LOWLAND TECHNOLOGY INTERNATIONAL Vol. 16, No.2, 103-116, December 2014
International Association of Lowland Technology (IALT), ISSN 1344-9656

INTEGRATED ASSESSMENT OF CHP SYSTEM UNDER DIFFERENT MANAGEMENT OPTIONS FOR COOPERATIVE HOUSING BLOCK IN LOW-CARBON DEMONSTRATION COMMUNITY

Liyang Fan [1, 2], Weijun Gao [2] and Zhu Wang [1]

ABSTRACT: As residential energy consumption increases recently, there is greater focus of the energy conservation activities in residential sector. The combined cooling, heating and power (CHP) system, a well-known distributed energy system technology, has been paid more and more attention. In this paper, the performances of typical CHP systems are investigated for a cooperative housing block (CHB), a mixed residential development pattern recently popularized in Japan. Based on the building's energy consumption, CHP technologies have been assumed and assessed following two design and management modes, namely heat tracking mode and electricity tracking mode. In order to obtain a comprehensive understanding of the performance of the assumed CHP systems in CHB, the system is assessed under different area functional proportion (AFP) and area social age structure (ASAS, the proportion of housing styles for different age groups). It can be proved that the cooperative use of CHP system in CHB is better than individual use in the conventional housing development. In addition, the CHP system can perform better if the urban planner properly design the function formation and consider the lifestyle of residents in different ages.

Keywords: Low-carbon, CHP, net-zero, mixed use, mixed age structure.

INTRODUCTION

Kyoto Protocol has been widely known as an international act to restrict the greenhouse gas (GHG) emission and 2012 was the fiscal year of the first period. Under this restriction, Japan was supposed to reduce six percent of the GHG emission in 2012, compared with 1990 (Lau et al. 2009). However, the statistics suggested that, its yearly GHG emission decreased by 0.4% until the end of the year 2010 compared to those of the base year (Ministry of the Environment, Japan 2011). Even worse, after Fukushima crisis, Japan cut down the nuclear energy. The Ministry of Environment reported that the greenhouse gas emissions in the year 2011 increased 3.7% (Ministry of the Environment, Japan 2013). Therefore, Japan had to place emphasis on other more efficient and independent electricity productions, preferential based on the renewable and untapped resource.

Distributed energy systems (DES) have been drawing increasing attention as a substitute for grid in the low-carbon society development (Sollia et al. 2009; Evans 1993). Compared with the traditional centralized energy supply system, the distributed energy generations can reduce the loss in energy transmission to minimum and are easy for renewable energy use as well (Matallanas 2012; Sadineni et al. 2012; Tascikaraoglu et al. 2011; Seth and Alisha 2012). From a long-term point of view, the utilization of renewable energy in DES should be a final solution for sustainable development and low-carbon society. However, most of the current renewable energy technologies, for example solar energy and wind power, have low energy utilization efficiency and high expense, thus cannot compete with conventional fossil fuels with respect to the economic performance. Therefore, from a short run, such as economic efficiency approach, the combined heat and power (CHP) plant is considered to be one of the feasible and effective solutions. In Japan, the CHP system was firstly used in industry area, but now it has also become popular in commercial area and residential area (Kimijima and Kasagi 2002). It can make use of the waste heat which comes from the electricity generation process. Instead of discharging into the environment, it is used for cooling, heating and hot water supply. As a consequence, the CHP system can achieve a primary energy efficiency around 60%-90% (Gu, et al. 2012). The higher energy use efficiency also contributed to the low carbon society.

[1] Department of Civil Engineering and Architecture, Zhejiang University, Yuhangtang Road No.388,Zhejiang Province, P.R.CHINA, happylamb68@hotmail.com
[2] Department of Architecture, The University of Kitakyushu, Hibikino1-1, Wakamatsu-ku, Kitakyushu, Fukuoka, JAPAN
Note: Discussion on this paper is open until June 2015

In Japan, many studies have reported on the introduction of the CHP systems in civil use. Yang and Gao (2007) analyzed the distribution system at a university site and optimized the system from the economic aspect. Ruan (2009) researched on the introduction of CHP systems in residential areas and analyzed how operating pattern and housing scale affect the system performance. Some studies began to combine CHP with renewable energy technologies such as a photovoltaic (PV) system or biological energy. Ren et al. (2009) introduced PV into the energy system and discussed its economic efficiency.

Besides economic feasibility, there are still many barriers for the introduction of CHP systems into residential area. As to the residential area, the electricity load and heat load varies with the season and fluctuates hourly during the day (Gu et al. 2012; Mehleri et al. 2013). In another word, operation of residential CHP system is subject to the variation of load demands. Many researches have been reported on how to design the optimal size of the CHP to get a higher efficiency (Ren et al. 2008). However, from the intermediate scale side, the cooperative energy use and the interactions between buildings have been more or less ignored. For example, the introduction of small commercial area or other function in the residential area can smooth out the electricity and heat load. Furthermore, residents in different ages (or family types) usually possess different lifestyles, thus energy consumption pattern are different. During the design process, if the life style of the residents can be considered, it can also take the edge off the variation of load demands.

In fact, the mixed residential development with various functions and age groups, have already been proposed by the city planners and stressed on its social meaning (Tu and Lin 2008; Bhata and Guob2007). The cooperative housing development, a participatory design and construction process which has been popularized in Japan, is one of the housing strategies that can deliver the mixed residential concept. In this process, developers would, given the different lifestyles and needs of the residents, design and assemble them into community (Clapham 2012). This kind of housing usually has a common space that can be introduced with different building functions and gathering residents in different age groups (Fumika et al. 2010; Satomi 2005). It is expected that the energy system can also work in the cooperative way, managed by a single energy center.

In order to understand the feasible benefits of the cooperative use of CHP system, the environmental evaluation on the effects of mixed functions and lifestyles is most important. There have been some studies on this subject. Yamaguchi et al. (2007a and 2007b) developed a model to set up an urban energy system, and applied it into a central commercial district which was formed with various building functions. However, these researches were in commercial areas and public areas. The mixed residential areas are paid little attention in the previous studies. Actually, the energy consumption in a residential building will be much more complicated. Boait et al. (2006) set up a simple computer model of the time distribution and use of the electricity output for micro CHP, based on trials with a real installation in a UK dwelling. There were six household scenarios comprising three different types of house. However, the studies only stress on the importance of marketing and the use of half-hourly metering, but does not emphasize on the environmental aspect.

This study proposes a cooperative CHP (CCHP) model, and applies it into the residential area with CHB development pattern. Taking the low carbon demonstration area in Kitakyushu, Japan as a case study, it analyzes the energy and environmental performance of the CCHP systems in CHB, and the effect of mixed using as well as mixed age structure (housing for different age groups).

In detail, this paper is structured as follows: Section Two presents the concept of CHB and CCHP model, assumes technical type, design and management options of the CHP system, as well as the evaluation methods. The third section proposes the CHB development pattern in the Low carbon demonstration area, the net-zero community of Kitakyushu. For the evaluation of the CCHP systems, study cases are also assumed in this section. Section Four illustrated the numerical application analysis. Finally, Section Five draws a conclusion for the study.

METHODOLOGIES

Account on the theory of CHB develop pattern and the DES system, this research proposes a CCHP model. The following discussions are based on the data collection, including the technical data and demand side information. Assuming that the CHP systems have been introduced into CHB, we can access the potential of the cooperative energy use and discuss the operation of the mixed function and the age structure (Fig.1).

Concept for CHB Development and the CHP System

The CHB, a distinctive form of housing development has recently become popular in Japan. The members in one CHB buy their own real estate and granted by way of a share management and development in the cooperative way. A primary advantage of the cooperative housing is the pooling of the members' resources so that they can build a common area as their common interest. They can design the house or apartment according to their own requirements and life styles. Therefore, this kind of housing block can gather the people in different ages into one block, making a safe and comfortable living environment for aging people (Fumika et al. 2010; Satomi 2005). Another key element is that they can manage and design the common area in cooperation to make some revenue, developing it into commercial, office or other kinds of functions.

