Information paper – 22

Chiller energy efficiency

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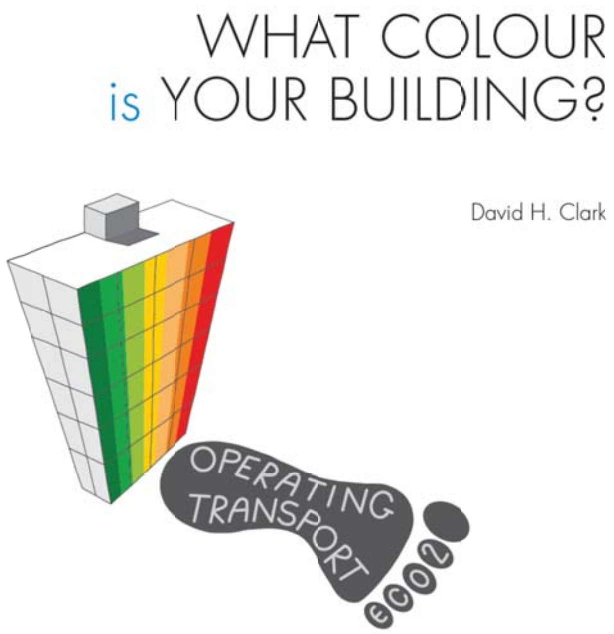
A paper referenced in the book:



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This information paper is one of a series of papers written during the preparation of the book **What Colour is Your Building?** (www.whatcolourisyourbuilding.com). The papers do not form part of the book and have not been peer reviewed. They provide further technical detail, analysis and information to support statements made in the book. All of the papers can be downloaded from www.wholecarbonfootprint.com.

Chiller energy efficiency

This information paper provides an overview of some of the issues influencing the energy consumption of chillers in operation, including:

- Efficiency of compressors at full and part loads.
- Condensor water temperatures.
- Chilled water supply temperatures.
- Maintenance and operation practices.

1. MEASURED PERFORMANCE

The actual energy efficiency of chillers can be different to that stated in the manufacturers' performance data, as this is based on idealised conditions. A report by the International Energy Agency in 2008, *Assessing the Actual Energy Efficiency of Building Scale Cooling Systems*, noted that: 'While a great deal of attention is given to the efficiency of the chiller itself, we have found very few studies or data relating to the total plant efficiency including the auxiliaries (cooling tower fans, condenser water pumps). Auxiliaries can have a significant negative impact on annual efficiency, particularly if fans and pumps are driven by fixed speed motors rather than variable frequency drives (VFDs).'

Table 1 summarises the efficiency of cooling systems from various case studies contained in the report.

Type	Size (kW)	Efficiency unit	Efficiency	Average system load
Air cooled	620	CoP	2.4	-
Variable speed screw	1550	CoP	2.9	-
Ultra-efficient, VSD and oil-less compressors	2640	CoP	6.3	-
District cooling plant	11,250	CoP	4	-
Package air cooled chiller and fan coils	50	EER	1 to 1.4	21%
Water cooled screw chiller and fan coils	1275	EER	0.8 to 1.6	19%
Packaged air cooled chiller and fan coils	100	EER	0.3 to 1.4	8.3%
DX split	8	EER	1.3 to 1.7	44%

Table 1 Summary of case study data in IEA Report on cooling system efficiency (source: IEA)

The report noted that although it is possible to obtain very high seasonal efficiencies (COP greater than 5) with well-designed, well-operated all-VSD plants operating in favourable climate conditions, during the course of the IEA study they were unable to obtain primary data documenting such performance.

2. COMPRESSORS

There are three main types of chiller compressors which come in different size ranges:

- Reciprocating (175 to 800 kW)
- Rotary [typically screw] (240 to 1,400 kW)
- Centrifugal (700 to 8,800 kW)

Centrifugal compressors are typically the most efficient followed by screw. Since 1990 there have been significant improvements in the part load efficiency of chillers, and with variable speed chillers maximum efficiency occurs at around 50% load. Below 40% loading the efficiency of chillers rapidly reduces – refer to Figure 1 for an example COP curve. At first glance this might suggest running chillers at part load will result in higher energy efficiency, but this performance does not consider the part load operation of fans and pumps in the condenser circuit which can significantly reduce the total annual plant efficiency, particularly if they are not variable speed.

