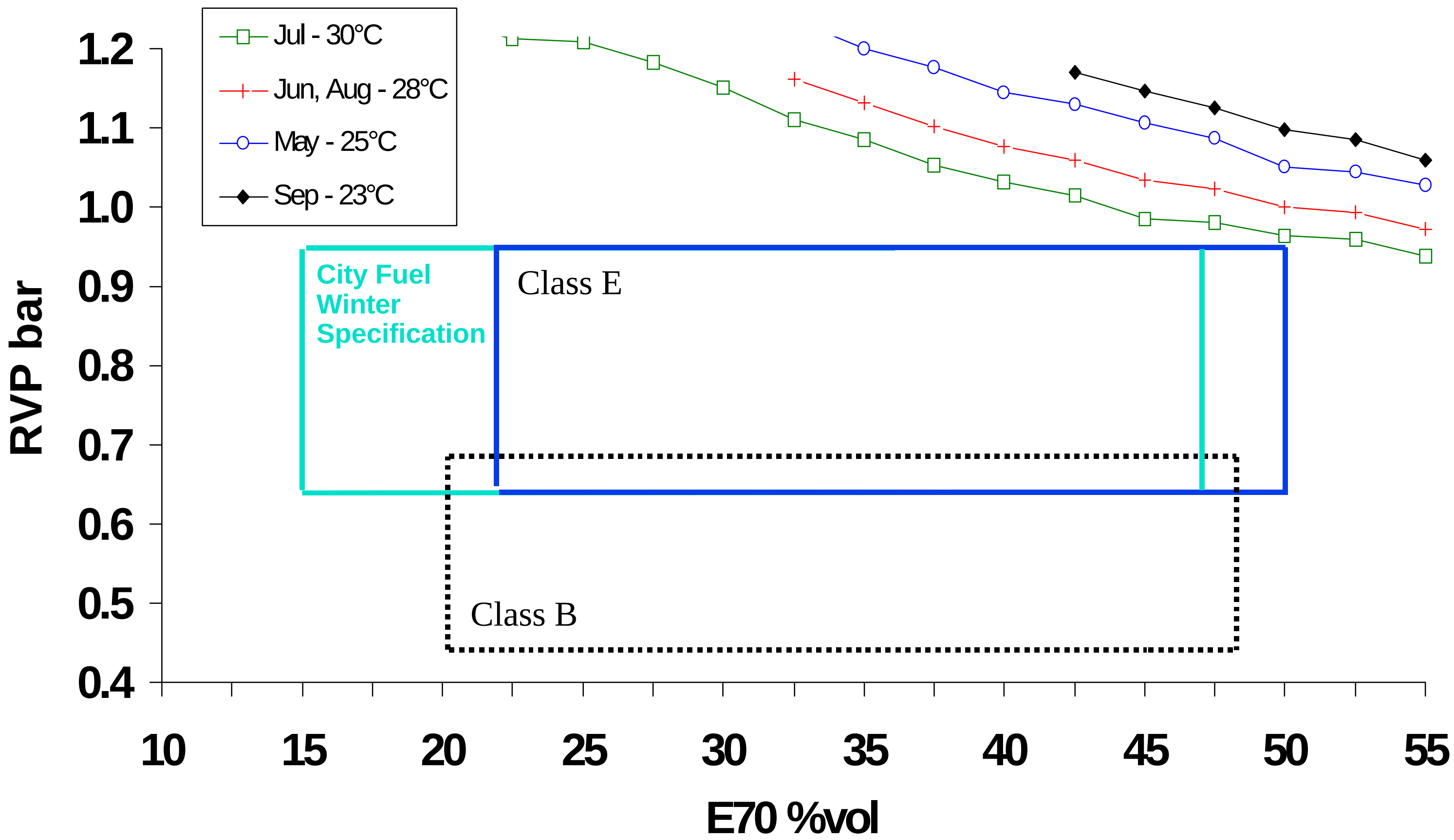
Market Satisfaction for Hot Fuel Handling - Spain

Year 2000 Satisfaction - Forecast Using 1997 Data



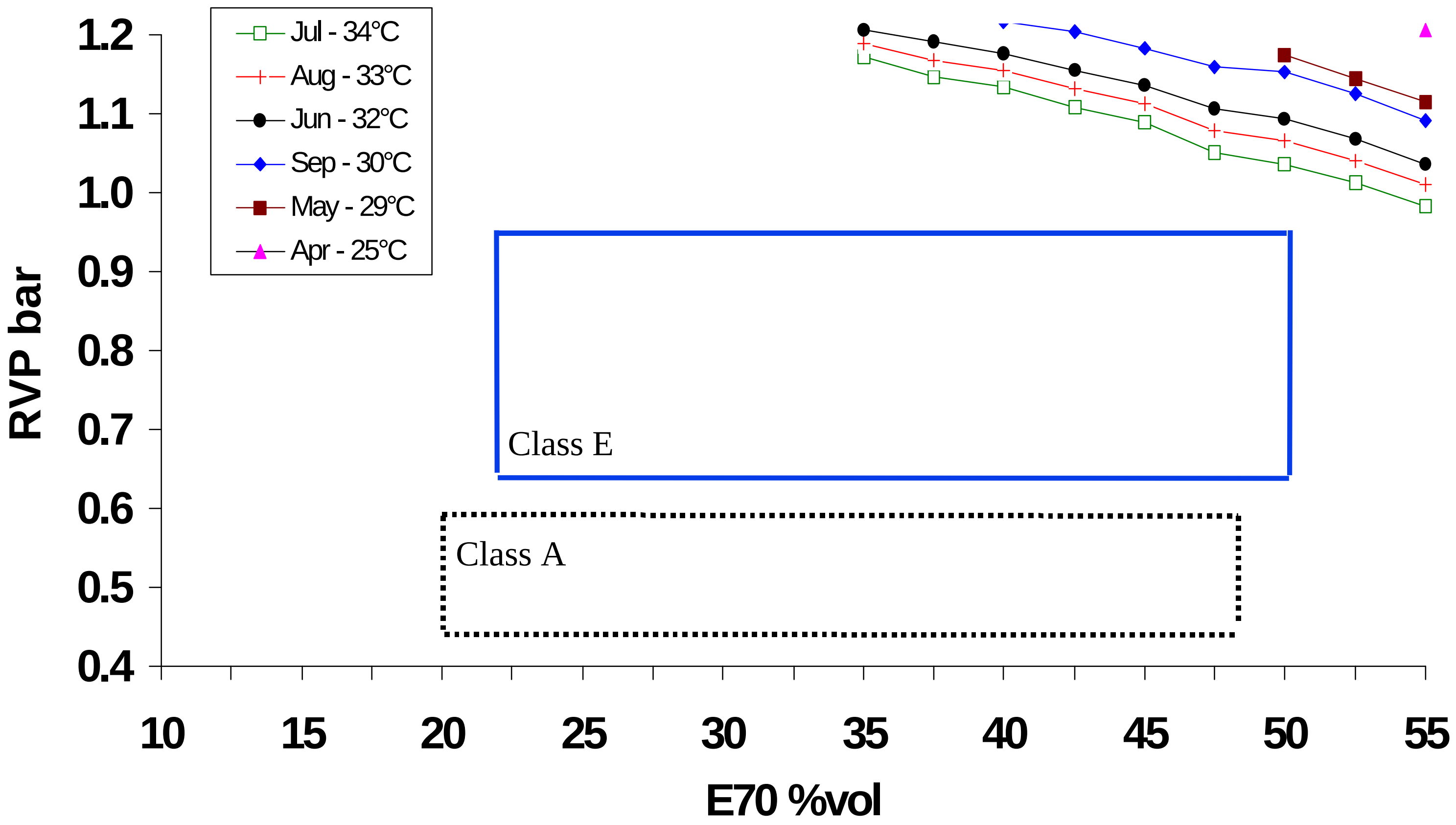
Market Satisfaction for Hot Fuel Handling - Sweden South

