Study on Low Carbon Energy Supply to the District Heating & Cooling Plants and Buildings with a Waste Heat Pipeline in Yokohama City

Toru Ichikawa[1,*], Ryota Kuzuki[1], Satoshi Yoshida[2], Satoru Sadohara[2]

[1] *Tokyo Gas Co., Tokyo, Japan*
[2] *Yokohama National University, Yokohama, Japan*
** Tel: +81 354007761, Fax: +81 354007766, E-mail: toithi@tokyo-gas.co.jp*

Abstract: District heating and cooling (DHC) in Japan's major cities are required to further lower their carbon emission. This study proposes to supply zero-carbon steam from a nearby waste incineration plant to the DHCs in the center of Yokohama, Japan's second largest metropolis by constructing a pipeline between them. To maximize environmental effects of the project, efficient cogenerations will also be integrated extending low carbon heat supply to large buildings along the pipeline. Construction cost of five alternative pipeline routes, revenue from steam sales and the environmental value of reduced CO_2 emission were estimated. Then the loan repayment period was calculated to figure out how to finance and manage the project. Because statistical data are used to calculate heat load, actual primary energy consumption and reduction of CO_2 emission may differ. Also, without a detailed field survey, assumed construction cost may not correspond to the actual amount to be financed. From the study it became clear that steam pipeline with cogeneration will reduce 3.6 PJ of primary energy use and 300,000 tons of CO_2 emission annually. The project will become feasible with loan repayment period of 8 and 10 years with and without subsidy by minimizing the construction cost.

Keywords: *district heating and cooling, low carbon, waste heat, CO_2 emission, steam pipeline*

1. Introduction

District heating and cooling (DHC) has been introduced to Japan's major cities from 1970s achieving efficient and reliable supply of energy compared to the installation of small appliances to the individual building. However, additional effort is being required to further lower the carbon emission nowadays. This study proposes to supply zero-carbon steam from a nearby waste incineration plant to the center of Yokohama, Japan's second largest metropolis, by constructing a pipeline between them. Environmental and economic benefits of the project have been examined in order to evaluate its feasibility.

1.1 Site review

Yokohama city center is one of most densely built up metropolis in Japan with good access to public transportation. Because density of energy consumption in the area is high, a few district heating and cooling plants are already in operation and most of the blocks have been assigned for urban renewal promotion area. Therefore it is easy to recognize that the area has a good potential of providing necessary heat more efficiently by networking the supply pipeline. If these networks are connected to the untapped low carbon heat sources, the entire city can reduce its energy use and CO_2 emission dramatically. This is why the study proposes to transport zero-emission heat source from a nearby waste incineration plant to two DHC plants and buildings in Yokohama city center. Following are the outline of the DHC plants.

1.1.1 Yokohama West DHC

It Started operation in 1998 with 6.5 hector of supplying land area and 350,152m^2 total floor area. Customers include department stores, hotels and a train station. Chilled water and middle pressure steam (0.8 – 1.0 MPa) are supplied by absorption chillers, boilers and two 1MW gas turbine cogenerations.

1.1.2 Minato Mirai 21 DHC

It Started operation in 1989 with total supplying floor area of 2,311,000 m^2 as of 2008. Major customers include 23 office and commercial buildings, hotels, public facilities and 6 apartments. Chilled water and middle pressure steam are produced by steam and electric turbo chillers, absorption chillers as well as boilers and delivered through utility tunnels.

2. Steam network pipeline

Besides above DHCs, the network will be extended to the separate buildings by to the following stages.
Stage 0: Waste incineration plant and DHCs are connected by a steam pipeline
Stage 1: Buildings over 10,000m^2 of floor area are connected to the pipeline
Stage 2: Buildings over 5,000m^2 of floor area are connected to the pipeline
Extension of pipeline will be planned by the distribution of the buildings (Fig.1). Because DHCs and most of the buildings use middle pressure steam as major heat sources for space heating, hot water supply and air conditioning (cooling), the network will deliver steam (up to 2.0 MPa) to them.

