Evaluation on Introducing a DHC System with Co-Generation System in the City Center of Shenzhen

Jian Wang*1, Weijun Gao2, Haifeng Li3, Penglin Zhao4, Jianxing Ren5 and Toshio Ojima6

1 Senior Engineer, The Architectural Design & Research Institute of Tongji University, P.R. China
2 Associate Professor, Faculty of Environment Engineering, The University of Kitakyushu, Japan
3 Research Associate, Department of Architecture, Waseda University, Japan
4 Chief Engineer, Shenzhen Municipal Planning & Land Bureau, P.R. China
5 Professor, Department of Power Engineering, Shanghai Institute of Electric Power, P.R. China
6 Professor, Department of Architecture, Waseda University, Japan

Abstract
In order to keep sustainable development in Asia in the 21st century, we have to solve the global environmental problems because of the huge energy consumption with rapid economical growth. One solution is to use new energy and environmental system. For example, co-generation system is one available approach. In this article, we make a District Heating and Cooling (DHC) system together with co-generation system (CGS) to meet the increasing energy demand in the quickly developed area-City Center in Shenzhen city, and evaluate the whole system from the viewpoint of energy saving and environmental protection.

Keywords: DHC; CGS; energy system; Shenzhen

1. Introduction
In order to keep sustainable development in Asia in the 21st century, we have to solve the global environmental problems because of the huge energy consumption with rapid economical growth. One solution is to use new energy and environmental system. For example, co-generation system is one available approach. In this article, we make a District Heating and Cooling (DHC) system together with co-generation system (CGS) to meet the increasing energy demand in the quickly developed area-City Center in Shenzhen city, and evaluate the whole system from the viewpoint of energy saving and environmental protection.

2. Outline of the City Center of Shenzhen
Shenzhen city is situated in the south of China, and adjacent to Hong Kong (Figure 1). Since Shenzhen city was founded in 1979 with a population about 30,000 as the Special Zone in China, Shenzhen has taken advantages of open policy and good location to become a big city with a population about 4,000,000 in 2000. Its development is the fastest in China, and that leads to the increase of energy consumption at the same time. Figure 2 and 3 show its Gross Domestic Product (GDP) and annual electricity consumption per person over the years. The GDP was increased three times from 1990 to 1996 and now reached at about USD6000 (RMB=51,000, RMB is the currency unit of China, 1USD=8.5RMB) while the electricity energy consumption was increased at almost same rate as GDP.

A new and large-scale city development is carried out in Shenzhen in recent years aiming to become a modern international city. The area, called City Center is about 413ha, which is planned to accommodate 260,000 employees and 77,000 residents. According to our land use plan in figure 1, the office and commercial buildings are in the southeast and southwest parts, government buildings and culture facilities in the north part, and the...
residential buildings in the surroundings.

3. Plan for a Ecological City with Energy Saving and Resource Recycle

In order to realize an ecological city, we consider the following methods.

① Energy and resource that consume in the buildings of the City Center should totally be effective from the viewpoint of the whole area.
② Energy and resource in the City Center should be recycled to the maximum.
③ Natural energy should be effectively used.
④ Safety in a disaster, extension of a life line and flexibility in location development should be considered.
⑤ A infrastructure allowing a mixed-use and expansion should be developed in the City Center.

In this plan, we aim to making a city with energy saving and resource recycle and propose a total system in the City Center.

For energy saving plan, we try to introduce Co-Generation System (CGS). CGS is a system to supply electricity to a group of buildings and at the same time, use the heat release to make cooling/heating energy to meet the heat demand of the buildings by using the pipe or duct. And we also introduce District Cooling System (DHC) to satisfy a group of buildings with the heat energy from a center plant through connecting the plant and user with pipe.

The merits of Co-Generation and District Cooling System are as followed

1. Decrease the discharge of pollution
   Compared with the conventional cooling supply system, it is easy to introduce pollution treatment equipment with a high efficiency in a CGS and DHC
2. Have a high efficiency of the total heat use-and save energy.
   CGS and DHC have a high efficiency about 70-80%
3. Have a safety, prevention of disasters and reliability.
   CGS and DHC have a high safety, prevention of disaster and reliability because the CGS and DHC decrease ignition points of heat source.
4. Economic
   Although there is a high investment cost in CGS or DHC, the running cost can be decreased.
5. Save space and be easy to management
6. Have a uniform electric power supply (Peak cut)
   In this mix-use area, through using the different peak point in the commercial, official and residential facilities, the efficiency can be raised to cut peak down.

