EXTENSION OF A METHOD OF CALCULATION OF CONSUMPTION OF AIR CONDITIONERS

Jérôme ADNOT and Philippe RIVIERE
Ecole des Mines de Paris
60 Bd St Michel
F-75272 Paris cedex 06
Email : adnot@ensmp.fr

ABSTRACT

To evaluate innovations and efficiency as regards air-conditioning, it is necessary to know for how long and in which conditions the equipment functions, an indication related with the COOLING LOAD and which is their effectiveness - EER - on average (or Seasonal) known as SEER. We extended the concept of SEER to include all sources of electricity consumption, namely the secondary equipment, and we called this extended concept the SYSTEM SEER. We know that such figures are highly uncertain and difficult to predict for one single building but we want to give a reasonable estimate and to help the final customer to search for optimum levels of efficiency, without having always to make use of detailed simulation programs. We extend here our method for SSEER calculation to Central Systems.

KEYWORDS

Air Conditioning, Energy Efficiency, Cooling, Electrical consumption

SEASONAL EFFICIENCY OF INDIVIDUAL PIECES OF A/C EQUIPMENT

Very few methods exist to estimate the seasonal efficiency of A/C equipment and no method for complete systems. Part load test conditions have not yet been developed in the EU. However, in the USA, the ARI 550/590 test procedure used in the ARI chiller certification programme does include part load ratings. The aim of these rating conditions is to try and represent part load performance over a range of operating conditions in order to give a better overall indication of chiller performance under real operating conditions.

The test conditions and weighting of part load test points used in ARI 550/590 is given in Table 1. This load profile is used to calculate the integrated part load value (IPLV), which is the seasonal average efficiency of a chiller in the USA and is calculated via:

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

Where A = EER at 100%, B = EER at 75%, C = EER at 50%, D = EER at 25%

Table 1. Chiller part load test conditions and weightings under ARI 550/590 (chilled water at 6.7°C)

Share of full load %	Dry-bulb temperature of air entering condenser	Temperature of water entering condenser	Share of total operating hours
100	35.0	29.4	1
75	26.7	23.9	42
50	18.3	18.3	45
25	12.8	18.3	12

The use of an IPLV is a distinct improvement over using a simple full load rating because it is more likely to give a realistic representation of a chiller's absolute and comparative performance under real operating conditions; however, an analysis conducted within the EECCAC study (Adnot, 2002) has established that both the "share of total operating hours" weightings and testing conditions used in the ARI test procedure are much more appropriate for the US climate and building stocks than for the European ones.

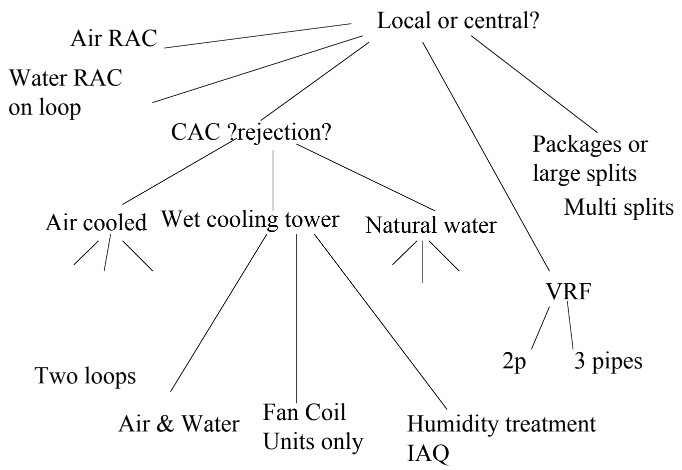
In fact, not unreasonably, both the temperature and share of operating hours weightings have been "sized" to represent the US climate, building stock and operating habits. Not only the load has been varied like in the CEN testing standard under discussion, but also the temperatures to correspond to some practical habits in the USA. This finding is supported by an independent analysis conducted by AICARR (the Italian HVAC engineers association) which also showed that the ARI coefficients were completely unsatisfactory and subsequently lead to a proposal known as EMPE (for European Method for Part Load Efficiency). On this subject see (AICARR, 2001) for more evidence.

