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TNO report

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Development of a procedure for the determination of the additional fuel consumption of passenger cars (M1 vehicles) due to the use of mobile air conditioning equipment
Final report

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Summary

The purpose of the project was to develop a test procedure, to be incorporated in the Type Approval test procedure for passenger cars, for measuring the additional fuel consumption resulting form the use of mobile air conditioner systems and auxiliary heaters. This project is the follow-up of an earlier study that looked into the basic requirements of such a procedure. This second study should further detail such a procedure, validate it and prepare amendments to the current Type Approval procedure for passenger cars in order to obtain the desired fuel consumption information.

One of the basic elements of the first study was to introduce a family- and subsystems concept in order to reduce the amount of actual tests and optimise cost-effectiveness of the data gathering. Such an optimisation proved not to be possible within the context of the project, because the automotive industry refused cooperation after the project was actually granted. This was contrary to statements made by the industry at the end of the first project, stating that the data to facilitate such an optimisation would to supplied by the industry. Even the establishment of a project steering group together with the automotive industry (to be executed by the EC) proved impossible during the project. Establishing the necessary data within the context of the project was not possible due to financial constraints. The testing budget was only sufficient to validate the draft test procedure, but not to gather a basic data set.

Given this situation the project further focussed on establishing a measurement procedure which would fit well within the boundary conditions of Type Approval testing, but which would not incorporate a family or subsystems concept. This meant developing a test procedure that was easy to use with good interlaboratory reproducibility, mainly based on driving the Eurotest driving cycle on a chassis dynamometer. Such a procedure would consist of establishing the additional fuel consumption caused by the use of the air conditioner (or auxiliary heater) by replicating the Eurotest once with the additional system being switched on (and, in case of the air conditioner test, the vehicle being subjected to a well-defined heat load) and once without the additional system being switched on (normal TA test conditions). The additional fuel consumption would be calculated by subtracting both test results.

In order to create realistic testing conditions and to enable distinguishing between higher and lower efficiency systems, an existing Euro 4 emission testing lab should be upgraded with: a battery of solar lamps, a cooling fan that matches the vehicle speed up to 120 km/h and in some cases a more accurate humidity control. The test with the AC on should be executed with the use of simulated solar radiation, starting from 25 ºC and 60 % rh after a short soak period. This set-up will generally result in the vehicle being cooled down with full AC load for part of the test and running on partial AC load towards the end of the test. Using these moderate conditions allows assessment of the impacts of intelligent climate control algorithms that minimize energy use under part load conditions. Using solar radiation would allow taking into account the effect of improved vehicle body design, for instance using reflective glazing, to reduce heat load on the vehicle interior.

The developed test procedure was validated intra-laboratory (on 6 vehicles) and inter-laboratory (1 vehicle). The intra-laboratory validation results showed limited repeatability and reproducibility in relation to the small absolute value of the additional

fuel consumption. This is the result of variations on the test results with the air conditioner switched on and the fact that the overall test result is obtained by subtracting two individual measurement results. The overall result ranges from 6 to 20% of the absolute value of these individual results. Due to this limited accuracy, differences in heat load (and related additional fuel consumption) between vehicles with different glass surface or body types could not be established with statistical significance. Therefore a family definition/concept could not be established.

One of the basic requirements of a Type Approval test procedure is good inter-laboratory reproducibility. The developed procedure failed this point with a relative deviation of 100% between 2 labs. Especially automatically controlled air conditioning systems show a low inter-laboratory reproducibility. This is probably due to the fact that these intelligent systems are influenced by small changes in a wide range of parameters in combination with the delicate adjustments that have to me made to the vehicle and laboratory equipment before testing. In addition the automatic systems take into account thermal comfort as well, which makes the results incomparable with the result of manual systems.

As a result of the investigations executed in this project it can be concluded that a labelling scheme, based on replicating the single vehicle Type Approval test with and without the air conditioner switched on, is not feasible. As a consequence supplying consumer information at the level of single vehicle Type Approval results is also seen as not feasible. Options for technical optimisations to the proposed procedure in order to improve the statistical significance of the single vehicle test procedure proved to be limited. In addition establishing such optimisations would only be possible after a large scale detailed inter-laboratory investigation process (like the PMP project for PM measurement). But even using an improved measurement procedure, the car dependent variations (especially for automatic systems) and the relative small additional fuel consumption (calculated from subtracting 2 larger numbers) would still result in limited repeatability and reproducibility.

With this inevitably limited repeatability and reproducibility of the single vehicle test procedure and the difficulties in inter-laboratory application of the procedure, two basic elements of a test procedure fit for Type Approval can not be met. Therefore no amendments to the current single vehicle type approval directives were proposed.

However, the insights from executing the underlying project can be used to obtain data for labelling and public information purposes, but then within settings in which the statistical significance of test results is increased by multiple testing outside of the Type Approval context. For this purpose TNO proposes two alternative approaches:

- Monitoring the trends in additional fuel consumptions from air conditioning systems in general as they are applied on representative cross sections of the typical European fleet. By measuring the additional fuel consumption of the typical fleet periodically, this would give information on the general progress made by the automotive industry to improve system efficiency;
- Benchmarking of individual systems or groups of systems, which in addition to monitoring may also give information suitable for labelling purposes, if for a certain vehicle the system incorporated can be identified.

The actual amount of tests, to be executed for all possible options in order to obtain statistical significance, will have to be established while setting up such a programme. Data from the underlying investigation do not allow such an assessment.

Based on a basic cost calculation by far the most efficient way to meet the EC's requirements for labelling and ranking is in an independent monitoring programme to assess overall progress with regard to the energy efficiency of air conditioning systems in general. A benchmarking programme to assess individual systems or groups of system still is less expensive than introducing an additional number of tests to Type Approval and will provide similar possibilities for labelling individual vehicles.

The investigation undertaken shows the basic possibilities for applying a family concept, when selecting vehicles to be tested for monitoring or benchmarking. Such family concept would be based on the current family definition from Directive 80/1268/EEC and would have to be widened towards air conditioner type and projected glazing surface.

Based on the technical properties of auxiliary heaters, assessing the additional CO_2 emissions of auxiliary heaters for labelling purposes will not serve the purpose of discriminating between types or encouraging technical development. Modelling these emissions will give some information, but this will not be well suited for customer information. The effect of the use of auxiliary heaters on CO_2 emissions is, however, already implicitly measured during basic Euro IV test at -7 ºC (without radiation).

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Appendices
A The draft procedure as developed in phase 1, incorporating a family approach and sub-systems

1 Introduction

1.1 A short review on the first study

Within the framework of monitoring (and controlling) the CO_2-emissions of light-duty vehicles, their CO_2-emission is measured in the type approval test, according to Directive 80/1268/EEC and subsequent amendments. There are, however, significant sources of CO_2-emission that are not addressed by this test in its current form. Two of such sources are the air conditioning and the auxiliary heater that are being installed in many cars for the European market in recent years. For this reason in 2002 the Commission commissioned a study with the following objectives:

- To generate insight into the size of CO_2-emissions resulting from the use of mobile air conditioning (MAC) and auxiliary heaters in comparison to the CO_2-emissions as measured in the type approval test;
- To receive an overview of existing and possible options to include measurement of such CO_2-emissions into the (or a) type-approval test;
- To receive a development of the option that seems to be most representative for the European situation;
- To receive the basic information for a cost-effectiveness study;
- To receive concrete proposals with regard to a possible amendment of Directive 80/1268/EEC (fuel consumption) and possibly Directive 70/220/EEC (emissions).

This study was reported in spring 2003 in [TNO 2002].

An important question in the first study was to define the exact purpose and application of the measuring procedure. As subsequently stated by the Commission, the main purpose of the project was to obtain a better insight in the influence of air conditioning systems and auxiliary heaters on the fuel consumption and CO_2-emissions of passenger cars. The purpose of any test procedure resulting from this investigation would be to obtain figures suitable for a labelling system that would:

- Serve as an incentive for the manufacturer to develop more efficient systems;
- Be the answer of the Commission to the consumer's ‘right to know’.

The report on the first study pointed to the following main conclusions:

- The use of air conditioners in European cars leads, on average, to an increase in fuel consumption of 0.28 litre/100 km (7 g/km CO_2). For auxiliary heaters the energy consumption is of the same order of magnitude or considerably lower, depending on the type of heater used. This increase in fuel consumption and CO_2-emissions is considered significant by the Commission, especially in the light of the Community's objective of lowering the average CO_2-emissions of new passenger cars to 120 g/km;
- The most straightforward approach to establish the environmental performance of any auxiliary system would be to perform the fuel consumption test twice: the first time with the auxiliary system switched off and the second time with the auxiliary system switched on under standardised test conditions. The subtraction of the results of the first test from those of the second then gives the effect of the auxiliary system. This set-up, however, would lead to at least a doubling of the amount of tests. The financial- and timing implications of such a procedure, especially if the test would have to be part of the test procedure for type approval, would likely imply costs for

the automotive industry and would make the cost-effectiveness of such a procedure doubtful;

- Taking these implications into consideration other options were investigated that would decrease the amount of actual test work, without compromising the basic requirements of the procedure. This led to a set-up in which car types on the market are grouped into certain families, enabling one test set-up per vehicle family (instead of one test per vehicle type). The subsequent proposal concentrated on the determination of the additional CO_2 emissions of mobile air conditioners (MAC), since it was felt that these would form the most challenging group and that other types of auxiliary equipment could be handled by a simplified version of the MAC-procedure.

The basis for the family defining process has to be the degree of similarities between vehicle types. These similarities on vehicle construction level can be split into 3 groups (subsystems):

- Subsystem I: the power generation system (engine)
- Subsystem II: the air conditioner system
- Subsystem III: the vehicle body and its environment

By means of establishing typical parameters for each subsystem (within a certain family) in relation to certain environmental conditions, while executing the fuel consumption test on a "parent vehicle", the actual amount of tests needed to address the topic under investigation can be reduced significantly. In order to live up to the basic requirement of the procedure to be able to rank systems (combinations of the three subsystems) based on their environmental performance; the testing in a climatic camber under stabilised conditions was assumed to be required.

A summary of the draft procedure as worked out in [TNO 2002] is given in Section 2.2. A more detailed description can be found in Appendix A.

Due to the complexity of the subject, the original objective to formulate a concrete proposal for a test procedure in terms of amendments to the existing Directive (item '5' of the list of objectives) could not be realised within the boundary conditions of the previous project. Instead an outline of a possible measurement procedure was presented, that still had to be tested and validated. In co-operation with the Commission it was decided that this testing and validation would have to be the subject of a follow-up study. The results of the first study were presented and discussed at a stakeholders meeting, at which the Member States present indicated a preference for such a follow-up study to be executed. Consequently, the Commission decided to commission a phase 2 study. The purpose of that second project, of which this report is the final deliverable, is described in Section 1.2.

1.2 The purpose and scope of the present study

The initial purpose of the present study was the detailed development of a test procedure based on the approach proposed in the first study and the evaluation of this procedure in terms of:
- A check on the practicability of the procedure in the laboratory;
- The exact definition of the requirements for the procedure;
- Insight in the value of parameters and the variability of the values in relation to surrounding conditions;
- Insight in the possibility to use default values for certain parameters based on the knowledge of the variability and the level (of importance) of the parameters;
- A more dedicated calculation of the actual cost-effectiveness based on actual measured data in a more final procedure set-up.

The first step in working out the procedure as proposed in [TNO 2002] would be a further detailing of the family concept based on subsystems. This would require detailed information from the industry on vehicle bodies (types, dimensions, glass surface, etc.), airco systems and engines. After intensive interaction with the industry in the first phase of this project, however, it turned out that the industry refused co-operation in the development of an airco test procedure and that the required information therefore would not become available. Without such information, however, development of a subsystem-based procedure and family concept is not possible.

Subsequently, further to a proposal from the contractor, the Commission has decided to continue the project, but to shift slightly the focus from a subsystem-based procedure to a vehicle-based procedure. The procedure is to be applied either as part of the European type approval, and the option of a benchmarking/monitoring programme was also to be investigated. In such a programme annual measurements on a representative sample of vehicles, containing vehicles of different models from different manufacturers, could be used to monitor progress in the application by the industry of measures to reduce the additional energy consumption resulting from the use of air conditioning systems.

The goals of the project are the following:
- Development of a vehicle-based test procedure for assessing the additional fuel consumption and CO_2-emission as a result of the use of air conditioning in passenger cars;
- A proof of concept and a first validation of this method by means of laboratory measurements;
- To gain insight into the possibilities of applying some sort of family concept to a vehicle-based test procedure;
- A detailed calculation of the cost-effectiveness based on actual measured data in a more final procedure set-up;
- Working out the proposed procedure in the form of proposals for amendments of Directives 80/1268/EEC en 1999/94/EEC (labelling).

Furthermore options have been explored to apply some form of family approach to the vehicle-based test procedure with the aim to reduce the amount of tests.

1.3 This report

- Chapter 1 summarizes some results of the previous study and outlines the objectives of the current study;
- Chapter 2 describes the various possibilities that were open for the development of a final procedure, given the budgetary restraints of this phase and the available information.
- In Chapter 3 the overall approach for the procedure is worked out;
- The development of the draft test procedure as such is described in Chapter 4;
- Chapter 5 describes the programme that was set up to validate the draft procedure developed in this project, presents the results of laboratory tests carried out according to that programme and gives possibilities to further refine the procedure, based on the experience from the results of the validation programme.
- A final proposal for the procedure is presented in Chapter 6;
- Chapter 7 presents considerations regarding application of the developed procedure in the context of Type Approval, benchmarking or monitoring;
- Costs and other practical aspects of implementation are discussed in Chapter 8;
- Chapter 9 ends this report with conclusions and recommendations;
- Appendix A summarizes the draft procedure as developed in phase 1, incorporating a family approach and sub-systems;

2 Different layouts for the procedure

2.1 Introduction: the options for a standardised procedure

The starting point of this project was the desire of the Commission to create a solid basis for a labelling system for the fuel penalty caused by the use of mobile air conditioners. Such labelling systems already do exist for other products, as well as for the basic fuel consumption of passenger cars. Their purpose is to make the consumer aware of the energy-linked consequences of this purchase, or the choice of product he makes in that context, and to stimulate him to take these energy-linked consequences into account when making that choice. This is one of the three pillars of the Community approach for reducing the greenhouse gas emissions of passenger cars, and therefore fully in line with existing and declared policy. This labelling as consumer awareness rising and the effect of that on consumers buying behaviour also gives an incentive to manufacturers to optimize their products towards increased efficiency.

In principle there are two basic options for assessing the fuel consumption and CO_2-emission consequences of the use of mobile air conditioners (and auxiliary heaters):

- **Option 1**: a subsystem-based approach using family definitions for vehicle bodies, airco systems and engines and a calculation model to determine the additional CO_2-emissions at the vehicle level on the basis of measurement data obtained at the subsystem level;
- **Option 2**: a vehicle-based approach in which the additional CO_2-emission is measured at the vehicle level.

2.2 Option 1: The subsystem-based approach

The possibility to apply a subsystem-based assessment procedure was proposed in the report of the first study [TNO 2002]. In principle this approach will have a limited accuracy, but it offers the possibility to seriously reduce the amount of testing required, and as a consequence to improve cost-effectiveness. Such an approach is fully new in Community legislation, and hence quite ambitious. When working out its basic proposal in the first study, the project team was nevertheless sufficiently optimistic that, provided sufficient input from the industry could be obtained, it would be possible to arrive at a realistic procedure that would realise far-reaching cost reductions without having to sacrifice the accuracy of the end result to an unacceptable extent. The Commission agreed and asked for further detailing in a second phase.

The essence of the proposed ‘subsystem-based assessment procedure’ is the use of a model-based calculation procedure (desk work) on the basis of a single test series on a ‘parent’ vehicle plus a limited number of test data from any number of ‘family members’. This procedure requires a good and reliable insight into the parameters that determine the real CO_2-emission penalty and the magnitude of their respective influences. On that basis is should be possible to introduce the following simplification steps:

- A workable definition of car body families, greatly reducing the number of actual vehicles to be tested;
- A workable definition of a/c component families, greatly reducing the number of individual components to be tested;

- A workable definition of engine families;
- A sensible selection of parameters that need actual determination through measurement, allowing other parameters to be determined in a less costly way;
- A sensible selection of parameters that may be determined by the simple application of ‘correction factors’ to other data that are measured.
- A sensible selection of parameters for which standard ‘default values’ may be used, as well as a realistic estimation of the magnitude of these ‘default values’.

This means that the elaboration of the intended ‘subsystem-based assessment procedure’ can only go ahead if a large body of actually measured data is made available, which can be used to:

- Analyse the influence of the different parameters on additional CO_2-emissions;
- To investigate the possibilities to group subsystems in a family definition,
- And to accordingly derive a calculation model that allows estimation of the additional CO_2-emissions based on a limited number of data measured at the subsystem level.

On the basis of this analysis the contractor should be able to work out a meaningful and workable procedure that can be used in the context of implementation in 80/1268/EEC or as basic procedure to undertake an annual air-conditioner benchmark (see par 9).

The table below summarizes the various steps of the draft subsystem-based procedure as developed in [TNO 2002]. A more detailed description is included in Appendix A.

Table 1: The proposed test approach in the first study.

Step concerns	Type of action	Input	Output
STEP 1 Determination a/c performance needed	Measurement on parent Check on family members	Temperature profile	Required CFF [K*kg]
STEP 2 a) Determination of a/c drive energy b) Determination of compressor speeds	Measurement on 'worst case' system	CFF of parent Standard test cycle	Drive energy over cycle X [kWh] mech. Y [kWh] electr.
STEP 3 Determination of: a) additional FC and CO_2 b) engine efficiency factor of parent (for use with family members)	Measurement/ calculation	Output of STEP 2 of family member, or STEP 3b of parent	FC [litre/test] and CO_2 [g/test] Reference engine efficiency factor
PRESENTATION Determination of label	Calculation	OUTPUT of STEP 3 and activity factor	LABEL FC [litre/year] CO_2 [kg/year]

2.3 Option 2: The vehicle-based approach

On the one hand there is the straightforward possibility to test every vehicle type twice, i.e. with and without the MAC in operation, and additionally, if applicable and necessary, for different MAC or vehicle configurations. This would fully satisfy the Commission's objectives, and it would be simple, straightforward and easy in terms of the test procedure, but expensive due to the large number of tests.

Below the two concrete options are worked out in more detail to show their possibilities for a test procedure. The first option was developed in concept in the first study [TNO 2002]. As already mentioned, implementation of the second option will lead to a larger amount of tests to be carried out, making this option an expensive one. For this reason the option to reduce the amount of testing by also incorporating a family approach in the vehicle-based approach should be investigated too. This is done in Section 2.4.

The vehicle based approach means no more or less than testing the vehicle once with the air-conditioner switched on (testing to be performed under non-standard climatic conditions simulating a heat load on the vehicle) and once with the air-conditioner switched off (reference testing to be performed under standard climatic conditions). The test with the air-conditioner on should be performed in a climatised test chamber under specified irradiation with light having a specified intensity and spectrum and should be accompanied by appropriate pre-conditioning in the same test chamber.

The effect of the use of the air-conditioner on fuel consumption is determined by the difference between the two tests.

Costs could be saved if the standard Type Approval test could be used as the reference test. In that case this simple approach would mean that for every vehicle model from a range offered by a manufacturer only one additional test should be performed, under special climatised conditions.

The major steps of a vehicle-based test procedure are displayed in Table 2. The procedure is worked out in more detail in the next chapter.

Table 2: The vehicle based approach.

Step concerns	Type of action	Input	Output
STEP 1 Determination FC With a/c off	Measurement	Driving cycle under standard ambient conditions	FC [litre/100 km] and CO_2 [kg/100 km] a/c off
STEP 2 Determination FC With a/c on	Measurement	Driving cycle under special ambient conditions (temperature and irradiation)	FC [litre/100 km] and CO_2 [kg/100 km] a/c on
STEP 3 Determination of: additional FC and CO_2	Calculation	Results of STEP 1 and STEP2	Additional FC [litre/100 km] and CO_2 [kg/100 km]
PRESENTATION Determination of label	Calculation	OUTPUT of STEP 3 and activity factor of a/c use	LABEL FC [litre/year] CO_2 [kg/year]

A first assessment of the cost implications has been presented in the report for phase I [TNO 2002]. These calculations show large costs of the vehicle based approach compared to the subsystem approach combined with the implementation of a family definition. An advantage of the vehicle based approach, however, is that it is straightforward, meaning it is not complex to perform, and rather accurate. A more detailed cost analysis, based on the exact procedure as worked out in Chapter 4 and the experience gained in its experimental validation is presented in Chapter 8.

2.4 Considerations regarding the use of a family definition in the vehicle based approach

Applying some sort of family definition to the vehicle-based approach would especially be desirable for the situation in which the procedure is incorporated in the test procedure for Type Approval (80/1268/EC), but also for the situation in which the procedure would be used as a monitoring procedure. In the first case the family approach would reduce the amount of testing and thus the costs. In the second case it would allow a better selection of vehicles based on discriminating parameters, making it possible to cover a wide range of ‘vehicle / air conditioner’ combinations by grouping them into families for which, to a certain extent, the same level of effect can be expected.

The possibilities to work out a family definition have proven to be very limited, due to the lack of detailed data on possible parameters discriminating families. This all due to the fact that the industry has not actively contributed to the project in supplying such data (which was stated as an absolute necessity in the project proposal from TNO for this project). The industry was even not prepared to take part in a project steering group that would have to be established by the EC. However considerations concerning the options for family concepts are discussed in chapter 8, based on the exact procedure worked out in chapter 7 and the results of the evaluation programme as presented in chapter 5.

Table 3: The vehicle based approach with inclusion of the family approach

Step concerns	Type of action	Input	Output
Preparation Definition of families and parents	Desk work	Manufacturer data	Families and parents
STEP 1 Determination FC with 'a/c off' of parents	Measurement	Parent vehicle Driving cycle under standard ambient conditions	FC [litre/100 km] and CO_2 [kg/100 km] a/c off
STEP 2 Determination FC with 'a/c on' of parents	Measurement	Parent vehicle Driving cycle under special climatic ambient conditions	FC [litre/100 km] and CO_2 [kg/100 km] a/c on
STEP 3 Determination of: a) additional FC and CO_2 b) efficiency factor of parent (for use with family members)	Calculation	Results of STEP 1 and STEP2	Additional FC [litre/100 km] and CO_2 [kg/100 km] Efficiency factor for use with family members
PRESENTATION Application of efficiency factor to family members and determination of label	Desk work	FC and CO_2 and activity factor of a/c use	LABEL FC [litre/year] CO_2 [kg/year]

2.5 Selection of the option to be worked out

The main characteristics of option 1 (subsystem-based approach) are on the one hand the complexity of the procedure and the limited accuracy, but on the other hand the limited amount of tests to be carried out as a result of the sub-system based family concept. Option 2 has the advantage of being a rather straightforward and accurate test procedure, but the disadvantage that tests have to be performed on all possible (i.e. significantly distinct) permutations of vehicle body, air conditioner type and engine type.

In principle the first option, based on subsystems would be preferred by the Commission and would also seem more in line with the interests of the industry as it is much more cost-effective. Working out the family concept and the calculation model for this option would require an active participation of the industry in the project, in the form of supplying detailed information on vehicle bodies (types, dimensions, glass surface, etc.), airco systems and engines. As the European car industry in the end has not enabled such co-operation, option 1 could not be worked out.

Consequently the consultant proposed and the Commission agreed to continue, working mainly towards the second option, being the vehicle-based approach. However in the end, discussion with individual experts from the industry[1] and research organisations together with the results of the validation measurement programme gave some information on family building within the context of AC systems and auxiliary heaters. This option is further worked out and analysed in the following chapters.

[1] The referred to experts participated on an independent bases (outside of the ACEA context) supplying general information (no data) on critical factors in airconditioner operation and in the end reviewed the draft final test procedure developed by the consultant

3 Definition of the overall procedure

In this chapter the general concept of the vehicle-based approach will be worked out. The development of this approach will be discussed in Chapter 4, while in Chapter 6 a final proposal is made.

3.1 General requirements

The main purpose of the procedure was defined by the Commission as delivering meaningful figures to consumers to allow comparison of vehicles and airco system across the range of passenger car makes and models on the European market and to increase consumer awareness of the additional fuel consumption resulting from the use of climate systems. This imposes several general requirements on the procedure to be developed especially related to its outputs e.g. in terms of the power to discriminate, reproducibility, repeatability and accuracy.

