ESL-IC-14-09-19

Study on Performance Verification and Evaluation of District Heating and Cooling System Using Thermal Energy of River Water

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Abstract

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The heating and cooling system used in Osaka's Nakanoshima district uses heat pumps and river water to achieve the efficient use of the heat source and mitigate the heat island effect. The system is properly operated and maintained continuously.

This presentation outlines the performance verifications and evaluations that have been conducted, operational results, plant performance, and heat source equipment performance since the operation was launched. Also, secular changes in river water heat exchangers are analyzed and the effect of cleaning heat exchangers are evaluated.

(1) Overview of the heating and cooling facilities
(2) Operational results since launch
(3) Secular changes in plant performance
(4) Secular changes in facilities using river water

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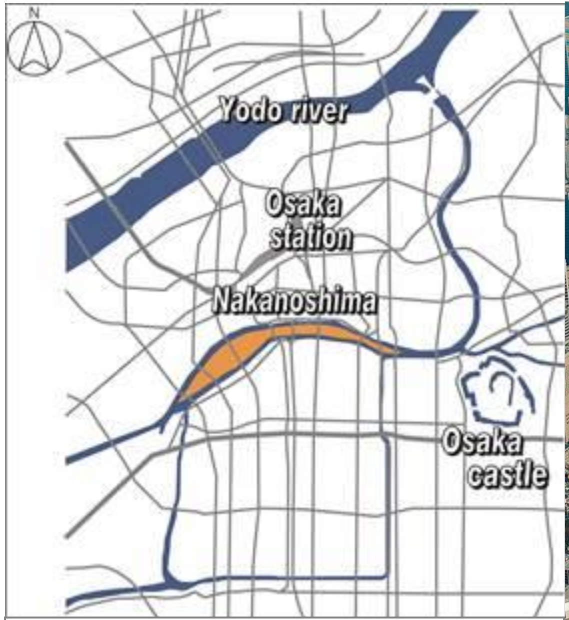
(1) Overview of the heating and cooling facilities

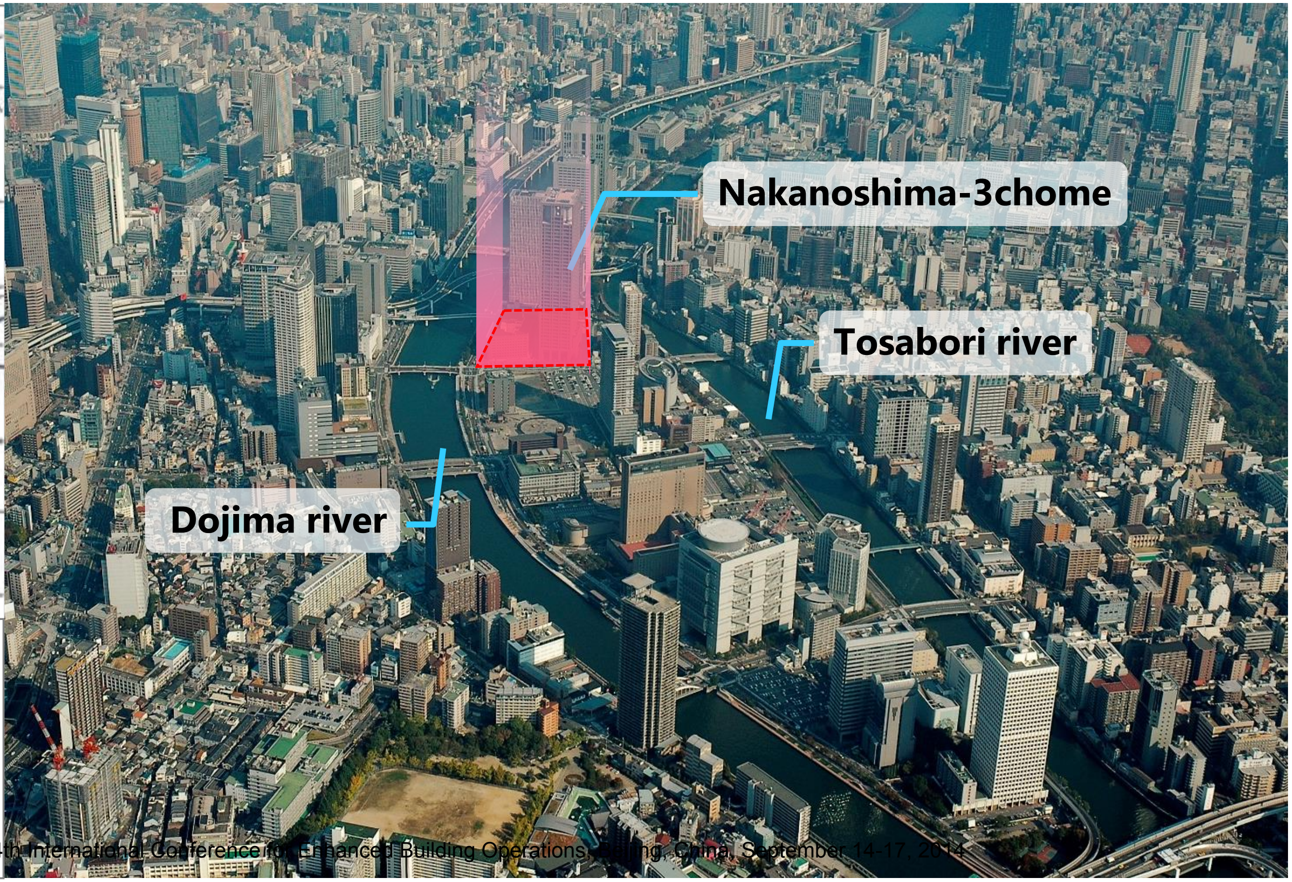
Overview of Nakanoshima, Osaka

- Nestled between the Dojima and Tosabori rivers, Nakanoshima is a sandbank stretching roughly 3 km in an east-west direction.
- As well as Osaka City Hall, the island is home to a number of leading Japanese companies and other public and business facilities.
- Pathways and other amenities help create an attractive riverside environment.



- Area space: about 50 ha
- Floor space: about 1 million m^2
- Daytime population: about 35,000

(As of 2006)



District heating and cooling system in Nakanoshima

Characteristics of heat supply plant in Nakanoshima district

-River water is utilized as heat source and cooling water overall (in comparison with normal system 15% of energy saving)

-Adopt large-scale ice heat storage system and realize equalization of electricity load

-Adopt turbo chiller and heat recovery facilities as high efficiency heat source

-Utilize waste heat discharged from substation, and supply in large difference of temperature

Water intake

Heat exchangers

Water discharge

Turbo chiller

Screw heat pump

pumps

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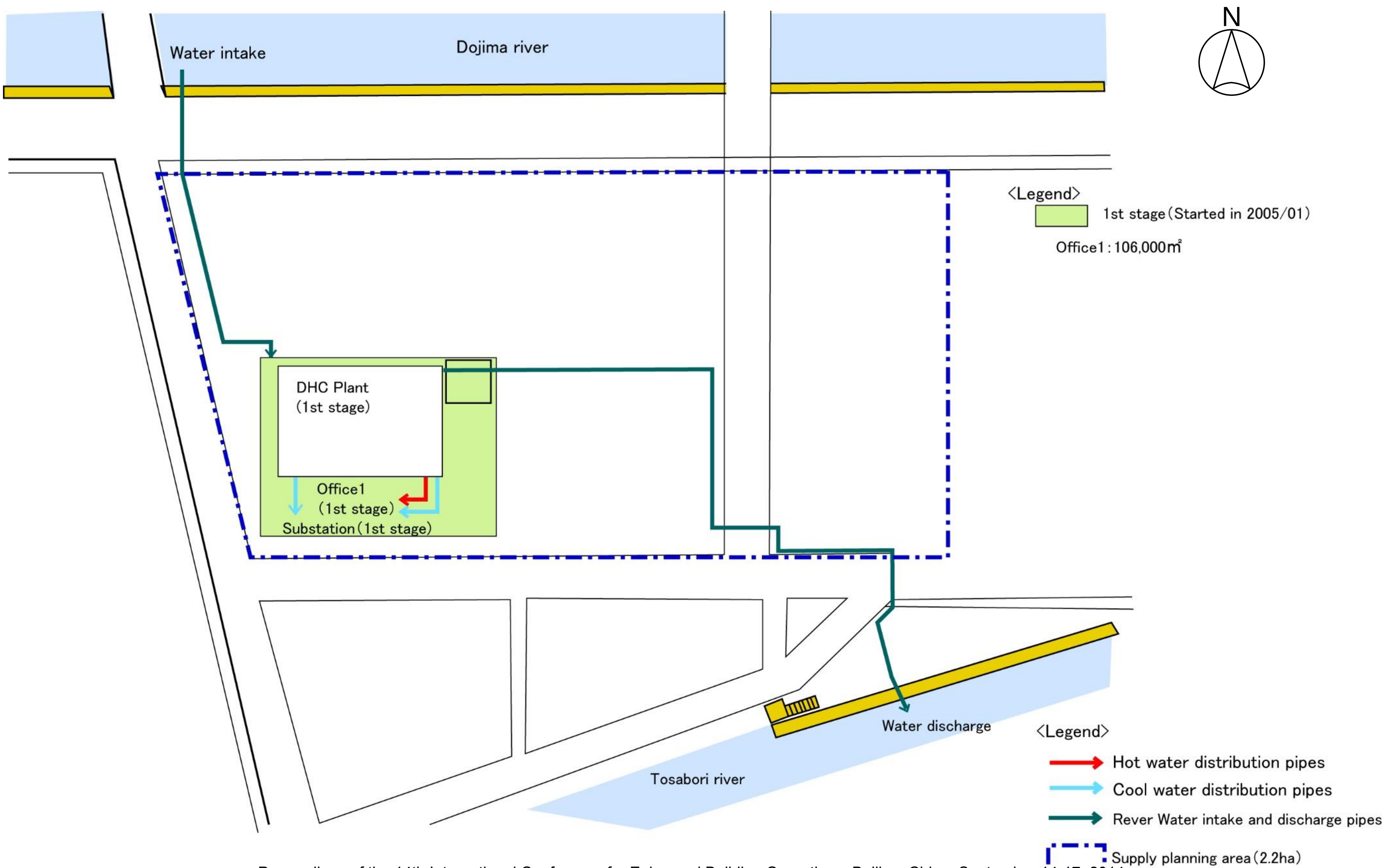
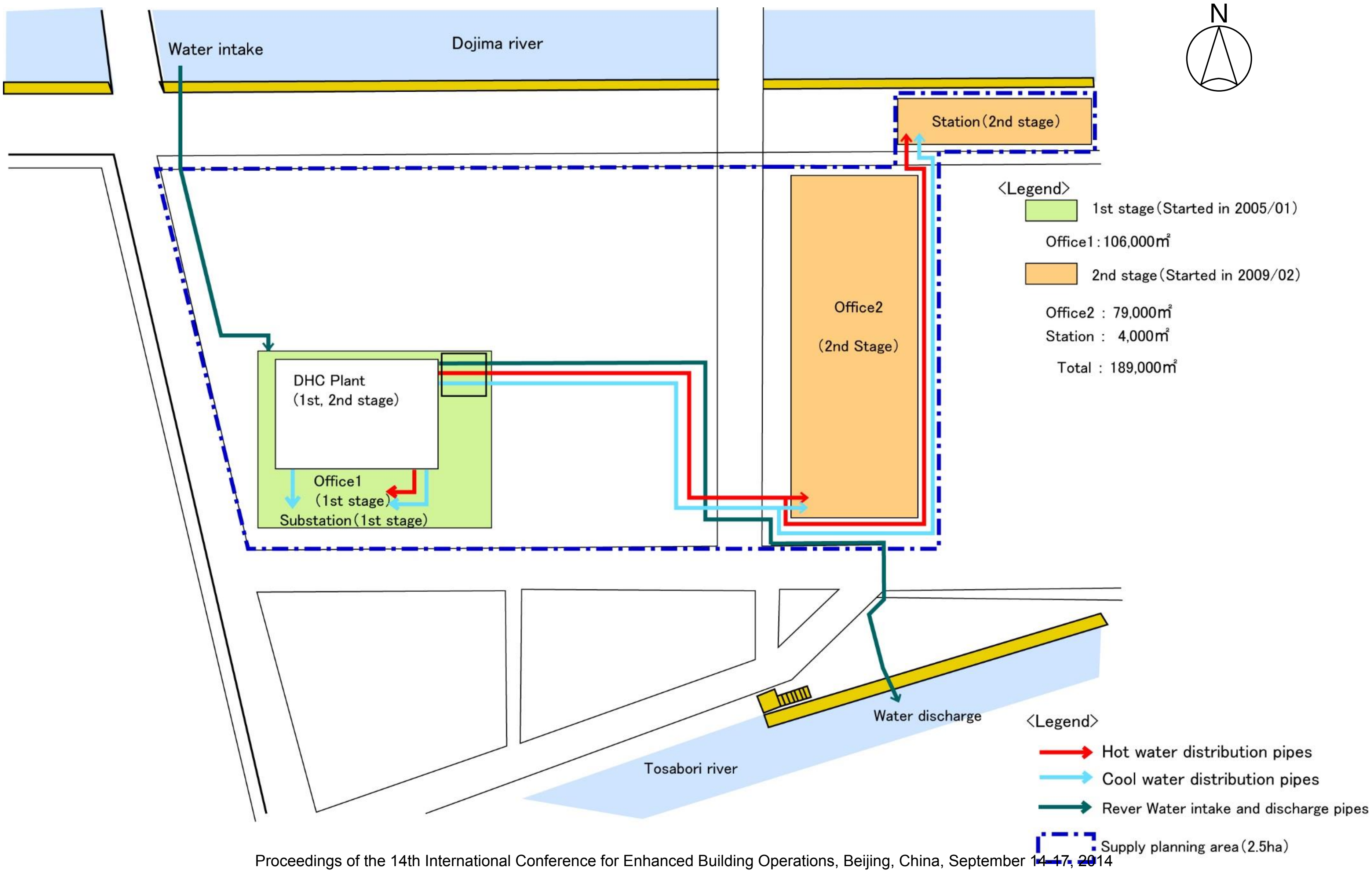
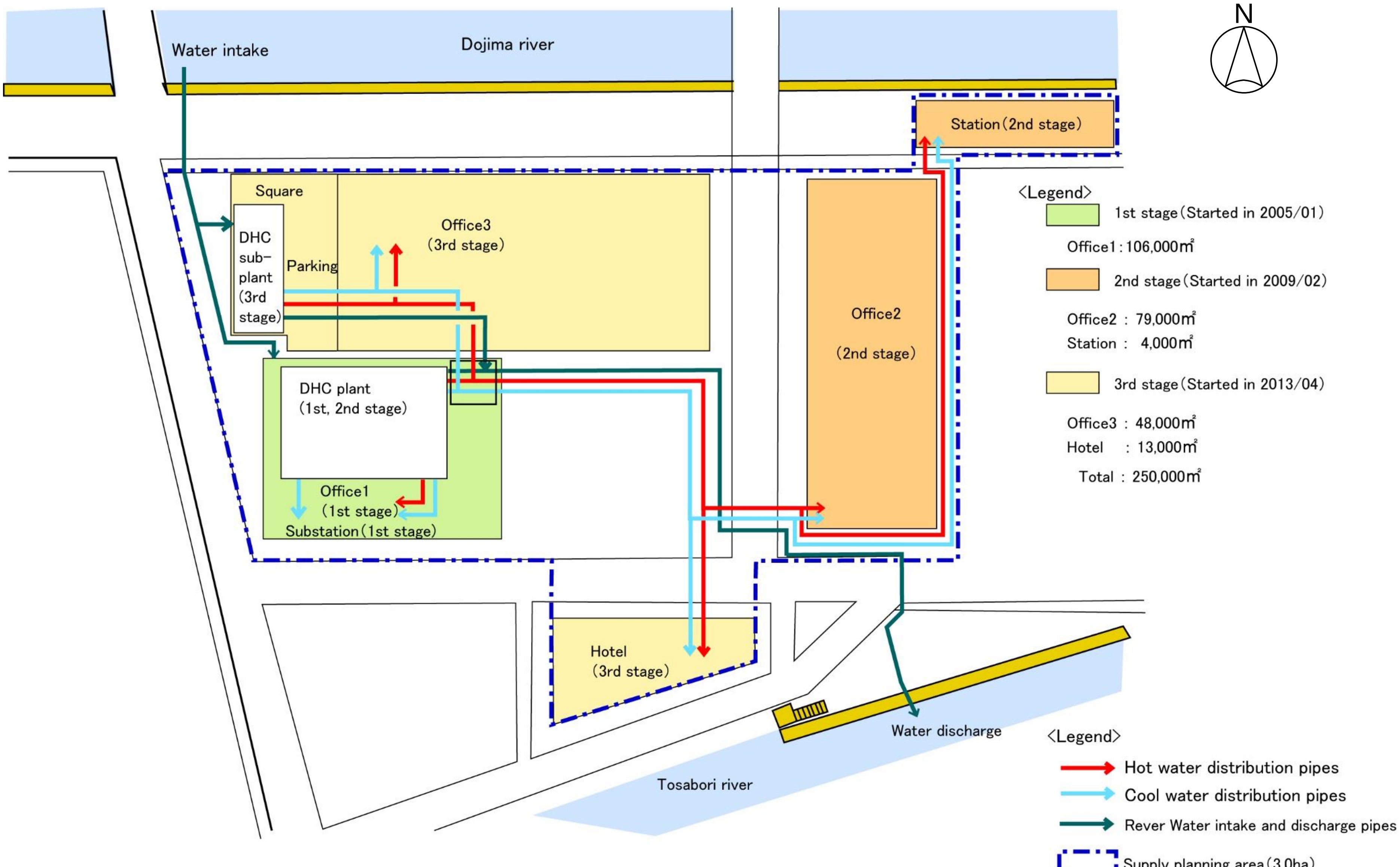
Heat supply area(1st stage : 2005-2008)



