GENERAL PRESENTATION AND USE OF A METHOD OF CALCULATION OF CONSUMPTION OF THE RAC (Room Air Conditioners)

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ABSTRACT

When studying improvements on room by room air conditioning appliances (RAC), it is necessary to know for how long these appliances function and which is their effectiveness - EER - on average (or Seasonal) known as SEER. A method was developed for Europe, taking into account the cycling losses, the fouling losses and the variations due to outside temperature and humidity. Further to this the load was represented by an equivalent number of hours at full load. Practically a user can just multiply the electric input called in nominal conditions (T1 of testing standard ISO 5151) by a number of hours which integrates the number of operating hours in ideal behaviour and the SEER effects listed previously. The results make it possible to define the total cost (LCC) of appliances and to find rapidly the minimum LCC appliance.

Models of phenomena

To select the best equipment or to evaluate innovations as regards air-conditioning, for room by room appliances (RAC), it is necessary to know for how long these appliances function and which is their effectiveness - EER - on average (or Seasonal) known as SEER.
For this we compute hour by hour the cooling load and then we take into account the cycling losses, the fouling losses and the variations due to outside temperature and humidity. It is possible to do so hour by hour, and then to summarise the results by simple yearly figures, the SEER and the total annual load.

Yearly Consumption = Yearly Load/SEER

Effect of outside conditions

An analysis of the market lead ENEA within the EERAC program (see references) to synthesise it by four models associated with functions F which link the electrical power demand to the cooling capacity and to the values of the indoor and outdoor temperature and humidity.

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

For the splits model:

- TAIIO: air temperature entering the outdoor unit, from 80°F to 110°F (26,7-43,3 °C)
- TAIII: air temperature entering the indoor unit, from 59°F to 95°F (15-35 °C)
- RHII: relative humidity of the air entering the indoor unit, from 40% to 85%

- RHIO: relative humidity of the air entering the outdoor unit, from 40% to 80% (does not influence the EER)

For single ducts:
TAIIO = TAIII = Tindoor

This is done for each hour of each week and weekend day.

Fouling of evaporator and condenser

Moreover a coefficient of degradation representingfouling faults is taken into account. Condenser and evaporator fouling is a substantial cause of performance degradation of air conditioners. The impact on the EER is to be heeded on the whole life cycle of the machines (13-15 years). According to an article (M. Breuker&J. E.Braun, Common faults and their impacts for rooftop air conditioners, July 1998, HVAC&R Research, p.303-318), a blockage of 56% of the face area of the condenser of a rooftop air conditioner results in a reduction of 18% of EER. In the same way, J.M. Taldir of EDF-DER (J.M. Taldir, Le fonctionnement des climatiseurs individuels split et windows dans les conditions des DOM, Août 1996, DER-EDF) noticed that the performance of a tested split could decrease by more than 30% with a reduction of the nominal air flow of the condenser by 50%.

Actually other common faults should be integrated in the performance degradation of air conditioners (refrigerant leakage, corroding, defective control…). That is the reason why we estimated that, as an average value, the EER is reduced by 20 % because of air conditioners conditions on the field as compared with the factory.

Cycling losses

Another coefficient of degradation is also applied to take into account the on-off cycles of the air conditioners and the transient state when air conditioners are set on (one to two minutes) . The degradation coefficient is defined by the usual ASHRAE default values as below.

$$Cd = \frac{(1 - \frac{EERcyc}{EERss})}{1 - F}$$

with Cd=0.25 and EER cyc(cycle) < EERss(steady state)

Selection of a simple representation of SEER and consumption

To represent the results of this simulation, we developed a method here where:

SEER = C1 x C2 x C3 x EER

Where C1, C2, C3 represent the cycling losses (C3), the fouling losses (C2) and the variations due to temperature and humidity (C1). At these stage these are only definitions, and we don't know how far they depend on specific RAC, on location, on country.

Further to this the load was represented by an equivalent number of hours at full load.

Consumption = Load/SEER
= Pelec x Practical number of hours at full load

= Pelec x (Ideal number of hours at full load) /C1/C2/C3

A number of base case simulations have been performed in order to be as representative as possible of the diversity of climates among the EU. A decoupled approach (building/system) has been used in this study. On the first hand, cooling loads (sensible + latent) are computed using COMFIE, a dynamic multi-zone software. On the second hand, electricity consumption is derived from the cooling needs and from the performance of a studied appliance. This means that we assume that cooling needs are independent of the system (which is equivalent to say that the system is not under-or oversized).