Implementation of the procedure is foreseen either as part of the European regulations for type approval or as part of a European monitoring or benchmarking programme in which the progress of improving energy efficiency related to cabin cooling and heating is monitored by annually testing a representative sample of vehicles on the market. These applications in principle pose very different demands on the procedure to be worked out. A monitoring programme in which a limited number of vehicles is tested could be very well served by a dedicated test procedure. In the case of application in the context of type approval the test procedure should preferably relate closely to the existing type approval test procedures and should entail a minimum number of additional tests to be performed. For type approval the procedure should have a higher degree of legal ‘water tightness’. Also the test does not *have* to be representative for real life conditions (but may be a worst case) as long as it correctly assesses the effectiveness of technical measures. A certain amount of representativity, however, could be desirable, see the paragraph about represenativity on the next page.

The demands posed by the application in type approval testing are not necessarily consistent. The vehicle-based approach can be based on the existing type approval test procedure, but requires one or more additional tests for every family currently discerned for homologation. The subsystem-based approach on the other hand greatly reduces the number of additional tests but involves a dedicated test procedure strongly deviating from the structure of existing type approval testing of light duty vehicles.

The general conditions defined below will be used to motivate choices with respect to the definition of a proposal for a vehicle-based test procedure. In the end they will determine whether the selected set-up for the procedure is successful or not, in relation to its declared main purpose(s).

Power to discriminate

In the first place the test procedure should be able to give results that discriminate the systems and vehicle configurations regarding their influence on fuel consumption. This first of all means that the order of magnitude of the measured additional fuel consumption should be such that observed differences in this parameter as measured on different vehicles / systems are still significant with regard to the overall accuracy of the measurement. If these differences are relatively small under normal operating conditions, the test conditions need to be defined in a rather extreme way. This may obviously conflict with demands regarding the real life representativity of the test results.

Representativity in real life

A certain amount of representativity of the test results is advisable. In order to serve the goal of increasing consumer awareness the test result should allow calculation of an indicative figure for the annual additional fuel consumption as a result of the use of air conditioning which relates to vehicle and airco use in normal / average vehicle operation. Unrealistic figures will undermine the credibility of the test results and as a result consumers may tend to ignore the provided information or corresponding label. On the other hand a full representativity for all situations occurring is neither possible nor desirable. As indicated above the demand for representativity may conflict with the requirements concerning the power to discriminate.

Reproducibility, repeatability, accuracy and tolerances

As a starting point the accuracy of the test should at least be of the same order as that of the present Type Approval test. As the additional energy consumption resulting from the use of air conditioning is an order of magnitude smaller than the vehicles' normal energy consumption, relevant differences between the additional energy consumption of different vehicle / airco system combinations are also quite small. Determination of these differences would then require a better accuracy than the standard energy consumption measurement. Reproducibility is important because the test procedure will be performed by different test houses in the field. Even tests on the same vehicle model but with different airco systems may be performed by different labs. The results from the different test houses should, to a certain extent, be the same for a given vehicle and air conditioner combination and should also be comparable for comparable vehicles / systems. Differences in test results on the same vehicle and airco system in different labs should thus be smaller than differences between different vehicles with different airco systems which are considered significant in the context of this issue. This requires a certain degree of absolute numerical accuracy of every test result. Repeatability (i.e. differences between similar tests carried out in the same lab) should be better than the desired reproducibility.

When two family members are tested, the difference in performance should not be larger than the repeatability of the tests. On the other hand two comparable vehicles of the same model but with slightly different characteristics (e.g. engine or body type) could be considered to be of the same family if the measured difference in additional energy consumption is smaller than the repeatability of the test.

For the reasons mentioned above, tolerances have to be set for different parts of the procedure, in order to be able to control to a certain extent the amount of variation between reproduced or repeated tests. What the level of the required reproducibility, repeatability, accuracy and tolerances is, has to be defined from hands-on experience with the procedure and from another already existing MAC testing procedure in the US (40CFR-Chapter I – Part 86, 86.161.00 and further). The US test procedures parameters can not be applied directly to the European proposal, since the US procedure is "full load " test. It has been elaborated that the conditions for the European setup should be close to average European operating conditions (allowing partial load), whereas the US conditions are set to create full load condition over the whole test.

The CO_2-measurement in the type approval test has an overall accuracy of about ± 2%. With an average CO_2-emission of about 160 g/km this comes down to an absolute accuracy of around ± 3 g/km. The additional fuel consumption due to the use of the air conditioner is determined by the difference between two measurements. The absolute accuracy of this difference is about twice the accuracy of the single measurement. Based on the first study the typical additional *measured* fuel consumption over a driving cycle, with the air conditioner in operation, resulting from the use of this air conditioner in a Euro III vehicles is expected to be of the order of 30 to 50 g/km. The exact value depends amongst others on the type of the system, the capacity of the system and the effective cooling demand under the defined test conditions. With an absolute test accuracy of about ±6g/km, the relative accuracy of the measurement of this additional fuel consumption by the use of an airconditioner will thus be around ±10 to ±20%.

Workability

Workability is used as a term here that represents the ease with which the test procedure can be carried out:

- Are laboratories in general sufficiently equipped so that no major purchases are imposed? It should preferably be possible to perform the tests in existing laboratories with the existing equipment. If that is not the case, then required investments should be minimised as far as possible, still keeping an eye on the other requirements;
- Is the procedure workable in a practical way? Is it technically possible to equip the test object, in this case the vehicle to be tested, at all, or at least without major modifications. Is the equipment needed available/purchasable/affordable?
- Does the procedure require an excessive amount of man-hours due to the imposed requirements for the tests? The amount of work to be performed for any given part of the procedure should be in line with its necessity for the procedure e.g. in terms of obtaining an end result with the required accuracy.

3.2 The elements of the overall procedure

The overall procedure will consist of several elements that together will form the procedure. The elements are:

- the definition of the test object (vehicle);
- if applicable the family definition;
- the definition of the test procedure;
- and the presentation of the results.

The elements described are largely based on the structure and elements of the Type Approval procedure 80/1268/EC. This is necessary to allow the possible incorporation of the airco test procedure into the procedure for Type Approval. Some elements (e.g. “Extension of approval”) will however not be necessary for a procedure that is only used in the context of a benchmarking or monitoring programme. Still, even for these applications the desire is to develop a test procedure that as much as possible relates to the existing procedures for type approval.

3.2.1 Test vehicle

European vehicle category

As a starting point the object that has to be evaluated should be defined. The definition of the object follows from 70/156/EC and its amendments in which the European vehicle categories have been described and 80/1268/EC, in which the measurement of the fuel consumption of M1 and the N1 category vehicles is described. In the specific case of testing the effect of the use of a mobile air conditioner on fuel consumption, the object concerned is a category M1 vehicle (category M, sub-category 1). This vehicle is meant for the transportation of up to 9 passengers, has a minimum of 4 wheels and has a Gross Vehicle Weight (GVW) lower than 2500kg or a GVW that is between 2500 and 3500kg.

Besides these definitions some other vehicle characteristics should be taken into account in the development of the procedure.

Exterior colour definition

With respect to the additional fuel consumption resulting from the use of a MAC, the exterior colour could be seen as a variable that may significantly affect the final result. After discussions with experts[2] it became clear however, that current vehicles bodies are that well insulated, that the heat exchange trough the metal parts of the body can be neglected. The heat exchange that is significant occurs through the windows and the ventilation system. Therefore the exterior colour of the body play no significant role in the additional CO_2 consumption due to the use of AC systems. And as the focus of the procedure is to evaluate the efficiency of the air conditioner system in relation to engine and overall vehicle design characteristics, it was decided not to include colour as a variable in the procedure. For carrying out the procedure and for meeting the requirements of reproducibility, repeatability and comparability among vehicle types it is however of relevance that a fixed colour is defined, so that any interference of colour with the test results is avoided and the test results can be compared.

Because silver metallic is the best sold colour in Europe it is chosen as the reference colour for the cars which are subjected to the procedure. If a manufacturer does not have this colour in its range, the closest metallic colour with respect to the absorption and reflection of sun light should be chosen or else the closest non metallic colour.

Interior colour definition

Like the exterior colour the interior colour could have an effect on fuel consumption: dark interiors absorb more heat than light coloured ones. At the moment, most passenger cars are sold with a mid dark to dark interior, varying from grey to anthracite and black, although some are sold with light (e.g. beige) interior. The most important part of the interior in this context is the upper side of the dashboard, since it is located immediately under the windscreen. The dashboard however is dark grey to black in al cases, in order to minimise reflections for the driver in the windscreen. Similar to exterior colour, for the procedure it was chosen not to include interior colour as a

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[2] See footnote on page 17

variable, but to define an prescribed interior colour range for the test car, in this case varying from dark-grey to black or any dark colour or a combination of colours nearing this range.

Fuel

Test should be carried out for a range of relevant engine types which are fitted on a given vehicle model, which should include all fuels available for the vehicle model. For the tests the right reference fuel should be used as laid down in paragraph 4.4 of Annex I of 80/1268/EC, also referring to Annex IX of 70/220/EC.

Other provisions

In 80/1268/EC, paragraph 5 of Annex I special provisions are laid down for the condition of the test vehicle. It is proposed to copy, for use in Part A of the air conditioner test procedure (measurement with air conditioner off), the provisions that concern:

- The odo meter reading (5.1.1.)
- Vehicle performance (5.1.3.)
- The radiator fan (5.1.6.)
- Pressure charging (5.1.7.)
- The lubricants (5.2.)
- The tyre pressure and type (5.3.)
- The test cycle (6.1.): the test cycle is as laid down in paragraph 6.1 of 80/1268/EC, referring to Appendix 1 of Annex III to Directive 70/220/EC, including both urban driving and extra-urban driving.
- Definition (6.2.)
- Reference mass (6.2.1.)
- Dynamometer adjustments (6.3.)
- Calculation of emissions (6.4.)
- Calculation of fuel consumptions (7.)

For Part B of the test procedure (measurement with air conditioner switched on) the same provisions are valid with the exception of:

- The general mechanical condition (5.1.1.): additional to the general mechanical condition of the car, the air conditioner system should be in good shape, i.e. driving belts of the compressor should be tight, there should be no leakage, and there should be enough refrigerant in the system. Furthermore, the cabin should leak no air. The windows and the cars' surface should be clean.
- The preconditioning: an alternative preconditioning sequence for Part B will be prescribed in which the vehicle will be soaked under adapted climatic conditions including simulated solar radiation.
- The setting of the other equipment (5.1.5):):
  - During the test with the a/c on, the air conditioner is in operation and should therefore be switched on, which is in contrast to the standard provision. Furthermore, windows, doors, hood and trunk should be closed during the test and during the short and long soak with adapted climatic conditions including simulated solar radiation.

The adapted provisions are developed within this study and are described in Chapter 4.

3.2.2 Family concepts

The possibilities to include a family definition proved to be limited due to the lack of detailed data from the industry. Based on information exchange with experts[3] and based on the data form the measurements executed within the context of the project, some more common parameters that could be used for family definitions were established. The possible considerations on the options for family concepts are presented in paragraph 7.1.2, based on exact procedure worked out in chapter 7 and the results of the evaluation programme as presented in chapter 5.

3.2.3 Test procedure

As a starting point for the development of a test procedure for testing according to the vehicle based approach the following test sequence is proposed. The procedure consists of a part for the determination of the fuel consumption with the air-conditioner switched off (Part A), a part for the determination of the fuel consumption with the air-conditioner in operation (Part B) and a part for the determination (calculation) of the additional fuel consumption (Part C).

[3] See footnote on page 17

Table 4: Overview of the testing procedure.

Part of sequence	**Laboratory**		**Desk (calculation)**
	Reference condions	**Climatic conditions**	
Part A: testing 'a/c off'	Preparation Preconditioning (soak)		
	Measure FC with A/C switched off over the prescribed driving cycle (FC from TA)		
			Calculate FC (A/C off)
Part B: testing 'a/c on'		Preparation Preconditioning (soak)	
		Measure FC with a/c switched on over the prescribed driving cycle	
			Calculate FC (a/c on)
Part C: Calculation			*Derive additional FC by substraction.*

Special provisions

Directive 80/1268/EC contains a provision in which promising future fuel efficient technologies can be taken into account and can be subjected to legislation even though they formally can not be tested using the existing test procedures. This provision could also be applied in the case alternative, energy efficient technologies for air conditioner systems would be offered, or other special measures would be taken to reduce the additional energy consumption or CO_2 emission resulting from the use of air conditioners.

Provision 10.1
In the future, vehicles with special fuel efficient technologies may be offered which could be submitted to complementary testing programmes. These would be specified at a later stage which can be claimed by the manufacturer in order to demonstrate the advantages of the solution.

Extension of approval

In Directive 80/1268/EC a possibility is defined for extension of approval. For the M1 category this means that type-approval can be extended to vehicles from the same type or from a different type differing with regard to the following characteristics of Annex II, if the CO_2 emissions measured by the technical service do not exceed the type approval value by more than 4%:

- Reference mass;
- Maximum authorised mass;
- Type of bodywork:
    - For M1: saloon, hatchback, station wagon, coupe, convertible, multi purpose vehicle;
- Overall gear ratios;
- Engine equipment and accessories.

In principle a similar criterion can be used as for the existing type approval procedure with respect to CO_2. The percentage of allowed variation of the additional fuel consumption and CO_2-emission is to be worked out based on the accuracy of the procedure and the differences in additional fuel consumption and CO_2-emission between structurally different vehicle/airco system combinations.

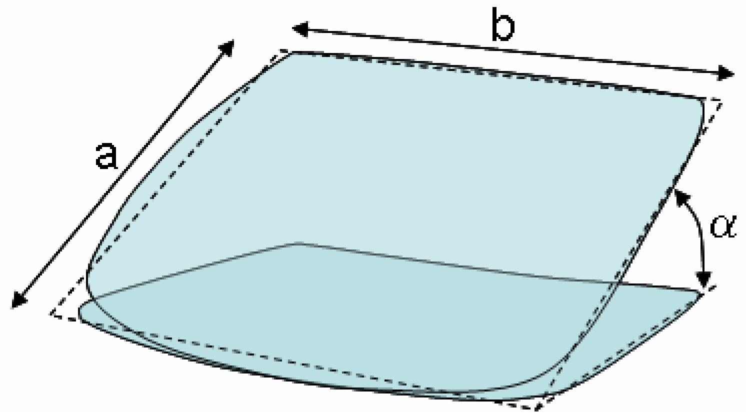
Vehicle categories with respect to the measurement of the additional fuel consumption resulting from the use of a MAC should be defined basically in relation to the characteristics of:

- The overall vehicle design, e.g. vehicle model, body type (saloon, hatchback, etc.), glass roof, and resulting glass surface;
- The applied engine type, type of drive line, and
- The applied air conditioner system.

With respect to the above vehicle configurations, the glass surface of a vehicle is of particular concern given the fact that larger glazing surfaces will allow more heat to enter the cabin by means of solar radiation and thus more cooling would be required, eventually resulting in a higher additional fuel consumption. For this reason the effects of projected glass surface should be investigated in the validation programme. To investigate the effect a definition of 'projected glass surface' is required;

- Projected glass surface: the area of the vertically projected surface of the windows of the test vehicle. This projected glass surface can be approximated by measuring the actual surface per window, correcting this figure for the average angle the window has with the floor: *Projected surface* $= a \times b \times \cos \alpha$, see the figure. Adding up the projected surfaces of all windows results in the Projected Glass Surface.

Figure 1: The projected glass surface and the parameters required to approximate the projected glass surface.



3.2.4 Presentation of the results

The results of the test procedure will be used either as input for a labelling scheme (in relation to Directive 1999/94/EC) or in the context of a monitoring programme. This chapter however does not consider any options for the reporting of a monitoring programme as the methodology and format of a labelling scheme are discussed in Chapter 8. Below only the reporting format for individual vehicle tests using the airco test procedure is presented (as addendum to Annex II of 80/1268/EC).

<u>Technical info required for Annex II (type-approval certificate):</u>

Mobile air conditioning / climate control system:
- Type of system (manual / automatic control)
- Compressor power [kW]
- Type of drive (belt / electrical / direct)
- Type of compressor (fixed displacement, variable displacement, other)
- Type of throttling/expansion device
- Refrigerant
- Compressor drive ratio [diameter out / diameter in] or [engine speed/ compressor speed] if fixed.

Vehicle body:
- Type of glazing
- Projected glass surface [m^2]
- Measures to reduce solar irradiation
- Exterior colour
- Exterior colour code
- Interior colour

Additional fuel consumption and CO_2 emissions
- Additional CO_2 mass emission combined (urban + extra-urban) [g/km]
- Additional fuel consumption combined (urban + extra-urban) [l/100km]

It does not make sense to split fuel consumption into an urban and an extra urban part. In general the cabin temperature is not yet stabilized going from the urban to extra urban part of the driving cycle. The additional fuel consumption over both parts of the cycle is then probably more determined by the capacity of the air conditioner system than by the difference in engine loads over the different cycle parts.

4 Development of the test procedure

4.1 Options within the basic design

Within the general design of the procedure there are several options for filling in some of the basic testing conditions. Some choices to be made, however, are strongly dependent on the general requirements as stated for this procedure. Besides, some choices may have consequences for other test conditions and so for overall costs as well. Therefore, this paragraph will deal with the options that may fundamentally influence the design and the way the procedure is completed.

The following aspects have been identified as being of relevance:

Using the same test room for 'a/c on' and 'a/c off' test or *allowing the use of different test rooms?*

Using the same test room obviously improves the accuracy of the result of the procedure. Here, it is important to realize that the effect of the use of a mobile air conditioner is determined by the difference in the results of two individual tests. For this matter the choice is between performing both tests in the same testing room or in different ones. If the two tests are conducted in the same test room, on the same chassis dynamometer and with the same emission measuring system, the final result will not contain any effects of reproducibility issues related to the road load applied to the vehicle during the driving cycle nor any effects of reproducibility issues related to the measurement of emissions, from which fuel consumption is calculated by means of the carbon balance method.

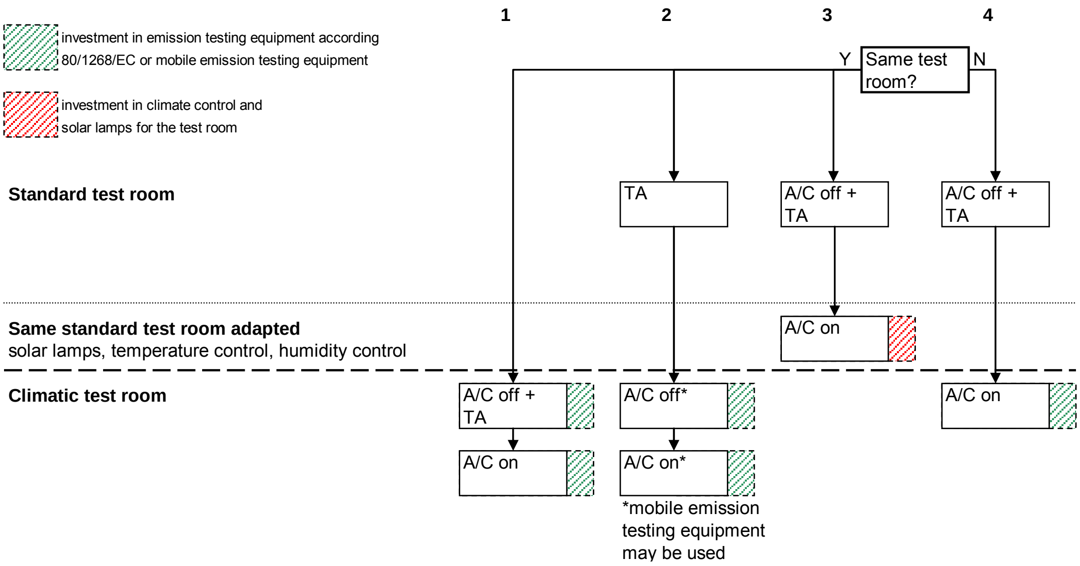
On the one hand using the same test room is recommended for the requirement of accuracy. On the other hand, however, this requirement would either force the TA test (which could serve as the reference test for the 'a/c off' situation) to be performed in a climatic test room with simulated solar irradiation (**option 1** in Figure 2) or require the performance of an additional reference test to be performed as part of the airco test procedure (**option 2** in Figure 2). In both cases this would lead to an increase of the costs. Testing in a climatic test room is more expensive than testing in a standard test room. This is mainly caused by the special requirements for the testing room that have to be met for the purpose of comfort testing: a climatic testing room is often equipped with a wind tunnel, temperature control by a heat exchanger in the circulation traject of the tunnel, humidity control, a wide control temperature range and in some cases even pressure control.
A third option, besides testing vehicles in fully equipped climatic test rooms as used for comfort testing, would be that laboratories make their existing standard testing facility suitable for testing under the climatic conditions as defined specifically for the airco test (**option 3** in Figure 2). This means investments in solar lamps and climate control (temperature and humidity).

If the use of different test rooms would be allowed within the procedure (**option 4** in Figure 2), it could be an option to define special requirements for the correlation of fuel consumption results between the two different test rooms. E.g. tolerances could be defined for the correlation. However, it would only be advisable to allow such tolerances if they are, or can be made small enough compared to the effects to be determined by the complete procedure.

Another aspect concerns the absence of emission measuring equipment in most of the existing test rooms with climate control and solar irradiation, because these test rooms are mostly used for comfort testing. These laboratories would have to invest in emission testing equipment for their climatic test rooms if they want to offer the possibility of testing the effect on fuel consumption of the use of an air conditioner. If testing in different rooms would be allowed by setting tolerances it could mean that at least the same quality of equipment should be installed as in the other test room to comply with the tolerances.

Another consequence of the choice for not using the same test room for the benefit of using the actual TA test as reference test, is that the engine start in the 'a/c on' situation should be performed as a cold start to be comparable with the reference test (a/c off and TA) as this is prescribed in 80/1268/EC. As can be read in the next paragraph the choice for cold or hot start leaves some consequences and options for the preconditioning sequence.

Figure 2: Options resulting from the choice to carry out the 'a/c on' and 'a/c off' tests in the same test room or not.



	1	2	3	4
Testing costs	--	---	+	-
Investment	-	-	-	--
Accuracy	+	+	+	-

Option 1 and 3 are technically equivalent and are the preferred options.

Hot start or cold start?

The choice of carrying out the test with a cold start or a hot start determines to a large extent how the vehicle is to be preconditioned and soaked. Important for testing fuel consumption and emissions over a driving cycle as repeatable as possible is having the temperature of the engine's oil and cooling water the same for every test that is conducted. In the case of the testing procedure to be developed this means that both the 'a/c off' and the 'a/c on' test should be started with the same engine temperature. In the situation of a hot started test some way of preconditioning, e.g. driving a preconditioning driving cycle, should lead to a certain level of engine warm-up, be it fully stabilized or not. In the situation of a cold started test, a certain amount of soak time at a prescribed soaking (ambient) temperature enables the test to have a good repeatability as long as the soaking time is sufficiently long to enable the engine's oil and cooling water to be stabilized at the given temperature.

