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# Application of Distributed Energy Systems in Subtropical and High Density Urban Areas

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**Abstract**

Distributed energy system has been attracting increasing attentions in recent decades due to high efficiency and environmental friendliness. It supplies users power, cooling and heat locally by using smaller power generators. Many studies have been conducted on the design and control of distributed energy systems. For subtropical and high density urban areas, cooling is required almost all the year and district cooling systems are regarded as an efficient alternative. Distributed energy systems therefore can be integrated with district cooling systems. However, the performance of distributed energy systems for subtropical areas, especially when being integrated with district cooling systems, is not well studied yet. This paper therefore attempts to investigate the performance of integrated systems and compare it with the conventional systems which totally depend on the central grid. Energy saving potential of distributed energy systems is analyzed under different control methods and in different periods. The impacts of the mechanisms of the distributed energy systems on the energy saving are analyzed. Results show that the distributed energy systems integrated with district cooling systems can achieve an energy saving of 12.8%. The control method following the cooling demand is preferred with a larger energy saving.


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*Keywords:* distributed energy system; subtropical area; district cooling systems; control; energy saving

## 1. Introduction

Distributed energy systems (DESs) are regarded as a promising alternative for the sustainability development and attract increasing attentions in recent decades[1]. The DESs integrate middle/small-scale on-site power generations with thermal energy production and storage devices to provide electricity, cooling and heating to end-users nearby

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[2]. Technologies such as renewable technologies, thermal storage, and clean fuel (natural gas, biomass) can be adopted to meet the electrical and thermal demands and produce less pollutions. The efficiency of DESs is high due to the energy cascade utilization. Recently, the Chinese government plans to replace coal with natural gas for power generation to address the serious environmental problems. On the other hand, the electrical and thermal demands keep increasing resulting from the urbanization development and high thermal comfort requirement. In this context, the DES can be an alternative to meet the excessive electrical and thermal demands and reduce the pollution emissions.

Many studies have been done on the performance of DESs. Di Somma et al. [3] proposed a design optimization method of DESs through cost and exergy assessment. The DESs consist of combined heat and power system, biomass boiler, PV panels and solar thermal collectors. The impacts of energy prices and energy demand variation on the optimized DES configurations are analysed. Kang et al. [4] studied the performance of combined cooling, heat and power systems with ground heat pump systems under different load following operational strategies. A new strategy was proposed, which is to follow the maximum electric efficiency of the power generator units. The feasibility of DESs with PV and wind turbines for an island in the eastern part of China was studied[5, 6]. Results show that the primary energy consumption, annual operating costs and electricity import can be reduced by using DESs. A mixed integer linear programming model [7] was created for design optimization of a DES for a cluster of buildings, where only the electricity and heating demands were required. Ren et al. [8] studied the optimal option of DES for building complexes locating in different climate zones of China. Results show that DESs can be preferable in the hot summer and cold winter areas.

The above research mainly concentrates on the DESs in areas with heating demand. In subtropical and high-density areas, cooling is required almost all the year while the heating is almost negligible. The high density of cooling loads enables the district cooling systems (DCSs) an energy efficient option to accomplish cooling and dehumidification. DESs integrated with DCSs (DES&DCSs) therefore should be a promising alternative to enhance the sustainable development. However, the performance of DES&DCSs is not sufficiently studied yet. It is therefore highly necessary to investigate the performance of DES&DCSs. Another highlight of this study is that the electricity and cooling loads used are collected from practical projects, instead of simulation or hypothesis which is adopted in many studies. These monitored data will reflect the operation of buildings more practically.

This paper therefore attempts to investigate the energy performance of DESs integrated with DCSs in subtropical areas, based on the on-site measurements of electricity demand and cooling demand. The characteristics of the DES in different periods are analysed. The energy savings of DES&DCSs under different control strategies are compared. The paper is organized as follows. In Section 2, the methodology to assess the performance of DES&DCSs and primary steps are presented. In Section 3, a DES&DCS serving a building cluster in a campus is introduced. In Section 4, the performance of the DES&DCS under different control strategies is analysed. Conclusions are summarized in Section 5.

