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ENERGY FOR THE FUTURE

TOHOKU UNIVERSITY

Design of the district heating system based on the heat density map

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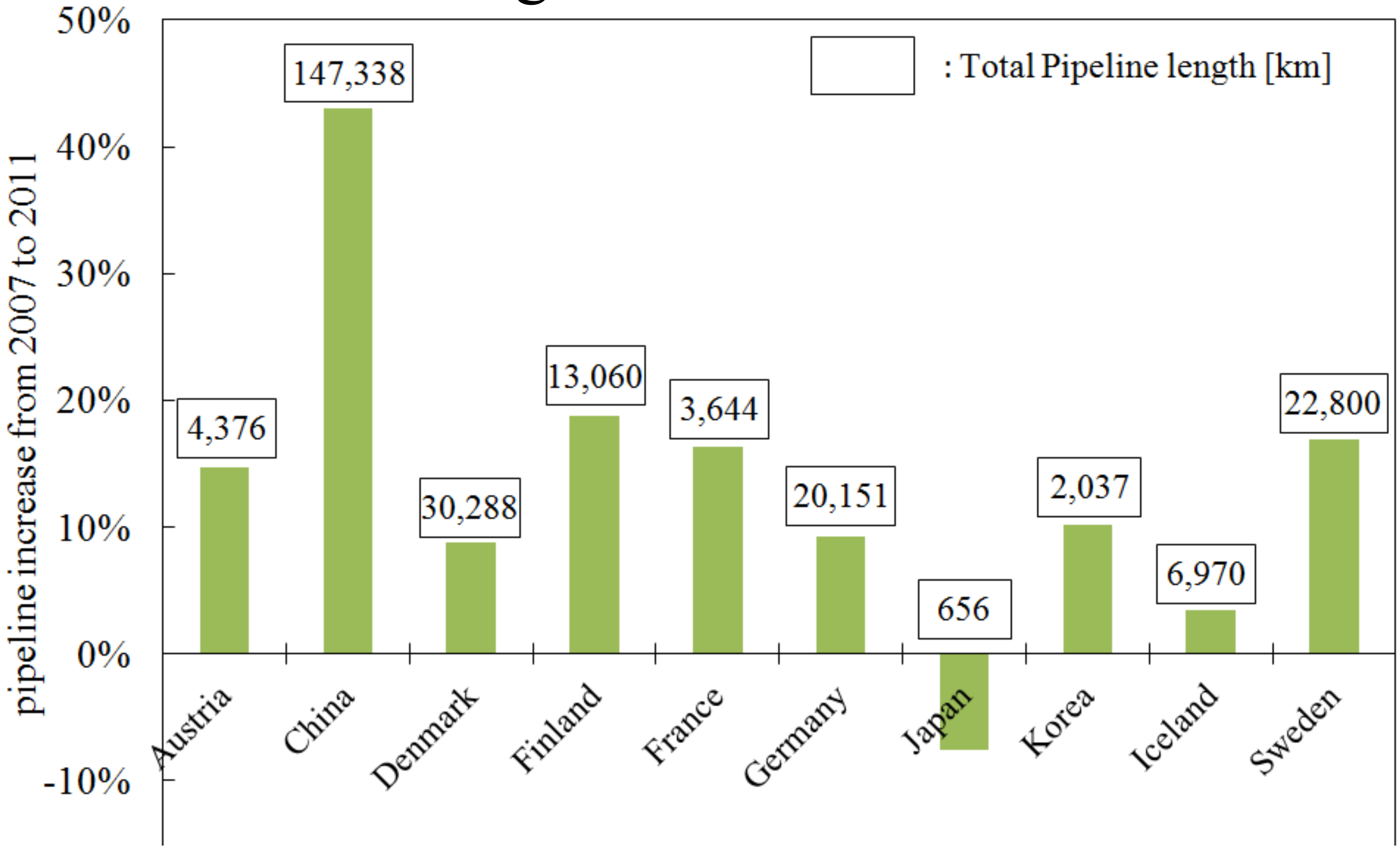
Outline

1. Objective
2. Methodology
3. Results and discussion
4. Conclusion

Objective

- To design the optimal district heating system (DHS) based on the heat density map.
- Feasibility study using inventory analysis in Hirosaki city, Japan.