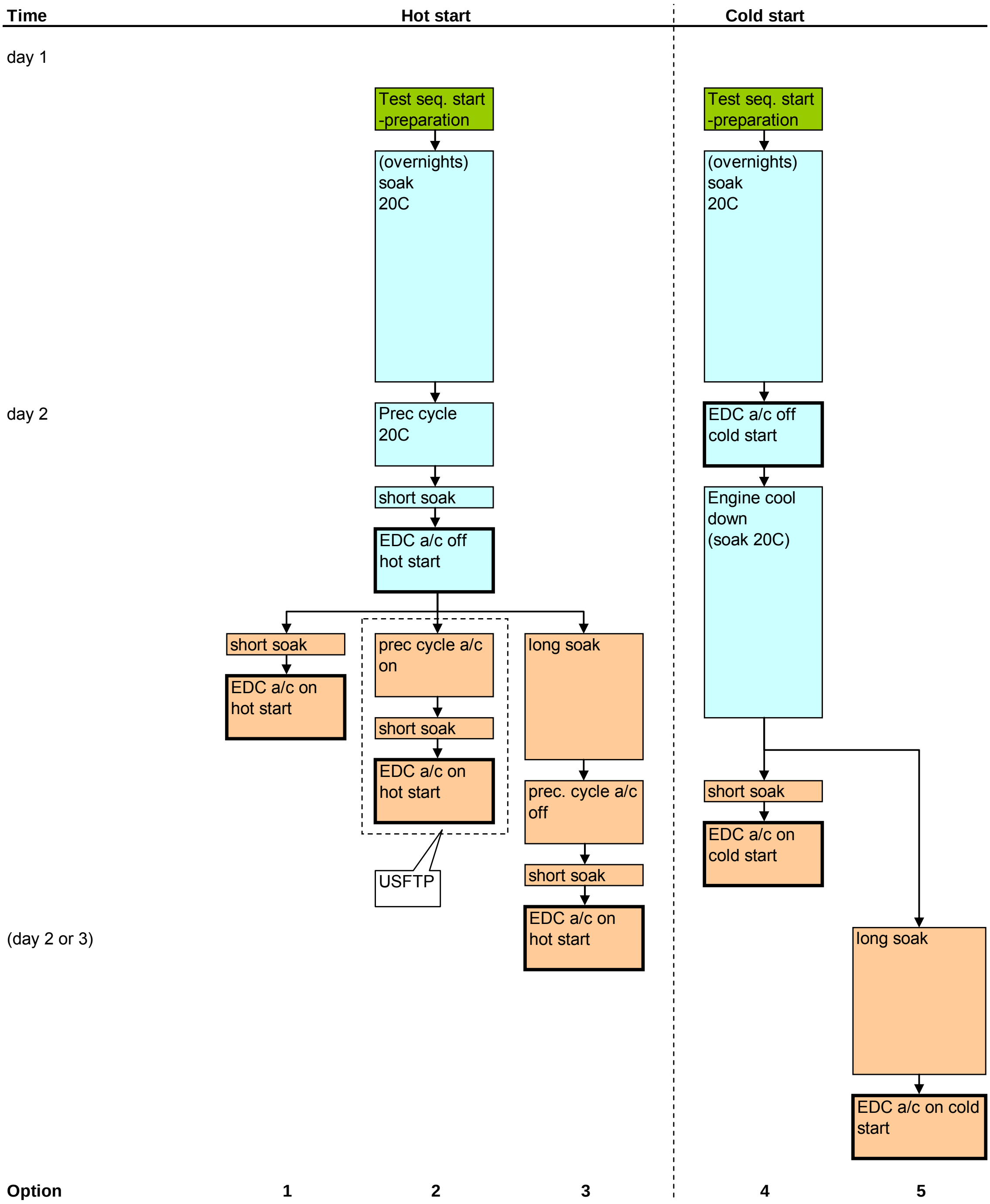
The advantage of carrying out the test with a hot start is that the 'a/c off' and 'a/c on' tests can be carried out on the same day reducing lead time and costs of the test.

The advantage of a cold start is that the TA test can be used as the reference 'a/c off' test. The TA test (80/1268/EC) prescribes the engine to be started cold, meaning an engine start after a soak period of at least 6 hours at a temperature between 20 and 30 ºC. Furthermore, even if the TA test would not be used as the reference test, for testing air-conditioners with a cold started engine it would still be preferable from the point of view of comparability and consistency to have the test in line with the TA procedure.

Whether the testing is conducted with either a cold or a hot start has consequences for the global design of the procedure, as is shown in Figure 3. Within the main options some variants can be defined that mainly concern matters like length of soaking time and the option to have one test cycle to act as preconditioning for the one following (hot start situation only). For the assessment of the options a distinction was made between a short soak and a long soak period. This was done to emphasize the choice to be made between going for a stabilized cabin temperature, needing a long soak period or going for a short soak period allowing the cabin to warm up only partially.

Option 1 is the most straightforward definition for carrying out the test with a hot start. After the standard overnight soak a preconditioning cycle is used to warm up the engine. Preceded by short soaks the tests with 'a/c off' and 'a/c on' are then carried out. **Option 2** is a copy of the US procedure for airco testing (with the SC03 cycle replaced by the EDC cycle). In **option 3** a longer soak and additional preconditioning before the 'a/c on' test are intended to better match the starting conditions of the 'a/c off' and 'a/c on' test. In **option 4** both tests are started with a cold engine. In this option the soak before the 'a/c on' test is minimised to be able to carry out the 'a/c off' and 'a/c on' tests on the same day. In **option 5** the 'a/c on' test is carried out after a longer soak which for practical reasons will be an overnight soak.

Figure 3: Options with regard to starting the test hot or cold.



In order to allow the TA test to serve as the 'a/c off' reference test it is proposed to start the airco test with a cold engine. For the 'cold engine start situation' the option to choose for a short or for a long soak period still remains. In the first study [TNO 2002] it was proposed to develop a procedure that does not test the system under worst case conditions. For this reason moderate test conditions were already laid down.

Tests conducted for this study have shown that the airco of a typical European car has difficulty to reach the desired end temperature of 21 ºC when the test is started after a long soak. The additional energy use resulting from the use of an air conditioner generally consists of a part resulting from cooling down the vehicle after parking and a part resulting from keeping the car cool while driving. If the required end temperature is not or nearly not met during the test, then the measurement result of the test will overemphasize the fuel consumption associated with cooling down the vehicle and will thus overestimate the additional fuel consumption resulting from airco use in daily practice.

Choosing for a short soak period of about 15 minutes, in combination with the already proposed ambient soak and test temperature, will lead to a moderate and more representative average heat load, enabling the cabin and the airco to reach stabilized conditions within the duration of the test, resulting in measurement results that are more representative for the average European situation.

Full flow wind tunnel versus smaller fan for air flow simulation?

Wind cooling of the vehicle body in principle influences the heat load on the cabin. The question is whether this influence is so large that simulation of this effect during the test is necessary.

The airflow surrounding a vehicle influences the operation of the airco system significantly. The influence can be divided into two phenomena:

1. The efficiency of the cooling process of the air conditioner depends largely on the temperature of the condenser in the front of the car (before the radiator). This temperature on its turn depends largely on the way the condenser is cooled and therefore on the temperature and de flow of the air surrounding it. Since the temperature during the proposed test is fixed (at 25 ºC) the wind speed directed at the front of the cars is the most important factor in this respect.
2. The heat exchange between the vehicle interior and the exterior is utilised through, ventilation, radiation and convection. This last effect occurs though the cars body surface (steel and glazing) and mainly dependant of the heat exchange rate through the body material and the air speed along the body. Since the body of current vehicles is well insulated, the heat exchange by convection is limited for the painted parts. The glazing is less insulating but for this part of the vehicle the heat exchange by radiation is much higher than by convection.

Having both effects and their magnitude in mind, the external experts[4] have declared that the effect of testing additional fuel consumption of airco systems in a full flow wind tunnel is not necessary, as long as the condenser is cooled in an appropriate manner. Appropriate in this case is equivalent to a speed proportional wind speed at the full surface of the condenser.
Test cells for comfort testing on the other hand are generally equipped as a full wind tunnel. This is necessary in order the properly establish the airflow through the vehicle (which is largely influenced by the vehicles' drag) which influences the airflow and temperature profiles throughout the whole vehicle. The local changes in "comfort level" throughout the vehicle interior do not effectively affect the total demand for cool air.

[4] See footnote on page 17.

80/1268/EC prescribes the use of a small fan for air flow simulation in order to facilitate proper functioning of the engine cooling. As described above the Air flow is also necessary to allow proper operation of the air conditioning system. Standard test cells for emission testing are generally equipped with a small fan, with minimum specifications according 70/220/EEC.

If the full wind tunnel option is prescribed, the test can be carried out in existing comfort testing facilities with such equipment, provided that these are upgraded with the required emission measurement systems. Allowing the use of smaller fans would enable the test to be carried out in emission test laboratories with standard equipment, temperature and humidity control, provided that these labs are upgraded with a battery of solar lamps and an adaptation of the climate control to meets the specific requirements for the airco test procedure (if necessary).

According to 70/220/EC the fan may also be a fixed speed type. For this procedure it is proposed to delete this option, because the fact that the air speed is fixed influences the capacity of the airco system in such a way that the system does not operate under representative conditions anymore. The air flow in front of the test vehicle should therefore be variable and linear with speed. Full flow wind tunnels are able to simulate these conditions accurately and up to more than the prescribed maximum speed of 120km/h occurring during the extra urban part of the test. In 70/220/EEC, however, it is prescribed that the air flow should be simulated linear with the speed of the rolls of the chassis dynamometer up to a speed of 50km/h, accurate within 5km/h of the speed of the rolls of the chassis dynamometer. This, however, does not seem appropriate for the airco test procedure for the same reason as mentioned for the fixed speed fan. Therefore, both options outlined above are satisfactory provided that the condensor and the evaporator receive the amount of air flow which is comparable with the on-road situation at all driving speeds.

4.2 Test conditions

Many of the test conditions were already proposed in the first study [TNO 2002]. However, after evaluating the procedure by means of actual testing and by working out the details of the programme some changes in the proposed conditions have occurred. This paragraph will give an overview of all the relevant conditions as defined for the testing procedure.

4.2.1 Ambient conditions

For the ambient conditions the choice is basically between more or less realistic part load conditions or worst-case conditions. Already in [TNO 2002] a choice was made in favour of partial load conditions. Full load conditions result in large values for the additional fuel consumption which at first instance may seem beneficial for the power to discriminate. Partial load conditions, however, enable the discrimination between less sophisticated systems that always run at ‘full load’ and mix in warm air to control the temperature of the air flow into the cabin and the more sophisticated systems (e.g. systems with a variable displacement compressor) that reduce energy consumption by their ability to better adapt to varying heat loads by means of partial load operation of the airco system. If a worst-case situation would be chosen every system would run at full load. Under these circumstances only differences in full load efficiency are measured but no discrimination would be made regarding the efficiency with which different systems deal with partial loads. Partial load conditions furthermore result in additional fuel consumption data that are to some extent representative for real-world driving.

Temperature

In the first study an ambient temperature of 26 ºC was proposed. Compared to the 35 ºC as prescribed in the US procedure, the 26 ºC chosen clearly implies the intention to apply a partial load situation during the test. Based on further evaluation, however, it is proposed to reduce the ambient temperature during testing to 25 ºC, because in combination with the prescribed solar load and the relative humidity of 60% a temperature of 26 ºC is still considered to constitute a relatively high load. It is chosen not to further reduce the temperature to decrease the overall testing load, but instead to use the soak time as another variable to control the amount of heat transfer to the cabin.

The allowed variation of the temperature in the test room has to be specified, because any variation in temperature will significantly affect the energy demand of the air conditioner system. This will in turn affect the results and the reproducibility of the overall procedure. In the first study a model was developed in which the additional load of the air conditioner was related to the ambient temperature. This model gives insight into the variation of air conditioner load in dependence of the ambient temperature and thus allows to make an estimation of the effect on fuel consumption. [EMPA] measured a selection of 6 vehicles at different ambient temperatures over different driving cycles and estimated the effect of temperature at about 2.6 gCO_2/km/K (gramme of CO_2 per kilometre per Kelvin) for urban driving and 1gCO_2/km/K for extra-urban driving, which comes down to respectively 0.11 and 0.04 l/100km/K (litre per hundred kilometer per Kelvin). Weighing both figures for the share of urban and rural driving, as present in the current test cycle, results in an average effect of ambient temperature on the fuel consumption of 0.07 l/100km/K. This effect is in the order of 1% of the overall fuel consumption. Considering the fact that the additional fuel consumption is determined by the difference between two tests, the impact of 2 times 1% allowed variance on the overall test result is regarded as the maximum permissible.

The choice for a certain accuracy of temperature control clearly affects the accuracy and reproducibility of the procedure, but obviously also affects the requirements for the climate control system in the test room. A small allowed temperature variation and the demand for a high accuracy will require the climate control system of the test room to have a large capacity and to be of a high quality. This of course will affect the costs in the case existing test rooms have to be equipped with more sophisticated climate control.

As a basis the accuracy requirements for the ambient temperature for the type VI test of 70/220/EC (-7 ºC test) can be used. It may be assumed that these requirements are feasible and that sufficient test houses exist that have climate control systems in their test rooms which comply with these requirements. For the type VI test the following requirements are prescribed. For the type IV test the average temperature over the complete test has to be maintained within a small bandwidth, while the actual temperature is allowed to vary within a somewhat larger bandwidth.

It is proposed that the average temperature must be 25 ºC ± 1K and must never be lower than 22 ºC or higher than 28 ºC. The ambient temperature must never be lower than

23 ºC or higher than 27 ºC for more than 3 consecutive minutes. The temperature must be recorded with a frequency of 1Hz.

Solar irradiation

When vehicle body variables are analysed with respect to their contribution to the heat flow to the cabin, the glass surface proves to be the most determinant variable. In general, for cars with large windshields more cold air is needed from the air conditioner than for cars with smaller windshields. This obviously results from the fact that more solar radiation can enter the cabin if larger windshields are installed. For discrimination of cars with regard to the size of the windshields and other glass surfaces a simulation of solar irradiation by means of solar lamps has to be applied to the vehicle during the test and during the soak time. Besides, some air conditioner systems use solar sensors for optimizing their control with respect to comfort. Applying simulated solar irradiation to the vehicle also allows the discrimination between vehicles with standard glass and special glass with reflective characteristics.

In the US Federal Test Procedure for vehicle emissions a solar load is prescribed of 850 W/m^2. This level of solar radiation (irradiance) is lower than the maximum observed in summertime under clear sky conditions. Maximum irradiance in Europe is in the order of $1000W/m^2$. The value of 850 W/m^2 was already proposed in [TNO 2002] and is maintained in this proposal. For the simulation of the irradiance the radiant flux should be checked and adjusted by means of a pyranometer. Furthermore, a special type of lamps simulating the solar irradiance should be prescribed.

Measurement of irradiance

The simulated solar radiant energy intensity should be adjusted and checked by means of a pyranometer. In the USFTP the simulated solar radiant energy intensity is determined as an average of two points:

- centreline of the test vehicle at the base of the windshield
- centreline of the test vehicle at the base of the rear window

The average value measured by the pyranometer should be within $25W/m^2$ of 850.
The pyranometer should have an accuracy within $50W/m^2$.

The pyranometer should be one that is designed to measure the irradiance on a plane surface, which results from the direct solar radiation and from the diffuse radiation incident from the hemisphere above. In this way the diffuse radiation from the test room walls will be measured too and will thus be taken into account. The pyranometer should be able to measure the irradiance within a spectral range of 305 – 2800nm. A pyranometer is almost not selective for the applied spectrum of the irradiance, it just measures the radiant flux within a given spectral range. This instrument is therefore not suitable to check the spectrum of the lamps. For this reason, special requirements should be defined for the lamps.

Solar lamps

Under clear sky conditions there is almost no infra red light coming from the sky. Because the lamps will be mounted on the ceiling of a test cell, a few meters above the test vehicle, it is important that the lamps do not emit infra red light. This infra red light would add to the heat transfer to the cabin and should therefore be avoided. Furthermore, the light should simulate solar radiation as good as possible when it comes down to the simulated spectral range. Metal halide lamps match the spectrum the closest and also do not or almost do not emit infra red light.

The battery of lamps should be mounted at least 3 meters above the roof of the test vehicle, measured from the cover of the lamp. Other dimensions may be approved if it can be shown that the ambient condition requirements are satisfied.

The uniformity of the intensity of irradiance over the footprint of the test vehicle should be defined. The US procedure gives a required uniformity of ±15% of 850W/m^2 over a grid of 0.5m over the entire footprint of the test vehicle. It is proposed to copy these requirements from the US procedure.

The intensity of the solar irradiance should be adjusted in advance of the long soak, or the solar simulation system may be switched on and adjusted at the beginning of the short soak if the system is able to simulate the intensity 850 ± 100W/m^2 within 2 minutes after switching on and 850 ± 25W/m^2 within 4 minutes after switching on.

Humidity

In a study [NREL] the effect of humidity was investigated. The study concluded that the effect of ambient humidity on the increase in fuel consumption is substantial; a higher ambient humidity leads to a higher additional fuel consumption. Obviously, more energy is needed to cool down humid air than energy is needed to cool down dry air. In the US-FTP SC03 (§86.161-00, Air conditioning environmental test facility ambient requirements) procedure a low value of 40% is prescribed for humidity, this value was probably chosen in combination with a high ambient temperature to simulate a hot, dry summer day, like they often occur in Arizona/Nevada. In Europe such low ambient humidity levels are not common during the summer. Besides, technically it is more difficult and thus more expensive to dry air than humidifying it. Therefore, it is proposed to prescribe a European average value for the relative humidity. On the one hand this would not increase the overall test load by having a high value for humidity. On the other hand it would not make the procedure unnecessarily expensive by increasing investments needed for air dryers, which are required for the low humidity.

For the procedure it was chosen to select a European average value for the summer time. The average European value for relative humidity during summer time is about 60%.

Because humidity influences the test results, it is proposed to define tolerances. During the test humidity will probably not change much. The tolerances should be defined to make sure that day to day variations that occur by changes in the weather would be levelled out by prescribing a bandwidth.

At a given test in a test room fulfilling the Euro 4 requirements the allowed variation is from 5.5 to 12.2 g/kg dry air at an ambient temperature. The ambient temperature is allowed to vary between 20-30 ºC. For the resulting relative humidity this range is clearly too wide. For a modern Euro 4 laboratory with humidity control for humidification and dehumidification accuracy of 5% RH is technically feasible and common.
[NREL] shows that the effect of changing the relative humidity by 50% (from 35% to 85%) has the same impact on required cooling power as an ambient temperature

increase of 10 ºC (going from 35 to 45 ºC). This comes down to 1 ºC temperature variation being roughly equivalent to a 5% RH variation. It is proposed to use this value for the procedure.

Proposed ambient conditions

Table 5: Overview of the ambient conditions.

Ambient conditions	**Target value**	**Tolerance**
Test room temperature • average • actual	 25 ºC 25 ºC	 ± 1 ºC Always between 22 and 28, and never lower than 23 or higher than 27 for 3 consecutive minutes
Test room humidity	60% RH (~12 g/kg dry air at 25 ºC)	± 5%
Solar radiation	850 W/m^2	± 100 W/m^2 within 2 minutes after start of solar simulation and ± 25 W/m^2 within 4 minutes after start of solar simulation

4.2.2 Preparation / preconditioning / soak

For Part A of the test procedure ('a/c off'), it is proposed to use the standard soak and preconditioning conditions as laid down in 5.1.4 of annex I of Directive 80/1268/EC. For Part B of the test procedure ('a/c on') adapted conditions are proposed which simulate prolonged parking of the vehicle under typical summertime solar irradiation conditions. These will force the air conditioner to be switched during the test to cool down the cabin to more comfortable temperature levels. Because the ambient conditions during the driving cycle were already fixed at 25 ºC, 850 W/m2 solar radiation and 60 % relative humidity, these climatic conditions will also be used for the pre-condition/soak phase of Part B. As a consequence the soak prior to the 'a/c on' test has to be carried out inside the climatic test room.

Depletion of the battery by switching on the air conditioner system when adjusting settings (e.g. fans will be running) should be avoided by running the engine at idling while setting the air conditioner or by driving a preconditioning cycle on the chassis dynamometer before the long soak.

The test room walls, floor and gear present in the room will be warmed up during a test by the solar radiation. If one Part B 'a/c on' test would be performed just after another, this heat would be transferred from the wall, floor and gear to the next vehicle to be tested when this vehicle is being mounted to the chassis dynamometer and is being soaked afterwards if no special measures are taken to control the temperature. Therefore, during mounting of the vehicle the room temperature should be maintained at 25 ºC.

Preconditioning of the vehicle then consists of the following elements:

- Preparation (instrumentation with thermocouples, inflating tyres, chassis dynamometer settings, etc.)
- Presetting air conditioner controls, running the engine at idle or;
- Driving a preconditioning cycle upon request of the manufacturer: driving 3 times the EUDC for diesel cars or the UDC directly followed by EUDC for cars with electric ignition.
- Long soak at 25 ºC without simulation of solar irradiance during at least 6 hours
- Mounting of vehicle on the chassis dynamometer
- Driver enters the car
- Short soak at 25 ºC +60% RH +850W/m^2 SR during 15 minutes ±20 seconds.
- Start driving cycle

4.2.3 Vehicle conditions for the 'a/c on' test

Interior target temperature and measurement

Although different people may (and do) prefer different inner climatic conditions, and whereas such preferences may (and do) even show a systematic variation with countries or regions of the world, the most practical approach seems to be to standardise one set of required inner climatic conditions.

In the first study [TNO 2002] 21 ºC was defined (together with the industry, at that time cooperating) as a realistic value for a comfortable interior temperature.
For vehicles with an automatic air conditioning the airco control has to be preset to this value prior to the soak preceding the 'a/c on' test. In the case of manual systems the airco has to be set to full load prior to the test. Once the temperature of 21 ºC has been reached, the manual controls need to be used to maintain this temperature within ± 1K. It is assumed that automatic systems will be able to control the interior temperature within this bandwidth.

The interior temperature has to be measured for the procedure according to a prescribed method. In the first place it is required to measure temperature and to have a reproducible way of defining a measure of the interior temperature, because the adjustment of the manual systems will have to be based upon it. In the second place, temperature measurement is required as a check of the performance of the automatically controlled systems. Although a waypoint could not be defined for this purpose (see [TNO 2002], the logged cabin temperature should act as a proof that the setting of 21 ºC leads to an acceptable interior climate within an acceptable time.

The accuracy of the measurement of the temperature should be within 0.5K.

<u>Location of temperature sensor</u>
For the check on cooling down performance by means of a temperature measurement the location of the sensor should be well defined. Some aspects need to be taken into account:

- The measured temperature of the cabin air temperature is strongly influenced if cold air is blown directly onto the sensor or the sun shining is onto the sensor.
- Passenger comfort is not so much determined by absolute temperature but more by the experienced temperature (ref. "chill factor" in whether).

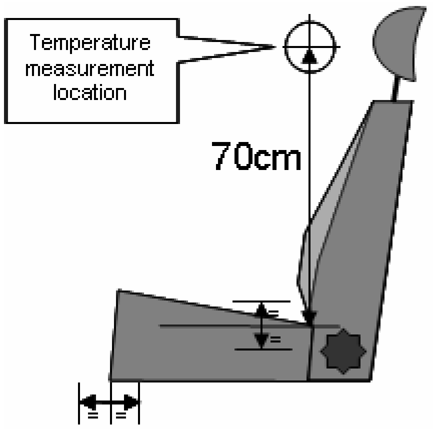
Although no general standardised locations have been defined for cabin temperature measurement in the context of comfort testing, most manufacturers have defined their own standardised locations for measuring temperatures during comfort testing in a climatic test room. Next to other locations in the cabin (seat, nozzles, knees, chest, etcetera), the most important location where manufacturers measure the temperature is near the head of the driver. Some locations are: left and right of the neck/ears, nose and mouth.

The exact definition of the location is of lesser importance compared to the positioning of the nozzles in relation to the measurement location. At the first trial tests it was noticed that the temperature distribution over the cabin was even within 1 ºC with exception of the locations in the direct sun light, locations close to warm surfaces, locations in the corners of the car (e.g. below the seats) and locations near the air flow from the nozzles. Therefore, the positioning of the nozzles will have to be determined as accurate as possible.

The following definition of fixed locations at or near the driver's and co-driver's head is proposed:

- In a straight vertical line 70cm up from the middle of the seat (distance from the left of the seat equals that from the right of the seat), where seat and back of the seat meet each other, see picture.
- Adjustment of the seat in the middle position or in such a way that an average person of 175cm is able to control steering wheel and pedals in a normal way.
- After positioning the temperature sensors, the seat may be adjusted to make room for the test driver.

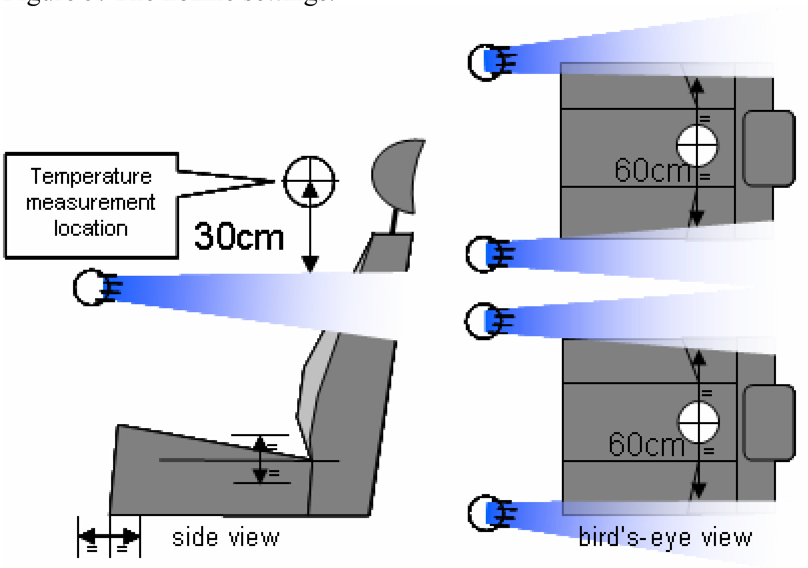
Figure 4: The temperature measurement location.