Heat Supply Area(From 1st to 2nd Stage : 2009-2012)



Heat Supply Area(From 1st to 3rd Stage : 2013-)



Heat supply system(1st stage2005-2008)

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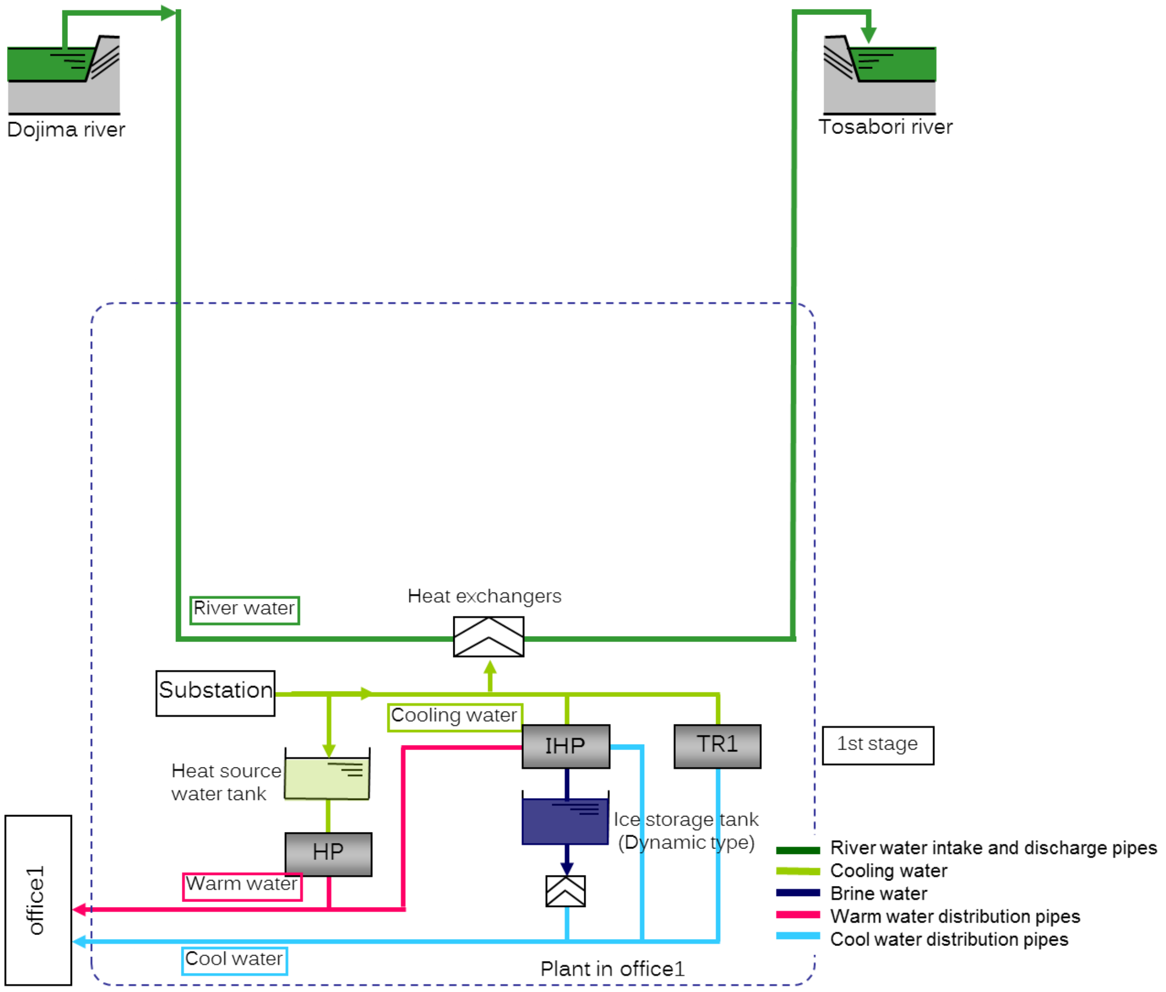
[1st Stage]

Heat source equipment	Cooling	Heating	Number
HP/Water source screw heat pump	-	838MJ/h	1
IHP/Water source screw heat pump (Ice storage and heat recovery)	Cool water：3,080MJ/h Ice Storage：1,936MJ/h	Cool water heat recovery：3,606MJ/h Ice storage heat recovery：2,448MJ/h	8Unit（16）
TR1 Water cooling turbo chiller	5,063MJ/h	-	1

Ice storage tank	Storage capacity	Number
Dynamic type	139,440MJ 870m^3	8



[Facilities using river water]

Water intake and discharge place	Intake : Dojima river Discharge : Tosabori river
Quantity of water intake	Summer : 0.426m^3/s　Winter : 0.348m^3/s
Use difference of temperature	Summer : 5°C　Winter : - 3°C
River water dependence rate	100%

Heat supply system(From 1st to 2nd stage : 2009-2012)

[1st Stage]

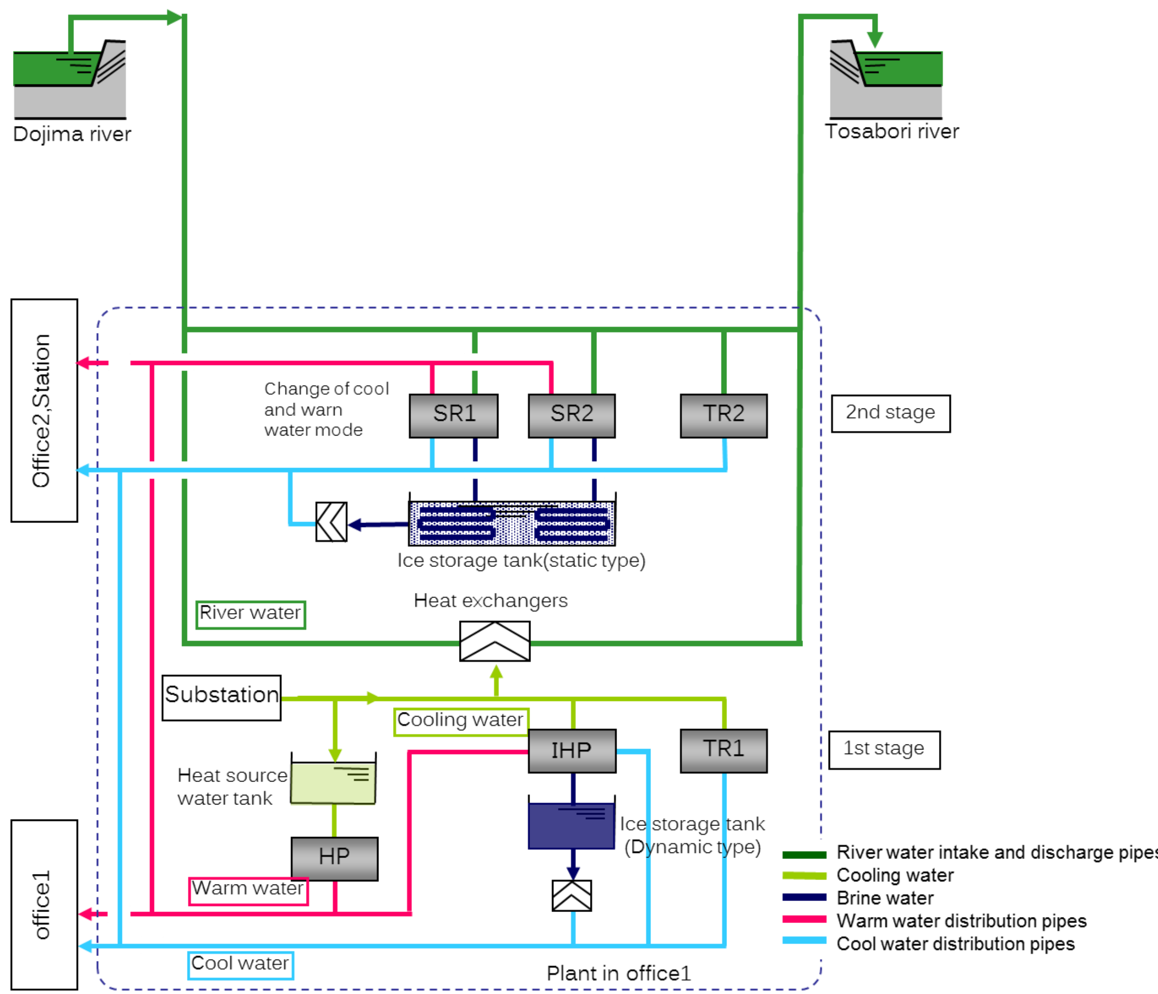
Heat source equipment	Cooling	Heating	Number
HP/Water source screw heat pump	-	838MJ/h	1
IHP/Water source screw heat pump (Ice storage and heat recovery)	Cool water : 3,080MJ/h Ice Storage : 1,936MJ/h	Cool water heat recovery : 3,606MJ/h Ice storage heat recovery : 2,448MJ/h	8Unit (16)
TR1 Water cooling turbo chiller	5,063MJ/h	-	1

