TRANSITIONAL METHOD FOR DETERMINATION OF THE SEPR (SEASONAL ENERGY PERFORMANCE RATIO) FOR CHILLERS USED FOR REFRIGERATION AND INDUSTRIAL APPLICATIONS

VERSION OF 1 MAY 2013

1 General

This document defines the operating conditions and the methodology to define the reference SEPR for refrigeration and industrial chillers, for operation at low, medium and high temperature.

2 Definitions

full load
P_{design}
refrigeration ($P_{designR}$) load of the application at T_{design} conditions
Note 1: It is possible to calculate the SEPR of a chiller for more than one P_{design} value.
Note 2: Expressed in kW.
Note 3: Power input of a chiller includes always power demand for pumps and fans to overcome pressure drop in evaporator and condenser for heat transfer fluids (e.g. brine, water, air). This power demand can be calculated by volume flow times pressure drop divided by total efficiency of fan or pump.

part load
refrigeration load of the application which is less than the full load

part load ratio
part load or full load divided by the full load
Note 1 : If 100 % part load ratio is mentioned, this equals full load.

declared capacity
DC
refrigeration capacity a chiller can deliver at any temperature condition A, B, C or D, as declared by the manufacturer
Note 1 : The temperature conditions for part load conditions A, B, C, D, E or F are explained in the tables.

capacity ratio
CR
part load or full load cooling demand divided by the declared refrigeration capacity of the chiller at the same temperature conditions

bin hours
h_j
sum of all hours occurring at a given temperature for a specific location
Note 1 : The number is derived from representative weather data over the 1996-2005 period.
Note 2 : For the reference refrigeration year, the specific location is Strasbourg.

energy efficiency ratio at declared capacity
EER_{DC}
declared refrigeration capacity of the chiller divided by the effective power input of a chiller at specific temperature
conditions A, B, C, D
Note 1 : Expressed in kW/kW, see Tables 1 to 5.

energy efficiency ratio at part load or full load conditions
EER_{PL}
refrigeration capacity at part load or full load conditions divided by the effective power input of a chiller at specific temperature conditions
Note : : The EER includes degradation losses when the declared capacity of the chiller is higher than the cooling capacity demand.
Note 2 : Expressed in kW/kW.

reference seasonal energy performance ratio
SEPR
reference seasonal efficiency of a chiller calculated for the reference annual refrigeration demand, which is determined from mandatory conditions given in this document and used for eco-design requirements
Note 1: For calculation of SEPR, only the electricity consumption during active mode is used.
Note 2 to entry: Expressed in kWh/kWh.

active mode
mode corresponding to the hours with a refrigerating load of the application and whereby the rerigeration function of the chiller is switched on
Note 1 : The unit has to reach or maintain a temperature set point and in order to do so, the unit may switch between being operational or not operational (e.g. by on/off cycling of the compressor).

capacity control
ability of the chiller to change its capacity by changing the refrigerant volumetric flow rate
Note 1 : Chillers are to be indicated as 'fixed' if the chiller cannot change its capacity, or as 'variable' if the capacity is changed or varied in series of two or more steps or increments.

degradation coefficient
Cc
measure of efficiency loss at part load operation due to additional temperature differences for heat transfer and for heat transportation in fluids

3 Air-cooled process chillers

The part load conditions for determining the reference SEPR are given in the following tables.

Table 1 – Part load conditions for reference SEPR calculation of air-cooled chillers on Low temperature application

	Part load ratio	Part load ratio [b] (%)	Outdoor heat exchanger	Indoor heat exchanger
			inlet air temperature (°C)	Evaporator Inlet / outlet brine temperatures (°C)
				Fixed outlet
A	80% + 20%*$(T_A-T_D)/(T_A-T_D)$	100%	35	-19 / -25
B	80% + 20%*$(T_B-T_D)/(T_A-T_D)$	93%	25	[a] / -25
C	80% + 20%*$(T_C-T_D)/(T_A-T_D)$	87%	15	[a] / -25
D	80% + 20%*$(T_D-T_D)/(T_A-T_D)$	80%	5	[a] / -25

