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E.U.



# Energy Efficiency and Certification of Central Air Conditioners (EECCAC) FINAL REPORT - APRIL 2003

## VOLUME1

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# CONTENTS

<b>ABSTRACT .....</b>	<b>7</b>
<b>SUMMARY OF RESULTS .....</b>	<b>7</b>
Definitions of all CAC systems found on the EU market have been given. ....	8
All CAC equipment test standards have been reviewed and studied to assess their suitability to represent energy efficiency under real operating conditions.....	9
CAC market and stock data have been assembled for the first time. ....	9
The present Energy Efficiency efforts have been reviewed.....	12
All the elements of a possible grading of Cooling market have been assembled .....	14
Splits and Packages are grouped in one single category (.....)	14
The impacts of BAU have been assessed.....	14
Optimisation of a chiller to improve its EER on the basis of capacity cost only .....	18
Optimisation of a chiller for its least LCC .....	18
Packaged units can also be improved a lot.....	19
System optimisation : all air systems.....	20
Part load performance has been quantified for the first time and the methods have been tested .....	21
Impact of load reduction on the efficiency – a reporting format proposed to Eurovent.....	22
Magnitude of gain/losses due to part load.....	22
The simulations leading to the reference values of SEER (HSEER) .....	23
EECCAC final figures for a European SEER method (ESEER) .....	24
EER alone is a poor selection tool .....	24
IPLV and EMPE are more accurate than EER for classification but do not give enough accuracy for comparison of chillers.....	25
The newly proposed ESEER method allows grading and ranking of chillers by order of merit.....	26
Energy efficiency options have been defined for each system configuration .....	26
Scenarios for energy efficiency have been established and quantified .....	27
All the elements for an action plan on Air Conditioning are available in the full report .....	27
<b>1. INTRODUCTION.....</b>	<b>29</b>
Selection of technical experts .....	29
Participation of energy agencies, utilities, manufacturers and national experts .....	30
<b>2. CENTRAL AIR-CONDITIONERS IN EUROPE: DEFINITIONS AND BASIC DATA .....</b>	<b>31</b>
<b>2.1. Importance of AC for human health and productivity performance, link with ventilation .....</b>	<b>31</b>
What is "comfort"? .....	31
Comfort level, Ventilation: our assumptions for the study .....	32
<b>2.2. Basic definitions .....</b>	<b>32</b>
RAC and CAC in competition .....	32
Basic Thermodynamics at one instant.....	32
Main technologies for cold production .....	33
CAC systems types based on distribution .....	36
Classification of the systems.....	36
<b>2.3. Description of other aspects of systems.....</b>	<b>37</b>
Terminal units and other peripheral equipment used .....	37
General classification of systems based on chillers .....	40
Number of water loops connected with the chiller .....	42
<b>2.4 Description of systems not using chillers .....</b>	<b>42</b>

VRF (Variable Refrigerant Flow) CAC systems .....	42
Water Loop Heat Pump CAC systems based on local packaged AC systems .....	42
Local package CAC systems: roof-tops and close control cabinets.....	42
Inclusion of RAC in the present study .....	42
Summary of choices in terms of local versus central systems .....	43
Sizing issues.....	43
Free cooling .....	44
<b>2.5. Testing standards and performance standards .....</b>	<b>44</b>
Chillers: the CEN and ARI approaches (at full load and IPLV) .....	44
Peripheral equipment of chiller based systems: testing and classification .....	46
A proposal for a better characterisation of AHU .....	47
Ventilation efficiency and Air Conditioning.....	47
Testing and performance setting for packaged systems .....	48
<b>2.6. Overall view of energy performance .....</b>	<b>50</b>
Year round thermodynamic balance .....	50
Definitions .....	50
Full system efficiency .....	52
<b>2.7. Statistical databases used and information gathered.....</b>	<b>52</b>
National surveys .....	52
Data from manufacturers associations .....	52
Correction and treatment of data.....	53

# Energy Efficiency and Certification of Central Air Conditioners

## ABSTRACT

Air-conditioning constitutes a rapidly growing electrical end-use in the European Union (EU), yet the possibilities for improving its energy efficiency have not been fully investigated. Within the EECAC study twelve participants from eight countries including the EU manufacturers' association, Eurovent, engaged in identifying the most suitable measures to improve the energy efficiency of commercial chillers and AC systems. Definitions of all CAC systems found on the EU market have been given. All CAC equipment test standards have been reviewed and studied to assess their suitability to represent energy efficiency under real operating conditions. European CAC market and stock data have been assembled for the first time. We can keep a few figures in mind : 1200 Mm<sup>2</sup> cooled in year 2000 (3m<sup>2</sup>/inhabitant), 2200 Mm<sup>2</sup> in 2010 (5m<sup>2</sup>/inhabitant), with a share of reversibility around 25%.

The present Energy Efficiency efforts have been reviewed. They play a negligible role, in a situation that may be called BAU and leads to electricity consumption around 51 TWh for all AC in 2000 (18 MtCO<sub>2</sub>) becoming 95 TWh in 2010 (33 MtCO<sub>2</sub>). One thing can be done rapidly : all the elements of a possible grading of chillers on the market, based on full load behaviour, have been assembled. Is there a margin for further improvement ?

Optimisation of a chiller for its least LCC shows a large possibility, namely thanks to part load control. The optimal level of performance for the chiller considered is about 40% more efficient than the present « bottom » of the market : it has an SEER between 3.00 and 3.50 and an initial overcost of +12% paying for itself rapidly. For manufacturers, there are certainly other ways to reach 3.25 SEER than the ones investigated, less expensive, but our objective was to find out if there is a margin for improvement. Impact of load reduction on the efficiency of a chiller may be positive but has to be certified by Eurovent : a reporting format has been proposed to Eurovent as well as a European SEER method (ESEER) for quantification.

Packaged units can also be improved a lot. We show that the life cycle cost minimum occurs for large packaged units with an EER of 3.22 W/W.

In terms of market transformation, EER is a poor selection tool ; the US IPLV and the Italian EMPE are more accurate than EER for classification but do not give enough accuracy for comparison of chillers. The proposed ESEER method allows perfect grading and ranking of chillers by order of merit . Energy efficiency options have been defined for each system configuration and for the components outside the chiller. Scenarios for energy efficiency have been established and quantified. All the elements for an action plan on Air Conditioning are available in the full report.

## SUMMARY OF RESULTS

Air-conditioning constitutes a rapidly growing electrical end-use in the European Union (EU), yet the possibilities for improving its energy efficiency have not been fully investigated. As opposed to room air-conditioners (RAC) central air conditioning (CAC) systems, which are defined as **air conditioning systems with more than 12kW of cooling capacity** in the EU, are not bought or selected in a shop. They may be selected by an installer of packaged units. They are usually designed by an AC engineer and the components selected following the engineers' recommendations.

The definition of CAC applied in the EU does not correspond to the definition used in the USA where a “Central Air Conditioner” is a ducted package AC system, which are relatively infrequent in Europe and sized often under 12kW, a piece of equipment that we would call a RAC in Europe. European CAC systems are commercial AC systems usually specified by engineers or technicians, who choose the system technology without any direct influence from the customer, except for the specification of the desired environment and other conditions such as maximum overall price, etc.. There are a **large variety of systems and technical options** (regarding system structure and control) in use while there is also a large variation in comfort conditions (not only in terms of the set-point, like space heating, but also in the nature of comfort) obtained.

Within the EECAC study twelve participants from eight countries including the EU manufacturers' association, Eurovent, engaged in identifying the most suitable measures to improve the energy efficiency of commercial chillers and AC systems. This study benefited from the co-operation between laboratories, consultants and Eurovent, which was established during the conduct of the SAVE sponsored EERAC study concerned with room air conditioners (EERAC 1999).

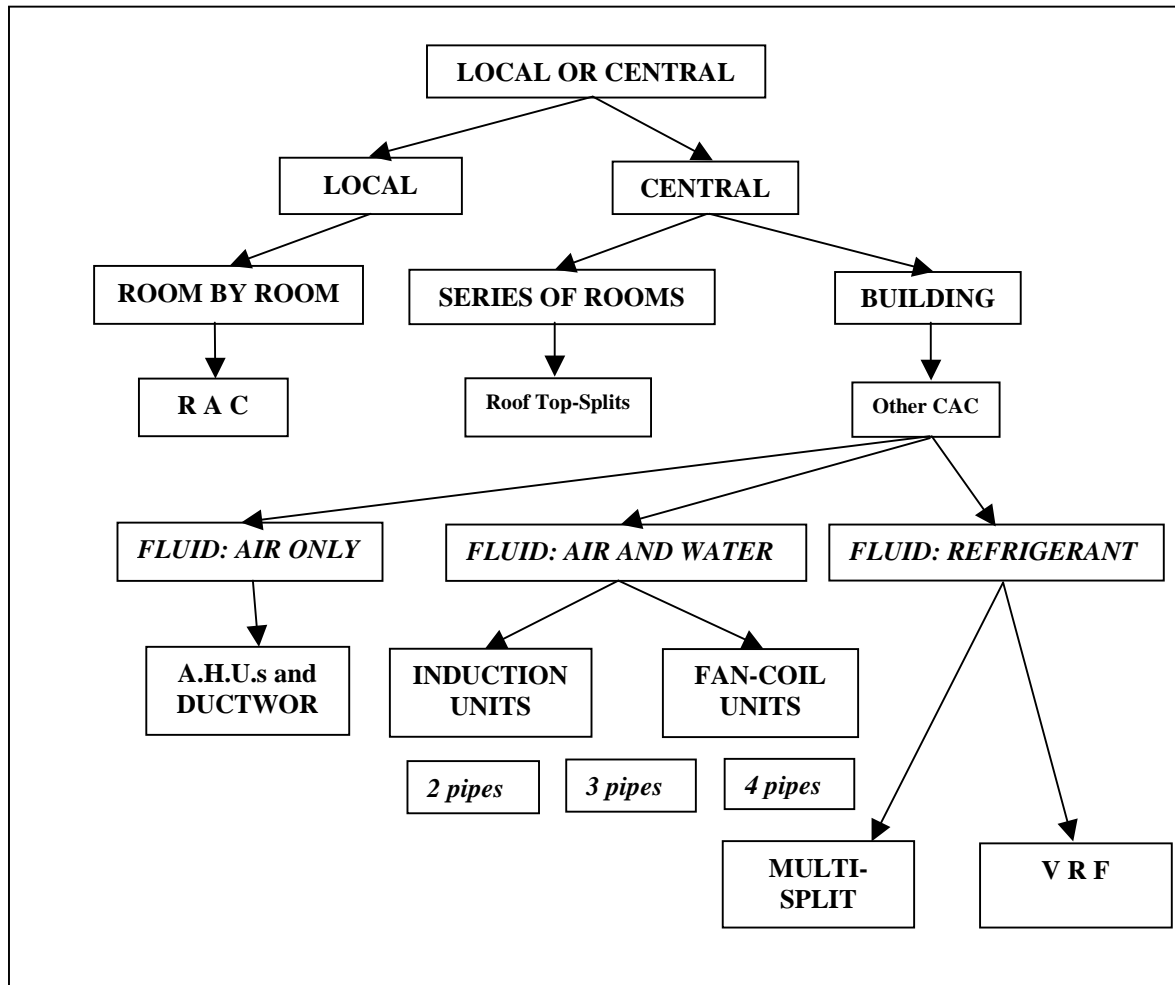
It was made easier by the existing information scheme by a subsidiary of the manufacturers' association called Eurovent-Certification. However the existing information scheme in Europe is based on testing at nominal operating conditions and lags behind the information available in some foreign countries for the same type of equipment (such as the ARI certification programme in the USA). To be really effective, energy efficiency options have to be defined not on the basis of nominal operating conditions but at a variety of part load conditions, which better reflects the CAC operating modes that occur in real use. The energy efficiency options list has also to cover secondary systems (distribution) which were found of equal importance for reaching the minimum cost of service.

### **Definitions of all CAC systems found on the EU market have been given.**

The structure of a CAC system and consequently its name results from the accumulation of a number of decisions on the choice of essential components. The first choice determining a system is the type of the fluid being centrally refrigerated and circulated. The most frequent (and really dominant option) is the use of a **chiller**, which generates cold water (typically at 7°C) and which is used to transfer "cold" to the building space in part via a water distribution network and in part via a centrally treated airflow. To transfer the “cold” to air, **Air Handling Units (AHU)** are used. In the majority of situations however, chilled water is circulated up to the rooms and the air of the room comes directly in contact with it. Even in this predominant CAC system a choice must be made on how to transfer “cold” to the air of the room. The two most common approaches are an “induction system” and a “**Fan-Coil Unit**” (**FCU**) and these both of these systems can operate with a water distribution network having two or three or four pipes.

Other AC systems are applicable to a series of rooms or spaces such that their applicability is dependent on the number of rooms and the general situation of the building. In many cases large Unitary Air Conditioners (or **Packaged**), which are self-contained direct-expansion (i.e. without using water as an intermediate heat transfer vector) apparatus can be applied as can Multi-Split systems, which are a particular assembly of small “split systems” and were originally investigated under the EERAC study. In addition a new variant of the “split system” concept most commonly known as the VRF (Variable Refrigerant Flow) system, but more generally as a modulated capacity system, is capable of significant energy savings and has occupied a market segment. These system descriptions lead to the idea of a CAC system description tree of which a non-exhaustive set of branches is presented in Figure 1.

Figure 1. CAC system description tree showing the most common CAC systems.



'Fluid' refers to the primary heat transfer fluid from the building to the refrigeration system

**All CAC equipment test standards have been reviewed and studied to assess their suitability to represent energy efficiency under real operating conditions.**

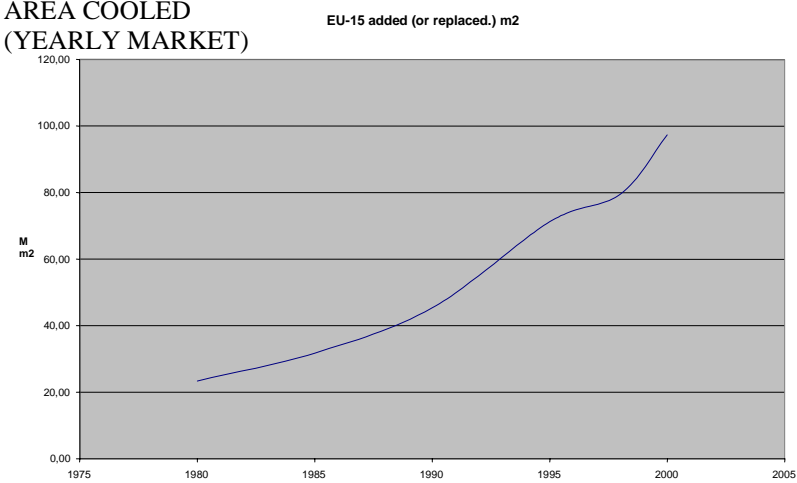
Eurovent-Certification, a branch of Eurovent has defined test conditions at which equipment energy performance is to be reported by European industry, based upon performance testing at full load, in accordance with CEN standards. The American Refrigeration Institute (ARI) and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) have defined US-national test standards in a similar way; except these involve a mixture of testing at full and part-load conditions so that the results can be extrapolated to provide the average annual performance of CAC equipment. This has enabled US legislative bodies to readily establish minimum performance criteria which are based upon comparative performance under representative operating conditions. Thus in some way, the US standards have progressed further than the European ones, although it has been established in this study that they are not suitable for use in European conditions without modification. There are ISO efforts for the testing aspect but the respective standards are not all available.

**CAC market and stock data have been assembled for the first time.**

National surveys of the CAC market, usage and regulatory environment were conducted by the EECCAC study participants for their country. This took advantage of each participants national contacts including assembling and synthesising rough data supplied by local manufacturers' or importers' associations or even involved subcontracting national consultants. It received a very significant help from the manufacturers

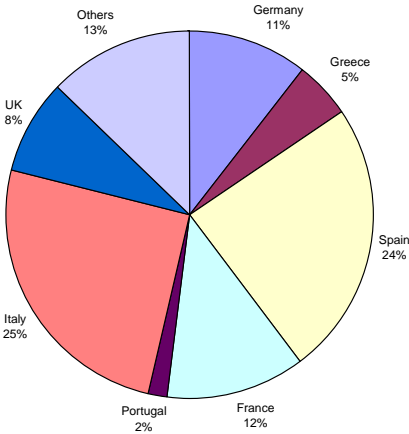
associations. The resulting set of **country reports** for: Austria, France, Germany, Greece, Italy, Portugal, Spain, United Kingdom (with special thanks to the BRE) provides a unique set of data at the national level. The CAC market is expanding rapidly in Europe, as can be seen from the additional cooled building floor-area installed from 1980 to 2000 for the EU-15, Figure 2 (including new systems and refurbishment).

Figure 2. Annual addition of building cooled-floor area by CAC in the EU (either really added or replaced)



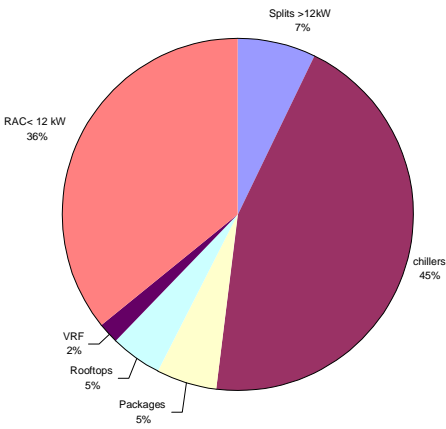
Because of a strongly differential growth rate across EU Member States, the relative share of the total EU cooled floor-area of countries such as France or Germany, which was large in the 1980's has become small in the 1990's. The high growth in CAC installed in Italy and Spain means that these countries now account for more than 50% of the EU market, as is apparent from the CAC floor-area installation figures for 1998 by country shown in Figure 3.