SEASONAL EFFICIENCY OF SYSTEMS : OUR DEFINITIONS

We start by structuring the list of A/C systems by starting from the refrigerating circuits which are of 5 types : air cooled chillers (with 6 subtypes), water cooled chillers using cooling towers (3 subtypes), real water cooled chillers using some outside water source like a river (6 subtypes), VRFs (Variable Refrigerant Flow -three subtypes), MS (Multi Splits) and "packages" (rooftops and other packaged systems of a certain size), these two last types with two subtypes only. We have also the reversible RAC operating on a water loop that have been counted in EERAC but should be mentioned here as a CAC, what they are indeed. Finally there are also systems with two loops (cold and hot) with a chiller in the middle.

The six standard subcategories applicable to the system with water cooling are: distribution by water, reversible or not, distribution by air, reversible or not, distribution by air with true control of moisture, reversible or not... For water cooled chillers operating on a cooling tower, reversibility seems impossible (hence the three subtypes). Air+Water systems are aggregated to water systems for the purpose (to be discussed, like the rest). The standard subtypes of the VRF are: reversible with two tubes, reversible with three tubesThe packages and MS are just reversible or not. Further distinctions seem not necessary in this provisional approach. There is something like a decision tree, as figured in figure 1.

Figure 1 Decision tree for Air Conditioning systems



That leads to a splitting of A/C systems in 18 categories :
MULTI SPLITS & SPLITS& Packages, large manufactured systems.(cooling only or reversible)
AIR COOLED CHILLERS
Air Cooled with water distribution.(cooling only or reversible)
Air Cooled with air distribution.(cooling only or reversible)
Air Cooled with air +humidity control.(cooling only or reversible)

USE OF COOLING TOWERS
Water Cooled + water dist.(cooling only)
Water Cooled with air dist.(cooling only)
Water Cooled +air +hum.(cooling only)
USE OF NATURAL WATER
Outside water + water dist.(cooling only or reversible)
Outside water + air dist.(cooling only or reversible)
Outside water +air +hum.(cooling only or reversible)
DRF
Direct Refrigerant (2tubes)
Direct Refrigerant (3tubes)
ONE WATER LOOP + WATER RAC .(REVERSIBLE)
TWO WATER LOOPS + CHILLER.(REVERSIBLE)
ROOM AIR CONDITIONERS
Single ducts
Split systems
Packaged systems (window units)
Small Multi Splits

The concept of SEER (Seasonal = Average Energy Efficiency Ratio) of the cooling equipment is very common. We extend it to the concept of SSEER (System SEER) because most equipment needs a secondary cool distribution and ventilation system, which is full of auxiliaries, and the associated electrical power has to be added to the consumption of the cold generating equipment itself. The care given to the secondary systems could lead to very different values of System EER as well. So, to summarise, we are developing a simplified calculation method applicable to all Air Conditioning systems and structured by the following equations:

Electricity Consumption (per m^2) = Cooling Load/System SEER (1)
Load = Sizing [W/m^2] x Nhours (2)

where
Nhours = Equivalent number of hours of operation (Load/Sizing), dependant on country, climate and economic sector.

SystemSEER = a function of nominal EER, system type and climate

We include in our definition of Consumption all the electricity needed for the ventilation provided by the Air Conditioning system (auxiliaries). We then select the following representation of part-load and system effects, which allows to relate actual performance with test conditions performance :

$$SystemSEER = C_1 \times C_2 \times C_3 \times C_4 \times C_5 \times C_6 \times C_7 \times C_8 \times EER \qquad (3)$$

In this equation, the EER is the full load value and the C_i coefficients (C_1, ..., C_8) are in charge of representing all non nominal parameters : the cycling losses, the fouling losses, the variations of EER due to outside temperature, the effect of part capacity control, the auxiliary consumption for final cool distribution from the refrigerating plant, the inefficiencies associated with centralisation, the auxiliaries which are directly related with the

, the "cold" losses, "free" cooling, etc. A first version of this method was presented at AIVC 22, limited to Room Air Conditioners (Rivière, 2001). The analysis has been extended here to centralised systems. More precisely :