Ice storage tank	Storage capacity	Number
Dynamic type	139,440MJ 870m^3	8

[2nd stage]

Heat source equipment	Cooling	Heating	Number
SR1/HP/Water source screw heat pump (Ice storage, change of cool and warm water mode)	Cool water : 5,062MJ/h Ice Storage : 4,404MJ/h	4,187MJ/h	1
SR2/HP/Water source screw heat pump (Ice storage, change of cool and warm water mode)	Cool water : 8,640MJ/h Ice Storage : 8,478MJ/h	13,860MJ/h	1
TR2/water cooling turbo chiller(inverter)	7,595MJ/h	-	1

Ice storage tank	Storage capacity	Number
Static type	78,230MJ 545m^3	8Unit



[Facilities using river water]

Water intake and discharge place	Intake : Dojima river Discharge : Tosabori river
Quantity of water intake	Summer : 0.660m^3/s Winter : 0.382m^3/s
Use difference of temperature	Summer : 5°C Winter : -3°C
River water dependence rate	100%

Heat supply system(From 1st to 3rd stage : 2013-)

[1st Stage]

Heat source equipment	Cooling	Heating	Number
HP/Water source screw heat pump	-	838MJ/h	1
IHP/Water source screw heat pump (Ice storage and heat recovery)	Cool water：3,080MJ/h Ice Storage：1,936MJ/h	Cool water heat recovery：3,606MJ/h Ice storage heat recovery：2,448MJ/h	8Unit (16)
TR1 Water cooling turbo chiller	5,063MJ/h	-	1

Ice storage tank	Storage capacity	Number
Dynamic type	139,440MJ 870m³	8

[2nd stage]

Heat source equipment	Cooling	Heating	Number
SR1/HP/Water source screw heat pump (Ice storage, change of cool and warm water mode)	Cool water：5,062MJ/h Ice Storage：4,404MJ/h	4,187MJ/h	1
SR2/HP/Water source screw heat pump (Ice storage, change of cool and warm water mode)	Cool water：8,640MJ/h Ice Storage：8,478MJ/h	13,860MJ/h	1
TR2/water cooling turbo chiller(inverter)	7,595MJ/h	-	1

Ice storage tank	Storage capacity	Number
Static type	78,230MJ 545m³	8Unit

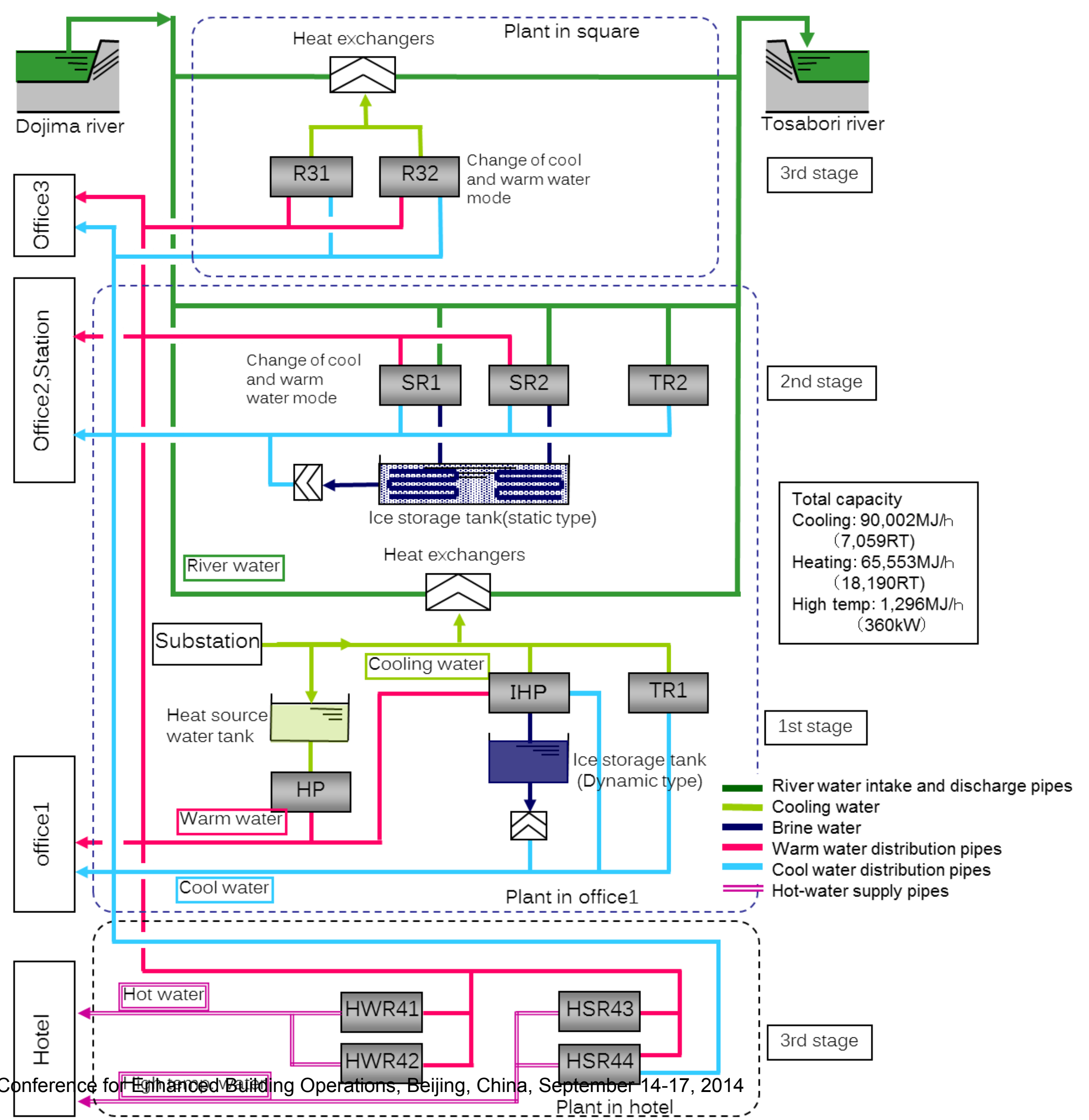
[3rd Stage]

Heat source equipment	Cooling	Heating	Number
R31･R32/HP/Water source screw heat pump (change of cool and warm water mode)	8,561MJ/h	8,910MJ/h	2

Heat source equipment	Cooling	Hot water	Number
HWR41･HWR42 Scroll heat pump(high temp.)	-	464MJ/h	2
HSR43 Scroll heat pump(high temp.)	-	184MJ/h	1
HSR44 Scroll heat pump (High temp.and heat recovery)	113MJ/h	184MJ/h	1

[Facilities using river water]

Water intake and discharge place	Intake : Dojima river Discharge : Tosabori river
Quantity of water intake	Summer : 1.204m³/s Winter : 0.808m³/s
Use difference of temperature	Summer : 5 °C Winter : 1-3 °C
River water dependence rate	100%



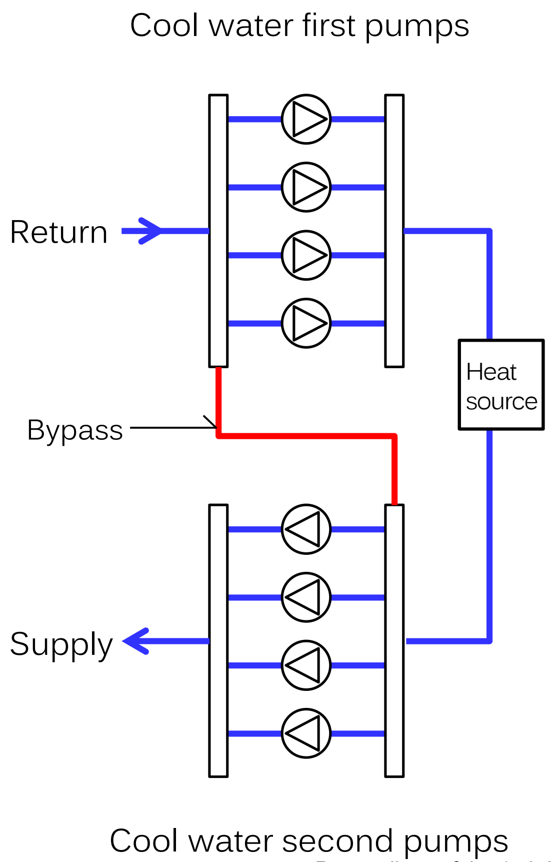
Developments in heat supply plant since operation started

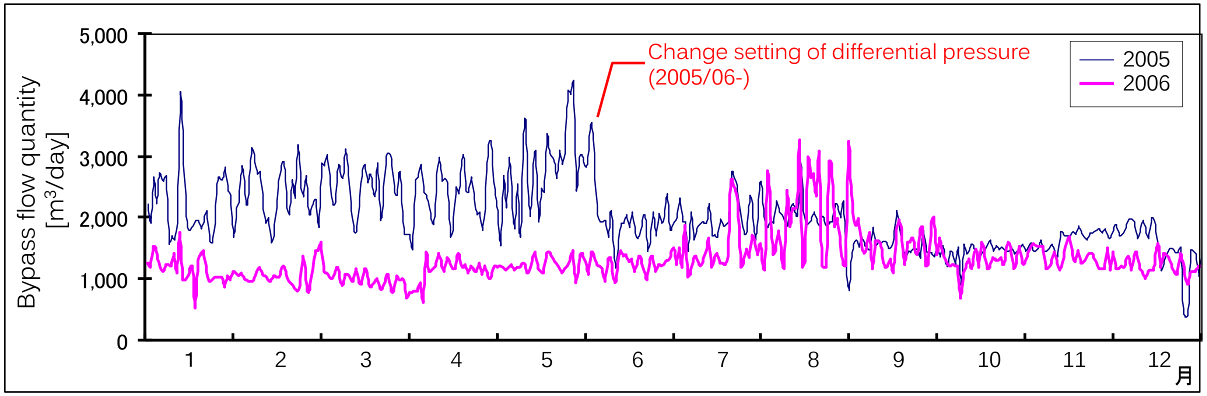
Performance has been continuously verified and evaluated to ensure proper operation and maintenance since the operation was first launched.

