Preliminary results on European investigations about Room Air Conditioners efficiency

J. ADNOT, C. CARRETERO, D. MARCHIO, M. ORPHELIN
Centre d'Energétique, Ecole des Mines de Paris
P. WAIDE, PW Consulting

This paper uses results obtained in the framework of DG XVII Save programme and the energy efficiency of room air conditioners (EERAC) project. This text is the authors' synthesis of the EERAC study; however, they wish to extend their thanks to all the participants of the EERAC study, including:
Carlos LOPES (CCE-Portugal)
Angel CEDIEL GALAN (IDAE, Spain)
Mat SANTAMOURIS, Nick KLITSIKAS (University of Athens)
Bill MEBANE, Milena PRESUTTO, Enzo RUSCONI (ENEA, Italy)
Herbert RITTER (EVA, Austria)
Sule BECIRSPAHIC (Eurovent / Certification)
Dominique GIRAUD (Inestene, France)
Stefano CASANDRINI, Luigi MELI (CECED)
Philippe AUFFRET, Hervé RIVOALEN (EDF-DER, France)
Alfredo PREVI (ENEL, Italy)
Michel CARRE (Ademe, France)
and Paolo BERTOLDI (Directorate General for Energy, European Commission)

1 - INTRODUCTION

Room Air Conditioners (RACs) constitute a rapidly growing demand for electricity in Europe. They are defined as having a cooling capacity under 12 kW and come in the following basic types: window, monosplit, multisplit and single duct. The European market is almost equally divided between the domestic sector where RACs are acquired either through direct or indirect purchasing channels and the tertiary sector (offices, hotels and small shops). In consequence, the impact of any European energy efficency policy measures targeting RACs needs to be studied on equally for both sectors.

The contribution of air conditioners to the greenhouse effect comes both indirectly from their energy consumption and directly from the airborne release of refrigerant. CO_2 emissions per kWh of electricity consumed depend on the specific generation mix in the country concerned although EU average values can be derived. The Total Equivalent Warming Impact (TEWI) index (defined as the global warming equivalent mass of CO_2 emissions produced over the life cycle of the equipment) is used to enable the direct contribution of the refrigerant emissions and the indirect contribution due to the energy consumption to be compared on an even basis

The objectives of the EERAC (Energy Efficiency of Room Air Conditioners) SAVE sponsored study are:
to estimate the electricity consumption of room air conditioners and their TEWI contributions,
to estimate potential energy savings deriving from the use of more efficient domestic room air conditioners,
to investigate ways in which these savings can be realised, including behavioural changes and policy options (labelling, minimum efficiency standards, procurement programmes, incentives etc..), to make appropriate recommendations, on the basis of a preliminary cost/benefit analysis. This paper gives a partial overview of the first two points, while the last two, which are not yet completed, will be presented in a future paper.

2 - WHAT IS AN ROOM AIR CONDITIONER AND HOW IS ITS EFFICIENCY DEFINED?

A room air conditioner is designed to cool a single room, through heat rejection to the outside.

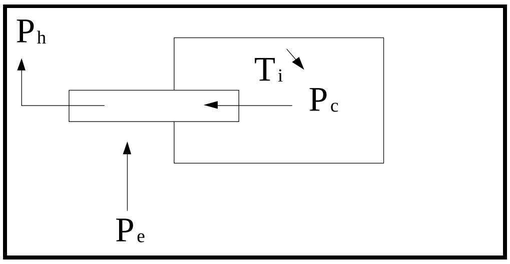

Figure 1. *Representation of a cooling system*

2.1. There are Four main classes:

Split packaged units (Split systems). This type of equipment is made of two packaged units (an inside and outside unit) connected by the refrigerant piping. The inside unit includes the evaporator and a fan, while the outside unit houses the compressor and the condenser.

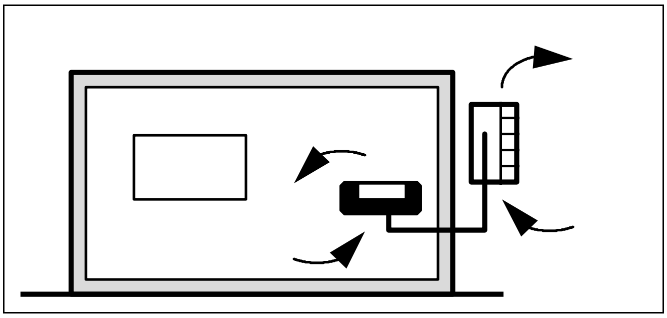

Figure 2*. Diagrammatic representation of a split-packaged unit.*

Multi-split packaged unit (Multi-split systems).Multiple inside units are connected to a single outside unit. Multi-split systems are not covered in EN 814 (the European room air conditioner test standard). However there is a multi-split test standard under development by ISO and testing laboratories already make defacto use of the standard by making assumptions concerning the connection of the indoor units. The 12 kW limit for a room air conditioner implies a maximum of about 4 indoor modules for a multi-split RAC.

