Implementation of District Cooling System in Hong Kong: Challenges and Experiences

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ABSTRACT

The Kai Tak Development (KTD) is a huge development project spanning a total area of over 320 hectares covering the ex-airport and nearby areas in which there has been a planned total of about 1.73 million square metres of public and private non-domestic air-conditioned floor areas requiring a large demand for air-conditioning of about 284 megawatt of refrigeration (MW). The Government aims to promote energy saving and took the lead to implement District Cooling System (DCS) which could be considered the most energy efficient air-conditioning system for the development at KTD.

The project of DCS at KTD is to construct a large scale centralized air-conditioning system which would produce chilled water at its central chiller plants and distribute the chilled water to consumer buildings in the KTD through an underground water piping network. Apart from constructing central chiller plant rooms, the laying of underground water pipes is another challenging task in view of the uncertainty in underground conditions. The operation of DCS is also one of the most challenging tasks to be dealt with. Energy efficiency as well as reliability of services are both important. This paper aims to present the challenges faced and also experience gained during the implementation and operation of the DCS.

Keywords: District Cooling System (DCS), Kai Tak Development (KTD), Energy Efficiency

1. INTRODUCTION

Since the operation of the Hong Kong International Airport at Chep Lap Kok in 1998, the Government started to develop the ex-Kai Tak International Airport and the nearby areas into a new development area – Kai Tak Development (KTD). KTD is a huge development spanning a total planning area of 320 hectares. It comprises various types of buildings including hospitals, hotels, schools, commercial buildings, sport facilities, residential buildings, government buildings, etc. With the high cooling demand and diversity of cooling load profiles, the Government took the opportunity to implement District Cooling System (DCS) at KTD.

2. BENEFITS

DCS consumes 35 percent and 20 percent less electricity as compared to traditional air-cooled air-conditioning systems and individual water-cooled air-conditioning systems using cooling towers respectively. With its high energy efficiency, the implementation of DCS at KTD will achieve estimated annual saving of 85 million kilowatt-hour (kWh) in electricity consumption, with a corresponding reduction of 59,500 tonnes of carbon dioxide emissions per annum.

Apart from energy saving, DCS would also bring along the following benefits to the consumers:

a. Reduction in upfront capital cost for installing chiller plants at their buildings which account for about 5-10% of the total building cost;

b. More flexible building designs for consumer buildings as they do not need to install their own chillers and the associated electrical equipment in their buildings;

c. Mitigation of heat island effects in KTD and elimination of noise and vibration arising from the operation of heat rejection equipment and chillers of air-conditioning plants in buildings as such equipment will no longer be necessary for buildings subscribing to district cooling services; and

d. More adaptable air-conditioning system to the varying demand as compared to individual air-conditioning systems. For each individual building, cooling capacity can be increased by requesting additional cooling capacity from the DCS without carrying out extensive modification works for the building in question.

3. IMPLEMENTATION

The DCS at KTD comprises two central chiller plants, namely the North Plant and the South Plant cum seawater pump house, underground chilled water distribution piping network, seawater supply and discharge pipes and consumer substations located in the buildings to interface with the building's own chilled water circulation systems. The total cooling capacity of the DCS at KTD would be about 284 megawatt of refrigeration (MWr) which could provide about 1.73 million square metres of public and private non-domestic air-conditioned floor areas. The cooling capacities of the North Plant and the South Plant would be 162 MWr and 122 MWr respectively. Both plants are underground structures for the chiller installations with aboveground facilities at the North Plant. Upon completion of the project, about 39 kilometres of underground chilled water pipes would have been laid and there would be around 60 buildings in KTD connected to the DCS.

Figure 1 - Kai Tak DCS North Plant

The project will be implemented in three phases. The construction works commenced in February 2011. Phase I and II include the construction of two plant rooms and some pipeworks to enable the provision of district cooling services to the Kai Tak Cruise Terminal and Ching Long Shopping Centre in the public rental housing in 2013. Phase III includes further pipes laying works and chiller installation to meet the cooling demand growth in KTD. Phase I and II were completed in 2013 and 2014 respectively. Phase III commenced in mid 2013 and is expected to be completed by 2022.

4. RELIABILITY

To assure the consumers of a reliable district cooling services, several design features have been incorporated into the DCS.

4.1 Electricity Supply

The electricity supply to the DCS plant is such a robust arrangement that each supply carries only 50% of the required electrical load such that failure of any one of the cable will result in no reduction in the power supply condition. To further enhance the power supply reliability for DCS, 11kV power supply fed from two supply sources is adopted such that when one source fails, the power supply will be automatically switched over to the other source.