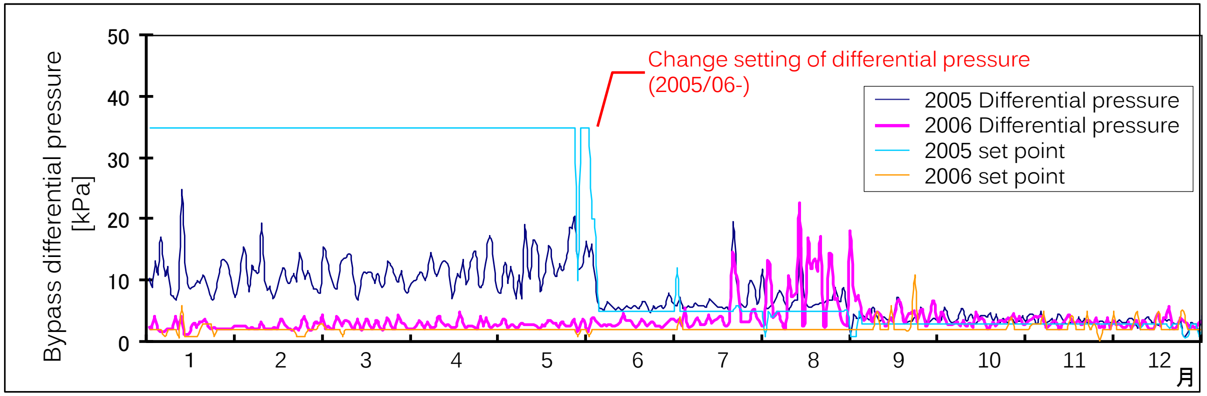
Year		1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Performance verification and evaluation phase		Phase-1		Phase-2				Phase-3			
		Initial performance verification and evaluation		Early performance verification and evaluation				Late performance verification and evaluation			
Topics		▽ 1st stage started operation		Mild winter		▽2nd stage started operation	Hot summer	Requested electricity saving ▽The Great East Japan Earthquake		Electricity-saving target ▽ 3rd stage started operation	
Supply status		▽ Started operation for Office1 in 2005/1			▽ Started operation for Station in 2008/10	▽ Started operation for Office2 in 2009/4		▽ Installed additional substations		▽ Started operation for Office3 in 2013/3	Started operation for Hotel in 2014/1 ▽
Performance verification framework		Initial performance verification and evaluation meeting ←→		Continual performance verification and evaluation meeting ←→		Performance verification of 2nd stage system ←‐‐→		Verification of saving effect ←‐‐→	Continual performance verification and evaluation meeting ←→	Performance verification of 3rd stage system ←‐‐→	
Verification and evaluation items		•Performance verification of heat source system •Performance verification of conveyance system •Verification of effectiveness of using river water •Verification of effectiveness of leveling load •Initial performance evaluation (first COP)		•Created system simulator •Considered operation improvement •3-year performance evaluation		•Performance verification of 2nd stage system •Considered heat source operation map •6-year performance evaluation		•Reviewed power-saving methods and effect	•Evaluated secular changes of heat source performance •Evaluated secular changes of river water utilization system	•Performance verification of 3rd stage system •10-year performance evaluation	
Efforts on demand side and plant side				•Optimized thermal storage in the building						•Optimized thermal storage in the building •Considered supply temperature mitigation	
Efforts on plant side	Cooling	•The ratio of cool water follow-up cooling operation was increased due to increased cooling load in summer •Adjusted bypass flow		•Increased TR operation				•Power-saving operation			
	Heating	•Prioritized IHP cool water heat recovery operation		•The ratio of cool water heat recovery operation was increased due to decreased heating load in winter		•Adapted IHP (Enabled separated operation)		•Optimized IHP and SR operation			
	Others	•Adjusted plant ventilating fan		•Secured temperature difference of river water				•Reviewed temperature difference of river water			

Example of efforts on plant side : Adjusted bypass flow

-Because setting of the bypass differential pressure was excessive, in the first half of 2005, bypass flow quantity increased, and the consumption electricity of the second pump increased.
-As a result of having lowered setting of the differential pressure after the latter half of 2005, bypass flow quantity decreased.







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(2) Operational results since launch

Outdoor air temperature and river water temperature

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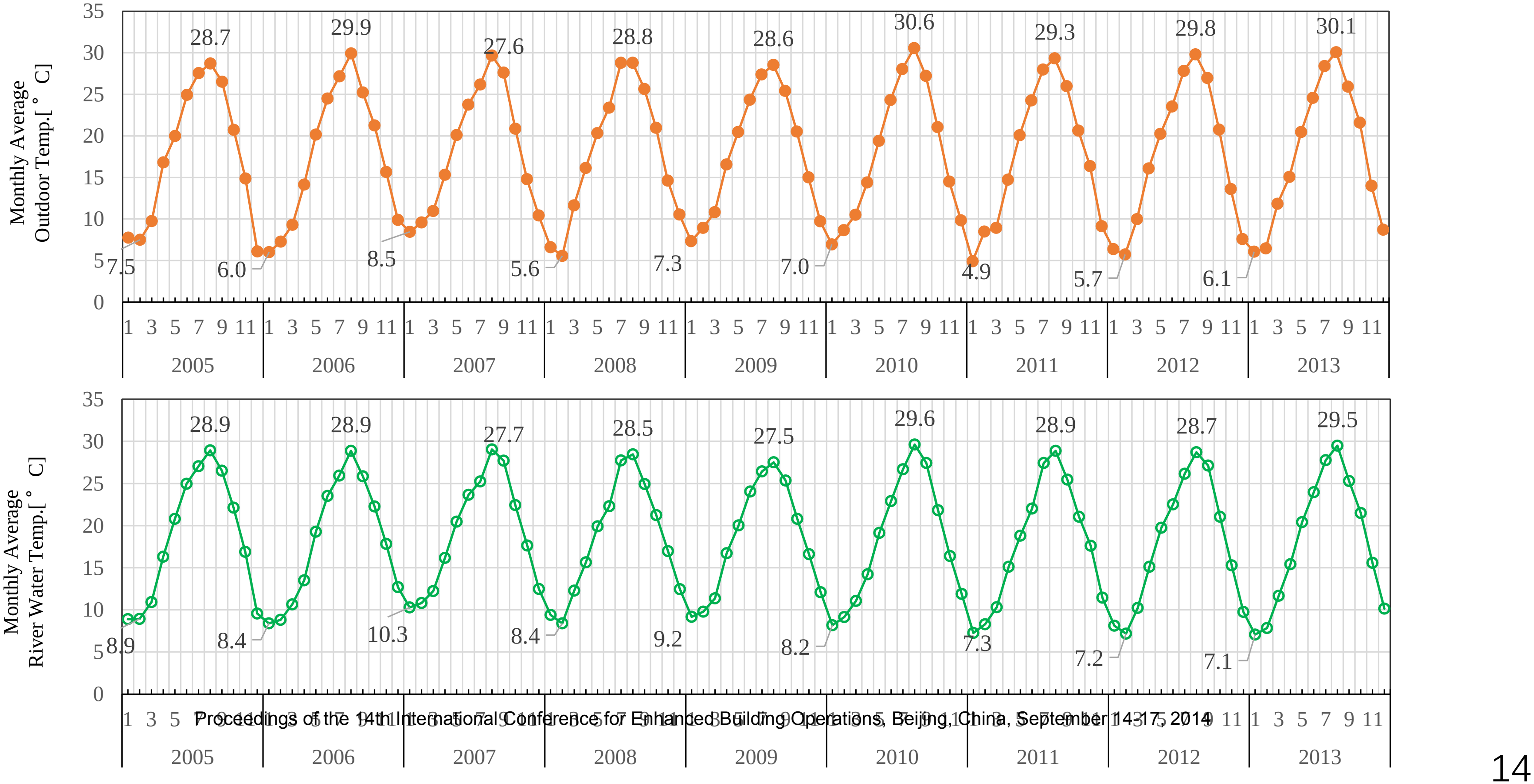
- Though affected by outdoor air temperature, river water temperature fluctuates less than outdoor air temperature.
- In summer, river water is advantageous as cooling water because it is 0.1 to 1° C cooler than outdoor air temperature.
- In winter, conversely, river water is advantageous as heat source water because it is 1 to 2.8° C warmer than outdoor air temperature.



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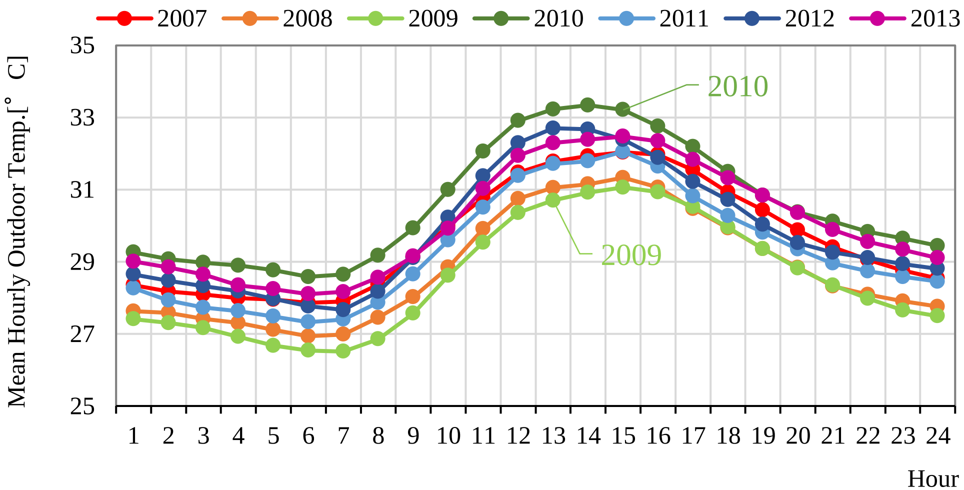
Hourly temperature fluctuations of outdoor air and river water

In terms of temperature, river water is more advantageous than outdoor air as a cooling agent.

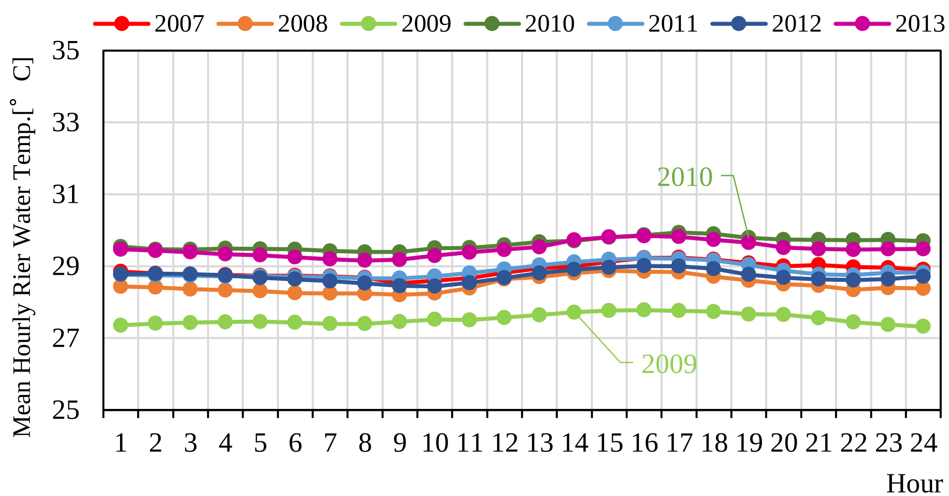
<Outdoor air temperature (August)>

- The temperature differential between a hot summer (2010) and cool summer (2009) is about 2°C.
- The temperature differential between daytime and nighttime is about 4 to 5°C.



<River water temperature (August)>

- The temperature differential between a hot summer (2010) and cool summer (2009) is about 1.5°C.
- The temperature differential between daytime and nighttime is maintained at a lower temperature than the air.



Amount of heat sold by the plant (Total)

