HVAC Water chiller selection and optimisation of operation

Introduction

Water-chiller is a broad term describing an overall package that includes an electrical control panel, refrigeration plant, water chiller, water tank, water circulation pumps and air or water cooled condenser. This name suggests that the compressor, condenser, chiller, internal piping and controls are all combined into a single unit.

Water chillers range in size from small capacity scroll or reciprocating compressor units with air or water-cooled condensers up to large units incorporating centrifugal or screw compressors. Large water chillers are normally water cooled using the recirculated water from a cooling tower or evaporative condenser although air-cooled condensers are now becoming more popular, especially where there is a likelihood of the occurrence of Legionnaires disease.

Central chilled water units are typically used in air-conditioning systems comprising air handling units each fitted with chilled water coils and fans. These air handling units can be located in a central plant room or more typically distributed throughout the building.

The types of compressor used vary depending upon the capacity of the chiller units. Generally, scroll or reciprocating compressors are used for small to medium capacity water chillers, whilst medium to large capacity water chillers incorporate screw compressors and very large capacity units utilise centrifugal compressors.

Selection Criteria

When selecting a water chiller it is essential that the following issues are carefully considered:

- Performance characteristic and system capacity control at maximum and part load operation. To achieve efficient operation, the water chiller refrigeration capacity must be adjustable to suit the cooling load of the building.

- Selection of the type of water chiller must also take into account the minimum load at which the chiller may be required to operate. As an example reciprocating compressors can unload to about 25%, screw compressors down to 10-15% and centrifugal chillers down to 20-25%. Should this turn-down ratio be insufficient to meet the minimum cooling requirement on the building, then multiple chillers, or chillers with multiple compressor may be necessary in order to achieve capacity control resulting in energy efficient operation.

- For water-cooled equipment to achieve maximum energy efficiency, it is important that the cooling tower water system operate at the lowest possible temperature. Data from water chiller manufacturers can be obtained in order to determine the minimum acceptable condenser water temperature. As a guide, for each 1°C reduction in the water temperature entering the condenser, power consumption of the chiller is reduced by approximately 2%. Most water chillers can operate satisfactorily with condenser water temperature down to 24°C.
- The chilled water temperature should be maintained as high as possible to reduce the energy consumption of the compressor. Typically, a 1°C increase in chilled water temperature can reduce the compressor energy input by approximately 2%.

- The temperature differentials across both the condenser and chiller heat exchangers should be optimized to be as high as possible. High temperature differentials will result in lower water flow rates with a consequential reduction of pumping energy.

- Adequate water treatment should be provided in order to maintain the heat exchange surfaces in a clean condition to achieve maximum heat transfer efficiency.

- Efficiency of water chillers is generally measured by the energy efficiency ratio (EER). This is the ratio of the electrical power input kW(e) to the refrigeration output kW(r). Information concerning the EER at varying operating conditions can be obtained from the water chiller manufacturers and assessment of this data should form part of the selection criteria for water chilling equipment.

**Water Chiller – Scroll or Reciprocating Compressors**

Water chillers with Scroll or reciprocating compressors incorporate either single or multiple reciprocating compressors. Reciprocating compressors are limited in size generally to between 350 kW – 500 kW(r) for economic reasons. A water chiller with multiple compressors can provide good staging and capacity control. The following is a typical energy consumption curve:

![Figure 1 Typical Energy Consumption Curve – Staged Compressors](image)

**Water Chiller - Centrifugal Compressors**

A centrifugal compressor is similar to a centrifugal pump and compresses refrigerant by means of a rotor spinning at high speeds. The capacity of a centrifugal compressor can be varied by a set of vanes at the compressor inlet to vary the refrigerant flow through the compressor. A more recent development is the application of variable speed motors to allow capacity reduction with a more significant energy reduction.

Capacity of centrifugal chilled water units would usually start at about 800-1000 kW(r) up to 4000 kW(r) or higher. The following is typical energy consumption curve.
Recent advances in centrifugal compressor design have led to it now also being used in chillers with capacities down to about 200 kW. The most recent designs also include magnetically levitated bearings that do not require lubrication. The ability to dispense with a lubrication system avoids the common problem of oil carryover into the condenser and consequent loss of cooling capacity that results when oil deposits on the surfaces of condenser tubes. These units are also significantly more energy efficient than other compressors in their size range.

Water Chiller Units – Screw Compressor

The screw compressor tends to be more compact than the equivalent centrifugal compressor and operates with less vibration. Capacity is varied by sliding inlet vanes.

