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Published in:
Energy Procedia

Published: 01/01/2014

Published version (DOI):
10.1016/j.egypro.2014.11.1193

Publication details:
Fong, K. F., & Lee, C. K. (2014). Performance analysis of internal-combustion-engine primed trigeneration systems for use in high-rise office buildings in Hong Kong. *Energy Procedia*, *61*, 2319-2322. https://doi.org/10.1016/j.egypro.2014.11.1193

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 61 (2014) 2319 – 2322

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Performance analysis of internal-combustion-engine primed trigeneration systems for use in high-rise office buildings in Hong Kong

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Abstract

The year-round dynamic performances of various types of internal-combustion-engine primed trigeneration (ICEPT) systems were analyzed and compared with that based on a conventional system powered by the grid electricity when they were applied to a high-rise office building in Hong Kong. It was found that the employment of the ICEPT systems reduced the total energy demand from the building by at most 10.9%. However, the saving in the carbon dioxide emission varied widely with the prime mover used with a maximum of only 13.2% for a natural-gas-fueled ICEPT system. One major reason was the relatively lower carbon dioxide emission index from the local grid electricity. In this regard, the sufficient supply of natural gas or biofuels is necessary in order to reduce the carbon dioxide emission through the employment of ICEPT systems in Hong Kong.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Trigeneration; Absorption chiller; Vapor-compression chiller; Carbon dioxide emission

1. Introduction

With the urge for reduction in carbon dioxide emission, the design for more energy-efficient power systems has been a hot issue nowadays. One feasible direction is the utilization of the waste heat from the power systems for heating and/or spacing cooling through the use of heat-driven air-conditioning equipment, thus forming a trigeneration system. The resulting system efficiency can be improved substantially. Al-Sulaiman et al. [1] reviewed the characteristics of various kinds of trigeneration systems with different prime movers. They remarked that internal-combustion-engine primed trigeneration

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.11.1193

(ICEPT) systems were among the most common types. Wu and Wang [2] highlighted the benefits of applying ICEPT systems to small- or medium-capacity applications. The merit of ICEPT systems depends on how frequent co-generation/trigeneration is required. In Hong Kong, most of the office buildings are multi-storey and that air-conditioning is usually required throughout the entire year with only limited heating demand in the perimeter zone during the winter time. Hence, it is highly probable that the adoption of ICEPT systems can lead to satisfactory results. To analyze, the year-round dynamic performance of three types of ICEPT systems, namely diesel engine fueled by diesel oil, gas engine fueled by natural gas and gas engine fueled by petrol gas, are investigated when applied to a multi-storey office building in Hong Kong. The corresponding system energy demands and the carbon dioxide emission levels are compared with those based on the conventional system powered by the grid electricity.

2. System Description

Fig. 1 shows the schematic diagram of the ICEPT system employed in this study. The waste heat from the engine jacket and the exhaust gas are recovered through the jacket and exhaust heat exchangers. The recovered heat is used to drive a single-effect absorption chiller and to provide space heating when necessary. An auxiliary water cooler is included which operates when the utilization of the recovered heat is low in order to maintain the jacket water temperature entering the engine at the desired level.

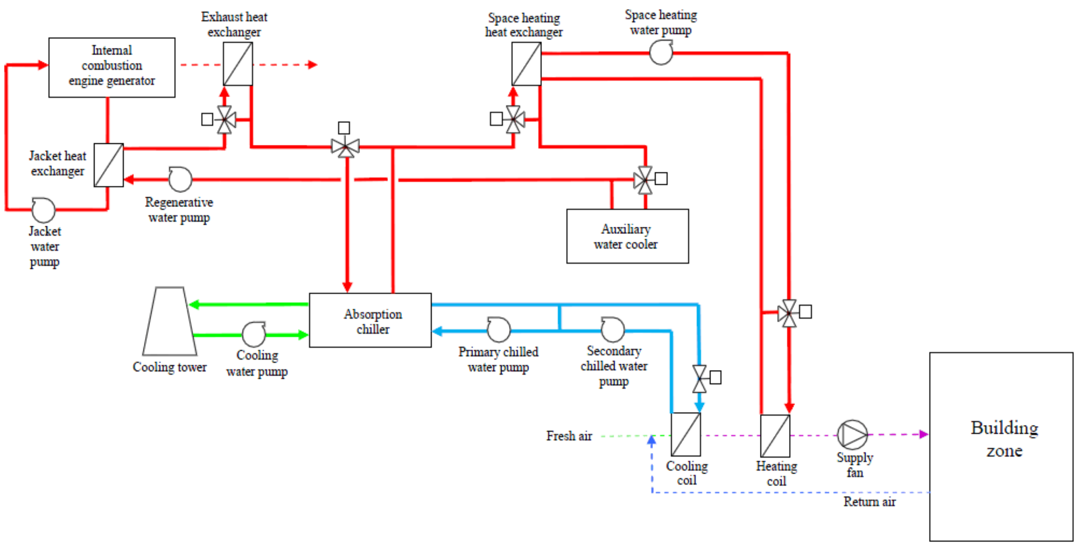

Fig. 1. Schematic diagram of an internal-combustion-engine-primed trigeneration system