Year 2000 Satisfaction - Forecast Using 1997 Data



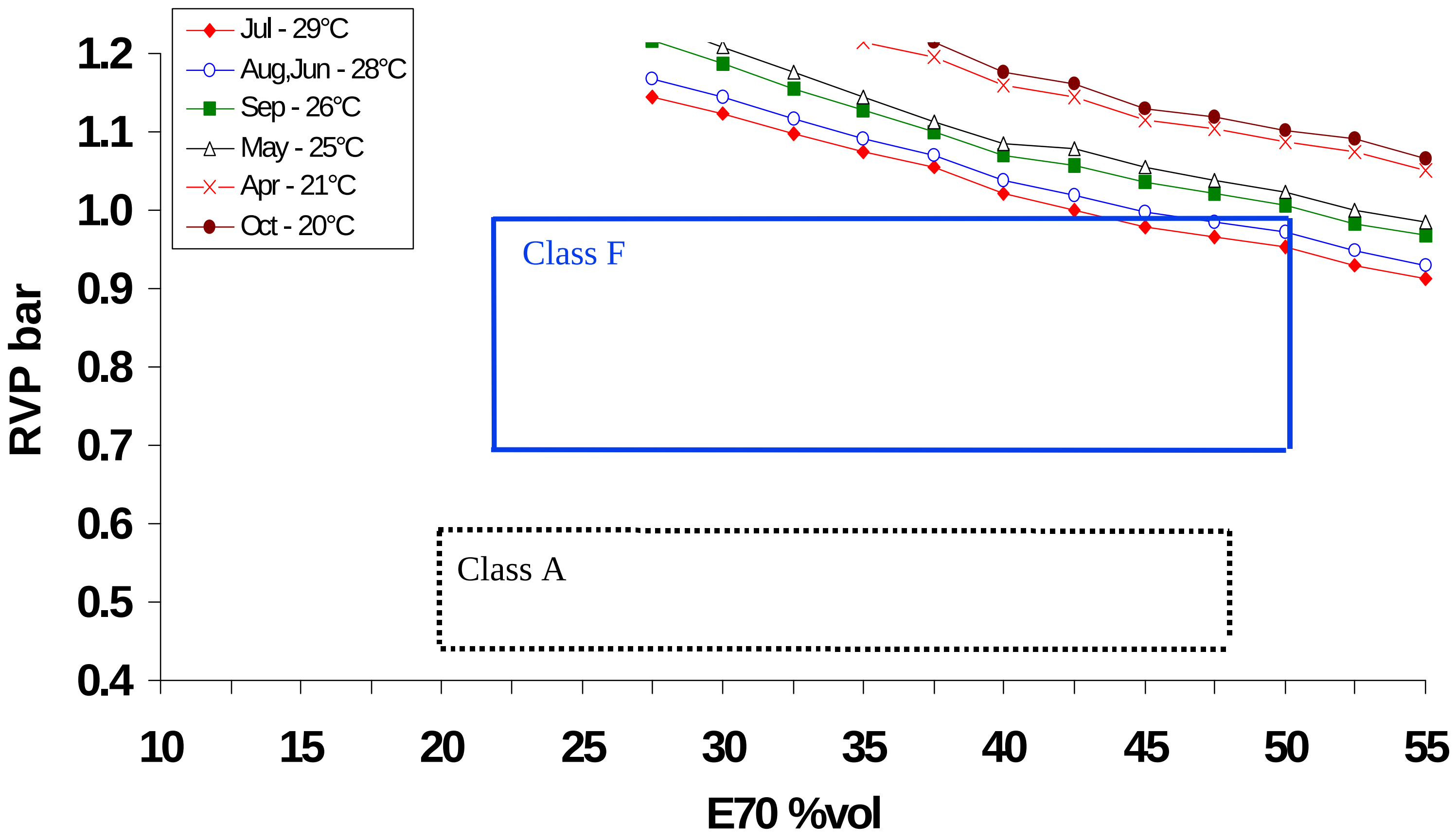
Market Satisfaction for Hot Fuel Handling - Switzerland

Year 2000 Satisfaction - Forecast Using 1997 Data



Market Satisfaction for Hot Fuel Handling - UK

Year 2000 Satisfaction - Forecast Using 1997 Data



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APPENDIX 2

BACKGROUND TO SATISFACTION ANALYSIS

REQUIREMENTS FOR ESTABLISHING SATISFACTION ANALYSIS

There are three criteria required to analyse a market for hot weather driveability satisfaction.

Firstly, an accurate ambient temperature profile of a market under analysis, which should include a range of temperature data for each month averaged over many years. Data supplied by the UK Meteorological Office, London was used in this analysis. From this, the average monthly maximum temperature is used to approximate the 95% worst case (equates to a temperature being held for 1 hour in any month) and the hottest month in any defined season, or for individual months, is used as the criteria.

