Performance Comparison
Inverter DX system and Air Cooled Chiller system

1. Purpose

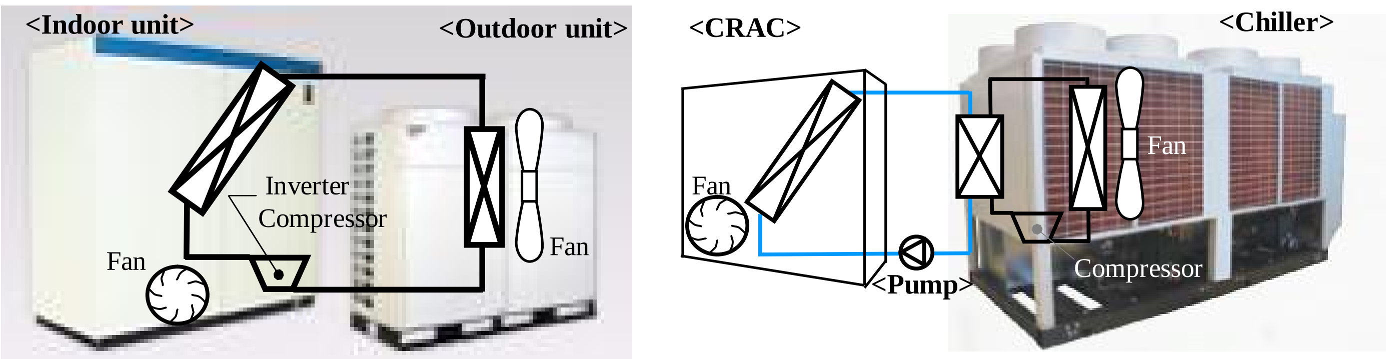
Best Practices version 1.0 section 4.4.2 recommends the choosing of air cooled chillers over DX type systems due to chillers having increased thermodynamic efficiency. However, Inverter DX systems (DX system with compressor frequency control) are quite common in Japan as a means to reduce energy consumption. It is important to note that Inverter DX systems are different and significantly more efficient than standard DX systems. We believe that Inverter DX systems can maintain a higher level of efficiency than air cooled chiller systems or standard DX type systems.

The description in 4.4.2 may preclude companies from considering higher efficiency cooling systems in the future like inverter DX systems. As a result, we would like to recommend including inverter DX systems as an additional consideration within section 4.4.2. We hope the information and case study contained within this document will prove useful in considering the inverter DX system as an alternative to air cooled chillers.

2. System configuration

Fig.1 shows the system structure for the inverter DX system and air cooled chiller system. The Inverter DX's power consumption is primarily down to the indoor/outdoor fan motors and the compressor motor. The compressor frequency control adjusts the inverter DX system cooling capacity, hence it does not consume unnecessary electric power for capacity control i.e electric heating. For this reason, the inverter DX system has a higher part load efficiency and is more effective in low ambient temperature conditions than the standard DX system.

Comparatively, an air cooled chiller's power is predominantly consumed by the CRAC fan motor, water pump motor, the fan motor (which is internal to the chiller), and the compressor motor. The standard air cooled chiller compressor is that of a normal non-inverter type (the compressor frequency is constant).



(a) Inverter DX system **(b) Air cooled chiller system**

Fig.1 System configuration

3. Total electric power consumption and *System COP*

The *COP* (Coefficient Of Performance) defines the energy efficiency of the cooling system and is obtained by the equation below:

$$COP = \frac{\text{Cooling capacity}}{\text{Electric power consumption}}$$

A high COP figure indicates high energy efficiency, which points towards a more effective cooling system.

This report uses [IT sensible heat load] as the cooling capacity, and the [total cooling system electric power consumption] as the electric power consumption to define the *system COP*. To denote the whole system efficiency, the *System COP* is defined as below.

$$\textit{System COP} = \frac{\text{Sensible heat load } Q_{\mathrm{IT}}}{\text{Total power } W_{\mathrm{total}}}$$

Fig.2 defines the total system power consumption ($W_{\mathbf{total}}$) for the Inverter DX system and air cooled chiller system.