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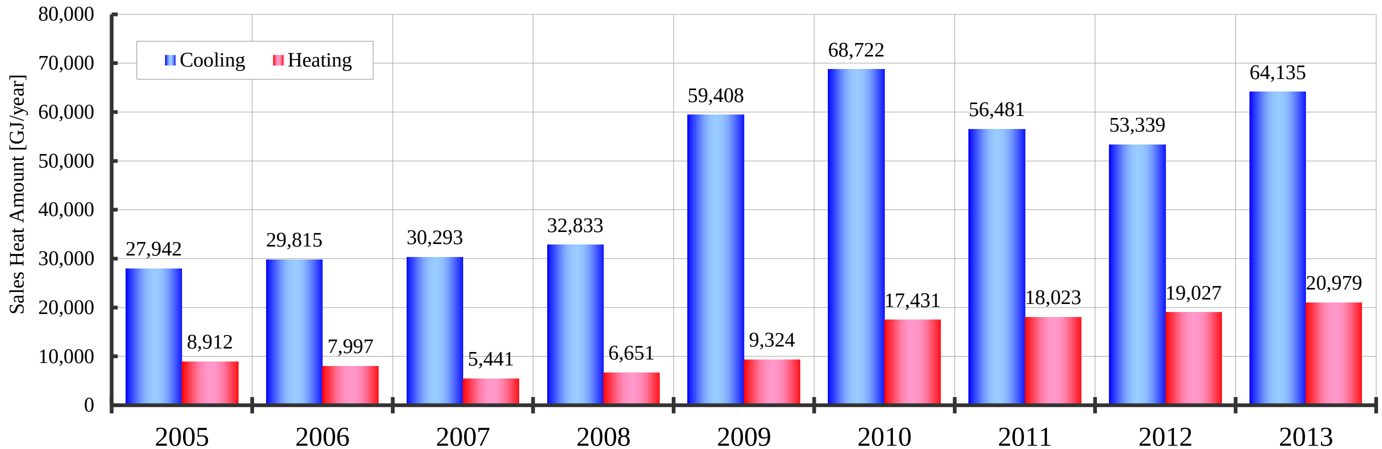
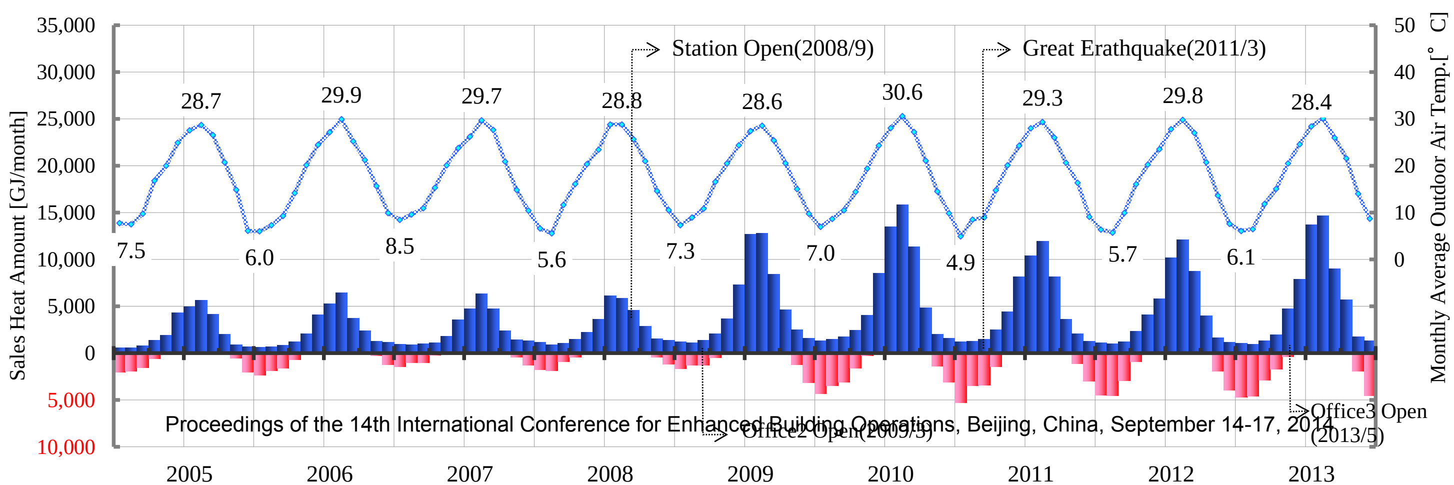
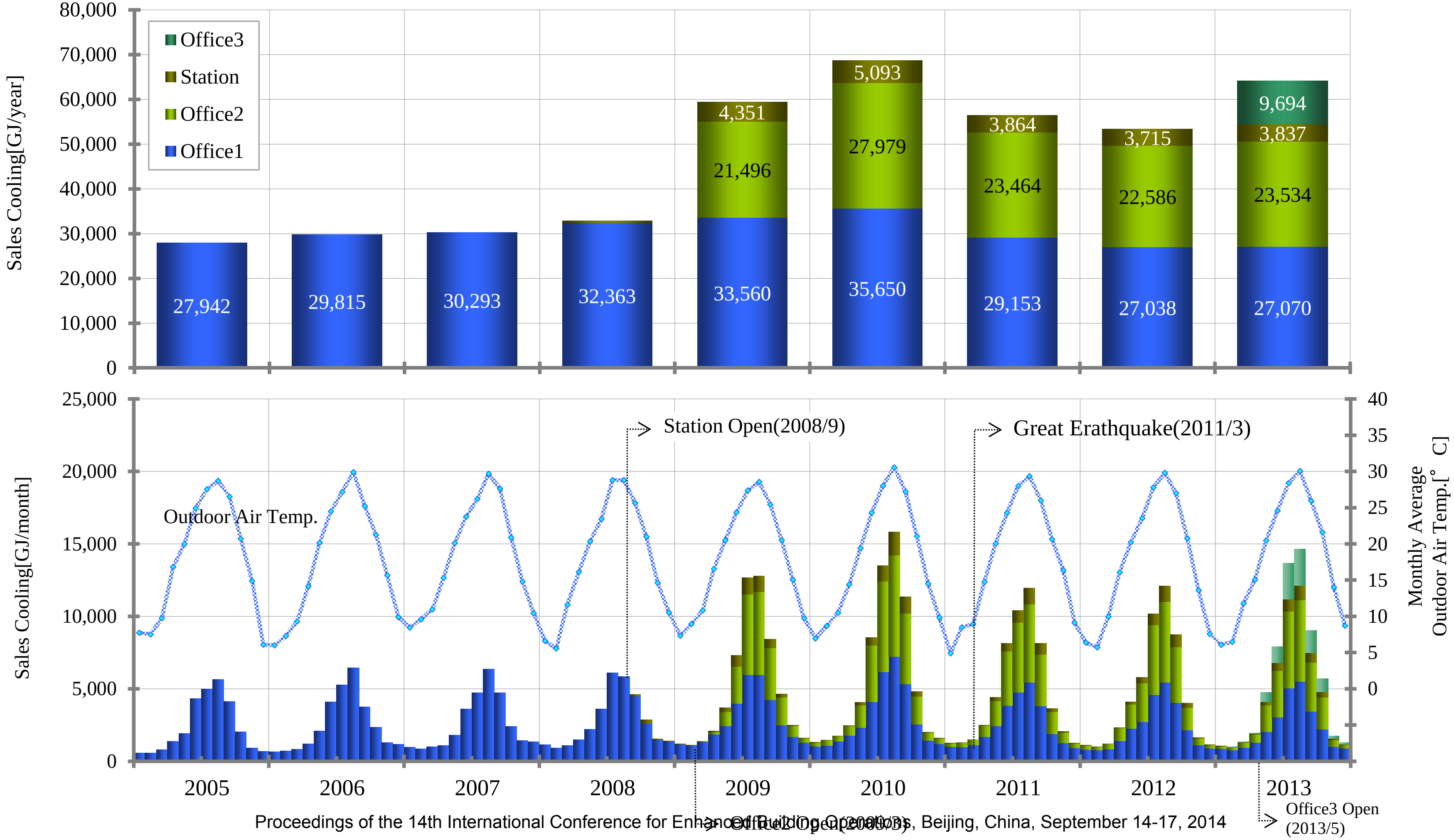
- Cooling demand was on the increase and heating demand on the decrease until 2008.
  → Due to more internal heat generation caused by the use of more large computers as well as a higher occupancy rate
- In 2010, cooling demand increased in summer due to a heat wave.
- Since 2011, the power-saving effect has become noticeable as an effect of power-saving measures on the demand side.





Amount of heat sold by the plant (per consumer, cooling)

When the 2nd stage work was completed in 2009, the amount of heat significantly increased. However, after the 2011 earthquake it decreased. Since then, the 2010 record (hot summer) has not been broken, even following the completion of 3rd stage work in 2013.



Amount of heat sold by the plant (per consumer, heating)

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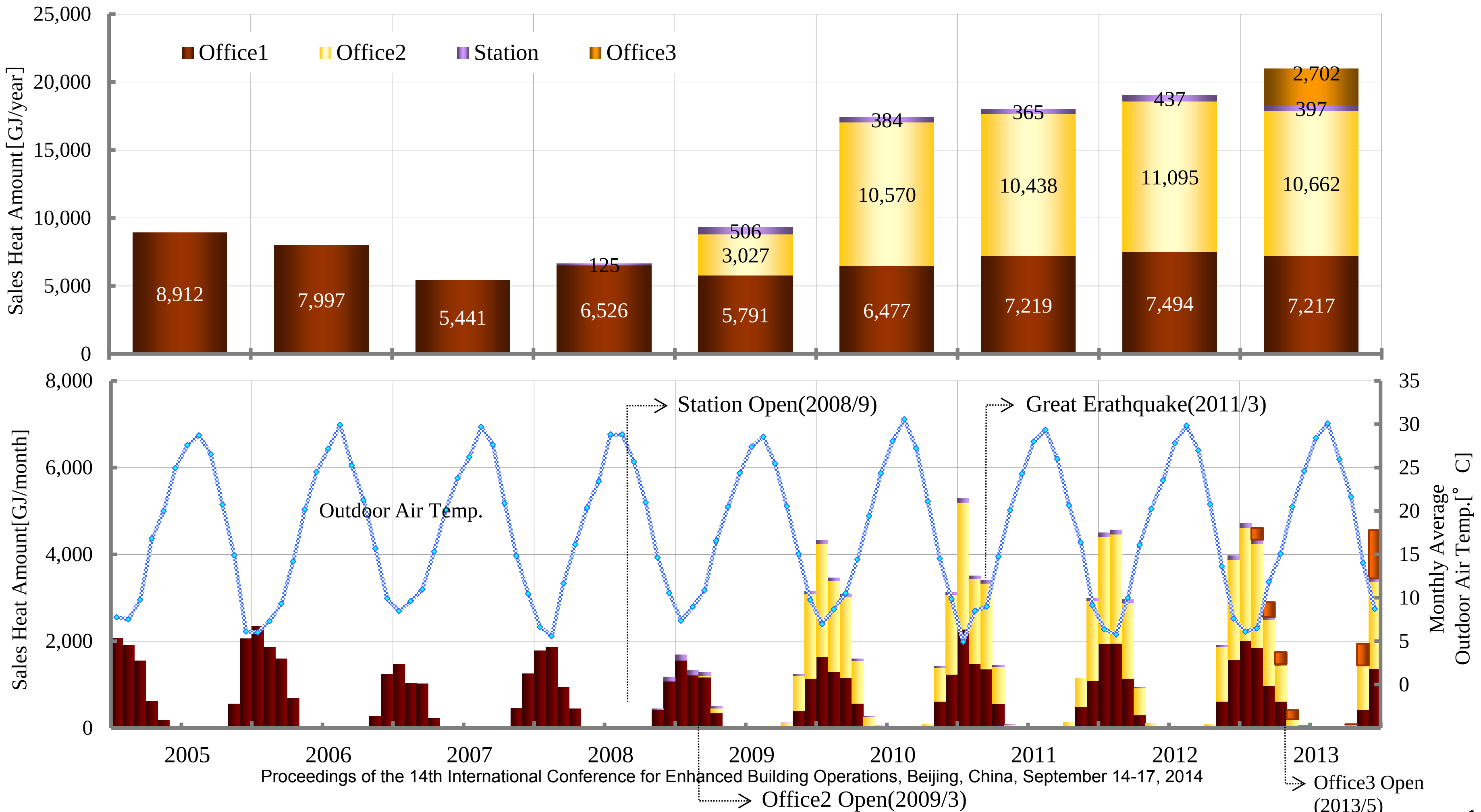
Since the 2nd stage work was completed in 2010, the amount of heat has significantly increased. After the 2011 earthquake it increased slightly.

→ After the earthquake, power-saving by consumers caused a decrease in internal heat generation.



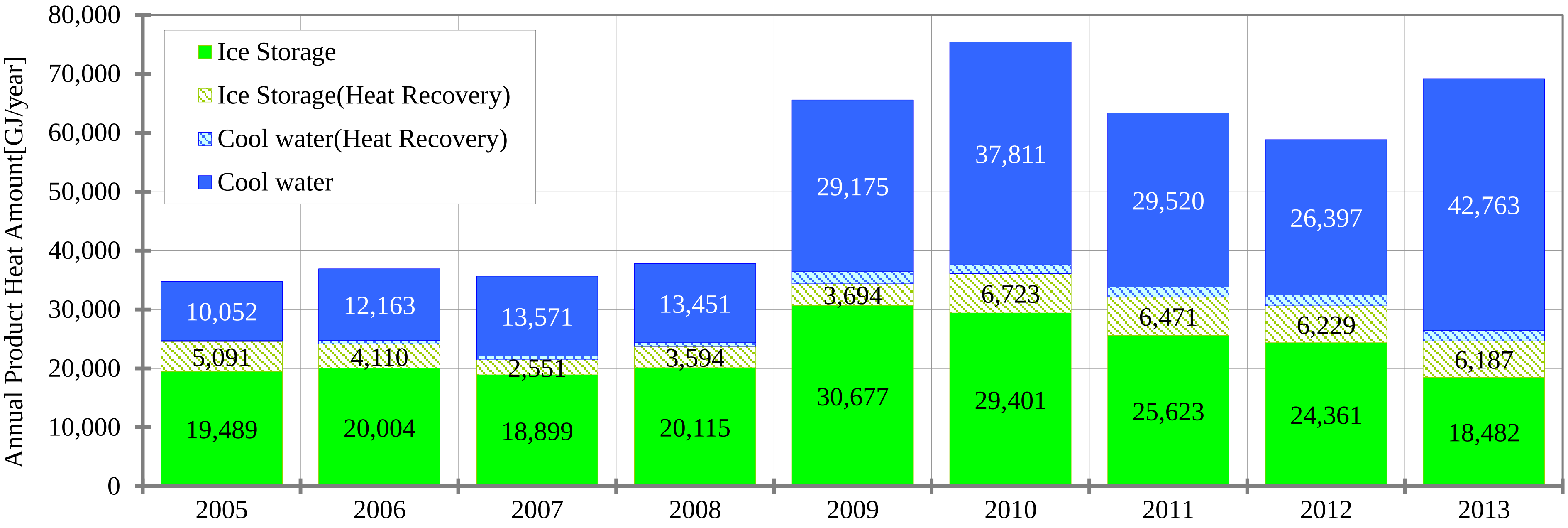
Changes to heat source operation policy since launch of operation

Mainly in order to cut down on power demand with heat storage utilizing nighttime electric power, heat source operation has been optimized considering heat load, installations of heat source equipment, and external factors such as earthquakes.