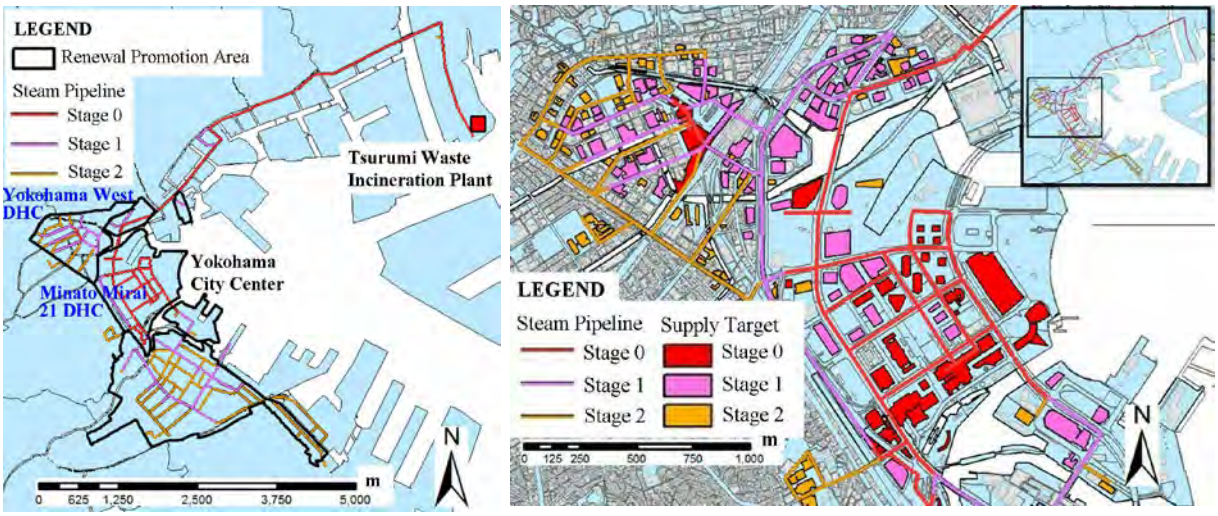

Fig. 1. Site map, steam pipeline and target buildings in Yokohama city center

2.1 Assumed heat supplying floor area by stage

Assumed floor area for supplying heat is 2,430,000m^2 at stage 0, 8,530,000m^2 at stage 1 and 10,620,000m^2 at stage 2. As for floor type shares, business, commercial and residential use rank top three with 36%, 33% and 19% of the total floor area respectively.

2.2 Assumed energy consumption

By multiplying assumed floor area and statistical unit energy consumption [1], energy consumption by purpose were calculated by hour, day, month and year. Because business and commercial floors with huge exhaust heat from appliances and human bodies prevail, annual cooling demand exceeds heating by about 50%.

3. Use of low carbon heat from waste incineration and cogeneration

3.1 Available heat from waste incineration

Three waste incineration plants are in operation in the vicinity of Yokohama city center. They are Kanazawa, Tsurumi and Asahi plants with 290, 270 and 120 thousand tons of annual handling amounts. These plants are equipped with total capacity of 66,000 kW of generators

which produce 293GWh of electricity annually. These generators, however, have low efficiency ranging from 13 – 18% because of the temperature restriction to avoid corrosion of the equipment. Therefore the study proposes among other options to halt generation and to supply entire amount of available heat to the city center by steam pipeline. This alternative will enable the plants to send 5,243 TJ of heat to the city center. (Table 1)

Table 1. Garbage Incinaration Plants nearby Yokohama City center

Plant Name	Handling Amount (t/year)	Generation Capacity (kW)	Generation Efficiency (%)	Generated Electricity (MWh/year)	Garbage Calorific Value (kcal/kg)	Incinerated Heat Value (TJ/Year)	Available Steam (TJ/Year)
Kanazawa	289,187	35,000	18	144,660	2,468	2998	2098
Tsurumi	266,640	22,000	16	107,181	2,838	3178	2225
Asahi	125,631	9,000	13	41,199	2,492	1315	920

Considering heat demand gap among seasons and daily hours, it is necessary to set appropriate supply capacity according to the base demand in order to avoid excess heat supply. Therefore the study cases accept steam only from the Tsurumi incineration plant with shorter pipeline to be built than with other plants. Assumed amount of heat to be supplied from Tsurumi is 2,225TJ/year.

3.2 Covered rate and used steam rate

Efficiency of steam driven appliances such as absorption chillers are determined to calculate demand of steam to be supplied by the network. Then the ratio of network steam to the demand is defined as “covered rate”. Also, the ratio of the used steam to its supply is defined as “used steam rate”. Both rates are calculated annually and monthly (Tables 2 and 3).