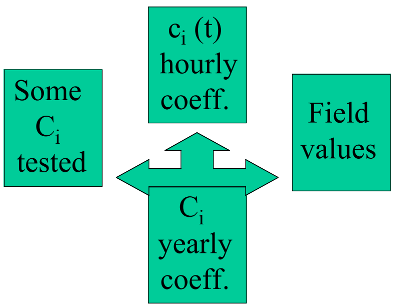
- C_1 is the effect of climate on EER; usually a benefit due to the averageoutside temperature and humidity conditions (wet or dry condensation) (C_1 is partly behind IPLV);
- C_2 is the effect of fouling; larger capacity AC equipment is generally associated with outside contracting of the maintenance and hence with a lower fouling coefficient ;
- C_3 is the effect of part load control, usually cycling, which is high in the case of RACs (a loss of around 10%) possibly positive for chillers (C_3 is partly behind IPLV);
- C_4 represents the auxiliary energy consumption needed to for the final distribution of cooling from the chilling equipment; such a definition implies that we group Ventilation and A/C as one single source of consumption;
- C_5 represents the inefficiencies associated with centralisation: over sized air flows, poor zoning, poor control, improper mixing of cold and hot fluxes, lack of free cooling;
- C_6 allows the integration of auxiliary energy consumption which are directly related with the chillers but not taken into account on testing, e.g. the cooling tower.
- C_7 allows "cold" losses in larger systems (pipes and duct gains) to be taken into account.
- C_8 is the energetic influence of "free cooling";
- EER and COP are measured values at T1 as certified by Eurovent.

The C_i are coefficients, not efficiencies, except C_7 which is the inverse of an efficiency. A similar analysis can be made at each hour of operations and that hourly c_i coefficients could be defined as functions of time or determining weather conditions, then averaged.

VARIOUS WAYS OF OBTAINING THE COEFFICIENTS NEEDED? PROVISIONAL VALUES

To obtain the C_i values, we have three potential methods (figure 2) : modelling (simplified or detailed like in Consoclim or DOE2, experiments on site, experiments on testing benches (for some coefficients only). In the case of simulation and full size experiments we can try to read from the total figures the C_i directly or -better- determine the hourly ci(t) as a function of time and other parameters and do the proper integration separately.

Figure 2 : Accessing the C_i values



Provisional C_i values for the cooling mode only are presented in table 2 as a range of potential values (extending from a minimum to a maximum), for reasons that will appear in the next part. Our sources are : the (Eurovent,1998) directory or (Adnot, 1999) for nominal EER values, one manufacturer directory (for C1 and C3), a North American monitoring report (Westphalen, 1999) for C4, some manufacturers directories for C6, and some practical experience for all....

Table 2 Range of Ci values

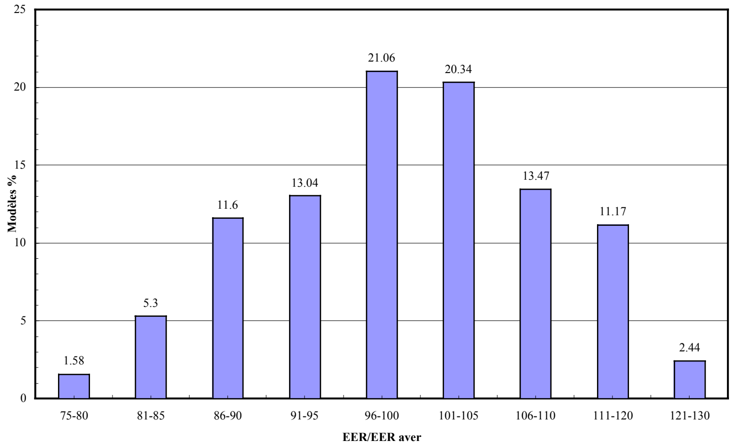
Value given in first line	EER MAX	C1 MIN	C2 MIN	C3 MIN	C4 MIN	C5 MIN	C6 MIN	C7 MIN	C8 MIN	SSEER MAX
Value given in second line	EER MIN	C1 MAX	C2 MAX	C3 MAX	C4 MAX	C5 MAX	C6 MAX	C7 MAX	C8 MAX	SSEER MIN
Definition of parameter	EER at T1	Climate	Fouling	Cycling	Auxiliaries	Multiz control	Chillers aux.	Cold losses.	Free cool.	System SEER
Large Manufactured										
Large MAX	3,78	1,30	1,00	0,92	0,9	1,00	1	1	1,30	3,37
Large MIN	1,58	1,09	0,90	0,80	0,8	0,80	1	1	1	1,23
AIR COOLED										
ACchill(MAX)	3,29	1,30	1,00	1,20	0,9	1,00	1	0,9	1,1	2,52
AC chill(MIN)	1,90	1,09	0,90	0,90	0,5	0,80	1	0,8	1	0,96
COOLING TOWERS										
Water Cooled chillers (MAX)	4,09	1,30	1,00	1,20	0,9	1,00	0,95	0,9	1,1	3,15
Water Cooled chillers.(MIN)	2,90	1,09	0,98	0,90	0,5	0,80	0,9	0,8	1	1,36
NATURAL WATER										
NWchill.(MAX)	4,09	1,7	1,00	1,20	0,9	1,00	0,95	0,9	1,1	4,21
NWchill(MIN)	2,90	1,5	0,98	0,90	0,5	0,80	0,9	0,8	1	1,84
DRF										
DRF (MAX)	2,77	1,30	1,00	1,50	1	1	1	1	1	4,27
DRF (MIN)	1,88	1,09	0,90	1,00	1	1	1	1	1	2,33
One Water loop +RAC										
W L (MAX)	5,42	1	1,00	1	0,9	1	0,95	0,9	1,1	3,79
W L (MIN)	2,11	1	0,98	1	0,8	1	0,9	0,8	1	1,44
2 loops Chiller										
2 loops (MAX)	4,09	1	1,00	1	0,9	1,20	0,95	0,9	1,1	3,09
2 loops (MIN)	2,90	1	0,98	1	0,5	1,10	0,9	0,8	1	1,51
RAC										
SD (MAX)	3,09	1	1,00	0,92	1	1	1	1	1	2,43
SD (MIN)	1,35	1	0,80	0,80	1	1	1	1	1	1,01
Split (MAX)	3,56	1,30	1,00	0,92	1	1	1	1	1	3,36
Split (MIN)	1,54	1,09	0,80	0,80	1	1	1	1	1	1,35
Pack. (MAX)	2,77	1,30	1,00	0,92	1	1	1	1	1	2,68
Pack. (MIN)	1,88	1,09	0,80	0,80	1	1	1	1	1	1,62
M S (MAX)	3,74	1,30	1,00	0,92	1	1	1	1	1	3,55
M S (MIN)	1,91	1,09	0,80	0,80	1	1	1	1	1	1,67