[a] with the brine flow rate as determined during "A" test for chillers with a fixed water flow rate or with a fixed ΔT of 6K for chillers with a variable brine flow rate;); and T_A,T_B,T_C and T_D temperatures at reference points A,B,C and D respectively.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

Table 2 – Part load conditions for reference SEPR calculation of air-cooled chillers on Medium temperature application

	Part load ratio	Part load ratio (%)	Outdoor heat exchanger: inlet air temperature (°C)	Indoor heat exchanger: Evaporator Inlet / outlet brine temperatures (°C) Fixed outlet
A	80% + 20%*(T_A-T_D)/(T_A-T_D)	100%	35	-2 / -8
B	80% + 20%*(T_B-T_D)/(T_A-T_D)	93%	25	[a] / -8
C	80% + 20%*(T_C-T_D)/(T_A-T_D)	87%	15	[a] / -8
D	80% + 20%*(T_D-T_D)/(T_A-T_D)	80%	5	[a] / -8

[a] with the brine flow rate as determined during “A” test for chillers with a fixed water flow rate or with a fixed ΔT of 6K for chillers with a variable brine flow rate and T_A,T_B,T_C and T_D temperatures at reference points A,B,C and D respectively.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

Table 3 – Part load conditions for reference SEPR calculation of air-cooled chillers on High temperature application

	Part load ratio	Part load ratio (%)	Outdoor heat exchanger: inlet air temperature (°C)	Indoor heat exchanger: Evaporator inlet/outlet water temperatures (°C) Fixed outlet
A	80% + 20%*(T_A-T_D)/(T_A-T_D)	100%	35	12/ 7
B	80% + 20%*(T_B-T_D)/(T_A-T_D)	93%	25	[a] / 7
C	80% + 20%*(T_C-T_D)/(T_A-T_D)	87%	15	[a] / 7
D	80% + 20%*(T_D-T_D)/(T_A-T_D)	80%	5	[a] / 7

[a] with the water flow rate as determined during “A” test for chillers with a fixed water flow rate or with a fixed ΔT of 5K for chillers with a variable water flow rate.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

4 Water-cooled process chillers

The part load conditions for determining the reference SEPR are given in the following table.

Table 4- Part load conditions for reference SEPR calculation for water-cooled chillers for Low temperature application

	Part load ratio	Part load ratio (%)	Outdoor heat exchanger	Indoor heat exchanger
			Inlet/ outlet water temperatures (°C)	Evaporator Inlet / outlet brine temperatures (°C)
				Fixed outlet
A	80% + 20%*(T_A-T_D)/(T_A-T_D)	100%	30 / 35	-19 / -25
B	80% + 20%*(T_B-T_D)/(T_A-T_D)	93%	23 / [a]	[a] / -25
C	80% + 20%*(T_C-T_D)/(T_A-T_D)	87%	16 / [a]	[a] / -25
D	80% + 20%*(T_D-T_D)/(T_A-T_D)	80%	9 / [a]	[a] / -25

[a] with the water and brine flow rate as determined during “A” test for chillers with a fixed water flow rate or with a fixed ΔT for chillers with a variable water and brine flow rate.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

Table 5 - Part load conditions for reference SEPR calculation for water-cooled chillers for Medium temperature application

	Part load ratio	Part load ratio (%)	Outdoor heat exchanger	Indoor heat exchanger
			Inlet/ outlet water temperatures (°C)	Evaporator Inlet / outlet brine temperatures (°C)
				Fixed outlet
A	80% + 20%*(T_A-T_D)/(T_A-T_D)	100%	30 / 35	-2 / -8
B	80% + 20%*(T_B-T_D)/(T_A-T_D)	93%	23 / [a]	[a] / -8
C	80% + 20%*(T_C-T_D)/(T_A-T_D)	87%	16 / [a]	[a] / -8
D	80% + 20%*(T_D-T_D)/(T_A-T_D)	80%	9 / [a]	[a] / -8

[a] with the water and brine flow rate as determined during “A” test for chillers with a fixed water flow rate or with a fixed ΔT for chillers with a variable water and brine flow rate.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