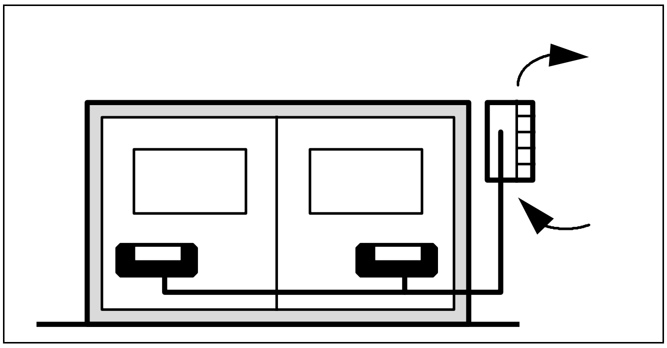

Figure 3. *Diagrammatic representation of a multi-split-packaged unit.*

Single packaged unit (Window units). A single packaged unit is defined as a factory assembly of components of a refrigeration system fixed on a common mounting to form a single unit. This type of equipment is made of a single packaged unit, one side of which (the condensing loop) is in contact with outside air to stimulate condensation while the other side (the evaporator loop) provides direct cooling to the inside air by forcing air over the evaporator with a fan. The two sides of the appliance are separated by a divider wall, which is insulated to reduce heat transfer between the sides.

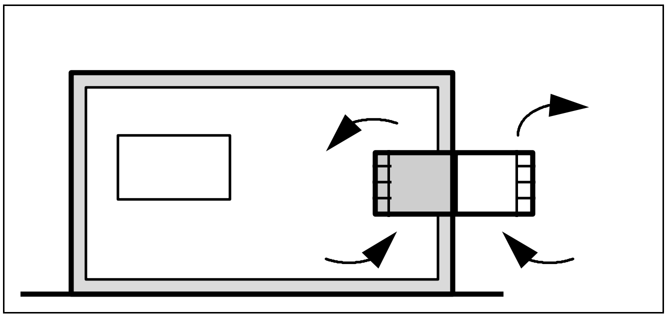

Figure 4. *Diagrammatic representation of a single-packaged unit.*

Single-duct air conditioner. These appliances are fully indoors and reject hot air at the condenser to the outside via a duct that is passed outdoors. They are generally movable but in order to operate they must be set close to a window or a door through which a duct eliminates hot air. In principle, a purpose built hole should be made in the building envelope for the ducting however, in practice the ducting is often hung through doors and windows, which increases the infiltration of hot air. This leads to additional thermal losses, and makes it difficult to asses the true thermal performance of single duct units. The European Commission has mandated CEN to review the EN814 standard in order to make the energy performance of single-duct RACs more readily measurable.

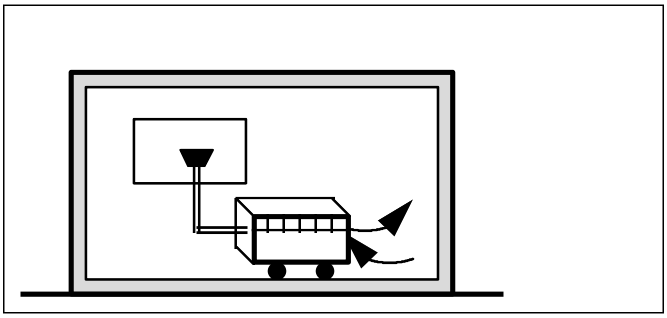

***Figure 5**. Diagrammatic representation of a single-duct unit.*

2.2. Performance rating :

he European Standard EN 814 (parts 1, 2 and 3) specifies the terms, definitions and methods for the rating and performance of air and water cooled air conditioners, air/air and water/air heat pumps with electrically driven compressors. The agreed performance index is the Energy Efficiency Ratio (EER) defined as follows:

$$\mathbf{EER = P_c / P_e}$$

Where P_c is the total cooling capacity in watts and P_e is the electrical power input in watts.
The different international standards for testing and rating RAC energy performance and EER are related as follows.

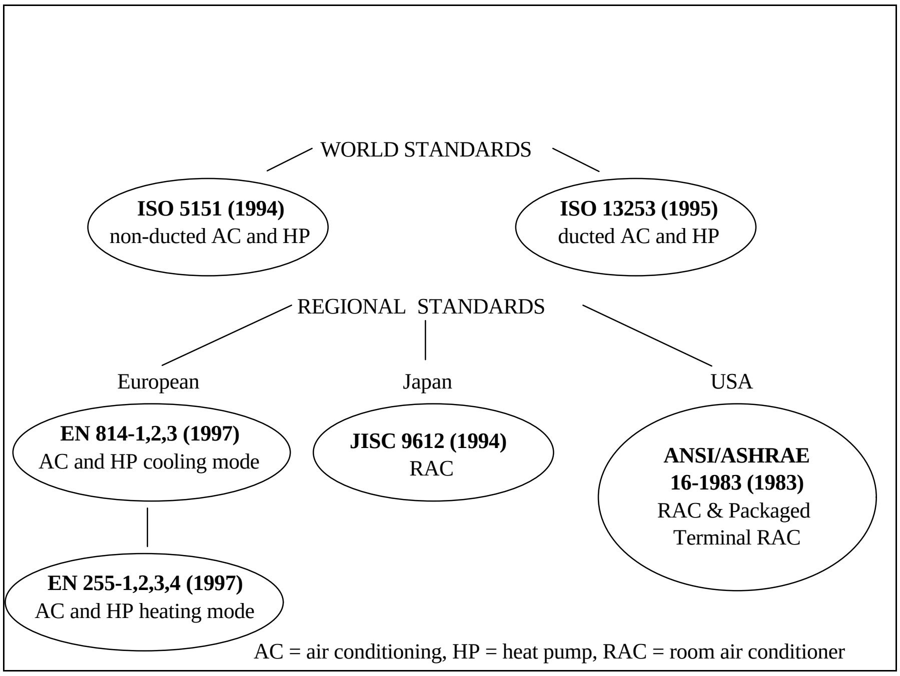

***Figure 6**. Standards on testing and rating.*

A major aspect of these standards is the definition of the set of «indoor» and «outdoor» temperature conditions used to rate the RAC EER.