Figure 3. National shares of installed CAC-cooled floor area in EU buildings in 1998



The market shares for all competing AC systems, have been determined in all usage sectors and for all years between 1990 and 2020, see Figure 4 for example based on year 1998.

Figure 4. AC market share by AC type expressed in terms of newly installed cooled-area in EU buildings in 1998



Similar data to the European data is available for the world’s largest market, the USA, from the CBECS programme of the US Department of Energy’s Energy Information Administration. The figures cover the same years (1999-2000) and the same type of building stock (non residential buildings in use); however, the choice of AC equipment is very different. Packaged AC accounts for the majority of cooled floor area in the USA while chiller based CAC systems dominate in Europe, Figure 5.

Figure 5a. The share of cooled-floor area by AC type in non-residential buildings in the USA for 1999-2000

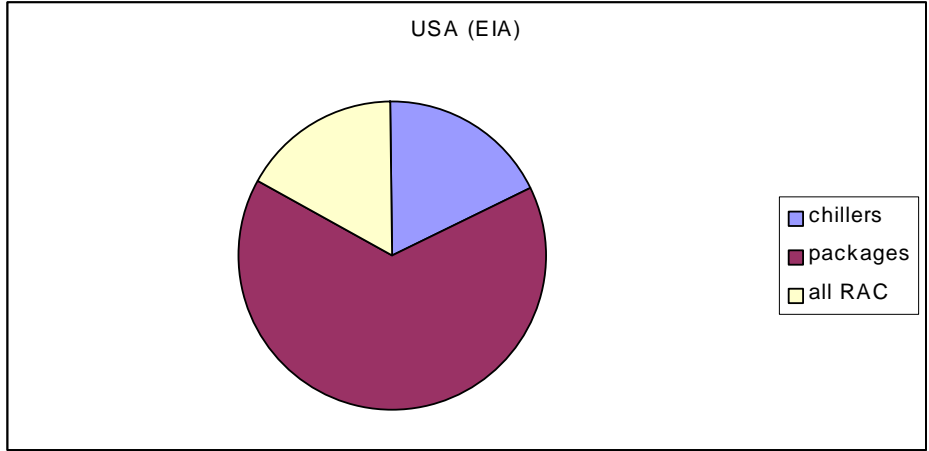
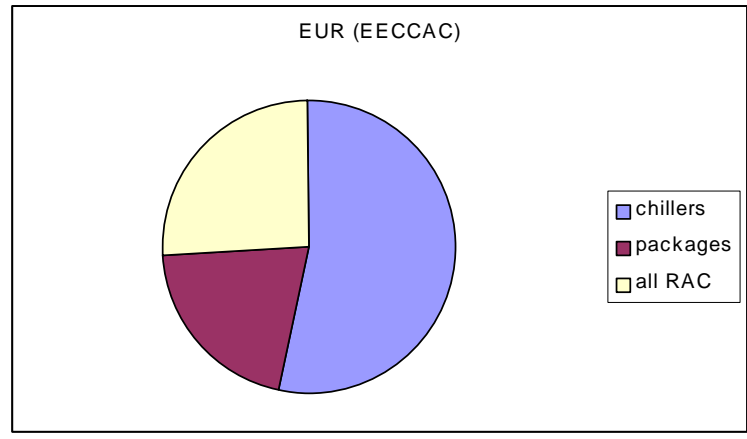


Figure 5b. The share of cooled-floor area by AC type in non-residential buildings in the EU for 1999-2000

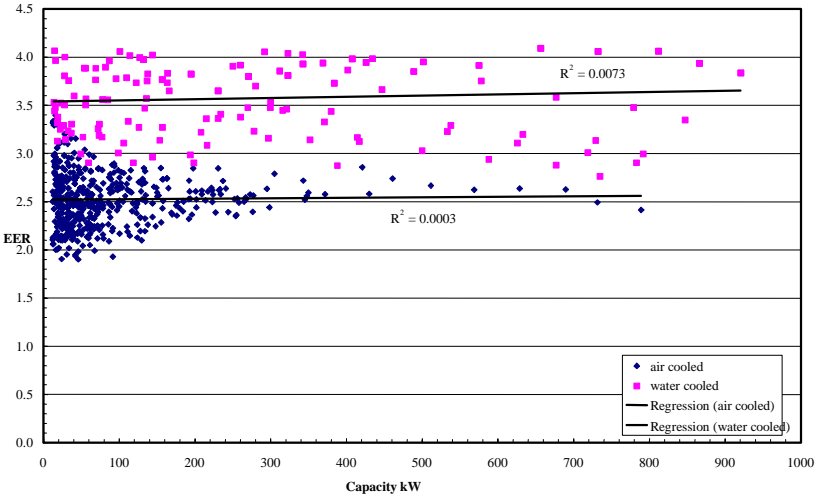


Despite this difference in technical preferences, the US market is so large in absolute terms that for every CAC type there are more square metres of cooled floor space in the USA than in the EU.

**The present Energy Efficiency efforts have been reviewed**

In the EU, the energy efficiency of the AC system **is not presently a criterion that plays any major role in the AC design and installation process; rather the efficiency improvements that do occur tend to happen haphazardly.** Through an analysis of data on chiller energy performance at full load test conditions, which is taken from the Eurovent directory, the distribution of chiller EER<sup>1</sup> as a function of cooling capacity and condensation cooling fluid has been determined, Figure 6. From this data it is clear that there is no statistical significant dependence of chiller efficiency on the chiller cooling capacity, however, units which use water as the condensing medium are significantly more efficient than those that use air. In fact this apparent difference is not internal to the chiller, but rather represents the temperature regime of cooling towers, for which an arbitrary estimate is made in the standard.

Figure 6. Chiller energy efficiency (EER) at full load as a function of cooling capacity for chillers available on the EU market in 1999. There are two groups of chillers, with distinct testing conditions (water cooled and air cooled, that cannot be compared)



The average EER is indeed 3.57 with water whereas it is 2.52 for the systems with air as a rejection medium under the conditions of the testing Standard, see Table 1. One could conclude in favour of a clear superiority of Water cooled systems over Air cooled systems. Nevertheless, water-cooled systems are expensive (for both when a cooling tower or natural ground water is used), and will therefore only be common among large capacity systems. The operating conditions on the field may be very different from the testing conditions and reverse premature conclusions.

<sup>1</sup> Energy efficiency ratio, which is measured under full load conditions

Table 1. The range of chiller energy efficiency (EER) for different types of chiller systems found on the EU market

Categories	Type	Condenser	Application	EER		
				min	ave	max
Complete unit	Cooling only	air	conditoining	1.9	2.53	3.29
	reversible	air	conditioning	1.9	2.48	2.96
			Floor	3.31	3.34	3.38
	Cooling only	water	conditioning	2.9	3.73	4.09
	reversible	water	conditioning	2.9	3.57	4.09
Condenserless	Cooling only	water	conditioning	2.76	3.21	3.64

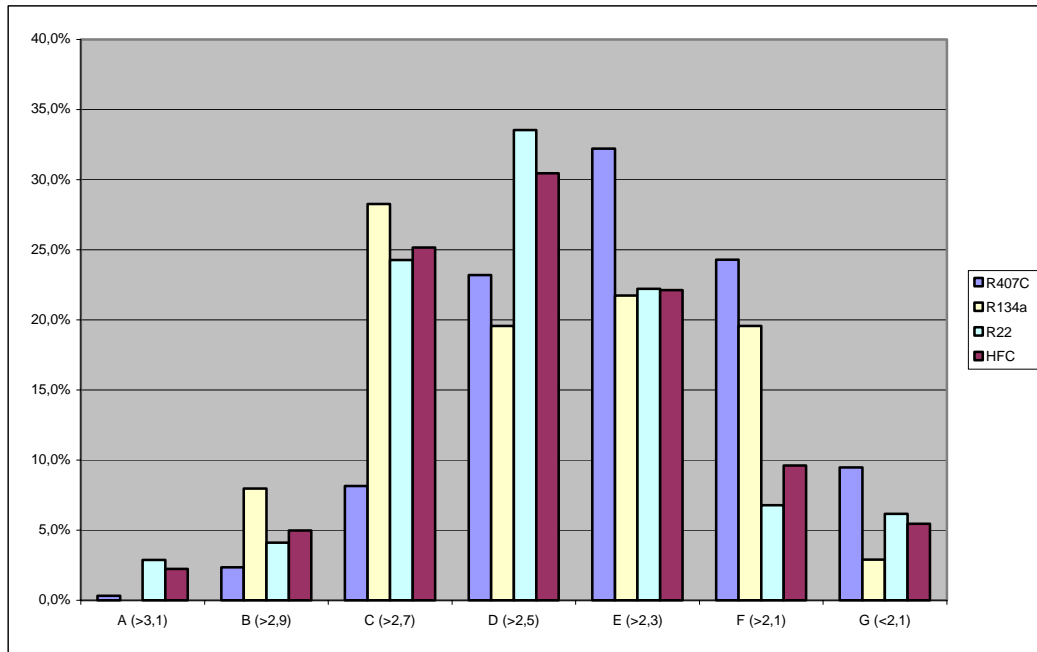
Interestingly, the reversible systems, which have an average EER of 2.48 W/W, have an almost identical energy efficiency to the cooling-only systems which have an average EER of 2.53 W/W.

A number of countries **outside the EU** have implemented market transformation policy measures to raise the energy efficiency of CAC systems installed in their markets, including: the USA, Canada, Mexico, Korea, Japan, Australia and New Zealand. Most policy measures have been aimed at packaged units, which are not so important on the European market; however, the US IPLV approach, which has been found to not be directly applicable in the EU, was -before this study and the AICARR's EMPE proposal, the only attempt to address the specific issues of chiller energy performance.

### All the elements of a possible grading of Cooling market have been assembled

Tables have been produced on the basis of the technical findings and of the market statistics that allow to define a grading scale for each segment of the market, allowing a fair comparison of equipment despite of testing conditions and technical differences. Statistics show for each segment (like figure 7 for the largest segment) which part of the market falls in each grade.

Figure 7 Air cooled chillers, Cooling, below 750kW , statistics with proposed grading and for each refrigerant



**Splits and Packages are grouped in one single category** (Air-cooled air conditioners) for presentation of results in table 2.

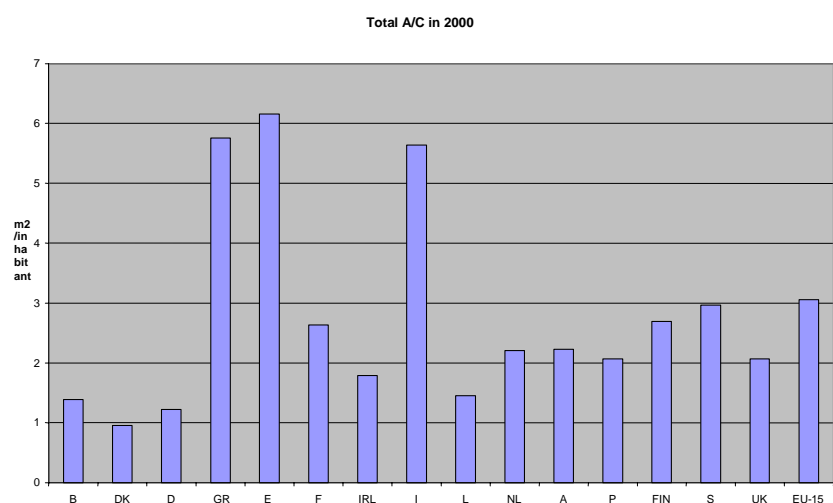
Table 2 Example of proposed grading in Cooling function -mixed statistics (splits and packages mixed) ; present market average = 2.46

Class definition	% on market	Grade	% with equal class width
$3.20 < EER$	2%	A	2%
$3.20 \geq EER > 3.00$	5%	B	5%
$3.00 \geq EER > 2.80$	7%	C	7%
$2.80 \geq EER > 2.60$	15%	D	15%
$2.60 \geq EER > 2.40$	22%	E	22%
$2.40 \geq EER > 2.20$	26%	F	26%
$2.20 \geq EER$	23%	G	11%

### The impacts of BAU have been assessed

Projections of energy consumption have been made. The penetration of AC can be expressed in a variety of standardised ways such as the unit cooled-area per inhabitant (in m<sup>2</sup>/hab.), Figure 8. The BAU definition is the absence of large regulatory actions and of significant changes in consumers choice. We have estimated the areas cooled in a way compatible both with manufacturers statistics (capacities, numbers of pieces) and with national statistics (square meters cooled), table 3, while taking into account typical over sizing. We can keep a few figures in mind : 1200 Mm<sup>2</sup> cooled in year 2000 (3m<sup>2</sup>/inhabitant), 2200 Mm<sup>2</sup> in 2010 (5m<sup>2</sup>/inhabitant), with a share of reversibility around 25%.

Figure 8. Average cooled-floor area per inhabitant for EU countries and the EU as a whole in 2000.



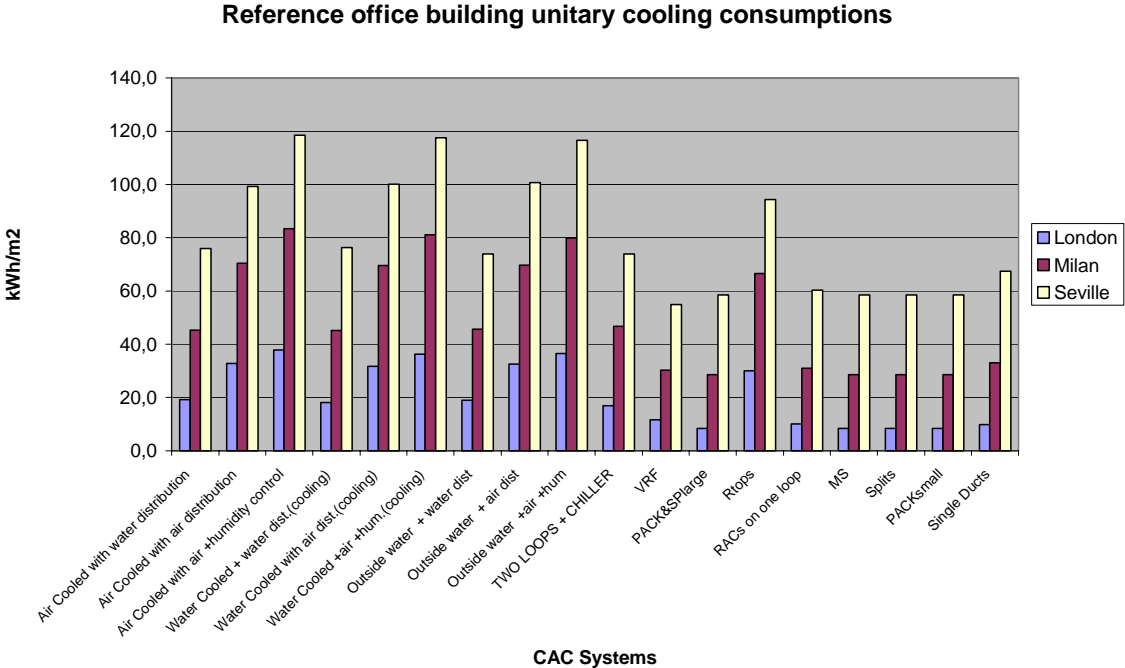
The evolution of the various economic sectors and their demand for comfort vary a lot. Only trade and offices really grow in relative terms and they may reach 70% of stock by 2020.