A reference office building with 30 storeys high as detailed in [3] is employed for the study. The total air-conditioning requirement is 4568 kW and the peak electrical demand is 2554 kW based on the conventional design. In view of the high ratio of the cooling to electric load requirements, auxiliary vapor-compression chiller is necessary to meet the air-conditioning demand. Two sets of engine generators and single-effect absorption chillers are employed with one set of vapor-compression chiller adopted. Year-round dynamic simulations are performed using TRNSYS [4] under the typical meteorological data for Hong Kong [5]. To avoid the engines to be operated at a very low part-load ratio, auxiliary electricity backup from the grid is required to serve the building during the time when the electrical demand is low. Decane is selected as the fuel for the diesel engine. The natural gas is assumed to be 100% methane, and that the petrol gas is composed of 60% propane and 40% butane by volume.

3. Results and Discussions

Table 1 compares the year-round performance of the three ICEPT systems investigated with that based on the conventional system. The rated electrical efficiencies of the diesel engine, natural-gas-fueled gas engine and petrol-gas-fueled gas engine were 31.2, 29.1 and 29.9% respectively which were similar to those indicated in ASHRAE [7] for naturally-aspirated systems. It could be found that with the adoption of the ICEPT systems, the total electricity demand from the building decreased by at most 10.9% for the ICEPT system fueled by natural gas. This could be explained by the fact the electrical efficiency was the lowest for this type of ICEPT system which implied that more waste heat was available for the absorption chillers and a smaller auxiliary vapor-compression chiller could be used. However, this could not outweigh the adverse effect due to the lower electrical efficiency and the total energy input to the natural-gas-fueled ICEPT system was still the highest. The sum of the total electricity supply from the ICEPT system and the grid was slightly higher than that consumed by the building. The reason was that the efficiencies of the ICEPT systems were assumed to remain constant during the part-load operation. Hence, a linear correlation was adopted between the fuel injection rate and the required ICEPT system output. This might not be fully appropriate so that the ICEPT system might over-supply electricity to the building at some instants which contributed to an electricity surplus.

Table 1. Comparison of year-round performance of the various trigeneration systems with that for the conventional system

System	Total electricity demand from building (MWh)	Total electricity supply from ICEPT system (MWh)	Total electricity supply from grid (MWh)	Total energy input to ICEPT system (MWh)	Carbon dioxide emission (Ton)
Conventional	7979	Not applicable	7979	Not applicable	5585
ICEPT system fueled by diesel oil	7187	5948	1307	18936	5681
ICEPT system fueled by natural gas	7106	5761	1374	19675	4848
ICEPT system fueled by petrol gas	7124	5848	1332	19400	5495

From Table 1, the total carbon dioxide emission was the lowest for the natural-gas-fueled ICEPT system which corresponded to 13.2% reduction as compared to that for the conventional system. On the other hand, no saving was achieved by using the diesel-oil-fueled one. The benefit was minimal when the petrol-gas-fueled ICEPT system was adopted. The main reason was that the carbon dioxide emission index for the local grid electricity supply was only 0.7 kg/kWh [6]. This was comparatively lower than that based on a conventional coal-fired power station due to the fuel mix adopted by the local power company and the utilization of nuclear power. To improve the situations, ICEPT systems with higher electrical efficiencies through the adoption of more advanced cycles should be used. Meanwhile, a sufficient supply of natural gas or biofuels is also necessary in order to achieve carbon dioxide reduction through the use of ICEPT systems in Hong Kong.

4. Conclusions

The merits of applying internal-combustion-engine primed trigeneration (ICEPT) systems to a high-rise office building in Hong Kong were analyzed. Year-round dynamic simulations were performed and the results compared with that based on a conventional system powered by the grid electricity by using TRNSYS. Three types of ICEPT systems, namely those fueled by diesel oil, natural gas and petrol gas, were considered. It was found that the employment of the ICEPT systems all led to a reduction in the total energy demand from the building. The maximum saving was 10.9% with natural-gas-fueled ICEPT system. However, the energy input from the fuel was also the highest due to its lower electrical efficiency. Meanwhile, the reduction in the carbon dioxide emission depended widely on the prime mover used which only reached at most 13.2% for a natural-gas-fueled ICEPT system. One major reason was that the carbon dioxide emission index for the local grid electricity was comparatively low. In view of this, it is necessary to have sufficient supply of natural gas or biofuels in order to reduce the carbon dioxide emission through the employment of ICEPT systems in Hong Kong or more advanced ICEPT systems with higher electrical efficiencies have to be employed.

Acknowledgements

This publication was made possible by the research funding from the Construction Industry Council (Project No. 9231098). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Construction Industry Council.

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Biography

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