Investigation on the Situation of Combined Heating and Power System in Japan

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Abstract
In Japan, during the last 20 years, combined heating and power (CHP) system has been developed rapidly. In order to grasp the present condition of introduction and the existing problems of CHP system, the questionnaire survey on CHP system had been carried out at Tokyo.

According to the results of investigation, it can be summarized as follows: 1) CHP system had been used widely in various sectors. The generating electricity capacity ranged several ten to several thousands kilowatt. 2) The percentage of CHP total capacity to the electricity demand peak was low and the average value for all users investigated was only 25%. 3) Gas turbine and gas engine achieved 60%–80% overall energy utilization efficiency with 20%–34.5% generating electricity efficiency and 19.5%–50% exhaust heat utilization efficiency. 4) Education buildings had the maximum average generating electricity efficiency with 30.6%, followed by hospital buildings with 29.6%, amusement facilities with 29.5%, office buildings with 28% and compound buildings with 25%. Hospitals attained the maximum average exhaust heat utilization efficiency with 46.1%, followed by offices with 41.3% and compound buildings 39.8%. 5) Various users had different motivation of selecting CHP system. Both office and compound buildings selected economy as the most important reason introducing CHP system; while hospital and education users concerned more saving energy. Hospital and office users were satisfied with the CHP system introduced; while compound building users were not satisfied very much with the CHP system.

Keywords: CHP; questionnaire survey; evaluation

1. Introduction
Co-generation, also known as CHP (Combined Heat and Power), is an efficient approach to generating electricity and thermal energy from a single fuel source. It recovers the waste heat from the electricity generating cycle, otherwise that would be discarded into the environment. The heat recovered is used to provide cooling or heating for the consumer. By recycling this waste heat, co-generation systems can achieve the primary energy efficiencies of 50% to 80%, a dramatic improvement over the average 35% efficiency of conventional fossil-fuelled power plants. Higher efficiencies reduce air emissions of carbon dioxide and sulphur dioxide. At the same time, co-generation can provide high-quality and reliable electricity supply. In Japan, during the last 20 years, CHP has been developed rapidly. The number of CHP systems has increased from 67 in 1986 to 4515 in 2003, and the total generation capacity has amounted from 200kW in 1986 to 6,504MW as of March 2003. And CHP had approximately 2.5% share of the electricity production in Japan. The annual capacity of CHP installed is increasing by the constant 400-450 MW every year since 1986[1]. In the “long-term energy supply-demand outlook” (June, Heisei 6), CHP system is expected to reach 1,002MW output scale by the year 2010. Currently, in Japan much research interest exists regarding cogeneration systems[2]–[5]. These research projects referred to theoretical simulations. However, very little research exists that is based on questionnaire survey of actual operating systems.

In order to grasp the use present situation of introduction and the existing problems of CHP system, the questionnaire survey on CHP has been carried out in Tokyo, Japan. This paper presents the preliminary investigation results. According to investigating data, generating electricity system and heat recovery system of CHP system are evaluated. It is helpful for further improving energy efficiency and spread of CHP. Moreover, it is important and beneficial to grasp these data for making system planning and optimizing operation of CHP.
2.2 Results of the questionnaire survey

The main results of building’s details and CHP system characteristics are shown in table 2. From the data, it can be concluded that CHP system has been used widely in various sectors, such as office, commerce, hospital, education, amusement and so on. The size of generator ranged from 40kW to 4500kW. Total floor area of buildings ranged from 3000m² to 264,140m². In these buildings, there were new buildings constructed in 2002 and also old buildings finished in 1962. Generator type included gas turbine and gas engine. CHP system achieved 20%~34.5% generating electricity efficiency and 19.5%~50% exhaust heat utilization efficiency. And the recovered heat had been used widely for various purposes, cooling, heating, hot water and others, such as DHC (district heating and cooling), heat load supply for pool and plant or factory.