Secondly, the vehicle population of a market which identifies the exact type and number of vehicles on the road in any market. This population data is purchased from DRI MacGrawHill, London on an annual basis.

Thirdly, the driveability performance of these vehicles at different ambient temperatures and fuels of different volatility. Such data is generated by the Intercompany Volatility Group whose purpose is to generate hot and cold weather driveability data on the CEC driveability cycle on a wide selection of vehicle technologies representative of the EU market. These tests are carried out by trained raters under critical driving conditions and are a severe test of vehicle performance.

The above data is used to calculate the percentage of vehicles technically satisfied (i.e. with no driveability problems) for any combination of temperature and fuel volatility. The market satisfaction analysis employed in this document is derived using the latest car parc data available which at the time of writing correspond to the 1997 car parc.

TECHNICAL VS. CUSTOMER SATISFACTION

Several chassis dynamometer / road trials were performed during validation of the CEC Hot Weather Driveability Procedure by the CEC CF-24 Driveability Group. These confirmed that CEC tests carried out on the dynamometer using trained raters under controlled conditions are more severe than on the road, but little knowledge was gained in how technical assessments reflected the actual driveability requirements of the motorist. Thus in order to establish motorist's perception to changes in volatility / temperature, a series of summer season trials were carried out independently by both BP (11) and Shell using common test cars and fuels.

Results from all these trials showed that the motorist and technician response to changes in volatility were similar (i.e. fuels of higher volatility generally created more driveability malfunctions) but their levels of perception were different. Motorists were considerably less critical of driveability malfunctions and fuel volatility than technically trained raters. The main reasons for this are as follows:

- Chassis Dynamometer tests give rise to higher fuel system temperatures due to reduced air flow over the vehicle. CEC tests (12) showed that this difference is equivalent to a 3.4°C change in ambient temperature or 90 mbar change in FVI at constant temperature.
- Motorists rarely drive in the manner of the CEC test cycle. Approximately 5% of driving corresponds to the portion of the CEC test cycle that will generate problems.
- Carburetted vehicles on dynamometer are tested with vapour traps, so fuel will not "weather" as it will on the road where high volatile fuels will lose some vapour into the atmosphere.

The BP trials showed that total customer satisfaction was equivalent to a technical satisfaction level of 70%. Work by Shell showed that total customer satisfaction was equivalent to a technical satisfaction of 80% (see Figures 4 and 5). The difference can be explained by the fact that the Shell analysis corrects test results for the dynamometer-road temperature difference whereas the BP calculations do not. Thus even though a different method of analysis was used, it can be seen in Figure 6 that both approaches to determining customer satisfaction are in very close agreement.

VALIDATION OF CUSTOMER SATISFACTION PREDICTIONS

The preceding paragraphs have discussed specific approaches to the analysis of hot driveability data generated by vehicle tests under strictly controlled conditions on chassis dynamometers. A critical step in the process is the interpretation and treatment of this data to predict customer response to road driveability performance from the response of trained technical raters on the dynamometer. Figures 4 and 5 show how technical and customer satisfaction levels were related in limited fleet tests conducted separately by BP and Shell.

The validity of selecting 70% technical satisfaction (BP analysis method) to represent Total Customer Satisfaction is confirmed on a much larger scale, by examining the hot driveability requirements of a full market population. Using the French market as an example, the predicted curves for total customer satisfaction have been calculated for the 1993 vehicle population in both summer and winter. The 1993 vehicle population was chosen to represent the situation when CEN EN 228 was introduced. These curves are shown in Figures 7 (summer) and 8 (winter), in comparison with the CEN volatility classes (1 and 6 respectively) chosen by DHYCA for those periods.

For summer, the curve for 1993 total customer satisfaction is slightly above the VLI line for CEN Class 1. For winter, the curve for 1993 total customer satisfaction is virtually identical to the VLI line for CEN Class 6. These diagrams indicate that both the CEN Classes were well matched to the seasonal volatility requirements of the 1993 French vehicle population. In both cases, the analysis results suggest that total customer satisfaction was achieved in 1993 and in all subsequent years (because of the decreasing sensitivity of the population). This analysis has been borne out in the French market, as CONCAWE is not aware of any customer complaints that could be related to hot driveability problems and gasoline volatility.

PREDICTION OF HOT WEATHER DRIVEABILITY PERFORMANCE OF YEAR 2000 CAR POPULATION

As previously mentioned, the analysis employed to determine the current level of EU market satisfaction is derived using 1997 car parc data, which are the latest data available at the time of writing. As the volatility limits within EN 228 specification will be revised for 2000, it is necessary to predict the hot weather driveability performance of a projected year 2000 vehicle population. This was performed for each individual EU market as described below. Essentially the annual change in hot-weather driveability satisfaction of each country's fleet was determined for each year between 1993 (mandatory introduction of catalyst equipped vehicles) and 1997. The average annual change in volatility to achieve customer satisfaction over this period was then used to extrapolate the change in performance to 1999, i.e. two years. 1999 fleet calculations have been used to represent the vehicle fleet which will be present in January 2000. This approach is more focussed on changes in individual markets than the first analysis (2) which was based on an EU average change in vehicle hot driveability performance.

An example of the predictive analysis for a single market, Italy, is shown in Figure 9. Individual driveability lines representing total customer satisfaction are depicted from 1993 to 1997 (inclusive) at a temperature representative of the proposed transition period (April and October) which, for this market, approximates to 30 °C. The delta RVP, or difference in RVP between the individual years' satisfaction lines (in mbar) are also shown in Figure 9, averaged over a range of E70 from 20 to 50 %v/v.