Table 3 Area conditioned in each country and year (such areas can be compared with national statistics)

Country		Years						
		1990	1995	2000	2005	2010	2015	2020
AU	Mm <sup>2</sup> cooling	12,01	15,68	20,06	26,29	30,29	33,01	33,95
	Mm <sup>2</sup> reverse	1,45	2,06	2,74	4,83	5,57	6,08	6,27
BE	Mm <sup>2</sup> cooling	4,03	8,98	20,36	32,41	42,77	52,09	54,29
	Mm <sup>2</sup> reverse	0,84	1,84	4,03	6,46	8,43	10,24	10,73
DE	Mm <sup>2</sup> cooling	3,78	6,62	11,30	19,92	29,24	37,57	42,30
	Mm <sup>2</sup> reverse	0,70	1,35	2,50	4,12	6,01	7,72	8,69
FI	Mm <sup>2</sup> cooling	15,88	24,06	36,43	43,28	47,28	50,19	50,99
	Mm <sup>2</sup> reverse	1,35	2,28	3,71	7,49	8,21	8,74	8,89
FR	Mm <sup>2</sup> cooling	93,40	129,39	180,37	293,24	390,57	472,24	502,39
	Mm <sup>2</sup> reverse	32,79	45,84	64,98	106,59	141,52	171,24	182,61
GE	Mm <sup>2</sup> cooling	34,07	66,29	127,64	216,74	298,51	365,63	400,13
	Mm <sup>2</sup> reverse	4,88	9,54	18,81	30,61	41,65	51,09	56,23
GR	Mm <sup>2</sup> cooling	11,04	23,06	48,23	80,47	108,97	140,88	145,99
	Mm <sup>2</sup> reverse	5,29	11,17	23,65	40,07	54,24	70,12	72,68
IR	Mm <sup>2</sup> cooling	5,03	6,81	9,37	13,84	17,07	19,39	20,37
	Mm <sup>2</sup> reverse	0,75	1,08	1,78	2,30	2,83	3,22	3,41
IT	Mm <sup>2</sup> cooling	130,85	175,63	258,76	368,74	414,88	450,33	467,85
	Mm <sup>2</sup> reverse	29,22	43,81	73,26	106,86	120,93	132,38	138,18
LU	Mm <sup>2</sup> cooling	0,25	0,43	0,87	1,34	1,76	2,07	2,20
	Mm <sup>2</sup> reverse	0,07	0,10	0,17	0,26	0,35	0,40	0,43
NE	Mm <sup>2</sup> cooling	22,25	39,02	66,88	87,71	101,28	110,49	113,62
	Mm <sup>2</sup> reverse	1,84	3,55	6,50	12,17	14,03	15,38	15,89
PO	Mm <sup>2</sup> cooling	8,46	12,51	18,73	34,84	52,08	68,41	78,27
	Mm <sup>2</sup> reverse	4,67	7,27	11,25	18,47	27,53	36,11	41,31
SP	Mm <sup>2</sup> cooling	64,24	102,68	172,69	248,07	295,71	342,20	352,20
	Mm <sup>2</sup> reverse	34,61	56,66	97,11	136,02	161,33	186,01	191,57
SW	Mm <sup>2</sup> cooling	38,41	53,26	69,38	78,17	83,23	87,28	88,21
	Mm <sup>2</sup> reverse	4,08	6,14	8,74	14,90	15,88	16,68	16,92
UK	Mm <sup>2</sup> cooling	94,29	127,63	173,15	248,36	294,19	326,80	340,28
	Mm <sup>2</sup> reverse	14,17	20,41	31,06	43,81	51,73	57,87	61,07
<b>Total Mm<sup>2</sup> cooling</b>		<b>538,01</b>	<b>792,07</b>	<b>1214,23</b>	<b>1793,42</b>	<b>2207,83</b>	<b>2558,59</b>	<b>2693,04</b>
Total Mm <sup>2</sup> reverse		136,71	213,10	350,28	534,96	660,23	773,29	814,88

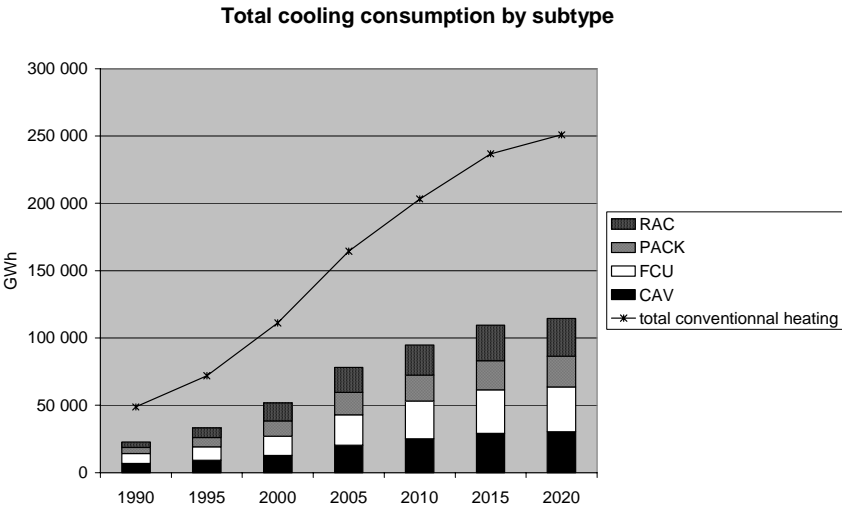
Then we had to move from area statistics to energy use statistics. We computed the electricity consumption of a square meter for AC depending on its location, its economic sector (typical use) and on the AC system. In other words, we have obtained (through DOE simulation and physical extrapolation) energy consumption figures for each system, each building use and each climate as shown in figure 9 under the form of a specific value : consumption per square meter.

Figure 9 Consumption of the 18 systems in three climates as simulated with DOE software



The three main sections of our BAU scenario predictions relate with : the actual cooling demand, the winter demand of the cooled areas if no reversible use took place, the winter demand of the cooled areas with the reversible use presently estimated. Figure 10 shows the first two values (cooling and associated heating consumption by technical type) for the BAU.

Figure 10 Energy for cooling consumption split by technical type of cooling and related conventional heating



The tables 4, 5 and 6 give the main values (EUR15) for the three functions. Note that gas is accounted for as a secondary energy, with the same value as electricity.

Table 4 Total energy demand generated by AC (TWh either electric or gas or added)

Energy demand (TWh)	1990	1995	2000	2005	2010	2015	2020
Cooling function (Electricity only)	22,879	33,683	51,636	78,103	94,727	109,631	114,579
Heating function Without REV.	48,726	71,912	111,084	164,517	203,330	236,765	250,844
Heating function With present REV. (El.)	7,274	11,390	18,894	28,913	35,875	42,333	45,040

Table 5 Cooling only energy consumption by country and year (for comparison with national projections)

Total Cooling GWh/ year	Year				
Country	2000	2005	2010	2015	2020
AU	469	549	633	689	707
BE	274	422	559	681	708
DE	71	122	180	232	260
FI	206	210	229	242	246
FR	5 010	8 213	10 954	13 240	14 071
GE	2 286	4 012	5 542	6 785	7 415
GR	2 909	5 365	7 269	9 399	9 734
IR	127	180	222	252	264
IT	16 209	24 336	27 445	29 795	30 890
LU	11	18	23	27	29
NE	605	690	797	869	892
PO	1 020	2 049	3 072	4 039	4 621
SP	19 689	28 333	33 573	38 719	39 915
SW	391	378	403	421	425
UK	2 359	3 227	3 826	4 241	4 401
Total	51 636	78 103	94 727	109 631	114 579

Table 6 Numerical results about CO2 emissions due to cooling in Europe

Kt CO2	2000	2005	2010	2015	2020
AU	164	192	221	241	248
BE	96	148	196	238	248
DE	25	43	63	81	91
FI	72	73	80	85	86
FR	1 754	2 874	3 834	4 634	4 925
GE	800	1 404	1 940	2 375	2 595
GR	1 018	1 878	2 544	3 289	3 407
IR	44	63	78	88	93
IT	5 673	8 518	9 606	10 428	10 812
LU	4	6	8	9	10
NE	212	242	279	304	312
PO	357	717	1 075	1 414	1 618
SP	6 891	9 916	11 751	13 552	13 970
SW	137	132	141	148	149

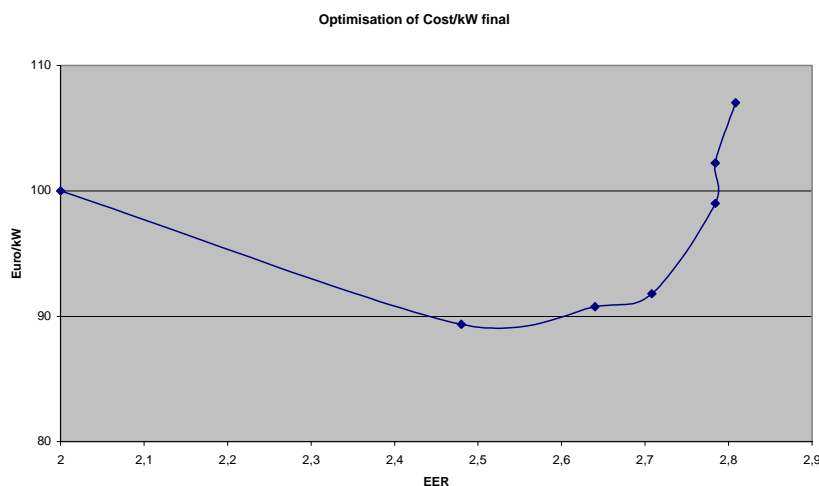
UK	826	1 129	1 339	1 484	1 540
Total	18 073	27 336	33 154	38 371	40 103

We can keep in mind a 51 TWh consumption estimate for all AC in 2000 (18 MtCO<sub>2</sub>) becoming 95 TWh in 2010 (33 MtCO<sub>2</sub>). Such impacts are not small, but limited if we compare them with other uses in buildings (heating, home electronics, better lighting, etc.). Remember the figures given correspond to BAU, and that there is no significant EE measure on that market. So the next question is : how far can we improve the balance? What is the potential of improvements paying for themselves but not realised by the present market structure? This question can be tackled at three levels : the most frequent cold generating equipments (chillers, packages), the cold generating plant (depending on its number of hours of operation, and climate), and the full system, including distribution.

### Optimisation of a chiller to improve its EER on the basis of capacity cost only

We have performed some engineer economic calculation and compared the technical improvements proposed in the study with the diversity found on the market. We introduce one by one the possible improvements (better compressor, better evaporator, etc.) and we see how the price of the service rendered (the kW of cooling capacity) varies. For a given electrical power the capacity varies proportionally to EER; for a given capacity, the compressor can be reduced when EER increases. So the cost per kW decreases with the first steps of performance and only increases later (see figure 11).

Figure 11 The cost of a chiller at nominal capacity according to its EER



Conclusion : the best chiller having the same cost (assumed here 100 Euros/kW) as the present “worst performer” has an EER around 2.80. The range from 2.00 to 2.80 shows reasonable prices for a chiller judged only on capacity. It corresponds exactly to the present market. The minimum cost chiller according to our analysis has the same EER as the average market (EER 2.50), which may be considered as a validation of our cost reconstruction.

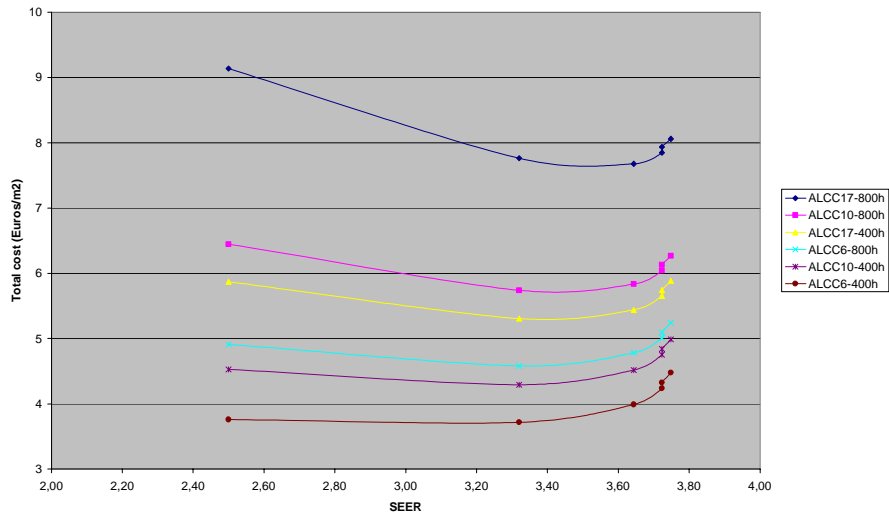
### Optimisation of a chiller for its least LCC

The energy consumption of equipment will be more and more considered in the equipment design process. One day, a definition of chillers performance based on SEER<sup>2</sup> and SCOP will be substituted to the ones given as EER and COP. The part load benefits will then be optimised and the optimisation can then be made on the basis of energy consumption. So it is interesting to define the “optimum” taking into account consumption. The search for the optimum has been done in the same way as previously, through successive additions, including part load options (Figure 12), with a 6% discount rate, electricity prices ranging from 6

<sup>2</sup> Seasonal energy efficiency ratio, the energy efficiency ratio which reflects the real usage conditions of the equipment over the year

to 17 cEuros/kWh (the most frequent being 10 cEuros for this type of customer in Europe), and equivalent usage durations (at full load) taken as 400 or 800 hours/year .

Figure. 12 The annual cost of the service rendered by a chiller in terms of SEER

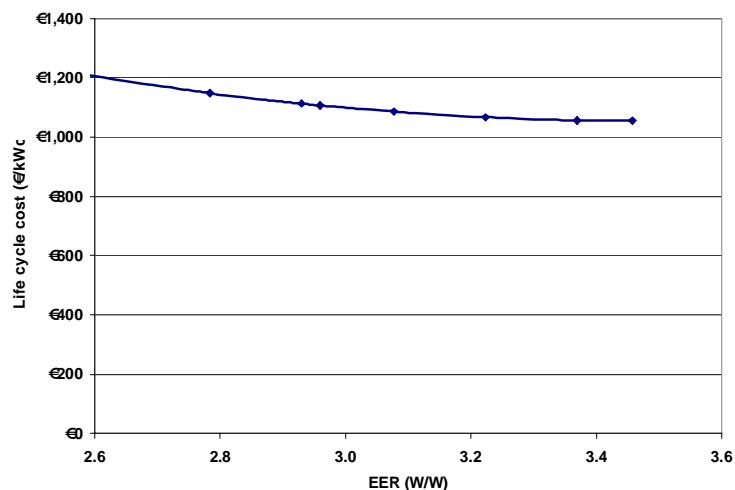


The optimal level of performance for the screw chiller considered is about 40% more efficient than the present « bottom » of the market : it has an SEER between 3.00 and 3.50. It may correspond to a chiller with a correct EER around 2.46 (enhanced evaporator and condenser, improved compressor) and a capacity split between 3 or 4 compressors. For manufacturers, there are other ways to reach 3.25 SEER, less expensive, but our objective was to find out if there is a margin for improvement.

### Packaged units can also be improved a lot

For 26kWc packaged units, analyses used for US regulations imply an average equivalent of 2097 hours of full load operation per year while 800 hours per year is deemed more likely for the EU. The results of the analysis taking these factors into account is shown in Figure 13 for the 26kWc unit, which is most representative of the EU market. They show that the life cycle cost minimum occurs for large packaged units with an EER of 3.22 W/W when a 6% real discount rate is applied. Although the overall life cycle cost per kW are lower for the 52 kW unit the minimum still occurs for an EER of 3.22 W/W.

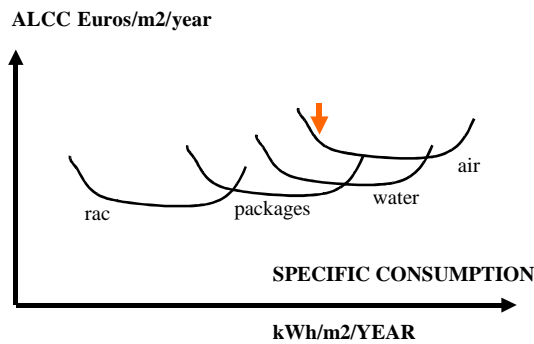
Figure 13 LCC curve of a 26kW package in Europe presented as an annual cost



### System optimisation : all air systems

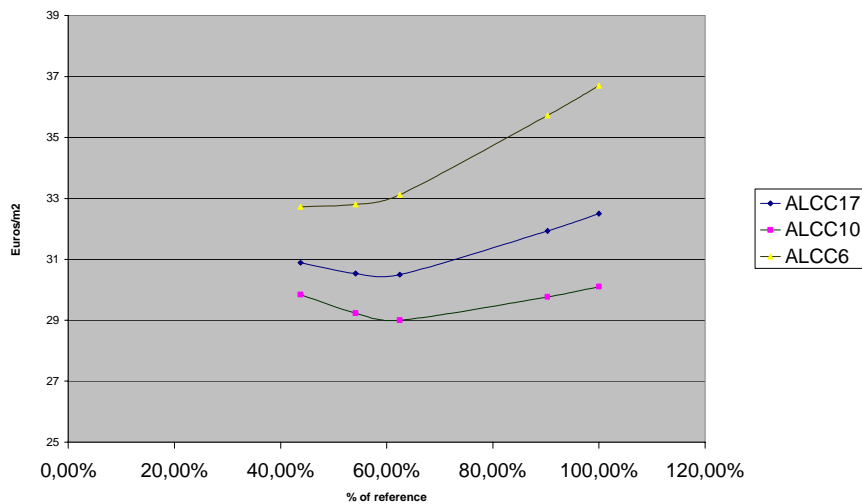
We have concentrated our efforts on air based distribution systems which show presently the most consumption and the highest cost. The designers need the whole range of AC solutions to cover the domain of geometries and air quality requirements. So the bottleneck to the expression of a global reduction in consumption will be the point (shown on figure 14 by an arrow) where the improved air based solutions start not to pay for themselves : the designers will find it is too heavy a constraint to get under this value.

Figure 14 The key point of energy efficiency : the best attainable air based system



The search for the optimum has been done in the same way as previously, through successive additions, including part load options (Figure 12), with a 6% discount rate, electricity prices ranging from 6 to 17 cEuros/kWh (the most frequent being 10 cEuros for this type of customer in Europe), and equivalent usage durations (at full load) taken as 400 or 800 hours/year. After sorting options and combinations, the optimal trajectory of improvement of the annualised cost of ownership (ALCC) is given in figure 15.

Figure 15 Optimising with 6, 10 and 17 cEuro/kWh a full all air system in Seville for lowest ALCC



The optimum is very flat, specially if we consider the highest cost of electricity. The regulatory measure could be taken anywhere between a 0% and a 60% reduction without generating overcosts (in the LCC definition) in Seville.

## Part load performance has been quantified for the first time and the methods have been tested

The report shows how in the case of most chillers, the part capacity performance can be better than full load at the same temperature. This results from the reduction in refrigerant flow –and consequent improvement in heat transfer efficiency at part load. The compression ratio is decreased so that compressor isentropic efficiency increases. There is much progress being made in the control of these part load phenomena. The issue is : how to represent, certify and translate in a single figure those improvements. There was on the table the original US-IPLV method and a European version called EMPE.

The percentage of operating hours assigned at each part load condition (in the US-IPLV) is intended to be representative of the US climate and buildings but not of the European ones. Further to this, an analysis of the method shows that the **ARI part-load temperature testing points** are "sized" to be "representative" of US buildings (cooling until in negative Celsius temperatures, for instance- as can be shown by drawing the loads in terms of outside temperatures).