Table 1. Test conditions under EN 814

Air cooled or air/air units		
Rating conditions	window & split RACs	Single-duct air conditioners
Mandatory		
T_1	A35(24)/A27(19)	A27(19)/A27(19)
T_2	A27(19)/A21(15)	
Optional		
T_3	A46(24)/A29(19)	A35(24)/A35(24)

The letter A indicates an air temperature in °C, given in the order of first the «outdoor» (hotter) temperature condition then the «indoor» (cooler) condition. Temperatures in parentheses are wet bulb temperatures in °C, while the first figure is the dry bulb temperature.

Ideally, the EERAC study would have been able to use EER and cooling capacity data for RACs rated at both the T_1 and T_2 test conditions in order to capture non-linear performance attributes as a function of the rating conditions; however, only T_1 full-load test results are widely available. As a result it was necessary to use simulation models to extrapolate energy performance at none T_1 operating conditions. It is to be hoped that the potential benefits of innovative products coming on to the market are not overestimated or underestimated as a result. The following comments show that some points are still unclear.

Improved components and optimum design will be evident under any test conditions and therefore will be visible under the EN 814 test conditions. For instance, a better compressor will give a better EER. Three different types of compressor can be found on split units: alternative, rotary and scroll. Scroll compressors allow variable speeds and are becoming increasingly penetrating common among room air conditioners. However this poses a control problem: how to compare inverter driven variable speed compressors with significantly higher part load performance to conventional single speed RACs when the test conditions only rate performance at full load? Inverters run under an adjustable frequency (from 40 % to 120 % of the nominal value), which results in varying compressor speeds (and eventually fan speeds). In consequence the fixed nominal test point is not appropriate for inverters.

3 - THE EUROPEAN ROOM AIR CONDITIONER STOCK

The total stock of RACs in use equals the number of RACs bought and installed in the past, minus the number retired from service. Statistically averaged survival functions for RACs: failure, obsolescence, definitive storage, etc… are not precisely known but they have been estimated by the various study participants to the best of their knowledge.

The data shown below indicate the summed stock of all four RAC types studied in the EERAC project .

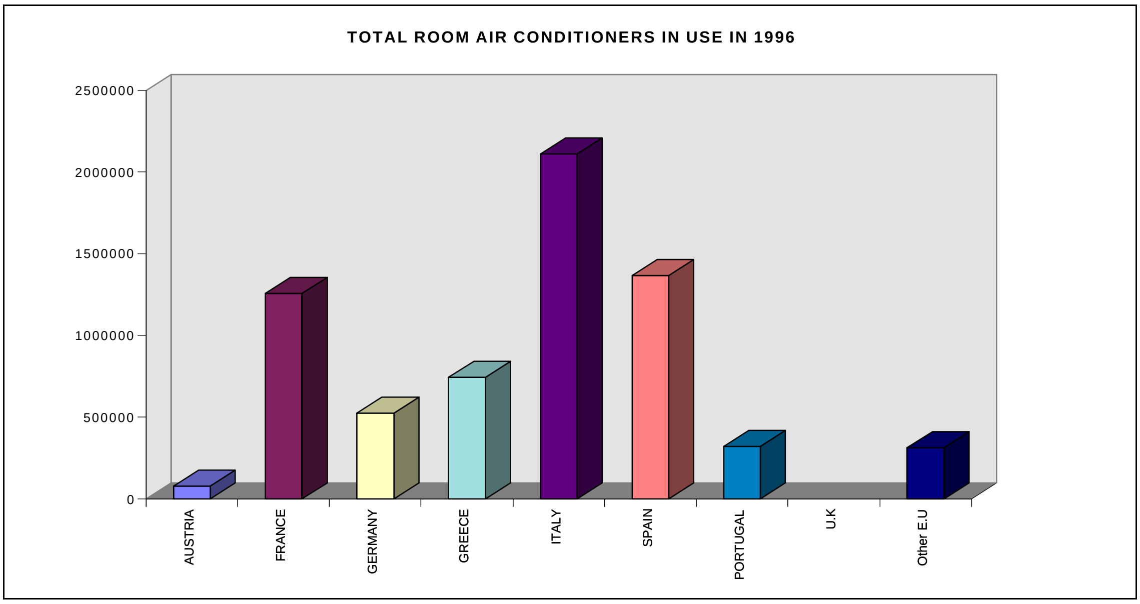

Figure 7*. Stock of RACs in use in Europe in 1996*

Country	Stock in 1990	Stock in 1991	Stock in 1992	Stock in 1993	Stock in 1994	Stock in 1995	Stock in 1996
AUSTRIA	8600	22600	29100	42600	58300	70300	79000
FRANCE	369200	502000	645000	760900	908100	1082100	1259100
GERMA.	144000	186400	261500	294400	352200	444400	526100
GREECE	76000	148010	223450	313020	439750	593950	744830
ITALY	198900	396450	641050	871400	1000000	1672640	2111740
SPAIN	-	-	350000	549000	777000	1051000	1369000
PORTUG.	136670	159900	199250	230210	261400	295930	322820
U.K	-	-	-	-	-	-	-
OTHERS	86400	111840	156900	176640	211320	266640	315660
TOTAL	1019770	1527200	2506250	3238170	4008070	5476960	6728250

The fraction of split units in the stock (68%) is lower than their market share among new RAC sales (of 72-78%) and confirms their rising popularity that is occurring at the expense of single packaged "window" units.