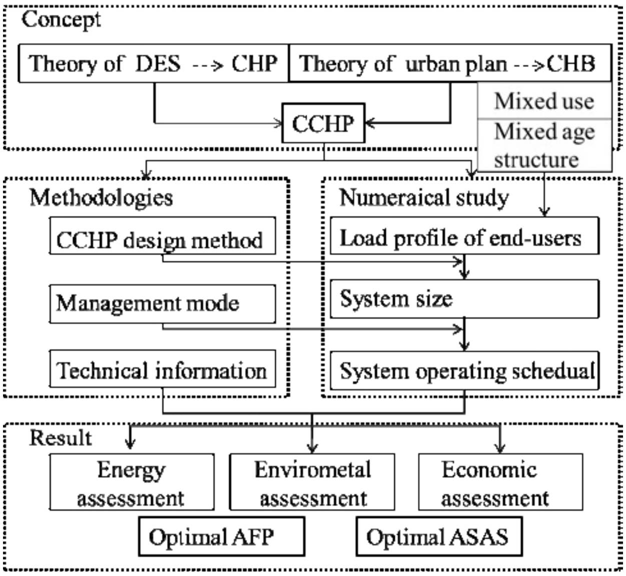

Fig. 1 Research flow

Figure 2(a) is the conventional plan for residential area. The apartments and detached houses are constructed individually. This kind of plan is much easier and faster for construction, with less housing styles. Therefore, in the communities with conventional pattern, the role of the environment is less immediate in the human-interaction group, which causes less social interaction, less citizen participation in the design process, and less community identity (Matsuoka and Kaplan 2008). Under this kind of plan, usually the energy systems are also introduced and managed individually. Figure 2(c) is the conventional community pattern with CHP system. The CHP systems are designed, introduced and managed individually in apartment, taking a single building as one unit. The detached houses are not introduced with the CHP system, because the small scale CHP for one household is still not so efficient under the existing tectonic condition (Hiroyuki et al. 2011).

This research proposed a plan with the CHB development concept, displayed in Fig.2(b). In this plan, the apartment and the detached houses were developed together by blocks, surrounding a common open space. Under this pattern, the CHP system can also be used in a cooperative way (suggested in Fig.2(d)). Every CHB will be introduced with one CHP plant under the public space, offering electricity, heating, cooling and hot water for both apartments and detached houses. The system assumed in this research is not an isolated system. It is connected to the energy networks, and can obtain electricity from the utility provider and send the surplus electricity back to the grid, which will be supplied to some other existing apartments.

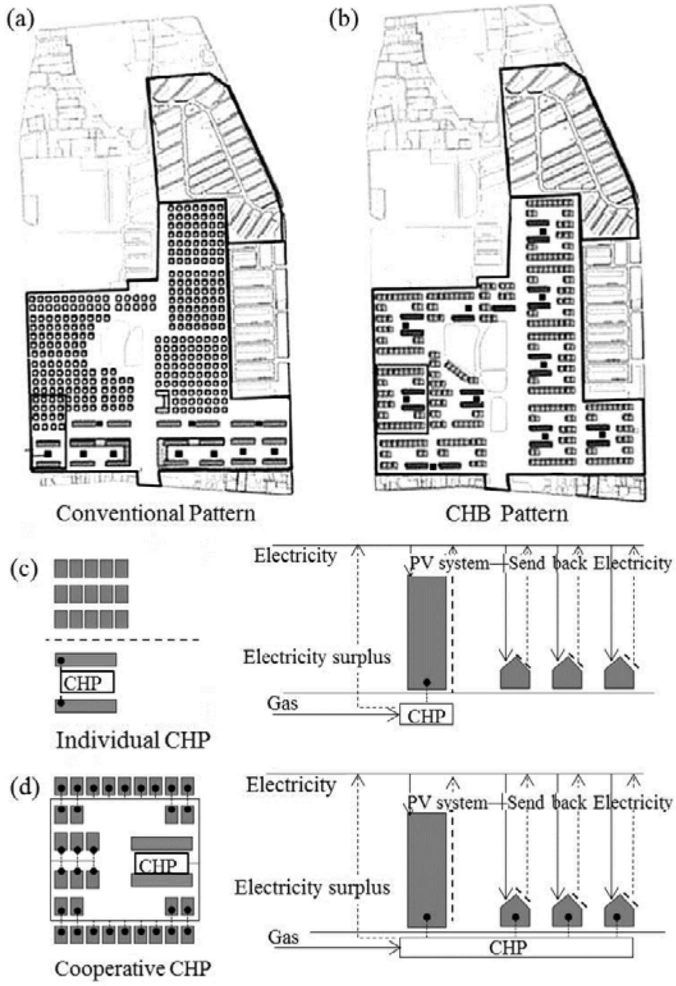

Fig. 2 The concept for urban pattern and the energy system

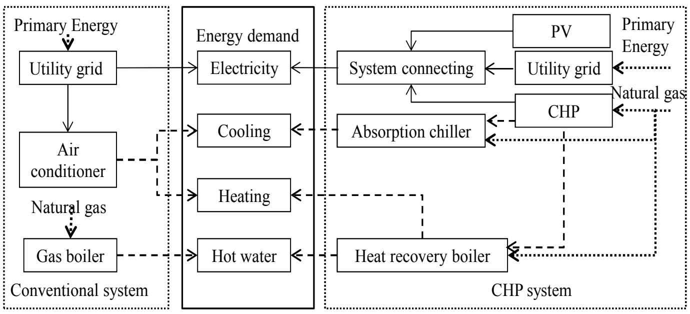

Fig. 3 The description of conventional system and the CHP system

Description of the CHP System

For a comparative study, this research assumes a conventional system as a baseline. The energy flows of the conventional system and the CHP system are illustrated in Fig.3. The left side is the conventional system and the right side is the CHP system. Direct electrical consumption for lights and equipment, heating and cooling demands, as well as hot water load have been considered in this research.

In the conventional system, the electricity demand is served all by utility grid, not only for the power consumption, but also for the space heating and cooling as well by using the air conditioner. Gas boiler, fueled by natural gas, serves hot water demand.

In the CHP system, the electricity demand refers to the power consumption. It could be met by either the utility grid, or the on-site generators, such as solar electricity system (PV) and CHP. The recovery heat from the CHP is used for meeting the cooling, heating and hot water demand through the absorption chiller and boiler. When the recovery heat is not enough, the auxiliary boiler can also be fired by the natural gas to satisfy the heat demand. On the contrary, if the recovery heat exceeds the local heat demand, the surplus thermal energy would be exhausted directly into the atmosphere. Similarly, according to the current electrical standard in Japan, the electricity produced by PV system can be sold back to the grid, but the electricity produced by CHP system is not allowed to sell. Only the surplus part can be send back to the grid.

In this research, gas engine is employed as the prime mover. As a widely used technology in Japan, gas engine is attractive for various scale CHP systems for its low first cost, fast startup, reliability, load-following characteristics, and heat recovery potential. The main technical and financial specifications of above four prime movers are given in Table 1.

Table 1 Specification for various equipment

Equipment	COP（Coefficient of preference）	
Utility	Generating Electricity	0.35
	Transport and distribution	0.9
Gas Engine	Electric generation efficiency	0.3
	Exhaust heat recovery efficiency	0.45
Gas Boiler		0.85
Air Conditioner	Cooling	3.22
	Heating	2.83

Design and management options of the CHP system

According to the demand features, the CHP designer may design its size and employ operation strategies which affect its performance. In the following, two typical design and management options are discussed in detail.

Heat tracking (HT) mode

The HT mode places emphasis on the heat production. It is assumed that all the recovery heat from the CHP system can be efficiently reused. Under this mode, the electricity production of the CHP system follows the variation of the thermal demand. The CHP system manages in this mode has possibility to produce excess electricity beyond local demand. As mentioned above, the overflow electricity generated from CHP is sent back to the grid without profit. This part of electricity is used in the nearby communities. Therefore the primary energy consumption in other districts reduces. In other words, this part of surplus electric energy cannot get extra economic benefit but still have environmental benefit.