DHS pipeline increase and total length（2007-2011）



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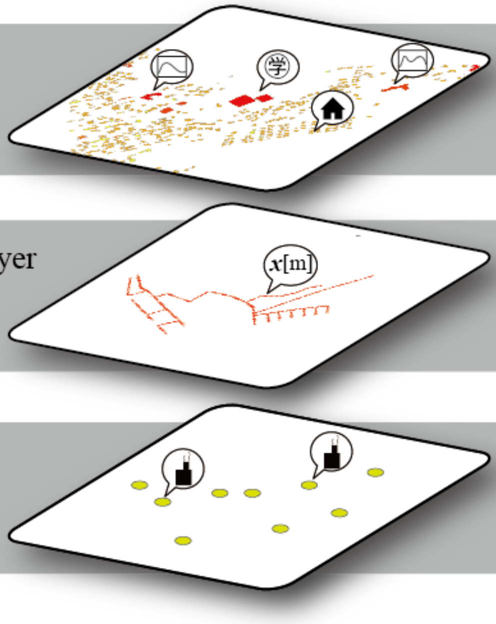
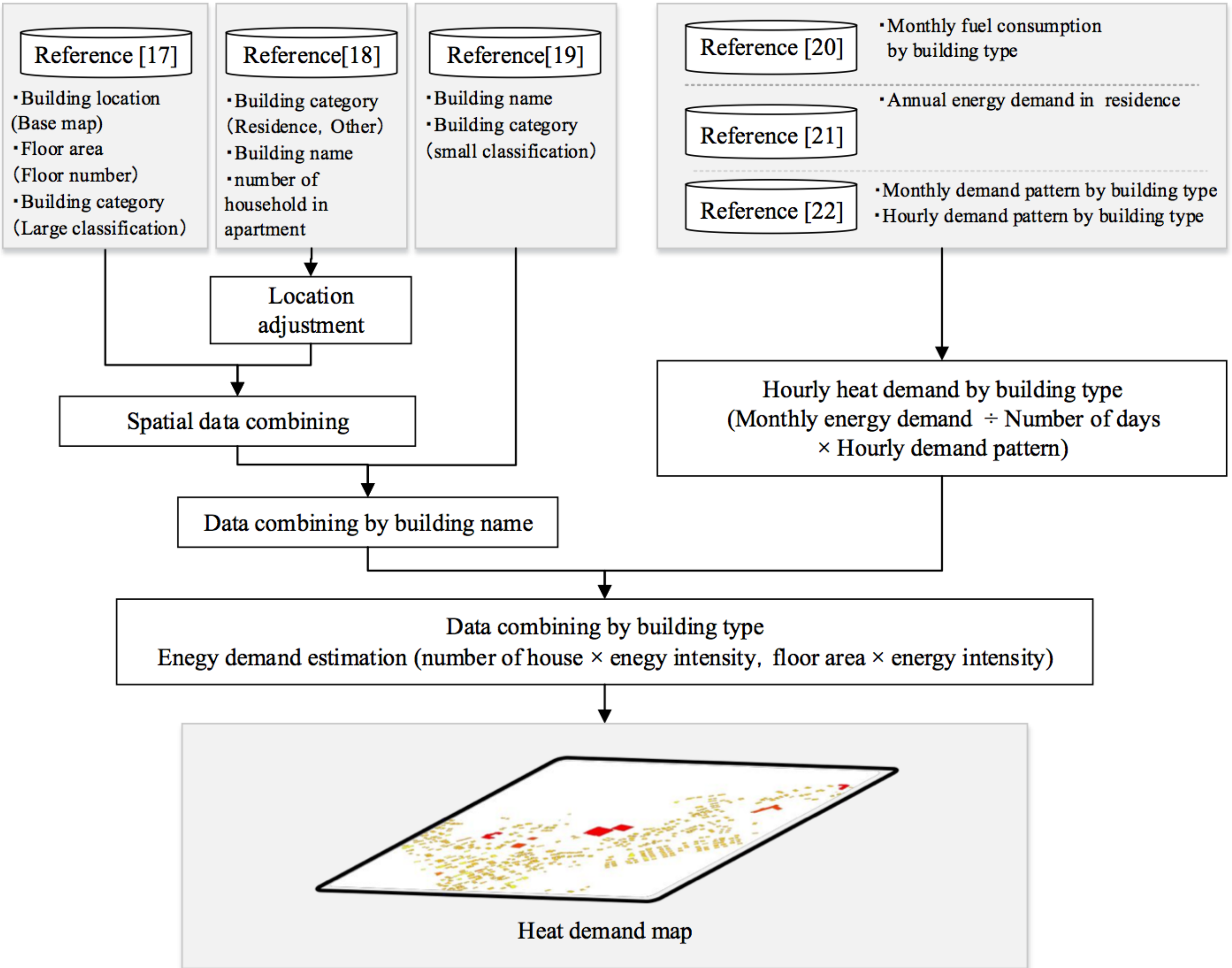
Methodology



Conponent of district energy system	Input data from GIS	Extarnal Database	Outout data from MILP
Dmd.layer	• Location • Floor area • Building type	• Heat demand by types • Heat load by hour • Electricity demand	• Ratio of Renewables • Carbon reduction
Network layer	• Pipeline layout • Pipe length	• Pumping power • Piping cost • Heat Resistance of pipe	• Network configuration • Heat loss from pipe • linear Heat density
Conv.layer	• Candidate of constraction • Location constraint	• heat efficiency • Constraction cost • Heat to Electricity ratio	• Heat source location • operating ratio • Amount of supply

Making heat density map



Demand calculation

Residential heating demand

$$dmd_{m,i,\text{Residence}}^{\text{SpaceHeating}} = annual\_SHdmd \times month\_loadptrn_{m,\text{Residence}}^{Spaceheating} \times N_i^{Household}$$

Residential hot water demand

$$dmd_{m,i,\text{Residence}}^{\text{Hotwater}} = \frac{annual\_HWdmd}{12} \times N_i^{Household}$$