Table 2. EERAC survey results of the European market for 1996

Country\Year	Total sales	Splits	Multi Splits	Single Ducts	Packaged
AUSTRIA	23800	10000	6040	3000	4760
FRANCE	177000	99750	29000	38250	11000
GERMANY	194500	65000	19500	90000	20000
GREECE	150880	138000	12880	600	1000
ITALY	439490	363360	20350	42127	13653
SPAIN	318000	250000	-	39000	29000
PORTUGAL	45800	35600	7400	900	1900
U.K	133800	104000	-	26000	3800
OTHERS	116700	39000	11700	54000	12000
EUR 15	1599970	1104710	106870	293877	97113
% types	100%	69%	7%	18%	6%

Figure 8 reveals that there was a substantial decrease in sales of all RACs in 1993, regardless of the type of unit considered. This decrease occurred most dramatically in Spain although other countries also experienced decreasing annual sales in 1993 of between 5% to 10%. The cause, against an underlying trend of increasing annual sales could have been due to the economic recession of 1993 stimulating an overall reduction in purchases of «comfort appliances » - combined with a cooler summer than in 1994 & 1995.

This gives historical sales data also gives an indication of how the expected long-term economic growth in southern EU Member States may sustain a comparable growth in the European RAC market although cultural fashions are also an important determinant. In Greece, the sales of split units underwent a remarkable expansion during period from 1987-1989 when annual sales increased from 20,000 units in 1987 to 43,000 in 1988 and 105,000 in 1989.

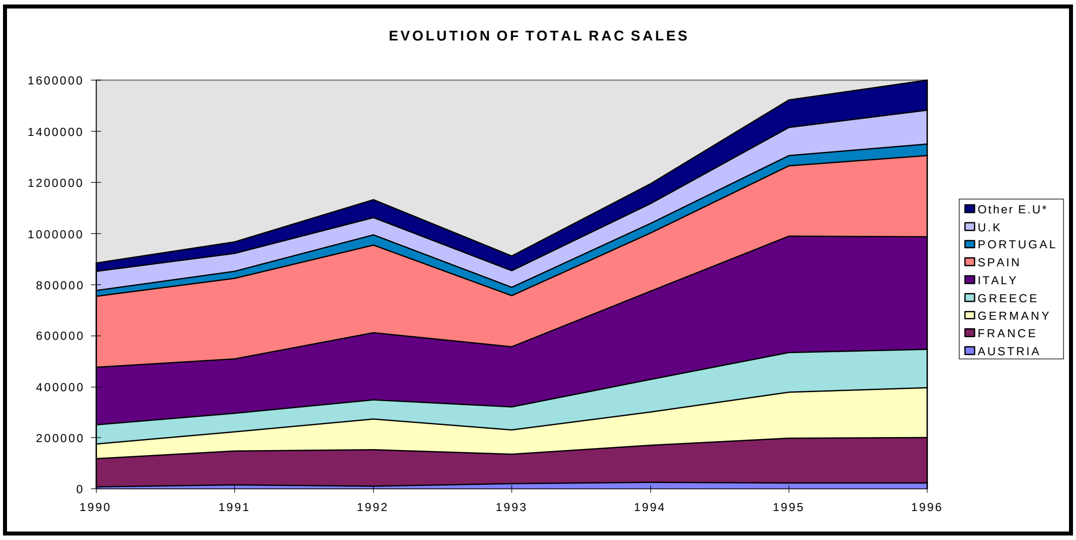

***Figure 8**. Evolution of total sales in recent years*

Despite this growth the total European RAC market remains small by international standards and is equivalent to the domestic market of one of the big US or Japanese manufacturers.

In the domestic sector RAC penetration is defined by the percentage of households having at least one air conditioner. EU national domestic RAC penetration rates of the order of 1% to 34% depending on the country reveals that European RAC ownership is far from the values reached in other major economies (e.g. 70 % in Japan and 55 % in the USA). The ownership of RACs in the tertiary sector (small offices, hotels, etc.) is higher due to different construction techniques, but mostly as a result of higher levels of comfort expectation in the workplace.

The present impact of the RAC, as well as their future impact has to be assessed globally and locally, namely because the various national electric distribution utilities and the various customers have different problems.

4 - HOW EFFICIENT ARE THE ROOM AIR CONDITIONERS USED IN EUROPE?

Two technical databases including models manufactured in 1997/1998 were assembled using model test data supplied by two manufacturers' associations, CECED and Eurovent. The models in these databases cover 80-90% of the models available for sale on the European market in 1997/8 for RACs of up to 12 kW of cooling capacity.