Deciding on the system size is the first obstacle to execute the HT mode. If the system is oversized, the CHP would waste too much electric energy. Many studies have been reported on how to optimize the size of the CHP system (Wang et al. 2010; Li et al. 2008). This research executes a common method called maximum rectangle method which can be easily applied. This method can avoid oversize or undersize CHP system. The idea is to size the CHP units to cover the average heat demand instead of the maximum. It is determined by the load duration curve and with the concept of maximizing heat amount supplied at full load (Cardona and Piacentino 2003; Shaneb et al. 2011; Haeseldonckx et al. 2007). It can be simply determined based on finding the ‘maximum rectangle’, where the 8760 hourly heat demand values are sorted in descending order and placed in a load duration diagram.

The operation of the CHP is controlled as below:

$$\begin{cases} Q_{elec}^{CHP}=0 & \forall 0 \le \mu_{heat} < \theta \\ Q_{elec}^{CHP}=\eta_e \times Q_{heat}^{Load} / \eta_{rec} & \forall \theta \le \mu_{heat} < 1 \\ Q_{elec}^{CHP}=R_{cap}^{CHP} & \forall 1 \le \mu_{heat} \end{cases} \tag{1}$$

Q_{elec}^{CHP} and R_{cap}^{CHP} denote the electricity generation and rated capacity of the CHP system; Q_{heat}^{Load} denotes the heat demand; η_e denotes the electricity generation efficiency of CHP plant; η_{rec} denotes the heat recovery efficiency of the CHP plant.

μ_{heat} is the instantaneous fraction of the CHP system for recovery heat, calculated as (2)

$$\mu_{heat}=\frac{Q_{heat}^{Load}\times\eta_e}{R_{cap}^{CHP}\times\eta_{rec}} \quad (2)$$

θ is the critical fraction determining to control the working status of the CHP plant. If $\mu_{heat}<\theta$, it means the CHP should turn off because the output is too low.

Electricity tracking (ET) mode

The ET mode pays attention to the electricity generation. The CHP system is operated following the electricity fluctuation so that the recovery heat is also based on the electricity generation. Therefore, in the ET mode, there is no surplus electric energy, but surplus thermal energy instead. This part of surplus thermal energy is discarded into the environment.

The direct electricity consumption in residential area does not fluctuate as its thermal demand, thus different from the HT mode. The size of the ET mode, determined by maximum rectangle method is similar with the maximum value. Therefore, the CHP system in ET mode is dimensioned to cover the maximum electricity and operated according to the real-time electricity load.

This design and management mode also means an option for isolated energy system that serves all types of energy demand through on-site generation. It is an independent option for electrification in remote areas where grid extension is not feasible or economical.

The CHP system is operated as below:

$$\begin{cases} Q_{elec}^{CHP}=0 & \forall 0\le\mu_{elec}<\theta \\ Q_{elec}^{CHP}=Q_{elec}^{Load} & \forall\theta\le\mu_{elec}<1 \end{cases} \quad (3)$$

Q_{elec}^{Load} denotes the electricity demand;

μ_{heat} is the instantaneous fraction of the CHP system for recovery heat, calculated as (4)

$$\mu_{heat}=\frac{Q_{elec}^{Load}}{R_{cap}^{CHP}} \quad (4)$$

In this mode, rated capacity of the CHP system is the maximum value of the electricity load. Similar to HT mode, θ is the critical fraction determining to control the working status of the CHP plant. If $\mu_{elec}<\theta$, it means the CHP should turn off because the output is too low.

Assessment Criteria

Assessment of energy performance

The CHP system provides higher utilization of the primary energy, thus the evaluation of the energy saving performance is one of the most important aspects of the CHP system. This research uses the primary energy saving ratio (ESR) as the key factor to determine the energy saving performance, which is defined as the rate of the energy savings of the CHP system (the difference between the conventional system and the CHP system) to that of conventional energy system. ESR is defined as (5):

$$ESR=\left(Q_{input}^{Conv}-Q_{input}^{CHP}\right)/Q_{input}^{Conv} \quad (5)$$

The annual primary energy consumption for CHP system includes the energy consumption for utility and the gas consumption for on-site power generation, in CHP unit. The primary energy used in CHP system also includes the primary energy consumption for absorption chiller and the auxiliary boiler to satisfy the cooling, heating and hot water.

The primary energy consumption in CHP system is as (6)

$$Q_{input}^{CHP}=E_{Pow}^{CHP}\times\varepsilon_{pow}+(V^{CHP}+V^{Boiler})\times\varepsilon_{gas} \quad (6)$$

Where Q_{input}^{CHP} is the primary energy input to the CHP system; E_{Pow}^{CHP} is the electricity input to the CHP system; V^{CHP} is the gas used by CHP unit; V^{Boiler} is the gas used for boiler. ε_{pow} is the primary energy consumption unit of grid in Japan, a value indicating the electricity generation efficiency of grid (10.3MJ/kWh). ε_{gas} is the primary energy consumption unit of gas in Japan ($45MJ/m^3$).

On the other hand, the annual primary energy consumption for the conventional system is composed of the energy consumption of boiler and electricity consumption, for direct power consumption, cooling and heating,

The primary energy consumption in conventional system is as (7):

$$Q_{input}^{Conv}=E_{Pow}^{Conv}\times\varepsilon_{grid}+V^{boiler}\times\varepsilon_{gas} \quad (7)$$

Q_{input}^{Conv} is the primary energy used by conventional system; E_{Pow}^{Conv} is the electricity consumption in conventional system.

Assessment of "zero energy"

The concept of Zero Energy Building (ZEB) has gained wide international attention during last few years and is now seen as the future target for the design of buildings (Haeseldonckx et al. 2007). It has become a new important evaluation criterion for the reduction of energy use. The definition of ZEB varies according to the situation in different countries. Basically speaking, there are two kinds of ZEB: the off-grid ZEB, unconnected to any utility grid, can autonomously supply energy, and has the capacity to store energy for night-time or wintertime use (Marszal et al. 2011). The on-grid ZEB, named as 'net zero energy', is connected with grid or other energy supply infrastructure.

Therefore, it can get energy or feedback energy to the grid, avoiding on-site electricity storage (Haeseldonckx et al. 2007). Actually, the net-zero ZEB receives more attention, which is considered as the final solution while the off-grid is regarded as an intermediate step (Marszal et al. 2011).

In this research, the ZEB refers to the net-zero system, a system connected to the energy networks that can obtain electricity from the utility provider and send back surplus electricity. The physical boundary of ZEB can encompass a single building or a group of buildings. This research defines "net-zero energy" as "a building or a district (here referred to one CHB), whose annual energy input can be entirely offset by the energy output".

Figure 4 displays the concept for "net-zero energy balance" in this research. The physical boundary encompasses the whole district, while the energy input to the district mainly refers to electricity and gas. The distributed energy system means all the CHP systems in CHB and the on-site renewable energy generation. The energy output is the timely surplus energy that sends back to the grid.