Another problem to be solved was the definition of each typical building and occupation features. Some information on walls composition (materials, windows, ...) is available from studies and/or thermal regulation codes and has been used. A typical occupancy scenario is also to be defined for each building. The occupation, internal gains, air controlled ventilation profile, infiltration rate and cooling/heating set point temperatures are defined on an hourly basis. All this has been done for the most important sectors of A/C : Trade, Offices, Hotels, Residences and for the 8 countries the most Southern in the EU.

The main considerations on the simulation results are the following : the Ci coefficients vary far less than the loads or "hours" to which they apply. It is thus useful to have a detailed description of cooling loads under the form of ideal or practical number of hours, location dependant and even microclimate dependant, but the Ci can be given by country or for a large climatic zone. Most countries are homogeneous territories in terms of Ci (at the accuracy of 0.02) except Spain and Portugal which have to be divided for presentation of results. Table 1 shows the C1 values obtained by averaging the gross results.

Table 1 C1 values by zones (outside conditions effect on SEER)

C1 for	Trade	Offices	Hotels	Residences	Average
France	1.17	1.14	1.22	1.24	1.19
Northern Iberia	1.21	1.25	1.27	1.27	1.25
Central Iberia	1.11	1.10	1.22	1.19	1.16
Southern Iberia	1.10	1.12	1.10	1.13	1.11
Italy	1.12	1.15	1.16	1.15	1.15
Greece	1.09	1.13	1.16	1.19	1.14
Others (Northern)	1.13	1.13	1.25	1.30	1.20
Average	1.13	1.15	1.20	1.21	1.17

Tens of C1 coefficients have been analysed. The C1 coefficients are insensitive to the specific appliance on which the study is conducted. The appliances seem different due to the aspect of the equation relating their performance with outside conditions, but they lead to the same result with an accuracy of 0.001. C1 is far more sensitive to occupation scenarios (coincidence of loads and cooler temperatures outside) than to climatic conditions by them selves. C1 values are higher for residential uses and hotels precisely because we have a higher coincidence of cooling loads and cooler outside conditions. Now, after reminding that C2 = 0.8, let's move to C3 results displayed on table 2.

Table 2 C3 values (cycling effects at part load)

C3 for	Trade	Offices	Hotels	Residences	Average
France	0.85	0.87	0.82	0.81	0.84

Northern Iberia	0.83	0.80	0.78	0.78	0.80
Central Iberia	0.89	0.91	0.82	0.84	0.87
Southern Iberia	0.90	0.89	0.91	0.88	0.90
Italy	0.89	0.87	0.86	0.87	0.87
Greece	0.92	0.89	0.86	0.84	0.88
Others (Northern)	0.89	0.89	0.78	0.77	0.83
Average	0.88	0.87	0.83	0.83	0.85

We see that C3 penalties due to cycling are not negligible. Cycling losses are smaller for offices and trades which, due to internal gains, display a more constant load. They balance C1 benefits for a new appliance in full condition or well maintained. This is similar to what we see with larger "chillers" for which the ratio IPLV/EER (similar to C1*C3) is around unity for unoptimised equipment (but may reach 1.40 for equipment optimised for part load).

The reader will find in the following tables the load values (under the form of a number of hours at 100W/m2 sizing in residential and 120 W/m2 in other sectors) obtained in our simulations, both the ideal number of hours not considering the field behaviour of the equipment, and the practical number of hours to be used in consumption calculation.

Table 3 Cooling load under the form of a number of hours at full load

LOCATION	Ideal Number hours Trade	Ideal Number hours Offices	Ideal Number hours Households	Ideal Number hours hotels	Practical Number hours Trade	Practical Number hours Offices	Practical Number hours Households	Practical Number hours Hotels
Salzburg (AU)	142	155	58	188	177	193	74	235
Vienna (AU)	108	118	43	141	134	147	55	176
Carpentras (FR)	1125	1037	438	478	1414	1307	547	595
Limoges (FR)	629	576	170	252	790	726	212	314
Paris (FR)	598	496	125	211	752	625	156	262
Centre (GE)	347	308	131	189	431	383	168	236
North (GE)	160	150	68	92	199	187	87	115
Athens (GRE)	789	717	591	1224	984	891	741	1530
Thessalo (GR)	689	587	383	940	859	729	480	1175
Cagliari (IT)	1009	795	656	719	1265	993	822	898
Milano (IT)	811	582	491	581	1017	727	615	726
Napoli	1089	773	665	878	1366	966	833	1097