Models were classified according to their technical characteristics and anticipated consumer «perceptions» of functionality. Taking into account the four modes to integrate RACs into the building (Split, Multi-Split, Single

Duct, and Packaged) and the differences in heat transfer fluid and cycle type, 19 RAC categories were defined from the database. The combined database, comprising more than 2,000 models, was analysed statistically to assess average performance regressions and the limits of RAC energy performance found on the EU market.

The spread in the distribution of EER (Energy Efficiency Ratio) around the average EER on the European market shows that there are clear differences in energy performance and a substantial margin for improvement.

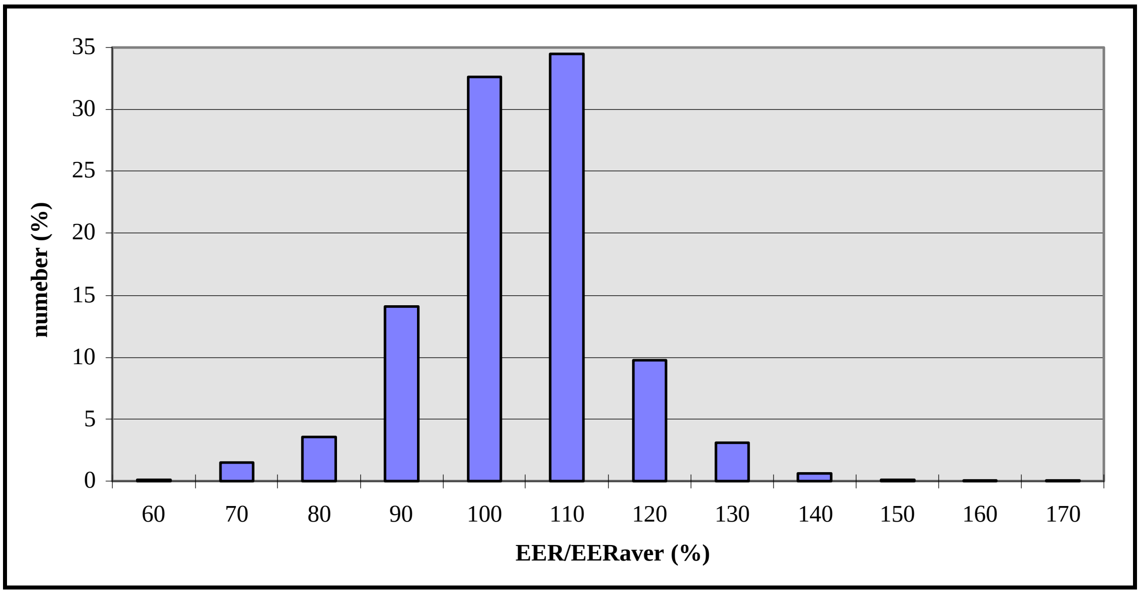

Figure 9. *Distribution of EER of European models*

Obviously the average EER values are not the same from one category to another, as shown in Table 3. However, even though the total range in performance is large, it should be said that most models are concentrated close to the average. Some 81.2% of the RACs in the technical database - 1,638 models out of the collected 2,019 - are included in the range 90-110% of the average performance for their category. One can say that only a small percentage of appliances are really good or really poor. Note that present testing tolerances are of the order of ±6% in terms of EER and that some uncertainties on practical test conditions remain for «single duct» models.

Table 3. Distribution of EER by major RAC category

RAC category 230V mono-phase	Cycle type Cooling mode	Heat transfer fluid	EER min	EER max	EER average
MULTI-SPLIT	Cooling only	Air	1.91	3.74	2.70
	Reverse	Air	2.08	2.94	2.53
SPLIT	Cooling only	Air	1.54	3.56	2.53
		Water	2.70	2.88	2.75
	Reverse	Air	1.45	3.45	2.48
PACKAGED	Cooling only	Air	1.88	2.77	2.38
		Water	2.11	5.42	3.32
	Reverse	Air	1.93	2.84	2.32
		Water	2.26	5.31	3.20
SINGLE-DUCT	Cooling only	Air	1.35	3.09	2.18
		Water	2.10	3.62	2.69

4.1. Clustering and selection of reference models

In order to summarise the large variety of models offered by manufacturers within a limited number of models suitable for use in a technical engineering analysis, the following four steps were applied:
statistical 'clustering' of models within categories in order to identify behavioural sub-categories,
whenever possible, reduction of cluster numbers through the elimination of redundant clusters or categories (e.g. in the case of too few models),
selection of representative models as base case models for engineering analyses within the remaining clusters.

Following this process resulted in 10 significant clusters. The method used to find non-hierarchical clusters is that of Beale, which determines the optimum number of groups or clusters. The method is based on a statistical test for the degree of improvement in the 'information' in going from one set of m1 number of groups to the subsequent set of m2 number of groups. The common Euclidian norm is used for measuring distances:

$$W = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{t,j} - \overline{X}_i)^2$$

The statistical test is applied in the following manner:

- for the first group of a category of data, the centre point which minimises the distance between the points of the group and the centre is calculated together with the standard deviation;
- then the number of groups is increased by one and two clusters are estimated with their relative centres and with the corresponding members of each cluster being defined;
- now the sum of the deviations for the two clusters is calculated, giving the value W(m2);
- the Beale's statistic can now be calculated for the passage from m1 (one) to m2 (two) groups. This statistic indicates if there is a significant gain in information.

The procedure is repeated, increasing the number of clusters, calculating the standard deviations and F(m1,m2), until an additional increase in the number of clusters no longer produces a significant gain in information. Following this process resulted in the division of the largest RAC categories into three sub-groups, Figure 10.