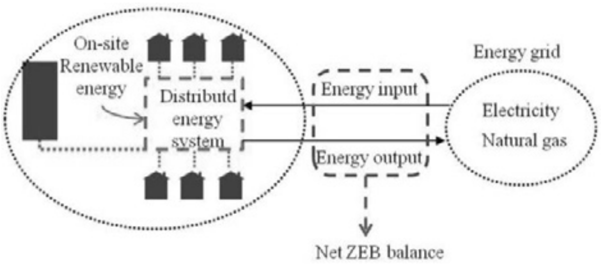

Fig. 4 Concept for "net-zero energy balance"

The factor to evaluate the net-zero balance is named as net-zero balance ratios (R_{NZ}), defined as below:

$$R_{NZ}=\frac{E_{Input}}{E_{Output}} \quad (8)$$

$$E_{Input}=E_{Input}^{grid}+E_{Input}^{gas} \quad (9)$$

$$E_{output}=E_{sur\text{-}elec}^{CHP}+E_{elec}^{PV} \quad (10)$$

E_{Input} is the energy input, including the electricity and the gas; E_{Input}^{grid} is the energy input from the grid; E_{Input}^{gas} is the energy input from the city gas; E_{output} is the electricity feedback of the community. In Japan, the electricity generated by the PV system can be sold back at a price twice higher than the grid purchased. Therefore, it is assumed that all the electricity produced by PV system will not be directly used by the building, instead, sending back to the grid. $E_{sur\text{-}elec}^{CHP}$ means the surplus electricity that produced by CHP system while E_{elec}^{PV} means the electricity produced by PV system, calculated as (11):

$$E_{elec}^{PV}=S\times\alpha\times\eta \quad (11)$$

S is the area for PV penal in a group (n)；

α is the hourly sun radiation rate, η is the efficiency of the PV penal (Ren 2007)；

Whether the community or buildings realizes "net-zero" or not is evaluated by the relative values between R_{nz} and 1. $R_{NZ}\geq 1$ means the community realized "net-zero". $R_{NZ}<1$ means the community can not realize "net-zero" or only near "net- zero".

Assessment of environmental performance

Environmental benefit is another concern for the introduction of the CHP system. This study uses CO_2 emissions reduction ratio (CERR) to assess the environmental performance (the difference between CO_2 emissions in the conventional system and the proposed system).

The CERR is defined as:

$$CERR=(EX_{CO_2}^{Conv}-EX_{CO_2}^{CHP})/EX_{CO_2}^{Conv} \quad (12)$$

Where $EX_{CO_2}^{Conv}$ and $EX_{CO_2}^{CHP}$ denotes annual CO_2 emissions of the conventional energy system and the CHP system, respectively.

A CO_2 emission from the conventional system includes the CO_2 emissions from the natural gas and grid electricity for both electricity and heat consumption, and they can be calculated according to (13).

$$EX_{CO_2}^{conv}=ex_{CO_2}^{gas}\times V^{Boiler}\times\varepsilon_{gas}+ex_{CO_2}^{Pow}\times E_{pow}^{Conv}\times\varepsilon_{pow} \quad (13)$$

$ex_{CO_2}^{gas}$ is the CO_2 emission unit of the gas（13.8 g-C/MJ）; $ex_{CO_2}^{Pow}$ is the CO_2 emission unit of the grid（153 g-C/kWh）.

Annual CO_2 emissions from the CHP system are composed of the emissions of grid electricity and natural gas consumption, as shown in (14).

$$EX_{CO_2}^{CHP}=ex_{CO_2}^{gas}\times(V^{CHP}+V^{Boiler})\times\varepsilon_{gas}+ex_{CO_2}^{pow}\times E_{pow}^{CHP}\times\varepsilon_{Grid} \quad (14)$$

NUMERICAL STUDIES

To analyze the application performances of the CCHP systems for low carbon community with the CHB development, a numerical study is presented below. Different CHP solutions are evaluated and compared by using the proposed general and systematic procedure described in Section 2. In particular, different function formations and the houses for different age groups are considered, to highlight the importance of residential impact of the mixed-use and mixed-age, as well as the different technical and management options on the CHP system performances.

Research Site

In this paper, the site is located in Kitakyushu, Japan, which is a city with a typical maritime climate. Annual average temperature is about 17ºC. The hottest month

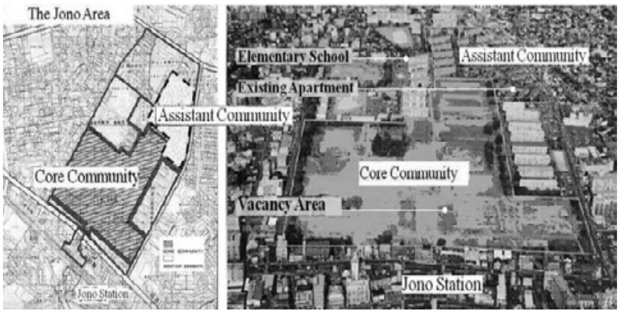

Fig. 5 Research site

Table 2 The research area and building area

Residential area	33Ha= 330,000 m²	
	18Ha=180, 000 m²	
Core community	Apartment	54 m²×860 h
	Detached House	120 m²×320 h
Assistant community	15 Ha=150, 000 m²	

occurs generally in August with a monthly average temperature of about 30ºC and the coldest month is in January, with a monthly average temperature about 7ºC (Ruan et al. 2009).

The city of Kitakyushu was selected as one of the environmental model cities in Japan and the low carbon demonstration area, Jono area, was one part of its total project. Jono area is in the northern part of Kokura, Kitakyushu, directly opposite to the Jono station (Fig.5). The low-carbon demonstration area aims to accommodate 860 families in the form of apartments and 320 families as detached houses [37]. The whole area is divided into core community and assistant community. All the newly increased households will be arranged in the core area and the latest technologies, such as the CHP, will also be introduced into this area.

In this plan, the community is developed in ten CHBs. Every CHB has two apartments (accommodated 86 families) and 32 detached houses, surrounding one open space. The site and building areas are set as Table 2.

Load Assessment

The detailed information about energy end-use loads is of vital importance for selecting the appropriate system components and corresponding operating strategies. In Japan, energy consumption in buildings is always obtained through direct on-site measurement. Some researchers also set up the database, named as energy consumption unit, which can represent the average energy consumption per area for various buildings with different functions and in different areas. In that case, the energy consumption can be estimated by multiplying the energy consumption unit by its building area. In this research, the energy loads are set according to the building area and the energy consumption unit in Kyushu area (Takao 2002; Ruan 2006).

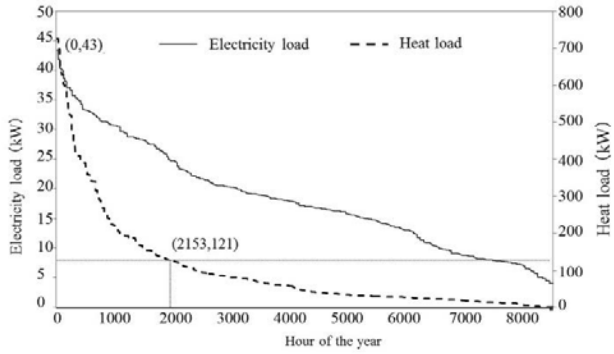

Fig. 6 Load demand and duration curves for CHB (e.g Case3)

Figure 6 shows the load demand duration curve, which reveals the characteristics of CHB's energy consumption. It illustrates the peak load demand and each demand level range with annual number of hours, which is important information in determining CHP capacity. As mentioned in Section 2, taking Case3 as an instance, for ET mode, the capacity of the prime mover can be easily determined as the peak electrical load (43 kW). In the HT mode, the capacity is determined based on the thermal duration curve. As shown in Fig. 6, based on maximizing the area below heat duration curve, the maximum heat (121 kW) from the power generation unit, and the duration time (2153h) are determined. Therefore, the CHP is set as 120kW in HT mode, Case3.

In addition, this research will discuss the CHP performance with mixed-use and the mixed residents in different ages. Therefore, the understanding of the relationship of the energy load and the CHB pattern is vital for the analysis. Figure 7 shows the typical daily energy consumption during the summer period (August), winter period (January) and the temperate season (May). Figure 7(a) represents the residential-only case; Fig.7(b) shows an example of mixed use including 30% commercial area; Fig.7(c) shows an example for mixed demographic structure, including 50% elderly residents.