<u>Nozzle settings</u>

The direction of the air flow from the nozzles in the dashboard should be chosen in such a way that the cold air flow does not point directly to the driver or the passenger or to the temperature measurement location. In the figure below values are given for the minimum distances of the air flow to the measurement location. In the vertical direction the beam should be 30cm below the position of the temperature sensor. In the horizontal direction the beam should be 30cm away from the middle of the seat leading to a separation of 60cm between the beams from the nozzles directly left and right of the seat. If manual adjustment is possible, all nozzles in the dashboard should be fully opened. The positioning is a delicate procedure that is effectively influenced by individual human operation. Although not found to be very sensitive, the positioning of the airflow should be prescribed (or set with a calibre) by the manufacturer in case this procedure will be used in future.

Figure 5: The nozzle settings.



Air conditioner settings

The automatic mode should be selected if available. For vehicles with an automatic air conditioning the airco control has to be preset to 21 ºC prior to the long soak preceding the 'a/c on' test. In the case of manual systems the airco has to be set to full load prior to the test. Once the temperature of 21 ºC has been reached, the manual controls need to be used to maintain this temperature below 21 ºC.

For vehicles with a separate temperature control for the driver and the passenger(s) both (or all) separate controls have to be switched on and set at a target temperature of 21 ºC. For automatically controlled air conditioner systems with no fixed set point of 21 ºC, but for example only a fixed set point at 20 or 22 ºC, the manufacturer should use the highest setting that is lower than 21 ºC. For manually controlled systems the temperature should be adjusted to full cool and the fans should be adjusted to full speed. For manual systems the fan speed may be decreased if the measured cabin temperature is below 21 ºC for a period longer than 1 minute. Decreasing the fan speed may never result in a measured cabin temperature higher than 21 ºC.

The mode selector, if present, should be set to 'dashboard nozzles only'. If the system is equipped with an 'Economic mode' or another comparable mode, it must be switched off. The 'recirculation mode' must be switched off in the case of a manual controlled airco.

The air conditioner should be switched on before the actual 'a/c on' test.

Other settings of the vehicle

- The hood should be closed allowing air to flow to the evaporator inlets and providing a normal route of the air flow through the condensor to the engine compartment. The heat dissipated by the condensor may heat up the engine compartment quicker than it would under the standard reference conditions. This may affect fuel consumption and emissions. Because this phenomenon is common for the situation the air condition is switched on, it is proposed to include the closed hood situation in the procedure. Furthermore, it should be closed because damaging the hood and the car is prevented in the case of using a wind tunnel to simulate air flow.
- All windows must be closed during the ‘a/c on’ test;
- Solar roof must be closed during the ‘a/c on’ test;
- Sun blinds or curtains may be closed during the soak period if these are closed automatically by the vehicle without interference by the driver;
- Sun blinds or curtains must be retracted (opened) during the ‘a/c on’ test
- Additional measures to direct or focus cooling with the intention to reduce the air conditioner load (e.g. ventilated seats) may be switched on if this is done automatically by the vehicle.

4.2.4 Driving cycle

The driving cycle for the ‘a/c off’ and ‘a/c on’ test is the European Driving Cycle as prescribed by the Type Approval test procedure (Directive 80/1268/EC).

5 Validation programme

After the basic procedure has been developed, it has been validated by running the entire procedure, bearing in mind that all work, equipment and results should be conform the stated conditions. In this project a validation programme has been used to:

- Check the workability of the procedure;
- Obtain information that helps to further motivate or improve choices made in the definition of the procedure;
- To validate the repeatability, reproducibility and accuracy of the procedure;
- Gain insight in the power to discriminate.

5.1 Test programme for validation

In the tables below the test programme that has been used in the context of this project for the validation of the procedure outlined in the previous chapter is worked out. The test programme contains some specific elements intended as tests to check whether the procedure meets the required demands as described in Section 3.1.

Test programme

The test programme was conducted in two different test houses, being Testing Center Delphi, Luxemburg and IDIADA, Spain. The different tasks of the testing programme are presented in the table hereafter.

Table 6: Overview of the test programme.

Task	**Test house 1**	**Test house 2**
Trial tests		
Check on preconditioning, soak and cooling performance on 1 passenger car	**X**	
Main test programme		
1 passenger car with automatic a/c	**X**	
1 passenger car, same model, same a/c, different body version + reproducibility + repeatability in different lab	**X**	**X**
1 passenger car, same model, same a/c, different body version with larger glass surface	**X**	
1 passenger car, same model, same a/c, with different engine capacity	**X**	
1 passenger cars, same model with manual a/c control + repeatability	**X**	
1 passenger car, other type (smaller or larger)	**X**	

Vehicle selection

One Opel vehicle was used for the trial tests, and two models of Peugeots (including one in 3 different variants – hatchback, break and SW panoramic roof and one with a different engine capacity) were used for the test programme. All vehicles used have:

- a silver metallic exterior;
- a dark interior;
- 5 doors;
- more than 3000km on the odometer;
- An air conditioner system with a variable displacement compressor;
- A spark ignition engine running on petrol.

Table 7: Overview of the vehicles selected for the test programme.

Type	Model	Engine	a/c	Specifics	Projected Glass Surface* [m^2]
Opel Astra	hatchback	1.6 16V 74kW	Manual	Used for trial test	n.a.
Peugeot 307	hatchback	1.6 16V 80kW	Climate control		1.9
Peugeot 307	break	1.6 16V 80kW	Climate control		2.1
Peugeot 307	SW	1.6 16 80kW	Climate control	Panoramic roof	2.1 + 1.2* = 3.3
Peugeot 307	hatchback	2.0 16 100kW	Climate control		1.9
Peugeot 307	hatchback	1.6 16V 80kW	Manual		1.9
Peugeot 807		2.0 16V 100kW	Climate control		2.0

* surface of the panoramic roof

5.2 Results and evaluation of trial tests

5.2.1 Trial tests: a first check.

The first testing for the validation of the procedure included some general learning time necessary to get familiar with the equipment and the procedure. In addition, the first testing for the validation programme included elements to answer specific questions regarding the design of the procedure that could not be answered without first actually testing a vehicle under the already defined ambient conditions of temperature, humidity and solar radiation. These elements are:

- Determination of the overall effect of the chosen ambient conditions and soak time on the cabin heat up and cool down time;
- A check on the cooling performance of the airco under the given conditions;
- Determination of the temperature distribution over the cabin to get insight in possibilities and problems for the definition of the location of the prescribed temperature measurement. The temperature was measured at 9 different locations in the cabin;
- Definition of the directional setting of the air nozzles.

For the first trial tests an Opel Astra, exterior colour silver metallic, interior colour dark grey/anthracite and with a manually controlled air conditioner was chosen and equipped with temperature sensors (thermocouple type-K). Thermocouples were mounted at the location of the drivers nose (TC2), one 15cm left (TC1) and one 15cm right (TC3) of the nose location, one on the nose location of the passenger (TC4) and one at the nose location of the passenger in the back seat (TC5). Additionally, 4 other thermocouples were mounted in the 4 discharge nozzles and 1 under the windscreen.

The following test sequence was used:

Preparation of the vehicle: mounting temperature sensors, setting a/c settings

↓

Overnight soak at 20 ºC

↓

Soaking the vehicle at 25 ºC, 60% RH and 850 W/m^2 SR to see raise cabin temperature (until temperature is stabilised)

↓

Driving one EDC (UDC and EUDC)
- full cool
- fans full speed
- mode dashboard nozzles only
- no recirculation

↓

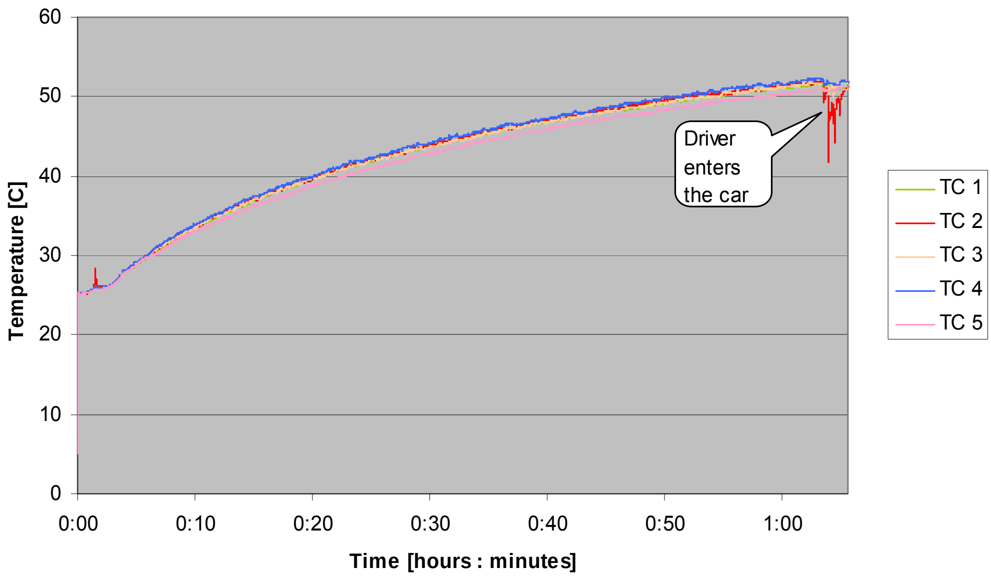
Soaking the vehicle at 25 ºC 60% RH and 850W/m2 SR for another 15 minutes to see raise in cabin temperature after a test for in case one EDC followed by a short soak period would be used as preconditioning for a hot started test (ref. US-FTP)

Soak phase

In the cabin temperature is shown at 5 different locations for the soak at an ambient temperature of 25 ºC and a solar radiation of 850 W/m^2. For the chosen typical test car the cabin warm up reaches more than 50 ºC under given conditions, within one hour.

At location TC 5 the cabin warms up the least. TC 5 is located at the position of the nose of a passenger sitting on the rear seat. The lower temperature at that location can be explained by the fact that it is further away from the windows than the other locations. The dip from all the TCs at the end of the warm up is from the driver entering the car. By briefly opening the door he allowed some cooler air at 25 ºC to enter the car. Due to the heat capacity of the mass of the interior the cabin quickly heats back up to the temperature before entering after the driver closed the door.

Figure 6: Cabin warm up of an average passenger car under the for the procedure prescribed conditions of 25 ºC ambient temperature and 850W/m^2 solar radiation.



Cool down phase

For the cooling down phase ('a/c on' test) the proposed driving cycle – the European Driving Cycle – was driven on a chassis dynamometer after the soak (cabin temperature at start of test just above 50 ºC) as shown in the previous picture, with the air conditioner switched on and the nozzles' air flow directed along the shoulders / upper arms of the driver and passenger.

As can be seen in Figure 7 the cabin temperature, as measured at the given locations, sharply decreases during the first 2 minutes, but only gradually decreases after that to reach the required 21 ºC only during the extra urban part of the driving cycle (EUDC). Furthermore, it depends on the (location of the) thermosensor selected and the margin set for the accuracy of the temperature (chosen at ±1K) at what time exactly the target temperature of 21 ºC is reached.

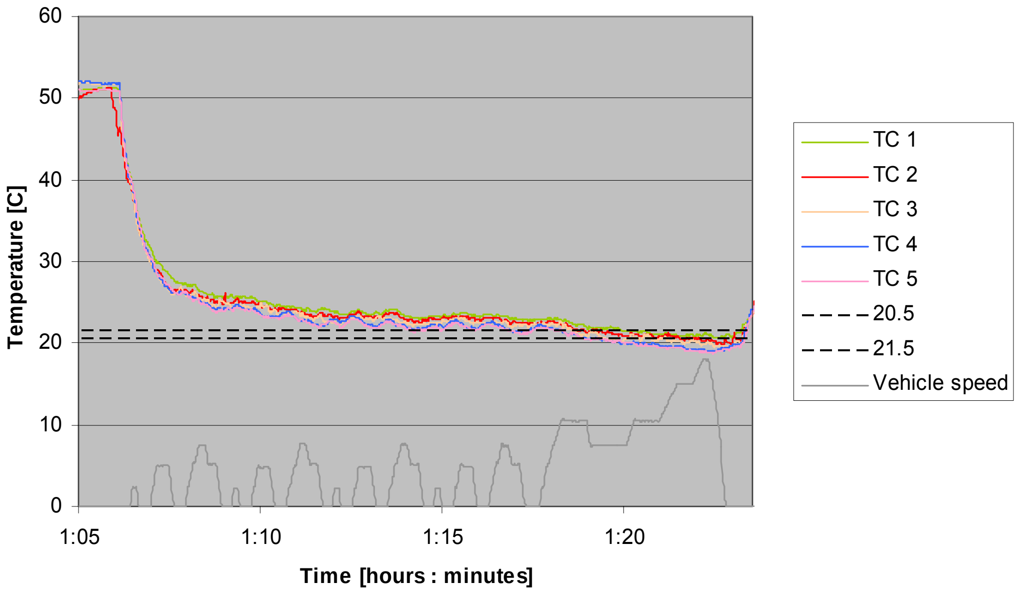
In the first study [TNO 2002] the use of a waypoint was proposed, meaning that all systems should reach a given target temperature within a given time after the start of the test and maintain the temperature at or below the target temperature for the remainder of the test. This waypoint method could serve as a performance check for the automatic systems and as a restriction for the control of manual systems. For the latter the target temperature would serve as the boundary below, which the fan speed of a manual system might be adjusted to maintain that the desired temperature.

Because the cabin temperature in the figure below, for the given car, only just reaches 21 ºC near the end of the test, it is very probable that there will be vehicles with air conditioner systems that will not reach a waypoint of 21 ºC at all during the test. Some factors of influence can be pointed out:

- Amount of heat absorbed during the soak;
- Capacity of the air conditioner system: size and efficiency of compressor and heat exchangers (condenser and evaporator);
- Compressor speed: The actual compressor power is limited by its actual speed, which in turn depends on the actual engine speed in the case the compressor is driven by the engine (at the moment most systems are). Because the start of the driving cycle is an urban driving sequence with relatively low engine speeds, the compressor can not deliver its full capacity. Electrically driven compressors (variable speed compressors, e.g. in hybrid or all-electric vehicles), however, can be driven independent of the vehicle's engine speed;
- Ambient conditions: The temperature of the air flow to the condenser and evaporator influences the cooling capacity of the system. At higher temperatures the cooling capacity decreases.
- The amount of air flow to the condenser might be of influence. However, fans will increase the air flow needed, e.g. at low driving speed.
- The control of an automatic system: because an automatically controlled airco system measures temperature on a different location, this temperature does not need to match the temperature at the prescribed measurement location. The temperature at the prescribed measurement location may be higher or lower than this temperature. Besides, the control of the system may be adjusted in such a way that 21 ºC will not be reached during the test, even if the automatic system is adjusted to 21 ºC.

All together it proved not feasible to use the waypoint method as a performance check. It depends too much on the car, the air-conditioner, the chosen conditions and the accuracy of the temperature measurement whether the 21 ºC will be reached within the test. There will be a lot of variation between systems with a high capacity and systems with a low capacity. The waypoint method could still be used for definition of the boundary below which a manual system can be adjusted, however. For some systems it will not be allowed to adjust fan speed, so long as they do not reach 21 ºC. In that case they run at full load during the complete test. Some systems will reach 21 ºC within the test and adjustment of the fan will be allowed to maintain the temperature at or just below the target temperature. This seems reasonable as for manual systems the fan speed will be adjusted downwards if the comfort temperature is reached.

Figure 7: Cabin cool-down of an average passenger car, driving the European Driving Cycle, under the for the procedure prescribed conditions of 25 ºC ambient temperature and 850W/m^2 solar radiation.



Because the tested car was a typical European car with an 'average' capacity air conditioner system that did only just reached the 21 ºC within the test, it was decided to decrease the soak time for the final procedure in order to decrease the amount of heat transferred to the cabin and allow a measurement with a significant period of stabilised cabin temperature for most vehicles. Decreasing the soak time also reduces costs, because less time is spent in the fairly expensive climatic test room. Furthermore, a shortened soak time will still enable the discrimination between cars with large and small windshields as the amount of heat transferred to the cabin will be different for both under the same soak conditions and soak time.

5.3 Results and evaluation of the main test programme

5.3.1 Results for six different passenger cars

The table below show the results of the measurements made in the course of this project. The additional fuel consumption is shown for each of the six tested vehicles. The additional fuel consumption for these vehicles ranges from 0.6 to 1.8 litre per 100km. Under the prescribed test conditions the six vehicles consume 6 to 20% more fuel in the 'a/c on' situation compared to the 'a/c off' situation.

Table 8: Overview of the additional fuel consumption of the different types (model, glazing, air conditioner control, engine).

Vehicle					Projected glass Surface [m^2]	ΔFC [l/100km] UDC	EUDC	Combined	ΔFC [%] UDC	EUDC	Combined
2	307	Break	1.6	Automatic	2.1	1.2	0.2	**0.6**	10	3	**6**
3	307	SW	1.6	Automatic	3.3	1.3	0.3	**0.7**	10	4	**8**
4	307	Hatchback	1.6	Automatic	1.9	1.5	0.6	**0.9**	13	9	**11**
5 test #1	307	Hatchback	1.6	Manual test 1	1.9	3.0	1.0	**1.8**	26	15	**20**
5 test #2	307	Hatchback	1.6	Manual test 2	1.9	2.7	0.8	**1.5**	24	12	**18**
6	307	Hatchback	2.0	Automatic	1.9	2.7	0.9	**1.6**	18	13	**16**
7	807		2.0	Automatic	2.0	2.7	1.3	**1.8**	15	16	**15**

The fuel consumption of the break, the break with panoramic roof (SW) and the hatch back (vehicles 2, 3 and 4 respectively) is more or less the same. This is not what was expected. The vehicle with the large glass surface (panoramic roof) was expected to have a higher additional fuel consumption than the version without this type of roof, because the cabin would warm up more through the larger glass surface and thus more cooling would be needed from the air conditioner. Although the cabin temperature was a few degrees higher at the end of the soak under the solar lamps, it was not the large temperature increase that was expected. The difference in cabin soak temperature and the additional solar load during the test was probably not large enough to have caused a significant increase in demand for cooling. The small increase in cabin temperature compared to the vehicle without the panoramic roof and the resulting fuel consumption being more or less the same for both may be partially explained by the use of special reflective glazing for the panoramic roof; the roof has exceptionally dark tinted glass. In a study performed by NREL [NREL 1999] it was concluded that special reflective glazing can reduce the heat load of the cabin substantially.

While the additional fuel consumption of the break, the break with panoramic roof and the hatch back (vehicles 2, 3 and 4 respectively) is more or less the same, the additional fuel consumption of the types with manual air conditioner control, the two litre engine and the 807 seems to be substantially higher.

The vehicle with the manually controlled air conditioner shows a higher additional fuel consumption. This can be explained by the difference in delivered performance compared to the automatic controlled systems. The manually controlled systems ran at ‘full cool’ during the complete test with no recirculation of cabin air, while the automatic controlled systems did not run at full capacity and recirculated a part of the cabin air. The measured cabin temperatures revealed the difference in cooling performance between the automatic and the manual controlled system; the cabin temperature of the vehicle with the manual controlled system just got below 21 ºC at the end of the test cycle, while the cabin temperature of the vehicle with automatic controlled systems only reached about 25 ºC at the end of the test cycle. This makes the result effectively incomparable. The 21 ºC however proved to be a realistic “set point” for (automatic) airco systems, but the actual temperature that was established by this setting at the defined head measurement position turned out to be about 25 ºC. The reason for this difference was provided by industry experts (after TNO had executed the tests) in 21 ºC being corrected with a “wind chill factor” towards 25 ºC. In other words: the comfort level of 21 ºC in non moving air and no radiation, corresponds to 25 ºC in a car with the airconditoning on while the sun is shining.

Being aware of this information only after executing the test work, the test at the manual systems were conducted with a setting that created a measured head temperature of 21 ºC , ware as the automatic systems were set on 21 ºC, resulting in 25 ºC at the head position. This constellation makes the comparison of the manual and automatic systems difficult, but has no further consequences for the applicability of the protocol.

The higher additional fuel consumption of the vehicle with the two litre engine may be partially explained by the difference in engine efficiency at which the compressor power is generated. A doubling of the additional fuel consumption, however, is not in line with expectations. The high additional fuel consumption is probably partially also caused by the variability between measurement results. This will be further discussed in the next paragraph about the repeatability and reproducibility of the test results.

The 807 has a higher additional fuel consumption. This is according to expectations; this vehicle has a separate temperature control for the driver and the co-driver, has a much larger interior volume, a large glass surface and a two litre engine, which altogether cause a high additional fuel consumption.

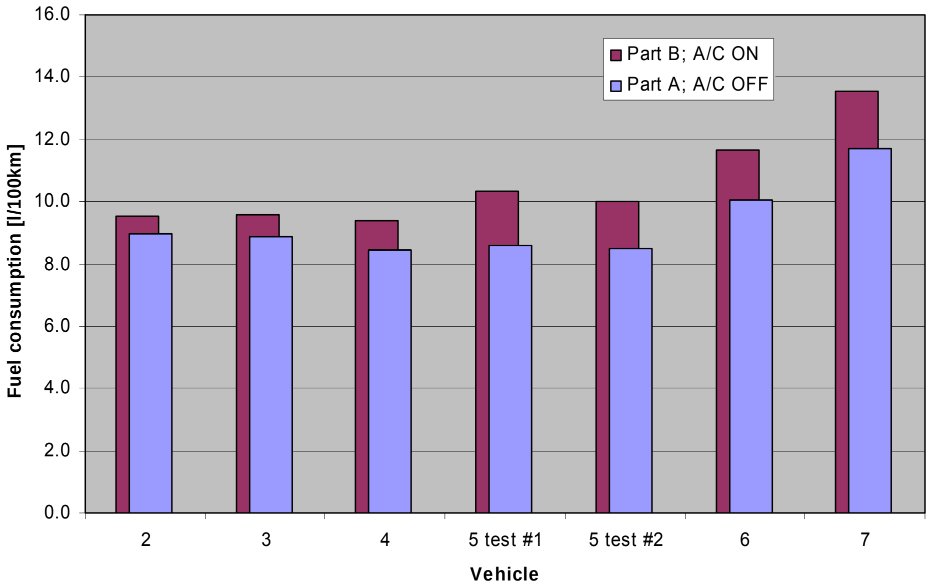


Figure 8: the results of the 6 different types of vehicles of the Part A and the Part B test, including the repeated tests for vehicle #5.

5.3.2 Repeatability and reproducibility

Repeatability and reproducibility are defined as follows:

- Repeatability is the variation in measurement results obtained when one person takes multiple measurements on the same test object, using the same instruments. For establishing this parameter in this investigation the emissions of the same vehicle have been measured twice, by the same testing team, on the same chassis dynamometer, in the same climatic test room, using the same sampling system and analysers, over the same test procedure.

- Reproducibility is the variation in measurement results obtained when different people take multiple measurements on the same test object, using different instruments, using the same measuring technique. For establishing this parameter in this investigation the emissions of the same vehicle have been measured twice, by different testing teams, on different chassis dynamometers, in different climatic test rooms, using different sampling systems and analysers, over the same test procedure.

For this investigation the repeatability is quantitatively defined as the relative or the absolute difference between two tests.

The repeatability of the test protocol has been determined for two vehicles, the reproducibility for one vehicle. One vehicle has been tested twice in test house 1 and one has been tested once in test house 1 and has been reproduced and repeated twice in test house 2.

Table 9: Overview of the test performed for repeatability and reproducibility.

Test house	Vehicle	Type	Model	Engine	a/c
1	5	307	Hatchback	1.6	Manual
1	5	307	Hatchback	1.6	Manual
1	2	307	Break	1.6	automatic
2	2	307	Break	1.6	automatic
2	2	307	Break	1.6	automatic

Repeatability

The results of the first vehicle with the manual controlled air conditioner (indicated as vehicle #5), tested in the first test house (indicated as test house #1) and the results of the second vehicle (indicated as vehicle #2) with the automatic controlled air conditioner tested in the second test house (indicated as test house #2), are presented hereafter.