Commercial heating demand

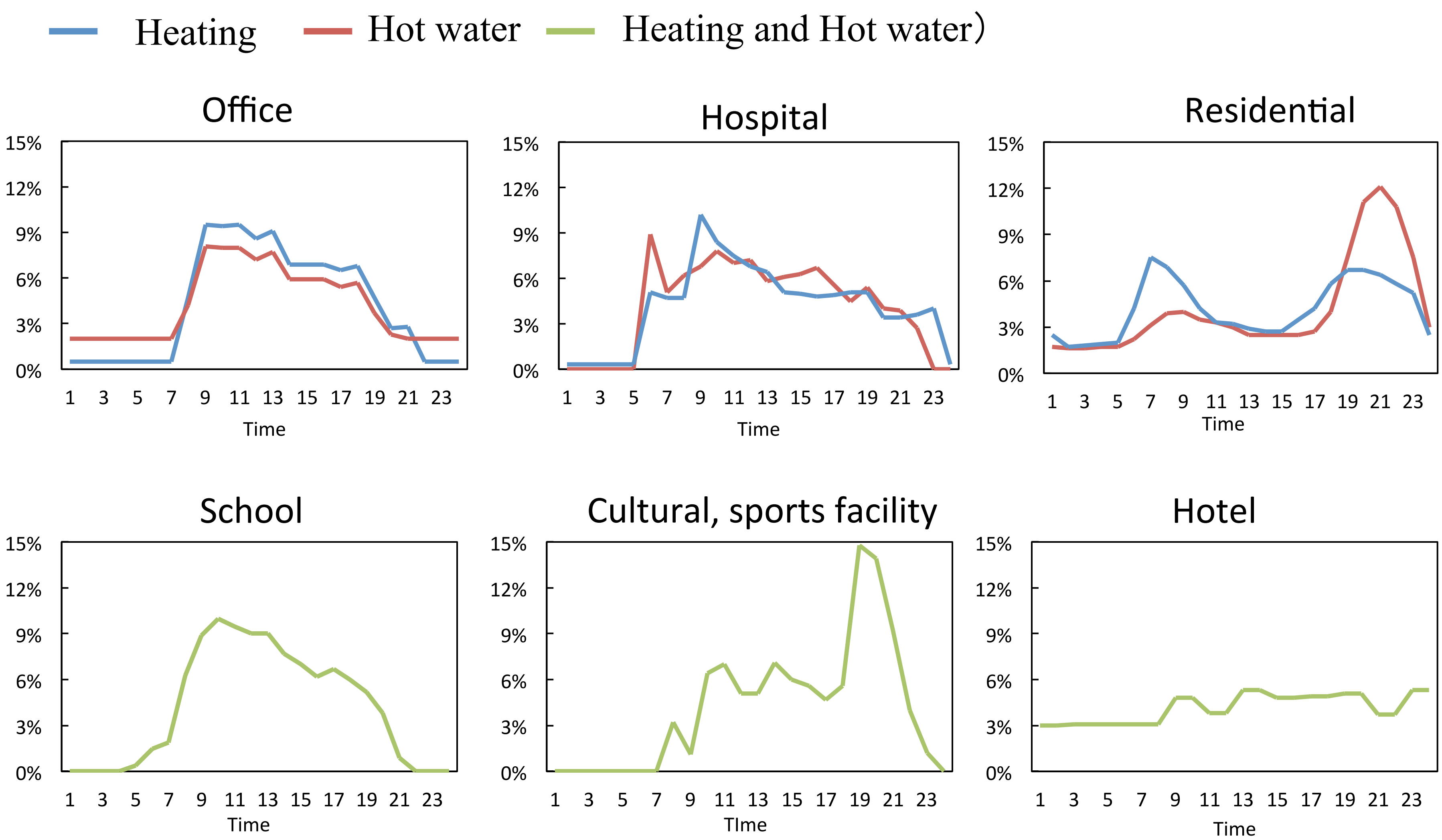
$$dmd_{m,i,\text{commerce}}^{\text{SpaceHeating}} = (Fcons_{m,type} + Econs_{m,type} - min\_Fcons_{type} - min\_Econs_{type}) \times A_i$$

Commercial hot water demand

$$dmd_{i,\text{Commerce}}^{\text{Hotwater}} = min\_Fcons_{type} \times A_i$$

dmd_{type}	Demand	[MJ]	A	Floor space	[m^2]
$annual\_SHdmd$	Annual heating demand	[MJ/year]	min_Fcons_{type}	Minimum unit fuel consumption of building type	[MJ/m^2]
$annual\_HWdmd$	Annual hot water demand	[MJ/year]	min_Econs_{type}	Minimum unit electricity consumption of building type	[MJ/m^2]
$annual\_Edmd$	Annual electricity demand	[MJ/year]	$Fcons_{type}$	Unit fuel consumption of building type	[MJ/m^2]
$N^{Household}$	Number of household	[-]	$Econs_{type}$	Unit electricity consumption of building type	[MJ/m^2]

Heat demand in an one day



Reference：地域冷暖房技術手引書（第4版） (in Japanese)