4. Calculating the Energy Demand in the City Center of Shenzhen
4.1 Determination of the building floor area for different uses

According to master plan, for the mixed-use facilities, the ratio of office and commercial use is 7:3. The floor area of different buildings in the City Center of Shenzhen

| Table 1. Floor Area for Different Uses in the City Center Plan (Unit 10000m²) |
|-----------------|---------------|---------------|---------------|---------------|
| North           | South west    | South east    | Total         |
| Residential     | 96.7          | 55.0          | 17.0          | 168.7         |
| Office          | 10.0          | 123.4         | 73.8          | 207.2         |
| Governmental    | 65.8          | 2.7           | 0.0           | 68.4          |
| Commercial      | 15.5          | 50.1          | 37.0          | 88.6          |
| Hotel           | 0.0           | 22.2          | 24.4          | 46.6          |
| Entertainment   | 0.0           | 0.0           | 0.0           | 0.0           |
| Culture         | 42.0          | 0.0           | 1.0           | 43.0          |
| Education       | 0.0           | 0.0           | 1.0           | 1.0           |
| Hospital        | 0.0           | 0.0           | 0.0           | 0.0           |
| Total           | 222.0         | 253.4         | 152.2         | 628.5         |
is shown in Table 1.

Generally, we can use the energy consumption unit to calculate the energy demand for different buildings, according to the floor area.

4.2 The energy consumption unit for Shenzhen

Because there is no energy consumption unit for buildings in Shenzhen, we use the index of Tokyo for reference and make relative amendments with climate. The difference of monthly average air temperature between Shenzhen and Tokyo is shown in Figure 4. Shenzhen has long intermediate seasons and there is no need heating, while Tokyo has obvious season change, and its temperature difference between winter and summer is quite big. Conditions from May to September in Shenzhen are equivalent to those in the summer in Tokyo, while conditions from January to April and October to December is similar to those in the intermediate seasons in Tokyo. According to the daily energy consumption unit of Tokyo, we get the corresponding equation in Shenzhen (1).

\[ S_y = T_s \times \sum_{n=5}^{9} H_n + T_m \left( \sum_{n=1}^{4} H_n + \sum_{n=10}^{12} H_n \right) \]  

Where, \( S_y \): annual energy consumption unit of Shenzhen  
\( T_s \): energy consumption unit of Tokyo in summer  
\( T_m \): energy consumption unit of Tokyo in intermediate seasons  
\( H_n \): operating days in “n” month

4.3 Calculation of the energy demand

According to the equation 1, we can calculate the annual energy demand in Shenzhen (Table 2). And the hourly electricity and heat demand is shown in Figure 5 and 6 respectively. The hot water demand is great in the North part because of large amount of residential buildings, government office and hospitals. And the office and commercial buildings are in the Southeast and Southwest areas, which have similar use and similar energy demand hourly.

5 Discussions about the Energy Systems in the City Center

5.1 Calculating the amount of unused energy in the City Center

In our plan we use the solar electricity system in the governmental offices in the north part, and set up a waste plant in the surroundings. Electricity generated by the Solar cell is calculated in the equation 2, and the heat coming from the waste plant is shown in the equation 3.

Hourly electricity generated = Solar radiation × Output of solar cell × General efficiency/Solar radiation density

\[ \text{Output of solar cell} = 2204 \text{ kW} \]  
\[ \text{General efficiency} = 0.57 \]
Solar radiation density = 1 kW/m²
Available waste heat per hour = Daily output of combustible waste/24 × Unit heat value × Boiler efficiency × (100-Pipe heat loss)/100

Unit heat value=9.42 MJ/kg
Boiler efficiency=0.85
Pipe heat loss=10%

5.2 System selection
Because governmental offices are in the north part, it is necessary to backup electricity supply in emergency. From the viewpoint of self-energy supply, the cogeneration system, solar cell and heat from waste plant are introduced in the north area. While the DHC system is used in the southeast and southwest areas, which have great energy demand, especially the heating and cooling load. And the thermal storage tank will be used in the southwest where has the biggest cooling load in summer to cut off the peak demand. Furthermore, the plants in three districts will make up a network system to get high efficiency. According to the flow chart of this system shown in Figure 7, we give out four cases, Type 1 to Type 4 in Table 3, and the outline of these plants are shown in Figure 8.

5.3 Simulation conditions
Heat and electricity from CGS will be supply to the 68,000m² governmental offices, 65,000 m² office buildings, 6,100m² hospital and 50,000m² cultural facilities, all together amounts to 784,000m² floor area. Figure 9 shows that the supplying area and pipe layout in these districts.