The repeatability of the additional fuel consumption of two complete consecutive tests as measured on the car with manually controlled airco in test house #1 is about 15% of the additional fuel consumption, as can be seen in the next table.

Table 10: Repeatability of the additional fuel consumption of the car with manually controlled air conditioner at test house 1.

Vehicle #5 test house #1	Part B – Part A (ΔFC)		
	UDC	EUDC	Combined
ΔFC repetition 1 [l/100km]	3.00	1.02	**1.76**
ΔFC repetition 2 [l/100km]	2.71	0.83	**1.51**
Absolute deviation [l/100km]	-0.29	-0.19	**-0.25**
Relative deviation [%]	-10	-18	**-14**

For test house #2 the repeatability of the additional fuel consumption of two consecutive tests as measured on the car with automatic air conditioner is higher than the repeatability of test house #1 and is about 40%, as can be seen in the next table. The large difference in repeatability may be explained by the difference between the test houses, but also by the difference in air conditioner control. The worst repeatability was found by the car with an automatic controlled air conditioner. This type of air conditioner controls the capacity of the system on the basis of ambient (test) conditions which could mean that they are more sensitive to variations of these conditions than a manually controlled system, at least in the automatic mode.

Table 11: Repeatability of the additional fuel consumption of the car with automatic controlled air conditioner at test house 2.

Vehicle #2 test house #2	Part B – Part A (ΔFC)		
	UDC	EUDC	Combined
ΔFC repetition 1 [l/100km]	1.62	0.38	**0.83**
ΔFC repetition 2 [l/100km]	2.18	0.57	**1.16**
Absolute deviation [l/100km]	0.56	0.19	**0.33**
Relative deviation [%]	35	50	**40**

From the results can be observed that the repeatability of two consecutive single tests in both test houses is in the order of 1 to 3%.

Table 12: Repeatability of the separate cycle parts and the combined cycle of the car with manually controlled air conditioner at test house 1.

Vehicle #5 test house #1	Part A (a/c off)			Part B (a/c on)		
	UDC	EUDC	Combined	UDC	EUDC	Combined
FC repetition 1 [l/100km]	11.60	6.84	**8.58**	14.60	7.86	**10.33**
FC repetition 2 [l/100km]	11.50	6.76	**8.51**	14.20	7.59	**10.01**
Absolute deviation [l/100km]	-0.10	-0.08	**-0.07**	-0.40	-0.26	**-0.32**
Relative deviation [%]	-0.9	-1.2	**-0.8**	-2.7	-3.4	**-3.1**

Table 13: Repeatability of the separate cycle parts and the combined cycle of the car with automatic controlled air conditioner at test house 2.

Vehicle #2 test house #2	Part A (a/c off)			Part B (a/c on)		
	UDC	EUDC	UDC	EUDC	UDC	EUDC
FC repetition 1 [l/100km]	10.67	6.68	8.14	12.29	7.06	8.97
FC repetition 2 [l/100km]	10.43	6.52	7.95	12.61	7.09	9.11
Absolute deviation [l/100km]	-0.24	-0.16	-0.19	0.32	0.03	0.14
Relative deviation [%]	-2.2	-2.4	-2.3	2.6	0.4	1.6

The results above are only from two cars and two test houses. Figures for the repeatability of the measurement of fuel consumption in a standard emission laboratory according to 80/1268/EEC are available from experience with emission testing, correlation reports and other investigations in which tests have been repeated and thus altogether allow to generate a more general and reliable figure for the repeatability of a fuel consumption test.

The repeatability of measuring fuel consumption according to 80/1268/EEC contains:

- The stability of the vehicle (emissions);
- The repeatability of driving the driving cycle (influence of the driver);
- The repeatability of the load applied to the vehicle by the chassis dynamometer;
- The stability of ambient and other test conditions and the impact on the emissions that determine fuel consumption (CO_2, CO and HC);
- The repeatability of the instruments (analysers, CVS).

In the 5th framework programme project Artemis attention was given to the stability of emission measurements. In [TUG 2004] the results were reported. Furthermore, from correlation reports in which repeated tests have been reported, and from TNO's own test data, information about the repeatability could be derived. In general the repeatability of Part A tests (European Driving cycle / standard conditions) is within 2-3%. While about 75% of the tests repeat within 1%, 25% of the tests repeat within 1-3%. These tests have not been identified as faulty tests and therefore also do contribute to the overall repeatability. The procedure as it is developed so far, does not prescribe repetition of the tests to improve the reliability of the result. It is therefore assumed that the maximum value of 2-3% for the repeatability of a single standard fuel consumption test is realistic and should be taken into account when evaluating the procedure with respect to accuracy, repeatability and power to discriminate. For the test under adapted climatic conditions (the Part B test) it is assumed that repeatability is worse than 2-3%.

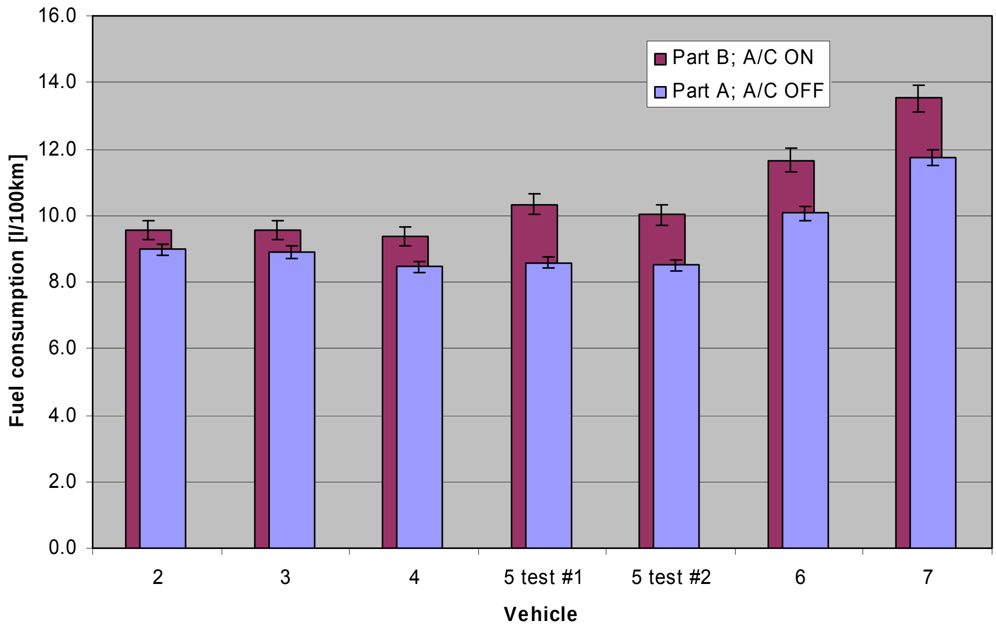


Figure 9: The results of the 6 vehicles of the Part A and the Part B test (UDC and EUDC Combined). The relative repeatability of both test is also presented. For the Part A test a repeatability of 2% is presented while for the Part B test assumed repeatability of 3% is presented.

Reproducibility

One vehicle, the Peugeot 307 break with automatic air conditioner, has been tested in two different test houses. In the table below the additional fuel consumption is given as measured for a complete test in test house #1 and two repeated complete tests in test house #2. From the results, it can be observed that the reproducibility of the additional fuel consumption of two tests in different test houses ranges from 44% for test #1 to a maximum of about 100% for test #2.

Table 14: Reproducibility of the additional fuel consumption of the car with automatic controlled air conditioner tested at test house 1 and 2.

Vehicle #2	Part B – Part A (ΔFC)		
	UDC	EUDC	Combined
test house #1	1.20	0.25	**0.58**
test house #2 test #1	1.62	0.38	**0.83**
test house #2 test #2	2.18	0.57	**1.16**
ΔFC #1 [l/100km]	0.42	0.13	**0.25**
ΔFC #2 [l/100km]	0.98	0.32	**0.58**
ΔFC #1 [%]	35	55	**44**
ΔFC #2 [%]	82	132	**101**

In the section above it was already observed that substantial relative variations could be found between the additional fuel consumption of two consecutive tests performed in one test house. By reproducing tests in another test house the deviations found were even larger. Two consecutive tests were performed in the second test house. The results of these tests were compared with the results of the tests of the first test house. While the first test did reproduce within 44% the second test did reproduce only within 100%. In the section about repeatability is was concluded that the substantial differences found between tests could be due to the fact that the tests concern an automatic controlled system which is suspected to be more sensitive to variations in ambient conditions. It is probable that ambient conditions between test houses vary even more than the conditions vary between two consecutive test in one test house. Test results are therefore expected to vary more between two test houses than between consecutive tests in one test house.

For the validation tests both test parts - Part A and Part B of the procedure - have been performed in one test house. From the results concerning the reproducibility it can be concluded that, if the reproducibility should be improved, both test parts should always be performed in the same test house and even on the same chassis dynamometer.

5.3.3 Calculation of the annual effect for presentation of the result

For the calculation of the annual effect the use of an air condioner has on the additional fuel consumption the method as presented in [TNO 2002] has been used. In this method three climatic zones have been distinguished within Europe for which different annual figures can be calculated. Next to the effect caused by executing the procedure, the effect of the additional mass of the air conditioner system could be taken into account. In [TNO 2002] it was calculated that the effect of mass would be about 0.05 l/100km.

Table 15: The results taking into account the efficiencies for the three climatic zones and the additional FC due the mass of an airco system.

Vehicle					Projected glass Surface [m^2]	ΔFC [l/100km] Combined	ΔFC annual [l/100km] Region 1	Region 2	Region 3
							15% +0.05 l/100km	**20% +0.05 l/100km**	**40% +0.05 l/100km**
2	307	Break	1.6	Automatic	2.1	**0.6**	0.14	0.17	0.29
3	307	SW	1.6	Automatic	3.3	**0.7**	0.16	0.19	0.33
4	307	Hatchback	1.6	Automatic	1.9	**0.9**	0.19	0.23	0.41
5 test #1	307	Hatchback	1.6	Manual test 1	1.9	**1.8**	0.32	0.41	0.77
5 test #2	307	Hatchback	1.6	Manual test 2	1.9	**1.5**	0.28	0.35	0.65
6	307	Hatchback	2.0	Automatic	1.9	**1.6**	0.29	0.37	0.69
7	807		2.0	Automatic	2.0	**1.8**	0.32	0.41	0.77

5.3.4 Other aspects relating workability

The practical workability of the procedure is as expected. The test procedure consists of a standard test (Part A) which is known to be practically feasible. The Part B test is not standard because of the adapted climatic conditions. It is prescribed that the driver should enter the car before the short soak period during which the solar system is switched on. This means that the driver will experience the warming up of the cabin during the soak. From temperature data is was observed that for a 15 minute soak the cabin temperature can reach more than 40 ºC under given conditions. After this soak the driver will also experience the cooling down of the cabin with the air conditioner in operation. Because the cabin temperatures and the temperature differences experienced by the driver are not extreme and do occur in real life, it is not expected to be a problem.

Mounting and preparation of the vehicle on the chassis dynamometer should be done at an ambient temperature of 25 ºC.

Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work and in specific *Directive 89/654/EEC concerning the minimum safety and health requirements for the workplace* do not refer to a certain allowable temperature level. The only reference made is the following: “During working hours, the temperature in rooms containing workplaces must be adequate for human beings, having regard to the working methods being used and the physical demands placed on the workers”. It is assumed that the given temperatures and conditions occurring during the tests are not in conflict with European legislation.

5.4 Conclusions based on the validation results

- The procedure can be applied in a standard Euro IV test laboratory if such a laboratory is equipped with a solar radiation device
- The additional CO_2 emissions due to the use of air conditioner systems under the given test conditions are in the expected range from 6 to 20%.

- The accuracy of the procedure (repeatability and reproducibility) in relation to the differences in CO_2 emissions to be determined between systems is too low to allow straightforward (option 2) use of the procedure in Type Approval.
- The differences between body types (interior volume and their effect on glass surface) are very small in relation to the absolute CO_2 emission of the vehicle. Only for fundamentally different airco types, different engine sizes and different vehicle models, the differences in additional fuel consumption seem to be significant. Differences between comparable vehicles of different brands was not studied in this project.
- In general, use of this procedure linked to the TA procedure to provide data for a labelling scheme related to airco efficiency does not seem feasible, due to its poor accuracy.

5.5 Options for refinements

In the last paragraph it was concluded that the test procedure as applied within the context of labelling and ranking of additional CO_2 emissions of mobile airconditioning systems is not feasible. This conclusion however, does not completely disqualify the use of the procedure. In the course of the execution of the validation measurements TNO has gathered insight about how the procedure could be refined in order to better meet the requirements of the EC.
Next such possible refinements (although not validated on their effect) are discussed.

5.5.1 The air conditioner temperature settings

During the main test programme, in which 6 vehicles have been tested using the complete procedure, it was observed that the automatically controlled systems did not reach the prescribed 21 ºC at the prescribed location during the test cycle. The manually controlled system, however, did reach this temperature well before the end of the test cycle. This situation is caused by the fact that the automatic systems control “thermal comfort” were as the manual systems control “temperature” only. This makes the comparison of both systems rather unfair; the manual system is forced to run at full power, while the automatically controlled system is allowed to run at a lower power and possibly take into account typical comfort parameters (radiation, airspeed) for establishing a typical set point.

To enable a fair comparison of both systems, the manual system could be adjusted in such a way that the cabin temperature of both types of systems reach the same temperature (25 ± 1 ºC) during the test. For the purpose of fair comparison, the manufacturer should also hand over the temperature, nozzle and fan-setting that ensure the 25 ºC to be reached, to the test authority for both the automatic and the manual system.

5.5.2 Increased repeatability and reproducibility

The variability of the obtained results of the procedure does not allow sufficient discrimination between airco systems in different vehicle bodies. This is caused mainly by the fact that the actual additional CO_2 emission caused by the use of the air conditioner is in some cases too small (6 to 20%) to be established statistically significant by subtraction of running the TA procedure with only twice (w/o airco). This again is already caused by the accuracy of the TA procedure itself(is about 2 to 3%) (interlab). The additional variability caused by differences in settings of the components in the vehicles and the accuracy of the settings of the ambient conditions (intralab) further decrease the accuracy.

The variability of the results of the Part A test under standard conditions has already been optimized as far as possible within the required accuracy for use as type approval test, generating figures for the fuel consumption of passenger cars on the level of the vehicle itself.
Relevant improvements for the developed procedure for airco's should therefore mainly be established on the level of the overall procedure. To improve or to secure the overall accuracy of the result the following could be done:

- Increase the number of tests per vehicle to increase the statistical reliability of the result.
- Increase the additional fuel consumption compared to the declared accuracy by increasing the airco load during the Part B test, but at the same time sacrificing the "partial load" approach and therewith the discrimination between fixed and intelligent systems.

For Part B possible improvements mainly concern the tolerances for the equipment and settings in the vehicles:

- Optimise Fan, nozzle and temperature settings in the vehicle (requiring intensive cooperation from the automotive industry)
- Put more stringent requirements to ambient conditions in the test cell (sacrificing cost efficiency). Concerned are the stability and size of the frontal air flow, the accuracy of the amount an location of radiation form the solar lamps.

5.5.3 Application of the options for refinement

Looking at the above stated and the data available from this project, TNO is unable to further optimize the test procedure towards adequate accuracy and power to discriminate air conditioner systems, for the purpose of type approval. The only feasible improvements for these matters are respectively;

- optimizing the comparability of air conditioner systems by having the manufacturer deliver improved temperature settings for the automatically controlled systems.
- increasing the statistical significance of the test results up to the level desired by significantly increasing the amount of actual tests per vehicle type.

The first refinement requires from the manufacturer to determine the temperature settings in advance of the actual test procedure. For every family in the vehicle range having an automatic air conditioner system, one or more additional pre tests will be needed to determine these settings. If the tests are performed solely for the goal of determination of the temperature settings, this will obviously increase the costs for the manufacturer. However, in legislative processes concerning type approval, it is known that manufacturers will be testing in advance of the actual type approval test to gain experience with the behavior of their systems under given conditions as a part of the development of their systems. Determination of temperature settings could easily become part of that process. It is up to the manufacturer, however, to what extent he wishes to optimize the settings within the restraints of the procedure. For the determination of temperature settings, it can be assumed that a few additional tests would be sufficient, thereby increasing the overall costs for the manufacturer with a few times the costs for performing the procedure, see Paragraph 8.1 for the costs of one procedure.

The second refinement requires more tests to be performed to improve the statistical reliability of the test result. Increasing the amount of tests per family directly increases the testing costs for the manufacturer. From the results of this investigation it could not be derived, however, how many tests would be needed to increase the statistical significance of the result up to a level that it would meet the requirements (Paragraph 3.1).

For such an evaluation a large set of actual test data would be needed together with a statistical analysis. Most important is the distribution of the results of multiple tests. Statistical evaluation methods rely on such distributions, they are used to define the confidence interval resulting from a series of measurements that show a certain amount of variability. To give an example, the statistical student T-test allows to give an indication of the improvement of statistical significance with an increased number of tests performed. This student T-test shows the largest reduction of the confidence interval within the first 5-7 tests (The probability that the average value lies within a smaller range increases sharply within the first number of tests, while after the first set of 5-7 test this increase is not as large anymore). It also strongly depends on the actual variability between tests, however, in how far, or if the significance can be improved to a satisfying level. The number of tests used to give the indication for the costing are therefore only an example and not an actual advise. In the costs calculations in Chapter 8 an indicative number of 5 tests is used.

The final basic test procedure is described (Chapter 6) and evaluated on it applicability within the context of several legislative schemes (based on cost effectiveness) in Chapter 7 and 8.

6 The final proposal for a test protocol

Based on the considerations and test results presented in the previous chapters a final proposal for a test procedure is formulated as presented in Table 16. This table describes the various steps in the procedure. Additional information, e.g. regarding vehicle preparation and test conditions, are described in numbered paragraphs below the table.

Table 16: Final proposal for a test protocol to determine the additional fuel consumption resulting from the use of mobile air conditioners in passenger cars.

Step	Action	Conditions
1	*Determination of fuel consumption with **a/c off***	
1.1	Preparation of the vehicle according to paragraph 5.1.2. / 5.1.3. / 5.1.4. / 5.1.5. and 5.3. of 80/1268/EC and adjust the chassis dynamometer as laid down in 70/220/EEC	
1.2	Soak according to paragraph 5.1.4. of 80/1268/EC	20 ºC ≤ T ≤ 30 ºC Standard conditions according to 80/1268/EC
1.3	Test of vehicle with a/c off by driving the EDC cycle and measuring emissions of CO, HC and CO_2 [g/km].	20 ºC ≤ T ≤ 30 ºC Standard ambient conditions, emission sampling and dynamometer adjustments according to 80/1268/EC
1.4	Calculation of fuel consumption over complete cycle using carbon balance method in accordance with 80/1268/EC	
2	*Determination of fuel consumption with **a/c on***	
2.1	Preparation of the vehicle according to paragraph 5.1.2. / 5.1.3. / 5.1.4. / 5.1.5. and 5.3 of 80/1268/EC (unless 'a/c off' test has been performed right before 'a/c on' test) and adjust the chassis dynamometer as laid down in 70/220/EEC	

2.2	Additional preparation of the vehicle:
	• installation of temperature sensors
	• air conditioner settings
	    • Set a/c switch to 'on'
	    • Select mode 'auto' for automatic systems
	    • 21 ºC (or highest setting that is lower than 21 ºC) for automatic a/c systems
	    • full cool for manual a/c systems plus fans at full speed
		See par. 6.1

	• for manual a/c systems, recirculation off • ECO or equivalent modes off • mode selector set to dashboard nozzles only • nozzle settings	
2.3	Long soak of at least 6 hours and at maximum 30 hours.	See par. 6.2.1 T = 25 ± 1 ºC
2.4	The vehicle is attached to the chassis dynamometer	
2.5	Driver enters vehicle and closes doors.	
2.6	The solar simulation system is switched on. From that moment the vehicle is soaked for 15 minutes ± 20 seconds before starting the driving cycle. Devices that reduce heat load to the vehicle during stand-still (e.g. curtains) which are switched on automatically by the vehicle without interference of the driver may be switched on during the short soak.	See par. 6.2.2 T = 25 ± 1 ºC RH = 60 ± 5 SR = 850 W/m^2
2.7	Test of vehicle with a/c on by driving the EDC cycle and measuring emissions of CO, HC and CO_2 [g/km]. For manual systems the fan speed may be decreased if the measured cabin temperature is below 21 ºC for a period longer than 1 minute. Decreasing the fan speed may never result in a measured cabin temperature higher than 22 ºC.	See par. 6.2.3 T = 25 ± 1 ºC RH = 60 ± 5% SI = 850 W/m^2
2.8	Calculation of fuel consumption over complete cycle using carbon balance method in accordance with paragraph 6.4. and 7. of 80/1268/EC	
3	*Determination of additional fuel consumption*	
3.1	Subtract result from ‘a/c off’ test from result of ‘a/c on’ test to obtain additional fuel consumption [l/100km] and additional CO_2-emission [g/km] resulting from the use of the air-conditioner.	
3.2	Report results in prescribed reporting format (addendum to Annex II of 80/1268/EC)	

6.1 Preparation of vehicle for ‘a/c on’ test

6.1.1 Temperature measurement

Thermocouples are to be mounted above the driver seat and the front passenger seat:

- 70cm in a straight vertical line above the middle of the line where the seat and back of the seat meet each other (distance from the left of the seat equals that from the right of the seat).

Seats should be adjusted in the middle position or in such a way that an average person of 175cm is able to control steering wheel and pedals in a normal way.

6.1.2 Air conditioner settings

The automatic mode must be selected if available. For vehicles with an automatic air conditioning the air conditioner control has to be preset to 21 ºC prior to the long soak preceding the ‘a/c on’ test. For manually controlled systems the settings must be adjusted to full cool and the fans should be adjusted to full speed. These settings should be altered whenever the temperature at the “head” measurement point reaches the waypoint at 25 ºC.
For vehicles with a separate temperature control for the driver and the passenger(s) both (or all) separate controls have to be switched on and set at a target temperature of 21 ºC.
For automatically controlled air conditioner systems with no fixed set point of 21 ºC, the highest setting must be selected which is lower than the required 21 ºC. It is up to the manufacturer to provide this setting to the testing authority and to provide proof that an acceptable temperature is reached at the given setting if the testing authority requires the manufacturer to do so.
The mode selector, if present, should be set to ‘dashboard nozzles only’. If the system is equipped with an ’Economic mode’ or another comparable mode, it must be switched off. The ‘recirculation mode’ must be switched off.

6.1.3 Nozzle settings

The positioning of the air flow from the nozzles in the dashboard should be chosen in such a way that the cold air flow does not point directly to the driver or the passenger or to the temperature measurement location. In Figure 5 in paragraph 4.2.3 values are given for the minimum distances of the air flow to the measurement location. In the vertical direction the centre of the air flow beam should aim 30cm below the position of the temperature sensor. In the horizontal direction the centre of the beam should be 30cm away from the middle of the seat leading to a separation of 60cm between the beams from the nozzles directly left and right of the seat. If manual adjustment is possible, all nozzles in the dashboard should be fully opened.

6.2 Ambient conditions during ‘a/c on’ test

6.2.1 Ambient conditions during the long soak

<u>Temperature</u>
The average ambient temperature in the test cell should be 25 ºC ± 1K and should never be lower than 22 ºC or higher than 28 ºC. The ambient temperature should never be more than 3 minutes lower than 23 ºC and higher than 27 ºC for more than 3 consecutive minutes. The temperature should be recorded with a frequency of 1Hz.

6.2.2 Ambient conditions during the short soak

<u>Temperature</u>
The average ambient temperature in the test cell should be 25 ºC ± 1K and should never be lower than 22 ºC or higher than 28 ºC. The ambient temperature should never be

more than 3 minutes lower than 23 ºC and higher than 27 ºC for more than 3 consecutive minutes. The temperature should be recorded with a frequency of 1Hz.

Humidity
The relative humidity of the air in the test cell must be conditioned at 60 ± 5%.

Solar irradiation
Solar irradiation must be simulated by means of solar lamps mounted above the vehicle.

The average intensity measured by a pyranometer should be within 25 W/m^2 of 850.
The energy intensity is determined as an average of two points:

- Centreline of the test vehicle at the base of the windshield
- Centreline of the test vehicle at the base of the rear window

The uniformity of the intensity of irradiance over the footprint of the test vehicle must be within ±15% of 850W/m^2.