Table 2. Covered rate and steam share (Annual)

	Heat Demand (TJ/year)	Available Steam (TJ/year)	Usable Steam (TJ/year)	Covered Rate (%)	Used Steam Rate (%)
Stage 0	1,702	2,225	1,690	99%	76%
Stage 1	5,872	2,225	2,225	38%	100%

Table 3. Covered rate and steam share (Monthly)

	April		August		January	
	Covered Rate (%)	Used Steam Rate (%)	Covered Rate (%)	Used Steam Rate (%)	Covered Rate (%)	Used Steam Rate (%)
Stage 0	100%	53%	94%	100%	100%	96%
Stage 1	60%	100%	26%	100%	31%	100%

Annual covered rate of Tsurumi plant is about 100% at stage 0, while it drops to 38% at stage 1. Looking by season, at stage 1, covered rate decreases to 26% in August while it increases to

60% in April, a off-peak month. With heat storage during night hours, used steam rates reach 100% at stage 1. Hourly heat demand and supply from three waste incineration plants are shown in Fig.2. During daytime hours network steam is not sufficient to meet the heat demand.

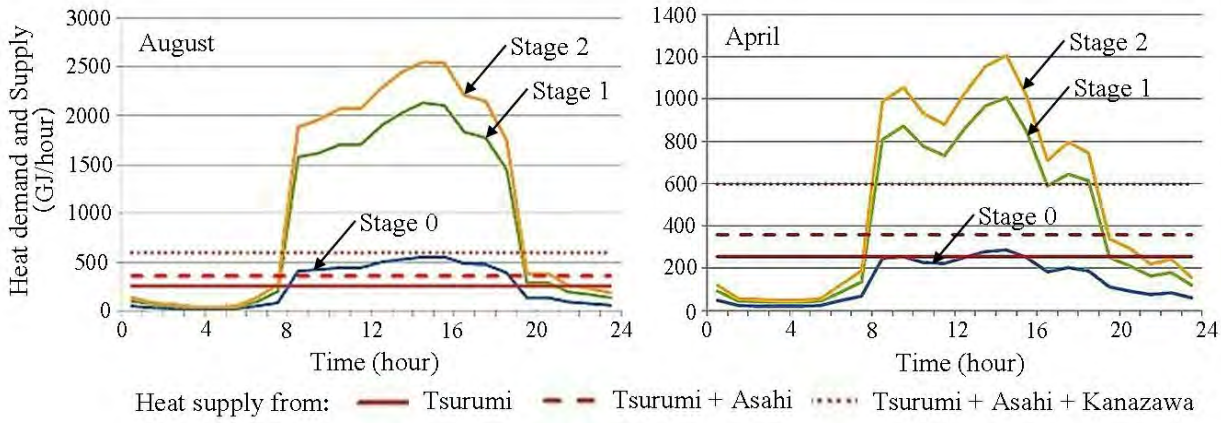

Fig. 2. Heat demand and supply from three waste incineration plants

3.3 Integrating cogeneration

Since daytime heat demand exceeds amount of steam supplied from Tsurumi throughout a year, it is appropriate to install and integrate cogenerations in the DHC plants and buildings along the network. To maximize the CO_2 reduction, gas engines with high generating efficiency and steam recovery capability from exhaust heat should be introduced instead of gas turbines. Capacities of gas engines were set so that they can meet most of the remaining steam demand at each stage. Covered rates will significantly increase by integrating cogeneration into the network.

4. Environmental effects expected by the network

Primary energy conservation and CO2 emission reduction by the network are calculated with following assumption.

4.1 Assumed condition for calculation

a) Priority of network steam use are: Cooling > Hot water supply > heating
b) Cogenerations operate to meet the electricity demand of the plants and buildings where they are installed. Priority of recovered steam use is same as a).
c) Chilled and hot water produced from excess steam during night hours are stored and used during daytime hours. Some steam accumulators, widely used in the factories, will be used too.
d) Marginal CO_2 emission factor is used for generated electricity by cogeneration. Flat emission factor is used for consumed electricity in the DHC plants and buildings as well as generated electricity at waste incineration plants.
e) Following alterative use of heat produced from waste incineration are compared
Case 0: discharged with no heat use
Case 1: exclusively used for electricity generation
Case 2: exclusively used for steam supply through network
Case 3: exclusively used for steam supply through network with cogeneration in buildings

4.2 Results

4.2.1 Energy conservation

At stage 0, primary energy conservation rate will be doubled from 18% to 35% by switching from electricity generation to steam supply. Also, if cogeneration is integrated in case 3, 3,616 TJ/year or 15% primary energy reduction will be attained at stage 2 compared to case 1 (Table 4).