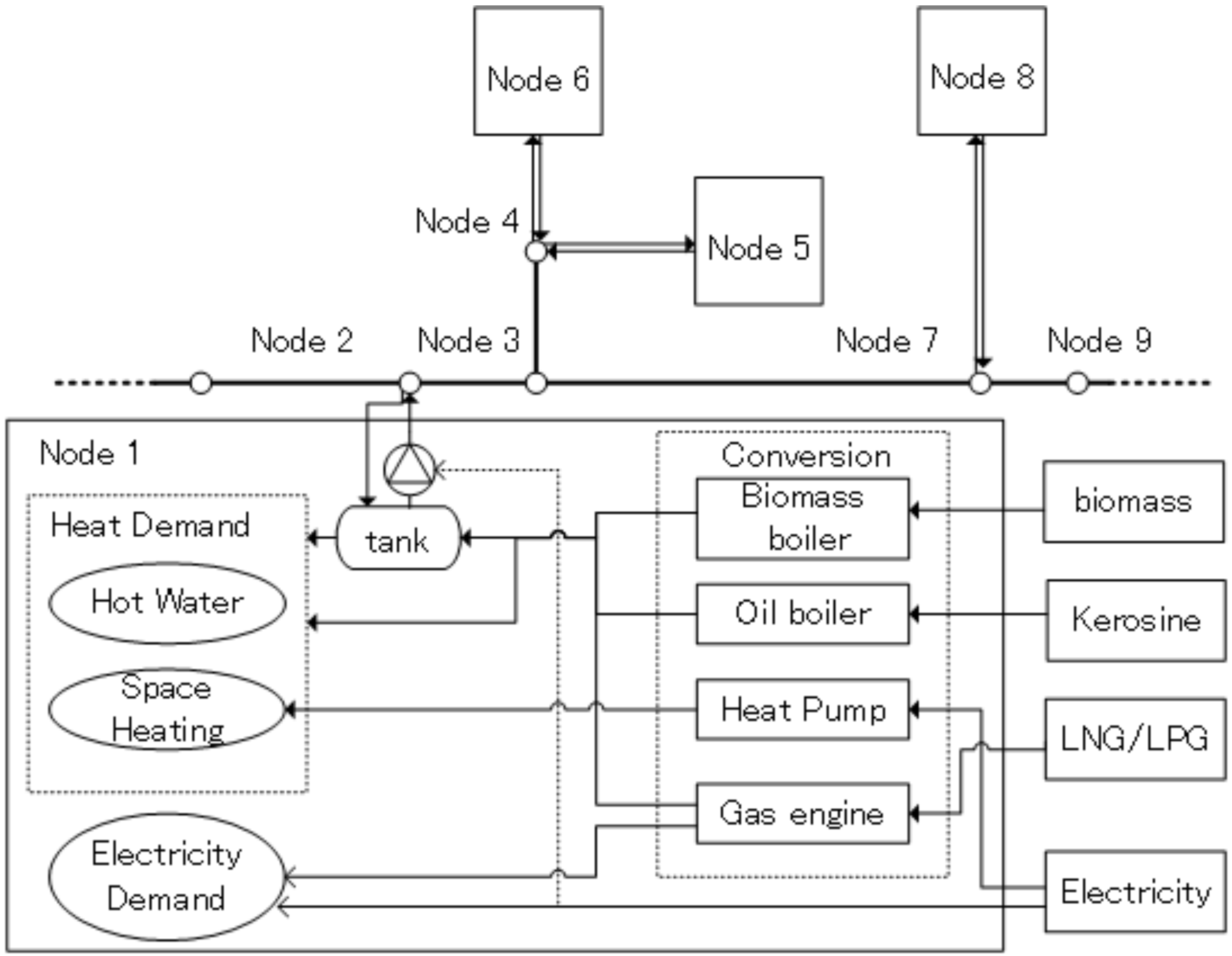
Network layer

$$L_{\text{pipe}} = \min.L_{\text{main}} + \min.L_{\text{branch}}$$

$\min.L_{\text{main}}$:Minimum mail pipeline length by Dijkstra's algorithm

$\min.L_{\text{branch}}$: Minimum branch pile length

System diagram



Objective function

$$\min.\quad Cost_{\text{total}} = C_{\text{capital}} + C_{\text{O\&M}} + C_{\text{network}} + C_{\text{DHSO\&M}} + C_{\text{electricity}} - C_{SAL}$$

Capital cost

$$C_{\text{capital}} = \sum_{i,t} (C_{\text{var},t} \cdot cap_{i,t} + C_{\text{fix},t} \cdot Nb_i \cdot BU_{i,t}) \cdot CRF_t + \sum_{i} (C^{HS}_{\text{var},i} \cdot cap^{HS}_i + C^{HS}_{\text{fix},i} \cdot Nb_i \cdot BU^{HS}_i) \cdot CRF^{HS}$$

$$CRF = \frac{int(1+int)^{life}}{(1+int)^{life} - 1}$$

O&M cost

$$C_{\text{O\&M}} = C_{\text{fuel}} + C_{\text{maintenance}} + C_{\text{input\_elect}}$$

$$C_{\text{fuel}} = \sum_{m,h,i,t} \frac{day_m \cdot cfuel_t \cdot G_{m,h,i,t}}{eff_t} \times Season_m$$

C_{capital}	Capital cost	[JPY]	C_{var}	Unit capital cost	[JPY/kW]
$C_{\text{O\&M}}$	O&M cost	[JPY]	$C_{\text{-fix}}$	Fixed cost for a new facility	[JPY]
C_{network}	Pipeline cost	[JPY]	Cap	Facility capacity	[kW]
$C_{\text{DHSO\&M}}$	DHS O&M cost	[JPY]	Nb	Number of buildings	[-]
$C_{\text{electricity}}$	Electricity cost	[JPY]	BU	Binary parameter $= \{0,1\}$	
C_{SAL}	Electricity sale revenue	[JPY]	CRF	Capital recovery factor	[-]
i	Node number		int	Interest rate (=0.03)	[-]
t	Heat source		$life$	Life time	[year]

Pipeline cost

Pipeline capital cost

$$C_{\mathrm{network}} = C_{pipe} + C_{pump}$$

$$C_{pipe} = \sum_{i,j,r} cpipe_r \cdot distance_{i,j} \cdot BP_{i,j,r} \cdot CRF^{PIPE}$$

$$C_{pump} = \sum_{i} (C_{\mathrm{var}}^{pump} \cdot cap_i^{pump} + C_{\mathrm{fix}}^{pump} \cdot BU_i^{pump}) \cdot CRF^{pump}$$

DHS O&M cost

$$C_{\mathrm{DHSO\&M}} = \left(\frac{C_{pipe}}{CRF^{PIPE}} + \frac{C_{pump}}{CRF^{PUMP}} \right) \times 0.02$$

C_{pipe}	Pipeline capital cost	[JPY]
C_{pump}	Pump cost	[JPY]
$cpipe$	Unit pipeline cost	[JPY/m]
$distance$	Distance between nodes	[m]
BP	Binary parameter = $\{0,1\}$	
i	Node number	
r	Pipe radius	

Parameters

	Minimum Capacity [kW]	Maximum Capacity [kW]	Minimum Load [%]	$C_{var.}$ [JPY/kW]	C_{fix} [JPY]	$EB_{var,t}$ [kW/kW]	$EB_{fix,t}$ [kW]	life [year]	eff_{elect} [-]	eff_{heat} [-]	HER [-]	fuel cost [JPY/MJ]
gas engine	180	5,200	50	104,305	25,057,000	0.0252	6.5127	15	0.4	0.35	1.14	2.0/6.0
biomass boiler	100	5,000	30	78,447	37,290,000	0.013	2.217	15	0	0.8	0	1.03
air-source HP	2.5	-	0	68,779	342,620	0	0	13	0	※	0	5.8
oil Boiler	100	-	0	6,755	1,208,600	0.0063	-0.9417	15	0	0.8	0	1.7

※air-source heat pump's COP is calcurated by following equation. $COP = -0.07(T_{sink}-T_{air})+5.83$