### Table 1. The Main Contents of Questionnaire Survey

| Item                        | Contents                                                                 |
|-----------------------------|--------------------------------------------------------------------------|
| Building characteristics    | Building's use, structure, stories, buildings total floor area, year of building be constructed, year of starting operation of CHP system, etc.; |
| CHP equipment characteristics | Equipment's kind, capacity, heat recovery system, heat recovery efficiency, purpose of recovered heat, etc.; |
| Operation system            | Operation period, Operation mode, etc.;                                  |
| Opinion questionnaire       | The motivation of introducing CHP system;                                |
|                             | Satisfied aspects of the introduced CHP system;                          |
|                             | Dissatisfied aspects of the introduced CHP system;                       |

### Table 2. The Results of the Questionnaire Survey

| Number | Building’s users | Year of the building be constructed (Year of starting operation of CHP system) | Supply total floor area (m²) | Unit size/Number of generator (kW/Unit×Units) | Utility electricity capacity (kW) | Generator type | Generating electricity efficiency (%) | Heat utilization efficiency (%) | Purposes of recovered heat used |
|--------|------------------|--------------------------------------------------------------------------------|------------------------------|-----------------------------------------------|----------------------------------|----------------|---------------------------------------|-------------------------------|-------------------------------|
| 1      | Office           | 1994 (1994)                                                                  | 264,140                      | 4,500×1                                       | 6,400                            | GT             | 27.2                                  | 44.0                          | C,H,W                         |
| 2      | Office           | 1990 (1990)                                                                  | 15,000                      | 300×2                                         | 1,550                            | GE             | 30.9                                  | 34.8                          | C,H,W                         |
| 3      | Office           | 1989 (1995)                                                                  | 20,000                      | 300×1                                         | 1,200                            | GE             | 36.0                                  | 45.0                          | O                             |
| 4      | Office           | 1993 (1992)                                                                  | 167,807                     | 1,100×2                                       | 4,300                            | GT             | 25.0                                  | 46.0                          | C,H,W                         |
| 5      | Office           | 1995 (1996)                                                                  | 27,054                      | 250×1                                         | 1,100                            | GE             | 30.9                                  | 47.5                          | C,H,W                         |
| 6      | Office           | 1962 (1989)                                                                  | 106,807                     | 1,086×2                                       | 6,000                            | GT             | 25.0                                  | 41.0                          | O                             |
| 7      | Hospital         | 1973 (1997)                                                                  | 13,595                      | 150×1                                         | 650                              | GE             | 29.0                                  | 46.6                          | W                             |
| 8      | Hospital         | 1996 (1996)                                                                  | 15,000                      | 150×1                                         | 610                              | GE             | 28.7                                  | 45.4                          | W                             |
| 9      | Hospital         | 1994 (1994)                                                                  | 57,036                      | 500×3                                         | 1,450                            | GE             | 32.6                                  | 49.4                          | C,H,W                         |
| 10     | Hospital         | 1987 (1996)                                                                  | 16,584                      | 100×1                                         | 442                              | GE             | 27.8                                  | 42.8                          | W                             |
| 11     | Education        | 1987 (1987)                                                                  | 170,000                     | 500×6                                         | 3,000                            | GE             | 31.6                                  | 39.4                          | C                             |
| 12     | Education        | 2002 (2002)                                                                 | 15,080                      | 310×1                                         | 1,610                            | GE             | 34.5                                  | 36.3                          | C,H                           |
| 13     | Education        | 1981 (1995)                                                                  | 3,000                       | 40×1                                         | 291                              | GE             | 25.5                                  | 40.2                          | C,H,W                         |
| 14     | Commerce         | 1964 (1996)                                                                  | 71,728                      | 900×2                                         | 6,300                            | GE             | 30.0                                  | 38.0                          | C,H,W                         |
| 15     | Commerce         | 1998 (1998)                                                                  | 174,500                     | 1,500×2                                       | 10,700                           | GT             | 26.0                                  | 42.0                          | C,H                           |
| 16     | Culture          | 1998 (1998)                                                                  | 145,076                     | 1,500×2                                       | 5,800                            | GT             | 21.0                                  | 39.0                          | O                             |
| 17     | Amusement        | 1994 (1994)                                                                  | 23,830                      | 200×2                                         | 1,350                            | GE             | 29.5                                  | 38.7                          | W                             |
| 18     | Commerce,Office and Hotel | 1992 (1992)                             | 141,803                     | 300×2                                         | 7,500                            | GE             | 30.0                                  | 41.0                          | H,W                           |
| 19     | Office, Hospital and Hotel | 1992 (1994)                             | 40,000                      | 265×4                                         | 4,000                            | GE             | 32.7                                  | 38.4                          | H                             |
| 20     | Office and Hotel | 1994 (1994)                                                                  | 47,493                      | 200×2                                         | 2,000                            | GE             | 30.0                                  | 40.0                          | C,H,W                         |
| 21     | Commerce,Office and Hotel | 1993 (1993)                             | 83,666                      | 1,100×1                                       | 2,050                            | GT             | 20.0                                  | 37.0                          | C,H,W                         |
| 22     | Refrigeration warehouse | 1994 (1994)                             | 70,492                      | 300×2                                         | 3,000                            | GE             | 34.4                                  | 19.5                          | O                             |
| 23     | Factory          | 1970 (1994)                                                                  | 52,811                      | 990×1                                         | 4,700                            | GT             | 24.0                                  | 44.0                          | O                             |
| 24     | Plant            | 1971 (1997)                                                                  | 10,530                      | 300×1                                         | 820                              | GE             | 28.0                                  | 43.0                          | C,H,W                         |
| 25     | Factory          | 1966 (1996)                                                                  | 260,000                     | 4,100×1                                       | 7,000                            | GT             | 28.0                                  | 37.8                          | C,H,W                         |