4.2.2 Reduction in CO_2 emission

At stage 0, reduction in CO_2 emission will increase by 33% from 73,955 tons/year to 98,412 tons/year by switching from generation to network steam supply. By integrating cogeneration into the system, reduction will be increased by 36% or 252,595 tons/year at stage 1 and by 35% or 298,906 tons/year at stage 2 compared to case 1 (Table 4).

Table 4. Environmenal effects of the pipeline

		Stage 0				Stage 1				Stage 2			
		Case 0	Case 1	Case 2	Case 3	Case 0	Case 1	Case 2	Case 3	Case 0	Case 1	Case 2	Case 3
Primary Energy Consumption	(TJ/year)	5,776	4,723	3,765		20,869	19,815	18,630	16,621	25,144	24,091	22,927	20,474
Primary Energy Reduction	(TJ/year)		1,054	2,012			1,054	2,239	4,248		1,054	2,217	4,670
Primary Energy Reduction Rate	(%)		18	35			5	11	20		4	9	19
CO_2 Emission	(t-CO_2/year)	216,340	142,385	118,197		776,137	702,182	672,991	449,587	937,389	863,434	835,597	564,528
CO_2 Emission Reduction	(t-CO_2/year)		73,955	98,412			73,955	103,146	326,551		73,955	101,792	372,861
CO_2 Emission Reduction Rate	(%)		34	45			10	13	42		8	11	40

5. Business scheme and feasibility

5.1 Pipeline route alternative

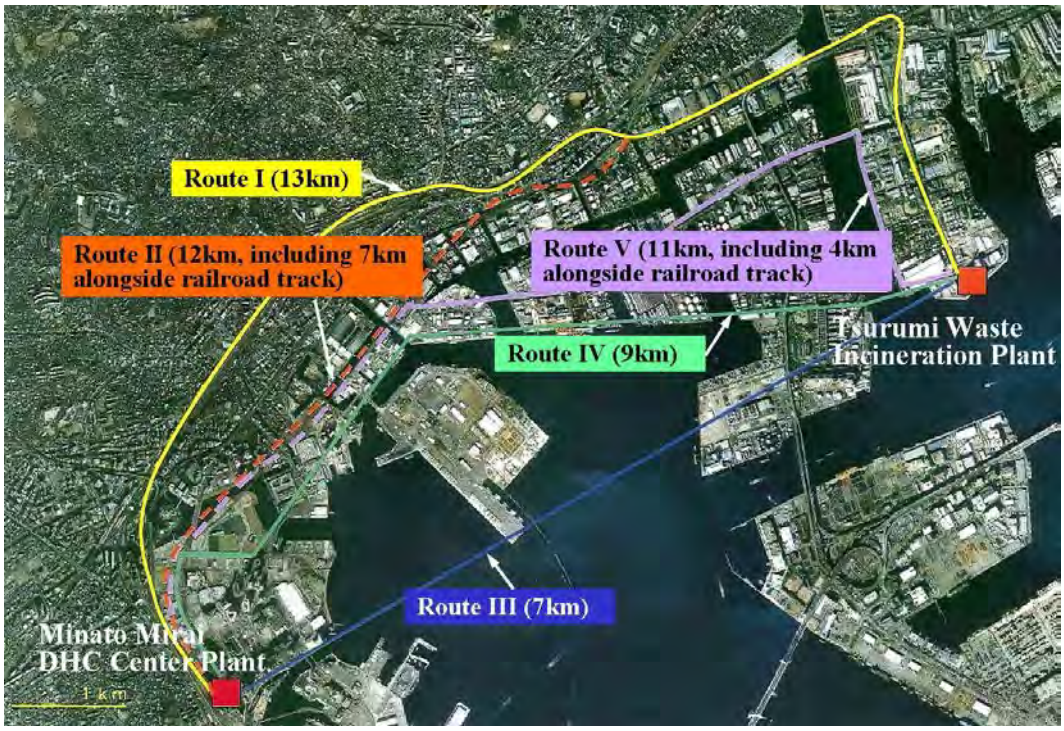

Fig. 3. Steam pipeline route study

Following alternative routes were proposed (Fig 3) and reviewed for case studies.