Table 6- Part load conditions for reference SEPR calculation for water-cooled chillers for High temperature application

	Part load ratio	Part load ratio (%)	Outdoor heat exchanger	Indoor heat exchanger
			Inlet/ outlet water temperatures (°C)	Evaporator Inlet / outlet water temperatures (°C)
				Fixed outlet
A	80% + 20%*(T_A-T_D)/(T_A-T_D)	100%	30 / 35	12/ 7
B	80% + 20%*(T_B-T_D)/(T_A-T_D)	93%	23 / [a]	[a] / 7
C	80% + 20%*(T_C-T_D)/(T_A-T_D)	87%	16 / [a]	[a] / 7
D	80% + 20%*(T_D-T_D)/(T_A-T_D)	80%	9 / [a]	[a] / 7

[a] with the water flow rate as determined during "A" test for chillers with a fixed water flow rate or with a fixed ΔT of 5K for chillers with a variable water flow rate.

[b] Note: for the purpose of calculation reference SEPR as explained in Chapter 5 of this transitional method, the part load ratios mentioned below shall be based on the part load ratio formulas (1st column of the tables in this chapter) and not on the rounded figures as mentioned in the 2nd column of the tables.

5 Calculation methods for reference SEPR

5.1 General Formula for calculation of reference SEPR

The calculation of the reference SEPR that applies to all types of chillers is given by the following formula:

Reference SEPR = reference annual refrigeration demand divided by the annual electricity consumption.

This annual electricity consumption includes the power consumption during active mode

NOTE: for refrigeration and industrial application, off mode and standby modes are not relevant as the appliance is running all year long.

$$\mathrm{SEPR} = \frac{\sum_{j=1}^{n}\left[h_j . P_R(T_j)\right]}{\sum_{j=1}^{n}\left[h_j . \frac{P_R(T_j)}{EER_{PL}(T_j)}\right]} \qquad \text{(Eq. 1)}$$

Where :

T_j = the bin temperature

j = the bin number, with $j \in \{1,2,\ldots \mathbf{n}\}$

n = the amount of bins

$P_R(T_j)$ = the refrigeration demand of the application for the corresponding temperature T_j.

h_j = the number of bin hours occurring at the corresponding temperature T_j.

$EER(T_j)$ = the EER values of the unit for the corresponding temperature T_j.

Table 7 – bin number j, outdoor temperature T_j in °C and number of hours per bin h_j corresponding to the reference refrigeration season

j	Tj	hj
1	-19	0,08
2	-18	0,41
3	-17	0,65
4	-16	1,05
5	-15	1,74
6	-14	2,98
7	-13	3,79
8	-12	5,69
9	-11	8,94
10	-10	11,81
11	-9	17,29
12	-8	20,02
13	-7	28,73
14	-6	39,71
15	-5	56,61
16	-4	76,36
17	-3	106,07
18	-2	153,22
19	-1	203,41
20	0	247,98
21	1	282,01
22	2	275,91
23	3	300,61
24	4	310,77
25	5	336,48
26	6	350,48
27	7	363,49
28	8	368,91
29	9	371,63
30	10	377,32
31	11	376,53
32	12	386,42
33	13	389,84
34	14	384,45
35	15	370,45
36	16	344,96
37	17	328,02
38	18	305,36
39	19	261,87
40	20	223,90
41	21	196,31
42	22	163,04
43	23	141,78
44	24	121,93
45	25	104,46
46	26	85,77
47	27	71,54
48	28	56,57
49	29	43,35
50	30	31,02
51	31	20,21
52	32	11,85
53	33	8,17
54	34	3,83
55	35	2,09
56	36	1,21
57	37	0,52
58	38	0,40

NOTE: the bin of Strasbourg used is based on ASHRAE 2009 (1453-RP 04.2009) climate data.

The refrigeration demand $P_R(T_j)$ can be determined by multiplying the full load value ($P_{designR}$) with the part load ratio % for each corresponding bin. These part load ratios % are calculated in Tables 1 to 6.