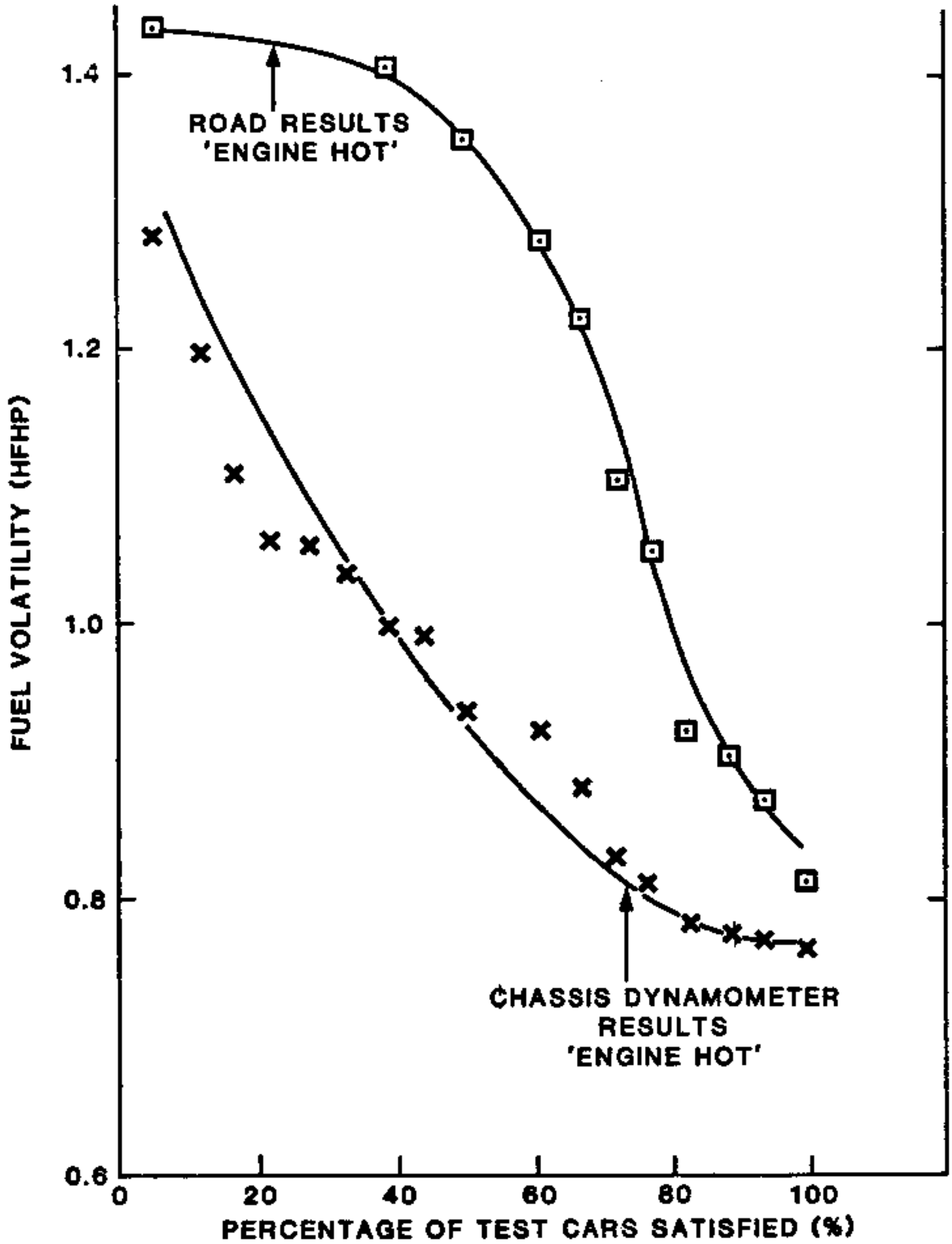
It can be clearly seen that the driveability performance of the Italian market has improved between 1993 to 1997, as expected, due mainly to the progressive replacement of carburetted vehicles by those with fuel injection. This improvement increases steadily on a yearly basis as can be seen by the increase in delta RVP from 9 mbar between 1993 to 1994 to 30 mbar between 1996 to 1997. On this basis, it could be technically justified to conclude that, for the Italian market, this trend would continue (assuming a reasonably constant vehicle scrappage and steady new registrations) over the next 2 years, up to the end of 1999.

However, in order to ensure complete customer satisfaction, a more conservative approach was taken. It was decided to use the average delta over the years between 1993 to 1997. On this basis, the annual delta RVP for the Italian market was calculated at 20mbar. This implies that the predicted 1998 satisfaction line would be 20mbar higher than for 1997, and that the predicted 1999 satisfaction line would be 40 mbar greater than for 1997.

This method of analysis was carried out for all other EU markets at the temperature corresponding to their proposed transition period. The calculated delta RVP for each market is shown in Figure 10. For comparison the European average predictions to year 2000 based on car parc data including 1996 data are shown which have been used in the first analysis (2).

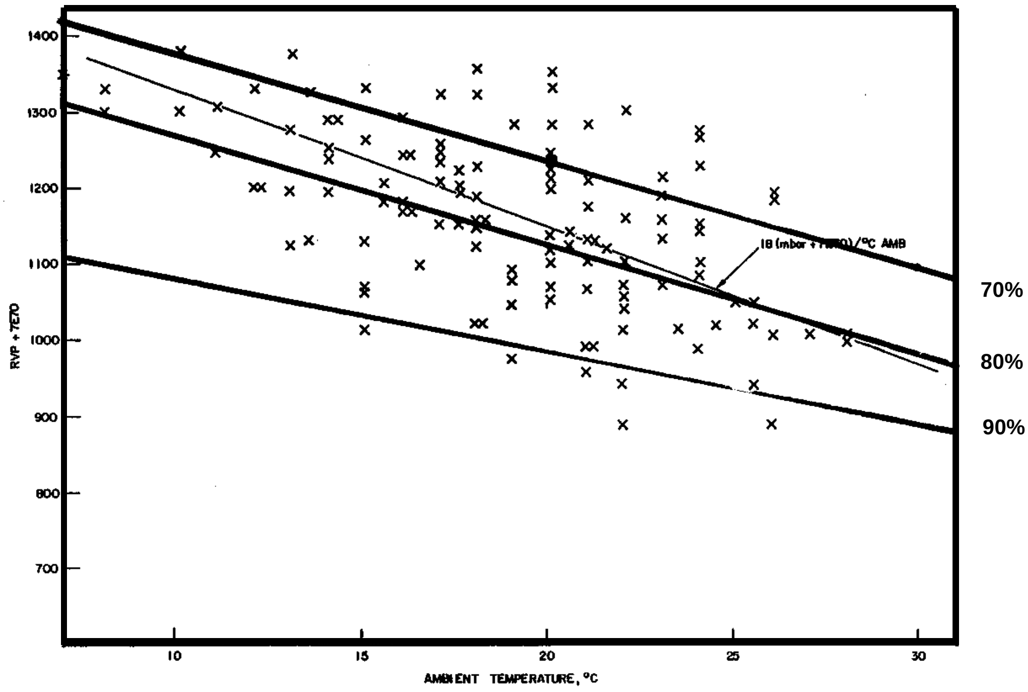
In order to verify this new updated prediction from a driveability satisfaction point of view, satisfaction lines for the Italian and French market have been compared to the first analysis (2) as can be seen in Figures 11 and 12. This demonstrates the validity of the revised analysis.