a) Route I: Laying pipes shallow underground along existing road (length: 13km)
b) Route II: Laying pipes shallow underground along existing road and railroad track (length: 12km)
c) Route III: Laying pipes deep undersea by excavating a tunnel (length 7km)
d) Route IV: Laying pipes under or over the private land on the waterfront (length 9km)
e) Route V: Laying pipes either under or over the green belt along the railroad track (length11km)

5.2 Assumptions for calculation

Costs and Prices in Japanese Yen are also converted to US dollars/cents using the rate of 1$US=82 yen as of February 4, 2011 and shown in parentheses.

a) Available amount of steam from Tsurumi Plant: 2,225 TJ/year
b) Acceptable amount of steam at DHCs and buildings: 1,690 TJ/year (Stage 0), 2,225 TJ/year (Stage 1)
c) Steam pricing: purchase price is set at 0.6 yen (0.73 cent) /MJ [2], 0.3 yen (0.37 cent)/MJ less than the base price assuming burning gas, wholesale price is set at 1.45 yen (1.77 cent)/MJ and 1.6 yen (1.95 cent)/MJ [3] assuming entire or a half of the surplus from the base price is to be refunded to the steam buyers respectively.
d) CO_2 emission reduction 24,188 tons/year for stage 0, and 252,595 tons/year for stage 1
e) Steam pipe size: 400 - 500mm in diameter for supply and 100- 150 mm for return
f) Construction cost [4]
   Route I : 1,500,000 yen ($18,293)/m for underground shallow plumbing along conventional road
   Route II : 800,000 yen ($9,756)/m for overground plumbing beside railroad track, 1,500,000 yen ($18,293)/m for u shallow underground plumbing along the conventional road
   Route III: 2,000,000 yen ($24,390)/m for undersea shielded tunnel construction and plumbing
   Route IV: 1,200,000 yen ($14,634)/m average for plumbing under and over the private land
   Route V: 800,000 yen ($9,756)/m for plumbing under or over the green belt along the railroad track
g) Subsidy: none (Case A), 1/3 of construction cost (Case B) parallel to the ongoing subsidy by the Ministry of Land Transportation and Tourism
h) Carbon credit: 2000 yen ($24)/t-$CO_2$ or 3000 yen ($37)/t-$CO_2$ credit added to the revenue
i) Managing expenditure
   - personnel cost: 6 million yen ($73,171)/year each for 4 operators, 8 million yen ($97,561) /year for a concu-
     rrent manager
   - road occupancy fee: 2,000 yen ($24)/m year
   - pipeline management cost: 1% of the construction cost each year
   - overhead expenses: 10% of personnel cost
   - depreciation period: 30 years with remaining book value of 10%

5.3 Business scheme

Following alternative are assumed.

a) PFI (Private Finance Initiative): Yokohama municipal government sells steam to a PFI enterprise. It will construct the pipeline, transport and sell the steam to its customers.
b) Private enterprise: Private companies will construct the pipeline by an open bid. They will also buy steam from Yokohama municipal government and sell to its customers.

c) A joint venture company: Yokohama municipal government and private enterprises cooperate to establish a so-called "third-party company" to construct the pipeline and operate the business.

5.4 Specifications of the business

a) Construction cost:
Route I (shallow underground): 19,500 million yen ($238 million)
Route II (overground and shallow underground): 13,100 million yen ($160 million)
Route III (deep undersea): 14,000 million yen ($171 million)
Route IV (underground and overground) 10,800 million yen ($132 million)
Route V (shallow underground and overground) 8,800 million yen ($107 million)
b) Terms of construction: Three years for connecting Tsurumi plant and two DHCs after start of construction at stage 0, another 2 to 3 years for connecting to the buildings at stage 1
c) Funding: 70% of the loan to be raised by senior bonds with an interest rate of 3 or 4%, 30% by subordinated bonds with an interest rate of 5 or 6%.
d) Insurance premium: 0.25% of the construction cost to be budgeted
e) Property tax: 1.4% of the opening book value can be exempted for the BTO (Build-Transfer-Operate) case of the PFI scheme

5.5 Results

Based on the basic case with relatively strict conditions, business feasibility under various conditions are compared. Loan repayment period will be extended to 24 years from 17 years without subsidy suggesting its availability will give a significant impact to the feasibility of the project.

