KOREA DISTRICT HEATING CORP.

The study on the effect of each District Heating substation's return temperature on the CHP electricity production opportunity cost

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Korea District Heating Corporation

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Introduction

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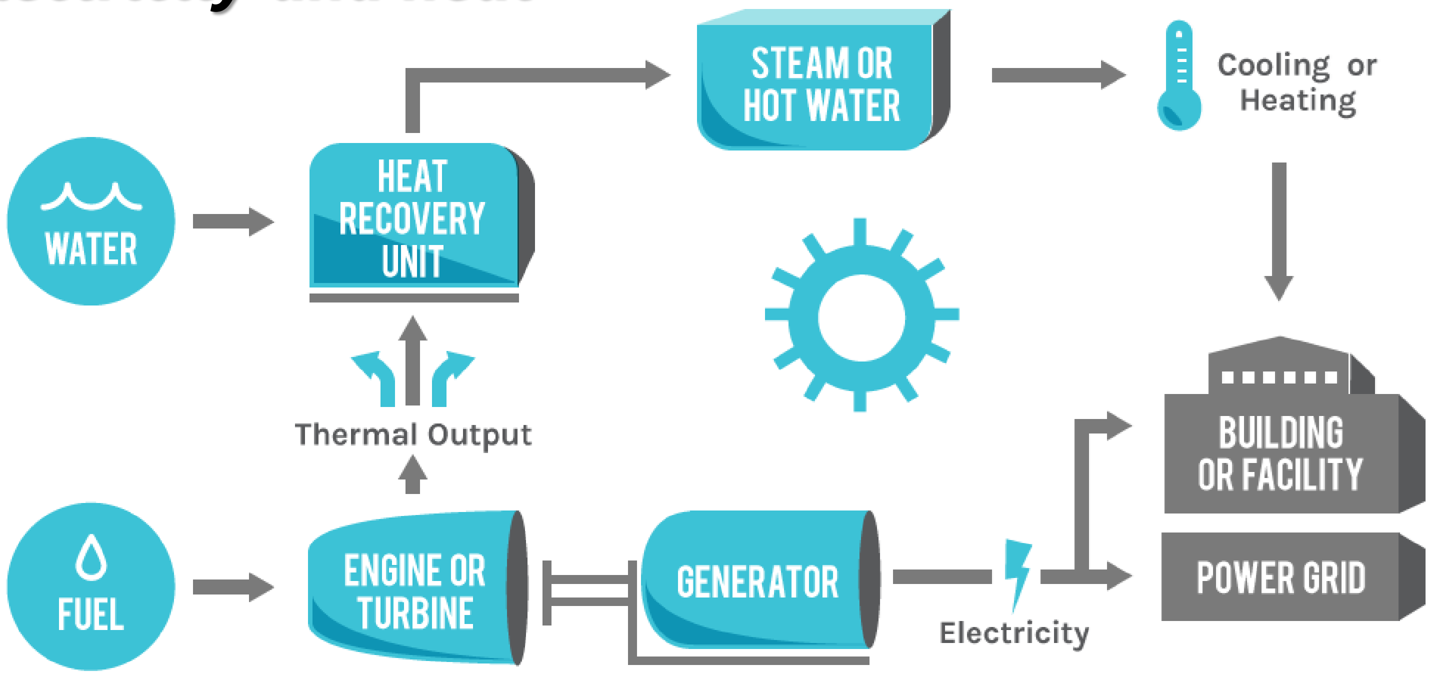
● Definition of CHP(Combined Heat & Power)

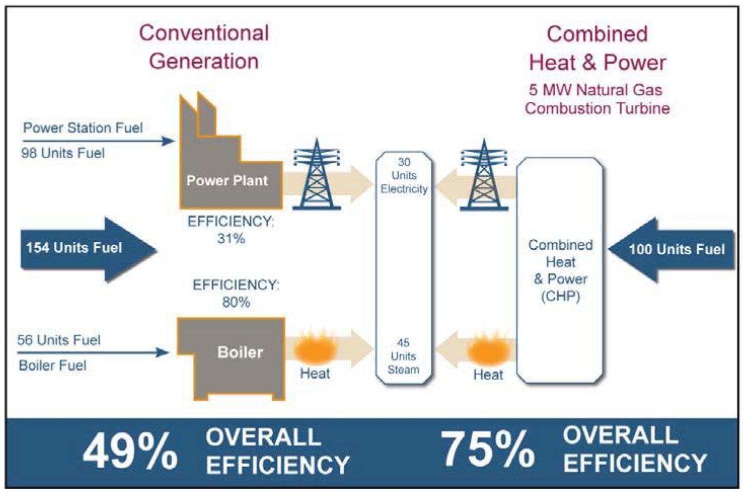
➢ One of the Power generation system which can generate electricity and heat