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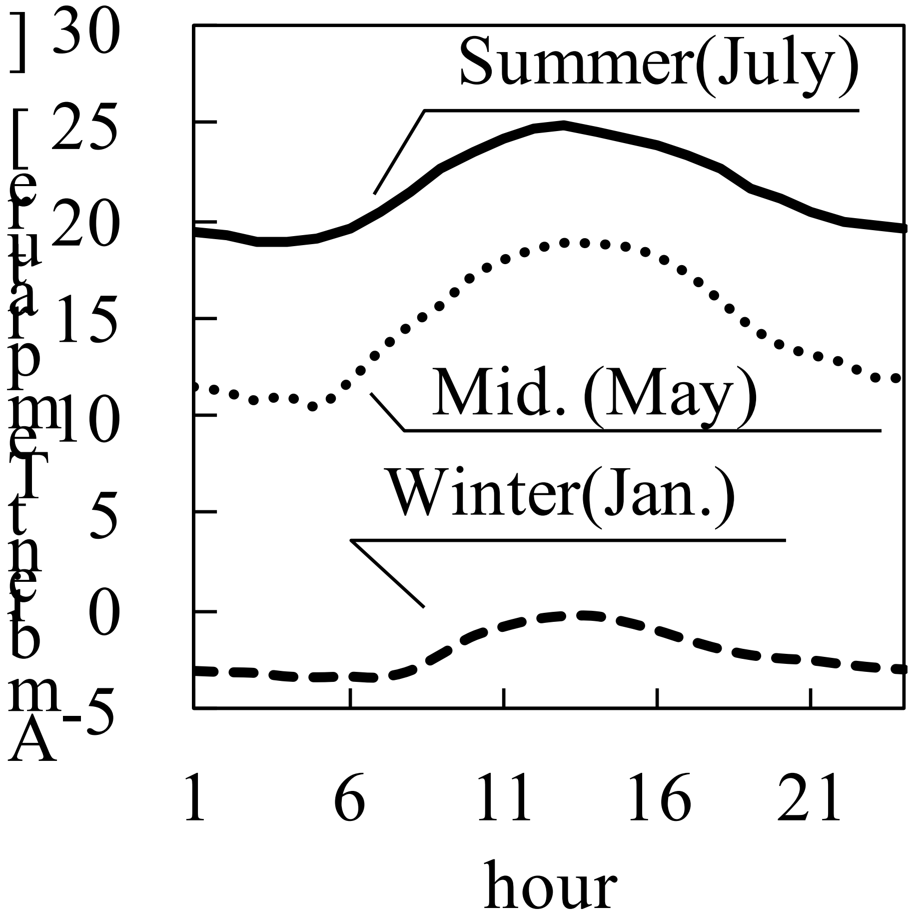
Pipeline parameters

DN [mm]	Diameter [mm]	R [W/m]	Capacity [MJ]	Cost [JPY/m]
50	51	1,663	2,929	19,625
100	96	1,139	10,414	32,325
150	137	942	21,386	52,625
200	182	703	37,743	60,625
250	225	597	57,684	78,525