The first remark in the Italian proposal is that the operating conditions are rather different from Southern Europe conditions. And even, if Northern Europe countries may need air conditioning in summer, it cannot be said that Italy would need air conditioning at 12.8°C as normal operating conditions. Therefore, AICARR proposed a new energy index, named EMPE (Average Weighed Efficiency in Summer regime in Italian) directly deriving from IPLV, with different energy weights and, in particular, with different temperatures at the condenser inlet, more suitable for the European climate and requirements in the air conditioning field.

The AICARR proposal, EMPE was not based on a sufficiently large climatic and technical investigation. Its strength (being very close to the existing US method, which aggregated many factors) was also its weakness. We had the opportunity to go further by constructing a data base of EU chillers at part load, understanding better part load, and proposing two separate methods, one for part load reporting and certification, the other one for the computation of SEER.

We have been able to define a **new method called ESEER** that enables to calculate the seasonal efficiency for all European chillers (centrifugal units are not treated completely in this document by lack of specific information but seem likely to be covered by the proposed method, due to the Us experience). The constraint was to minimize the testing time while ensuring maximum precision, it is to say that the error coming from the reduction of the data to single points should be inferior to the testing uncertainty. The new ESEER method has been compared with the US-IPLV and EMPE proposal under both respects : time spent and accuracy.

Original knowledge has been generated during the “Joint project” of EDF R&D facility and manufacturers from Eurovent wanting to promote part load performance. The main tool used was actual testing of EU equipment but a number of group meetings allowed to build a common thinking frame. The technical description of the chillers tested follows on tables 7 and 8, split by condensation type.

Table 7. Tested air-cooled chillers

Name	Type	Circuits	Compressors	Available Stages
N° 5	Scroll	1	2	3
N° 7	Scroll	2	4	4
N° 8	Herm rec	2	2	2
N° 9	Scroll	2	4	4
N° 2	Screw	2	2	Partially continuous

Table 8. Tested water-cooled chillers

Name	Type	Circuits	Compressor	Available Stages
N° 1	Screw	2	3	8
N° 3	Screw	2	2	4
N° 4	Scroll	2	4	4
N° 6	Screw	1	1	Continuous

For all the tested chillers, some common testing points were made according to either the US-IPLV or the EMPE conditions depending on the manufacturer will. For all chillers, a supplementary point was added to fulfil the CEN EnV requirement : nominal inlet condensing temperature (35°C for air and 30°C for water) and 50% load ratio referred at this nominal inlet condensing temperature For chillers n° 2, 3, 4 and 8, only IPLV or EMPE points plus the CEN one were available. For the others as many testing points as desirable have been obtained. In all circumstances a simple model has been used to draw the performance maps from existing testing points.

### Impact of load reduction on the efficiency – a reporting format proposed to Eurovent

One important finding is that a percentage (like 50%) is not enough to report the part load behaviour of a chiller. It is so when there is one single compressor per chiller, or various identical circuits. A significant market share of chillers have various compressors and a complex circuiting, leading to improved part load performance. But a given part load regime has to be defined by the actual status of each piece of equipment.

For discrete stages chillers, it would be easier to describe performance at a given stage not at a given percentage. For the very few continuously controlled chillers, four stages can be defined in terms of input. Since temperature and load can be tested independently and recombined, there is no need for combined testing & weighting (like IPLV).

About certifying Part Load : what the manufacturers give to their customers is a « map » of performance, not only values at the four arbitrary percentages and temperatures, plus the final Eurovent grading when it is available, based on a SEER. The customer can rely on the Eurovent SEER computed from this map ... or compute its specific SEER for its specific demand. No need to test every condition reported in the “map”: the benefit of Eurovent is the fair and independent choice of a few points on the map, as usual, and the associated independent testing.

We arrived also at applicable conclusions on the way to report the SEER in the Eurovent directory. We started from HSEER, the DOE reference that we generated. It is proven that each set of outside conditions (for each sector, climate, type of chiller, type of secondary system) can be reduced to four or five external conditions without loss of accuracy. **The ESEER index proposed here is a set of 4 conditions given for E.U. as a whole, but there can be as many similar indices as specific demands: sector, country, etc.**

We have introduced a format for the description of the stages of a chiller, like in table 9 and following, suitable for Eurovent specification. For each stage, the manufacturer has only to declare which piece of its equipment is operating and to indicate CC , the cooling capacity and EP, the electric power absorbed. The certifying body has only to check a few of the values, selected in the same conditions as usual. Note that this procedure is in fact already used for some chillers with various speeds, namely “low noise” chillers with the possibility of reduced fan speed.

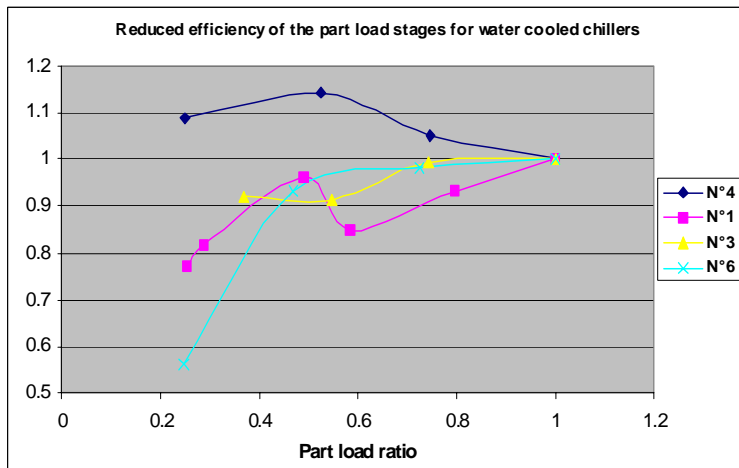
Table 9 : Part load performance of water cooled scroll chiller N°4, as could be reported in Eurovent part load certification scheme

N° 4 // WT : 30°C	STAGES	1	2	3	4
Circuit 1	Compressor 1	0	0	0	1
	Compressor 2	0	1	1	1
Circuit 2	Compressor 3	0	0	1	1
	Compressor 4	1	1	1	1
EP (kW)		8,80	17,60	27,17	38,27
CC (kW)		37,50	78,00	112,50	150,00
EER		4,27	4,47	4,12	3,92

### Magnitude of gain/losses due to part load

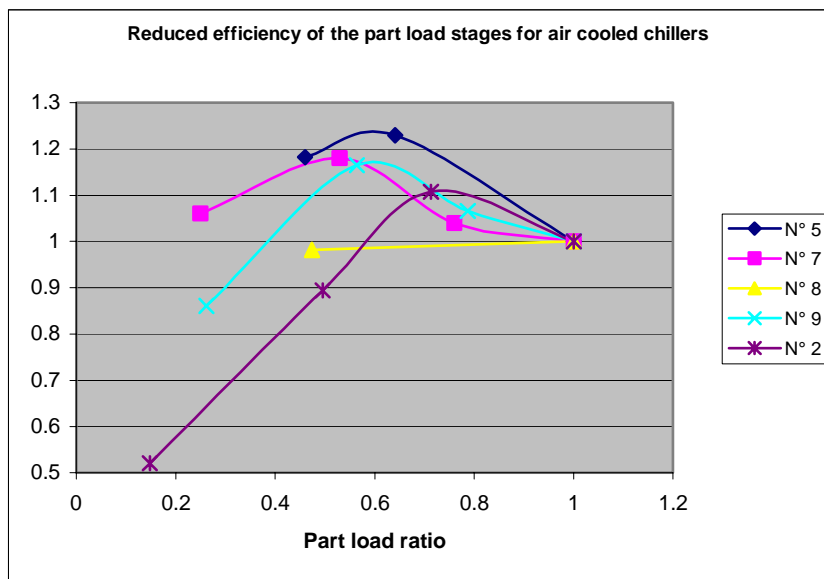
The overall performance improvement (or degradation) at part load (temperature effects being subtracted) is given on figure 16 for the four air cooled tested units.

Figure 16 Reduced efficiency while decreasing part load ratio (same source temperatures) for the tested water cooled chillers



The overall performance improvement (or degradation) at part load (temperature effects being subtracted) is given on figure 17 for the five water cooled tested units.

Figure 17 Reduced efficiency while decreasing part load ratio (same source temperatures) for the water cooled chillers



### The simulations leading to the reference values of SEER (HSEER)

Two buildings were simulated on computer, but buildings that do exist : an office and a commercial mall. For each one, three climates have been simulated, adopting different envelope characteristics when moving the building around Europe. The different systems identified in the stock and market study have been simulated. CAC air and water distribution equipments have been simulated using the European average efficiency values.

Hour after hour, the simulation uses then the characteristics of the real chillers modelled to compute the exact yearly performance index : the HSEER (Hourly SEER), used then as a reference for other methods. At each hour the outside enable to calculate all known stage capacities and respective electric powers, including the high pressure control impact on each stage. Then the load is compared to each stage capacity. If the load is lower than the smallest available capacity step, the cycling formula enables to calculate the electric power. Otherwise, the weighting of electric power of each stage is found by the expression of the weighted average.

## EECCAC final figures for a European SEER method (ESEER)

Our work clearly shows also that the methodology for air and water cooled chillers enabled to extract seasonal operating temperature conditions with errors on the seasonal efficiencies that are inferior to the experimental uncertainties, for all chillers, included single compressor units. However, it also shows that the experimental uncertainty is quite high. It mainly comes from the uncertainty measurement on the temperature difference at the evaporator. In order to simplify the application of the index, some rounding can be done without modifying noticeably the ESEER figures obtained, largely under the experimental uncertainty. A comparison of the conditions of the 3 available indexes is proposed Table 10 for air cooled chillers.

Table 10. Comparison of the ESEER conditions with the EMPE and IPLV for air cooled chillers

Part load ratio	ESEER		ARI		EMPE	
	Temperatures	Weighting coefficients	Temperatures	Weighting coefficients	Temperatures	Weighting coefficients
100	35	3%	35	1 %	35	10 %
75	30	33%	26.7	42 %	31.3	30 %
50	25	41%	18.3	45 %	27.5	40 %
25	19	23%	12.8	12 %	23.8	20 %

Temperatures of the ESEER are comprised between EMPE temperatures above and ARI temperature under. ESEER weighting coefficients give more weight to the 25% point load than both index. For 50 and 75%, coefficients are nearer to the EMPE index. The 100% coefficient is 3%, nearer from the IPLV one. A comparison of the conditions of the 3 available indexes is proposed Table 11 for water cooled chillers.

Table 11. Comparison of the ESEER conditions with the EMPE and IPLV indexes for water cooled chillers

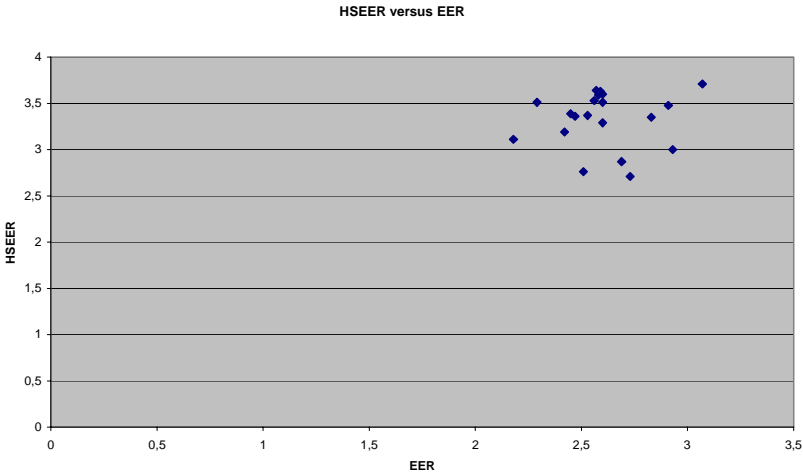
Part load ratio	ESEER		ARI		EMPE	
	Temperatures (°C)	Weighting coefficients	Temperatures	Weighting coefficients	Temperatures	Weighting coefficients
100	30	3%	29,4	1%	29.4	10%
75	26	33%	23,9	42%	26.9	30%
50	22	41%	18,3	45%	23.5	40%
25	18	23%	18,3	12%	21.9	20%

Temperatures of the ESEER are embedded by the EMPE ones above and ARI temperature beneath except for the 25% point. The ESEER weighting coefficients give more weight to the 25% point load than both index. For 50 and 75%, coefficient are nearer to the EMPE index. The ESEER 100% weighting coefficient is nearer from the IPLV one.

## EER alone is a poor selection tool

We shall compare now four classifications : according to EER, US-IPLV, EMPE, ESEER, using as a reference the actual EU values obtained by simulation in the three locations and properly weighted. We take the point of view of a user of the Eurovent certification system : by selecting a “better” chiller, am I really selecting a better chiller? This is completely false if we base ourselves only on EER (figure 17).

Figure 17. Comparison of HSEER with EER on the tested chillers



**IPLV and EMPE are more accurate than EER for classification but do not give enough accuracy for comparison of chillers**

A classification based on US-IPLV or EMPE would be largely false but would not distort completely the market (figures 18 and 19).

Figure 18 comparison of US-IPLV with HSEER for the tested chillers

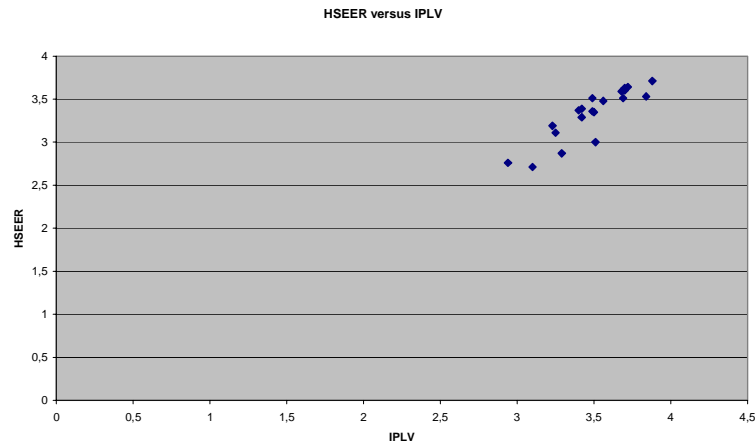
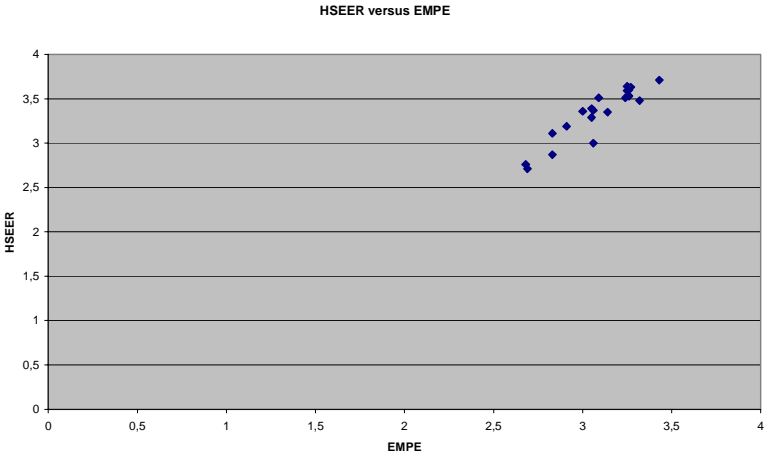


Figure 19 comparison of EMPE with HSEER for the tested chillers

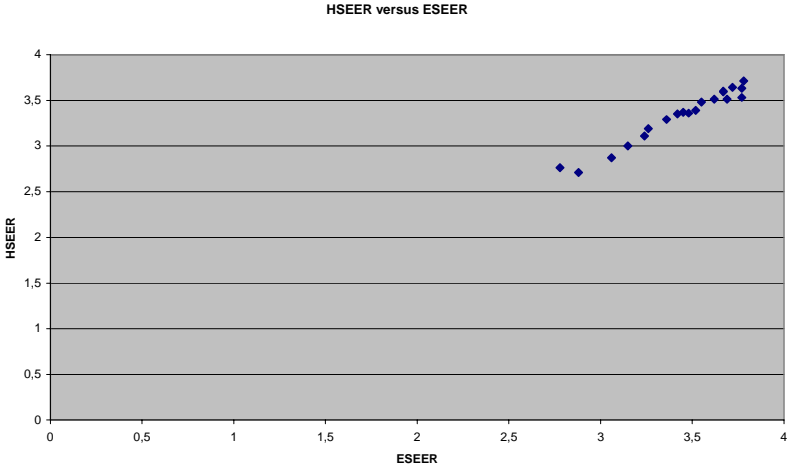


Based on similar assumptions, the two methods, IPLV and EMPE have at the end the same advantages and disadvantages.

**The newly proposed ESEER method allows grading and ranking of chillers by order of merit**

We see on figure 20 that the new method has the most important characteristic expected from a market transformation tool : almos no misclassification; a piece of equipment graded better than an other one is better or equivalent.

Figure 20 . comparison of ESEER with HSEER for the tested chillers



Conclusion : the differences are relatively large between existing methods and reality, and not always in the same direction. The newly proposed ESEER method is more accurate in a noticeable manner and satisfies the needs of Eurovent certification process as well as the expectations of the DGTREN in a market transformation.

**Energy efficiency options have been defined for each system configuration**

Th possibilities are so numerous, and so system dependent that the process of “filtering” the most promising was difficult. More than 20 basic systems and 100 variations were considered on a qualitative basis and then "filtered". A number of systems and energy efficiency options do not need detailed quantitative simulation because one or more of the following apply: they are infrequent; their use is are not expanding; the literature

is already sufficient to enable the savings potentials and costs to be defined; or simulation is impossible. For the others a detailed simulation has been organised.