Similar to most centrifugal compressor chillers, screw compressor water chillers usually commence at between 800-2000kW(r) cooling capacity. The following is a typical energy consumption curve:

System Diversity

Diversity is very important in the design and operation of a central chilled water plant. The term diversity takes account of the fact that an air conditioning system will only operate at peak design conditions for some 3 – 5% of the year. At other times the system will operate at greatly reduced load.

As mentioned previously, it is important that the compressor be capable of reducing capacity to meet the reduction in load. This capacity reduction can be achieved by turning down the capacity of the chilled water unit or on larger installations, by providing multiple water chilling units to achieve the diversity of operation.
A system design engineer should carefully consider the system diversity - as in any installation – seldom will all the air conditioning units will operate at peak load at the same time. The diversity factor applied to system design can take account of this. The water chiller load is the sum of the peak design loads of all air conditioning units served by the central plant. In some installations the diversity factor could be as low as 0.6. Hence, lower capacity chilled water equipment can be installed and still be capable of meeting the design requirements of the air conditioned spaces.

**Constant Flow**

It is usual for small to medium water chilling systems to operate as constant flow systems. This means that the same quantity of water is circulated at all times regardless of the load. It is essential that the flow to the water chillers be maintained at a relatively constant value in order to avoid the possibility of water freezing within the tubes.

Constant flow chilled water systems can be energy inefficient as it is often necessary for the full water flow rate to circulate through the equipment to maintain constant flow even though at light load this flow rate is not required by the cooling coil and the temperature difference between supply and return water may be only 1°C or 2 °C.

The following diagram illustrates a constant flow water chiller system.

![3.2 WATER CHILLER SYSTEM](image)

**Figure 3.2 Constant Flow System**

**Variable Flow System**

The main reason for using constant flow systems is the requirement to maintain constant water flow rate through the water chiller unit. A variable flow system can achieve the same result whilst allowing the flow in the distribution system to vary with the load on the building.

Two basic systems, by-pass control and secondary chilled water piping system are described.

**By-pass Control**

The by-pass arrangement illustrated in Fig. 3.3.1 incorporates a pressure operated by-pass valve in conjunction with two-way valves at each air conditioning unit. As the air conditioning unit control valves modulate, the distribution flow will vary. This variation in
flow results in a change in the differential pressure between supply and return piping. This change is sensed by the pressure differential controller which then modulates a by-pass valve to compensate. As a result the water flow through the chillers remains essentially constant.

The by-pass valve should be sized to accommodate the maximum flow which could be envisaged. In the case of duplicate water chillers, the valve should be sized for the flow rate of 1 chiller. As the load on the air conditioning installation increases, the by-pass valve will modulate towards the closed position allowing the water flow through the piping system serving the load to increase.

![Figure 3.31 By-Pass Control System](image1)

**Figure 3.31 By-Pass Control System**

**Secondary Chilled Water Piping System**

In this instance, the primary water circulating pumps provide circulation through the chillers at a constant rate in a closed loop arrangement. The secondary system pumps provide circulation out to the air conditioning load system. The secondary chilled water pumps are normally provided with variable speed motors in order to allow the flow to vary in accordance with requirements of the cooling system. The short section of piping (A – B) is generally known as the hydraulic isolator and is common to both pumping circuits. It should have a low resistance to flow compared to the total system.

![Figure 3.3.2 Primary/ Secondary System](image2)

**Figure 3.3.2 Primary/ Secondary System**
With a single chilled water system operating, control is usually by means of the units’ temperature controller.

Where multiple chillers are installed, it is essential that correct control be maintained in order to achieve energy efficient operation. Allowing multiple chilled water units to operate independently under the control of their own equipment will result in extremely high energy costs.

Staging of multiple chiller installations can be achieved by utilising an electronic control system to calculate the actual cooling load on the building. This load can be calculated by assessing the positions of each chilled water valve and using this information to estimate the actual cooling load at any given time.

An alternative scheme is to measure the chilled water flow rate together with flow and return temperatures and use this to calculate the cooling load. Having calculated the cooling load it is then possible to stage the chilled water equipment to achieve minimum energy consumption. It is important that the load profile for each chiller be considered and that the sequencing be carried out by operating the water chillers at their most efficient operating point to achieve minimum energy consumption.

In this way, the water chilling unit which has the capacity closest to the actual requirement can be energised to operate at peak efficiency. Variable speed drives on centrifugal chilled water units will allow a more economic operation of the equipment at lower capacity operation.

The use of electronically controlled refrigerant expansion valves on chiller evaporators can result in significant energy savings compared with the use of float type expansion valves. It is often economic to retrofit electronically controlled expansion valves to an existing chiller set, especially if the chiller is relatively old but in good condition.

**Conclusion**

Selecting the correct chiller for the appropriate application can lead to significant energy savings and reduce greenhouse gas emissions. **Contact ALTITUDE** for more information.