Target area


ウラジオストク
Владивосток
日本海
札幌
Hirosaki
仙台
日本
東京
Tokyo
名古屋
大阪
広島
福岡
부산
Osaka

Temperature in Hirosaki city



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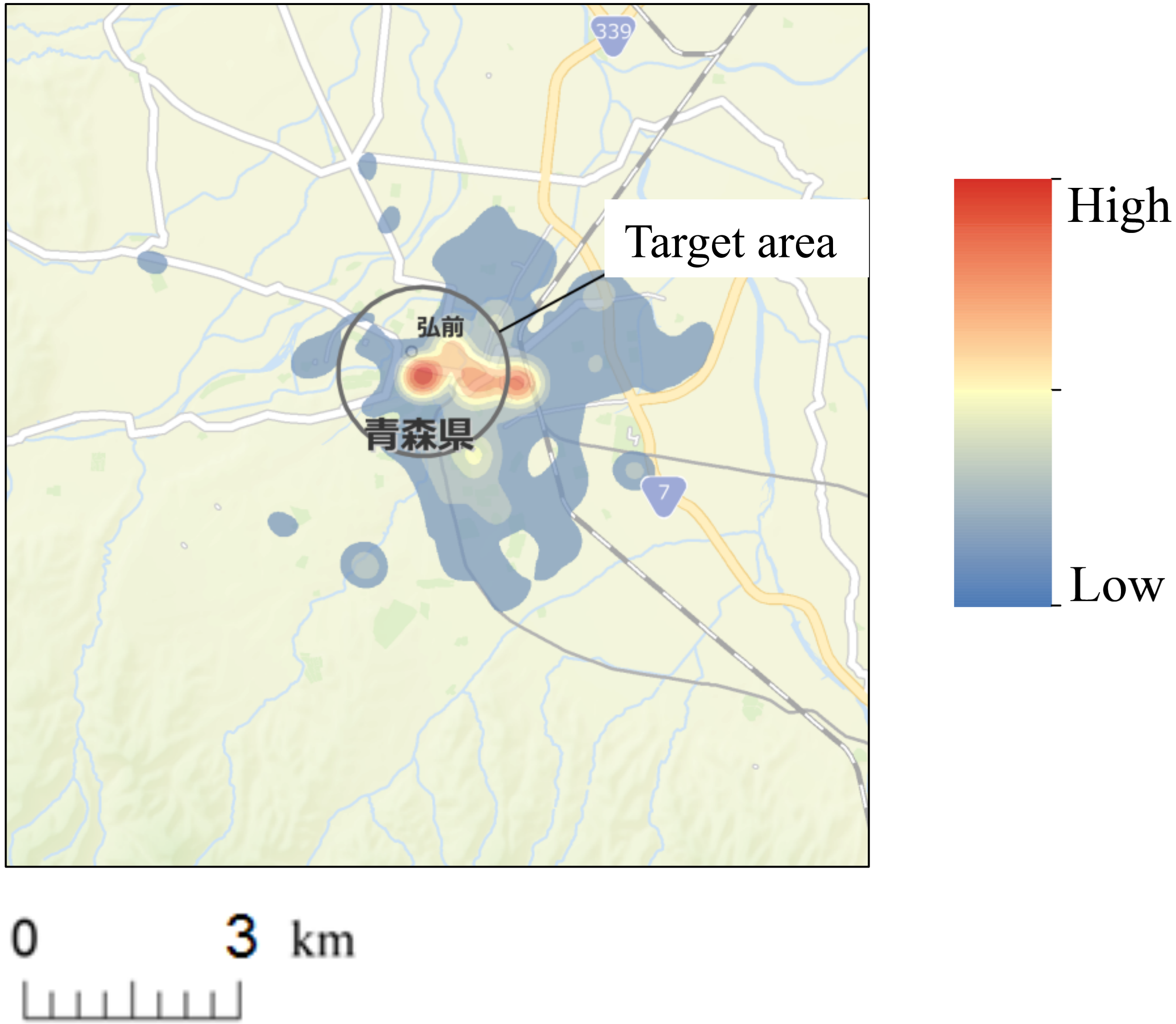
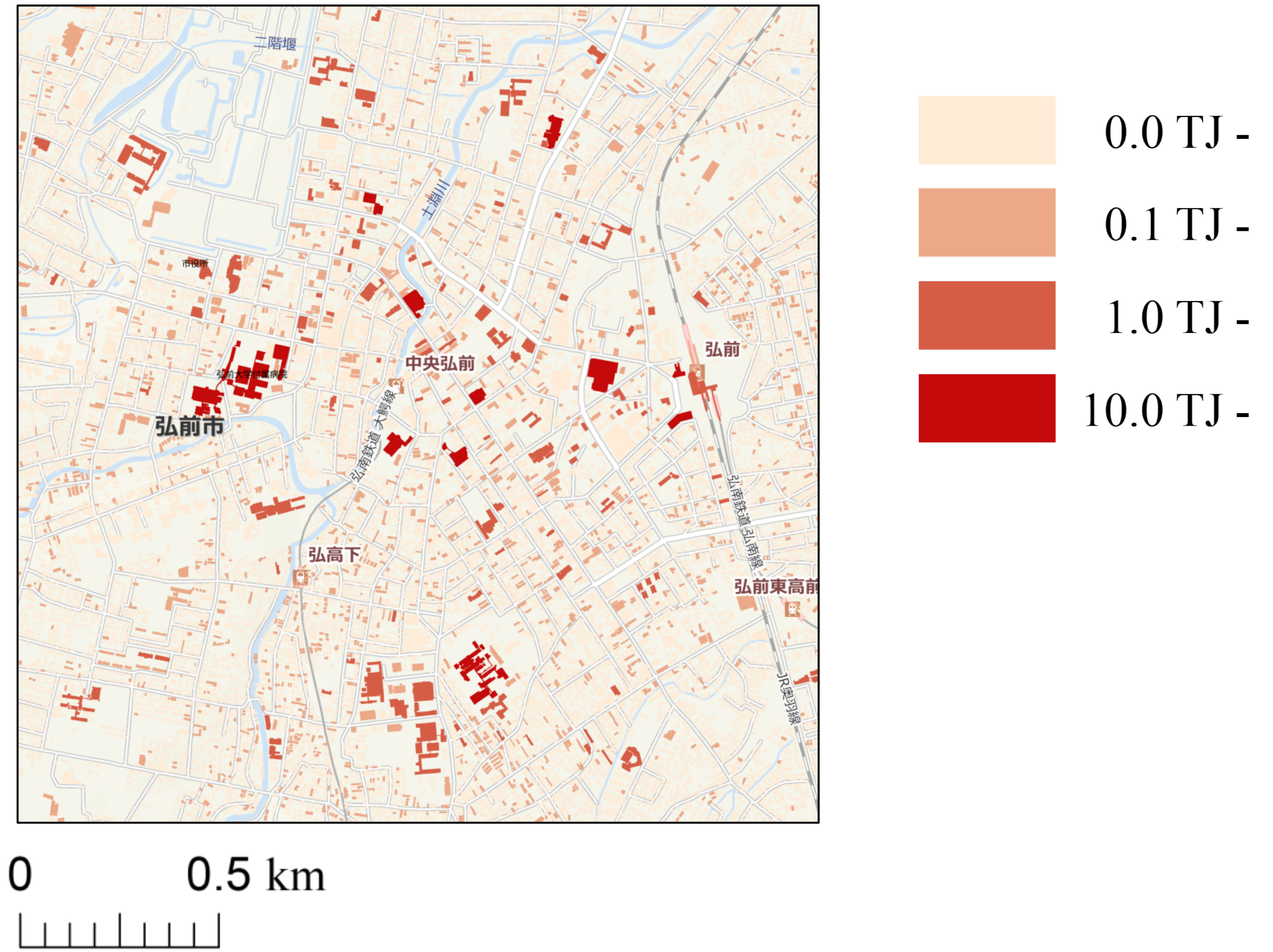
Heat density map (mesh type)