From Fig.7, the characteristics of energy consumption can be described as follows:

(1) For a residential apartment (Fig.7(a)), yearly energy consumption electricity and hot water are higher than cooling and heating, which is due to the temperate climate in Kyushu. Relatively speaking, the heating period in Kyushu is longer than heating period, because of the cool weather. Therefore, the yearly heating load is higher than the yearly cooling load. Further, the hourly

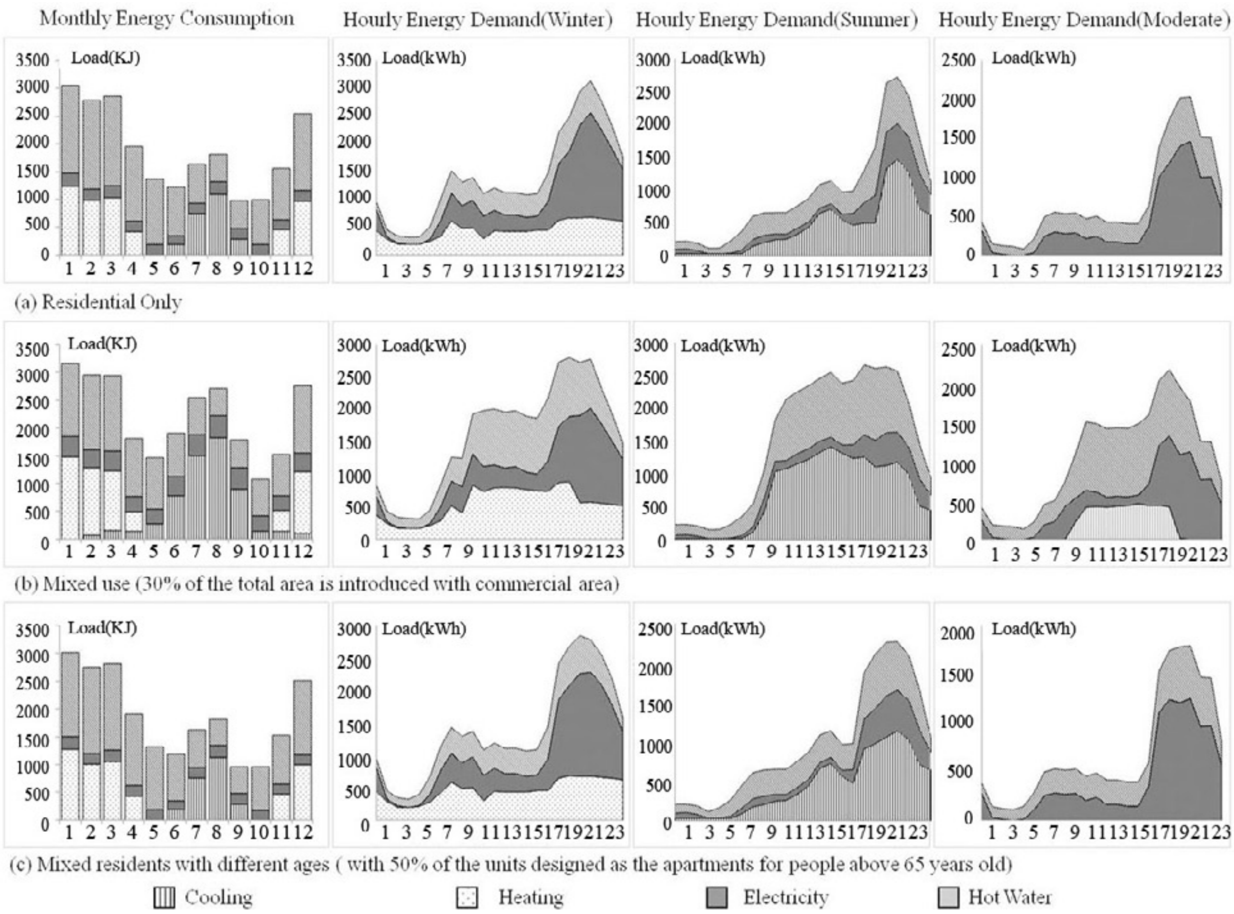

Fig. 7 Monthly and yearly energy consumption

electricity and hot water load fluctuate less than the hourly cooling. The peak period for heat and electricity load starts at about 18:00 h and continues until 23:00.

(2) Figure 7(b) includes an assumption that 30% of the apartments are converted to commercial functions. This results in higher overall energy consumption, but the hourly energy load variation is smooth out compared with residential housing (Fig.7(a)). Compared with residential building, the energy used in hot water for commercial units is relatively low and electricity usage is higher. Thus, by adding a proportion of commercial floor space, the ratio of hot water to total energy consumption is reduced.

(3) Figure 7(c) assumes that 50% of the families in the apartments are aging families. Generally speaking, the yearly electricity and hot water load of apartment for old person are lower than the usual apartment. On the other hand, the yearly heating and cooling load are higher. The peak of energy consumption for old people occurs earlier than usual family. Therefore, with the mixed age structure, the energy consumption is lower and slightly stabilized compared with the residential only pattern (Fig.7(a)).

Case Setting

Case 1–Case 3: Residence-only CHB

Case 1: (conventional urban pattern with individually using CHP). The energy systems for apartment and the detached houses are separate systems. A CHP system is introduced into the apartment part and the detached houses retain as the conventional system.

Case 2: (CHB urban pattern with CCHP, cooperative using only for hot water). Hot water pipes connect the energy systems for apartment and the detached houses. In this case, the CHP systems are only introduced into the apartment, while detached houses remain in conventional system. However, the interchanging system can transfer the surplus hot water to the detached houses.

Case 3: (CHB urban pattern with CCHP) In this case, all the apartments and houses in every CHB are connected, sharing a CHP system, which offers electricity, hot water, cooling and heating load to the housing in the block.

Case 4–Case 5: mixed pattern (with mixed function and mixed residents in different ages)

Case 4: Based on Case 3, the commercial areas are introduced into the CHB. In order to understand the

Table 3 Case setting

Case	Urban pattern	Floor area (m^2)		Cooling (GJ/kW)	Heating (GJ/kW)	Hot water (GJ/kW)	Electricity (MWh/kW)
		Apartment	Detach houses				
Base	Convention	46440(R)	38400	2675/1562	16264/6087	12627/1271	1611/434
Case1	Convention			2675/1562	16264/6087	12627/1271	1611/434
Case2	CHB			2675/1562	16264/6087	12627/1271	1611/434
Case3	CHB			2675/1562	16264/6087	12627/1271	1611/434
Case4	CHB	*(R/C) 46440/0	38400	2675/1562	16264/6087	12627/1271	1611/434
		37152/9288		8083/1849	16739/6017	12366/1119	3840/795
		27864/18576		13492/2965	17213/6199	12105/1095	5350/1369
		18576/27864		18900/4080	17687/6383	11843/1112	7220/1943
		9288/37152		24308/5194	18161/6567	11582/1130	9089/2516
		0/46440		29717/6310	18636/6751	11321/1149	10958/3090
Case5	CHB	**(R/A) 41796/4644	38400	2669/1536	16262/6088	12627/1243	1602/415
		37152/9288		2663/1536	16260/6088	12627/1216	1593/405
		32508/13932		2657/1538	16259/6089	12627/1234	1584/399
		27864/18576		2651/1538	16257/6090	12627/1265	1575/393
		23220/23220		2646/1539	16255/6090	12627/1295	1566/387

*R/C: Residential area/ Commercial area **R/A: Residential area/ Area for elderly housing