In Europe and US, certification schemes provide a efficiency metric which is designed to be representative of the seasonal annual performance of a chiller. These are based on taking the chiller efficiencies at full and part loads, and estimating the proportion of time the chiller runs at each of the loads based on the assumed average climate in either the US or Europe.[1]

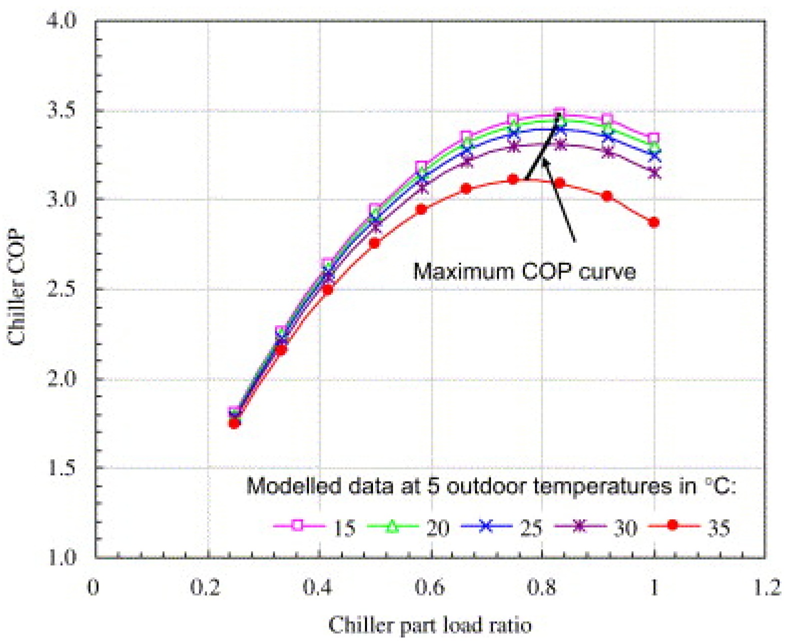

Fig 1 **Part load performance curves of a chiller operating under head pressure control. (source: Yu & Chan)[2]**

3. CONDENSER TEMPERATURES

Chillers are more efficient at lower heat sink temperatures which typically occur when the air temperature is lower. An energy saving of 3 % is obtained for each 1°C reduction in condenser water temperature supplied to a chiller.[3] The savings are even greater when using variable speed drives on centrifugal chillers.

Cooling towers provide lower condenser water temperatures than air cooled systems and are consequently more energy efficient. Unfortunately, cooling towers have two major disadvantages: water consumption and the risk of legionella. The health risks posed, and the stringent maintenance regimes required to manage this risk, are leading to cooling towers falling out of favour in office buildings in the UK.

An alternative to cooling towers are evaporative cooling heat rejection units. Their performance falls between dry air heat rejection units and cooling towers. Because they don't produce a mist of water droplets the legionella risk is minimal.

If a large expanse of water is near to the building, then this could be used for heat rejection. For example, many buildings in Hong Kong use sea water for heat rejection.

4. CHILLED WATER SUPPLY TEMPERATURE

Chillers are more efficient when the chilled water leaving the chiller is higher. Chilled water is typically supplied at 6°C for dehumidification (the coil needs to be cold enough for water vapour in the air to condense on it) but when this is not necessary the temperature can be increased. Chilled beams and ceiling systems typically require water at 13°C (to avoid condensation on their surface) and so chillers can run more efficiently in these systems.

If the chilled water supply temperature can be increased to match the condenser water temperature then the chiller compressors can be switched off. This is known as 'free cooling.'

5. CHILLED WATER STORAGE

The principle of chilled water storage (CWS), which should not be confused with ice storage, is the generation of chilled water overnight when the cooling demand in building is lower and there is therefore spare capacity in the chillers. The chilled water generated overnight is stored in a large insulated vertical tank for use the following day during the peak cooling period (typically the afternoon).

CWS is suited to large buildings (e.g. hospitals) or in district cooling systems. The cost benefit of CWS include:

- Reduced no. of chillers – capital and maintenance cost savings.
- Reduced peak electricity demand charges.

- Reduced energy tariffs – chillers run at night (off peak tariff) to charge chilled water tank which is then used during peak afternoon cooling period.

CWS can reduce CO_2 emissions because, due to lower air temperatures at night, the chillers run more efficiently at night when generating the chilled water for the tank. Ideally the insulated storage tank needs to be quite large – a 6m diameter by 12.5m high tank is a practical minimum to provide sufficient stratification. Horizontal tanks are possible but need careful design of baffles to avoid warmer return water mixing with the chilled water being drawn from the tank.