**High energy savings are possible**, as well as significant CO<sub>2</sub> emissions reductions, at a net negative cost, such that all parties (manufacturers, consumers and utilities) would find a benefit in the deployment of efficient CAC. However the chain going from the manufacturer (most have already improved equipment in their directories together with simpler one) to the final consumer is distorted by a number of factors including: the consideration of initial cost as the only decision criterion by most designers and installers; the problem of certifying something built on site and only once; the lack of incentives for operators to optimise efficiency; the absence or inadequacy of building codes addressing this new and rather complex equipment segment, which is very difficult to model; different incentives caused by the separation between the plant owner and the building renter, between the building renter and the CAC operator, etc. As a result the policy measures to be proposed in the EECCAC study should not only address the offer of more efficient CAC equipment, which in fact seems to be the smaller difficulty, but should also address all the factors which have to reshape and activate the chain relating the energy used to the final service: the conditioned square meter.

**The French measure** is basically a minimum efficiency threshold above which AC systems can benefit from EDF's marketing and financial support. **The Portuguese measures** cover a number of sizing obligations, and require the use of a central AC system with a number of energy saving features such as 'heat recovery', 'part load staging', and 'free cooling' over a certain cooling capacity threshold (usually 25kW). Monitoring and maintenance are also included in the Portuguese RSECE the local regulation applicable to CAC). **The UK Market Transformation Programme** is a comprehensive set of possible policy measures including: obligations written into building codes (i.e. the imposition of limits on cooling demand); information (through a national release of the Eurovent directory database and the later elimination of the least efficient equipment) and voluntary "best practice " initiatives. The US ASHRAE 90.1 standard is a fully integrated set of policy measures which include minimum energy performance thresholds, design guidelines and specific system requirements. It is fully described in the report.

At the European level a draft Directive on **Energy Efficiency of Buildings** is currently under transposition. This requires the calculation of building energy performance, which itself demands knowledge of Air Conditioning (and other) system efficiencies. This will help the adoption of the best technical solution in new buildings. Article 8 requires that central air-conditioning systems of greater than 12 kW cooling capacity shall be regularly inspected. On the basis of this inspection, which shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building, the competent authorities shall provide advice to the users on the possible improvement or replacement of the air-conditioning system and on alternative solutions. So there will be a movement towards improvement also in the existing buildings.

### **Scenarios for energy efficiency have been established and quantified**

Fifteen technical scenarios have been simulated in every economic sector, country and for every type of systems up to year 2020. The very efficient scenarios are the following : 8 (combination of MEPS and building codes as in the USA), 3 (Eurovent part load MEPS), 2 (Eurovent full load MEPS). The maximum flexibility in demand is around 40TWh in 2020 if we start right now to apply the US Energy Efficiency standard, something which is far from the present prospects of regulation in Europe, except in two countries : Portugal and the UK. The Portuguese and British regulations would have a large impact if applied in the rest of countries. Significant gains can be obtained by introducing full and part load performance certification of equipment. A very strong commitment on full load EER only would achieve about the same gains at a very large cost.

### **All the elements for an action plan on Air Conditioning are available in the full report**

The analysis presented in this study has shown that there is a significant variation in energy efficiency for all types of CAC equipment that have been investigated when tested under standard test conditions. The measures which can be considered to encourage the higher energy efficiency levels for new CAC equipment are:

- Provision of information (labelling, grading, efficiency ratings)
- Removing less efficient models from the market (MEPS or voluntary agreements)
- Encouraging higher sales-weighted average efficiency levels through negotiated agreements (e.g. fleet-average efficiency targets)
- Financial and/or fiscal incentives for higher efficiency equipment
- Public procurement and general market transformation programmes

**The European Commission and/or a coalition of willing Member States should consider:**

- the development of an EU model building code that addresses air conditioning amongst other energy end-uses. (an EU equivalent to ASHRAE 90.1 and which like ASHRAE 90.1 is subject to continuous improvement)
- The development of practical public domain CAC system design tools which: a) can aid system designers to develop energy efficient CAC designs, b) can enable to compare of the relative benefits of different system designs, c) can be used in building thermal regulations to demonstrate compliance with requirements
- The development of EU benchmarks for CAC system efficiency expressed in terms of: building function and size; occupancy and purpose; quality of comfort provision and climate (e.g. cooling and heating degree days)

**Further to this, Member States should undertake a revision of their building thermal regulations to address a number of specific issues aimed at reducing CAC energy consumption which are described in the report.**

**The European Commission and/or a coalition of willing Member States should also consider:**

- Making efforts to define best practices in operation and maintenance
- Making efforts to define best practices in operation and maintenance performance contracting

**With an aim of informing national building thermal regulations and the implementation of the Energy Performance in Building Directive.**

Member States could also consider the development of low cost mechanisms to encourage the adoption of good practice for CAC operation and maintenance (namely by ESCOs).

## 1. INTRODUCTION

SAVE II is an EU programme to promote the rational use of energy within the European Community. The EECCAC working group began a study in April 2001 to investigate the technical and economic potential of measures to raise the energy efficiency of Central Air-Conditioners (CAC). The EECCAC study follows-on from the EERAC SAVE study which investigated the potential for measures to raise the energy efficiency of room air-conditioners (RAC) and which is available from the same co-ordinator (EERAC 1999). Since the EERAC study covered all types of AC of under 12 kW cooling capacity, the present study is concerned with air-conditioning systems over 12 kW and will eventually integrate the two segments in a common picture of the European industry and market.

The objectives of the study are:

- to estimate the electric power consumption of CAC,
- to estimate potential energy savings deriving from the use of more efficient CAC,
- to investigate ways in which these savings can be realised,
- to make appropriate recommendations, on the basis of a cost–benefit analysis.

The working party has been gathered and co-ordinated by Jérôme Adnot from Armines. The work has been organised in tasks for which the best experts have been chosen as task leaders. A broad coverage of energy agencies, utilities, technical experts and manufacturers' representatives are involved in the work in order to be sure that state of the art knowledge is available for each aspect of the study.

### Selection of technical experts

The following technical experts are participating in the EECCAC study:

- Armines is a research association supported by the Ecole des Mines de Paris and is especially active in the field of energy efficiency, with activities ranging from technological development to socio-economic investigations.
- PW Consulting is a UK-based consultancy specialising in equipment energy-efficiency initiatives and programmes around the world.
- INESTENE and –later- Energie Demain are leading consultancies on demand-side management (DSM) in France,
- Eurovent Certification was established by the Eurovent/Cecomaf manufacturers' association for the certification of performance of air-conditioning and ventilation equipment.
- The University of Athens, in particular the Group of Building Environmental Studies, is very active in the field of solar cooling and energy conservation in buildings; the group carries out research, specialised studies, application projects, education, and dissemination of information.
- Politecnico di Milano, and namely the Department for Energy studies is the main supporting laboratory for the HVAC engineers gathered in AICARR,
- AICIA supports the research by ETSIS, the famous HVAC engineering school in Sevilla,
- UTCB is the Romanian Technical University for building sciences,
- ITF is an HVAC consultancy in the region of Chambéry, France

## Participation of energy agencies, utilities, manufacturers and national experts

The coverage of national and industrial expertise in the study was ensured through the participation of the following bodies:

- EdF (Electricité de France), the French electricity utility, who brings an important contribution to the study of this growing electrical end-use. EDF are represented by Pascal Dalicieux and Frank Colomines
- ADENE-CCE, the Portuguese energy-conservation agency, has a significant experience;
- AICARR, the Italian association of Air Conditioning, Heating and Refrigerating engineers, who includes professionals working on international standards development, maintains special Observatories on Hospital air conditioning technology and Refrigerant fluids and cycles.
- EVA, the Austrian energy research and policy institution in which the federal and provincial administrations ('Bund' and 'Länder', respectively) and some 30 important institutions and corporations from a variety of economic sectors co-operate.
- IDAE, the Spanish energy-conservation agency, has close relationship with all bodies having an influence on CAC in Spain,
- BRE is the leading UK centre of expertise on buildings and construction. Its energy-related activities include technical research and consultancy, managing the Government's buildings energy-efficiency information programme, providing strategic analysis of energy-efficiency policy options and modelling the energy performance of the UK building stock.
- Eurovent/Cecomaf and Eurovent/Certification is the manufacturers' associations for refrigeration, air-conditioning and ventilation equipment, represented by a number of members, namely Mr Sormani from Climaveneta, Mr Van de Velde and Ms Jacques from Daikin, Mr Coates from Airedale, Mr Zucchi from AERMEC, Mrs Huguet and Ferrand from Carrier, Mrs Goral and Legin from Trane.

Not only did Eurovent actively participate in the plenary meetings of the EECCAC working groups, but they have also held a number of specific working meetings with their members (European manufacturers), including those of WG6A (May, 28 and November, 23, 2001 and October, 3, 2002), with the following companies in attendance: ACE-Airwell, AERMEC, Airedale, Carrier, Climaveneta, Daikin-Europe, Ferroli, Galletti, Lennox-Europe, Multiclimate, Teba, Trane, York. The manufacturers have opened their laboratories for visits by the EECCAC co-ordinator and some of them (Carrier & Trane) have shared some valuable data bases for use in the study. Through the course of the EECCAC study an agreement to conduct a common part load testing programme for chillers on the European market has been reached between EDF and Eurovent on the basis of a shared costs procedure.

During each of the EECCAC working meetings held in Paris, Athens, London, Lisbon<sup>3</sup>, Madrid, Milano and Vienna, a number of national AC experts were invited to attend and express national views and policies, which has been a valuable input to the work. On total 50 professionals or representatives of associations attended our dissemination and exchange meetings.

Further contact concerning present EECCAC study or EERAC results or paper copies of the reports can be obtained through:

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<sup>3</sup> See final report to contract no. XVII/4.1031/Z/ XXXX co-ordinated by Prof. Roriz, IST, Lisbon.

## 2. CENTRAL AIR-CONDITIONERS IN EUROPE: DEFINITIONS AND BASIC DATA

### ***2.1. Importance of AC for human health and productivity performance, link with ventilation***

The use of air conditioning is increasing rapidly in Europe, as a result of an increasing trend towards control of the indoor environment and a wider diffusion of air-conditioning systems as a consequence of economic growth, which has made them more affordable. However, this is also partly a consequence of a movement towards higher economic productivity. Accurate figures have shown that a better indoor working environment leads to less quality problems, higher productivity and less accidents in the workplace, provided it does not create too much noise. We are not in a situation where air conditioning specialists and companies generate an artificial need, but are rather in a situation where they offer new ways to answer existing needs or decrease total costs. However there is a need for them to be able to prove case by case that their techniques are cost effective for the intended purpose and that they have optimised their proposed solution, which is a major reason why industry has been so active in co-operating with the EECAC study.

#### **What is "comfort"?**

In any case, the comfort level to be reached should reflect the nature and quality of the activity which takes place in the conditioned space. There is no value in "cooling buildings", but there is in being able to establish desired comfort levels in the internal spaces where people work or perform other tertiary activities.

To give a rough presentation of the range of comfort conditioning requirements and circumstances that can be encountered, the following main cases are listed:

**NC- Natural Cooling** which is obtained, day or night time, by forced-ventilation, when outdoor conditions permit, or by any other ways of transferring heat to the outside, provided they are not based on the operation of a compressor. Natural cooling is usually insufficient to attain always and everywhere the required comfort levels but can be found sufficient in most circumstances in climates like the UK or Northern Europe.

**PC- Partial Cooling** which is obtained with air conditioning equipment that provides partial control of the temperature. For instance, the rooms are cooled but fresh air may be introduced without cooling, or the installed cooling capacity of the AC system may be insufficient for all circumstances, as a result the internal air cannot be kept at a constant temperature. This may be felt as comfortable in France or Germany.

**TC- Total Cooling**, wherein the AC system provides full temperature control and includes the provision of the minimum rate of ventilation air changes required for hygienic purposes at an adequate temperature. This type of equipment allows a degree of dehumidification consequent to the cooling effect– it is a very frequent level of comfort today.

**TAC- Total Air Conditioning**, which includes full control of temperature and humidity as well as provision of the minimum ventilation rate required for hygienic purposes but is not capable of attaining air purity conditions for specific IAQ (Indoor Air Quality) levels.

**AAC- Advanced Air Conditioning**, same as TAC but with a full control of IAQ. These systems are particularly applied in hospitals or clean rooms in the electronic industry.

The variation in comfort level changes the consumption of energy. If one wanted to make a complete comparison, it would be necessary to give a monetary value or some other proxy quantity to discomfort and to balance it with the total cost of the service. The question was less difficult for the RAC studied in the EERAC study which were deemed to provide " equal service" at the PC or TC level of comfort. The differentiation of comfort has substantial consequences for the systems' energy consumption, but one should not regard a decrease in the quality of the indoor environment as a means of saving energy without being conscious of the trade-offs involved.

## **Comfort level, Ventilation: our assumptions for the study**

From one extreme to the other both the cost of installing the initial AC equipment purchase and of operating it can vary by a factor 10, but consideration of the choice of who or what really needs a certain level of comfort is outside the scope of the present project. Most comparisons between systems are thus to be done internally to a given assumed comfort level even if it is possible to gain an idea of the relative cost of the various possible comfort levels. Total Cooling will be used as the appropriate value for benchmarking. It is more difficult to predict the future level of comfort expectations and even more the speed of change.

There is a strong interaction between two functions: ventilation (i.e. air changes) and cooling. The technical systems used differ from one country to another depending on the basic philosophy embedded in the regulations and building codes. Two philosophies of ventilation seem to exist in Europe : in the first one (adopted by Northern countries), ventilation comes first as an hygienic necessity and then a further decision leads to cool the space or not. In the second one (apparently Southern States), the decision of A/C comes first and leads to more air changes with the outside, and to controlled ventilation. **Central ventilation (with cooled “primary air”) is the base of our technical study together with the TC comfort level.**

## **2.2. Basic definitions**

Air conditioning is a technology, supported by thermodynamic and physical science, intended and designed to change and improve the conditions (mainly temperature and moisture content) of the outdoor air to be supplied in an enclosed space in order to make it possible to fulfill an industrial process (Industrial Air Conditioning ) or maintain specific conditions needed by equipment installed in the space (Control Air Conditioning) or for the well-being of the human presence (Tertiary<sup>4</sup> and Residential Air Conditioning).

The EECCAC study is concerned with tertiary air conditioning and is focused on the important and practical issues that surround the design of "conventional" air-conditioning systems of types that are already well established in the market-place and thus does not include the so-called "low energy cooling options" : passive buildings, desiccant or evaporative cooling. Despite this the range of equipment and technical issues included in the EECCAC study is very wide and therefore the related energy conservation topics of lowering cooling loads, and deploying innovative but, as yet, little-used systems are outside its scope.

### **RAC and CAC in competition**

Central Air Conditioning systems (CAC), the subject of our study, are characterised by a central refrigerating unit operating together with an air treatment unit and make use of a fluid (air and/or water) to transport cold to the air conditioned space. They perform other functions than just refrigerating, like controlling air change, air quality and humidity. Their specifications are determined by engineers or technicians, who usually design the system and its associated energy performance without any direct influence from the final customer or user (except for the preliminary limitations on cost).

A ‘Room Air-Conditioner’ (RAC), as opposed to an ‘air-conditioning system’ (CAC), is an appliance that can be bought by a household, with a direct link between the customer and the selection of the purchased good – either direct purchase by the household or through an installer with whom negotiation and specification of the appliance takes place. The existing results of EERAC, the previous study on RAC, can be used as a basis for the present study, when we come to such RACs. We have excluded from our research absorption machines (running on gas or waste heat), and the use of any other fuel than electricity, which are still very infrequent solutions.

### **Basic Thermodynamics at one instant**

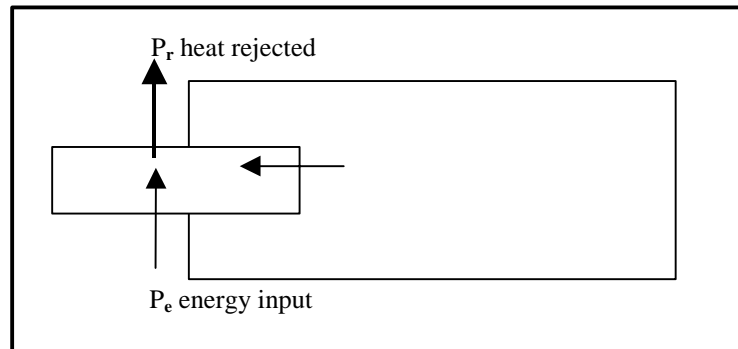
The simplest AC system, as illustrated in Figure 2.1, cools the space around the people or the process in summer by rejecting the heat outside the room, with a limited or complete control of the room humidity

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<sup>4</sup> Tertiary is a European word indicating all human activities and related buildings other than industry or households

and air quality. From an energy perspective, this situation is summarised by a “load” to be extracted or cooling effect  $P_c$  (the minimum thermodynamic quantity necessary to maintain the defined comfort conditions). In fact the desired comfort conditions may include thermal comfort (which is expressed in terms of a mix of convective and radiative temperatures), humidity control and indoor air quality (IAQ), which is usually obtained through ventilation, i.e. by the change of indoor air, and filtration components.

Figure 2.1 Essential quantities in the process of air-conditioning in summer, seen from an energetic perspective



The accepted energy performance index is called the ‘energy efficiency ratio’ (EER) and is defined as:

$$EER = P_c / P_e$$

Cooling only systems (not including ventilation, or air quality, or humidity control) extract heat in summer from inside the room ( $P_c$ ), approximately equivalent to the value of the “load”, through the use of electricity ( $P_e$ ). Usually the heat rejected outside ( $P_r$ ) has an energetic value equivalent to  $P_e + P_c$ .