Note: GT: Gas turbine; GE: Gas engine; C: Cooling supply; H: Heating Supply; W: Hot water supply; Generating electricity efficiency and heat utilization efficiency are annual average values; The black font rows represent the cases with the maximum or minimum of overall energy utilization efficiency in all users.
3. Analysis on the results of the questionnaire survey

3.1 Building’s details

The categories of the user and the CHP system’s generator are shown as figure 1. Offices accounted for 24% (6 pieces) of the total amount investigated, followed by hospitals with 16% (4 pieces), education institutions with 12% (3 pieces), commerce buildings with 8% (2 pieces), and culture and amusement institutions with 4% (1 piece). Next, there were four compound buildings (16%), which main facilities are hotels. In addition, there were four other buildings (16%), two factories, one plant and one refrigeration warehouse.

Generator’s type comprised gas turbine and gas engine. 17 consumers had used gas engine system, accounting for 68%; the other 8 consumers had used gas turbine as described as Figure 1.

Figure 2 is the relationship between year of building constructed and the year of starting operation of CHP system. From the Figure, about 14 sites had introduced CHP simultaneously with new building and 10 sites were later than the completion of the buildings. In all kinds of buildings, CHP systems had been started to be introduced since 1987.

3.2 Generating electricity system

The electricity demand peak per square meter was described as Figure 3. The range of the electricity demand peak per square meter varied from 32W/m² to 143 W/m². Considering the average electricity demand peak, commerce buildings had the biggest value with 95 W/m² and the hospitals had the smallest value with 48 W/m². The average for all users investigated reached 77 W/m².

The electricity demand peak was satisfied by the total capacity of CHP system and the utility electricity from the electric company. Figure 4 is the percentage of CHP total capacity to the electricity demand peak and shows that the maximum value reached 50%, that is to say, CHP system supplied the half of the electricity demand peak for users. The minimum value is less than 10%. This means that CHP system cannot satisfy the 10% of the electricity demand peak. According to the profiles, it can be found clearly that new buildings had generally bigger value of the percentage of CHP total capacity to the electricity demand peak than existing buildings. The average value in all new buildings reached to 28.5%, a dramatic improvement over the 21.5% average value of existing buildings. The average value for all users investigated is only 25%. This can be explained by the following aspects. Firstly, the introduction of CHP in existing buildings intends generally to improve the security and reliability of electricity. Therefore, the users select relative smaller CHP capacity from the economy. While the users of new buildings took into account better saving energy and environmental effect during lifetime in the introduction of CHP. On the other hand, the introduction of CHP in existing buildings is confined to some factors, such as bargain of utility electricity, the reuse of existing equipments. Furthermore, various samples have different value. The compound buildings
had the average value with 19.7% and hospitals had the average value with 29.5%.

Figure 5 illustrates the annual electricity supply of CHP system per square meter. From the data, it can be concluded that CHP system provided 150kWh/m²~400 kWh/m² electricity supply for various users.

Generating electricity efficiency is an important index to evaluate CHP system. Figure 6 illustrates the relationship between unit size and generating electricity efficiency. As the figure shown, gas turbine had the bigger unit size with the range from 990kW to 4500kW. On the contrary, gas engine had the smaller unit size; the maximum unit size in all users investigated was only 900kW, which was smaller than the minimum unit size of gas turbine. On the other hand, it can be found that gas engine had the higher generating electricity efficiency than gas turbine. The maximum generating electricity efficiency for gas engine achieved 36% and the maximum one for gas turbine was only 28%. The average generating electricity efficiency for gas engine in all users was 30.6% and the value for gas turbine was 24.2%.