CONSEQUENCES FOR THE RANGE OF SEASONAL EFFICIENCIES IN EUROPE

We decided to determine the range of seasonal efficiencies in Europe by propagating the individual uncertainty ranges down to the final System SEER. The final consumption. can then be determined by using an equivalent Nhours (hours at full load) like the one given in (Rivière, 2001).

For the propagation of individual parameter ranges up to the SSEER range, we used the quadratic method : we assume there is an average value in the middle of the range of potential parameter values and that deviations are gaussian. This may be true for factors resulting from many system design aspects, which is the case of most Ci. Provided that we do not change the confidence level in the process, we obtain a restricted range of final values of SSEER, resulting from the hidden assumption of independent errors on the Ci, an acceptable assumption in our case. To support our assumptions about the gaussian nature of the deviations, we can display on figure 3 the scattering of the normalised values of EER of all chillers on the EU market (normalised in each towards the average of its category).

Figure 3 EU chillers performance, from (Eurovent,1998), normalised



About, the independence of the Ci, we can only give examples, in the absence of a systematic simulation exercise. We know for instance that C1 (the effect of temperatures on a chiller) is linear and independent of the load (part load being represented by C3). The formulae to be used, given the assumptions made, are :

$$\Delta SystemSEER^2 = \sum_{i=1}^{8} (\Delta C_i^2 \times \prod_{j \neq i} C_j^2 \times EER^2) + (\prod_{i=1}^{8} C_i)^2 \times \Delta EER^2 \qquad (4)$$

$$\Delta Cons.^2 = Sizing^2 \times (\Delta Nhours^2 / SSEER^2 + Nhours^2 \times \Delta SSEER^2 / SSEER^4) \qquad (5)$$

The results about SSEER were in the last array of table 2 and the results about electricity consumption are given in table 3