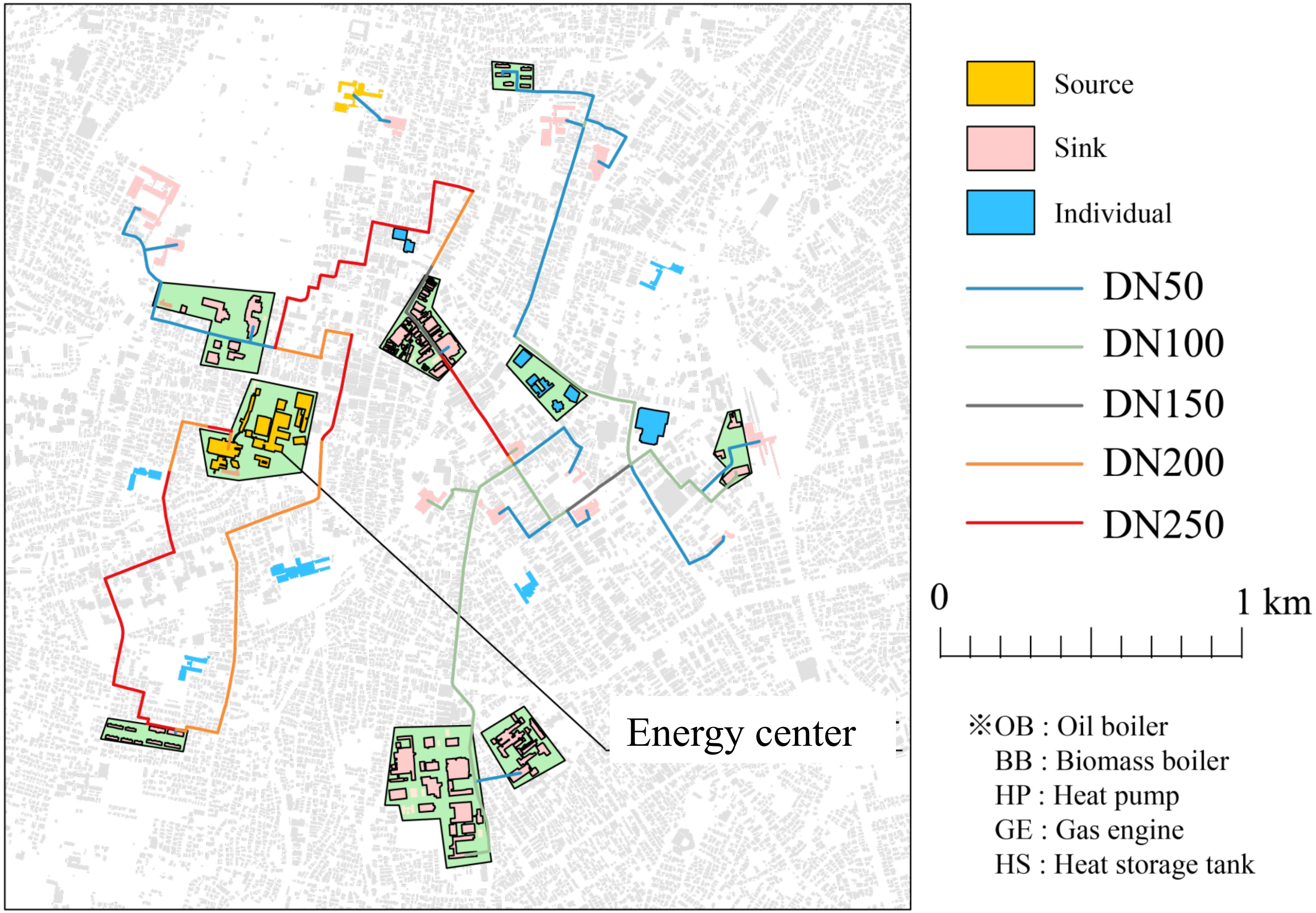


Heat density map (detail)