The pyranometer:

- Must be one that is designed to measure the irradiance on a plane surface, which results from the direct solar radiation and from the diffuse radiation incident from the hemisphere above. In this way the diffuse radiation from the test room walls will be measured too and will thus be taken into account.
- Must be able to measure the irradiance within a spectral range of 305 – 2800nm.
- Must have an overall accuracy within 50 W/m^2.

The battery of solar lamps:

- Must have metal halide lamps
- Must cover the footprint of the vehicle
- Must be mounted minimum 2 meter above the roof of the test vehicle, measured from the cover of the lamp. Other dimensions may be approved if it can be shown that the ambient condition requirements are satisfied.
- Must be adjusted in advance of the long soak, or the solar simulation system may be switched on and adjusted at the beginning of the short soak if the system is able to simulate the intensity 850 ± 100W/m^2 within 2 minutes after switching on and 850 ± 25W/m^2 within 4 minutes after switching on.
- Must be directed in the vertical direction.

6.2.3 Ambient conditions during test

Temperature
As defined in paragraph 6.2.2.

Humidity
As defined in paragraph 6.2.2.

Solar irradiation
As defined in paragraph 6.2.2.

Driving wind simulation
The driving wind simulation should be proportional to the driving speed of the vehicles on the chassis dynamometer up to the maximum speed of the test cycle used (TA 120

km/h). This proportional wind speed should be available for the full width (without mirrors) and bonnet height of the vehicle.

7 Applications for the test procedure

The initial goal of the underlying project was to develop a procedure enabling labelling and ranking of mobile airconditioner systems and auxiliary heaters based on their respective additional CO_2 emissions. This procedure should in principle be applicable within the context of Type Approval testing. During the process of developing the procedure (and in line with some considerations of the Commission in the technical annex of the contract) it turned out that applying the procedure within the context of Type Approval was not the only option. According to the technical annex, alternative options for application had to be established and evaluated.
In view of the general objectives, aimed at by the Commission (section 1.2), the developed procedure could in principle be used for three different applications:

1. integration into the Type Approval procedures, with results possibly to be used in a labelling scheme or to define CO_2-credits/penalties;
2. a programme for benchmarking (reference points) of typical systems, with results possibly to be used in a labelling scheme or to define CO_2-credits/penalties;
3. a monitoring programme, possibly related to some kind of voluntary agreement with the automobile industry aimed at improving airco efficiency.

A monitoring procedure (option 3) aims at assessing trends in average performance of systems over time, whereas a benchmarking procedure (option 2) aims at assessing the performance of individual systems or groups of systems. A benchmarking programme can be set-up independently from Type Approval legislation, but one could think of the option to include the procedure in 80/1268/EEC, so that every manufacturer is made responsible for the presentation of the performance of airco systems as built into their cars (option 1).

Option 1 would require a test procedure that is as much as possible consistent with the existing procedure for Type Approval. For options 2 and 3 this is not necessary, but still desirable to some extent.

Below the different options are discussed. For options 1 and 2 the possibility of applying a family definition is evaluated. In line with the project objectives of the Commission, for all options the possibilities for using the results in the context of a labelling scheme or other means to provide information to consumers are discussed.

7.1 Integration in the Type approval scheme and the labelling scheme (80/1268/EC and 1999/94/EC)

7.1.1 Applicability of test procedure in the context of the Type approval Directive for fuel consumption 80/1268/EC

Integration into the Type Approval scheme means that every type of vehicle from a manufacturer that belongs to the European Vehicle Category (70/156/EC) should be tested over the given procedure to deliver the results to the Type Approval Authority. Such results could than e.g. be used in a specific labelling scheme (1999/94/EC).

In section 5.4 it was concluded that the procedure can not be used for benchmarking and ranking *individual* systems (vehicle / airco combinations) by running a *single* test, because the differences between individual systems are in the order of the accuracy of the procedure. The reliability of the results of the procedure could be increased by increasing the number of tests within the procedure to be performed for one vehicle or family, see also chapter 5.5 about possibilities for improvement.

On the bases of the data that became available from the measurement programme, it proved not being possible to execute a statistical evaluation towards a minimum of tests that should be performed to make ranking and thus labelling of individual systems possible. In order to obtain information for such a statistical evaluation the procedure should be replicated a minimum of 20 times on at least 20 different vehicle types.

7.1.2 Considerations regarding application of a family concept

The types of vehicles within the European Vehicle Category can be grouped in families with certain characteristics, with respect to the influence on the overall fuel consumption, for application in 80/1268/EEC. In this Directive an extension of approval is described that even allows to extend the groups, as already defined, to larger groups (families), because it is considered useful to test only the vehicle types that do give significantly different results. For the determination of the additional fuel consumption due to the use of an airco, one could think of a similar approach. The development of such an approach was originally part of the underlying project, but proved impossible to be executed due to the lack of detailed data to be supplied by the industry.
However, in the course of executing the project the parameters determining additional energy use due to airco operation have been established. Based in these insights additional group definitions within the existing family definition of 80/1268/EEC could be established. It has become clear that the existing family, definition should be enlarged with additional categories and will thus increase the amount of families and tests to be carried out on the parents of these families. Below a possible extension of the current family definition for the sake of mobile air conditioning testing integrated in the Type Approval scheme is discussed.

The effect of different body versions (in this case hatchback vs. station) within one vehicle model range on the additional fuel consumption is found to be small for the vehicles tested for this investigation. Airco type, engine size and body size (in this case medium vs. large) of these vehicles did appear to significantly influence the additional energy consumption resulting from airco use. Different engine sizes already lead to different families under the existing type approval procedure. Additional families therefore only have to be defined within a given existing family if a certain vehicle model is sold with (significantly) different airco- and body types. For the latter, however, it is not expected that large differences can be found within existing families, because in the current legislation the ‘extension of approval’ is limited by a defined CO_2 range of 4% for the family members. Vehicles with a substantially different shape and size (other types) will therefore automatically fall within another family due to the impact size has on road resistance (drag) and thus on CO_2.

On the other hand the additional fuel consumption resulting from airco use may be quite similar for vehicles from different existing families, provided that the airco system and engine are the same. This would enable a grouping of existing families into a larger family for the test procedure. It can be left to the manufacturer to show that vehicles from different existing TA families perform similarly with respect to the airco test.

Following the above it can be concluded that, when testing the CO_2 emissions of airconditioning systems the family definition currently applied in the context of type approval should have to widened with:

- the number of significantly different airco types (automatic / manual, variable / fixed, type of refrigerant, type of airco powering) fitted on vehicles from the same existing TA family;
- the number of body variations (e.g. body type, panoramic roof or reflective glazing) in as far as they result in a significant additional fuel consumption over the airco test procedure, with "significant" in this context still to be defined as a certain percentage or absolute number of gram/km higher or lower than additional fuel consumption of the parent vehicle.

7.1.3 Applicability of Type Approval data for labelling (1999/94/EC) or consumer information

If, in the context of type approval testing, the airco test is only performed once on a vehicle, the results are not sufficiently accurate for use in a labelling scheme. If the procedure is repeated a sufficient number of times within the TA test, then a sufficiently accurate average for the additional fuel consumption can be obtained which allows discrimination of individual vehicles / systems and the use of the test results in the context of labelling and/or providing consumer information. The number repetitions needed in order to obtain statistical significance, can not be determined from the data currently available. In order to obtain sufficient data, the proposed test procedure should be replicated at least 20 times, on at least 20 types of different vehicles. Having executed this kind of testing work will provide information on the necessary test work within the type approval context needed to make TA testing applicable for the purpose of labelling and ranking of individual types of vehicles.

The application of the TA related procedure is largely linked to the performance of an individual vehicle type. Therefore information to the customer information can be linked directly to the typical vehicle, which gives the possibility for energy labelling of those individual vehicle types.
Such an energy label related to the additional fuel consumption due to airco use should be defined as a relative indication of the performance of a given airco system/vehicle combination in comparison to other vehicles of the same class. Classes of comparable vehicles could be defined in relation to a certain parameter for the functionality. In principle this could be a similar definition relating to vehicle size (e.g. projected ground surface) as currently used in several national fuel consumption labelling schemes. In larger cars generally a larger airco is fitted which consumes more energy as a larger volume with larger solar irradiation is to be cooled. Dividing the result of the airco test by a parameter measuring vehicle size, results in a relative measure of the efficiency of the airco system.

Other types of consumer information could consist of:

- an absolute figure for the additional fuel consumption and CO_2 emission per kilometre driven for the vehicle;
- an absolute figure for the average annual additional fuel consumption and CO_2 emission, e.g. differentiated for three European climate zones.

7.1.4 Development of amendments to existing Directives

As stated in the technical annex of the contract, an explicit goal of the project has been to develop amendments to existing Directives to incorporate the developed test procedure for measuring the additional fuel consumption due to the use of air conditioners or auxiliary heaters into the existing test procedures for Type Approval of passenger cars. The main directive to be amended would be Directive 80/1268/EEC.

From the discussion in previous paragraphs, however, it is clear that the developed procedure shows the poor repeatability and reproducibility of the single vehicle test procedure and involves difficulties with applying this procedure in a lab. As a result two basic requirements of a test procedure fit for Type Approval are not met at the moment of finalising the investigation. Therefore it was decided not to propose any amendments to the current single vehicle type approval directives.

7.2 Benchmarking procedure (reference points)

7.2.1 Options for setting up a benchmarking procedure

Given the fact that application of the procedure within the context of TA has not yet completely established and (in case of application) will involve intensive testing, other options leading to insights and possibilities for generating customer information should be investigated. One of these options is “benchmarking”. In case of the application of the developed procedure for benchmarking the procedure could be used to compare:

1 the performance of individual systems or;

2 the performance of groups of systems (using a suitable kind of family or class definition).

Benchmarking may be performed on the basis of type approval test results or on the basis of results obtained in a measurement programme run independently from type approval.

For the first case every vehicle type should be tested. For the second case for every class or family one ore more representative vehicles should be tested. Benchmarking individual systems requires a test procedure with sufficient accuracy to discriminate between vehicles. In section 5.4, however, it was concluded that the procedure as developed does not allow the comparison of individual systems, at least not by running only *one* additional test per vehicle/airco system combination to determine the additional fuel consumption. For benchmarking individual vehicles the test should be repeated a sufficient number of times to obtain a useful average. In the case of benchmarking classes of systems a sufficiently accurate average could also be obtained by performing single tests on a significantly large number of vehicle/airco system combination combinations within the same class.

For the second option – comparing the performance of classes of systems – a promising route could be to adapt the level at which the systems are benchmarked. An example is only benchmarking general types of systems not distinguishing between manufacturers, but aiming at the comparison of technologies. In this way the effectiveness of the development of a certain technology could be benchmarked. This resembles the monitoring option discussed in paragraph 7.3, but includes a discrimination between technologies. If the choice is made primarily for a monitoring programme, the benchmarking process could at some point also become part of the monitoring programme if the results for individual systems would show significant deviations from the trend demanding closer attention.

7.2.2 Labelling / Consumer information based on benchmarking

The results of a benchmarking scheme can be used to obtain figures for the information of the consumer. In case of benchmarking of individual vehicles the same options for labelling and consumer information exist as described in paragraph 7.1.3. In case benchmarking is performed on classes of vehicles or systems, labelling is not an option because it lacks the vehicle individual functionality parameter the label should be based on. The results can, however, be used to provide the consumer with general information on the additional fuel consumption related to airco use and on the average difference in additional fuel consumption between different types of airco systems.
If such a benchmarking approach is feasible within the context of the EC’s ideas, depends largely on the final goal of the process of labelling and/or informing. In this context it must be mentioned that during the execution of the project the energy efficiency of airco systems has improved significantly, due to the large scale application of variable displacement compressors. A benchmarking procedure could very well be used in order to distinguish between fixed and variable displacement technology and would therefore very well fit important goals of the EC’s labelling scheme.

7.3 Monitoring procedure

7.3.1 Options for setting up a monitoring procedure

Monitoring the development of the additional fuel consumption over time would allow the Commission to assess trends and to take action if necessary. The monitoring procedure could also be used to obtain representative figures for the average additional fuel consumption related to airco use. Such data can be used in a consumer awareness campaign.

Although accurate figures could not be established so far because of the lack of measurement data and the absence of a standardised test procedure for mobile air conditioners, a general trend can already be observed towards systems with a higher overall efficiency. This trend is stimulated by the increasing demand for more comfort and driveability. The heat transfer to the cabin is decreased by fitting reflective glazing, especially in the case an additional panoramic roof is installed, and by controlling the temperature more accurately and efficiently. Furthermore nowadays most of the airco systems of European cars have a variable displacement compressor to better adapt the capacity of the airco system to the available propulsion power provided by the engine and the cooling load required to reach and maintain a certain comfort level.

Without a standardised procedure to measure the effects and some sort of monitoring programme of sufficient size, giving statistically reliable figures to compare for example annual results, however, these trends can not be assessed quantitatively.

A monitoring programme can be set up in different ways, with different levels of detail. At the highest aggregations level the average additional fuel consumption is determined for a sample representative of the full spectrum of newly sold vehicles on the European level. At lower aggregation levels averages could be determined separately for e.g.:

- different technology classes
- vehicles form different manufacturer associations;
- vehicles from different manufacturers.

Depending on the aggregation level a suitable procedure needs to be defined for selecting a representative sample of vehicles to be tested. The amount of vehicles to be tested will increase if different classes of vehicles are discerned in the monitoring programme. Per class the sample size needs to be determined on the basis of the observed spread in measurement results within the vehicle class. For this no information is available yet, so that the required sample size needs to be determined in the first year(s) of running the monitoring programme. Furthermore statistical procedures need to be worked out to properly deal with the test results in order to derive statistically significant averages.

If the airco test procedure is part of the type approval, the TA results can be used to monitor the technical progress in airco system and vehicle technologies. Otherwise a monitoring programme can be set up independently of the type approval. In that case the number of vehicles to be tested in order to achieve statistical significance of the value to be presented, can be significantly smaller.

7.3.2 Labelling / Consumer information based on monitoring

The results of a monitoring scheme can not be used for labelling individual vehicle types , but can be used to provide general information to consumers on the additional fuel consumption related to airco use. Depending on the aggregation level of the monitoring programme either only general information regarding average additional fuel consumption can be supplied or more detailed information on the performance of different types of systems.
If such a labelling approach is feasible within the context of the EC's ideas, depends largely on the final goal of the process of labelling and/or informing. In this context it must be mentioned that during the execution of the project the energy efficiency of airco systems has improved significantly, due to the large scale application of variable displacement compressors. A labelling procedure could very well be used in order to distinguish show progress made over the years (and stimulate such progress) due to improved technology and would therefore very well fit important goals of the EC's labelling scheme.

7.4 Auxiliary heaters

7.4.1 Considerations regarding the assessment of heaters.

The contract for this investigation stipulates mobile air conditioning systems as well as auxiliary heaters to be addressed. The reason for this is that both systems consume high levels of energy during operation (up to 5 kW), and therefore it is considered that labelling just these systems will lead to significant reductions in CO_2 emissions. The effect of labelling on CO_2 emissions decreasing, however, is determined mainly by the

technological differences and improvements that can be found, by stimulating towards the best in it's class.
For mobile air conditioning systems this labelling approach can be seen as in principle adequate, since technologies used vary to a certain extend and can be effectively improved. For auxiliary heaters the situation is completely different, since most of the systems burn fuel with the purpose of generating heat, which is utilized with an overall efficiency of about 90% in all cases. Although the thermal efficiency of some deployed electrical heating systems are much lower than the direct fuel burning types, possible efficiency improvements are limited, and almost solitarily to be utilized through improved alternator efficiency and/or increased engine efficiency, which can both already be addressed by labelling via the CO_2 emission data that become available by applying the method from Directive 80/1268/EC.
Possible improvements directly linked to the efficiency of the auxiliary heater itself are therefore very limited. The only actual gain by measuring and labelling would be that actual data on the additional CO_2 emissions of these systems become publicly available and create customer awareness. The consumer however in most cases is not able to effectively deal with the additional fuel consumption of the auxiliary heating system, since these systems in most cases operate fully automatic, they heat up the cooling liquid whenever its temperature is below a certain temperature level. The driver is not aware of this and is mostly unable to switch the system on or off. Only the so called "Standheizungen" can be switched on and of manually, but these systems heat up the vehicle *before* driving and are therefore not linked to a typical driving cycle. This makes it impossible to address them within the context of Type Approval which expresses CO_2 emissions in g/km.

Looking at the technology of auxiliary heaters and their utilization, the sense of monitoring and labelling the fuel consumption is very limited compared to that of mobile air conditioning systems. Furthermore the application in a Type Approval setting will be difficult, because in many cases the auxiliary heating system can not be manually switched on or off in order to perform one test with and one without the system working. By executing a standard -7 ºC Euro IV Type Approval test however, the CO_2 emissions of the auxiliary heater systems are implicitly measured because vehicles equipped with such a system will (in most cases) automatically switch on the auxiliary heater until the cooling liquid reaches a certain temperature level. Thereby heating up the engine faster will in most cases reduce the cold start emissions of the regulated emission components and even compensate with lower CO_2 engine out emissions, which puts a relevant positive effect next to the implicit additional fuel consumption.

Taking into account the above it can be concluded that determining the CO_2 emissions due to the operation of auxiliary heaters is difficult to establish using a measurement protocol similar to the proposed protocol for airconditioner systems, because of the lack of possibilities to switch of the systems for testing. The availability of detailed information in the context of labelling will encourage only very little technological improvement. Within the context of the objectives of the EC using the CO_2 emission results form a standard Euro IV -7 ºC test as a labelling value, will most probably give sufficient information on the topic, without additional tests to be executed, at the same time addressing the positive effects of the auxiliary heaters on the cold start emissions of the vehicle . This approach will however not allow any kind of technology differentiation.

On the other hand modelling of the CO_2 emissions due to the operation of auxiliary heaters, can most be modeled in more detail allowing a technology differentiation. Such a modelling is elaborated next.

7.4.2 Modelling considerations

Due to the technological differences between fuel fired and electrical auxiliary heaters both systems have to addressed separately when modelling their additional CO_2 emissions.

Fuel fired heaters
From [TNO 2002]: "A fuel-fired heater operates stand-alone because this system only relies on the supply of fuel stored in the tank of the vehicle. The operation of this system is rather simple: inside a burner housing fuel is injected and mixed with air. A piëzo-electric ignition or a glow plug fires the mixture at start-up of the system. A fan forces the hot gases to blow along a gas to liquid or gas to gas heat exchanger. In this way it is possible to respectively heat-up the engine's coolant or the air supplied to the vehicle's interior."
Applied as a "supplemental heater" a fuel fired heater is used to help to warm up the engine coolant quicker under cold ambient conditions, because some modern engines lacks waste heat because of it's high efficiency. This is especially the case for direct injected diesel engines at which the auxiliary heaters are commonly applied.

To obtain a realistic estimation of the additional fuel consumption, a model can be set-up in which typical parameters, applicable for fuel fired heaters, can be used as input for the model. If the ambient temperature during the test is -7 ºC, the heater will run at full load. The additional consumption of the heater over the European Driving Cycle is determined by the following formula:

CO_2 emission heater [g/km] = full load CO_2 emission heater [g/h] x (1180 / 3600) / 11 [km]

In which:

1180 =Eurotest duration (s)
11 = Eurotest mileage (km)

As an example the typical fuel consumption of a fuel fired heater, operating at full load over the European Driving Cycle can be calculated, using 0,5 l/h (=1350 g CO_2/h for diesel or 1200 g CO_2/h for petrol) as a typical value for a 5 kW output fuel fired heater for a medium size passenger car (source: Webasto):

CO_2 emission heater = 1350 x (1180 / 3600) / 11 = 40 g/100km (diesel)

Electrcial heaters
Electrical heaters are applied with the same purpose as fuel fired heaters. The obvious difference between them is the way they are powered. From [TNO 2002]: "Electrical heaters do not operate stand-alone, but fully rely on the electric power supplied by the vehicle's low voltage battery and generator (as applied in a conventional powertrain). An electrical heater system is very simple of construction. A PTC (Positive

Temperature Coefficient) thermistor directly supplies the required heat to the engine's coolant or to the air that is blown past the PTC element to the cabin. A PTC is a thermally sensitive semiconductor resistor. Its resistance sharply rises with the increase of the temperature. The opposite effect is used for heating: supplying electrical power to the PTC causes it to become highly resistive. The high resistance reduces the absorbed power. A state of equilibrium is then set up in which the electrically absorbed power equals the thermally dissipated power, which also means that the power supplied to the thermistor is temperature dependent; at a higher temperature the power decreases. The thermally dissipated power is used for heating a forced airflow directed to the cabin or for heating the coolant of the engine."

Different from the fuel fired heaters the available heating power is limited by the capacity of the electrical generator of the vehicle. This limitation is due to a) the maximum power of the generator and b) other electrical power components demand power. Electrical systems are set up in a manner such that only the surplus of generated power is used for heating (prohibiting the battery to be drained).
In line with the operation of the fuel fired systems, for an ambient temperature of -7 ºC an electrical heater works at the full capacity that is available from the electric system, which is the full capacity of the generator minus the power consumption of all other electrical components and the power required to recharge the battery.

An electrical heater system typically consists of 3 to 5 PTC elements which can be switched on individually, hereby creating the possibility to control the power output in as many steps as there are PTC elements in the system. Typical automotive systems for passenger cars have a total capacity of 1 – 2kW. The power output is also dependent of the ambient temperature. At a low temperature one element will require more power to operate and dissipate more heat than at a higher temperature.

An example from the literature [Haus der Technik 2001] shows that an average of 1.8 PTC elements are switched on during an -7 ºC MVEG cycle, which corresponds to an average power consumption of about 600W over the cycle. The additional CO_2 emission resulting from this additional required electric power over a driving cycle can be approximated by:

$$Additional\ Energy Consumption[J] = \frac{Average\ Electric\ Power[W] \cdot Cycle\ Duration[s]}{Average Generator\ Efficiency\ [-] \cdot Average\ Engine\ Efficiency[-]}$$

$$Additional\ CO_2\ Emission\left[\frac{g}{km}\right] = Energy\ Consumption\ \ [J] \cdot \frac{Specific\ CO_2\ emission\left[\frac{g}{l}\right]}{Caloric\ value\left[\frac{J}{l}\right] \cdot Cycle\ Distance\ [km]}$$

As an example the typical additional CO_2 emission of an electrical heater over the -7 ºC European Driving Cycle can be approximated, using 600W as a typical value for the average power consumption, 36 MJ/l as a typical caloric value for diesel fuel, 2700 g/l CO_2 emissions for diesel, 60% as a typical generator efficiency and 17% as a typical engine efficiency of a diesel engine over the European Driving cycle:

$$Additional\ Energy Consumption[J] = \frac{600[W] \cdot 1180[s]}{0.6\,[-] \cdot 0.17[-]} = 6941000$$

$$Additional\,CO_2\,Emission\left[\frac{g}{km}\right] = 6941000\ [J] \cdot \frac{2700\left[\frac{g}{l}\right]}{36*E9\left[\frac{J}{l}\right]\cdot 11\,[km]} = 47.3$$

In which:

1180 s =Eurotest duration
11 km = Eurotest mileage

In relation to the presented calculation some important remarks have to be made:

a) It must be mentioned that this calculated additional CO_2 emission does not constitute the benefit the heating system has on the efficiency of the engine under cold ambient conditions. The heater, in addition to the climatic comfort, speeds up the warming up of the engine, as a result of which fuel consumption is reduced. The calculated additional CO_2 emission over the -7 ºC part of the Eurotest (at full load) will therefore be less than the actual value.
b) The calculated value is a ”full load” value over the -7 ºC test cycle. The additional CO_2 emissions due to the use of a fuel fired auxiliary heater on an annual bases however, is largely dependant of the average cold start temperature and the amount of cold starts. Because these two mentioned factors are totally dependant on local circumstances and individual consumers use, no calculation is feasible to model the real world annual additional CO_2 emissions due to the use of auxiliary heaters.

Altogether it can be concluded that detailed modelling of the worse case power consumption of auxiliary heaters is feasible within the context of a type approval procedure. It shows that the fuel powered heater is far (almost factor 10) superior to an electrical system when generated heat input in relation to CO_2 emissions are considered.

