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Technical and Economic Evaluation of District Cooling System as Low Carbon Alternative in Kuala Lumpur City

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Kuala Lumpur (KL) city which has started its initiatives to become one of the low carbon cities in Malaysia, has the potential of implementing District Cooling System (DCS) in its existing energy system. Nowadays, most office buildings in Malaysia are utilising the conventional air-conditioning at each individual premise for space cooling purpose. In the development into a low carbon city, DCS could replace the conventional air-conditioners as it is more energy-efficient and subsequently reduces carbon emission to the environment. This study aims to compare and evaluate on four different cooling systems that are suitable to be implemented in KL city. A case study is created where a cooling load of 250,000 kWh/month of five office buildings in the same vicinity in KL city is to be met. Three parameters are studied to evaluate the cooling systems, namely energy consumption, costing and carbon emission, on a yearly basis. The result shows that centralised DCS is expensive in term of its initial investment and operational costs compared to individual air-conditioner. However, the type of energy source in DCS is an important factor to determine the total energy consumption and carbon emission of the cooling system. DCS that combines biogas-fired steam boiler and absorption chiller is the best option to be implemented. The system can generate own electricity to be used on-site, while the use of biogas effectively can achieve a carbon-neutral electricity production.

1. Introduction

District cooling system (DCS) is a utility which produces and supplies chilled water from a central plant to multiple buildings. The chilled water supplied is used for space cooling and process cooling in the buildings (Augusto et al., 2013). DCS consists of three main components: the central cooling plant, the distribution system and the energy transfer stations (ETS) which are on the customers or buildings' side. Central cooling plant constitutes of the cooling equipment, chillers, cooling tower, power generation and thermal storage. Chilled water is generated at the central cooling plant by chillers. Water-cooled chiller (cooling processes as shown in Figure 1) is the most common type of chiller because it is relatively cheaper and is able to cater the cooling demand diversity between different buildings within the district. Cooling towers are used to reject waste heat from the chillers into natural make-up water from the oceans, deep lakes or rivers (Energy Land, 2016).
The second element of DCS - the distribution system are made of a piping network that transfers the chilled water from the central cooling plant to different individual ETS, with the help of pumps at controlled rates and loads. In hot climate regions, underground buried pipelines should be used (Kaushik and Nand, 2015). At ETS, plate type heat exchangers (HEX) which serves as a connection interface to deliver chilled water supply to customers, via secondary pumping system and chilled water piping inside the entire building. Figure 1 illustrates the how the DCS is operated from the central plant to the customers' ETS.

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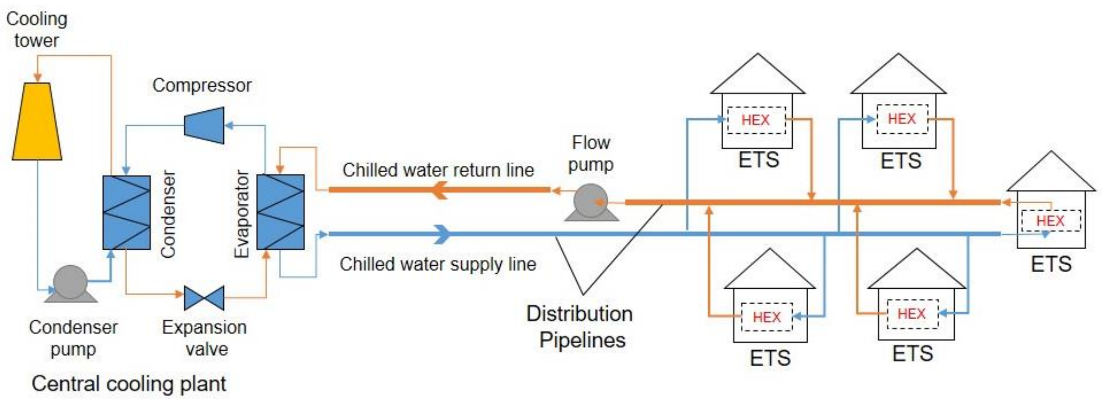

Figure 1: Configuration of the three main components of DCS operating with water-cooled chiller unit

DCS is an energy-efficient air-conditioning system that offers massive cooling energy (chilled water) production. The fact that DCS consumes about 20–35 % less electricity than the conventional air-conditioning systems at individual premises, making DCS a desirable and well-suited urban utility service, particularly in commercial districts with high cooling load density (Tey, 2010). Via its large-scale operation, DCS is able to create more economic advantages when compared to in-building chiller plants. Centralised DCS also allows users to utilise building space more effectively. Energy efficiency in buildings can be improved via DCS because the maintenance can be streamlined.

1.1 Kuala Lumpur towards a Low Carbon City

Malaysia government aims to have a city or township of zero carbon emissions in all 14 states by 2026. To date, Malacca City (a tourism propagated city) and Iskandar Malaysia (a new developed region in Johor) have been developed and implemented the Low-Carbon Cities Framework (LCCF) to reduce the national carbon emission target up to 45 % by year 2030. There are four key areas which LCCF is tapping into for carbon emission reduction: transportation, environmental quality, buildings and energy, waste and water management (The Star, 2016).