Year			1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year
			2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Performance verification and evaluation phase			Phase-1		Phase-2				Phase-3			
			Initial performance verification and evaluation		Early performance verification and evaluation				Late performance verification and evaluation			
Topics			▽ 1st stage started operation		Mild winter		▽2nd stage started operation	Hot summer	Requested electricity saving ▽The Great East Japan Earthquake		Electricity-saving target ▽3rd stage started operation	
Situation of the heat load							Incerasing load due to 2nd stage started operation	Increasing cooling load due to hot summer	Decreasing cooling load		Incerasing load due to 3rd stage started operation	
Policy of heat source operation			Utilizing nighttime electric power				Utilizing nighttime electric power High efficiency of follow-up heat source		Restraint of demand electricity Electricity saving		Restraint of demand electricity Electricity saving	
			Heat storage use and heat recovery operation				Heat storage use, heat recovery operation and increasing of follow-up operation		Keeping of heat storage use		Priority driving of high efficiency heat source	
Driving order of heat sources	Cooling	Daytime	1)IHP Melting ice 2)TR-1 3)IHP Cool water				1)TR-1 2)TR-2 3)IHP Melting ice 4)SR Melting ice 5)IHP Cooling 6)SR-1 or 2		1)TR-1 2)TR-2 3)IHP Melting ice 4)SR Melting ice 5)IHP Cooling 6)SR-1 or 2		1)TR-1 2)TR-2 3)R-31 4)R-32 5)IHP Melting ice 6)SR Melting ice 7)IHP Cool water 8)SR-1 or 2	
		Nighttime	1)IHP Melting ice				1)TR-1 or 2 2)IHP Melting ice		1)TR-2 2)IHP Melting ice		1)TR-2 2)IHP Melting ice	
	Heating	Daytime	1)HP 2)IHP Ice storage heat recovery				1)HP 2)IHP Cool water heat recovery 3)IHP Ice storage heat recovery 4)SR-1		1)HP 2)IHP Cool water heat recovery 3)IHP Ice storage heat recovery 4)SR-1		1)HP 2)IHP Cool water heat recovery 3)SR-2 4)R-31 or 32	
		Nighttime	1)HP				1)HP 2)IHP Cool water heat recovery		1)HP 2)IHP Cool water heat recovery		1)HP 2)IHP Cool water heat recovery	

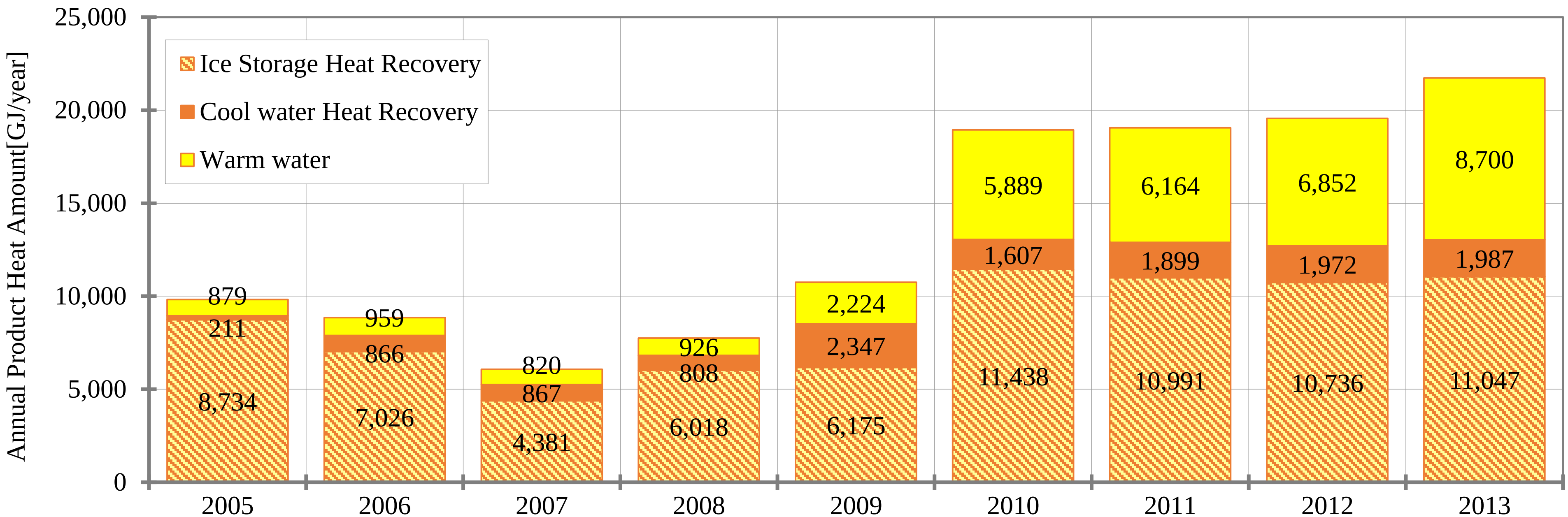
Amount of heat produced by the plant (per operation mode, cooling)

- During 1st stage, heat storage operation using nighttime electric power and highly efficient ice storage heat recovery operation were implemented.
- During 2nd stage, heat storage operation was increased and the operation of highly efficient follow-up heat source equipment was implemented.
- After the earthquake, heat demand decreased and heat storage was maintained to cut down on power demand.
- During 3rd stage, the operations of highly efficient equipment were prioritized to save power.



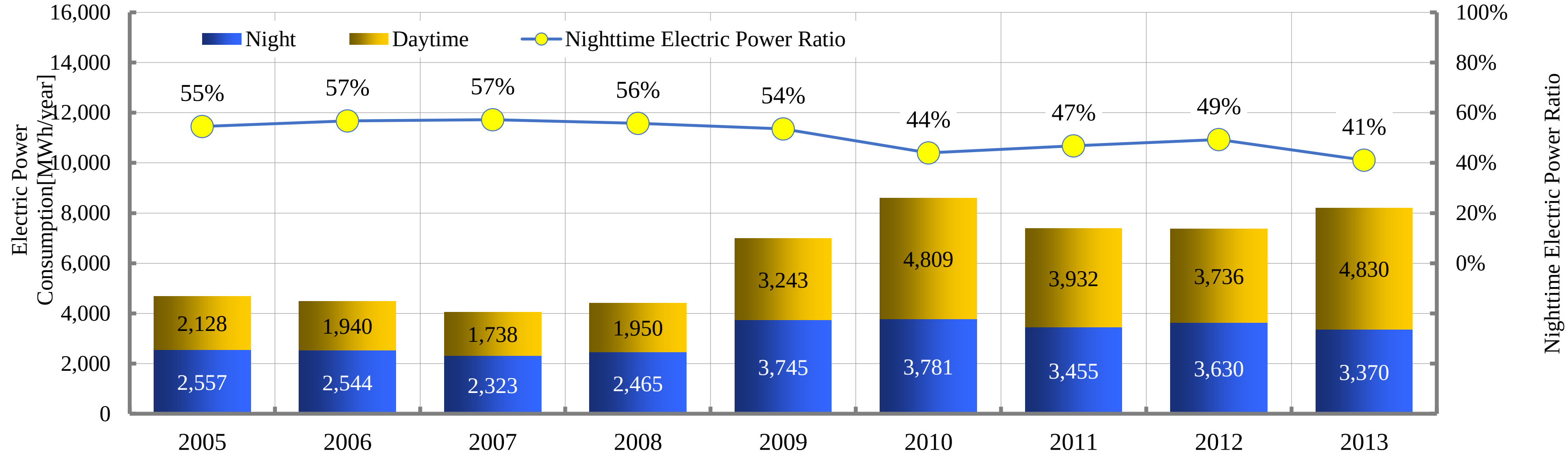
Amount of heat produced by the plant (per operation mode, heating)

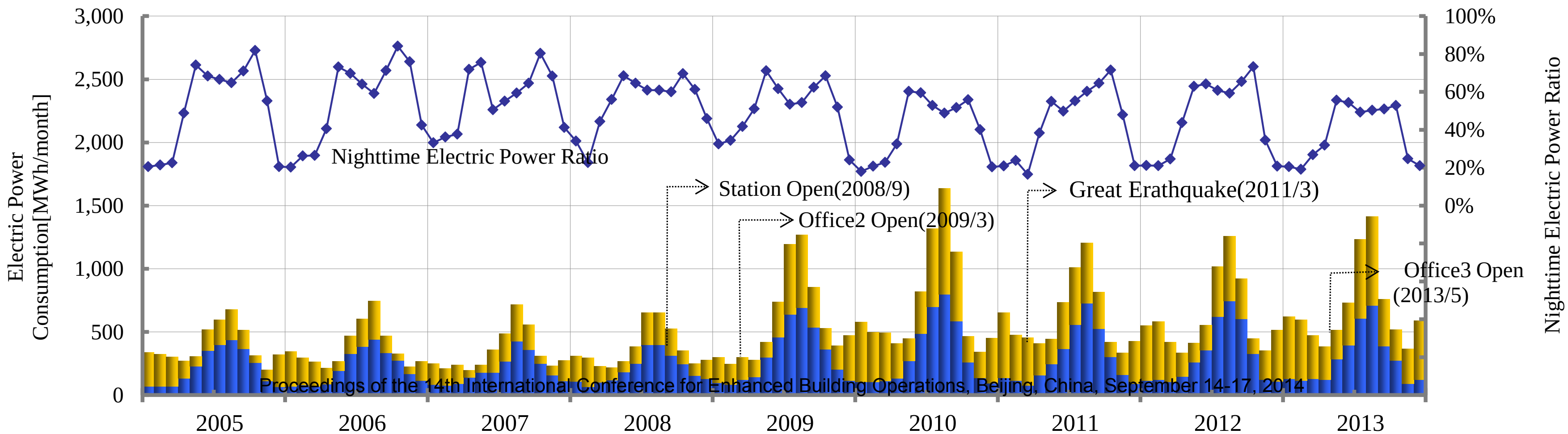
- During 1st stage, highly efficient ice storage and cool water heat recovery operation were implemented.
- During 2nd stage and later, highly efficient ice storage and cool water heat recovery operation has mainly been used, along with highly efficient follow-up heat source equipment.



Amount of power consumption by the plant (daytime and nighttime) and nighttime electric power ratio

- During 1st stage, the nighttime electric power ratio was 55% and higher. This contributed to leveling the electric load.
- During 2nd stage, the nighttime electric power decreased to 44% due to increased cooling and heating demand. After the earthquake, cooling demand decreased and the ratio relatively recovered to 49%.





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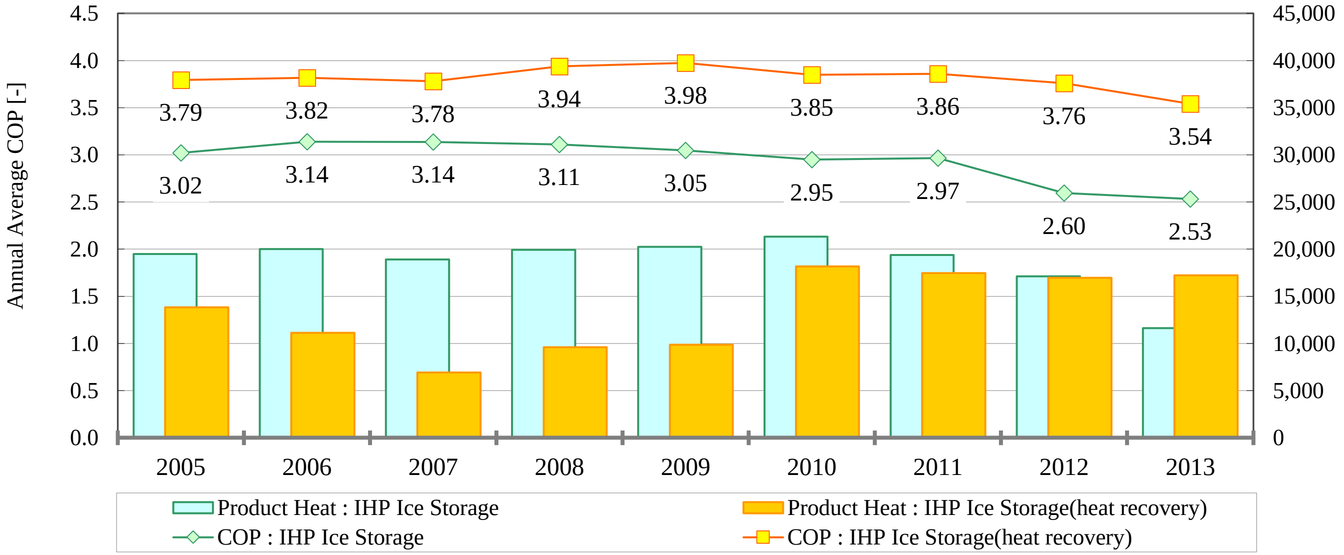
(3) Secular changes in plant performance