From the energy consumption in the City Center, we can divide this area into three parts. One is north zone with the City Hall in the center, residential houses and office buildings. In the south zone, we can separate into two parts: west zone and east zone where the commercial buildings and residential building is mainly concentrated. To consider the pattern of the energy consumption, the...
office and commercial building reach their peak in day and the residential buildings reach its peak in evening. To balance the energy consumption pattern, we suggest introducing co-generation system into the three zones. Use the pipe network to connect these three plants. In the result, we can raise the energy efficiency and have uniform energy supply. The exhaust heat will be used for hot water supply first, then for cooling. The cogeneration system’s operation follows up to surplus heat of the waste plant. The ratio of heat and electricity in the north area is shown in Figure 10. And the efficiency of heating and cooling systems and CGS system can be seen in Table 4 and 5, and the capacity of heating and cooling systems is shown in Table 6.

Table 5. Efficiency of CGS

<table>
<thead>
<tr>
<th>GAS turbine</th>
<th>Electricity generating</th>
<th>28%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat recovery</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td>Electricity consumption</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 6. Capacity of Heating and Cooling Systems

<table>
<thead>
<tr>
<th>Area</th>
<th>Equipment</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Gas turbine</td>
<td>13200kW × 5</td>
<td>13200kW × 5</td>
</tr>
<tr>
<td></td>
<td>Electrical water heater</td>
<td>37200RT</td>
<td>37200RT</td>
</tr>
<tr>
<td></td>
<td>Boiler</td>
<td>205kW/h</td>
<td>205kW/h</td>
</tr>
<tr>
<td></td>
<td>Boiler</td>
<td>38kW/h</td>
<td>38kW/h</td>
</tr>
<tr>
<td></td>
<td>Double effective absorption chiller</td>
<td>3972RT</td>
<td>3972RT</td>
</tr>
<tr>
<td></td>
<td>Centrifugal chiller</td>
<td>35700RT</td>
<td>35700RT</td>
</tr>
<tr>
<td></td>
<td>Boiler</td>
<td>45kW/h</td>
<td>45kW/h</td>
</tr>
<tr>
<td></td>
<td>Double effective absorption chiller</td>
<td>5880RT</td>
<td>5880RT</td>
</tr>
<tr>
<td></td>
<td>Centrifugal chiller</td>
<td>53500RT</td>
<td>53500RT</td>
</tr>
<tr>
<td></td>
<td>Ice thermal storage</td>
<td>015000RT</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 10. Distribution of Electricity/Heat Ratio in North Area

Table 4. Efficiency of Heating & Cooling Devices

<table>
<thead>
<tr>
<th>Use</th>
<th>Device</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>Boiler</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Electrical water heater</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Double effective absorption chiller</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>Reciprocal chiller</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Centrifugal chiller</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Fig. 11. Comparison between Type 3 and Type 4
5.4 Comparison between Type 3 and Type 4
The comparison between Type 3 (non-network system) and Type 4 (network system) in summer is shown in Figure 11.
Type 3: CGS follows up to the heat demand in 24 hours to supply heat, and there is no surplus heat in the waste plant in the north district. And the heat demand in the southeast and southwest areas is met by their own energy plant respectively.
Type 4: The load of CGS decreases from 23:00 to 7:00 next morning in the north, which can be met by two gas turbines with full load; the surplus heat can be supplied to the southeast and southwest areas. Moreover, the surplus electricity will be used by the electrical centrifugal refrigerators in the southwest area, and the cooling can be stored in the ice storage tank, which will cut down 28% of the peak load in the peak hours during the daytime.

5.5 Energy saving and environmental protection assessment
Figure 12 and 13 gave the energy saving and CO₂ reduction. Compared with Type 1 and 2, Type 3 and 4 systems have good assessment in energy saving and environmental protection because of using the CGS, exhaust heat from waste plant and solar cell. Furthermore, Type 4 is the best because of using the network system.

6. Conclusion
In this study, we selected a new development area in Shenzhen, China to have a new energy system planning. First, we analyzed the thermal characteristics in this area. According to the energy demand characteristics, we suggested a DHC system with CGS system for City Center in Shenzhen. In order to evaluate our proposal, we set up four cases to have a comparison study. The results showed, compared with the individual and conventional systems, DHC system with CGS system has good effect in energy saving and environmental protection. And the network system will get the best assessment. The more detailed will be discussed later from the viewpoint of economics.

References
1) Shenzhen Land Bureau, The atlas of Shenzhen, 1998
2) National Bureau of Statistical, China, Shenzhen Statistical Yearbook, 1998
3) Shenzhen Land Bureau, The General Plan of Shenzhen, 1997
4) Ojima Toshio Lab, Light Heat and Water Consumption Units in Buildings, 1995
6) Japanese Air Conditioning and Equipment Institute, Gas Cogeneration Plan, Design and Assessment, 1994