There are several cities in Malaysia that are in queue for their way to be transformed into a low carbon city; one of them is Kuala Lumpur (KL) City. KL city is Malaysia's metropolis, which its population and economic growth are rising exponentially in the past decade. In 2015, 1.78 M population has occupied KL city with an area of 243 km^2 (Department of Statistics Malaysia, 2016). The local energy demand in KL is surging significantly, especially in commercial (34 %) and residential sectors (21 %). This growing trend subsequently leads to issues concerning energy security, rising fuel prices and environmental effect.

In tropical countries like Malaysia (temperature range is 22–32 °C), space conditioning is important that cooling demand is crucially high to be met for thermal comfort. Saidur (2009) conveyed that in a typical mid-rise office building, air-conditioners (AC) consumes the largest amount of energy (57 %), followed by lightings (19 %), lifts and pumps (18 %), and other equipment (6 %). In line with the LCCF, DCS becomes one of the most potential technologies that could be implemented in buildings and energy sector.

This paper will discuss on the benefits of DCS implementation as one of the low carbon initiatives in KL city, by comparing DCS with KL city's current energy cooling system for governmental office buildings. The following section will discuss about case studies considered for the analysis, including the parameters which will be compared.

2. Methodology

2.1 Case Study

In this section, four different cooling systems that can be implemented in KL city are studied. Their descriptions and relevant data are listed in Table 1. A typical governmental office building in Malaysia has an average cooling load of 250 kW per building. Five similar buildings in the same vicinity are considered in this case study of DCS application. Assuming the operation hour is from 0800 h to 1800 h (total 10 h), 5 d a week, 4 weeks a month, the total cooling load of the five buildings is 250,000 kWh/month. According to Tariff C1 (medium voltage general commercial tariff) from TNB (2016), for each kW of maximum demand per month, it will be charged at a rate of RM 30.3/kW, while for the total kilowatts used, RM 0.365/kWh.

2.2 Mathematical equations

For each cooling system, three parameters including energy consumption and the associated cost and carbon emission are estimated via the following equations: Eq(1) for energy consumption, Eq(2-6) for costing and Eq(7) for carbon emission. Due to limited data, several assumptions have to be made.

2.2.1 Energy consumption

Assuming that the coefficient of performance, COP of cooling system is 1.0,

Total Energy Consumption, TC (MWh/y)
= Unit power (kW) x 2,400 (h/y) x No. of cooling unit x 0.001 (MW/kW) (1)

Table 1: Cooling systems used in the case study

Cooling system	Type of energy source	Description and data	Source
S1: Conventional Individual AC	Gas-generated grid electricity	• Type: Ceiling Cassette Split Unit • Working fluid: R410A (refrigerant) • Cooling Capacity: 23,000 Btu/unit • Power: 3.6 kW/unit • Price: RM 3,388/unit • Maintenance: RM 400/unit.y	DAIKIN, 2016
S2: Conventional Individual AC	Biogas-generated grid electricity	• Same cooling system model as in S1. • Biogas selling rate = RM 0.2786/kWh	SEDA, 2016
S3: DCS with Refrigerant Compression Technology	Natural gas-fired electricity	• Chiller power: 1,250 kW • Chiller capacity: 1,375 kW • Working fluid: R134A (refrigerant) • 1 kWh cooling needs 0.5 kWh electricity • Installation price: RM 4,562,000 (Including chiller, cooling tower, distribution pumps, and other cooling equipment) • Maintenance: RM 34,300/y	Zabala, 2009
S4: DCS with Absorption Cooling Technology	Biogas-generated Combined Heat & Power (CHP) cogeneration plant	• Single-effect chiller with a steam boiler and turbine • Chiller power: 1,250 kW • Chiller capacity: 1,375 kW • Working fluid: R134A (refrigerant) and LiBr (absorbent) • 1 kWh cooling needs 1.1 kWh heat (steam) • 1 kWh of biogas consumed can produce 78 % steam, 20 % electricity and losses 2 %. • Installation price: RM 3,287,209 (Including chiller, cooling tower, distribution pumps, and other cooling equipment) • Maintenance: Negligible	Zabala, 2009

2.2.2 Life-Cycle Costing

Costing is based on annual worth analysis. It is assumed that the life-cycle of all four cooling systems in this study is 10 years. The annuity factor, $A_{10,0.1}$ is 6.1446 for an investment of 10-year period and a 10 % rate of return.

Investment cost, IC (RM) = No. of cooling unit x Unit price (RM) (2)

Operational Cost for Electricity, OC_e (RM/month)
= No. of unit x [P (kW) x 30.3 (RM/kW) + P (kW) x 200 (h) x 0.365 (RM/kWh)] (3)

Operational Cost for Biogas, OC_b (RM/month) = No. of unit x [P (kW) x 200 (h) x 0.2786 (RM/kWh)] (4)

Maintenance Cost, MC (RM/y) = No. of cooling unit x Unit maintenance cost (RM) (5)

Equivalent Annual Cost, EAC (RM/y) = $IC/A_{10,0.1}$ + OC x 12 months + MC (6)

2.2.3 CO_2 emission

Assuming that the grid power is generated from natural gas, the major fuel source contributing to 52.7 % of the total fuel mix generation of electricity in Malaysia (Tan et al., 2013). With this, the baseline CO_2 emission factor for Peninsular Malaysia is 0.741 tCO_2/MWh (SEDA, 2016).