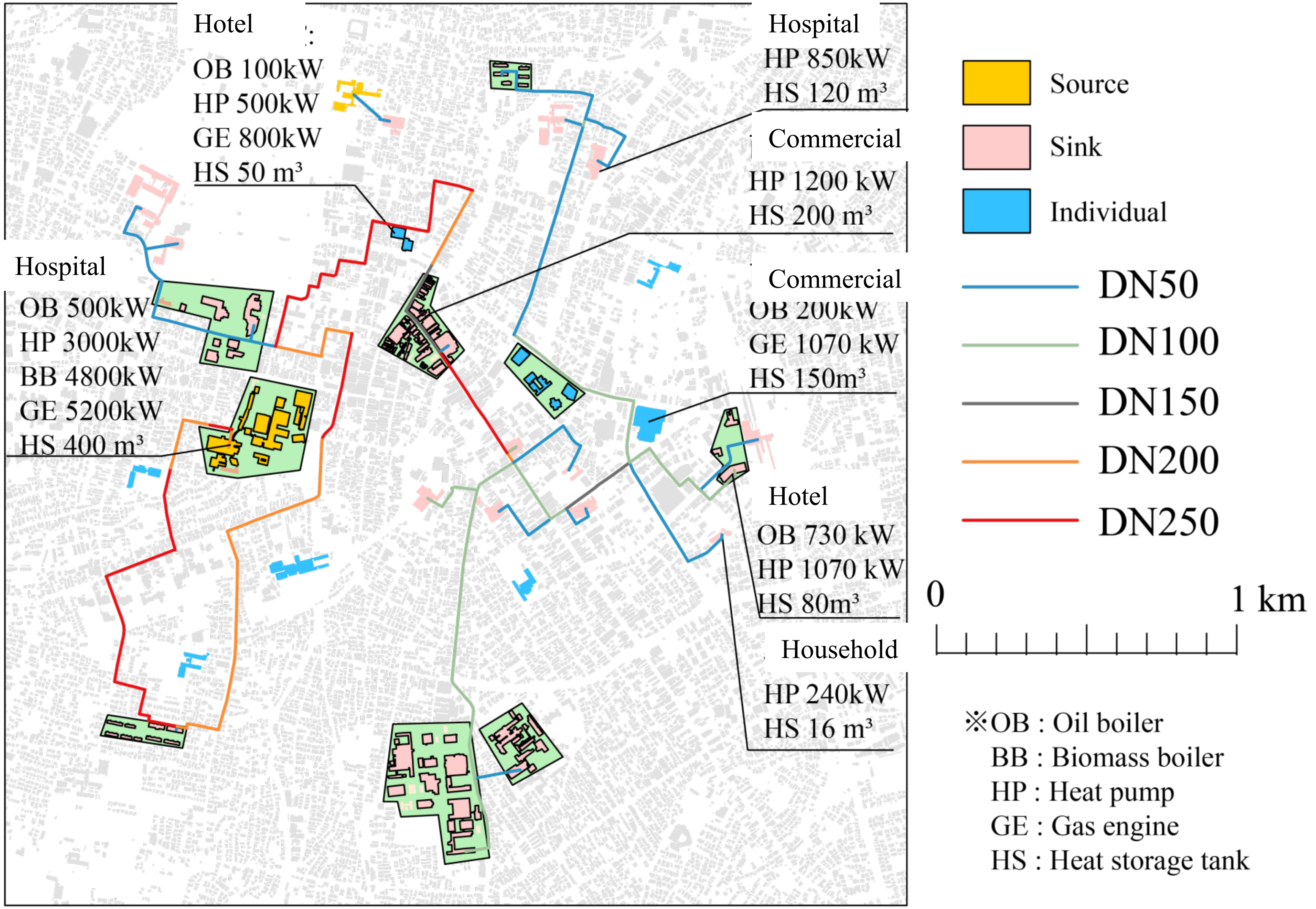
Average heat density: 2.01 TJ/ha



District heating network

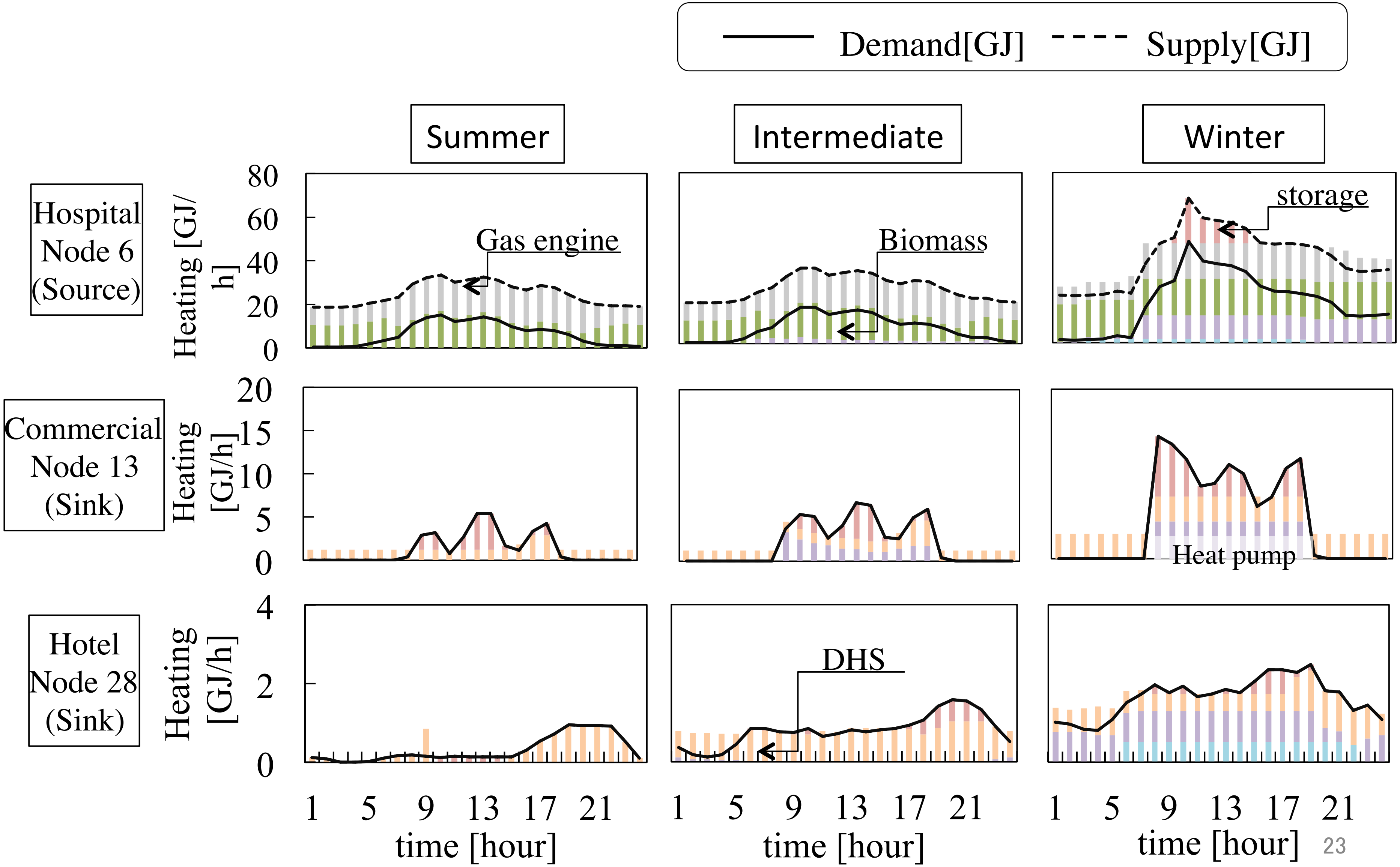


Heat generation facilities



※OB : Oil boiler
BB : Biomass boiler
HP : Heat pump
GE : Gas engine
HS : Heat storage tank

Operation details



System performance

	BAU	DHS	
Primary energy consumption	1,130	956	TJ/year
CO_2 emission	73,400	48,800	t-CO_2/year
Heat supply cost	2-3	1-2	JPY/MJ

Error of the demand calculation

	Actual data	Calculation
Hotel 1	3,940	3,984
Hotel 2	14,070	14,561
Hotel 3	2,545	2,542
Commercial 1	20,434	25,875
Commercial 2	15,702	17,892
Commercial 3	6,863	10,627
Hospital 1	8,300	8,221

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Conclusion

- Optimal district heating system is designed in Hirosaki city.
- Although the heat demand density in Hirosaki is smaller than the city area target 4.2 TJ/ha, the small scale DHS can reduce the CO_2 emission using biomass boiler.
- Gas CHP and high efficient heat pump can reduce the primary energy consumption and CO_2 emission.
- Hospital is main target because of the stable and high heat demand, and the location.