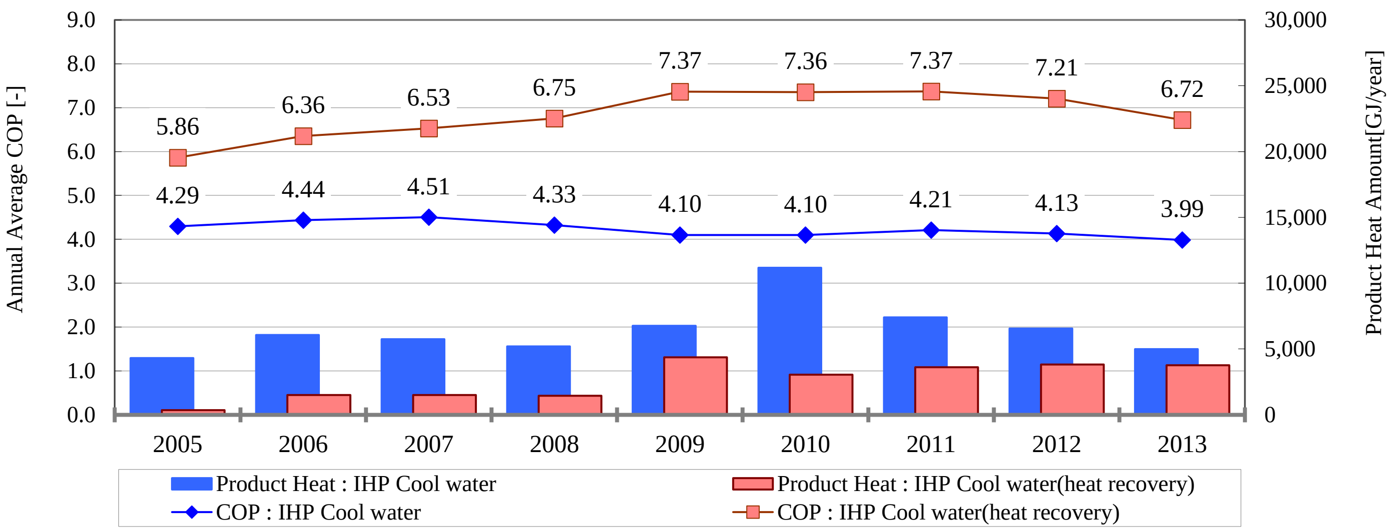
Annual average COP of IHP



<Ice storage heat recovery>
In 2013, the downward trend was remarkable.

<Ice storage>
A downward trend has been noticeable for these two years.

Normal rate COP
(Ice storage) 3.03
(Ice storage heat recovery) 5.43



<Cool water heat recovery>
In 2013, the downward trend was remarkable.

<Cool water>
There is a slight downward trend.

Normal rate COP
(cool water) 4.23
(cool water heat recovery) 7.56

Annual average COP of TR-1,2 and HP

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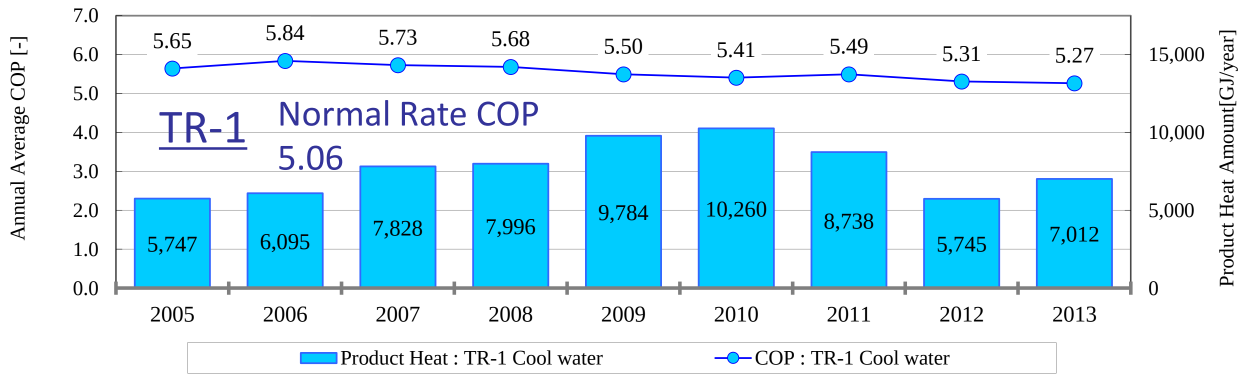
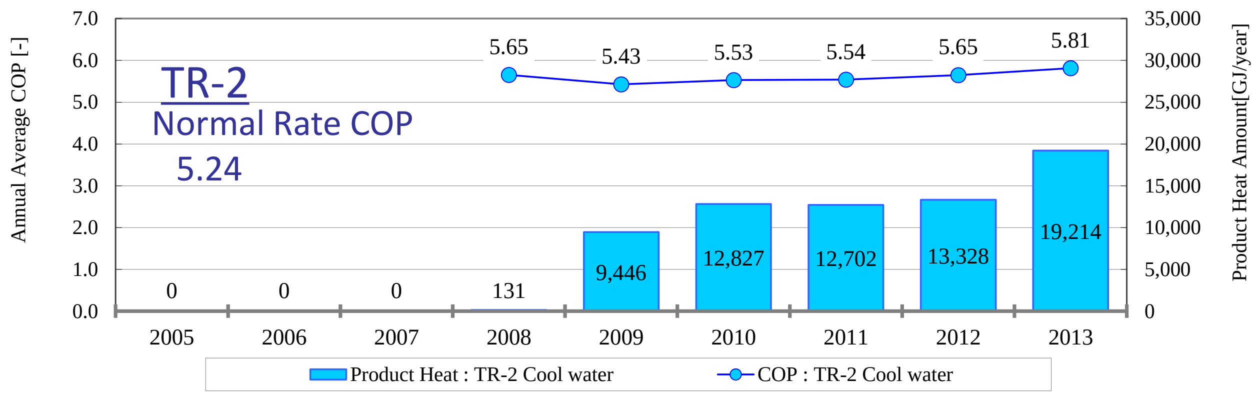
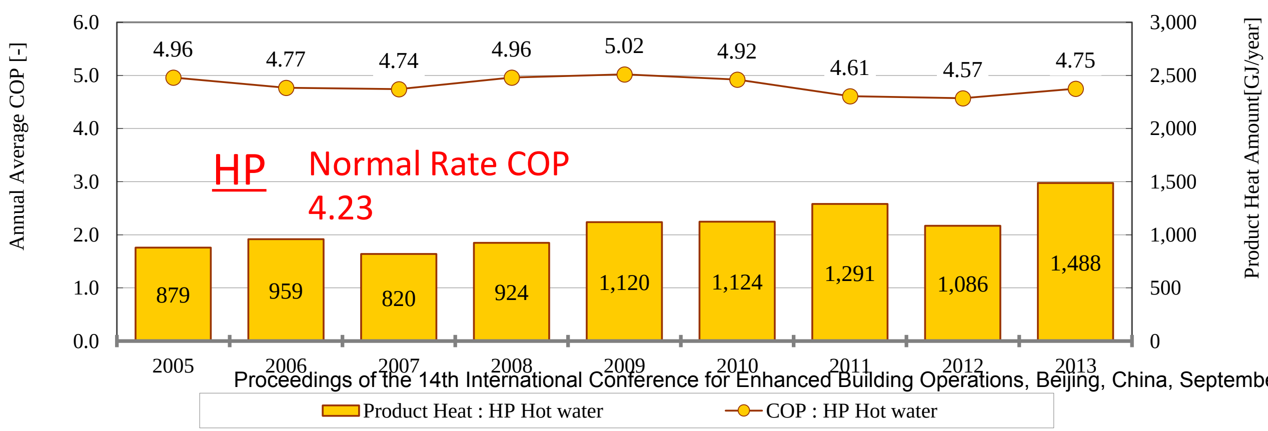


<TR-1>
There is a slight downward trend and it is within secular deterioration.



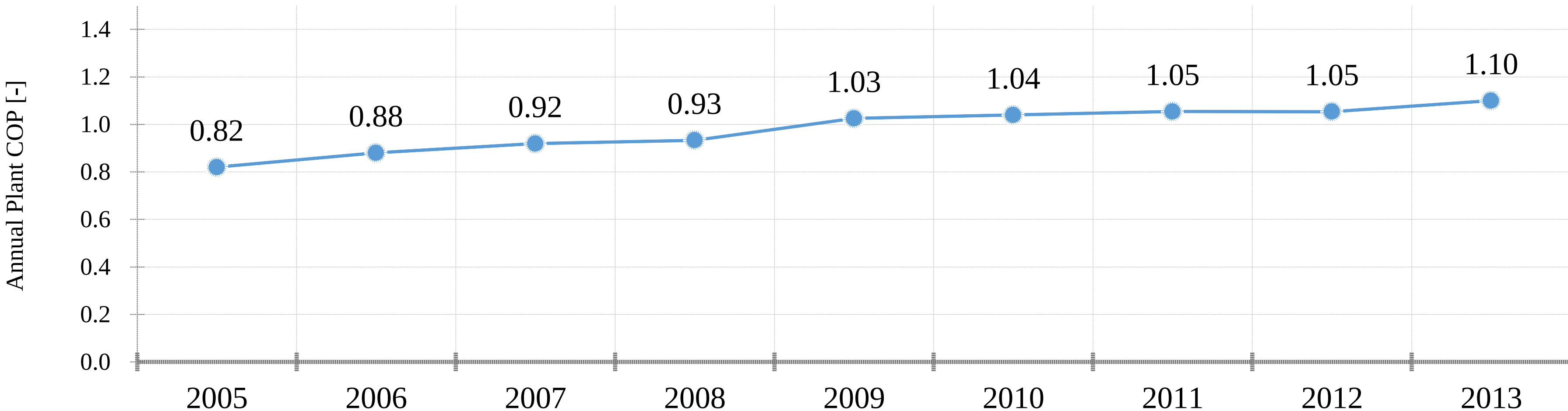
<TR-2>
An upward trend is observed due to the increased amount of heat.

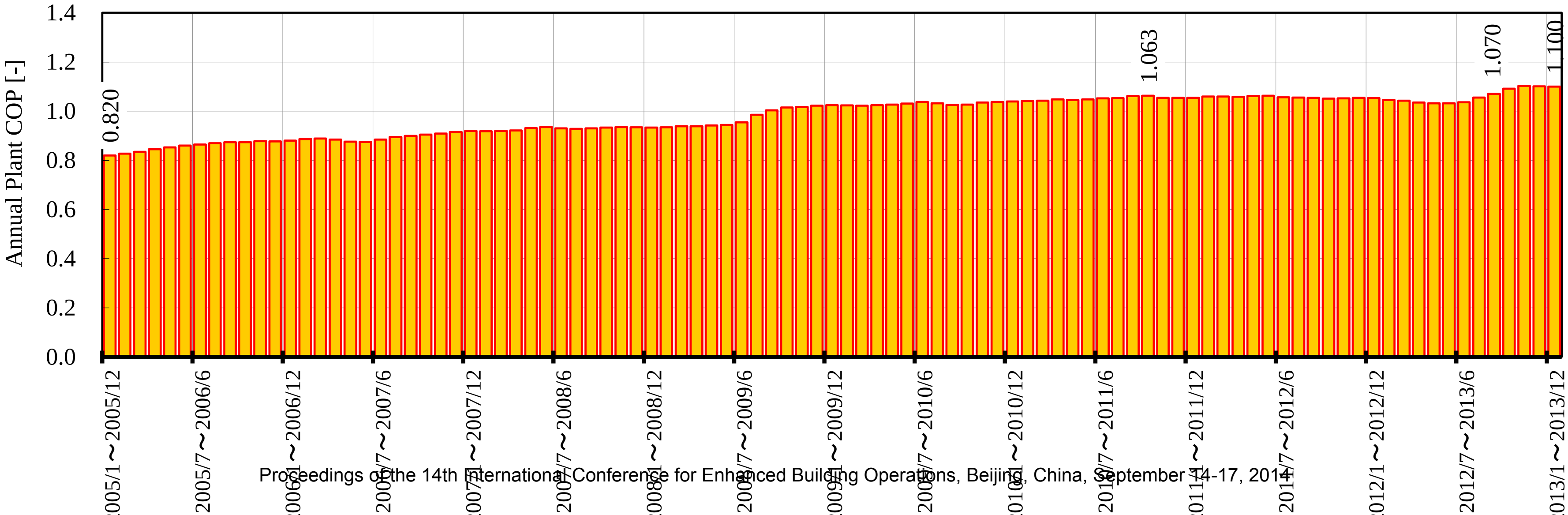


<HP>
There is a slight downward trend and it is within secular deterioration.