Modelling the CO_2 emissions for the purpose of labelling and customer information however is far from appropriate. Too many parameters that are influenced by typical customer behaviour/location, determine the additional CO_2 emissions of the auxiliary heaters and make the modelling result inappropriate for customer information. The customer would have large difficulties interpreting the results towards his actual user patterns.
As a relatively simple alternative (to modelling) for ranking the additional CO_2 emissions caused the heater systems could be measured during the -7 ºC test of the Type Approval procedure. This, however, is an implicit approach, not resulting in solitary data for the auxiliary heating systems. Since the progress that could be made toward energy efficiency of using auxiliary heater systems will arise form improvements on the vehicles *engine* and not on the heaters themselves, such an implicit approach will serve the labelling and ranking purpose as well. Since the additional CO_2 emissions caused by the full load use of the auxiliary heaters is significant (compared to the CO_2 emissions for driving the cycle) and there are very limited influences from settings on the vehicle (no nozzles, or automatic systems reacting to radiation) no problems are foreseen with the repeatability and reproducibility of test.

7.5 Euro V

One of the questions in the technical annex of the contract has been to describe to what extent the proposed procedure could be incorporated into a Euro V regulations scheme.

This question was raised at a moment in time at which the Euro V process was just starting up and it was not yet clear what kind of changes were feasible to the Euro IV regulations. After staring up this project the point of addressing additional CO_2 emissions for mobile airconditioner systems and auxiliary heaters within the context of Euro V has been discussed with representatives form DG-ENT and DG-ENV. It was at that time concluded that it was not foreseen to take mobile airconditioner systems and auxiliary heaters into account within the Euro V process. At that point the Commission decided to take no further actions on this point out of the technical annex of this study.
Meanwhile the discussion on Euro V has evolved further and up to the publication date of this report, no other information was received from the EC about integrating the additional CO_2 emissions for mobile airconditioner systems and auxiliary heaters into Euro V legislation.

8 Cost aspects

Within this study a test procedure has been developed starting from the draft concept as worked out in the first study [TNO 2002] up to completion in this study. The cost aspects of the application of the study have been generally addressed in this first study as well. Having worked out the procedure in more detail in the course of this study, the cost implications for the test procedure can now be calculated more accurately.
The cost implications are closely related to the way the procedure is incorporated in the European legislative process. To this end there are 3 options for implementation:

- Integration in the Type Approval scheme
  - With or without the application of a family concept within the Type Approval scheme
- Integration into a benchmarking programme
- Integration into a monitoring programme

The costs aspects of the possible way of implementing the test procedure are discussed next.

8.1 Cost aspects of the test procedure

The costs for the execution of one full procedure consist of the costs of labour and the costs for the use of equipment. As the basis for the calculation a laboratory is taken that complies with the specifications needed for testing emissions for Euro 4 and especially the type VI test (the test at low ambient temperature of -7 ºC). It is expected that a test house with such a test room can comply with the requirements for the control of the ambient temperature and the ventilation of the radiator, condensor and evaporator, but not with the requirements for humidity and solar radiation. For the latter two the basic test room will require investments to make simulation of solar radiation possible and besides to enable a more accurate control of the humidity. Therefore, additional to the costs for execution of a complete procedure the implications of the required investments for the hourly rates should be determined resulting in additional costs on top of the complete procedure.

The cost calculation of the test procedure will be made for a test house that complies with Euro 4 minimum specifications. The cost impact of the investment in solar lamps and a more accurate humidity control will be calculated separately assuming a period of amortisation of the additional required equipment and an estimated amount of testing performed during that period over which the costs of the investment will be distributed.

The costs for the execution of the procedure itself can be calculated using the estimated times for labour, use of equipment/facilities and their hourly rates.

The test procedure itself consists of:

- Preparation of the vehicle, the dynamometer, the ventilation, the emission instruments and the test room: coast down, a/c settings, temp measurement, temp/hum and SR setting of the room
- Handling of the vehicle
- A long soak at 25 ºC (6-30 hours).
- A driving cycle (a/c on) measuring emissions at standard conditions (20 minutes)

- Soak time at an ambient temperature of 25 ºC and 850W/m^2 solar radiation (15 minutes)
- Driving a driving cycle measuring emissions (a/c on) at the prescribed ambient conditions (20 minutes)
- Processing of the data and generating the test report (1 hour)

There are some options within the development of the procedure that influence the costs of the procedure:
- The choice for a cold or a hot start
- A prolonged soak time at elevated ambient conditions, including solar radiation.

In the above calculation only costs for the actual (in cell) testing are included. For completely executing a test protocol additional cost will arise, such as:
- Administration
- Transportation and external handling of the vehicle
- Fuel
- Supplying of the test car

These costs are estimated as being 50 % of the stated test costs.

The rates for labour and standard equipment are estimated at 100 and 400 Euro per hour respectively. The additional investments are estimated at 225 kEuro including maintenance costs and are distributed over 5 years for the solar lamps (as their life time is limited) 50 kEuro with 10 years of life time for the humidity control, assuming 50 complete tests performed per year. Any increase in amount of tests per year will result in a non proportional decrease in equipment cost and an proportional increase of the labour costs. For the sake op the simplicity of the calculation these scale effects are not taken into account in the calculations and therefore the costs have been fixed.
For comparison reasons the costs for using a full climate test cell with wind tunnel are also presented, showing consequences if a wind tunnel would have been required instead of a blower that meets the standard requirements of 70/220/EC.

The table below shows the additional costs for performing the complete procedure, split up into different possible options.

Table 17: The costs for performing the complete procedure in a laboratory that initially meets Euro 4 requirements,

	Costs per complete test procedure [€]
Complete procedure in a standard test room	2000
With basic investment*	+1000
Additional costs hot start	+250
Additional costs hot soak time (Euro per additional hour of soak)	+400
Complete procedure in a full size wind tunnel/climate room	+1500…2000

* investments on solar lamps and more accurate control of humidity

8.2 Cost aspects of implementation of the test procedure

The way in which the proposed test procedure will be incorporated in the EU regulatory process will influence the costs. Three main alternatives were presented:

- The procedure could be incorporated in the Type Approval 80/1268/EC, and the resulting figure(s) could be used for a type specific labelling system (1999/94/EC). All of this with our without a family approach.
- The procedure could be incorporated in a benchmark programme.
- The procedure could be incorporated in a monitoring programme.

The cost aspects of the subsequent approaches are described next.

8.2.1 Costs aspects in the context of Type approval

Integration into the Type Approval scheme means that every type of vehicle from a manufacturer linked to the European Vehicle Category (70/156/EC) should be additionally tested using the given airco test procedure in order to supply test results to the Type Approval Authority. Such results could then be used in a specific labelling scheme (1999/94/EC).

8.2.1.1 Current TA families

As a baseline the costs are calculated for a single family, without taking into account any change in number of families for the airco procedure. Increasing the number of individual tests required to increase the accuracy of the test result will linear increase the costs for testing, as can be seen in the next table.
In addition an example for the calculation of the cost using an increased amount of single tests is presented. Such an increase of the individual test is nessessary in order to improve the statistical significance of the test result. As an example a number of “5” replications has been chosen. This figure must be seen as an absolute minimum in required and is not based on any actual insights from the project. The actual necessary number of replications will have to be established in the course of executing a trail programme.
The costs for performing the complete procedure once have been fixed at 1.5 (+50% for additional costs) x 3 kEuro = 4.5 kEuro, provided that test will be performed in an upgraded Euro 4 laboratories with a) advanced climate control and b) a solar radiation set up.

Table 18: Additional costs per existing Type Approval family, not taking into account a change in number of families for the airco procedure.

	A single test	More duplicates
Costs per procedure	4.5 kEuro	4.5 kEuro
# existing families	1	1
# a/c variations per existing family	1	1
# glazing variations per existing family	1	1
# test duplicates	1	5
Additional costs per existing family	4.5 kEuro	22.5 kEuro

8.2.1.2 *Application of a family concept in the context of Type Approval*

As discussed in 7.1.2 integration in the Type Approval procedure will require additional families to be defined next to the existing families. This will mean that the amount of vehicle families will increase and subsequently the amount of tests to be performed will increase.

In the example below it is assumed that in average the amount of families would increase with 1.8 air conditioner variants and 1.2 glazing variants per existing Type Approval family. For the air conditioner variants it can be assumed that no more than 2 variants per vehicle model exist: the first one being the air conditioner (manually controlled system) and the second one being the climate control (automaticly controlled system). Because some models will have only 1 variant (small cars often only have a manually controlled system and large cars often only have an automaticly controlled system) the amount of variants is slightly reduced to 1.8. Taking into account the suggested increase in families to be tested, the costs per existing family will roughly double, as can be seen in the next table.

Table 19: costs per existing Type Approval family, taking into account a change in number of families for the airco procedure.

	More duplicates	More duplicates + more families
Costs per procedure	4.5 kEuro	4.5 kEuro
# existing families	1	1
# a/c variations per existing family	1	1.8
# glazing variations per existing family	1	1.2
# test duplicates	5	5
Costs per existing family	22.5 kEuro	48 kEuro

8.2.1.3 *Costs per vehicle of the application of the procedure in the Type Approval scheme*

The costs per vehicle of the application of the procedure in the context of a Type Approval scheme can be calculated. This information is necessary in order to be able to elaborate in the cost effectiveness of the procedure.
Such elaboration however is not possible within the context of this project since:
The effectiveness of the labelling and ranking scheme has not been established. Although technical progress would allow improvement in airconditioner efficiency in the range of 10 to 50%, it is unclear at this moment to which amount of such improvements would be induced by the labelling and ranking scheme.
Only the costs for gathering the data needed to facilitate a labelling and ranking are established in this project. Costs effectiveness calculations on this topic however require additional information on a) the costs for implementation of the customer information scheme and b) the costs for the application of advanced vehicle technology in order to arrive at the desired progress in airconditioner efficiency.
Taking into account the above, no actual cost effectiveness could be determined. This is why in the context of the project only the “cost aspects of the procedure” are addressed.

As a starting point, the application costs per existing Type Approval family as calculated in paragraph 8.2.1.2 have been used, because these costs are realistic concerning the fact that integration in the TA scheme will require more families and that a multiplication of tests is required to arrive at a result that is accurate enough.

The annual costs can be determined by multiplying the costs per existing Type Approval family with the number of type approvals performed per year.

The number of annually performed Type Approvals for 80/1268/EC is determined by:

Number of families per manufacturer [-] x number of manufacturers [-] / refreshment rate [-]

The CO_2 reduction [tonne] over the life time of a car is determined by:

Life time [year] x annual mileage [km] x reduction per km [g/km] / $1x10^6$

The costs per car are determined by:

Total annual costs consumer [Euro] / (Annual sales [-] x A/C sales rate [-])

It is assumed that the costs as calculated will be equivalently charged to the consumer. The result of the calculation made above in the context of this project is shown in table 20.

Table 20: costs per vehicle sold, charged to the consumer. For a complete procedure, replicated 5 times (indication) to obtain statistical significance.

# families / manufacturer	50	
# EU manufacturers	25	
refreshment rate families	5	Year
# TA / year	250	
Costs / TA (as from 8.2.1.2)	48	kEuro
Total annual costs	12000	kEuro / year
# annual car sales EU manufacturers	12	Million
A/C sales rate	0.95	
Km / year / car	15000	Km
Life time	15	Year
Costs / car	1.05	Euro

Not included are the costs for communication of the information to the consumer, development of improved technology by the manufacturer and the costs of the improved system as integrated in a vehicle sold on the market.

8.2.2 Cost aspects of benchmarking (reference points)

As an alternative to the TA approach a benchmarking set-up could be perused. Next an elaboration is presented on the cost aspects of such an approach.

The costs for a benchmarking programme will consist of costs for:
- determination and organisation of the testing programme
- testing
- processing of the data and reporting of the results

In this set up the testing work is analogue to the testing basic single vehicle test work in the TA setup, but in addition to the pure testing a programme will have to be managed.

The number of tests to be performed in the benchmarking approach strongly depends on the level at which individual systems or groups of systems should be assessed. The following formula can be used to obtain the number of tests for a benchmarking programme:

 # tests = # duplicates x # cars per group # airco types x # fuels x # size categories + # exotics + # correlation tests

In order to fill in the parameters needed it should be established what kind of vehicles (groups of vehicles) should be tested in order to obtain the level of detail desired. An example calculation can be made for a benchmarking programme that would be started in order to assess the additional fuel consumption at the level of car type and airco type, see below and in the next table.

The minimum number of duplicates was determined as an indicative figure to gain statistical reliable results from the procedure, as can be read in paragraph 5.5.3.
For the number of cars per group it was assumed that, like the number of duplicates, five would be some sort of minimum to test a group of cars from different manufacturers. This group is needed to cover the differences within size categories, the differences in equipment used and also the level of optimisation within the group. For airco types two types were distinguished, assuming that in the next few years mostly automaticly and manually controlled airco systems will be sold, both with a variable compressor. Other airco systems could be tested under the category exotics. For the category fuel, petrol and diesel are the most important in Europe. Alternative fuels could be gathered under the category exotics. At least three different size categories should be distinguished to cover small, medium and large cars, thereby assuming that they will show significantly different effects. The category exotics is used for vehicles or air conditioner systems that are not common, or not common yet but demand further inspection. Examples are: hybrid vehicles, systems with CO_2 as refrigerant, exclusive cars, CNG or Autogas (LPG) fuelled cars. Finally, it is advisable to check the results over a few test houses in a correlation programme to avoid the possibility that the results are based on one test house that gives figures containing systematic errors. Three test houses testing a single car 5 times results in 15 additional test for the purpose of correlation testing.

Table 21: The costs for testing in the context of a benchmarking approach on the level of car and airco type.

# duplicates	5
# cars per group (different manufacturers)	5
# airco types	2
# fuels	2
# size categories	3
# exotics	15
# correlation tests (3 test houses)	15
# tests	330
Costs per basic test	3 kEuro
Costs for testing	990 kEuro

The costs in the table have been calculated taking into account the basic testing costs per single test (3 kEuro). Similar to the TA approach, additional costs next to the basic testing of vehicles arise. Because in the context of benchmarking arise within to context of a consolidated programme, the additional costs are lower (compared to TA). These cost constitute:

- supply of the vehicles
- transportation of the vehicles
- management of the programme

However a benchmarking set-up should result in an consolidated report (and not in single vehicle data) and therefore additional costs have to be taken into account:
- steering group
- data analysis, calculation of the effects and reporting/presentation of the results.

The total additional costs are estimated at about 500 kEuro and if added to the 990 kEuro for the testing programme make a total of about 1.5 Meuro for a benchmarking programme.

8.2.3 Cost aspects of monitoring

A monitoring programme has more or less the same elements as a benchmarking programme, but for a monitoring programme fewer tests need to be performed. The reason is that a monitoring programme focuses on the monitoring of a group of vehicles that is representative for the sales of a certain period. The number of vehicles in such a group is expected to be much smaller than the amount of vehicles that would be part of a benchmarking programme.

The size of the group of vehicles needs to be determined based on actual results from a first trail campaign. Taking into account the actual and large variability of the results and the implications this variability has on the statistical significance of the overall group average, will determine the sample size and composition. This is mainly important concerning the fact that for monitoring significant changes in trends must be detected.

Because the required sample size could not be determined with the context of the underlying programme, an example is given for the monitoring of the additional fuel consumption based on a representative selection of 50 vehicles.

Table 22: The costs for testing if the procedure would be used for monitoring on the level of a group of representative vehicles.

# duplicates	-
# cars per group (different manufacturers)	50
# airco types	-
# fuels	-
# size categories	-
# exotics	-
# correlation tests (3 test houses)	9
# tests	59
Costs per test	3 kEuro
Costs for testing	180 kEuro

Next to testing the additional work would consist of the same elements as for the benchmarking programme. The additional costs are estimated roughly at 100 to 200 kEuro and if added to the 180 kEuro for the testing programme make a total of about 300 - 400 kEuro yearly costs for a basic monitoring programme.

8.3 Elaboration on an optimal choice

Choosing the most adequate solution in order to fulfil de requirements for labelling and ranking of the additional CO_2 emissions of mobile airconditioner systems is not a straightforward exercise. Based on the information gathered in this project it can be concluded that the route via Type Approval is still a possibility, but needs further detailed investigations before being applicable.
However two alternatives to gather labelling and ranking information have been addressed as well, which both prove to be applicable within the context, but involve much lower costs. The next table shows the costs for the procedure per vehicle.

Table 23: Overview of the costs per vehilce

	Type Approval	Benchmarking	Monitoring	
Costs / car	1.05	0.13	0.04	Euro

The assessment made taking into account the alternatives is unable to address what will be the effectiveness of the 3 schemes in terms of influencing customers and (linked) manufacturers behaviour in response to the schemes. The TA approach in this context could in principle be most effective since this would be the only approach being able to “label” individual vehicles and so bringing the problem/effect close to the customer. But given the low accuracy of the procedure such individual data gathering is far from achievable (or only at elevated costs).

Given the described situation it is TNO’s opinion that in the end the choice for an alternative approach (to TA) is most adequate. Which of the alternatives is best depends on the application the Commission in envisaging with the information, and needs to be determined.

9 Conclusions and recommendations

Conclusions and recommendations

Conclusions:

I. Basic test set up

- The initial purpose of the project was to develop a test procedure for measuring the addition fuel consumption of mobile air conditioner systems and auxiliary heaters that could be incorporated in the type approval test procedure for passenger cars. Such a procedure, which can be applied on a single vehicle level, has been developed.
- The test procedure can be used in existing Euro 4 emission testing labs when these are upgraded with:
  - a battery of solar lamps;
  - a cooling fan that matches the vehicle speed up to 120 km/h;
  - if necessary a more accurate humidity control.
- Alternatively the procedure can be applied in existing comfort testing laboratories (with full wind tunnel) when these are upgraded with emission testing equipment that meets the specifications set out in the type approval procedure.
- The test is carried out under moderate climatic conditions (in contrast to the worst-case conditions as for example used in the US SC03 test) with respect to ambient temperature, solar radiation, cabin temperature after soak, and relative humidity. Using moderate conditions allows assessment of the impacts of intelligent climate control algorithms and adaptive equipment like variable displacement compressors that minimize energy use under part-load conditions. As a consequence of the moderate test conditions, the results can also be considered more or less representative for real-world use in Europe and thereby can be a bases for labelling purposes.
- As a result of the moderate test conditions and the fact that the tested cars where equipped with modern efficient variable displacement compressors, the measured additional CO_2 emissions were low, ranging from 6 to 20%.
- For addressing the CO_2 emissions of auxiliary heaters a modelling approach has been developed. This approach enables calculation of full load additional CO_2 emissions but, due to lack of field data on the real world duty cycles of the equipment, it is unable to supply information fit for labelling.
- The project goals on auxiliary heaters can, however, be partially addressed by using the -7 ºC test result form the TA, which more adequately addresses the vehicle’s components that play a role in the improvement of the efficiency of auxiliary heating: the engine and the generator. This test also takes into account the benefits in CO_2 emissions that rise from the faster engine heat up due to the use of the auxiliary heater systems.

II. Validation

- As a result of the fact that the overall test result is obtained by subtracting two individual measurement results, each having a certain accuracy, the theoretical repeatability and reproducibility of the air conditioner test procedure is about a factor 2 less than that of the standard type approval test.
- The poor repeatability and reproducibility of the developed single vehicle test procedure, in combination with the limited absolute differences in heat load (and

related CO_2 emissions) between vehicles with different glass surface or body shapes (although theoretically significant), makes that differences between vehicles with different glass surface or body shapes could not be established with statistical significance. Ranking is therefore not feasible with the basic single vehicle test set-up.

- The inter-laboratory reproducibility proved to be very poor. This is probably due to automatically controlled air conditioning systems reacting on small changes in a wide range of parameters. Parameters like interior nozzle settings and solar array intensity are difficult to be described/controlled precisely on a inter-laboratory bases.
- One of the basic requirements for a Type Approval test procedure is good inter-laboratory reproducibility and ease of execution. The developed procedure failed these points with a relative deviation of 100 % between laboratories. This result is caused by the mentioned behaviour of the automatic airco systems which react very sensitively to variations in climatic conditions and the delicate adjustments that have to be made to the vehicle before testing.

III. Applicability

- A labelling scheme based on replicating the Type Approval test with and without the air conditioner switched on is not feasible. As a consequence supplying consumer information at the level of single vehicles Type Approval is also seen as not feasible.
- Options for technical changes in the proposed procedure in order to improve the statistical significance of the single vehicle test procedure are limited. Establishing such optimisations would only be possible after a large scale detailed inter-laboratory investigation process (like the PMP project for PM measurement).
- But even using an improved measurement procedure, the car-dependent variations (especially for automatic systems) and the relative small additional fuel consumption (calculated from subtracting 2 large numbers) that is the result of already improved airco technology and the requirement of the moderate test conditions would still contribute to poor repeatability and reproducibility.
- With this inevitable poor repeatability and reproducibility of the single vehicle test procedure and the difficulties with applying the procedure in a lab, two basic elements of a test procedure fit for Type Approval are not met at the moment of finalising the investigation. Therefore no amendments to the current single vehicle type approval directives are proposed (even though this was part of the technical annex of the contract).
- The investigation undertaken in this project shows the basic possibilities for applying a family concept, when selecting vehicles to be tested. Such family concept should be based on the current family definition from directive 80/1268/EEC and should be widened with the airco type. Additionally, projected glazing surface and glazing type play an important role in a family definition. This role, however, could not be quantified within the context of the project. In terms of a legislative approach the definition of this role could be left up to the manufacturer. If the manufacturer can prove that for a set of vehicles both parameters have a smaller influence that for instance 2% on the additional CO_2 emissions due to the use of the airco system, it could be allowed to classify the vehicles in the same family. The actual allowed bandwidth would have to be established by means of a statistical evaluation of measurements on a large sample of vehicles.

- Based on the technical properties of auxiliary heaters, assessing the additional fuel consumption of these systems for labelling purposes will not serve the purpose of discriminating between types or encouraging technical development. Modelling the CO_2 emissions of these systems will not lead to discrimination either. The effect of the use of auxiliary heaters on fuel consumption and regulated emissions is however already implicitly measured during basic Euro IV test at -7 ºC (without radiation).

<u>Recommendations:</u>

- The insights from executing the project can be used to obtain data for labelling and public information purposes, but the current Type Approval approach is not appropriate for this purpose. Only by repeating the TA test several times on the same vehicle, statistical significance could be achieved, but this will result in significantly elevated costs when applied to every single TA.
- In order to improve the statistical significance (by multiple testing using the described procedure) at lower costs and at the same time meeting the EC's objectives on labelling and ranking TNO proposes two alternative approaches:
    - Periodic (for instance: annual) monitoring of the trends in additional CO_2 emissions from air conditioning systems in general as they are applied on typical cross sections of a typical fleet. Such a monitoring programme would consist of measuring the additional CO_2 emissions due to airco use on a significant cross section of such a typical fleet. Such a programme would give information on average additional CO_2 emissions due to airco use of the fleet and would show the general progress made by the automotive industry in order to improve system efficiency.
    - Periodic (for instance: annual) benchmarking of individual systems or groups of systems, by applying the developed test procedure to a significant amount of typical airco systems. This set up will, in addition to the monitoring, also give information for labelling purposes, if for a certain vehicle the system incorporated can be technically identified.
- The actual amount of tests to be executed in order to obtain statistical significance will have to be established while setting up such programmes as mentioned above. Data from the underlying investigation do not allow such an assessment. For the sake of cost analyses the amount of tests has been set at 5.
- Based on a basic cost calculation, by far the most efficient way to obtain general labelling information is in an independent monitoring programme that will assess the overall progress over time with regard to the energy efficiency of air conditioning systems in general. A benchmarking programme to assess individual systems or groups of system will even allow ranking and is still almost one order of magnitude less expensive than introducing an additional test to type approval and will provide similar possibilities for labelling individual vehicles as this TA approach.
- Independent of the context in which the procedure is applied, a family concept can be adopted to a certain extent. Such a family concept would use the basic vehicle differentiation of directive 80/1268/EEC, but further sub-categorisation would need to be adopted towards body types, glass surfaces or airco types. Grouping of different sub-categories within one existing family for type approval as a new family for the airco test can be done if the differences in additional fuel consumption between the different vehicles are sufficiently small. It could be left to the manufacturer to prove this to the type approval authority for a given group of vehicle types. Definition of a family concept grouping vehicles of different existing

families seems a highly unlikely option. As a result the procedure, when applied for type approval, greatly increases the number of tests to be performed.