4.2 Chilled Water Piping Network

The underground chilled water piping network is designed to be in ring circuit forming a dual-feed supply so that if the supply from one side of the distribution pipework is not available, chilled water can still be supplied to the consumer buildings from other side. Moreover, the whole chilled water distribution piping network is designed as a 3-pipe system such that when one of the duty supply or return pipe is damaged or under maintenance, the standby pipe can be put in operation to maintain the district cooling services.

4.3 Chiller Plant

There are always at least one standby chiller and chilled water pump such that if any one of the chillers or pumps fails, the standby equipment will be put in operation to maintain full cooling capacity to serve the consumers.

5. DCS PIPELINES AND CHALLENGES

The DCS pipelines (including chilled water pipes and seawater pipes) are mostly laid along the carriageway while branch pipes and valve chambers are located in the footpath in order to minimize conflict with other underground utilities. Due to their large sizes, the DCS pipes are normally laid at the bottom among other underground utilities.

The DCS chilled water pipes are pre-fabricated with a pair of leakage detection cables secured externally at 4 o'clock and 8 o'clock positions of the pipeline, then annular insulated with polyurethane foam and protected in an extruded high density polyethylene (HDPE) outer jacket. Polyurethane insulation together with HDPE outer jacket are considered with good thermal insulation performance, mechanically stable and close structure which provide good resistance to moisture penetration for direct buried application.

As most of the DCS pipelines are laid underground, water leakage detection cables fixed on the chilled water pipes allow monitoring the condition of pipes continuously and give early warning of any water leakage. On site, leakage detection panels are installed at an interval of approximate 1.5 kilometres of pipe run to closely monitor any water leakage point and identify any fault signal due to broken cable.

Figure 2 - Prefabricated chilled water pipe with leakage detection cables and polyurethane insulation with HDPE outer jacket

In general, open trench excavation secured with sheet-pile walls are adopted for the laying of DCS pipes. However, in some locations, there are prohibitively existing site constraints for constructing any open trench. To surmount such construction difficulties, trenchless excavation method are adopted.

Other than the congested underground utilities, there are also various existing and new structures including Kwun Tong Bypass, Kai Tak Tunnel, box culverts, Kai Tak Taxiway Bridge, Shatin-Central Link, Central Kowloon Route and Kai Tak Approach Channel in close proximity of the DCS pipelines which are the constraints in laying the DCS pipes.

There are about 11 sections of DCS pipelines to be constructed with trenchless method at KTD, where open trench excavation method is not practical or the space required for laying of DCS pipes above the existing structure is inadequate. In which, about 1km of DCS pipes are constructed or will be constructed by heading method or hand dug tunnel. Over 5km of DCS pipes are constructed or will be constructed by pipe jacking method with the use of tunnel boring machines (TBMs). The largest TBM size is 2,800mm in diameter which is the largest one ever used in pipe jacking in Hong Kong.

In order to have smooth construction of pipe laying works, considerable pre-construction precautionary measures to identify the actual underground conditions and to determine the appropriate type of trenchless excavation method are necessary.

In view of this, the following measures will be carried out before construction.

a. Sufficient trial pits to expose and verify the existence, extent, location and elevation of all underground utilities, natural or man-made obstructions and structure; and

b. Suitable underground detection equipment are used to locate underground utilities; to further check the underground conditions along the proposed pipe jacking route; and to assess the feasibility of the proposed route, locations and inverts of jacking and receiving pits.

The formation level of the Kai Tak Development is generally at +5.0mPD whilst the mean sea level in 50 year return period is approximately +3.5mPD. As some of the pipelines and excavation pits are as low as (-)2mPD to (-)4mPD, the chance of seepage of underground water is high. For open trench excavation, the toe-in of the sheet-pile wall need to be carefully determined to prevent the inflow of underground water from the bottom of the trench. Installing grout curtain to control groundwater inflow into the excavation, as well as dewatering from inside the cofferdam excavation for all excavation levels are required. For trenchless excavation method, ground treatment need to be carried out to control ground water flows to stabilize ground prior excavation.

Figure 3 - Grout curtain and dewatering provided at deep open trench for pipe laying

Due to deep excavation and trenchless excavation construction involved, establishment of settlement control points and survey of the existing ground levels are required to be set up for close monitoring of the underground condition. Measurements at settlement points are carried out at least twice a day before and after any jacking works. The alarm-alert-action (3As) measures are adopted in ground movement monitoring.

6. DCS OPERATION AND CHALLENGES

The cooling energy required by each consumer building will be transferred from the DCS to the individual building’s central air-conditioning system via plate type heat exchangers installed inside the substation of the consumer buildings. The primary side of the heat exchanger is connected to the DCS distributing chilled water pipes and the secondary side is connected to the consumer’s chilled water system pipework.