Total CO_2 emission, TE (tCO_2/y) = TC x 0.741 tCO_2/MWh (7)

3. Results and Discussion

Table 2 shows the calculated values of three parameters studying on four cooling systems, as to fulfill a total cooling demand of 250,000 kWh/month of five buildings in the same vicinity. In the current office buildings in Malaysia, most of them run on individual AC system which is less efficient. To meet a minimum cooling load of 250 kW, a building needs 37 conventional electrically driven AC compressor system. As a result, individual AC has the highest electricity consumption about 1,600 MWh/y. Comparing S3 and S4, S3 consumes a higher electricity because compression work is needed in producing chilled water. For S4, with biogas of 4,230 MWh/y used, a side electricity output of 846 MWh/y can be generated. If this electricity is used on-site for the chiller operation, a surplus of 605 MWh/y electricity can be sold for profit.

S2 has the same consumption and cooling capacity as S1. However, due to the different fuels used for electricity generation, S2 is cheaper in term of operational cost. Since DCS is a large-scale centralised utility site, its installation and operational costs are relatively higher than individual AC systems. Note that the power and costing calculation for both DCS types do not consider steam boiler nor ETS, because the main aim of this study is to compare between the cooling systems. The type of fuel used in cooling systems is an important factor which directly affect the costing, especially the operational cost, and the environmental impact. Assuming biogas is carbon neutral, the electricity generation for S2 and S4 has zero CO_2 emission.

Table 2: Comparison of four different cooling systems in term of three parameters

Cooling system	Total Energy Consumption (TC)	Costing	Total CO_2 emission (TE)
S1: Individual AC-Gas-generated grid electricity	Electricity = 1,598.4 MWh/y	IC = RM 626,780 OC = RM 68,797.80/month MC = RM 74,000/y EAC = RM 1,001,579.16/y	1,184.4 tCO_2/y
S2: Individual AC – Biogas-generated grid electricity	Electricity = 1,598.4 MWh/y	IC = RM 626,780 OC = RM 37,109.52/month MC = RM 74,000/y EAC = RM 621,319.80/y	0 tCO_2/y
S3: DCS – Refrigerant Compression Technology	Electricity = 1,500 MWh/y	IC = RM 4,562,000 OC = RM 83,500/month MC = RM34,300/y EAC = RM 1,778,744.50/y	1,111.5 tCO_2/y
S4: DCS – Absorption Cooling Technology	Electricity = 240.9 MWh/y Electricity production = 846.15 MWh/y Biogas = 4,230.77 MWh/y	IC = RM 3,287,209 OC = RM 84,172.38/month MC = Negligible EAC = RM 1,545,047/y	0 tCO_2/y

4. Conclusion

This is a preliminary study to compare and evaluate the feasibility of introducing DCS in replace with conventional single air-conditioning system in office buildings in KL city. As a city with compact population and limited land mass, the implementation of a large-scale centralised DCS in KL is a more energy-efficient and sustainable approach for space conditioning. In real scenario, it should be noted that a high dense urban city like KL city would have reached more than 500 MW of cooling load, which could be served by more than one district cooling plants and the piping network could have been more complicated.
From this study, despite of large investment cost, DCS with biogas fuelled CHP and absorption cooling system not only can reduce electricity loads by generating electricity for on-site usage, but also reduces carbon emission compared to other cooling systems. DCS is thermally driven cooling system, which is indirectly fired by either gas or renewable sources such as biogas or biomass. The hot and humid weather in Malaysia makes DCS using absorption cooling feasible as the technology are able to use the “free” and abundant waste heat or renewables as fuel, therefore it is more sustainable and reduces the reliance on grid electricity.
Governmental policies and energy prices will influence the pace of sustainable development and deployment of new energy-efficient technologies in KL metropolitan city, by considering the economic factors and global market conditions. However, prior to construction and implementation of DCS, it is important to conduct more system simulations and optimizations that represents the real scenario which is able to perform at its optimal operation conditions while minimizing the system cost and avoid unnecessary energy wastage.

Abbreviations

AC Air conditioners
CHP Combined Heat and Power
DCS District Cooling System
ETS Energy Transfer Stations
GDP Gross Domestic Product
HEX Heat Exchanger
KL Kuala Lumpur

Variables

A Annuity factor [no unit]
COP Coefficient of performance [no unit]
EAC Equivalent annual cost [RM/y]
IC Investment cost [RM]
MC Maintenance cost [RM/y]
OC Operational cost, OC_e for electricity, OC_b for biogas [RM/month]
P Power [kW]
TC Total energy consumption [MWh/y]
TE Total CO_2 emission [tCO_2/y]

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