## 2. Method to assess the performance of DES&DCSs

The method used in this study to assess the performance of DES&DCSs is shown in Fig. 1. Detailed steps are explained as follows.

**1) Data collection**

In this study, the performance assessment of DESs is based on monitored electricity and cooling loads. The first step therefore is data collection. The building cluster of the Hong Kong Polytechnic University and their loads are involved. The electricity load is monitored by CLP, which is the major utility company in Hong Kong. The cooling demands of each building are monitored by building management systems (BMSs). The design information of the existing individual cooling system (ICS) is also collected, which provides the basis for the performance comparison. It includes the number and capacity of chillers, the hydraulic head and efficiency of chilled water pumps/cooling water pumps, the power of cooling towers, etc.

**2) Data re-organization**

The collected data are analysed and re-organized. For different BMSs, the data resolutions vary. Some BMS records the data every 15 minutes while others may collect the data every 30 minutes. Partial data may be missing or abnormal. The data therefore are needed to be carefully re-organized to keep complete, accurate and consistent.

**3) System design**

The DES&DCSs can be designed based on the annual hourly electricity and cooling demands. The numbers and capacities of generators, absorption chillers, electrical chillers, pumps and cooling towers are determined. The hydraulic head of chilled water pumps can be obtained according to the layout of buildings.

**4) System modelling**

Models of the generators and chillers are built. The performance of generators can be expressed using the electrical efficiency $\eta_e$ and the thermal efficiency $\eta_t$. Double-stage absorption chillers are adopted in this study. The COP of electrical chillers follows a curve under different partial loads [9]. The cooling water and primary chilled water pumps work with a constant speed and efficiency $\eta_p$. Variable-speed pumps are used in the secondary chilled water network and the required pressure varies with the cooling loads.

**5) Performance analysis**

By importing the hourly demand data in models, the energy performance of DES&DCSs can be obtained. Primary energy saving is used to indicate the comparative performance of DESs. Different control methods are used and the optimal one is obtained.

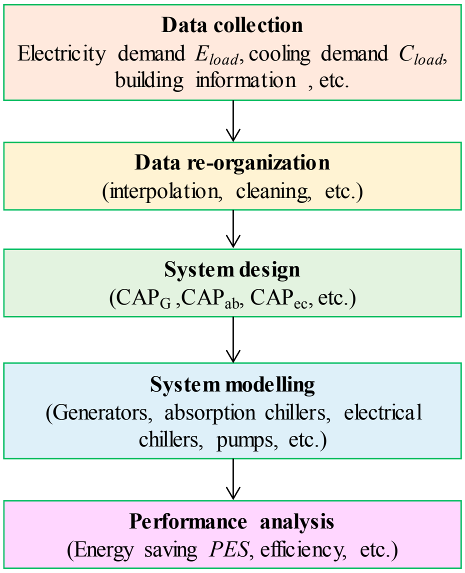


Fig. 1 Method to assess the performance of DES&DCSs

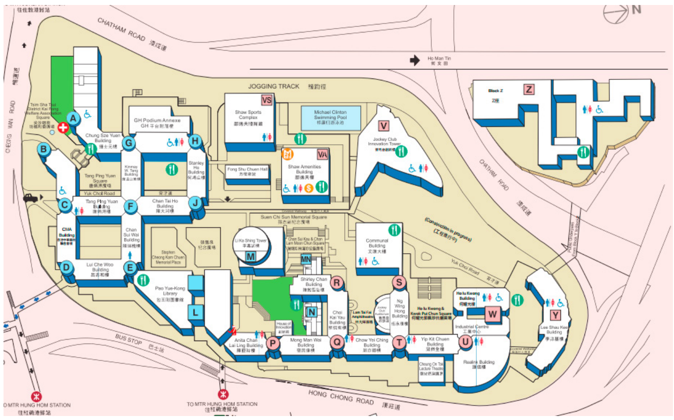


Fig. 2 The layout of buildings in the campus

## 3. A DES&DCS for a building cluster of a campus

To investigate the performance of DESs in subtropical area, a building cluster of the campus of the Hong Kong Polytechnic University is selected. The layout of buildings is shown in Fig. 2. These buildings are grouped into different phases according to the construction schedule and a separate cooling plant is built for each phase. The buildings and the gross floor areas of each phase are shown in Table 1.