Figure 4 Technical vs. Customer Satisfaction (11)



PERCENTAGE OF CARS SATISFIED ON THE ROAD AND CHASSIS DYNAMOMETER AT VARIOUS FUEL VOLATILITY LEVELS FOR AN AMBIENT AIR TEMPERATURE OF 28°C

Figure 5 Technical vs. Customer Satisfaction (extracted from Shell Data)



Relationship between ambient temperature and volatility for 1979 and 1980 test fleets

Figure 6 Comparison of BP vs. Shell Technical Satisfaction

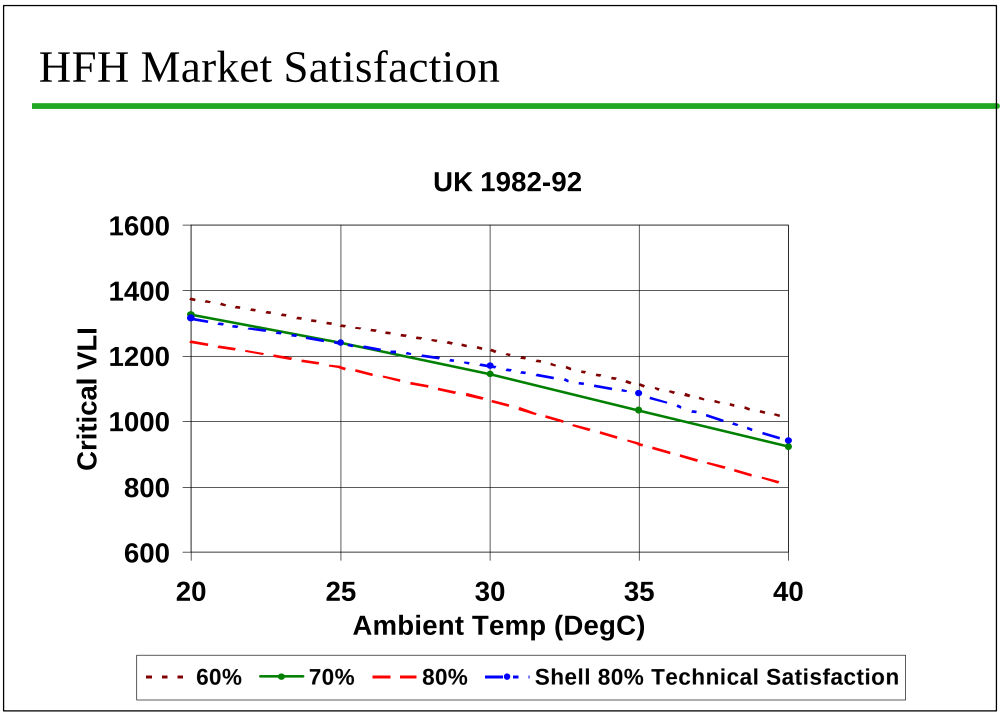


Figure 7 Total Customer Satisfaction for France (Summer 1993)

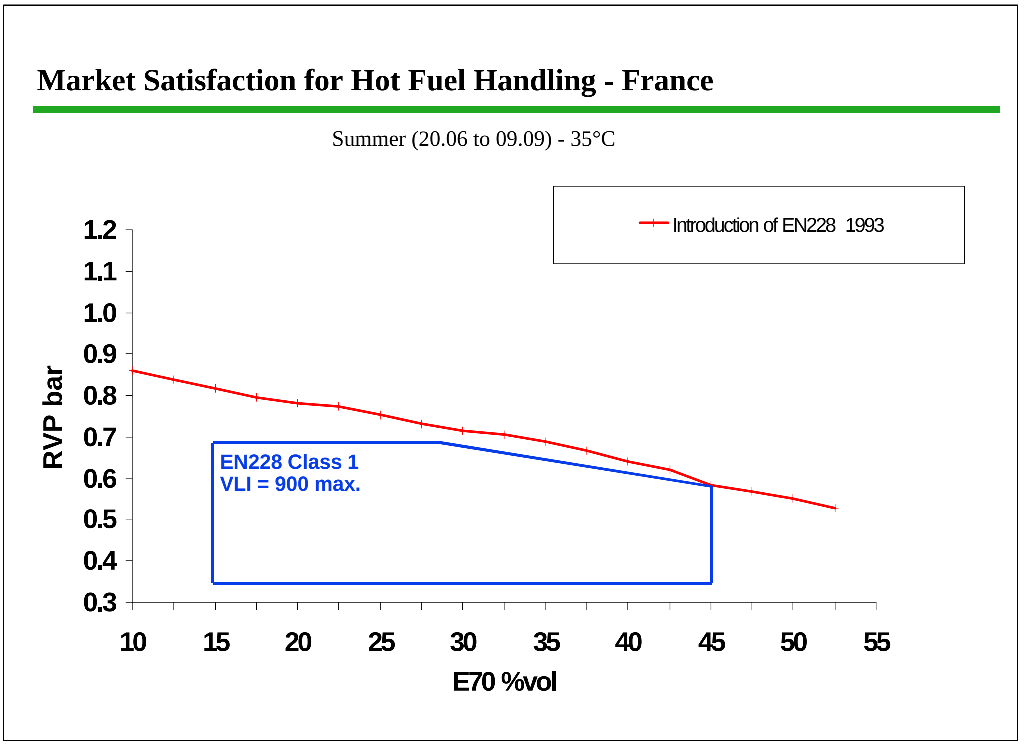


Figure 8 Total Customer Satisfaction for France (Winter 1993)