There are also some cooling systems which offer the possibility to produce heat instead of cold by reversing their refrigeration cycle: such systems are called ‘reversible’. A similar index to the EER, the coefficient of performance (COP), is applied to indicate the performance of reversible AC in the heating mode. It is the ratio of the heat input into the conditioned space and the electric power consumed to transfer it.

### Main technologies for cold production

**Evaporation** of the liquid "refrigerant" (R22, R407C, R134a, etc.) creates the "cold" in the evaporator, which subsequently absorbs heat from the refrigerated space. We shall describe the steps of the technology and give the specific names for the chillers, the largest single equipment (figure 2.2). The characteristics of the evaporator technology depend primarily on the required application and the type of cold source. Two broad categories exist:

- air-cooled evaporators, or direct expansion evaporators consisting of a pack of finned tubes through which the air is forced;
- liquid-cooled evaporators, or flooded evaporators consisting of a tabular shell in which the refrigerant expands and cools a fluid circulating in a bundle of tubes inserted in the shell.

After its full evaporation the refrigerant vapour is compressed using a **compressor** for which the following main technologies are used:

- reciprocating compressor
- screw compressor
- scroll compressor
- centrifugal compressor.

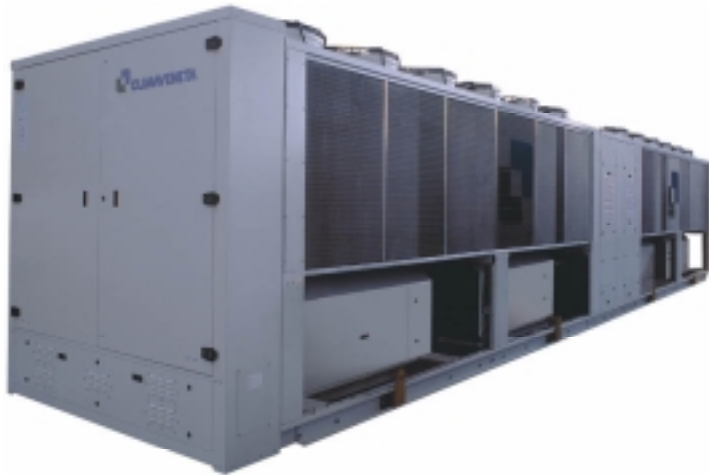
The centrifugal compressors will not be studied in details in this report. They are relatively infrequent industrial compressors of a large size and very efficient<sup>5</sup> and we can relate them more with “district cooling” or “block cooling” that really with “Air Conditioning”.

A wide range of technologies are used to couple the compressor to the electric motor:

- open type or accessible compressors, presenting detachable parts to access the compressor’s main components and coupled to separate electric or thermal engines. They can be used with any refrigerant but are generally employed in systems with medium to high cooling capacity.
- "Semi-hermetic" compressors that are similar to the open type compressors but have a common casing with the electric motor; they are generally used for systems with medium cooling capacity.

Hermetic compressors, which have their body directly coupled to an electric motor cooled by the refrigerant and enclosed in a totally sealed shell; these are generally used for systems with a small to medium cooling capacity.

Figure 2.2 An aircooled chiller (courtesy Climaveneta)



After its compression the refrigerant vapour is condensed while evacuating the heat corresponding to the one absorbed at evaporator level and the thermal equivalent of the work of the compressor. The **condenser** technology depends primarily on the required application and the heat source. Condensers used in CAC systems are divided into three categories:

- air-cooled condensers consisting of a finned tube heat exchanger (figure 2.3). The primary factor which influences the performance of the condenser, is the outside air temperature.
- water-cooled condensers consisting of finned tubes with internal grooves to increase the heat transfer surface area and the overall heat transfer coefficient. The temperature and flow rate of water have the greatest influence on the condensing temperature. The water used as the coolant may be from a natural water source (such as a river or aquifer) or from re-circulated water that’s been cooled in a cooling tower.

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<sup>5</sup> They enable a high pressure ratio because of the absence of alternative compression. The compression ratios can vary between 2 and 30. The turbine is called the impeller. If the fluid enters the impeller with a tangential component or swirl, that would occur only at non-nominal or bad designed points, the speed of the refrigerant would be consequently reduced as related to the speed of the impeller. The ratio of pressure producing work to kinetic energy output is known as the impeller reaction and ranges from 0.4 to 0.7. That’s why, after the impeller, one can find a diffuser that ends converting kinetic energy into pressure lift. The observed performance is around 6.00 in terms of EER and 5.7 in terms of SEER, between 50 and 100 % better than the chillers of smaller size.

- Evaporative condensers, which are used in industrial applications and combine a condenser and a cooling tower in a single apparatus.

Figure 2.3 Inside an air cooled chiller (Courtesy Airedale)



A water cooled chiller (figure 2.4) is generally used with a cooling tower. Among **cooling towers** there are three principal systems:

- Indirect contact (Dry) cooling towers where there is no contact between the cooling fluid (air) and the fluid to be cooled (water)
- Direct contact (Wet) cooling towers where there is a direct contact between the two fluids thus providing better heat transfer
- Wet-dry towers, which contain a conventional wet type tower in combination with an air-cooled heat exchanger. They are especially used to reduce water vapour plumes and hence water consumption.

A wet cooling tower (which displays better energy performance) is more at risk of cultivating the legionella bacillus and consumes water.

Figure 2.4 A water cooled chiller (Courtesy Carrier)



After condensation the refrigerant is expanded by an **expansion valve**, which is used to throttle the refrigerant fluid back to the evaporator pressure and to control the refrigerant flow. Three systems are used:

- expansion devices with a constant pressure difference.
- thermostatic expansion valves that are controlled via the superheating.
- electronic expansion valves that are also controlled via the superheating.

The consequences in terms of energy consumption of all these technical choices will be investigated in the rest of the study.

### **CAC systems types based on distribution**

The system is integrated by a number of interrelated elements controlling the total comfort, such as air filtering, humidity treatment, central or local re-heat , etc.. In many cases the same system has to also take care of the heating mode. Essential components of a CAC system are:

- Water chiller with an electrically driven vapour compressor,
- Air treatment central unit if we want to provide refrigerated air,
- Distribution structure including networks of fans, ducts and pumps for refrigerated air and water circulation,
- Terminal room units for local air treatment (most frequent),
- Assembly of automatic controls to keep the requested conditions and general safety.

The number of possible systems that can be obtained by the combination of these elements is very large: the EECCAC study has developed a set of documents (additional to this report) to cover the systems that can be defined in an exhaustive manner, so as to create a common vocabulary and terminology in further EU regulatory work on CAC.

### **Classification of the systems**

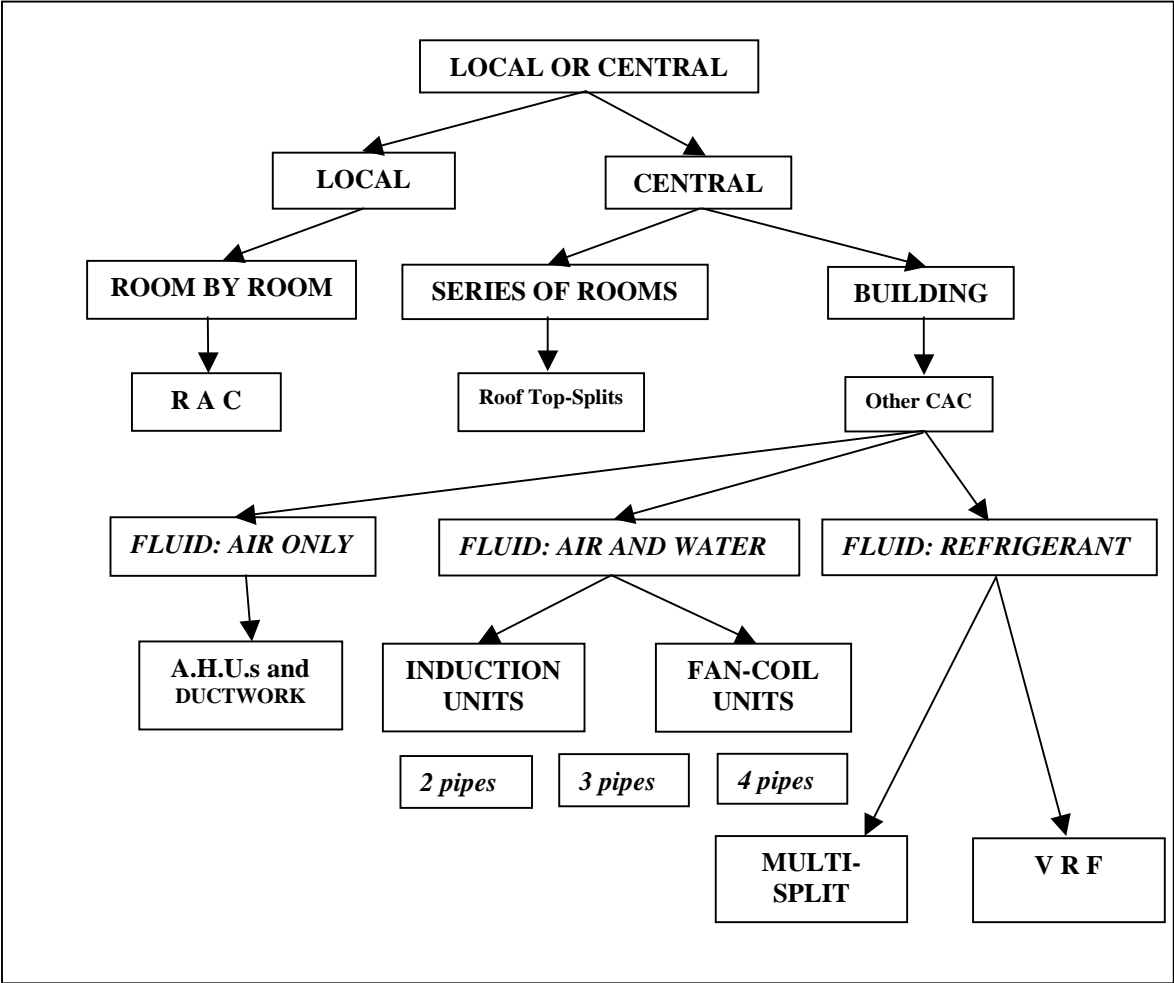
Most large plants have to combine a number of systems, each of them addressing different parts of the space having different loads, occupation scenarios, load levels. In this study we have considered only generic systems (one system for one zone) and not the combinations of various systems in such larger plants. Among the many systems to consider (50 or so), some are obviously too complicated, some are infrequent and costly and only half a dozen deserve real interest for their low initial cost or for their comfort or adequacy to the needs.

The structure of a CAC system (and consequently its name) results from the accumulation of a number of decisions on the essential components. The first choice determining a system is the choice of the fluid being refrigerated centrally and circulated. The most frequent (and really dominant option) is the use of a chiller that generates cold water (typically at 7°C), which is used to transfer "cold" to the building space partly through a centrally treated flow of air and partly through a water distribution network.

Even in this predominant CAC system a choice must be made regarding how to transfer "cold" to the air. There are, for instance, "induction systems" or "fan-coil systems" and these can be used with a water distribution network including two or three or four pipe assemblies.

Other systems are applicable to a series of rooms and their application depends on the number of rooms and the general situation of the building. In many cases large Unitary Air Conditioners (or Packages), which are self-contained, direct-expansion (without water) apparatus can be applied as well as Multi Split systems, a particular assembly of residential "split systems", originally covered in the previous EERAC study. The VRF (Variable Refrigerant Flow) system (also sometimes called a "modulated capacity" system) is a relatively new development on the CAC market that is based on the "split system" and has the potential to produce some interesting energy savings. These descriptions lead to the idea of a descriptive systems tree, of which some significant branches are presented in Figure 2.5.

Figure 2.5. CAC system description tree showing the most common CAC systems



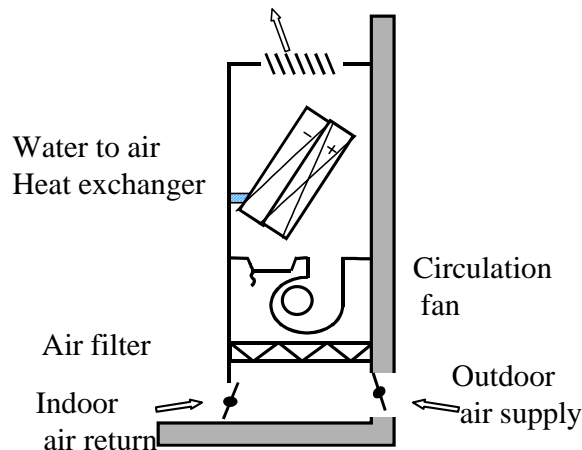
**2.3. Description of other aspects of systems**

**Terminal units and other peripheral equipment used**

The optimisation of many pieces of equipment is required to attain the optimal operation of the system: constant or variable flow mixing boxes (air), fan coil units, air handling units, induction units, humidifiers and de-humidifiers, balancing valves and dampers, controllers, etc.

The main devices which provide comfort are Fan Coil Units, which transfer heat from the air in the locally cooled zone to a cold water circuit (Figure 2.6) and Air Handling Units which cool air more centrally before its distribution and diffusion into the rooms (Figure 2.7).

Figure 2.6. Plan of a fan coil unit



There are **various kinds of FCU**:

- a 2 pipe fan coil (2P) for cooling only; the heat exchanger comprises one supply and one return pipe only for refrigerated water;
- 2 pipe fan coil with change-over (2PR). The same system is used in all zones and comprises one supply and one return pipe as the previous one but circulation of which can be of either hot or cold water. A reversible chiller supplies either cooling or heating and changeover from one mode to the other is centrally regulated according to season. This system cannot heat and cool simultaneously in two different rooms and hence is used when the summer-winter transition is easily distinguishable;
- 2 pipe fan coil with electric heating (2PE). This system may be reversible or not, according to needs. An additional electric resistance heater can be complementary to the reversible heating mode or can be the main heating source for weak loads during the winter period. This system can heat or cool simultaneously in two different rooms;
- 4 pipe fan coil (4P) with two coils frequently assembled together. The same system can be used in all zones, and comprises a supply and return for both hot and cold water and can thus heat or cool simultaneously different rooms of the same building. A 3 pipes system as well as a 4 pipes system with only one coil existed and disappeared.

There are also a **wide-variety of air handling units** (AHU –see figures 2.7 and 2.8) used for the remote preparation of cold air.

Figure 2.7 Air Handling Unit with heating, cooling and variable air flow distribution

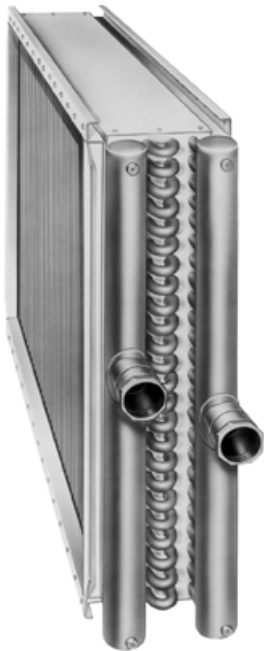
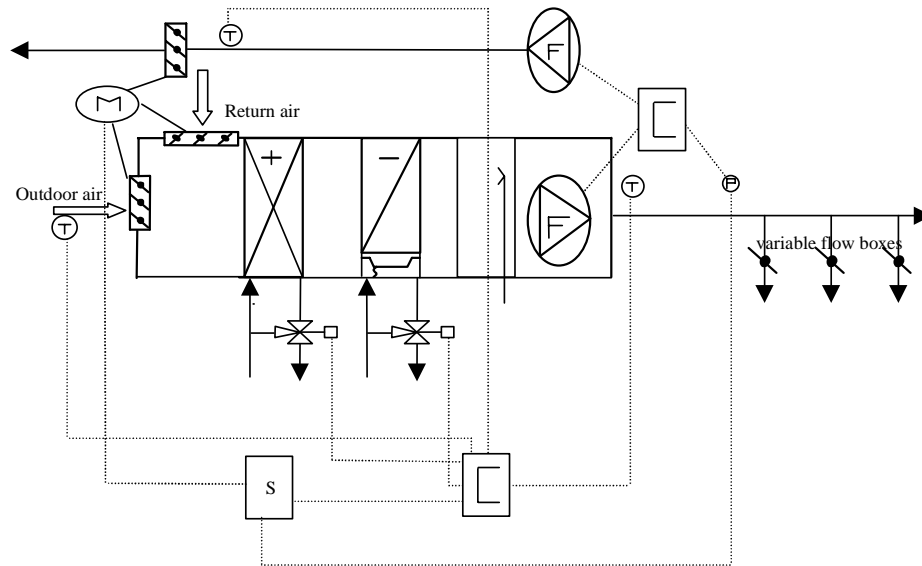
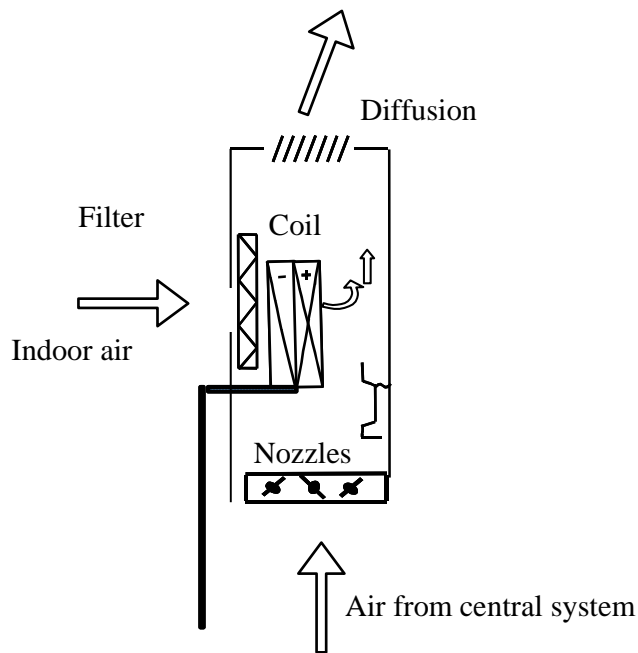


Figure 2.8 The « coil » providing heating and cooling inside an AHU (Courtesy Trane)

**Induction units (IU)**, less frequent nowadays, are used when centrally distributed air is further cooled at the local level through thermal contact in the IU with refrigerated water circulated in a central water loop, Figure 2.9.