Figure 4 - Distribution of district cooling services

Under normal operating conditions, the designed chilled water supply and return temperatures are as follows:-

a. At the primary chilled water side of the heat exchanger, i.e. DCS side:

- Supply Temperature = 5℃
- Return Temperature = 13℃

b. At the secondary chilled water side of the heat exchanger, i.e. consumer side:

- Supply Temperature = 6℃
- Return Temperature = 14℃

It is desirable for both the DCS plant operator and the consumers to meet the above design conditions in order to achieve energy efficient DCS plant operation and reliable chilled water supply to the consumers.

Since the commencement of district cooling services in 2013, in some circumstances like low load condition, it is noted that when the chilled water return temperature at the consumer side fall below 14℃, the temperature difference (Delta-T) at DCS side and consumer side are reduced. Accordingly, the chilled water flow rate as compared to the design flow rate for a given cooling load demand has to be increased. As a result, more pumping energy is consumed and the system efficiency is adversely affected.

In order to enhance the energy efficiency of the DCS, the consumers are recommended to incorporate the following design features in their chilled water system of the consumer side.

6.1 Variable Flow Chilled Water

Variable flow chilled water system together with two-way equal percentage control valves for controlling all air handling units (AHU) and fan coil units (FCU) should be adopted. Each control valve should be capable of controlling the flow throughout the entire range of designed operating conditions of the equipment.

6.2 Temperature Oriented Control

Operation of the control valves for controlling the AHU/ FCU should make reference to the Return Air Temperature (RAT). Since RAT represents the actual heat load from the building, adjusting the control valve based on the RAT instead supply air temperature or off-coil temperature could maintain the designed chilled water Delta-T.

Figure 5 – Return air temperature control on air handling units

6.3 Interlocking Control Mechanism

When the status of the AHU/ FCU is off, the associated control valves should also be closed in order to save energy and enhance the system’s efficiency. Such interlocking control mechanism could be implemented by programmable logic controller (PLC) or similar mechanism.

7. CHARGING PRINCIPLES

The public and private non-domestic building owners or their authorized agents in KTD who have central air-conditioning system of their buildings being subscribed to district cooling services are required to pay the district cooling services charges to the Government. The District Cooling Services Bill is being introduced to the Legislative Council in 2014-15 to set the tariff mechanism and tariff rate.

The district cooling services tariff is proposed to be set out with the following charging principles.

a. The district cooling services tariff should be set at a competitive level comparable to the cost of individual water-cooled air-conditioning systems (WACS) using cooling towers which is one of the most cost-effective air-conditioning systems available in the market;

b. Both the capital and operating costs should be recovered from the consumers over the project life which is estimated to be 30 years as taxpayers should not subsidize such air-conditioning charges;

c. Price stability could be achieved under the proposed charging mechanism; and,

d. The proposed charging mechanism should be a simple charging regime with common charge rates for all consumers regardless of their load profiles.

8. KEY TARIFF COMPONENTS

In line with international practices, the proposed tariff of district cooling services comprise two major components, namely the capacity charge and consumption charge:-

8.1 Capacity Charge

The capacity charge serves to cover the capital cost of the DCS plant and equipment and operation and maintenance (O&M) cost. The capacity charge will be levied according to the contract cooling capacity, which will be determined by the consumer and agreed by EMSD before the commencement of district cooling services.

8.2 Consumption Charge

The consumption charge will be levied to cover costs that will vary according to the demand of the consumer. The major part of the charge is the utility cost such as electricity used to generate chilled water being delivered to the consumer.

9. TARIFF ADJUSTMENT MECHANISM

Having regard to the composition of the two charges, the capacity charge rate is proposed to be adjusted annually based on the Composite Consumer Price Index while the consumption charge rate is proposed to be adjusted annually to take into account of the change in electricity tariff rate.

10. CONCLUSIONS

Subsequent to the project commencement in early 2011 and the completion of the early phases of the project, the DCS at KTD has been providing services to consumer buildings including Kai Tak Cruise Terminal and Ching Long Shopping Centre in the public rental housing since 2013. The construction of the remaining phase of the DCS project is in progress and will be completed along with the growing needs of air-conditioning of the new buildings which are coming up progressively. It is expected that the whole project will be completed around 2022 and will achieve an estimated annual saving of 85 million kilowatt-hour (kWh) in electricity consumption.