5.2 Calculation procedure for determination of EER_{PL} values at part load conditions A, B, C, D

In part load condition A (full load), the declared capacity of a unit is considered equal to the refrigeration load ($Pdesign_R$)

In part load conditions B,C,D, there can be 2 possibilities:

1) If the declared capacity (DC) of a chiller matches with the required refrigeration loads, the corresponding EER_{DC} value of the chiller is to be used. This may occur with variable capacity chillers.

   $$EER_{PL}(T_{B,C\ or\ D}) = EER_{DC} \qquad \text{(Eq. 2)}$$

2) If the declared capacity of a chiller is higher than the required refrigeration loads, the chiller has to cycle on/off. This may occur with fixed capacity or variable capacity chillers. In such cases, a degradation coefficient (Cc) has to be used to calculate the corresponding EER_{PL} value. Such calculation is explained below.

5.2.1 Calculation procedure for fixed capacity chillers

In order to obtain a time averaged outlet temperature as indicated in Tables 1 to 6, the inlet and outlet temperatures for the capacity test shall be determined using Equation (3):

$$t_{outlet,\ average} = t_{inlet,\ capacity\ test} + \left(t_{outlet,\ capacity\ test} - t_{inlet,\ capacity\ test}\right) \cdot C_R \qquad \text{(Eq. 3)}$$

Where

$t_{inlet,\ capacity\ test}$ = evaporator water inlet temperature (for conditions B, C or D in tables 1 to 6)

$t_{outlet,\ capacity\ test}$ = evaporator water outlet temperature (for conditions B, C or D in tables 1 to 6)

$t_{outlet,\ average}$ = mean evaporator water average outlet temperature over a on/off cycle (for instance +7°C in tables 3 and 6)

C_R = the capacity ratio

Then, for each part load conditions B, C, D the EER_{PL} is calculated as follows:

$$EER_{PL(B,C,D)} = EER_{DC\ (B,C,D)} \cdot \frac{CR_{(B,C,D)}}{CC_{(B,C,D)} \cdot CR_{(B,C,D)} + (1 - CC_{(B,C,D)})} \qquad \text{(Eq. 4)}$$

Where

EER_{DC} = the EER corresponding to the declared capacity (DC) of the chiller at the same temperature conditions as for part load conditions B, C, D.

C_c = the degradation coefficients for chillers for part load conditions B, C, D

C_R = the capacity ratios for part load conditions B, C, D

For chillers, the degradation due to the pressure equalization effect when the chiller restarts can be considered as negligible.

The only effect that will impact the EER at cycling is the remaining power input when the compressor is switching off.

The electrical power input during the compressor off state of the chiller is measured when the compressor is switched off for at least 10 min.

The degradation coefficient Cc is determined for each part load ratio as follows:

$$CC = 1 - \frac{\text{measured power of compressor off state}}{\text{total power input (full capacity at the part load conditions)}} \qquad \text{(Eq. 5)}$$

If Cc is not determined by test then the default degradation coefficient Cc is 0,9.

5.2.2 Calculation procedure for variable capacity chillers

Determine the declared capacity and EER_{PL} at the closest step or increment of the capacity control of the chiller to reach the required refrigeration load. If this step does not allow reaching the required refrigeration load within ± 10 % (e.g. between 9,9 kW and 8,1 kW for a required cooling load of 9 kW), determine the capacity and EER_{PL} at the defined part load temperatures for the steps on either side of the required refrigeration load. The part load capacity and the EER_{PL} at the required refrigeration load are then determined by linear interpolation between the results obtained from these two steps.
If the smallest control step of the chiller is higher than the required refrigeration load, the EER_{PL} at the required part load ratio is calculated using Eq. 4 as for fixed capacity chillers.

5.3 Calculation procedure for determination of EER_{PL} values at other part load conditions, different than part load conditions A, B, C, D

The EER values at each bin are determined via interpolation of the EER values at part load conditions A,B,C,D as mentioned in the tables of chapter 3 of this transitional method

For part load conditions above part load condition A, the same EER values as for condition A are used.

For part load conditions below part load condition D, the same EER values as for condition D are used.

Figure 1: Schematic overview of the SEPR calculation points for a fixed capacity unit