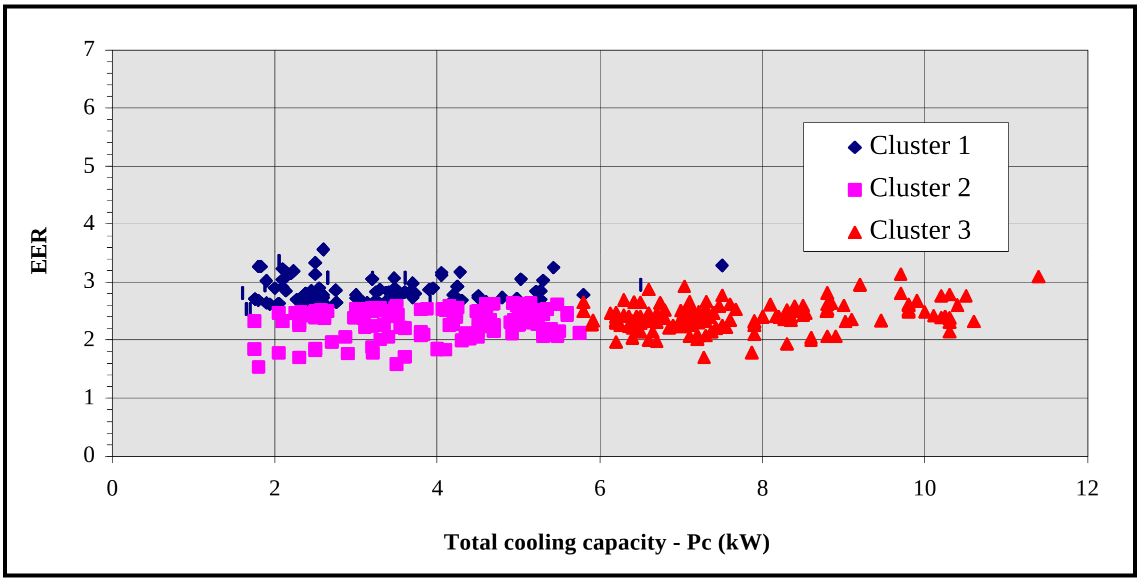

***Figure 10**. Clusters for the following RACs, Split, 230V, Cooling only, Air cooled*

The final clusters and their centre points, on which the technical and economic analysis are to be made are given in Table 4.

Table 4: Final clusters and their EER and Cooling Capacity (Pc) centre points

RAC		Cluster centre points									RAC
Category		Cluster 1			Cluster 2			Cluster 3			Models
Abrev.	No	mod. n.	EER	Pc	mod. n.	EER	Pc	mod. n.	EER	Pc	Tot. n.
MS1	01	23	3.16	4.33	32	2.50	4.51	28	2.57	6.81	83
MS2	02	49	2.53	5.42	--	--	--	--	--	--	49
S1	03	189	2.83	3.09	216	2.36	3.99	205	2.42	7.44	610
S2	04	259	2.68	3.46	137	2.15	4.75	147	2.44	7.59	543
P1	06	32	2.38	4.36	--	--	--	--	--	--	32
P3	08	34	3.59	3.19	34	2.64	6.68	--	--	--	68
P4	09	37	3.11	2.51	15	3.43	6.50	--	--	--	52
SD1	10	58	2.18	1.75	--	--	--	--	--	--	58
S4	14	123	2.24	6.21	105	2.59	9.37	--	--	--	228
S5	15	96	2.38	6.60	89	2.55	10.0	--	--	--	185

4.2. Use of reference models at non nominal conditions

Simulations with a detailed RAC energy simulation software tool showed that for a given RAC the parameter that most influences its in-use EER will be the air temperature entering the outdoor unit (TAIIO). Four specific models selected as cluster centre points from the model database (A, B, C and D) were simulated in great detail from which it was revealed that on average a 16% TAIIO decrease caused an approximate 20% EER increase, while a 16% TAIIO increase caused an 18% EER decrease.

The air temperature entering the indoor unit (TAIII) influences the EER less than the TAIIO does. A 20% TAIII decrease caused an approximate 8% EER decrease, while an 18% TAIII increase caused a 7% EER increase except for Model B and Model D which had even greater variations.

The relative humidity entering the indoor unit (RHII) influences the EER very little. A 17% RHII decrease caused a less than 2% EER decrease, while a 35% RHII increase caused a 3% EER increase. Model C showed no influence of TAIIO because it is of a «single duct» type.

Finally, it was noticed that the relative humidity entering the outdoor unit (RHIO) did not significantly influence the EER. The TAIIO, TAIII and RHII are correlated with average EER according to the following functions:

- Model A: EER = -0.0243 TAIIO + 0.003075 TAIII + 0.0230 RHII + 4.796
- Model B: EER = -0.0211 TAIIO + 0.00659 TAIII + 0.0573 RHII + 3.940
- Model C: EER = -0.0183 TAIII + 0.0270 RHII + 3.406
- Model D: EER = -0.0209 TAIIO + 0.00774 TAIII + 0.0676 RHII + 4.150

These correlations allow RAC energy consumption estimates to be calculated using real climatic data and known operating patterns.

5 - HOW MUCH ENERGY IS CONSUMED BY ROOM AIR CONDITIONERS IN EUROPE?