Generating electricity efficiency profiles for various users were assessed and shown in Figure 7. From the profiles, it can be concluded that education buildings had the maximum average generating electricity efficiency with 30.6%, followed by hospital buildings with 29.6%, amusement facilities with 29.5%, office buildings with 28% and compound buildings with 25%.

3.3 Heat recovery system

Modes of heat recovery comprised hot water, steam and exhaust gas and they were described as Figure 8. There were 11 CHP systems using hot water heat recovery system and their generators all were gas engines. Next, seven steam heat recovery systems were applied. In these systems, most generators were gas engine, sharing of 6 pieces. In all consumers, four hot water & steam systems and one exhaust gas heat recovery systems were used to capture the waste heat from CHP system. In sum, hot water heat recovery was more attractive than other modes of heat recovery.

Figure 9 is the purposes of recovered heat and shows that most recovered heat were used complexly for hot water, heating and cooling, which was responsible for 11 users, accounting for 44%, followed by others purposes, such as district cooling and heating (DHC) and steam with 5 pieces (20%), hot water with 4 pieces (16%), cooling and heating with 1 pieces. Consequently, the recovered heat was used widely to various purposes for the consumer.

Exhaust heat utilization of CHP system is another important index to evaluate system. Exhaust heat utilization efficiency for various buildings was described as Figure 10. It can be concluded that gas turbine achieved average 40.5% exhaust heat utilization efficiency, higher about 1% than gas engine.

In addition, various users have different exhaust heat utilization efficiency, mostly ranging from 35%~45%.
The maximum exhaust heat utilization efficiency reached 50%. The average value was 41% for all users. Hospitals attained maximum average 46.1% exhaust heat utilization efficiency, which is the largest average value in all various buildings. Next, office buildings achieved average 42.4% exhaust heat utilization efficiency. The smallest value occurred at other buildings with average value 36.1%. Accordingly, in this survey, exhaust heat from most CHP system can be used fully. This main reason was that the percent of CHP total capacity to the electricity demand peak was very low with only 25% as described in the sector 3.2.

Exhaust heat utilization efficiency is also influenced by the percent of onsite generating electricity. Their relationship was illustrated in Figure 11. From the results, it can be concluded that exhaust heat utilization efficiency decrease with the rise of the percent of onsite generating electricity. The increasing of the percent of onsite generating electricity leads to the improvement of the whole capacity of CHP system. Bigger CHP system will discharge more exhaust heat than the demand of the users. Recovered heat can not be used fully by users. Therefore, the exhaust heat utilization efficiency will drop, which causes overall energy utilization efficiency to fall.

Figure 12 is the overall energy utilization efficiency and shows that gas turbine and gas engine had 60%~80% overall energy utilization efficiency with 20%~34.5% generating electricity efficiency and 19.5%~50% exhaust heat utilization efficiency. One hospital (No. 9, in Table 2) has the maximum overall energy utilization efficiency because it had large number of heat energy demand with the maximum annual average exhaust heat utilization efficiency of 49.4% in all systems. Summarily, one refrigeration warehouse (No. 22, in Table 2) had the

Table 3. The Results of Opinion Questionnaire

|          | Office | Hospital | Education | Compound building |
|----------|--------|----------|-----------|-------------------|
| Q1       |        |          |           |                   |
| Q2       |        |          |           |                   |
| Q3       |        |          |           |                   |

Notes:
1) Q1 stands for the motivation of introducing CHP system; Q2 stands for the satisfied aspects of introduction CHP system; Q3 stands for the dissatisfied aspects of introduction CHP system;
2) The value of axis stands for the important degree for economy, saving energy and environment.
3) The shade field or arrow is the average weight result for various buildings.

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minimum value because its exhaust heat did not be utilized fully with only annual average exhaust heat utilization efficiency of 19.5%.

3.4 The opinion questionnaire of CHP introduction
In order to grasp the motivation of selecting CHP system and satisfied or dissatisfied aspects for the CHP system introduced, an opinion questionnaire had been carried out regarding economy, environment and saving energy. According to the important degree for the options, three weights were classified as 2, 1 and 0. 2 stands for the most important aspects. 1 means that users care the aspect but not the most important aspects. 0 suggest that consumers don’t concern the options at all.

Based on the investigation, 4 type buildings with more samples were evaluated and showed in Table 3. Q1 is the motivation of selecting CHP; Q2 stands for the satisfied aspects of introduction CHP system; Q3 stands for the dissatisfied aspects of introduction CHP system. The value of axis displays the important degree for the options. The shade field or arrow is the average value for various buildings. From the results, the following characteristics were derived:

Q1: The motivation of selecting CHP system (Q1 line in Table 3)
Office users selected economy as the most important reason introducing CHP system with average weight value 1. At the same time, they also considered environment and saving energy factors with average weight value 0.83.