Annual plant COP

Since operation started, COP has steadily been increased and 2013 saw a record high of 1.10.





(4) Secular changes in facilities using river water

Maintenance history of river water heat exchangers

From work completion to 2009:

Inspection and cleaning (by blown air only) was conducted every April.

In 2010:

Eddy current testing (ECT) was conducted for the first time.

- Since 2010, cleaning with a brush has been conducted.

In 2011:

Flaw detection was performed on No.3 HEX, which had the worst pipe wall thinning, and its corrosion over one year was confirmed.

In 2012:

No.1 HEX: 141

No.3 HEX: 409 thin tubes were replaced.

In 2013: Flaw detection

In 2014: Thin tubes will be replaced depending on the inspection results.

Performance evaluation of river water heat exchangers (RHEX1 to 4)

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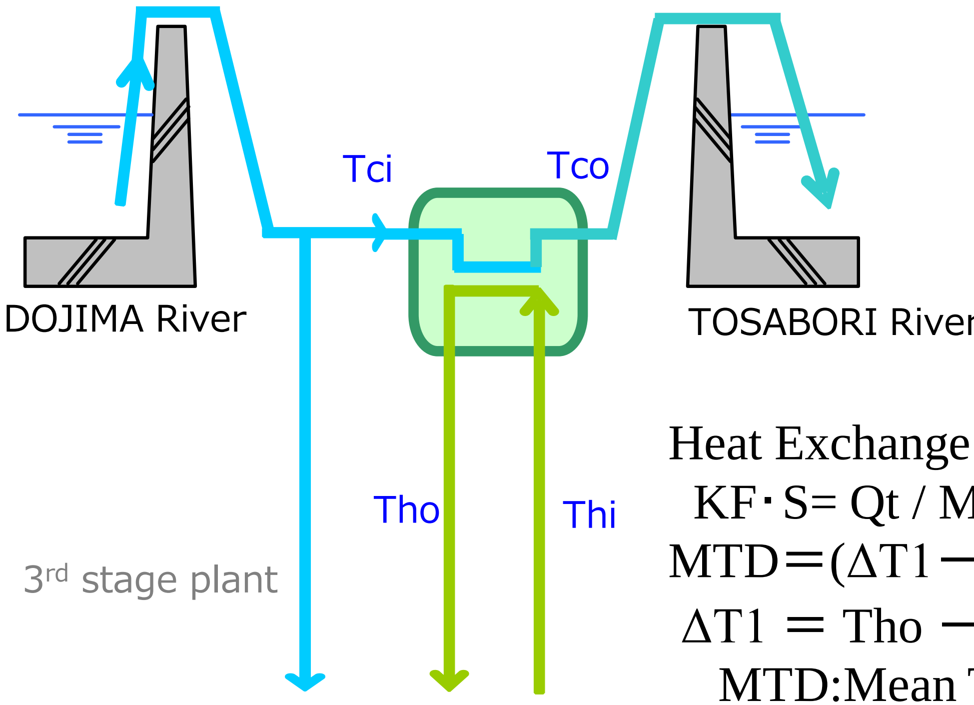

Heat Exchange Coefficient

KF・S= Qt / MTD

MTD＝(ΔT1－ΔT2)/ln(ΔT1/ΔT2)

ΔT1 ＝ Tho － Tci   ΔT2 ＝ Thi － Tco

MTD:Mean Temperature Difference

Qt:Heat Exchange Calorimetry [MW]

S:Heat Exchange Area[㎡]

By checking the change in the heat exchange coefficient, the efficiency of maintenance such as cleaning and secular changes in heat exchangers are confirmed.

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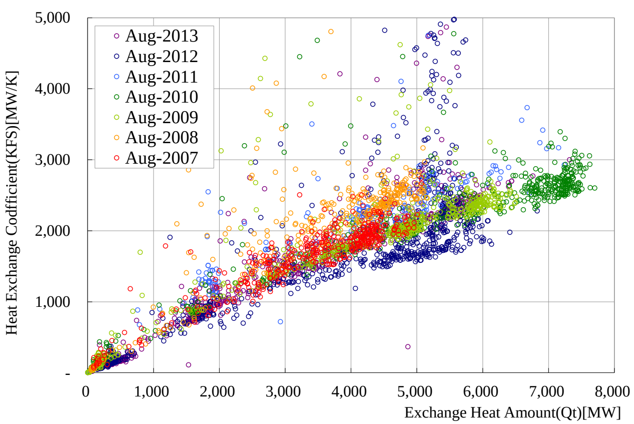
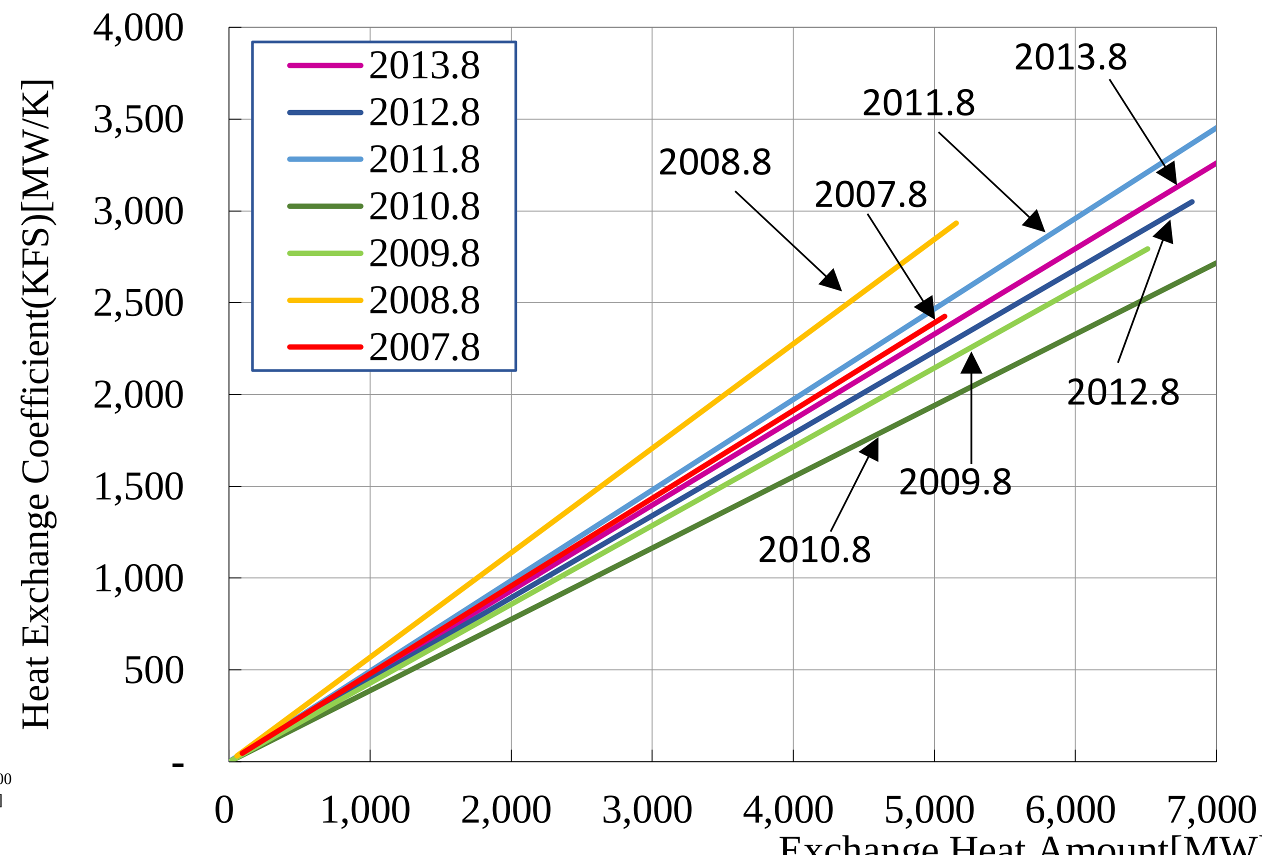
Evaluation of secular changes in heat exchangers

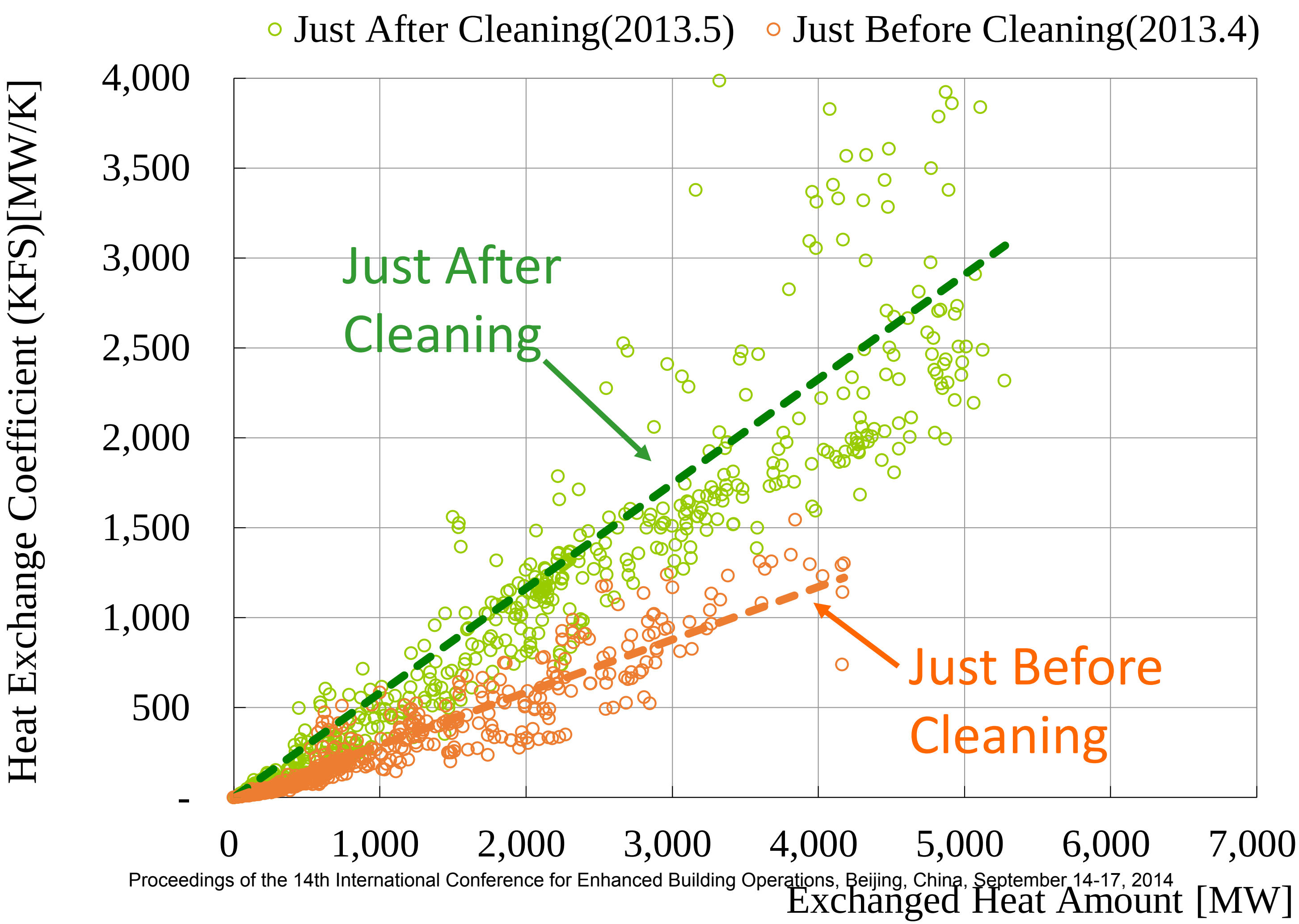
- Comparing the coefficients of each August since 2007, large secular change is not observed. The planned maintenance has helped maintain initial performance.
- The effect of replacing thin tubes in 2012 has not been confirmed.





Effect of cleaning river water heat exchangers

Comparing coefficients after cleaning (in May) to those before cleaning (in April), the improvement is apparent. The effect of annual cleaning is confirmed.



Conclusion

We have seen the performance verification and evaluation of the heating and cooling system in Osaka's Nakanoshima 3-chome district, which utilizes river water.

-Performance of this heating and cooling system has been continuously verified and evaluated to ensure proper operation and maintenance since the operation started. We have shown one example of efforts to ensure proper operation on the plant.

-We looked at the nine-year operational results since the plant was launched. Heat source operation has been optimized considering the change of heat demand, heat source arrangement, and external factors such as earthquakes.

-We have also seen the results of plant performance. Some heat source facilities indicate a slight downward trend, but since the operation started, the plant COP has steadily been increased and 2013 saw a record high of 1.10.

-We have seen the secular changes in facilities using river water. The planned maintenance has helped maintain the initial performance.

Thank you for your attention.