The objective of this part of the study was to calculate the average energy consumption load curves of room air conditioners as a function of the outdoor climatic conditions, the characteristics of the building and its occupation, and the energy performance characteristics of the room air conditioner.

Computer models for building simulation and thermodynamic performance of appliances.

A decoupled approach (building/system) was used in this study. Building cooling needs (sensible and latent cooling) were computed using COMFIE, a dynamic multizone software package developed by Armines. Model reduction techniques, user friendliness and object oriented programming allowed a quick calculation.

The ORNL (Oak Ridge National Laboratory) model was chosen to simulate the thermodynamic performance of specific air conditioning systems. The performance of the compressor is modelled in two ways: either using a simple «Loss and efficiency model» or a more advanced «Map-based model». If the user calculates the performance of the model using the simplified model then various data on the efficiency and the heat losses of the compressor must be provided. Otherwise, if the map based model is used, then the user must provide a series of data measured under specific conditions (preferably 10 points), that correlate the compressor power with the compressor mass flow rate. This data can usually be supplied by the manufacturers.

5.1. Methodology

The cooling loads were calculated for each base case simulation, i.e. for 16 climatic zones and for 4 sectors (commercial, office, residential and hotel sectors), which gave a total number of 64 annual dynamic simulations. For each of them, two representative days of climatic data per month (one week day and one week end) were chosen.

For each base-case simulation, the total energy consumption is given by summing the power demands. Two coefficients ((5/7)*365/12 and (2/7)*365/12) are applied in order to weight the week and weekend days to obtain the energy consumption QE, TOTAL. The equivalent number of hours at the nominal rating conditions is then calculated by the following formula :

$$n_{EQUIVALENT} = \frac{Q_{E,TOTAL}}{Q_{E,RATING}}$$

where the subscript 'RATING' refers to the nominal energy consumption at the T_1 test conditions.

All the information needed as an input for the simulations (building thermal characteristics, occupancy scenarios, etc.) was collected through national questionnaires sent to each participating country. Using performance equations given by the ORNL model, the equivalent number of hours at nominal conditions were calculated for each sector in each climatic zone.

The degradation of nominal performance due to on-off cycling[1] and fouling faults[2], in addition to the influence of specific outdoor and indoor conditions on RAC EER were all taken into consideration. In order to size the cooling load of the air conditioners under investigation, a ratio of 120 W/m^2 of conditioned floor area was defined for the commercial sector (assuming higher internal gains) while 100 W/m^2 was used for the office, hotel and residential sectors. This sizing was adapted to the simulated needs of the different climatic zones found in Europe.

---

1 O'Neal D.L., Katipamula S., Performance degradation during on-off cycling of single-speed air conditioners and heat pumps: model development and analysis', 1991, ASHRAE Transactions part B, p. 316-323
2 M. Breuker&J. E.Braun, Common faults and their impacts for rooftop air conditioners, July 1998, HVAC&R Research, p.303-318

Comparison of the number of equivalent cooling hours in different sectors

The number of cooling hours needed in a given zone does not only depend on the zonal temperature. The building humidity, solar radiation, internal gains, occupation, ventilation control, etc. are all factors that significantly influence the cooling load. The demand for cooling in winter in some countries, in spite of a moderate outdoor temperature, illustrates this fact. All these parameters are taken into account in the energy consumption model. Results for each zone and a synthesis of the main results of the number of hours of operation (at full load) are presented in Table 5.

Table 5: equivalent cooling hours of the different sectors of Europe

		Number of hours at constant EER				
		Commercial	Office	Household	Hotel	Weighted average
Austria	Salzburg	177	193	74	235	153
Austria	Vienna	134	147	55	176	116
France	Carpentras	1414	1307	547	595	1028
France	Limoges	790	726	212	314	544
France	Trappes	752	625	156	262	468
Germany	Middle	431	383	168	236	264
Germany	North	199	187	87	115	129
Greece	Athens	984	891	741	1530	888
Greece	Theso	859	729	480	1175	742
Italy	Cagliari	1265	993	822	898	1057
Italy	Milano	1017	727	615	726	819
Italy	Napoli	1366	966	833	1097	1104
Portugal	Lisbon	1226	931	611	413	851
Spain	Murcia	2157	1402	1049	1870	1494
Spain	Oviedo	678	300	143	382	338
UK	London	230	276	94	331	247

Based on this data it is possible to define an average number of full-load operating hours per sector (weighted by the penetration rates in each climatic zone).

Weighted number of hours			
Commercial	Office	Household	Hotel
1019	803	519	768
All sectors			
773			

Of all the sectors analysed the commercial sector is the one with the greatest cooling needs (~1000 hours/year), twice as much as the residential sector (~500 hours/year). The European hotel and office sectors both need around 800 hours of air conditioning per year on average. The residential sector is the sector with the least air conditioning needs.

There is a noticeable difference in the average annual cooling hours for the Mediterranean regions and for the others. In the Mediterranean zones, average annual cooling hours are always above 500 hours in all sectors. Despite, differences in the scenarios, the resulting values for the average hours of operation were very homogeneous across the Mediterranean region. By contrast, in Northern Europe, the average number of hours of RAC operation is under 500 hours/year and is very low in the residential sector.

The number of cooling hours also depends on the model of air conditioner installed since the EER of a given model is very sensitive to the indoor and outdoor conditions.