In hospital users, saving energy become the important factor of select CHP system with average weight value 1.25, next, environment and economy are equal with average weight value 0.75.

Education users considered saving energy as the important reason with average weight value 1.3, followed by economy with 0.67 and environment with 0.3.

In compound buildings (main facilities are hotels), economy and saving energy were believed as the factors of selecting CHP system and economy was the most important factor with average weight value 1.75.

In sum, economy, environment and saving energy may be important factors of selecting CHP system for various users. Both office and hotel users selected economy as the most important reason introducing CHP system, while hospital and education users concerned more saving energy effect of CHP system.

Q2: The satisfied aspects of introduction CHP system
(Q2 line in Table 3)
Office users selected economy as the most satisfied aspects for the introduction the CHP system with average weight value 1, followed by saving energy (average weight value 0.75) and environment (average weight value 0.5). Therefore, environment can not reach the expected value of 0.83.

Hospital users were satisfied with economy, saving energy and environment. And the weights for three options are equal with the average value 1, that is to say, the motivation of introduction CHP system had been satisfied in the actual operating.

Education users were satisfied very much with saving energy with average weight value 1.33. And economy and environment also can reach to the expected demand with the average weight of 0.5.

Compound building users were not satisfied very much with the CHP system and the maximum weight value for three options was only 0.75.

Q3: The dissatisfied aspects of introduction CHP system (Q3 line in Table 3)
Office users and hospital users were satisfied with the CHP system, therefore, the average weight value of dissatisfied aspects of introduction CHP system were 0.

In education users, economy became the most dissatisfied aspects of introduction CHP system with average weight value 0.67. Compound buildings were not satisfied economy and saving energy and economy was the most important aspect with average weight value 1.

4. Conclusions
In this paper, the present situation of the introduction of CHP system was investigated. The results of the investigation can be summarized as follows:

1) CHP system has been used widely in various sectors. Office and hospital users shared of 40% of the total users’ number. The electricity generation capacity ranged several ten to several thousands kilowatt.

2) The range of the electricity demand peak per square meter varied from 32W/m² to 143 W/m². Commerce buildings have the biggest average electricity demand peak with 95 W/m² and the hospital have the smallest value with 48 W/m². The percentage of CHP total capacity to the electricity demand peak is low and the average value for all users investigated is only 25%.

3) Generating electricity efficiency and heat recovery efficiency was high. Generating electricity efficiency for gas engine achieved 30.6% and 24.2% for gas turbine. Exhaust heat utilization efficiency for gas turbine reached 42.4% and gas engine also captured 39.4% exhaust heat from CHP system. Considering various users, exhaust heat utilization efficiency was relative high, mostly ranging from 35%~45%.

4) Various users have different motivation of selecting CHP system. Both office and compound building selected economy as the most important reason introducing CHP system, while hospital and education users concerned more saving energy. Office users and hospital users were satisfied with the CHP system introduced; while compound building users were not satisfied very much with the CHP system.

Acknowledgement
This research is partly supported by JSPS “Grants-in-Aid for Scientific Research” (KibanC14550591). The authors would like to express thanks to respondent for cooperation in data analysis.
References
1) http://www.cgc-japan.com/
2) Yingjun Ruan1, Bill Batty2, Weijun Gao3, Noriyasu Sagara4, Yuji Ryu4 (2004). Examination of the viability of Co-generation for a small-scale housing development in Kitakyushu, Japan. International Housing Conference in Hong Kong.
3) David Bonilla, A survey on the performance of, and plant manager satisfaction with, co-generation plants in the Japanese manufacturing sector, Second international symposium on Distributed Generation, Oct, 2-4, 2002, Stockholm, Sweden.
4) Moriya Hiroyuki, “Research (the comparison with the conventionally cogeneration system) on the introduction of the fuel cell cogeneration system in district cooling/heating system” Annually conference of AIJ, D-2 separate volume, p.943, 1996
5) Shiise WARAGAI, Shuji FUJII, Kazuhiro YUASA, Tsuneo UEKUSA and Yukiko MUROTA, Influence of cogeneration system design and fluctuation in building load on energy saving, Journal of Archit. Plann. Environ. Engng., NO.531, p.59, May 2000