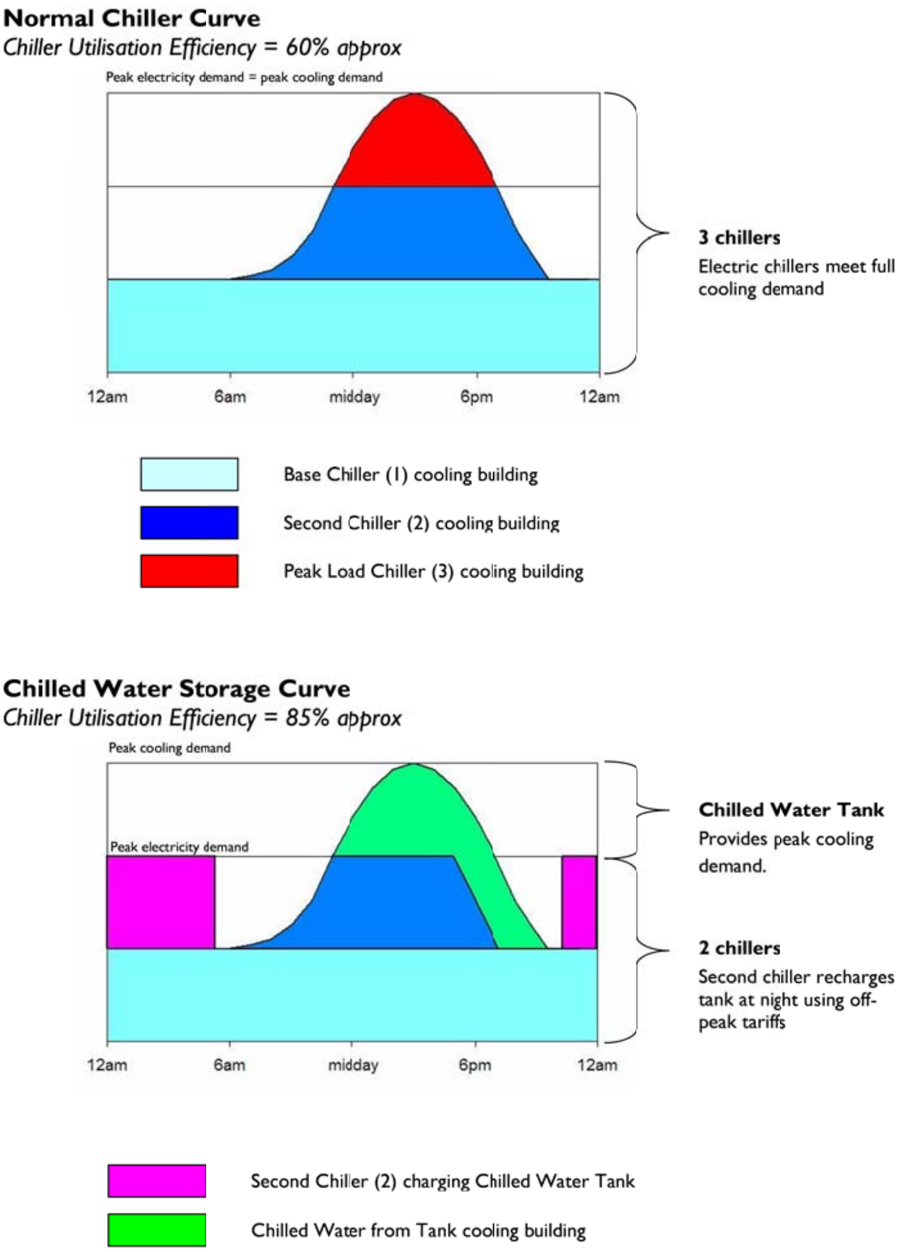

Fig 2 **Example utilisation of chilled water storage compared to chiller only approach**

Notes

All websites were accessed on 15 June 2013 unless noted otherwise.

1. The metric in Europe is the European Seasonal Energy Efficiency Ratio (ESEER) and the certification scheme is administered by Eurovent (www.eurovent-certification.com). In the US the metric is the Integrated Part Load Value (IPLV) as defined by the Air-conditioning and Refrigeration Institute in ARI 550.

2. Reprinted from *Building and Environment*, Volume 42, Issue 11, W. Yu & K.T. Chan, Part load performance of air-cooled centrifugal chillers with variable speed condenser fan control, Pages 3816–3829, Copyright 2007, with permission from Elsevier.

3. Taken from Section 47.5 of 2011 ASHRAE Handbook – HVAC Applications.