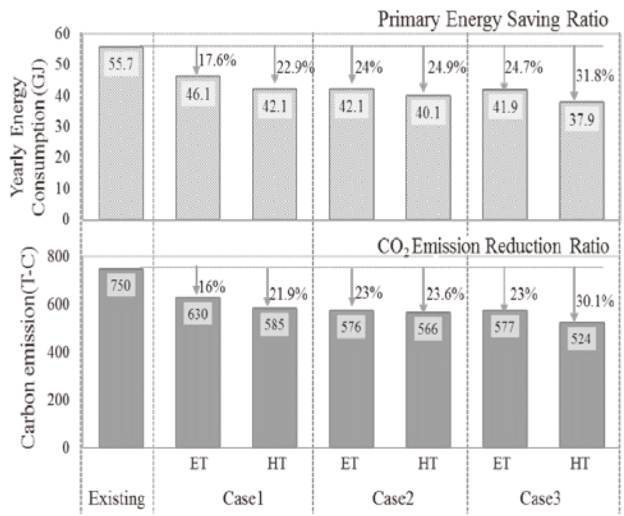

Fig. 8 Energy saving ratio and CO_2 emission reduction ratio for Cases1-3

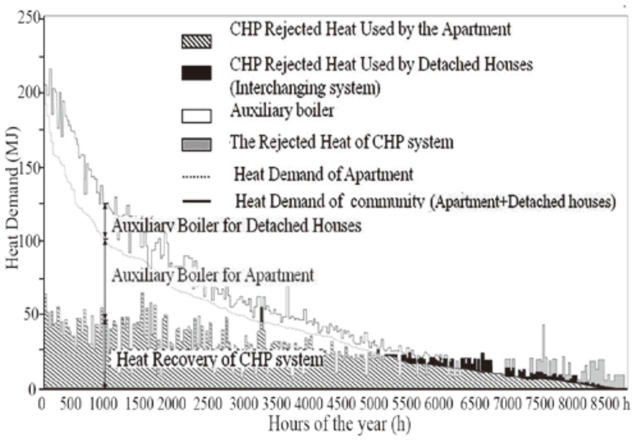

Fig. 9 The energy sharing in Case 2

effect of mixed function and get an optimal AFP, the research introduced the commercial area into the CHB. As the total building area is a constant, when the commercial area increases, the residential area reduces.

Case 5: Based on Case 3, the CHB is introduced with mixed residents in different ages. The energy consumption unit can suggest that the people in different age groups usually had a different life style, which can smooth out the energy fluctuation and help to improve the environmental performance of the CHP system. In these cases, various proportions of elderly residents are suggested to display the effect of the mixed residents and system performance deriving an optimal ASAS.

The energy consumption information of the cases is calculated and listed in Table 3.

SIMULATION RESULTS AND DISCUSSIONS

The Effect of Urban Pattern

Besides the social benefit, an important and indisputable aspect of CHB development is its cooperative energy using. In this study, different energy using patterns will be introduced into the residential only community (Case 1 - Case 3) to suggest the environmental and energy saving potential of CCHP.

Assessment of energy performance

Usually, the aspect of energy-saving of the CHP system is always considered as the most important aspect. In this study, the primary energy saving ratios for various options with different urban pattern, energy system design and management modes are calculated and illustrated in Fig.8(a). The results suggest that CCHP system can achieve higher ESR.

In Case 2, the hot water pipe line can make full use of the surplus heat of the CHP system in apartment by transferring energy to detached houses. Compared with case3, the infrastructure of the hot water pipes is lower, which makes the case more feasible from the economic aspect. The cooperative using of hot water Case 2 reduced 24% primary energy consumption in the ET mode while the individual using Case1 can only reduce 17.6%. According to our calculations, 28.4% of the CHP rejected heat from the apartment in Case1 can be reused for the detached houses. The relationship between the hourly recovery heat from CHP system and the heat demand in the district are displayed in Fig.9. However, the total amount of CHP rejected thermal energy is not so high, which limits the benefit of this system. In addition, as the cooperative using is only related to the hot water, the ESR is almost the same with the individual case. The cooperative CHP using for all kind of energy, Case 3, can achieve a higher ESR. Especially in HT mode, the ESR can reach up to 31.8% while the individual using in conventional pattern can only realize 23% (Fig.8).

Above all, from the viewpoint of energy performance, for the gas-engine based CHP energy system, the CCHP in the CHB development is a suitable option for the residential block. Among the examined design and management options, the HT mode achieves better energy performance.

Assessment of environmental performance

Environmental impact is an important factor that cannot be neglected in any energy related projects. Figure 8(b) shows the CERR values for various options. Generally, the application of the CCHP system in the CHB has almost the same environmental performance as the energy saving performance examined in previous sub-sections. To the same management mode, the cooperative using for all kinds of the energy in Case3 enjoys the best environmental performance with a CERR more than 30%, followed by cooperative use of hot water (Case 2) and the individual CHP using in conventional urban pattern. In addition, the comparison between the two running modes can tell that the HT mode results in higher CERR.

Therefore, similar to the energy performance, due to the cooperative energy use, the CHP system in the CHB is considered to be the better option for the conventional individual development. Alternatively, if the system cannot realize the cooperative use for all kinds of energy in consideration of infrastructure investment, it can take the cooperative hot water use as an intermediate step.

The Effect of Mixed Use

In CHB, the residents can design their housing at their personal will. In other words, they can develop the common open space into the commercial or other functions that they like to make some revenue. In that case, the CHB is tending to develop into a mixed residential block mixed with other functions. The energy consumption peak load comes in different time for different functions. For example, the energy consumption peak for commercial area comes during the daytime. However, for the residential area, it comes during the evening time. Further, the heat to electricity ratio of the commercial buildings is not as high as in residential buildings. Therefore, as Fig.7(b) suggests, the replacement of the commercial area can smooth out the energy fluctuation, and slightly cut the peak. On the other hand, the pattern of the function formation can affect the performance of the CHP system, which is of vital importance to determine the ratio for the mixed function. This section takes the commercial as an example, to suggest the performance of the CCHP system with mixed building function and get the optimized ratio of commercial area.

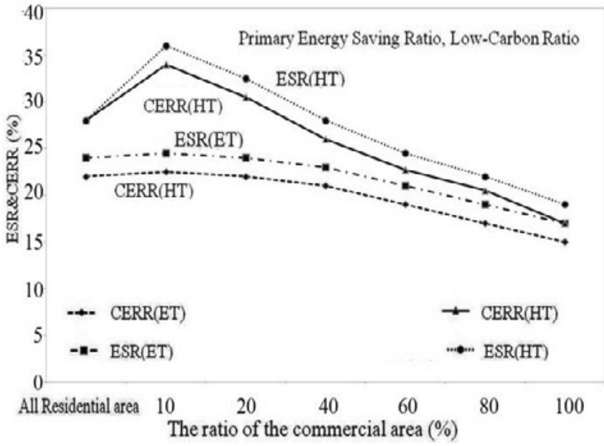

Fig.10 Energy saving ratio and CO_2 emission reduction ratio for Case 4

Figure 10 shows the ESR and CERR of Case 4. In this case, the residential area is replaced with the commercial area. Generally speaking, with the replacement of the commercial function, both the ERS and CERR increased as the increasing commercial share. When 10% of the residential area is replaced with the commercial area, the CHP system achieved the optimal performance. However, when the commercial sharing is more than 10%, the efficiency of the system will come down. The efficiency of the system is almost same when the commercial area shares 40% of the total area and even gets worse when the commercial area increase.

On the other hand, from the viewpoint of management, the HT mode is better than the ET mode. When the commercial area accounts for 10% of the total area, the efficiency of HT mode achieves 38% ERS and 34% CERR. The ET mode can only get 25% ERS and 22% CERR. However, when the commercial area increases, the difference between the HT and ET mode reduces.

In general, because of the replacement of the commercial areas, the efficiency of the CHP system increases, but too much commercial area effect is in the reverse. That means the mixed use of residential area can help to increase the energy saving and environmental performance of CHP system, but the area of other functions such as commercial use should remain in a low share. For gas engine CHP system (taking the mixed residential-commercial area as an example), the optimal ratio is around 10%. In other words, the designer should encourage the mixed use in CHB, but better control it near the optimal AFP.

The Effect for Mixed Housing Style for Different Ages

In the CHB block, even the unit in the apartment can be designed according to the lifestyle of the residents. In that case, the housing styles can be varied to meet the demand of young couple, elderly people and the family of four. From the social aspect, these kinds of mixed communities are safe to live in and have intimate neighborhood relationship. It creates a suitable living condition especially for elderly people. As Japan has now become a serious aging society, it is vitally important to discuss the CHP performance under the mixed housing style for elderly people. Therefore, as a study for usual residential area, we suppose that the aging rate of on block is no more than 50%, in consideration of the existing social age structure.