The inverter DX system specification illustrate the *System COP*, on the other hand the Air Cooled chiller specification only gives the details of the *COP* for a single chiller. As the comparative element is different, it is impractical to carry out the study with the information just described; therefore this report defines *System COP* as the above.

$$\textit{Chiller COP} = \frac{\text{Chiller cooling capacity } Q_{\mathrm{chiller}}}{\text{Chiller power consumption } W_{\mathrm{chiller}}}$$

Fig.2(b) *Chiller COP* does not indicate the *System COP* but is of a value that indicates the efficiency for a single chiller unit.

Using the IT sensible heat load, the next chapter will calculate the *system COP* and analyse the energy efficiency of the Inverter DX system and the Air Cooled chiller system.

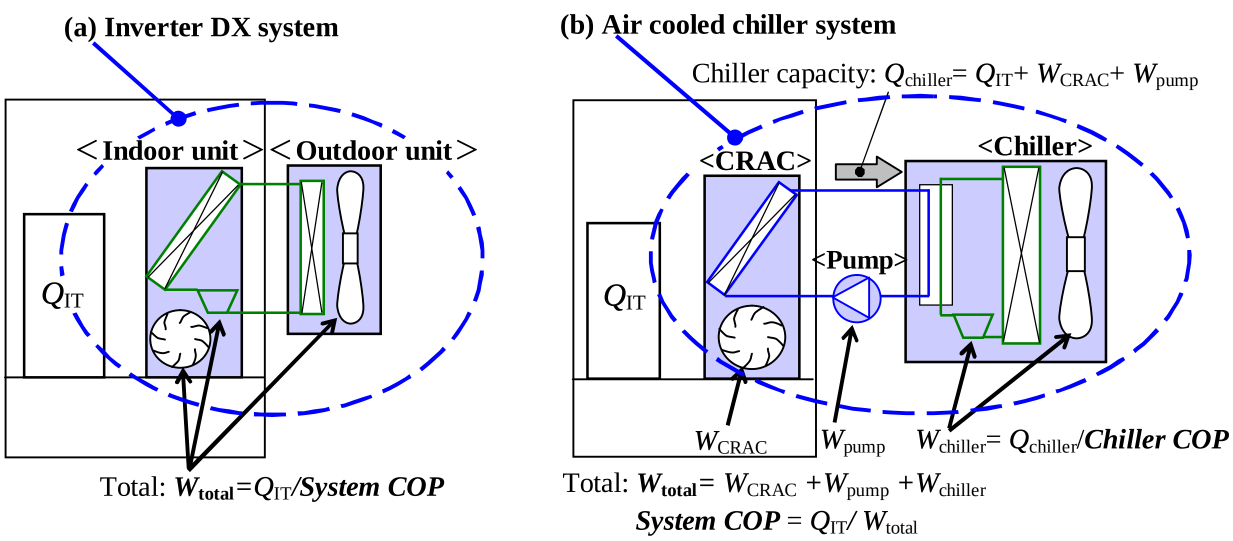


Fig 2. Electric power consumption

4. Case study
4.1 Standard condition

By presupposing the sensible heat load (IT heat-generation) and the system structure, the inverter DX system and the air cooled chiller's *system COP*, the power consumption has been calculated. Calculation assumptions are detailed in Table 1. Here we use 1,500[kW] as the sensible heat generation which is equivalent to 1,000[m^2] of the heat generating density of 1.5[kW/m^2]. The standard condition is: Indoor air 24[deg C], 50[%RH], ambient temperature 35[deg C].

The information gathered for this study has been obtained from several sources:
Inverter DX system – Hitachi product(1), available in Japan (see Appendix A Table A1)
Air Cooled Chiller System – Hitachi product(2), available in Europe (see Appendix A Table A2)
CRAC – Airedale product(3), available in Europe (see Appendix A Table A3)

The pump power consumption has been assumed at 2% of the IT load. Please refer to Appendix 2 for the detailed calculation.

Table 2 shows the calculation results under the conditions outlined above. As illustrated in Table 2, the *system COP* for the chiller system is significantly lower than the *chiller COP*; this is because the chiller *system COP* takes into account the power consumption of the CRAC and the pump (whereas *chiller COP* does not), hence giving it a lower *COP* than the Inverter DX system.