(IT)								
Lisbon (PT)	969	746	489	330	1226	931	611	413
Murcia (SP)	1708	1118	840	1488	2157	1402	1049	1870
Oviedo (SP)	545	240	113	303	678	300	143	382
London, UK	185	222	73	265	230	276	94	331

Application to RAC optimisation

Practically a user can find the consumption of an appliance just by multiplying the electric input called in nominal conditions T1 by a number of hours which integrates the true number of operating hours and the effects called here C1, C2 and C3.

This method was applied to several technical improvements of the RAC
:

- increase of heat exchange surfaces;
- variable speed (inverters) ;
- improvements of compressors.
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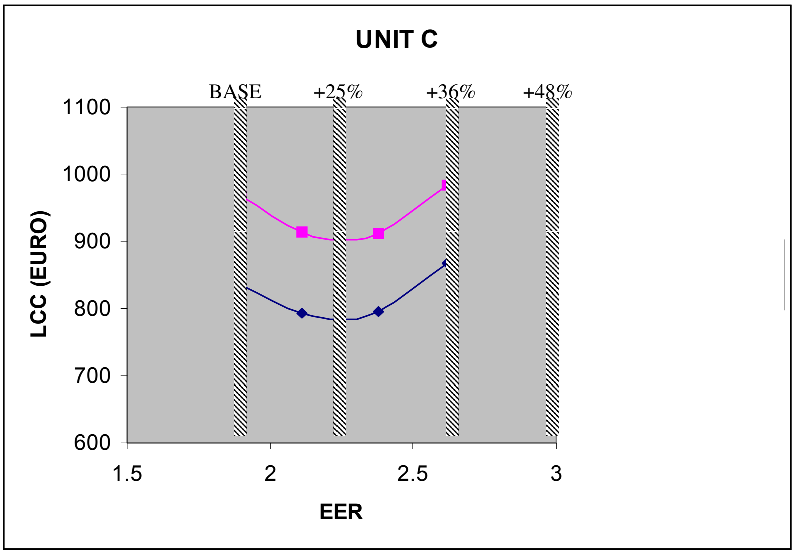
A thermodynamic simulation performed by University of Athens on the ORNL Mark V software applied to all four appliances studied lead to the following results: In the case of inverters the improvement reflected here by a better nominal EER is in fact an improvement on seasonal EER which has been applied here in a rough and underestimating manner, in order to summarise information.

TECHNICAL FEATURE	EFFECT ON EER OF A	EFFECT ON EER OF B	EFFECT ON EER OF C	EFFECT ON EER OF D	AVERAGE INCREASE (%)
EXISTING APP.	2.72	2.48	1.92	2.75	
DOUBLE HEAT EXCHANGERS	3.80	3.69	2.93	3.88	46
BEST COMPRESSOR	2.94	2.68	2.04	2.97	8
VARIABLE SPEED	3.05	2.78	2.15	3.08	12%
Best on market in class	3.20 (+20%)	3.56 (+46%)	3.09 (+63%)	3.25 (+25%)	+37%

The gains were parameterised (more or less increase in HE area for instance) and combined and lead to a more or less continuous cost/efficiency curve. One sees that the best on the market coincide with the best appliances generated by our analysis, showing the feasibility of what we propose. Obviously there is a cost associated with the improvement. The results make it possible to define the total cost (LCC) and to find its minimum.

The tendency is very general: a 25% EER improvement over the present market average is always cost-effective to every user (it represents half of the studied alterations to the present heat exchangers).. A further improvement to 36% is cost-effective for some users, but not for residential ones. A graphical presentation of the results is given below with two different sets of financial assumptions for the "C" single-duct unit studied. The figures are very similar for the two dominant types of air-cooled appliances (splits and single-ducts). The small remaining part of the market is primarily made up of multi-splits (7%), which obviously tend to follow the pattern for splits. The three categories studied represent together 89.5% of the market, the classic "packages" and the water cooled RAC representing the rest.

. Example of improvements on the single-duct appliance



The use of inverter technology at the costs presently indicated is not cost-effective if only financial factors are considered, disregarding the effect on comfort. Specifically, it results in a 12% energy efficiency improvement and leads to a total 48% savings potential when combined with the all other proven technical options.

REFRENCES

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