In this section, the CHP system in the CHB will be tested under the different shares for elderly housing to suggest its effect to the system performance.

From the point of energy using, different housing styles have different kinds of energy consumption pattern. Some existing researches are reported on the energy consumption for aging people in Japan (Tanaka 2008). Figure 7(c) is an example for the energy consumption curve under the mixed housing. It suggests that a mixed age structure reduces energy consumption, especially cuts off the peak load. Although the mixed housing style can smooth the energy consumption fluctuation, it’s less effective than mixed use. Figure 11 shows the comprehensive evaluation for case5:

In all, it suggests that the CHP system in CHB with the mixed housing for different age can affect the energy saving performance and the environmental performance. With the replacement of the housing for aging people, the efficiency of the CHP system improves and reaches the optimal efficiency when the housing for aging people possesses 20% of the whole building area. However, if the share keeps growing, the CHP efficiency will come down. The optimal value of the ESR is 37% and CERR is 34%.

Compared with the ET mode, the HT mode is better. However, the ET mode performs with more stability, be less affected by the increasing aging housing. Generally speaking, if the designers construct the CHB as mixed housing for different age, it can benefit the performance of CHP system. In addition, it is of vital importance for the designers to balance the share of the housing for aging people in one CHB according to the optimal ASAS.

Evaluation of Net-Zero Ratios for Various Cases

“Net-zero” energy consumption is one of the targets for this demonstration area. The ZEB concept is already perceived as a realistic solution for the mitigation of CO2 emissions and the reduction of energy use in the building sector. The R_{NZ} is an index that determines whether the community can achieve energy self-sufficiency in a dynamic view. Following the calculation method assumed in Section 2, the research listed out the R_{NZ} for cases in Fig.12. The results suggest that:

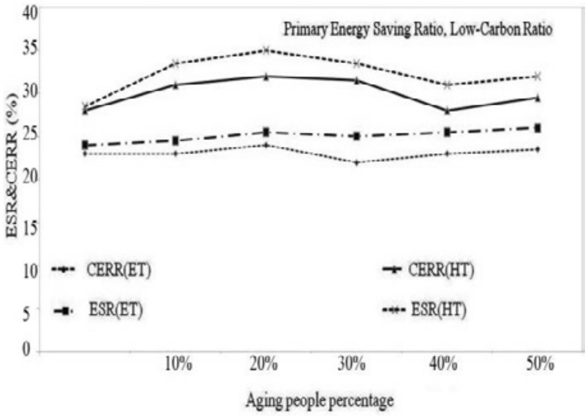

Fig.11 Energy saving ratio and CO_2 emission reduction ratio for Case5

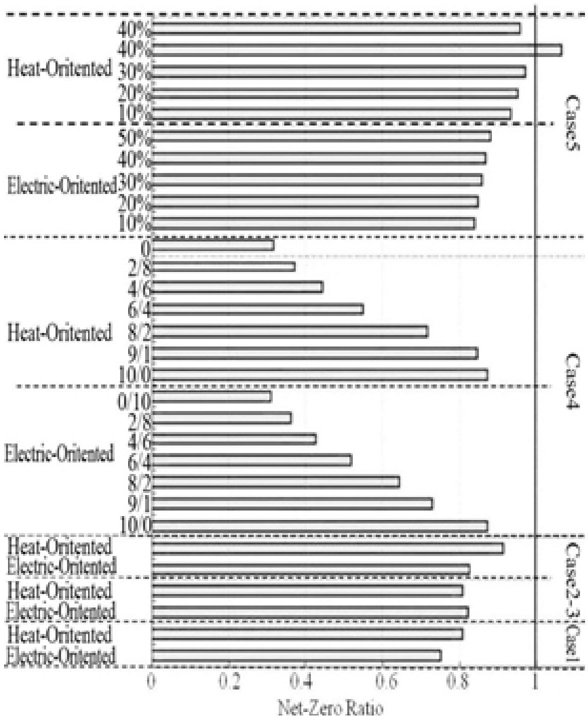

Fig. 12 Net-zero potential evaluation for cases

Generally speaking, almost all the values of are under 1. This means the net-zero community is difficult to realize under the current technology situation. From the viewpoint of urban pattern, for the residential-only community, the CCHB has greater potential to achieve “net-zero”, especially under the HT mode.

The CHB is common for the mixed use. However, the introduced functions such as the commercial and the office usually have higher energy consumption. Therefore, although the replacement of other functions in CHB can contribute to the ESR and the CERR, but it also adds to the energy consumption. As a result, the mixed use design pattern in CHB is difficult to achieve a “net-zero” outcome either in HT mode or in ET mode.

The scenario with a proportion of elderly residents not only improves the environmental performance, but also lowers the energy consumption of the total area. Therefore the CHB that has mixed housing style (taking the housing for elderly people as an example) is near one, which suggests the possibility of “net-zero” community. Especially, when 40% of the housing is substituted for elderly housing, the community can realize the “net-zero” energy consumption under the HT mode. In another word, the mixed housing design pattern in CHB, in consideration of the lifestyle, not only can contribute to the ESR and CERR, but also to “net-zero”. In addition, in this pattern, the HT mode is better than ET mode in consideration of “net-zero”.

Generally, under the current technologies, the “net-zero” community is not easy to realize. The CHB design pattern, which encourages the cooperative energy use between the buildings, can contribute to the “net-zero”, especially in the HT mode. From the view of the “net-zero”, the CHB with the mixed housing style by considering the life style is more efficient than the mixed use.

CONCLUSIONS

This study proposes a CCHP model within CHB pattern, the housing development pattern that has become popular in Japan recently. One innovation is that the study shed light on the relationship of the urban design pattern and the energy using effect, proposed general and systematic procedure suitable for the energy, environmental and net-zero assessment of the CHP system, considering various design and management modes. Further, the research discusses two features in the CHB : the mixed use for buildings with various functions and mixed housing styles for people in different age groups. Their effects to the CCHP system are also assessed. The research chooses the low carbon demonstration community in Kitakyushu as a case study, executing the urban design pattern and the energy using model. Various scenarios are examined as a means of optimizing a proposed CHP system by variations in the urban pattern, operating mode, AFP and ASAS in consideration of the lifestyle. According to the results, the following conclusions can be deduced:

(1) In the residential-only community, under the conventional city development pattern, the individual CHP systems can make sense to the energy saving and carbon emission reduction, but the effect is not so obvious, especially under the electricity tracking mode. The comparison studies between the individual CHP system and CCHP can suggest that the CCHP system in the CHB development has better energy saving performance and environmental performance, especially under the HT mode. From the urban design view, the CHB pattern is better for distributed energy use.

(2) The CHB block can be designed into a mixed use residential community, according to the composition of residents. This characteristic can help to increase the energy and environmental performance of the CCHP system, but should remain in a limited commercial share (the optimal share is around 10%). Then efficiency of the system gets worse than the residential-only area when the commercial share surpass 40%. In another word, the urban planner should consider the mixed use in CHB, and the optimal commercial share is around 10% but no more than 40% in consideration of the distributed energy use.

(3) From the social aspect, the CHB constructed a comfortable living environment for aging people, sharing the life with other people with different ages. This kind of mixed age structure can also make benefit to the energy and environmental performance of CCHP system, the optimal share is around 20%. That means both the urban planner and engineers should consider the life style of the residents in different ages to construct a CHB with optimal ASAS, offering a better living environment for aging society.

(4) Even with the CCHP system, under the current technologies, the “net-zero” community is not easy to realize. The CHB design pattern, which encourages the cooperative energy use between the buildings, can contribute to the “net-zero”, especially in the HT mode. From the view of the “net-zero”, the CHB with the mixed housing style by considering the life style is more efficient than the mixed use.