Table 1 Buildings and gross floor areas of each phase

| Phase | Blocks | Area ($m^2$) | Phase | Blocks | Area ($m^2$) |
|---|---|---|---|---|---|
| Phase 1 | library; CD; DE; EF; CF; FJ | 47271 | Phase 6 | M; N; MN | 12307 |
| Phase 2 | VA; VS; | 7980 | Phase 7 | Y | 25000 |
| Phase 2A/B | HJ; FG; GH | 24419 | Phase 8 | Z | 44000 |
| Phase 3A | AG; BC | 16782 | PCD | QR; R | 10196 |

| | | | | | |
|---|---|---|---|---|---|
| Phase 3B | QT;TS; Communal building | 23400 | JCA | JCA | 4800 |
| Phase 4 | Industrial center (U; W) | 19330 | JCIT | JCIT | 15317.5 |
| Phase 5 | P; PQ | 10078 | | | |

The electricity consumption and cooling loads of the whole camps in 2015 are collected. The monitored electricity consumption include that used for cooling, lighting, elevators and all other electric appliances. If a DES is installed, partial or total cooling loads will be satisfied by absorption chillers. The electricity used for cooling, especially electrical chillers, will be decreased or eliminated. It is therefore necessary to separate the electricity for cooling from the overall records. In this study, the electricity consumptions of the cooling systems of each phase are evaluated based on the collected cooling loads and cooling plant design information since they are not well recorded in current BMSs. The obtained non-cooling electricity loads and cooling loads of the campus are shown in Fig. 3 and Fig. 4.

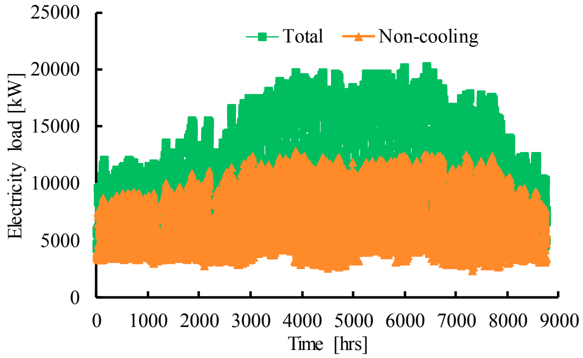


Fig. 3 Annual hourly electricity loads of the campus

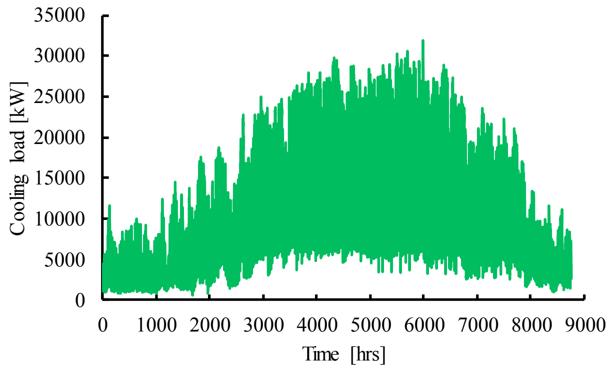


Fig. 4 Annual hourly cooling loads of the campus

The DES can be designed according to the non-cooling electricity loads and cooling loads. Many methods can be used to determine the capacity of DESs. In this study, the capacity of generators is designed to meet the non-cooling electricity peak demand and the electricity required by the pumps of absorption chillers. The capacity of absorption chillers is determined based on the thermal efficiency. Then the electrical chillers can be sized. Parameters of primary components in the DES&DCS are shown in Table 2. The control strategy plays a significant role in the performance of DES&DCSs. Three methods are adopted in this study:1) following the electricity demand method (FEM), which may discharge excessive cooling production; 2) following the cooling demand method (FCM), which may send surplus electricity to the grid; 3) following the one requiring less primary energy (FLM), which has no cooling waste and no surplus electricity.