It is evident from Table 2 that the inverter DX system has a 40% higher *System COP* than an air cooled chiller system, hence, demonstrating that the inverter DX system can be more efficient than air cooled chiller systems.

Table 1 System configuration

Sensible heat load Q_{IT}		1,500[kW]
Inverter DX system		Sensible cooling capacity 53.5 [kW/unit]×28[units]
Air cooled chiller system	CRAC	Sensible cooling capacity 60.8 [kW/unit]×25[units]
	Pump	30[kW] (2% of sensible heat load Q_{IT})
	Air cooled chiller	Cooling capacity 978[kW/unit]×2[unit]

Table 2 Total power consumption and *System COP*

		Inverter DX system	Air cooled chiller system
Sensible heat load $\boldsymbol{Q}_{\mathbf{IT}}$	[kW]	1,500	1,500
Total power consumption $\boldsymbol{W}_{\mathbf{total}}$	[kW]	551	773 W_{CRAC}: 199 W_{pump}: 30 *$W_{chiller}$: 544 (*Chiller COP* 3.18)
System COP	**[-]**	**2.72 (140%)**	**1.94 (100%)**

*Water flow/return temperature 10/16[deg C]

4.2 Annual electricity consumption and *Annual system COP*

As mentioned in the Code of Conduct, the objective of future data centres is to reduce energy consumption, and the analysis of annual energy consumption is the most important element when making system judgments. This section will compare the energy efficiency of the two systems under the condition of the real environment (variable temperature). It will take into account the annual varying temperature and calculate the annual energy consumption of both systems. The calculation uses the *annual system COP* defined below.

$$\textit{Annual system COP} = \frac{\text{Sensible heat energy } (= Q_{IT} \times 24 \times 365)}{\text{Annual electricity consumption}}$$

Sensible heat energy – the IT sensible heat load is defined at 100% constant for 24 hours, 365days .

Annual electric energy consumption – see below:

Step 1: each annual electric energy consumption is obtained by multiplying the power consumption with its emerging number of hours at the ambient temperature. This calculation is done for each ambient temperature(1°C interval).

Step 2: work out the summation of the above to obtain the annual electric energy consumption.

The emerging number of hours is obtained from the hourly annual London meteorological data, arranged in a list for each 1°C interval (refer to Fig. 3).

The equipment configuration is the same as noted in section 4.1. The inverter DX system's *system COP* for each ambient temperature and the Air cooled chiller's *chiller COP* is shown in Fig.4. The CRAC and pump power consumption is defined as constant (as shown in Table 2) for 24 hours, 365 days. Please refer to Appendix C for the detailed calculation.

The calculation result under the above conditions is given in Table 3. As Fig. 4 illustrates, *the system COP* for the Air cooled chiller system is significantly lower than that of the *Chiller COP* alone. As explained earlier, this is because the *Chiller COP* does not take into account the power consumption of the CRAC and the pump.

As the inverter DX system *COP* is much higher than that of an Air Cooled Chiller system under lower ambient temperature T_a, the DX has a 94% higher *annual system COP*. This can be observed and is evident in Table 3. Therefore, even on a yearly basis the Inverter DX system still proves to be higher in efficiency than the air cooled chiller system.