For the base case split system RACs analysed (models A, B and D) that represent the majority of the room air conditioner market, the above figures can be reduced since their performance under actual operating conditions is better than defined at the nominal T1 test conditions. Conversely, for the single duct base case model studied, the number of average operating hours should be slightly increased.

6 - WHAT COST EFFECTIVE OPTIONS ARE AVAILABLE TO REDUCE RAC ELECTRICITY CONSUMPTION?

A key study aim is to analyse the technical options available to improve RAC energy efficiency and to appraise the economical implications of raising RAC energy efficiency using proven technical options in order to reduce the electricity consumption of room air conditioners

6.1. Technical analysis

The list of proposed technical options involved the conduct of RAC EER simulation scenarios for three main types of technical modification.

6.1.1. Scenarios in which the heat transfer surface area is increased

Increased frontal coil area
Increased coil depth
Increased fin density
Addition of subcooler to condenser coil

6.1.2. Scenarios in which the heat transfer coefficients are increased

Improved fin design
Improved tube design

6.1.3. Other scenarios

Improved fan efficiency
Improved compressor efficiency
Variable speed compressors
Alternative refrigerants
Electronic expansion valves
Thermostatic cyclic (fuzzy) controls

To calculate the impact of employing a specific technical option on the overall efficiency of each air conditioner, precise and detailed data were required. This data, along with information regarding each unit's compressor performance, were supplied to the study by some specific manufacturers and their associations and for which this paper's authors would like to thank them.

All simulations (as all simulated units use air to air heat exchangers) were performed using the ORNL RAC simulation software (Mark V). It must be noted here that the ORNL software is capable of simulating the performance of an air conditioning unit under specific indoor and outdoor conditions. In our case these were the T_1 standard test conditions (28°C indoor and 35°C outdoor temperature). At first the EER of each unmodified base case model was calculated and compared with the one measured under standard test conditions. For two of the simulated units (A and B), the calculated EER is in very good agreement with the measured values (2% difference), while regarding the other units the difference between the calculated and the measured EER values is higher (9% for the D unit and 16% for the C unit) but acceptable given that some key details had to be estimated

Next, the impact of each of the proposed improvements to the units' overall performance was simulated by calculating each unit's EER after the application of the intervention and under standard test conditions. In order to do this, the required modifications were simulated through the software inputs regarding each technology option scenario.

For each scenario and unit the EER under standard test conditions was calculated and compared to the EER value calculated previously regarding each unit's present state (base case). Also, the percentage increase in the EER due to the application of improved technology was calculated per scenario and unit

6.2. Economic analysis

As a preliminary step to analyse the proposed scenarios and evaluate their economic impact the simple payback period has been calculated. In order to do this, data regarding the additional cost of each proposed technical option needs to be known.

In this preliminary analysis, the following hypotheses are made:

- the purchase price of RACs increases by 7% if the EER is increased by 5%.
- the price of models is around 0.23 euros/W of cooling power.

The initial payback period, that is the payback period of the first 5% EER increase with a 7% overcost, is calculated for the four models.

Table 8: Initial payback periods for design improvements to the specific RAC models considered assuming a 7% price increase for a 5% EER increase

Models	Payback (years)
A	8.4
B	7.7
C	6
D	8.2

For Mediterranean countries where the number of cooling hours is 1.5 to 2 times higher than the average, the payback can be as low as 3 years for a 13-year RAC life time. These preliminary results indicate that it is in an average consumers economic interests to invest in a higher efficiency appliance.

The choice of a 7% purchase price increase for a 5% efficiency increase may well be too conservative (5 or 4% should also be considered). The initial payback is proportional to the percentage price increase assumed. For instance, for a 4% increase in the purchase price, the hypothetical payback period would be as shown in Table 9.

Table 9: Initial payback periods for the specific RAC models assuming a 4 % price increase for a 5% EER increase

Models	Payback (years)
A	4.8
B	4.4
C	3.4
D	4.7

7 - CONCLUSIONS & PERSPECTIVES

The EERAC study has shown that the European room air conditioning market is growing rapidly and that as a result RAC energy demand is likely to pose a major supply side challenge for electricity utilities in the near future. A number of technical issues have been examined and from them we can conclude that there is a major opportunity to improve RAC energy efficiency that would avoid a significant amount of the forecast Business as Usual growth in RAC energy consumption. The next step is to study which of the market transformation tools is the most appropriate to translate the technical potential into a market potential.

8 - REFERENCES

ARMINES, 1998 : **'EERAC - Energy Efficiency of Room Air Conditioners',** J. Adnot et al., Interim report under the EC - SAVE programme, 1998

CEN 814, 1997 : Air conditioners and heat pumps with electrically driven compressors - Cooling mode, Testing and requirements for marking'

EUROVENT, 1996, 1997, 1998 : Eurovent Directory of Certified products

ISO 5151, 1997 : Non-ducted air conditioners and heat pumps -- Testing and rating for performance

TNO, 1998 : Common final report to Contracts no. XVII/4.1031/Z/95-055 "Energy labelling of room air Conditioners" and no. XVII/4.1031/Z/96-024 "Energy labelling of domestic air to air heat pumps", under the EC - SAVE programme, also financially supported by: NOVEM, the Dutch organisation for energy and environment and NUTEK, the Swedish national board for technical development