Table 2 Parameters of primary equipment in the DES&DCS

| Items | Values | Items | Values |
|---|---|---|---|
| Capacity of generators (kW) | 2×7300 | COP of absorption chillers | 1.1 |
| Capacity of absorption chillers (kW) | 4×4000 | Nominal COP of electrical chillers | 5.5 |
| Capacity of electrical chillers (kW) | 4×4000 | Hydraulic head of cooling water pumps (m) | 25 |
| Electrical efficiency of generators of DESs | 0.4 | Hydraulic head of primary chilled water pumps (m) | 20 |
| Thermal efficiency of generators of DESs | 0.4 | Hydraulic head of secondary chilled water pumps (m) | 40 |
| Electrical efficiency of generators of the grid | 0.45 | Efficiency of pumps | 0.75 |

## 4. Energy performance of DESs

The energy performance of the DES&DCSs are analysed in two approaches: 1) to analyse the performance of DES&DCSs under different control methods and compare with that using DCSs and totally depending on the grid (Grid&DCS); 2) to compare the energy performance of DES&DCSs with that using ICSs and totally depending on the grid (Grid&ICS).

*4.1 Energy saving of DES&DCSs under different control methods*

The performance of the DES&DCS under different control methods is summarized in Table 3. The Grid&DCS is taken as the base case. Table 3 shows that the DES can achieve energy saving, which varies from 4.9% to 8.2%. It demonstrates that the DES can be an energy efficient alternative for subtropical and high density areas. The energy saving under the FEM is the least because surplus cooling is wasted instead of being stored. It can be deduced that the energy saving will be larger if a thermal storage system is installed. The energy saving of the DES under FCM is the largest because it makes full use of the DES. The cooling provided by absorption chillers in the DES is 84%, which is much higher than that under the other two methods. The FCM is therefore recommended if energy saving is the key factor for decision makers. However, this control method needs the policy support that permits the surplus electricity to be sent to the grid, which may be a problem for some regions.

Table 3 Energy performance of the DES under different control methods

| Item | FLM | FCM | FEM |
|---|---|---|---|
| Local electricity generation ($\times 10^6$kWh) | 64.8 | 77.3 | 73.0 |
| Electricity taken from the grid ($\times 10^6$kWh) | 16.2 | 5.5 | 8.5 |
| Surplus electricity to the grid ($\times 10^6$kWh) | 0 | 13.8 | 0 |
| Cooling provided by the DES (kWh) | 63% | 84% | 65% |
| Energy saving | 5.4% | 8.2% | 4.9% |

The energy consumption of the DES and the energy saving compared with the base case in different months are shown in Fig. 5. It shows that both systems have higher energy consumption in the summer months and the energy saving of the DES is also larger. It can be up to 9% in June. The energy consumption of the DES in a typical summer week is shown in Fig. 6. It indicates that the absolute energy savings are larger during the daytime while the relative ones are larger during the nighttime.