- In order to implicitly address the effect of auxiliary heaters on CO_2 emissions, the CO_2 emissions measured in the -7 ºC test form TA could be used effectively.

10 References

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A The draft procedure as developed in phase 1, incorporating a family approach and sub-systems

A.1 Introduction

This appendix summarizes the subsystem-based approach as worked out in the phase I project [TNO 2002].

General requirements
The following general requirements have been taken as the starting point of the approach:

- It should be possible to perform the test as much as possible in existing laboratories;
- The test method should not require major modifications to the test vehicle;
- The test method should be robust and reproducible;
- The test result should be sufficiently meaningfull for the consumer, but without the requirement of an absolute numerical accuracy (since the purpose is labelling).

Such an approach does require a fair degree of 'standardisation', which on the one hand inevitably produces somewhat schematic end results (but so does the standard fuel consumption test), yet on the other hand will allow a sufficient degree of 'modelling', which can simplify the determination of results in a significant way.

The 'family approach'
From discussions with the industry it became clear that the number of permutations of system components that together form a complete vehicle/engine/airconditioning system can be very large. It was therefore decided to adopt a 'family approach' so as to minimise the necessary amount of testing. This family approach does concern:

- A sufficient degree of variation in the basic vehicle, incorporating:
    - a certain range of variations within the body
    - the complete range of engines available within that body family
- The complete range of variations in airconditioning systems available within this vehicle family.

This means that *on the 'parent' airconditioning system, as installed in the 'reference vehicle' variant, a number of basic characteristics has to be measured, that subsequently can be used to skip a number of steps in the measuring of further family members*. The vehicle manufacturer will always have the option, however, to avoid these additional measurements and to measure any further family member in full.

The basic test approach
The basic approach of this proposal for a test methodology is to determine the necessary input energy needed to drive the compressor and the further auxiliaries (i.e. the fans) in the test cycle according to 80/1268/EEC under characteristic circumstances of use.
The basic approach focuses on three sub-systems separately, because these three systems all have their (different) impact on the final result. The three sub-systems are:

- the vehicle body
- the air conditioner
- the engine

The characteristic circumstances of use require the use of a climatic chamber. It is suggested that the use of a climatic test cell as used for the type VI test (the low temperature test) could be fitted out for such testing. The energy input determined in this way should then be the basis for the energy label. Since the energy 'consumption' of the compressor is primarily dependent on its speed, and secondarily on its control, the testing of subsequent family members can be performed as a bench test consisting of a compressor speed cycle with a check on the required system output (in terms of flow and outlet temperature).
The proposed approach is graphically outlined in the flowchart on page [53]. The procedure is divided over four columns. The first column represents the existing standard test, as performed under Directive 80/1268/EEC. The second column represents the testing in the climatic chamber. The third column represents the testing done on a separate test stand, outside the climatic chamber. The last column represents calculation procedures that only are deskwork. The major aim has been to skip in the case of family members the work in column 2 (the climatic chamber), in order to limit costs, and to shift as much as possible to column 4 (calculating procedures). So as to enable this it turned out to be necessary

- to perform some additional measurements during the procedure with the parent in the climatic chamber that has to be performed anyway, and which then can be used to check the performance of family members outside the climatic chamber, and
- to perform one measurement per family member on a system test stand where no vehicle is needed).

All of this has led to a procedure that looks relatively complicated at first sight, but which asks for the minimum of actual testing, and is reasonably straightforward for the extension of an already granted certification to family members, both on the system side and on the vehicle side. In the final reckoning this will save unnecessary work and costs.

A.2 Description of the methodology

The family definition

The proposed methodology does start with subsystem III. This step needs to determine the specific need for cool air for the vehicle family. It is obvious that it would be far too detailed to determine the need for cool air for each individual body type, let alone body colour. So as to make the procedure workable at all, the determination has to be performed for a family of bodies. The main question here is how to define such a family. A too narrow definition would greatly increase the number of permutations and therefore tests. A too wide definition would make the final result insufficiently accurate. The industry would prefer to limit the possible variants to models, but just on the basis of a verbal term this might be too wide a definition. Our proposal would be to define a model on the basis of the following characteristics:

- Same basic vehicle model indication [1)]
- Same interior volume, with a margin of ([10] % [2)]
- Same exterior surface, with a margin of ([10] % [2)]
- Same total glass surface, with a margin of ([10] %
- Same angle of the windscreen, measured over the centreline, with a margin of ([10] degrees
- Same angle of the B-post, with a margin of ([10] degrees

- Same angle of the rear window, measured over the centreline, with a margin of [20] degrees [2)]
- Same reflective coefficient of the glass (possibly limited to that of the windscreen), with a margin of [10]%

Notes:
1) It will be necessary to cater for the possibility that the same ‘model’ is also marketed under another brand name, and hence under another model name (e.g. VW Lupo/Seat Arosa; or Fiat Ulysse/Lancia Z/Peugeot 806/Citroen Evasion; etc.)
2) It could be further studied if it is possible to handle model variants, such as sedan, hatchback (and stationcar) through the use of calculation: i.e. correction factors for volume and surface.

Hereafter the proposed methodology based on family definitions will be described. This methodology is characterised by a number of options at various stages, in order to make the approach as workable as possible for the manufacturers, without losing accuracy to an unacceptable extent. So as to assist in understanding, the whole procedure is summarised the table below and in a flow chart at the end of this paragraph.

Table 24: the proposed test approach.

Step concerns	Type of action	Input	Output
STEP 1 Determination a/c performance needed	Measurement on parent Check on family members	Temperature profile	Required CFF [K*kg]
STEP 2 a) Determination of a/c drive energy b) Determination of compressor speeds	Measurement on ‘worst case’ system	CFF of parent Standard test cycle	Drive energy over cycle X [kWh] mech. Y [kWh] electr.
STEP 3 Determination of: a) additional FC and CO_2 b) engine efficiency factor of parent (for use with family members)	Measurement/ calculation	Output of STEP 2 of family member, or STEP 3b of parent	FC [litre/test] and CO_2 [g/test] Reference engine efficiency factor
PRESENTATION Effect on FC and CO_2 of air conditioner per test	Calculation	Output of STEP 3	LABEL FC [litre/100 km] CO_2 [kg/100 km]

Parent air conditioner system in reference vehicle: STEP 1

Determination of the necessary flow and outlet temperature of the air conditioner system.
For this determination a climatic chamber will be needed. The cooling performance of an air conditioner system is checked for two requirements:

- Cooling down of the interior of the vehicle that has been subjected to a simulated parking, to a defined interior temperature within a given length of time. This temperature/time point may be regarded as a 'way point' (See Figure 10) that needs to be 'passed' by the temperature/time curve on the 'correct side', i.e. in an equal or shorter time and/or at an equal or lower temperature.
- Maintaining that interior temperature, once it has been reached, for the remainder of the test cycle. For the purpose of the test 'maintaining' is taken to mean not exceeding the temperature of the 'way point' mentioned under '1'. If, on the other hand, the interior temperature of the vehicle drops to a lower value, this is regarded as acceptable for the test.

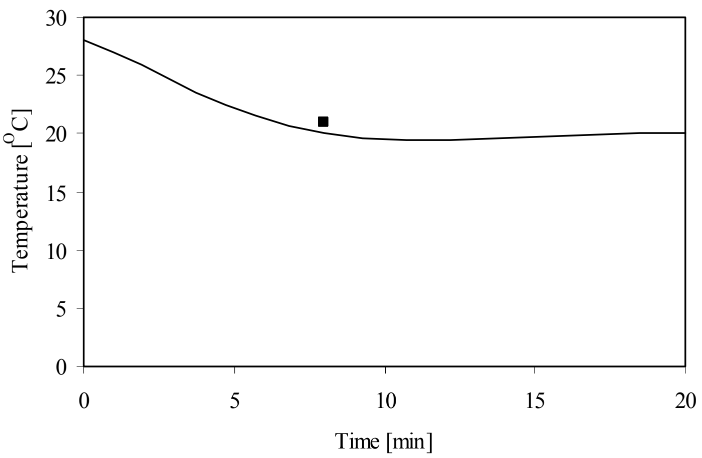

Figure 10: example of the course of the cabin temperature during a test passing the defined waypoint at the correct side.

It is proposed that the cooling down phase has to guarantee that a vehicle interior temperature of [21 ºC] has to be reached within [8] minutes from the start, and that the stabilisation phase has to guarantee that this temperature is not exceeded during the remainder of the test. The vehicle's interior temperature has to be measured at a standardised location. It is suggested that this is done at the level of the head of the driver. For the height and the position of the driver the standardised values for the 50-percentile dummy of the standardised crash test could be taken; these are very strictly defined.

Selection of the vehicle
A vehicle is selected for the test. This vehicle needs to be eligible as the 'reference' vehicle for the 'family' it has to represent. There needs to be an agreement on a 'standard' colour for the body; preferably this colour should represent a kind of average in terms of absorption/radiation characteristics. In all other respects the reference vehicle needs to be the 'worst case' vehicle that falls within the vehicle definition of the vehicle family. The engine in this vehicle needs to be a representative engine, e.g. the

best selling one within the range. Alternatively the engine could be chosen that will produce the worst case drive energy requirement for the compressor (see under STEP 2).

Preconditioning of the vehicle
The vehicle selected is placed in the climatic chamber, and is parked there for at least [2] hours under circumstances of standardised ambient temperature and humidity and standardised radiation:

- Temperature T_{amb} = 299 K (26 (ºC)
- Humidity = 60 % relative humidity at 26 ºC (ca. 13 g of water per kg of dry air)
- 'Solar' radiation = 850 W/m^2

As an alternative to the requirement of a simulated solar radiation, a need for cold air may be determined without radiation, but in that case a default multiplier factor must be used for the equipment drive energy as determined in STEP 2. This multiplier needs to be set at a worst case value. If a manufacturer feels that he is put at a disadvantage with this default value, he has the option of determining the true influence by a real radiation of 850 W/m^2. The exact value of this multiplier still has to be determined.

Testing of the reference vehicle

- After at least [2] hours the air-conditioner is switched on and run through a cycle of compressor speeds equivalent to those occurring in the fuel consumption test cycle. The most straightforward way of doing this is by starting the vehicle's engine and running the vehicle through the actual driving cycle (in which case suitable measures may be taken to avoid heating up of the climatic chamber through the engine's cooling system and exhaust), either on a pair of free turning rollers, or on an actual chassis dynamometer. Alternatively it may be done by means of a separate dedicated drive of the compressor and fans, installed for the purpose.
- As far as necessary the airconditioner system will be initially adjusted for phase 1, the cooling down of the vehicle interior. The time needed to cool down the interior to the prescribed interior temperature will be checked. If the prescribed time is exceeded (or the prescribed temperature cannot be reached at all) the test will be regarded as invalid, unless the system has been running at full power and no other family member would be able to fulfil the requirement either (the "Panda option").
- As far as necessary after the cooling down phase the setting of the airconditioner system may be readjusted for phase 2: maintaining the vehicle interior temperature at or below the stabilised prescribed interior temperature. This adjustment will be kept constant for the remainder of the test cycle. If the prescribed temperature is exceeded during this phase of the test, the test will be regarded as invalid.

Alternative options
The manufacturer will have two options for determining the fuel consumption effect of the air-conditioning system:

- Under OPTION 1 he may determine the fuel consumption directly during the test described above, and subtract the fuel consumption determined in a test without the airconditioning system in operation. This latter test may have been executed on a standard chassis dynamometer in a standard (non-climatised) test chamber. This option is only available if the test in the climatic chamber did include the simulation of solar radiation.
- Under OPTION 2 he may determine the fuel consumption in a separate test, further described under STEP 2 and STEP 3.

Parent air conditioner system in reference vehicle: STEP 2

Under Option 2, STEP 2 determines the energy input needed to drive the airconditioning system (under Option 1 this is not needed, since the extra fuel consumption resulting from the operation of the airconditioning system is determined directly). Option 2 is needed in any case whenever the manufacturer desires to use the simplified method for subsequent members of the airconditioning system family. If the test in the climatic chamber did not include the simulation of solar radiation, the drive energy so determined should be multiplied with the multiplier mentioned under the paragraph on preconditioning. This multiplier should represent a worst case condition.

Item to be measured for 'Option 2'
By means of a torque measuring device in the compressor drive (usually a system with belt and pulleys) the speed dependent torque will be measured and converted into an overall energy consumption. In the case of an electrically driven compressor the necessary electrical energy is determined, in this case independent from the engine speed. The electrical power needed to drive the fans providing the air flow over the heat exchangers is also determined, either as a separate figure (in the case of a mechanically driven compressor) or as a figure to be added to the compressor drive energy (in the case of an electrically driven compressor). The final output figure of this step is the requirement of X kWh of mechanical energy and/or Y kWh of electrical energy over the total test cycle. The additional fuel consumption resulting from the engine needing to provide this drive energy consumption will be determined in STEP 3.

Additional items to be measured for Option 2, in the case of a family
In the case of a family of airconditioning systems the drive energy consumption of each system may be determined directly, in the same way as for the parent, or an alternative approach may be followed. In this last case the following additional items shall be measured and determined:

- On the parent system the air-conditioner flow (Q) and the temperature drop of that flow (ΔT) will be measured. If the flow is partially reheated after the first cooling, the temperature drop will be determined by taking the difference between the ambient temperature in the climatic chamber and the system's final outlet temperature (i.e. after the reheating).
- The CFF (as defined below) will be determined and averaged over the cooling down phase (measurement values phase 1).
- Likewise the CFF will be determined and averaged over the stabilisation phase (measurement values phase 2).

The averaging of the flow and outlet temperature is done by determining for each phase of the cycle the 'cold flow factor' CFF, as follows:

$$CFF_{phase} = (Q * \Delta T)_{phase} = \Sigma (Q_{instant} * (T_{amb} - T_{outlet.instant}) * dt) \, [\, K \,.\, kg]$$

With: $Q_{instant}$ = the instantaneous flow of the a/c system in the relevant phase [kg/s]

T_{amb} = the standardised ambient temperature in the climatic chamber [K]

$T_{outlet.instant}$ = the instantaneous outlet temperature of the a/c system in the relevant phase [K]

dt = the time interval over which the instantaneous measurement is made [s]

<u>Parent air conditioner system in reference vehicle: STEP 3</u>

When the fuel consumption of the operation has not been measured directly (Option 1), it shall be determined in the following way (Option 2):

- The engine of the reference vehicle is loaded with a simulated 'external' mechanical and/or electrical load equivalent to the load(s) determined under STEP 2.
- The additional fuel consumption due to this (these) external load(s) is measured.

NOTE: The industry has proposed to replace the necessity to measure the engine with a simulated external load by a calculation method. They offered to come with a proposal. The acceptability of this proposal as a possible alternative will have to be judged when it comes.

Additional item to be calculated for Option 2, in the case of a family
From the total mechanical and/or electrical load as measured under STEP 2 and the additional fuel consumption as determined under STEP 3 an average engine efficiency for the generation of this additional load shall be determined. This generation efficiency will be used for subsequent calculations for family members.

<u>Airco system family members for the same vehicle family</u>

- Additional members of the airconditioning system family may then be measured separately (on a dedicated test rig, outside the vehicle and independent of a climatic chamber). They should be driven in an appropriate way over a speed pattern equivalent to that in the vehicle in the case of the standard fuel consumption cycle. It should be checked that the CFF over both phases of the test is at least equal to that of the parent system. The temperature and humidity of the inlet air should be the same as that specified for the climatic chamber.
- By means of similar means as for the parent system the total drive energy consumption shall be measured.
- From this drive energy the additional fuel consumption should be calculated by using the engine efficiency as determined for the parent system in the reference vehicle.

<u>Adaptation to different engines available for the vehicle family</u>

The proposal as it was made above would apply to a pattern of characteristic compressor speeds for each installation that is available for that particular vehicle family, with that particular engine. The use of different engines within that family could result in different compressor speeds, however:

- The first possibility would be that, even with an engine that itself has different engine speeds over the driving cycle, the pulley ratio has been so adjusted that the compressor speeds are similar to that of the reference engine (margins further to be determined). In that case the drive energy would be the same, and no further adjustment of the additional fuel consumption is necessary.
- When for a different engine of the family the compressor speeds are different, the most straightforward way of dealing with that is to do the actual measuring with the engine that provides the worst case situation (presumably the combination that produces the highest compressor speeds) and to use that figure independent of the engine actually used.
- If the manufacturer desires to determine the actual system drive energy for the different engines available for the vehicle family, he can opt for the same procedure as was described above for different airconditioning systems (alternative 1). This test needs only to be done for the worst case airconditioning system layout, as it was identified in the tests with the reference engine.
- If the manufacturer wants to make use of an even further simplified procedure (alternative 2) he may determine the ratio in drive energy between the mean drive speed for the reference engine and that for the alternative engine, and apply this ratio to the overall drive energy as determined in the full test cycle with the reference engine. It is suggested that this further simplified method is only applicable when the ‘correction’ ratio does not fall outside the interval limited by the values [1/1.5] and [1.5].

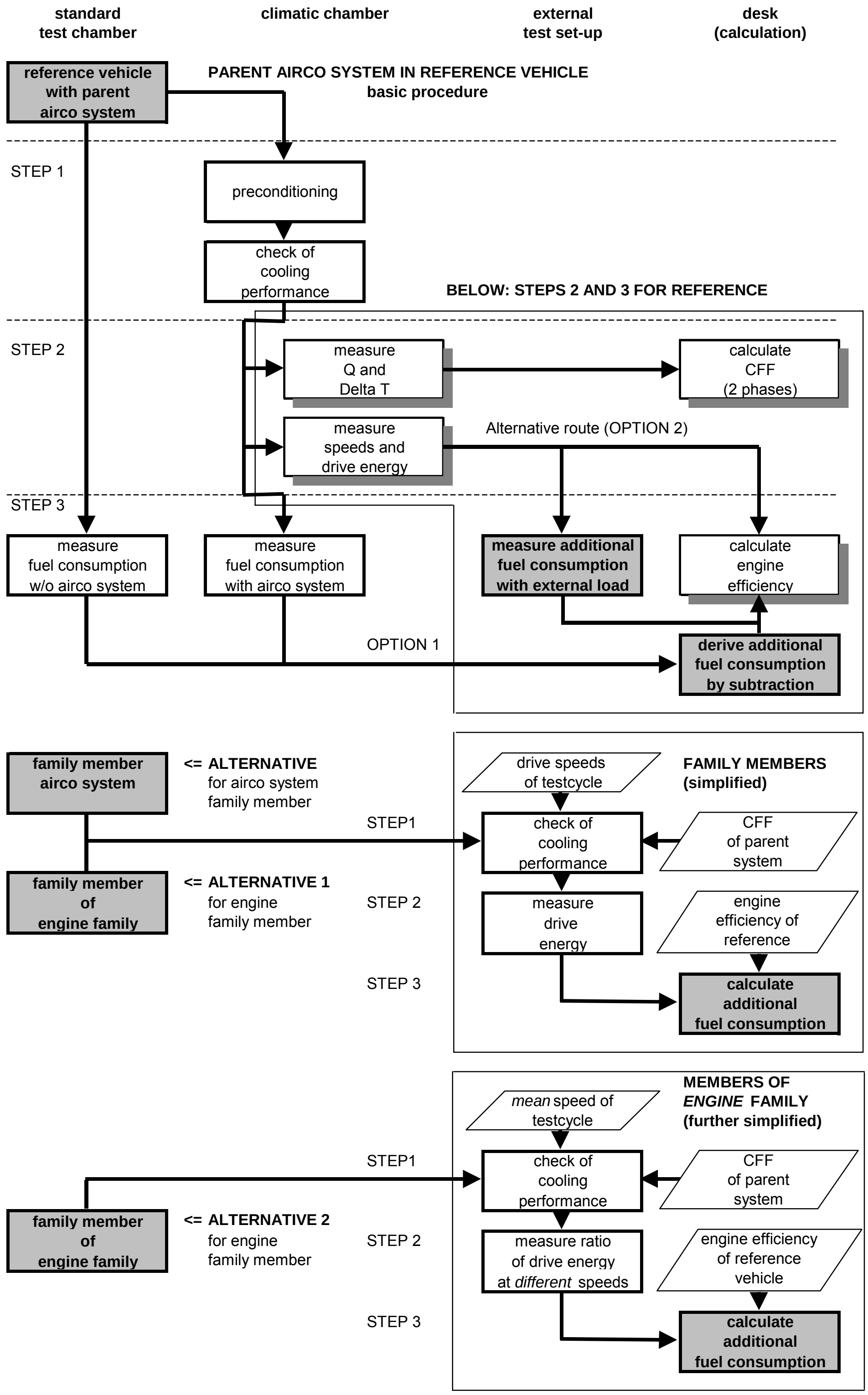

Figure 2: Flowchart: summary of the alternative testing possibilities.

The results relevant for the label

The energy required to drive the airconditioning system has to be determined by the vehicle manufacturer for each airconditioning system combination available on that vehicle family. A system is defined as a possible combination of a compressor, a condenser, an expander and an evaporator. The ‘worst case’ system combination (the one requiring the highest drive energy) is selected for the certification and labelling procedure. This is necessary, since the consumer is not in a position to choose any particular combination; he has to accept whatever he happens to get. The result of this test will be x kWh of drive energy over the test cycle. The figure on the label will show an additional fuel consumption of y litre/100 km for the average operation of an air conditioning system available on that vehicle family (and possibly with that particular engine option). If so desired it could also have the dimension of z litre of fuel per hour of operation.

A.3 Auxiliary heaters

The methodology described can also be used for other auxiliary equipment that ultimately derives its mechanical or electrical energy from the vehicle’s power source. The main example discussed here will be auxiliary heaters.

Auxiliary heaters can be classified as:
- Stand alone heaters, fuel fired by on-board fuel.
- Electrically powered ‘stand alone’ heaters, externally powered.
- Heaters powered by mechanical or electrical power derived from the vehicle’s own power source.

Usually such heaters are either ‘on’ or ‘off’. In any case a characteristic ‘duty cycle’ will have to be determined. In the simplest case such a duty cycle would only need to specify x time of operation after a cold start, and y km of vehicle operation after a typical cold start.

STAND ALONE HEATERS

In the case of a fuel fired stand-alone heater it would be simple to measure the fuel consumed per cold start directly. This figure can be ‘translated’ into a CO_2-emission through the usual formula used to calculate a measured CO_2-emission into a fuel consumption (but then in reverse). The figure can then either be used for labelling in that format, or recalculated into an additional average fuel consumption per 100 km or per year, by taking the average trip length per cold start, or the average number of cold starts per annum, into account.

EXTERNALLY POWERED ELECTRICAL SYSTEMS.

In the case of externally powered electrical systems the characteristic electrical energy can be measured in the way that has been prescribed for the determination of the (external) electrical energy consumption of electrical cars. This can then be translated into CO_2-emission as for electrical cars, and expressed per cold start, per 100 km or per annum in the same way as for fuel fired heaters above.

HEATERS POWERED BY THE VEHICLE’S ON-BOARD POWER SOURCE

In the case of a system powered by the vehicles own on-board power source a procedure equivalent to that for the air conditioning systems can be used.

If the system would only operate full power for an automatically set length of time, the amount of mechanical and/or electrical energy absorbed can be determined straightaway. If the system is not necessarily operating full power, but has either an operating time or an operational load condition depending on a certain operational temperature (e.g. of the interior or of the engine’s coolant) being reached, a STEP 1 procedure as in the flowchart on page 32 is needed, where only the word ‘cooling’ needs to be replaced by ‘heating’. For the check of the ‘heating performance’ a minimum requirement needs to be specified, e.g. with the specification of a ‘way point’ as in the cooling case. It is proposed that the preconditioning is performed as for the type VI (-7 ºC test). STEP 2 and STEP 3 would be the full equivalent to those for the air conditioning system, with the term ‘airco system’ replaced by ‘heating system’ where applicable.

The procedure for family members can be performed fully in accordance with the procedures as shown in the flowchart for family members.

FOR ALL TYPES:

If the system, e.g. by heating the engine coolant, has a positive influence on the engine efficiency during the cold part of the test, it is proposed that:

- this additional effect is determined separately or additionally, and
- the fuel consumption in the type VI test is used for the baseline.

A.4 Other auxiliary equipment

In the case of other auxiliary equipment the same basic set-up of this procedure would still apply. The main item would be a fundamentally solid determination of a characteristic duty cycle and the format that is given. And although that can be a formidable task for certain types of equipment, once that has been performed the further procedure can be fully covered by the approach that is outlined in the flowchart in and its description.