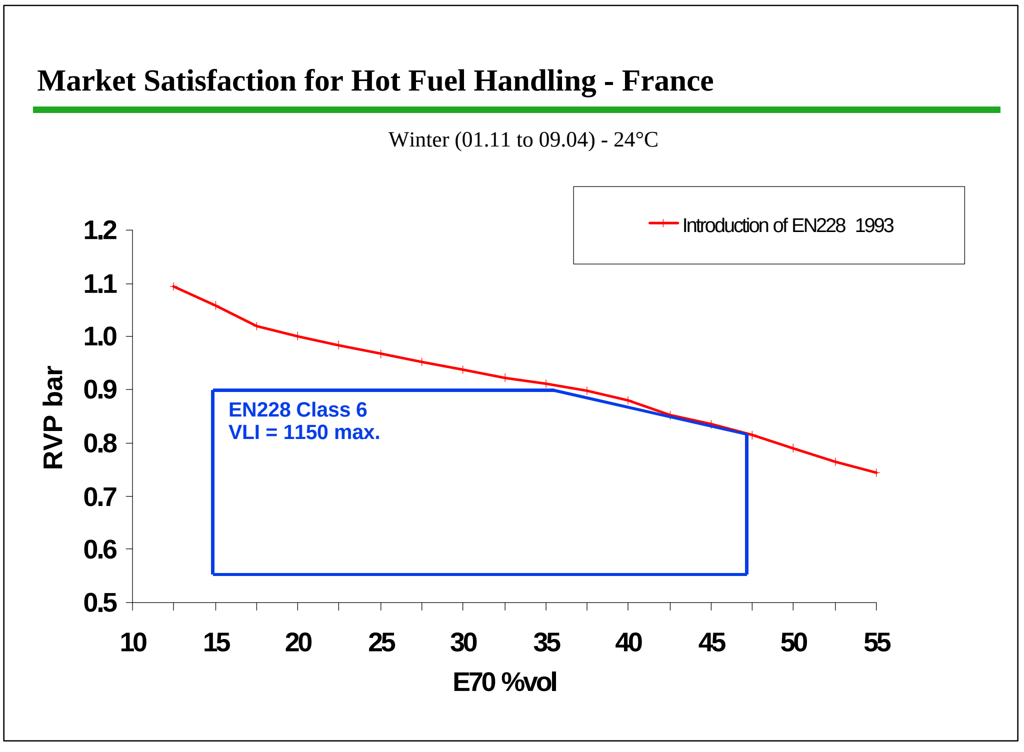
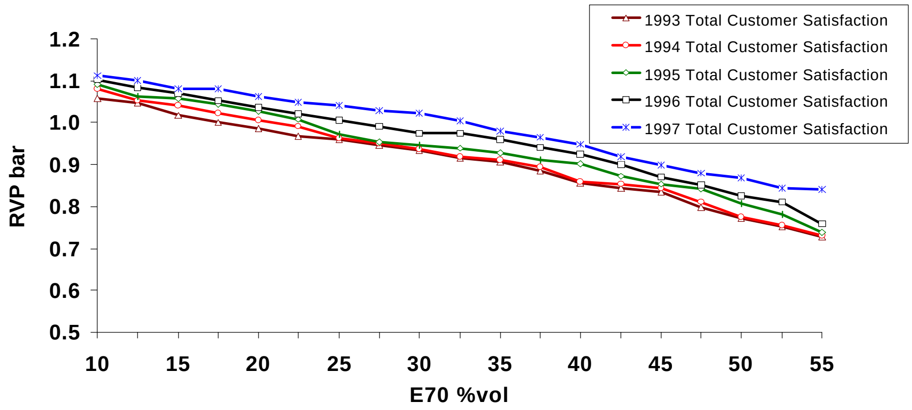


Figure 9 Total Customer Satisfaction for Italy from Year 1993 to 1997

Market Satisfaction for Hot Fuel Handling - Italy



	E70 %v/v																			Average
Year	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**	**27.5**	**30**	**32.5**	**35**	**37.5**	**40**	**42.5**	**45**	**47.5**	**50**	**52.5**	**55**	**(20-50)**
94-93	22	4	24	23	21	24	4	3	4	3	6	9	3	8	9	13	4	4	4	9
95-94	11	11	17	20	20	16	8	5	10	22	17	18	43	19	9	32	33	26	8	19
96-95	11	22	11	9	10	14	35	37	28	34	32	29	22	29	18	10	18	29	20	24
97-96	9	16	12	28	26	27	35	36	48	30	20	25	25	17	27	27	43	35	82	30
														Average change in RVP per year						**20**

Figure 10 European Average and Individual Market Predictions for Yearly Change in RVP for Total Customer Satisfaction

Prediction of Yearly Increase in Market Satisfaction for Europe

Country	Estimation Based on 1996 Car Parc & EU Average Predictions Yearly Delta (mbar)	Estimation Based on 1997 Car Parc & Individual Market Predictions Yearly Delta (mbar)
Austria	20	30
Benelux	20	35
Denmark	20	33
Finland	20	13
France	20	29
Germany	20	41
Greece	20	23
Italy	20	20
Norway	20	20
Portugal	20	23
Spain	20	15
Sweden South	20	24
Switzerland	20	33
UK	20	28
Average	**20**	**26**
Min.	**-**	**13**
Max.	**-**	**41**

Figure 11 Year 2000 Predicted Total Customer Satisfaction for Italy Comparing 1997 and 1996 Calculations