Figure 2.9 Induction Unit



### General classification of systems based on chillers

These can be divided into single-zone or multi-zone systems, which may be: single duct or dual duct; use fresh air only, or employ a heat recovery system; have terminal reheat or not; etc. Terminal reheating carried out with an electric resistance heater or a gas furnace heater but never with a water coil. AHU systems can also be distinguished between those that have a variable flow and those which have constant flow. The EECCAC study has developed a specific terminology to describe this variety of systems.....

As mentioned before, systems using water chillers are the most frequent type of central air conditioning system used in the EU.

A water chiller, comprising a group of equipment to refrigerate water, cools water, which in turn is used to cool off centrally supplied air in an air handling unit and/or is circulated to room terminal units (RTU) for local air treatment.

Due to the complexity of descriptions involved, it is useful to present all the possible systems which could work with chillers in a synthetic table (2.1).

Table 2.1 Classification of central systems based on chillers

SYSTEM CLASSIFICATION SUMMARY				
1. ALL AIR SYSTEMS				
refrigeration: chiller (air or water cooled with/out cooling tower)				
air treatment: central station type, air handling units				
CONDITIONED ZONES	AIR DISTRIBUTION	AIR VOLUME	AIR TEMPERATURE	A.H.U. CONFIGURATION
SINGLE-ZONE	SINGLE DUCT	FIXED	VARIABLE	CAV with terminal re-heat with by-pass on re-

				circulation with by-pass on mixed air with control on coil capacity
MULTI-ZONE	SINGLE DUCT PER EACH ZONE	FIXED PER ZONE VARIABLE VARIABLE	VARIABLE PER ZONE CONSTANT VARIABLE	Multi-zone CAV  VAV systems VVT systems
	DUAL DUCT	FIXED	VARIABLE	with terminal re heat first duct - cold air second duct – hot air
	DUAL CONDUIT PRIMARY AIR SECONDARY AIR	FIXED VARIABLE	VARIABLE CONSTANT	Hgh pressure systems

2. AIR-AND-WATER SYSTEMS				
refrigeration: chiller (air or water cooled with/out cooling tower)				
Air treatment: primary air – central station type, air handling units				
secondary air – room treatment				
TYPE OF AIR	AIR VOLUME	AIR TEMPERATURE	AIR DISTRIBUTION	
PRIMARY AIR	FIXED	VARIABLE	SINGLE DUCT	std velocity for systems with fan coils high velocity for systems with induction units
SECONDARY AIR	Treatment by room terminals: fan coils, induction units, radiant panels			

## **Number of water loops connected with the chiller**

The simplest solution is to have one single water loop in the conditioned space. It can be used for cooling when connected to a water chiller and for heating, when connected to a boiler, the transition being called “change over”. The same loop can be served by a reversible chiller provided refrigerated water in cooling mode or hot water in the heat pump mode. For more comfort, two water loops are installed (hot and cold) with distinct generators, or alternatively to each side of the chiller (reversible heating and cooling). The chiller is still only connected to one loop at the same time. In a further refinement the chiller is installed between the cold and the hot loop, taking complete advantage of COP and providing at each instant a reversible solution.

## **2.4 Description of systems not using chillers**

### **VRF (Variable Refrigerant Flow) CAC systems**

VRF or modulated capacity systems are based on the “residential split system” technology although in this case a large series of rooms potentially up to the level of an entire building can be served. Although they are similar to multi-split systems (a residential split system serving several rooms), they have not been accounted for in the previous EERAC study due to their higher cooling capacity.

VRF systems are classified as built-on-site systems; because when the outdoor condensing unit is selected in accordance to the indoor units needed for the entire system, the installation has to be done and adapted to the site.

VRF indoor units are equipped with electronic expansion valves which continually adjust the flow of refrigerant to match their specific cooling capacity to the local “load” requirements. In addition, VRF systems are capable of being controlled to simultaneously satisfy different building zones requiring different thermal conditions. They are able, in fact, to transfer “heat” and “cold” according to the local need with a very low energy consumption. VRF units are available in three versions: cooling only, heat pump and heat recovery.

### **Water Loop Heat Pump CAC systems based on local packaged AC systems**

This system is based on a closed loop of water-cooled packaged reversible heat pumps which can potentially operate independently with some in cooling and some in heating mode. The advantage of the system is that the closed water circuit can transfer heat rejected from the units operating in cooling mode to the others which are operating in heating mode and thereby minimise energy consumption. Although the use of a central chiller and a central boiler is often also necessary, their sizing can be minimised. A more efficient version of this system makes use of thermal storage and in some cases of ground water sources.

As for VRF systems, the installation needs to be adapted to the site. This system is particularly viable when there are simultaneous cooling and heating needs in the building.

### **Local package CAC systems: roof-tops and close control cabinets**

Although these systems are not installed far from the rooms that they have to cool, they don't use water pipes to distribute cold and have no, or very limited use of, air ducts. The two commonly used systems, Roof Top Units and Close Control Cabinets, are still considered to be “central AC systems” because they don't work on a room-by-room basis and their cooling capacity is often much higher than 12 kW. They are frequently used in super markets and in telephone central technical rooms although in other economies (i.e. the USA) they are commonly used in much wider applications. Roof top units are always air cooled whereas close control cabinets may be water or air cooled; in all cases they are self-contained units which are completely assembled in a factory. “Free cooling” can be available in many types of Roof Tops and two operating modes are possible for most of the available technologies: cooling only and reverse heat pump cycle.

### **Inclusion of RAC in the present study**

Should we neglect RAC or include them here? To answer this question, figures about the market and level of cooling provided by RACs drawn from the EERAC study have been utilised in the present study. RAC are used for 78% in the economic sectors and for 22% in households. It is better to compare the shares of all competing AC types in a single scenario for a given economic sector and country. This also helps to understand the real basis of competition between RAC and CAC systems; and should thereby avoid potentially distorting impacts from isolated policy actions.

Four types of air-cooled RAC are widely used:

- Split-packaged units; consisting of two sections (one indoor and one outdoor unit) connected only by two pipes that transfers the refrigerant and a cable for the electric power. The indoor unit includes the evaporator and a fan, while the outdoor unit has a compressor and a condenser. There is a range of “large split systems” over 12 kW of cooling capacity and therefore are usually classified separately from the residential splits.
- Multi-split-packaged units; consisting of several indoor units (usually four or more) connected to one outdoor unit. This family of AC equipment is partly under 12 kW of cooling capacity and partly over. VRF (Variable Refrigerant Flow) systems can be considered as a version of multi-split systems but are always over 12 kW in cooling capacity.
- Single-packaged units; are commonly known as ‘window’ or ‘wall’ RACs wherein one side of them is in contact with the outdoor air for condensation, while the other provides direct cooling to indoor space by means of an air circulation fan.
- Single-duct units; which are packaged AC appliances that are kept inside the room while cooling the space, and reject hot air from the condenser to the exterior space through a duct.

Water-cooled units of any type under 12 kW cooling capacity were part of the previous EERAC study. The water used in RAC could in principle be drawn from a natural water source, but this is seldom available; the main use of water-cooled RAC is therefore limited to closed-loop heat pumps as previously described in this section as one of the CAC systems with a comparatively high system efficiency.

**Summary of choices in terms of local versus central systems**

A growing distance between the “centre” and the rooms increases losses and auxiliaries, leads to the choice of a carrier but generates positive scale effects. Heating, ventilation and air conditioning systems can be split in secondary (air-side) and primary (water side) systems. There is always an air side, but it can be generated far from the room or close to it. To sum up, most system types can be classified according to the air handling situation (central versus zonal) and cold source (hydronic versus package) criteria. This classification based on the EE view is shown in table 2.2 .

Table 2.2 Summary of choices having in mind internal factors of Energy Efficiency

ST	AH SITUATION	COLD SOURCE
CAV	Central	Hydronic
VAV	Central	Hydronic
RT	Central	Package
FC4P	Zonal	Hydronic
FC2P	Zonal	Hydronic
WLHP	Zonal	Package
PTAC	Zonal	Package

**Sizing issues**

In general all the related issues within the borders of CAC energy efficiency have been treated as diligently as possible. In particular, the potential problem of equipment over-sizing had to be treated explicitly. Since a CAC system is designed and sized by a professional engineer who is usually concerned to minimise the

initial investment cost, we can expect that on average there is no over-sizing in this case. There are however many examples of oversizing, which should be related to some specific factor (type of contractor, level of expertise, time allocated for sizing, etc). We made the assumption of a fair and economic sizing. In the case of RAC, which are bought directly without any advice or even from a retailer interested achieving the highest purchase value or from an installer who enjoys a margin on the equipment sold, it is assumed that the average European RAC is over-sized by a factor of 2 (i.e. 100% over sizing). For consistency reasons we have chosen a single value for sizing all CAC systems and converting capacities into areas and later areas into capacities (120 W/m<sup>2</sup>) and another one for all RAC systems (240 W/m<sup>2</sup>). This value, being used twice in opposed ways, has no influence on our statistics.

The ratios of consumption per square meter and the cooled areas are all presented as “standardised” area (based on 120 W/m<sup>2</sup>) but on one occasion figures have been produced with a variable sizing depending on location, building, system type to allow national comparison. Note that the notion of conditioned area is uncertain in national statistics : not the gross built area, not the strict area of activity rooms; conventions may vary from one country to another, a fact that gives interest to our repeatable “standardised” area.

### Free cooling

At some time during the year, outside air can be used directly to cool the space without any special thermal treatment. There are control issues associated (flow rate, movement of dampers, nature of control : based on temperature only or on enthalpy), etc.

## 2.5. Testing standards and performance standards

A branch of the trade association Eurovent has defined the set points for which performance is reported by industry, thus allowing performance comparison at full load, in accordance with CEN standards. In the same way the American ARI (American Refrigeration Institute) and ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) set US standards. Efforts have also been made by ISO to define internationally applicable testing standards, but ISO standards are not currently available for all the required equipment types.

The European method to test chiller cooling capacity is defined in the proposed European standard prEN 12055 and in the equivalent Eurovent Certification standard 6/C/003-2001. The US test method is defined in ARI 550/590-1998 ‘Water-Chilling Packages Using the Vapor Compression Cycle’. However the ARI documents often mix pure testing standards, testing conditions and extrapolation to yearly behaviour of equipment in the US in order to facilitate energy performance requirements to be set by a legislative body. Thus in some ways, the US standards have progressed more than the European ones, although they are not directly applicable in European conditions. An international test standard is being developed as ISO PWD 19298-2001-Draft 5: ‘Liquid-chilling packages using the vapour compression cycle – testing and rating for performance’ This ISO standard, which is being developed by ISO TC 86, is not yet ready and is not expected to be for some time.

### Chillers: the CEN and ARI approaches (at full load and IPLV)

The US and European full-load chiller test conditions (with a built in condenser) are as follows:

#### -- Cooling operation

	<b>Eurovent Certification (at full load)</b>	<b>ARI Standard 550/590 – 98</b>
Leaving chiller water temperature	7°C	6.7°C (44°F)
Entering chiller water temperature	12°C	About the same (the water flow is fixed by the standard)
Entering condenser water temperature	30°C (water cooled)	29.4°C (85°F) (water

		cooled)
Entering condenser air temperature	35°C (air cooled)	35°C (95°F) (air cooled)

**-- Heating operation**

	<b>Eurovent Certification (at full load)</b>
Leaving condenser hot water temperature	45°C
Entering condenser hot water temperature	40°C
Evaporator inlet air temperature	7°C dry-bulb 6°C wet-bulb ( air cooled)
Evaporator inlet water temperature	10°C ( water cooled)

There is no great difference in the full load chiller test conditions under ARI (US) or Eurovent (European) specifications. For this reason energy efficiency measurements at full load are directly comparable between the two systems. The only difference is that the pumping power is “forgotten” in ARI values, which overestimates by 1% air cooled chillers EER, and by 3% water cooled chillers EER. ISO harmonisation on full load is easy. However the situation is not the same for part-load operation, which is the normal operating condition for AC systems and the one where very significant energy efficiency improvements appear to be possible.

**ARI Standard 550/590 – 98 testing at part load conditions**

The current European test standards do not include part-load ratings, whereas the chiller certification programme operated by ARI in the USA does include part-load performance ratings. The intention of part load rating is to enable the energy and cooling performance at part-load to be assessed over a wide range of typical operating conditions.

The weighing of part load points in ARI 550/590 are given in Table 2.3.

Table 2.3 Parameters used in the US IPLV

% load	Air entering condenser (DB)	Water entering condenser	Operating hours %
100	35	29.4	1
75	26.7	23.9	42
50	18.3	18.3	45
25	12.8	18.3	12

This load profile is the basis used to calculate the integrated part load value (IPLV), the seasonal average efficiency of a chiller.

The Integrated Part Load Value is thus calculated using the following equation:

$$IPLV = 0.01A + 0.42B + 0.45C + 0.12D$$

Where A = EER at 100% of full load

B = EER at 75% of full load

C = EER at 50% of full load

D = EER at 25% of full load

The suitability of this index for European operating conditions is considered in Chapter 7. Before our study a first proposal by the Italian AICARR was made, called EMPE.

### **Peripheral equipment of chiller based systems: testing and classification**

The following European test standards are in use for **Air Handling Units (AHUs)**: prEN 13053: 1999 'Ventilation for buildings - Air handling units - Ratings and performance for units, components and sections' prEN 1886: 1997 'Ventilation for buildings - Air handling units – Mechanical performance'

In the USA the ARI 430-1999 'Central station air-handling units' test standard is used.

The following international standards are also under development by ISO TC 86/SC 6: ISO NP 17524 'Testing and Rating of Air Terminals' and ISO NP 17515 'Testing and Rating of Air Diffusers'

Under prEN 1886-1997 the casing air leakage of the assembled AHU is tested and the system is graded according to the measured leakage rate, which must always be less than  $3.96 \text{ l.s}^{-1}.\text{m}^{-2}$  at 400 Pa negative test pressure for units that always operate under negative test pressure and should be less than  $5.70 \text{ l.s}^{-1}.\text{m}^{-2}$  at 700 Pa negative test pressure for the positive pressure sections of units that operate under both positive and negative test pressure. An additional test is conducted on the filter bypass leakage and the filter leakage performance is classified according to the results.

The thermal performance of the AHU casing is also tested and classified under prEN 1886-1997 such that the AHU thermal transmittance is measured under a 20 to 25 K steady-state temperature difference. Units with a transmittance of less than  $0.5 \text{ W.m}^{-2}.\text{K}^{-1}$  are classified as T1 while those with a transmittance of greater than  $2.0 \text{ W.m}^{-2}.\text{K}^{-1}$  are classified as T5. The T2 to T4 classes occur at intermediate values. Additional testing of thermal bridging in the casing is required and the casing's thermal bridging performance is classified on a non-linear one to five scale.

Performance testing requirements are stipulated in prEN 13053 for fans, coils, heat recovery sections, damper sections, mixing sections, humidifiers, filter sections and sound attenuation sections. Coils are tested and rated according to ENV 1216-1998 'Heat exchangers – forced circulation air-cooling and air-heating coils – test procedures for establishing the performance'. In addition individual coils must be sealed within the AHU casing such that the resulting air gaps do not exceed maximum permissible levels.

Three types of heat recovery section are recognised: recuperators, heat recovery sections with intermediate heat transfer medium, and regenerators (heat recovery sections containing thermal accumulating mass). Heat recovery sections are tested according to EN 305 'Heat exchangers. Definitions of performance of heat exchangers and the general test procedure for establishing the performance of all heat exchangers'.

Damper sections are tested according to EN 1751-1998 'Ventilation for buildings – Air distribution and diffusion – aerodynamic testing of dampers and valves' and must satisfy maximum permissible air leakage requirements. Mixing sections are tested for air mixing efficiency.

Room fan coil units are the subject of a proposed working draft of a new ISO standard (ISO/PWD 5) in ISO/TC 86/SC 6. An ISO test standard for air terminal units, known as ISO NP 17524, is under development by ISO TC 86/SC 6.

The following test standards are in use by Eurovent: Eurovent 6/3 'Thermal Test method for Fan Coil Units' and Eurovent 8/2 'Acoustic testing of Fan Coil Units in Reverberation Room'.

An ISO Committee Draft on testing of 'Air Conditioning Condensing Units' has been produced as CD 13258. As of August 2001 a DIS was being prepared for ballot which would include refrigeration condensing units. In the USA the following test standard is used: ARI 365 – 1987 'Commercial and industrial unitary air conditioning condensing units'.

ISO TC 86/SC 6/WG 8 has developed a proposed working draft PWD 16345 for 'Cooling Towers – Testing and Rating for Performance'. The Cooling Tower Institute in the USA has also issued a test standard to rate the performance of Cooling Towers, CTI 201-1986 'Certification Standard for Commercial Water Cooling Towers'.

### **A proposal for a better characterisation of AHU**

An AHU is characterised by the following information:

1. Nominal flow, intended as the working flow recommended by the manufacturer expressed in m<sup>3</sup>/h.
2. Available static head, intended as the difference between the static pressure measured upstream and downstream the AHU working at nominal flow without air recirculation.
3. Expected treatment typology: Heating; Cooling; Humidification Dehumidification
4. Filtration class, expressed according to the EN 779 standard.
5. Possibility of partial or/and total air recirculation
6. Presence of sensible or total heat recovery
7. Location of the AHU (indoor/outdoor)
8. Partial load efficiency, subdivided in:
  - a. Partial load exchange efficiency
  - b. Partial load air efficiency
9. Nominal power consumption, expressed in kW.