5.5.1 Basic and Alternative cases

a) Routes: Loan repayment period will significantly shorten with reduction in construction cost. 17 years for the basic case (Route I) will be shortened by half to 9 years for Route IV and 8 years for Route V.
b) Steam price: Loan repayment period will shorten by three years to 14 yeas if a half of 0.3 yen (0.37 cent)/MJ surplus obtained by the steam purchase from Tsurumi plant is reserved for the enterprise rather than giving all out to the end users
c) Carbon credit: Loan repayment period will shorten by one year if the carbon credit price will be increased from 2,000 yen ($24)/t-$CO_2$ to 3,000 yen ($37)/t-$CO_2$.
d) Subsidy: Loan repayment period will be extended to 24 years without subsidy. However, even in that case, retained earnings which is a sum of the profit after tax and depreciation will be kept in black suggesting it is possible to run the business if long-term loan can be raised at a low interest rate.
e) Property tax: BTO case of the PFI scheme, in which the pipeline and facilities will be transferred to the Yokohama municipal government after completion, property tax will be exempted shortening the loan repayment period by three years.
f) Interest rate: Loan repayment period will be extended by one year if the interest rate of both senior and subordinated bonds increase to 4 and 6%.
g) Schedule: Even if the start of operation for stage 1 is extended from 2 to 3 years after the completion of stage 0, loan repayment period will not change significantly.
h) Surplus: No significant effect will be expected by investing surplus with 3% annual gain.
All above alternative are listed in Table 5.

Table 5. Loan repayment period for basic and alternative cases

Condition Loan Payback Period	Deteriorating Cases	**Basic Case**	Improving Cases			
Route/Construction Cost（million Yen）		I/ 19,500 17years	II/ 13,100 11years	III/ 14,000 12years	IV/ 10,800 9years	V/ 8,800 8years
Steam sales price（Yen/MJ）		1.45 17years	1.6 14years			
Carbon credit（Yen/t-CO2）	None 19years	2,000 17years	3,000 16years			
Subsidy ratio to the construction cost	None 24years	1/3 17years				
Property tax on the opening book value		1.4% 17years	None 14years			
Interest rates of senior and subordinated bonds	4%,6% 18years	3%,5% 17years				
Stage 1 operation start (after stage 0 completion)	3years 17years	2years 17years				
Interest rate of surplus investment (%)		None 17years	3% 16years			

Currency rate: 1$US=82yen as of February 4, 2011

5.5.2 Combination of alternative cases

If most of the favorable alternative are applied together, loan repayment period will be shortened to 8 years. In that case, even without subsidy, the project will retain its profitability with loan payback period of 10 years.

6. Conclusions

A steam pipeline network is planned to transport zero-emission heat from Tsurumi waste incineration plant to the Yokohama city center. The study made it clear that by integrating cogeneration into the network, 3.6PJ or 15% of primary energy reduction as well as reduction of 300,000 tons of CO_2 emission will be achieved annually for the district heating plants and buildings over 5,000m^2 of floor area. The network will be able to provide inexpensive carbon-free heat with loan payback period of only 8 to 10 years by lowering the construction cost with an appropriate pipeline route selection. However, following limitations must be stated on the accuracy of above conclusions: (a) Because statistical data such as energy consumption by unit floor area are used instead of measured data to calculate heat load, actual primary energy reduction and reduction in CO_2 emission may decrease; (b) Without a field survey, assumed construction cost may not correspond to the actual amount to be financed, which may affect the feasibility of the project. These limitations should be cleared in a more detailed study to be followed.

References

[1] Japan District Heating & Cooling Assication, District Heating Technology Guide (Rrevised Edition) , 2002
[2] Tokyo's 23 Wards Cleaning Association, Working Report of the Waste Incineration Plants in FY 2009, 2010
[3] The Japan Heat Service Utilities Association, Heat Supply Business Handbook, 2009
[4] Japan District Heating & Cooling Assication, Feasibility Studies of Exhaust Heat Utilization from Waste Incineration plants in Central Tokyo District, 2010
[5] Japan Environmental Systems Co., Basic Research on the Improvement of Urban Thermal Environment by the Reduction of Anthropogenic Heat Disposal, 2009
[6] Japan District Heating & Cooling Association, Research on the Application of Untapped High-temperature Energy Sources in Japan's Metropolis, 2010