Of course, the numerical results obtained in the case study cannot be generalized to other CHP systems. However, the conceptual exploration of the results has provided a useful indication of the type of CCHP solution relevant to urban pattern, AFP, ASAS design and management strategies. In the following studies, the assessment procedure presented in this study is expected to be used to other CHP prime movers, so that the feasibility of CCHP system can be examined in a more comprehensive way. In addition, the CCHP system will be assessed from the economic aspect, which is also important for the application of CHP system. In this way, an integrated assessment of the CCHP system can be realized from energy, environmental and economic performance.

REFERENCES

Bhata, C. and Guob. J. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transportation Res. Part B: Methodological, June 2007, 41(5):506-526.

Boait, P., Rylatt, R. and Stokes, M. (2006). Optimisation of consumer benefits from micro combined heat and power. Energy and Buildings, 38:981-987.

Cardona, E. and Piacentino, A. (2003). A methodology for sizing a trigeneration plant in mediterranean areas. Appl. Thermal Engrg., 23(13):1665-1680.

Clapham, D. (2012). Cooperative Housing/Ownership. International Encyclopedia of Housing and Home:243-247.

Evans, R. (1993). Environmental and economic implications of small-scale CHP. Energy Policy, January 1993, 21(1):79-91.

Fumika, N., Yasuhiro, F. and Kazuoki, O. (2010). A Study on the continuity of elderly living in old co-operative houses. Architectural Inst. of Japan, F-1, Urban Plann., ISSN:1341-4534, 2010-07-20:1491-1494, http://ci.nii.ac.jp/naid/110008113331/en/

Gu, Q., Ren, H., Gao, W. and Ren, J. (2012). Integrated assessment of combined cooling heating and power systems under different design and management options for residential buildings in Shanghai. Energy and Buildings, August 2012, 51:143-152.

Haeseldonckx, D., Peeters, L., Helsen, L. and Haeseleer, W. (2007). The impact of thermal storage on the operational behaviour of residential CHP facilities and the over-all CO_2 emissions. Renewable and Sustainable Energy Reviews, 11(6):1227-1243.

Hiroyuki, I., Shin-ichi, A. and Jun, S. (2011). Study on the energy consumption and CO_2 emissions intended for all electrification house and gas using house: Part 3, comparison between household-use, fuel cell using house and the two houses. Architectural Inst. of Japan, ISSN:0385-9622/0385-9622, 2011-07-10:259-262.

Kimijima, S. and Kasagi, N. (2002). Current status and perspective of micro gas turbine and distributed energy system. Design Engrg., 38(8):367-374.

Lau, L., Tan, K., Lee, K. and Mohamed, A. (2009). A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol. Energy Policy, 37:4771-4778.

Li, C., Gu, J. and Huang, X. (2008). Influence of energy demands ratio on the optimal facility scheme and feasibility of BCHP system. Energy and Buildings, 40(10):1876-1882.

Marszal, A., Heiselberg, P., Bourrelle, J., Musall, E., Voss, K., Sartori, I. and Napolitano, A. (2011). Zero energy building – A review of definitions and calculation methodologies. Energy and Buildings, April 2011, 43(4):971-979.

Matallanas, E., Castillo-Cagigal, M., Gutiérrez, A., Monasterio-Huelin, F., Masa, E. and Jiménez-Leube, J. (2012). Neural network controller for active demand-side danagement with PV energy in the residential sector. Appl. Energy, March 2012, 91(1):90-97.

Matsuoka, R. and Kaplan, R. (2008). People needs in the urban landscape: Analysis of landscape and urban planning contributions. Landscape and Urban Plann., 84:7-19.

Mehleri, E., Sarimveis, H., Markatos, N. and Papageorgiou. L. (2013). Optimal design and operation of distributed energy systems: Application to Greek residential sector. Renewable Energy, March 2013, 51:331-342.

Plan for a Low Carbon Demonstration Area in JOYNO, Kitakyushu Government (2009). 2009.5.

Ren, H. (2007). Effect of carbon tax and electricity buy-back on the optimal economic adoption of PV system for residential buildings. J. Environ. Engrg., December, 2007, AIJ., 622:49-55.

Ren, H., Gao, W. and Ran, Y. (2009). Economic optimization and sensitivity analysis of photovoltaic system in residential buildings. Renewable Energy, March 2009, 34(3):883-889.

Ren, H., Gao, W. and Ran, Y. (2008). Optimal sizing for residential CHP system. Appl. Thermal Engrg., 28:514-523.

Ruan, Y. (2009). Integeration study on distributed energy resource and distribution system. J. Environ. Engrg., 2009-06, AIJ , 640:745-752.

Ruan, Y. (2006). Integration Study on distributed Energy Resource and Distribution System. Ph.D. Thesis, The University of Kitakyushu.

Ruan, Y., Liu, Q., Zhou, W., Firestone, R., Gao, W. and Watanabe, T. (2009). Optimal option of distributed generation technologies for various commercial buildings. Appl. Energy, 86:1641-1653.

Sadineni, S., Atallah, F. and Boehm, R. (2012). Impact of roof integrated PV orientation on the residential electricity peak demand. Appl. Energy, April 2012, 92:204-210.

Sartori, I., Napolitano, A. and Voss, K. (2012). Net zero energy buildings: A consistent definition framework. Energy and Buildings, 48:220-232.

Satomi, K. (2005). A study on dwelling process of the cooperative house in a period of 20 years: In the case of cooperative house Deneb in Toyonaka. Architectural Inst. of Japan, 2005-07-31, ISSN: 1341-4526, E-2:139-140, ,

Seth, B. and Alisha, F, (2012). Ready or not, here comes the smart grid. Energy, January 2012, 37(1):61-68.

Shaneb, O., Coates, G. and Taylor, P. (2011). Sizing of residential μCHP systems. Energy and Buildings, 23(8):1991-2001.

Sollia, C., Anantharaman, R., Strømmana, A.H., Zhanga, X. and Hertwicha, E. (2009). Evaluation of different CHP options for refinery integration in the context of a low carbon future. Intl. J. Greenhouse Gas Control, March 2009, 3(2):152-160.

Takao, K. (2002). Natural Gas Cogeneration Plan/Design Manual 2002. Japan Industrial Publishing Co., Ltd., Tokyo, 2002.

Tanaka, A. (2008). Attribution analyses of family area and of household energy use and its future prediction. J. Environ. Engrg., June 2008, AIJ, Nov.628, l73:823-830.

Tascikaraoglu, A., Uzunoglu, M., Vural, B. and Erdinc, O. (2011). Power quality assessment of wind turbines and comparison with conventional legal regulations: A case study in Turkey. Appl. Energy, May 2011, 88(5):1864-1872.

The Ministry of the Environment, Japan (2010). Japan's National Greenhouse Gas Emissions, FY-2010, http://www.nies.go.jp/whatsnew/2011/20111213/20111213-e.html, 2011.

The Ministry of the Environment, Japan. (2011). Japan's National Greenhouse Gas Emissions in Fiscal Year 2011, http://www.env.go.jp/en/headline/headline.php?serial=1935,2013.

Tu, K. and Lin, L. (2008). Evaluative structure of perceived residential environment quality in high-density and mixed-use urban settings: An exploratory study on Taipei City. Landscape and Urban Plann., 87:157-171.

Wang, J., Jing, Y. and Zhang, C. (2010). Optimization of capacity and operation for CCHP system by genetic algorithm. Appl. Energy, 87(4):1325-1335.

Yamaguchi, Y., Shimoda, Y. and Mizuno.M. (2007a). Transition to a sustainable urban energy system from a long-term perspective: Case study in a Japanese business district. Energy and Buildings, January 2007, 39(1):1-12.

Yamaguchi, Y., Shimoda, Y. and Mizuno.M. (2007b). Proposal of a modeling approach considering urban form for evaluation of city level energy management. Energy and Buildings, 39:580-592.

Yang, Y. and Gao, W. (2007). Economic optimization model for operation of distributed energy system and case study on Kitakyushu science and research park in Japan. J. Environ. Engrg., 2009-11-30, AIJ, 621:77-82.