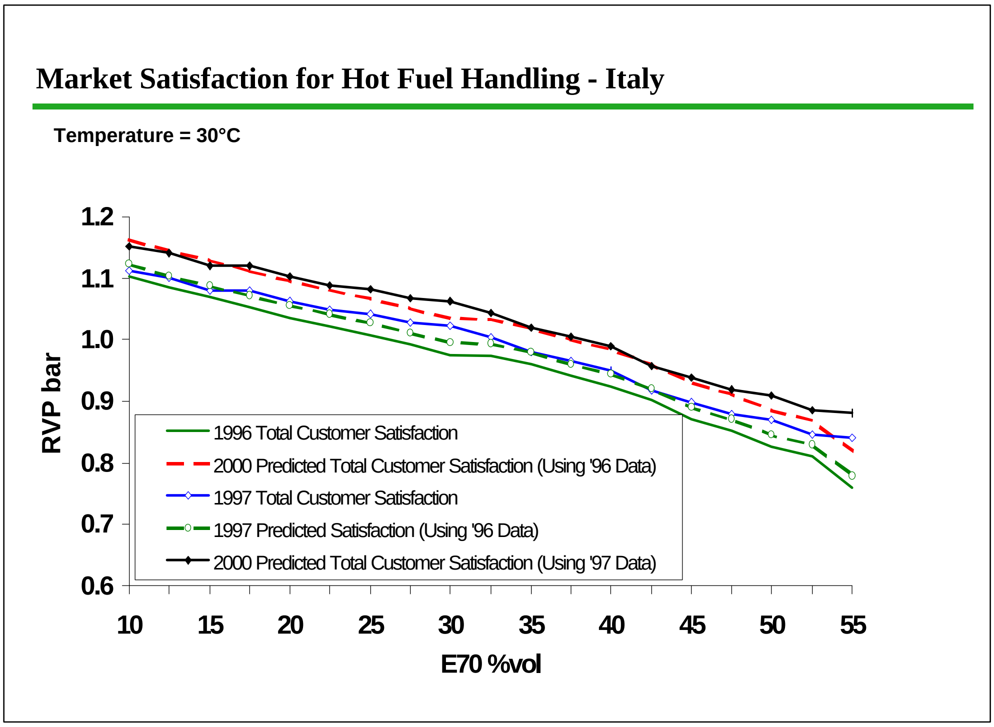
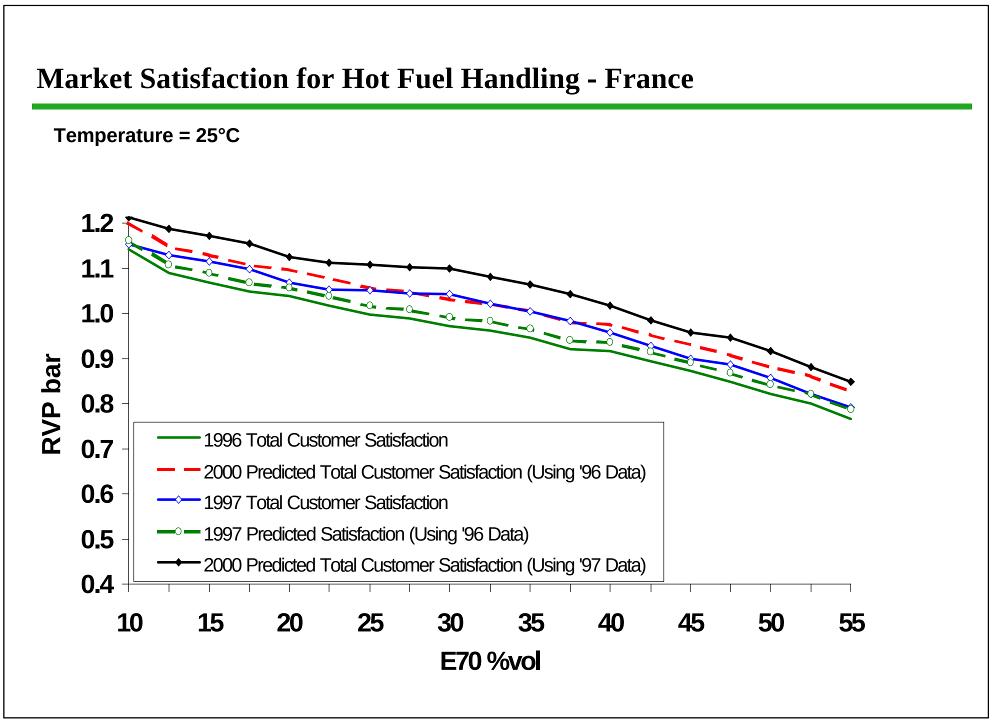


Figure 12 Year 2000 Predicted Total Customer Satisfaction for France Comparing 1997 and 1996 Calculations



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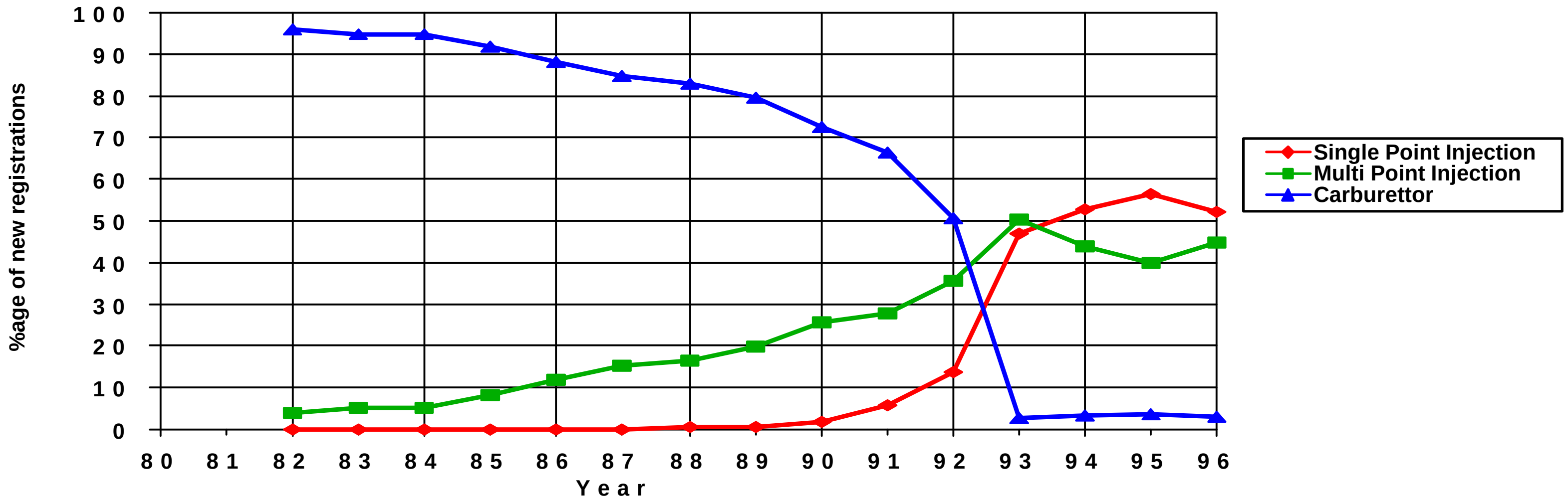
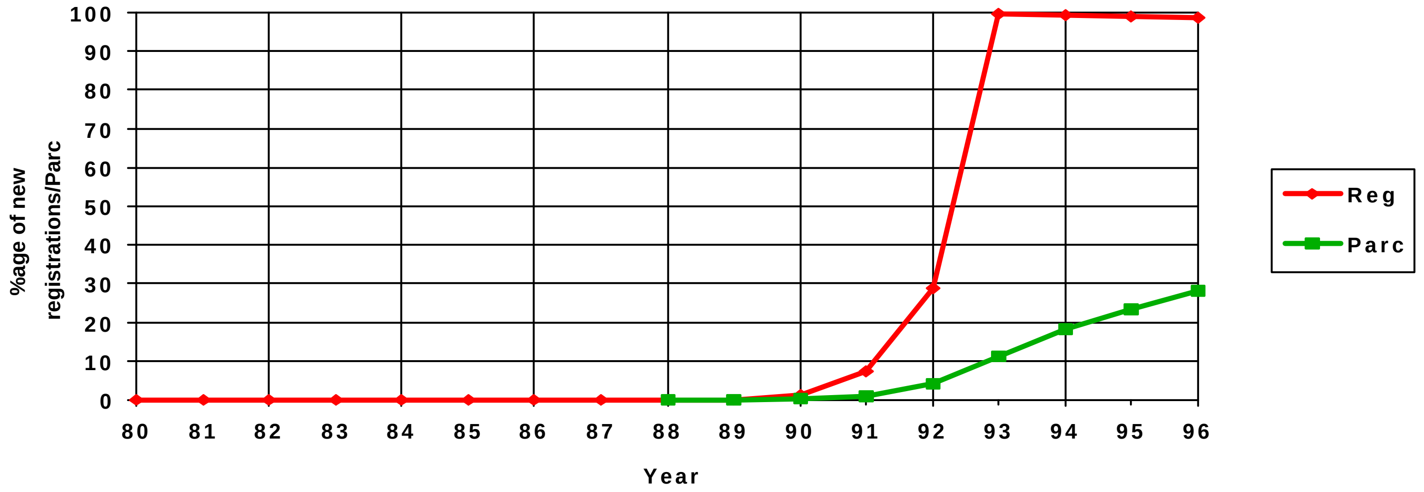
APPENDIX 3