Figure 1 - Kai Tak DCS North Plant

Figure 2 - Prefabricated chilled water pipe with leakage detection cables and polyurethane insulation with HDPE outer jacket

Figure 3 - Grout curtain and dewatering provided at deep open trench for pipe laying

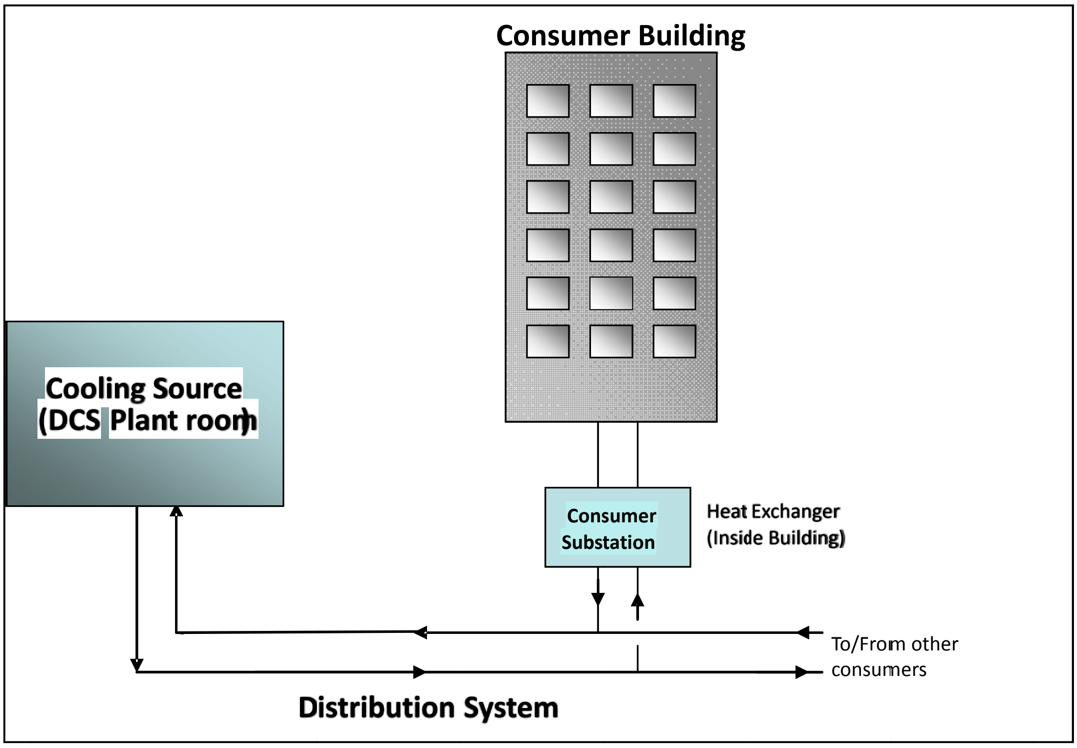

Figure 4 – Distribution of district cooling services

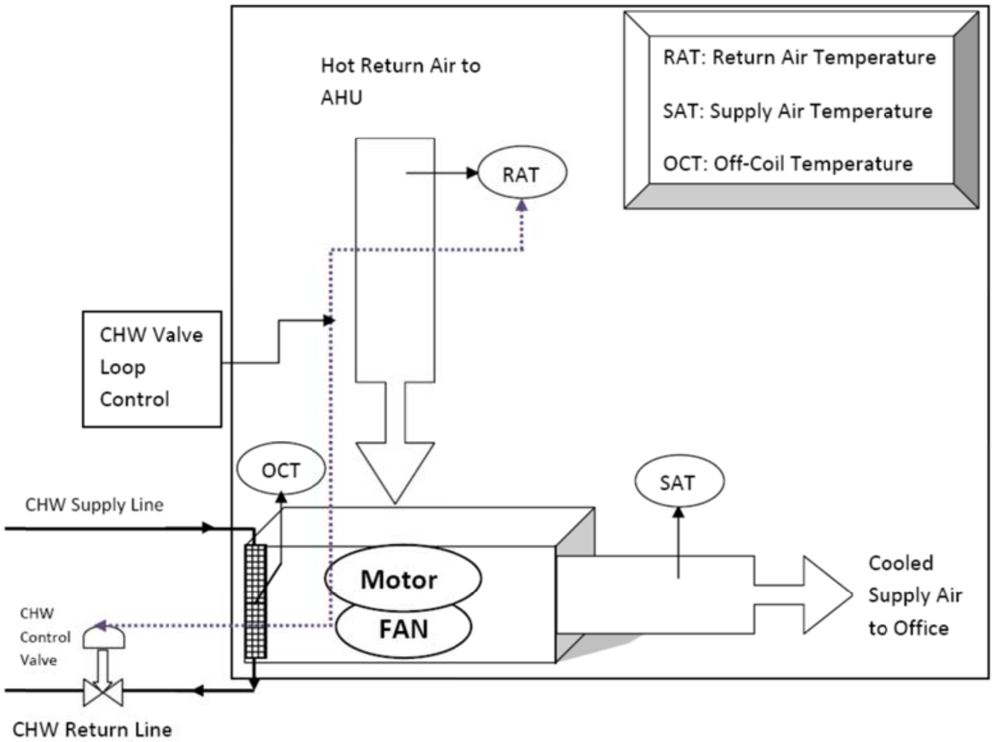

Figure 5 – Return air temperature control on air handling units