Table 3 : the likely range of electricity consumption per cooled square meter

Climatic zone+ building use	Trade IT + South PT,SP,GR	Offices IT + South PT,SP,GR	Hotels IT + South PT,SP,GR	Res. IT + South PT,SP,GR	Trade FR + North PT,SP,GR	Off. FR + North PT,SP,GR	Hotels FR + North PT,SP,GR	Res. FR + North PT,SP,GR
Range of Nhours	1000/1700	600/1100	600/1500	500/800	600/1100	500/1000	500/900	200/400
Value given in first line	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN	KWH/M2 MIN
Value given in second line	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX	KWH/M2 MAX
Large Manufactured								
Manufactured MAX	113	73	99	54	73	66	60	26
Manufactured MIN	27	16	11	14	16	12	13	5
AIR COOLED								
AC chillers.(MAX)	146	93	125	69	93	84	77	34
AC chillers (MIN)	41	24	20	20	24	19	20	8
COOLING TOWER								
Water Cooled chillers (MAX)	112	72	98	53	72	65	59	26
Water Cooled chillers.(MIN)	32	18	14	16	18	14	15	6
NATURAL WATER								
Outside water chiller.(MAX)	86	55	77	40	55	51	45	20
Outside water chiller.(MIN)	22	12	7	11	12	9	10	4
DRF								
DRF (MAX)	76	50	70	36	50	46	41	18
DRF (MIN)	22	12	6	12	12	9	10	4
Water loop + RAC								
Water RAC on a cooling loop (MAX)	100	65	88	47	65	59	53	23
Water RAC on a cooling loop (MIN)	24	13	8	12	13	10	11	4
Two loops + Chiller								
2 loops (MAX)	107	69	95	51	69	63	57	25
2 loops (MIN)	34	19	14	17	19	15	16	6
RAC								
Single duct (MAX)	145	93	124	69	93	84	76	34
Single duct (MIN)	44	26	22	22	26	21	22	8
Split system (MAX)	109	70	95	51	70	64	57	25
Split system (MIN)	29	16	12	15	16	13	14	5
Packages (MAX)	110	71	98	51	71	65	58	26
Packages (MIN)	41	24	19	21	24	19	20	8
Multi splits (MAX)	96	62	86	45	62	57	51	23
Multi splits (MIN)	28	16	11	14	16	12	13	5

The numbers of hours at full load (equivalent to the cooling load) were obtained by treating data in (Rivière, 2001). It's only a range since the actual value for a specific building depends on distance from reference climatic station, microclimate, occupation schedule, envelope, etc. Obviously, more detailed values can be found in the original paper and report (Adnot, 1999) for specific climatic locations, but this will not solve everything. So, national approaches like cooling degree days or CEN standards can be used to limit uncertainties. A specific mention of the building code RCCTE in Portugal that can be applied to refine the values and make better predictions of the energy needed to meet the cooling requirements - called NV and limited in the Portuguese regulation.. This regulation and computation method takes into account the insulation levels, and also the use of sun protections in summer (e.g. shading devices and convection through the envelope, depending on a building's inertia, orientation and colour).

The reader may ask : what is the interest of computing a range of consumption values, not the exact consumption of MY building? To draw lessons for policies or to make strategic choices... We see for instance that decentralised systems and centralised systems are really in the same range of specific consumption, by compensation between the various factors (local systems are better controlled, central systems have better part load behaviour) and this is a useful indication. We see a few direct expansion systems performing well in terms of operating costs, which (added to their modularity and their series manufacturing) may explain their success on the market. We can also estimate the EU consumption for Air Conditioning, which may support the need for specific policies or not. The dominant systems consume between 30 and 100 kWh/m2 (weighted value) for ventilation and Air conditioning jointly. Since we are in the order of magnitude of 1 billion air conditioned square meters in Europe, this would mean 30 to 100 TWh electricity consumption for the purpose of comfort.

We see also that there is a challenge in terms of performance (at least a factor 4 between the worst and the best) and that the manufacturers can give half of the answer (a factor 2 of improvement) and the designers of systems the other half (another factor 2). This challenge is addressed partly in an upcoming report (Adnot, 2002). Better values, smaller ranges, may be obtained by proper interpretation of detailed simulations like Consoclim or DOE2 or by treatment of results of monitoring campaigns, a potential direction of progress.

CONCLUSIONS

The concept of SEER has to be extended to include all sources of electricity consumption, namely the secondary equipment, to become a "SYSTEM" SEER. SSEER figures are still uncertain and we expect soon first reasonable estimates by detailed simulation. In the meanwhile, a comparison of centralised and decentralised system was generated which we hope to pursue. We think that the structure proposed will help experimenters to extract real transferable knowledge from their monitoring campaigns. We cannot reject the hope of laying the bases of a simplified consumption calculation method on the foundations just described.

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