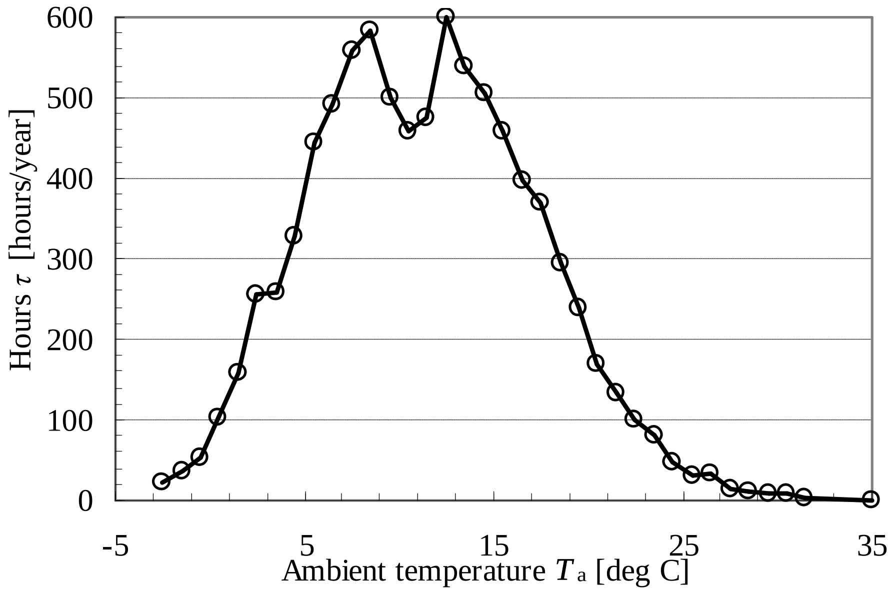


Fig.3 Ambient temperature distribution in London

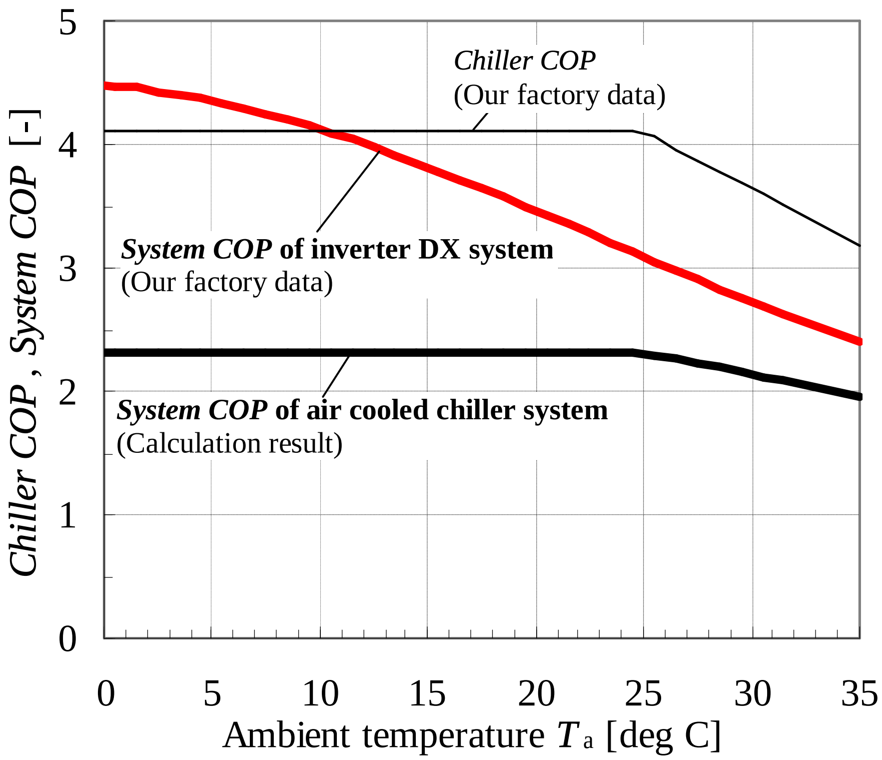


Fig.4 *Chiller COP* and *System COP* for each ambient temperature

Table 3 Annual electric energy consumption and *Anuual system COP*

		Inverter DX system	Air cooled chiller system
Sensible heat energy	[kWh]	13,100,000	13,100,000
Total annual electric energy consumption	[kWh]	2,940,000	5,680,000 **CRAC**: 1,740,000 **Pump**: 260,000 **Chiller:** 3,680,000
Annual system COP	**[-]**	**4.47 (194%)**	**2.31 (100%)**

5. Conclusion

Section 4.4.2 currently recommends the selection of air cooled chiller systems over DX type systems. This document highlights key characteristics of the air cooled chiller system and inverter DX type system including system configuration, power consumption for entire system configurations, and COP statistics for the two systems. The case study contained within this document provides a foundation for taking into consideration Inverter DX type systems over or along with the conventional air cooled chiller systems.

Hitachi Europe looks forward to discussing the contents of this document and providing additional information to support our recommendation.