The listed information is necessary and sufficient to exhaustively define the functions and performances of an AHU. A proposal of a comparative method has been made. The comparative method is based on the principle that each AHU can be evaluated at every working condition comparing it with a reference AHU with the same functional characteristic. The reference machine is built keeping the layout of the AHU being evaluated and adopting conventional values for losses and efficiencies at nominal load and partial load values obtained by simplified methods. The conventional nominal values would be reported in tables and settled on the basis of criterion that allow for economics and technical factors. The approach will be tested as a possible UNI (Italian) standard.

### **Ventilation efficiency and Air Conditioning**

The capability of an air diffusion system to usefully introduce air in a room is described by the ventilation efficiency conventional parameter  $e_v$  defined by the ratio between the air flow ideally needed to keep the required air quality level in the room with the hypothesis of perfect air mixing and the real air flow required in the real air diffusion systems.

The nominal efficiency value of an air diffusion system depends on the following factors:

1. Diffuser typology,
2. Diffuser arrangement,
3. Supply temperature.

These three factors are combined together and they can not be considered independently from the performances standpoint. Yet, there are some directions, published by each manufacturer, which recommend the right installation conditions and the maximum operating temperatures at nominal load.

In particular, two different categories of air diffusion system can be identified:

- Mixing system with the air introduced above the occupied zone.
- Displacement systems or mixing systems with the air introduced below, or inside, the occupied conventional space.

The following tables 2.4 and 2.5 indicate the ventilation efficiency values for each system category, in the hypothesis that every system is projected, realized and installed in conformity with the manufacturer directions and that we remain at nominal conditions.

Table 2.4 – ventilation efficiency for mixing system with the air introduced above the occupied zone.

Diffuser typology	$e_v$	$e_v$
	$Dt < 0^\circ\text{C}$	$Dt \geq 0^\circ\text{C}$
Helicoidal effect diffuser	1,00	1,00
Cones diffuser	0,90	0,75
Linear slot diffuser	0,75	0,60
Outlet with single or double fin rows	0,70	0,60

Table 2.5: ventilation efficiency for Displacer systems or mixing systems with the air introduced below, or inside, the occupied conventional space.

Diffuser typology	$e_v$	$e_v$
	$Dt < 0^\circ\text{C}$	$Dt \geq 0^\circ\text{C}$
Floor helicoidal diffuser	1.2	1.1
Underseat diffuser or similar	1.3	1.3
Displacement diffuser	1.3	0.8

The efficiency value characterizes the share of the flow rate introduced that actually reaches the occupied zone, contributing to cut the heat loads and the air pollutants down. There is much to gain by this approach, embedded into a UNI standard but not yet quantified here.

### Testing and performance setting for packaged systems

ISO 5151-1994(E) – 'Non-ducted air conditioners and heat pumps -- Testing and rating for performance' is applicable to all packaged air conditioners. An equivalent standard exists for ducted equipment: ISO 13253-1995 – Ducted air conditioners. The European Standards EN 814 and EN 255 are fully consistent with the ISO standards although they classify AC equipment by whether it is operating in the cooling or heating mode and not whether it is ducted or not. A new version is being prepared.

The ISO test procedure applies to packaged air conditioners of any capacity and type provided they are non-ducted including cooling-only and reversible, single-phase and three-phase, and air-cooled or water-cooled units. Testing for these systems was discussed in the previous EERAC study. Water-cooled heat-pumps are not included and neither are part-load test conditions thus in practice it is not possible to use the test procedure to properly rate the performance of variable or multiple speed drive air conditioners. The standard test conditions for the cooling capacity test are shown in Table 2.6. The test conditions are always at full-load and with a single set of stable environmental conditions, thus the part-load performance of variable or multiple speed drive units is not reflected.

Table 2.6: Test conditions for the determination of cooling capacity, ISO

Parameter	Standard test conditions		
	T1	T2	T3
Temperature of air entering indoor side (°C)			
dry-bulb	27	21	29
wet-bulb	19	15	19
Temperature of air entering outdoor side (°C)			
dry-bulb	35	27	46
wet-bulb <sup>1)</sup>	24	19	24
Condenser water temperature <sup>2)</sup> (°C)			
inlet	30	22	30
outlet	35	27	35
<p><b>T1</b> = Standard cooling capacity rating conditions for <b>moderate</b> climates</p> <p><b>T2</b> = Standard cooling capacity rating conditions for <b>cold</b> climates</p> <p><b>T3</b> = Standard cooling capacity rating conditions for <b>hot</b> climates</p>			
<p>1) The wet-bulb temperature is not required when testing air-cooled condensers which do not evaporate the condensate.</p> <p>2) Representative of equipment working with cooling towers. For equipment designed for other uses, the manufacturer shall designate the condenser water inlet and outlet temperatures or the water flow rates and the inlet temperature in the ratings</p>			

**The USA has an extensive program for air conditioners and heat pumps**, that includes the following product types:

- central air conditioners and heat pumps
- small commercial package air conditioners and heat pumps
- large commercial package air-conditioners and heat pumps

With some minor differences, Canada and Mexico have adopted the US approach. The definition of “central air conditioners” used in the USA and Canada is much narrower than that applied in the EECCAC study because they are limited by the maximum cooling (or heating) capacity and they must be packaged units. Central air conditioners in the USA include both ducted systems and ductless split systems (i.e. split-packaged units) although ducted systems are predominant on the market. Small ducted systems are either split systems or single package systems, but mostly the latter. The US efficiency regulations classify a central air conditioner depending on its cooling (or heating capacity). Units with cooling or heating capacities above 135000 Btu/h (40 kW) are classed as ‘large commercial systems’ and have different efficiency requirements from other types. All ‘commercial’ units with capacities below 135 000 Btu/h (40 kW) are classed as ‘small’. Small commercial units with capacities between 65000 Btu/h (19.05 kW) and 135000 Btu/h (40 kW) are tested in the same way as large systems but have different efficiency requirements. Unitary air conditioners or heat pumps of below 65000 Btu/h capacity and which are not single-packaged room air conditioners or heat pumps nor packaged terminal air conditioners or heat pumps are classed as ‘central’ systems and have a different test procedure and set of efficiency requirements. All central air conditioners, with capacities up to 65000 Btu/h, including split-packaged systems, are rated using a seasonal energy efficiency ratio, SEER, that is based on the amalgamated results of testing cooling capacity at four different test conditions. Note that performance degradation due to real part load is determined in the standard and that variable speed or capacity systems are tested in a way which allows their advantages to be apparent.

Similarly all central heat pumps with capacities up to 65000 Btu/h are rated using a similar approach to produce a heating seasonal performance factor, HSPF. The commercial (small and large) air conditioners and heat pumps can be air, water or evaporatively cooled.

For small-commercial air conditioners and heat pumps with capacities above 65000 Btu/h but below 135 000Btu/h, the cooling performance is regulated for the EER (static test conditions) and Integrated Part-Load Value (IPLV), which is a measure designed to reflect performance under part-load conditions. The heating performance is measured and regulated using a static COP test.

For large commercial air conditioners and heat pumps, defined as those with capacities above 135 000 Btu/h (40 kW), a distinction is made depending on whether the capacity is above or below 760 000 Btu/h (205 kW) and whether the unit is an air cooled air conditioner, an air cooled heat pump or a water/evaporatively cooled air conditioner. Efficiency is measured and regulated in terms of the EER, COP and IPLV.

**Korea** is unique in having devised AC efficiency standards and targets that treat constant speed air conditioners (those using a single-speed compressor) differently from those using a variable speed. Both the fixed and variable-speed air conditioners (either room or unitary) must satisfy MEPS (Minimum Efficiency Performance Standards), energy labelling and are also subject to aspirational efficiency targets. The variable speed units are tested and rated using a seasonal energy efficiency ratio (SEER). Reversible units are not subject to COP requirements but are required to satisfy the cooling-mode performance requirements.

In **Japan** a central air conditioner would be classified as a unitary air conditioner. Larger room air conditioners, of a packaged type, are classified as unitary air conditioners and are subject to energy efficiency targets, not MEPS and labelling. The existing targets differentiate depending on whether an appliance is integral (windows) or split-type and whether it is cooling-only or reversible. The targets for reversible units are a combination of EER and COP targets. Multi-split systems are currently excluded but are about to be included in new energy efficiency target regulations, due to come into effect between 2004 and 2007. This implies that either the draft international test procedure for multi-split units is to be adopted or that a new unique Japanese test procedure will be created.

## **2.6. Overall view of energy performance**

### **Year round thermodynamic balance**

EER and COP figures can be measured for AC equipment submitted to testing under specified steady-state conditions, however these would not be representative of the year round energy performance of the component nor of the energy performance of the on-site AC system for many reasons that are now described. The performance of the equipment at part load is significantly different from what it is at full load. In many situations there is a possibility to take advantage of “free cooling”, which is available whenever the outside air is cooler than inside air, furthermore there are plenty of ways of recovering cold from some parts of the system in order to cool other parts. Free cooling increases the time during which the building is only ventilated, but it’s not related with the ventilation function but with cooling.

In addition complex buildings often experience simultaneous cooling and heating demands within different parts of the building because the heating and cooling seasons are not cleanly separated and the internal spaces have different uses and loads and different sun exposures; there are thus possibilities of using the AC system to simultaneously heat and cool different building zones without relying on thermal energy drawn from outside the building.

### **Definitions**

To facilitate understanding AC system energy performance, a common vocabulary has been defined based upon the specification of seasonal or annual quantities. In establishing this balance, you separate the auxiliaries according to the function being performed, that we consider being only two : heating with ventilation, cooling with ventilation.

To apply this strict definition, we should come back to each time step and make some sophisticated computation on the effects of the auxiliaries, mostly the ventilation auxiliaries at that time : do they act in the

direction of heating or in the direction of cooling? We have done something far simpler : when there is heating only or cooling only, ventilation is integrated in the demand ; at the end of the year the unaffected auxiliaries (floating or simultaneous heating and cooling) are allocated to heating and to cooling in proportion of the total yearly demand.

The quantities of interest are :

1. SCL: the Summer Cooling Loads or "cooling energy"; it is assumed that the total summer cooling load, including the energy for cooling and humidity treatment, is completely satisfied by the AC system. The SCL takes into account zone loads, outdoor air load, the heating of air that is passed through fans and the real system operating schedule and thermostatic control. It is also sometimes called the "coil cooling energy" (kWh) or "coil cooling load" (kW).
2. SEC: the Summer Electricity Consumption for cooling; SEC = the electricity consumption of the compressor of the cooling equipment (e.g. the chiller, package, etc).
3. SSEC: the System Summer Electric Consumption for cooling; SSEC = electricity consumption of the whole system i.e. that of the: Fans + Pumps + Primary equipment.
4. WHL: "Winter Heat Loads" represent the heat demand of the building , the equivalent of SCL in winter season.
5. WHG: "Winter Heat Gains" represent the heat generated by the equipment and effectively used (used in substitution of normal heating mode in winter for reversible equipment); reversible heating has some limitations and not all the load can be satisfied by the cooling equipment.
6. WED: the Winter Electricity Demand (Consumption) for reversible use of air-conditioning, including all auxiliaries.
7. WEC: the Summer Electricity Consumption for reversible cooling; WEC = the electricity consumption of the compressor of the cooling equipment used to heat (e.g. the chiller, package, etc).
8. SEER: Seasonal energy efficiency ratio during the summer: the ratio of SCL to SEC. This parameter could be miscalculated due to the large preponderance of electricity consumption by auxiliary applications in most systems; the same may be said about the SCOP (the seasonal coefficient of performance during the winter for reversible systems);
9. SSEER: System Seasonal EER for summer: the ratio of SCL to SSEC, the real index of performance;
10. SCOP the Seasonal COP for winter: the ratio of WHG to WEC.
11. SSCOP the System Seasonal COP for winter: the ratio of WHL to WED, the equivalent of SSEER for winter.

This study is concerned with identifying beneficial means to increase the SEER, SCOP, SSEER, SSCOP and partly WHL. As far as the cooling loads are concerned this study is confined to an investigation of the ways of decreasing the SCL that are related with equipment and control choices (i.e. addressing the family of "free cooling" options). It is well known that with a suitable budget it is possible to deploy passive measures which can provide an elevated degree of comfort without the use of AC; however, this is not the subject of the present study.

Note that the use of the terms Summer and Winter in relation to AC comfort loads refers to the typical seasonal period during which they apply and in some cases there will be parts of the building that have to be cooled all year round. To give a clear definition of quantities we have called Winter the total of time periods during which the heating demand is higher than the cooling demand and Summer the sum of all times where the opposite occurs. The study does not address issues concerning the total heating load or the nature of the back-up heating system because it is only concerned with that part of the heating which is provided by the AC equipment.

Some countries, such as Switzerland, have targeted their CAC energy efficiency efforts purely on the reduction of cooling loads through measures to improve the thermal performance of the building shell in conjunction with electro-mechanical ventilation; however, this is made possible mainly because of the milder climate. In some other countries, such as France and Portugal, a combination of policy measures have been deployed that combine passive measures to increase comfort in unconditioned spaces (and thereby resulting in a lower demand for AC) with those that are intended to raise the efficiency of AC equipment used in conditioned spaces. The Mediterranean countries, because of their geographical position, have to rely in many cases on air conditioning to attain desired comfort levels in the existing building stock.

### **Full system efficiency**

The total efficiency value results from a combination of all the system components efficiencies at different load conditions, with an evaluation of the weight that each part load condition takes in comparison to the whole yearly functioning cycle. We need a computer program to do this accurately. The simplified IPLV approach, effective for the chiller, could also be extended to the whole plant, by evaluating with similar procedure air water system and terminals, and the hot/cold water generators.

The results depend on the application context intended as the whole of the following factors:

- Climatic factors

- Building type

- Type of the activity carried out in the air-conditioned environments

- Plant type

For all plants the estimation can be carried out by means of a simulation. Simulation results, expressed by airflow, temperature and humidity trend graphs, can be analysed to directly get the weights associated to the different part load conditions. Thanks to the simulation the weights related to the partial load working conditions for the space of a year are obtained.

## ***2.7. Statistical databases used and information gathered***

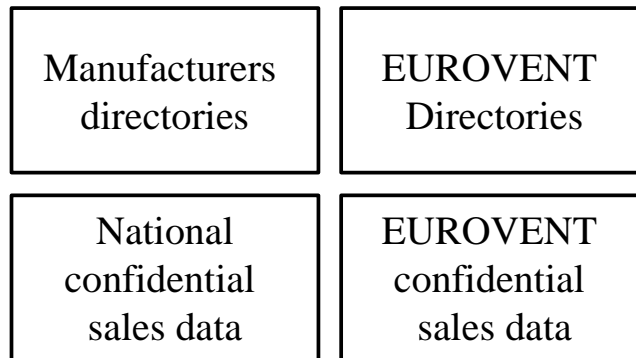
The conclusions of this study are based upon information gathered from four technical and market databases, the results of simulations using computer models and from national survey data gathered for each of the countries that are directly represented in the study.

### **National surveys**

The national surveys of the CAC market, usage and regulatory environment were conducted by the EECCAC study participants for their country. This took advantage of each participants national contacts including assembling and syntheting rough data supplied by local manufacturers' or importers' associations or even involved subcontracting national consultants. The resulting set of country reports for: Austria, France, Germany, Greece, Italy, Portugal, Spain, United Kingdom (with special thanks to the BRE) provides a unique set of data at the national level.

### **Data from manufacturers associations**

Here are some details on the four databases used in the EECCAC study.



Two database are permanently maintained by Eurovent at EU level. The first one is public: the directory of certified products. The second one ("sales"), which is a data base on total units sold without reference to performance, is confidential although some segments have been made available for use in this study, under the condition that any data pertaining to a specific manufacturer is strictly anonymous. At the time of the EECCAC study Eurovent had also assembled a temporary data base on the numbers of AC units sold in 2001 that included their efficiency although this was not made available for use in the study. There are also directories and technical literature of some manufacturers that constitute by themselves a data base that can be considered a good representation of the market, with the additional benefit of giving an idea of public prices, at least in relative terms hence allow an indication of the relationship between cost and efficiency to be established. A data base similar to the Eurovent sales database exists in some countries within the national associations and some of these have been made available to the study.

### Correction and treatment of data

This being said, the Eurovent market data provide an extraordinary means to reconstitute CAC stocks, both in terms of numbers and cooling power. The data is generally based on the year 1998, except the particular case of the AHUs which were for 1999. The Eurovent market figures need to be corrected for the following three reasons:

- Eurovent does not incorporate all the market, but approximately 90% of the total sales
- Part of the chillers which were sold are not used in air-conditioning applications
- There is a renewal rate (how many pieces replace identical worn or obsolete equipment?).

We used some estimated ratios to correct for these issues when no better data were available. Obviously real national data from country reports have replaced these ratios whenever they became available from the countries with a national participant. Checks on the consistency of various sources of information have found them to be reasonably high (i.e. with discrepancies of a few tens of percent only). Obtaining good market figures for the year 1998 was not the real objective but rather to gather enough data that would allow reasonable projections of the AC stock to be assessed. Projections on the size of the stock going back in time were made using rates based on measured data from 1996 to 2000, and estimated data from prior to 1996.

It should be stressed that all percentages are based on **weighed statistics**, with no figure being an arithmetic average. The statistics are intended to give the right weight to the country, climate, type of AC system, etc.