TRENDS IN HOT WEATHER DRIVEABILITY PERFORMANCE

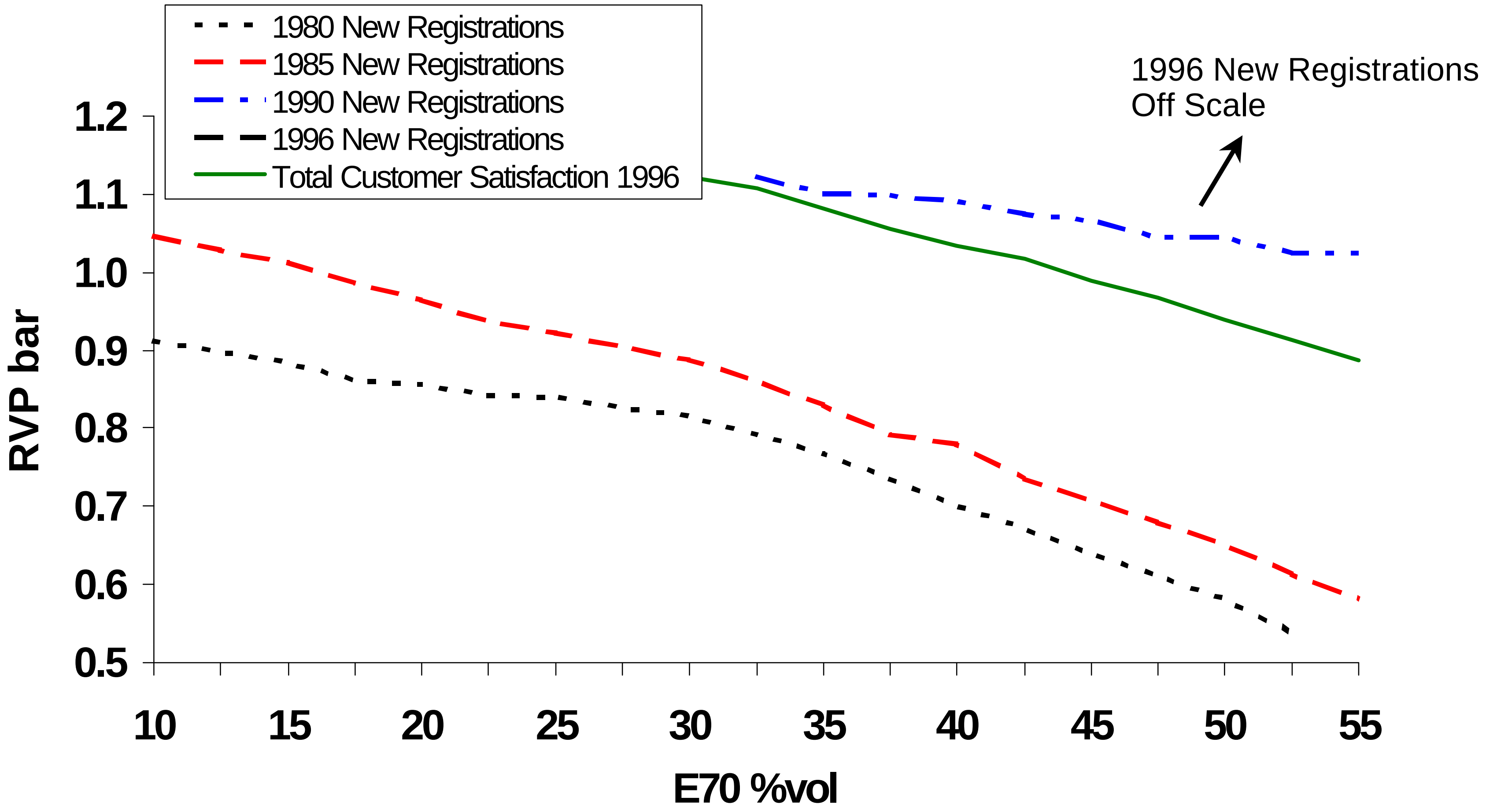
Fuel System / Catalyst Penetration among New Registrations SPAIN





Trends in Total Customer Satisfaction - New Registrations

Germany - Summer



Fuel System / Catalyst Penetration among New Registrations GERMANY