6. Reference

(1)Hitachi, Ltd., : Air conditioner for IT equipment :
http://www.hitachi.co.jp/products/it/harmonious/greenit/catalog/datacenter16.pdf?bcsi_scan_3795F366BBE6D01C=0&bcsi_scan_filename=datacenter16.pdf, 2009 (in Japanese)

(2)Hitachi Europe Ltd. : Samurai Chiller Sales Catalogue :
http://www.hitachiaircon.com/argws/files/attachment/SalesManuals/92173_HitachiChillerCat%2028pp.pdf, 2009

(3)Airedale : Alpha Cool Down flow – Close Control System 8kW – 101kW Technical manual :
http://www4.modine.com/web_server_content/en_gb/publication/airedale_int/TM_ALPHACOOL_DF_UK.pdf?bcsi_scan_3795F366BBE6D01C=0&bcsi_scan_filename=TM_ALPHACOOL_DF_UK.pdf, 2009, p.52-p.54.

Appendix A - Inverter DX system, air cooled chiller and CRAC unit specifications

Table A1 Inverter DX specification (Hitachi factory data)

Make	Hitachi Ltd.
Type	RP-NP560AVD/RCR-NP560AD
*Sensible cooling capacity [kW/unit]	53.5
**System COP* [-]	2.72

* Indoor air 24[deg C], 50[%RH], ambient temperature 35[deg C]

Table A2 Air cooled chiller specification (Hitachi factory data)

Make	Hitachi Europe Ltd.
Type	RCUE350AG2
*Cooling capacity [kW/unit]	978
**Chiller COP* [-]	3.18

*Water flow/return temperature 10/16[deg C], ambient temperature 35[deg C].

Table A3 CRAC unit specification

Make	Airedale

Type	DF80CW
*Sensible cooling capacity [kW/unit]	60.8
Quantity / Motor Size [kW/unit]	2×4 (=8)

* Indoor air 24[deg C], 50[%RH]. Water flow/return temperature 10/16[deg C].

Appendix B –Calculations under standard condition

B.1 Air cooled chiller system

Sensible heat load Q_{IT}: 1,500[kW]

CRAC: $W_{CRAC}=Q_{IT}/60.8\times8=1{,}500/60.8\times8=199$[kW]

Pump: $W_{pump}=Q_{IT}\times0.02=1{,}500\times0.02=30$[kW]

Chiller: $W_{chiller}=(Q_{IT}+W_{CRAC}+W_{pump})/\mathit{Chiller\ COP}=(1{,}500+199+30)/3.18=544$[kW]

Total: $W_{total}=W_{CRAC}+W_{pump}+W_{chiller}=199+30+544=773$[kW]

$\mathit{System\ COP}=Q_{IT}/W_{total}=1{,}500/773=1.94$

B.2 Inverter DX system

Total: $W_{total}=Q_{IT}/\mathit{System\ COP}=1{,}500/2.72=551$[kW]

Appendix C - Calculations under annual condition

C.1 Air cooled chiller system

Annual electric energy consumption

CRAC: $W_{CRAC}\times24\times365=199\times24\times365=1{,}740{,}000$[kWh]

Pump: $W_{pump}\times24\times365=30\times24\times365=260{,}000$[kW]

Chiller: $\sum(Q_{IT}+W_{CRAC}+W_{pump})/\mathit{Chiller\ COP}(T_a)\cdot\tau(T_a)=3{,}680{,}000$[kWh]

T_a : Ambient temperature [deg C]

$\mathit{Chiller\ COP}(T_a)$: *Chiller COP* at T_a (Fig.B2)

τ : Hour at T_a [Hours/year] (Fig.B1)

Total: 1,740,000+260,000+3,680,000=5,680,000[kWh]

Annual system COP

Annual system COP $=(Q_{IT}\times24\times365)/5{,}680{,}000=2.31$

C.2 Inverter DX system

Annual electric energy consumption

Total: $\sum Q_{IT}/\mathit{System\ COP}(T_a)\cdot\tau(T_a)=2{,}940{,}000$[kWh]

Annual system COP

Annual system COP $=(Q_{IT}\times24\times365)/2{,}940{,}000=4.47$