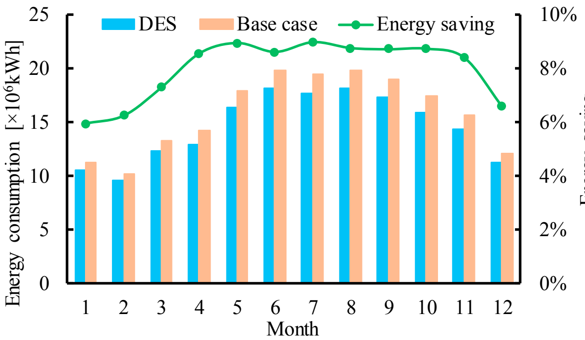


Fig. 5 Monthly energy consumption of the DES in a typical summer week

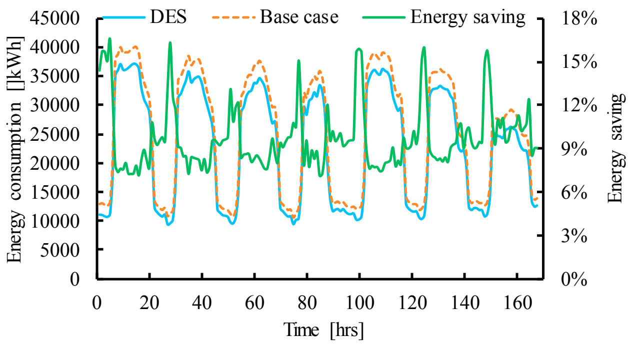


Fig. 6 Energy consumption of the DES under the FCM method

*4.2 Performance of the DES&DCS compared with the Grid&ICS*

The existing electrical and thermal systems of the campus totally depend on the grid. Each phase has an individual cooling systems (Grid&ICS). The energy consumption of the DES&DCS and the Grid&ICS is shown in Fig. 7. It shows that the monthly energy saving is larger than that when being compared with the system using a DCS and depending on the grid. The additional energy saving results from the higher efficiency of the DCS compared with the ICS. Fig. 7 shows that the energy saving of the DES&DCS is higher in cool seasons, which is different from the case in Fig. 5. That is because the energy saving potential of DCSs is larger when the part loads for each building/phase are lower. The annual energy saving of the DES is 12.8%, which is very promising.

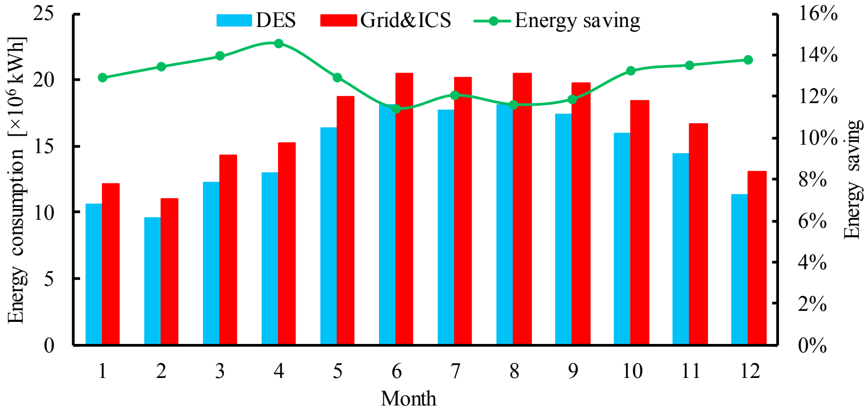


Fig. 7 Monthly energy consumption of the DES&DCS compared with the Grid&ICS

### 4.3 Impacts of the mechanisms of DES&DCSs on energy saving

The DES&DCS can be an energy-efficient option as discussed in Section 4.1 and 4.2. The mechanisms can be explained from two aspects. One is that the cascade utilization of the primary energy. Although the electrical efficiency of generators in DES is lower, the heat recovery for cooling generation can finally increase the overall efficiency of the primary energy. The other is the energy efficiency of DCSs. When the buildings locate closely and the cooling load density is high, DCSs can be more energy efficient. Therefore, in subtropical and high density areas, DES&DCS can be more energy efficient. Consequently, the control strategy that makes the DES&DCS operate longer will obtain higher energy saving, which is proved in Section 4.1.

## 5. Conclusions

Distributed energy system is considered as one of the most promising options to provide a more secure, clean and more efficient energy supply. However, studies on the application of DESs in subtropical areas are not sufficient yet, especially when being integrated with district cooling systems. This paper investigates the energy performance of DESs in subtropical and high density areas. The DES and DCS serving a building cluster of a campus is studied. Based on the monitored electricity and cooling loads, the energy saving potential of DES&DCSs can be obtained. According to the results and discussions, the following conclusions can be summarized:

1) DESs serving a district and integrated with DCSs can be an energy efficient alternative in subtropical areas. The energy saving varies from 4.9% to 8.2%.
2) When surplus electricity from DESs is permitted to be sent to the grid, the control method following cooling load is more energy efficient and the energy saving is 8.2%. Larger energy saving arises during the night time and in summer.
3) When being compared with the commonly-used system (Grid&ICS), the DES&DCS can achieve larger energy saving, which is 12.8%. Higher energy saving arises in cool seasons.

Currently the thermal energy of DESs is used for cooling only and the hot water load is not considered. In addition, for different types of buildings, the electricity demand and cooling demand profiles vary significantly. The most suitable customers for DESs should be investigated. The design optimization of DES&DCSs to maximize the energy saving should but not be conducted yet. All these issues will be addressed in future studies.

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