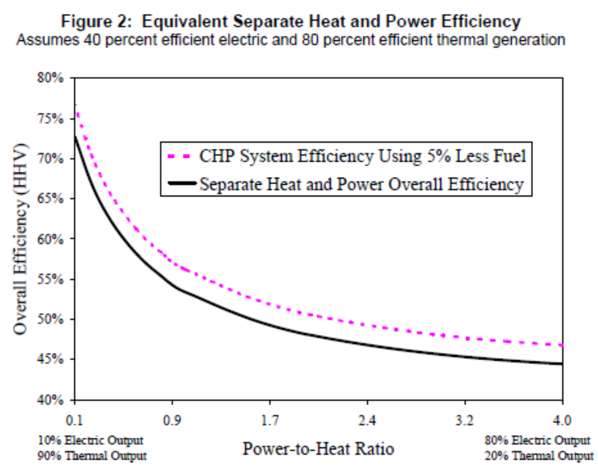


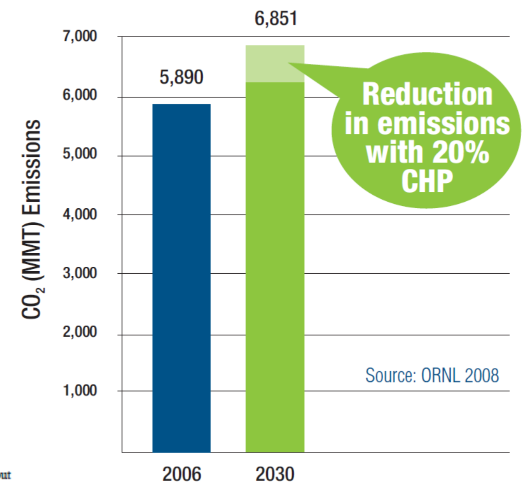
- Source : http://www.dynamicenergyusa.com/solutions/combined-heat-power/

CHP System is very valuable system for reducing Energy consumptions

- ***Combined Heat & Power(CHP) System is one of the solution for using energy more efficiently***
  - ***High efficiency and low emissions comparing to conventional Electricity and heat generation***





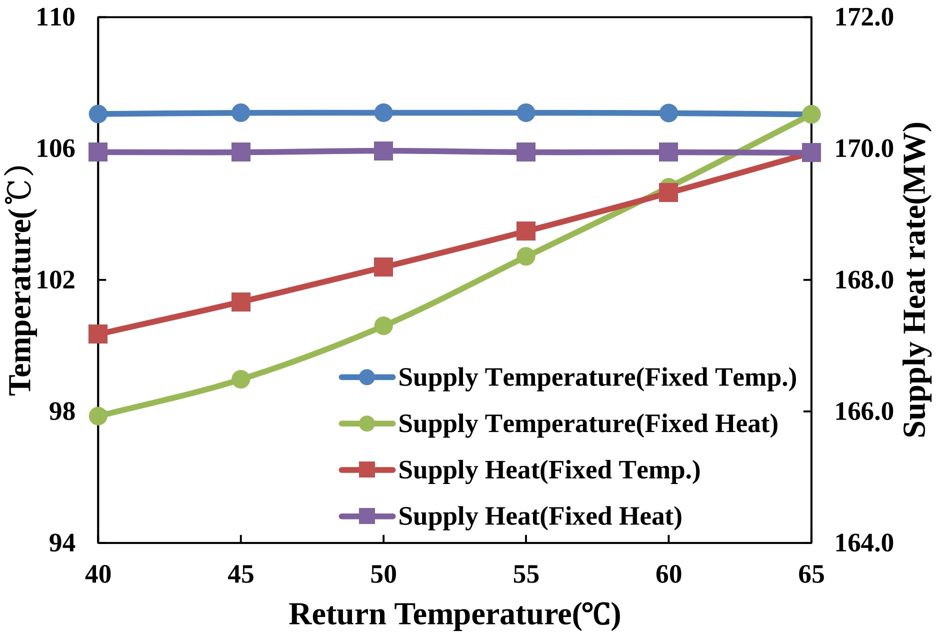


CHP Can Avoid 60 Percent of the Potential Growth in Carbon Dioxide Emissions Between 2006 and 2030

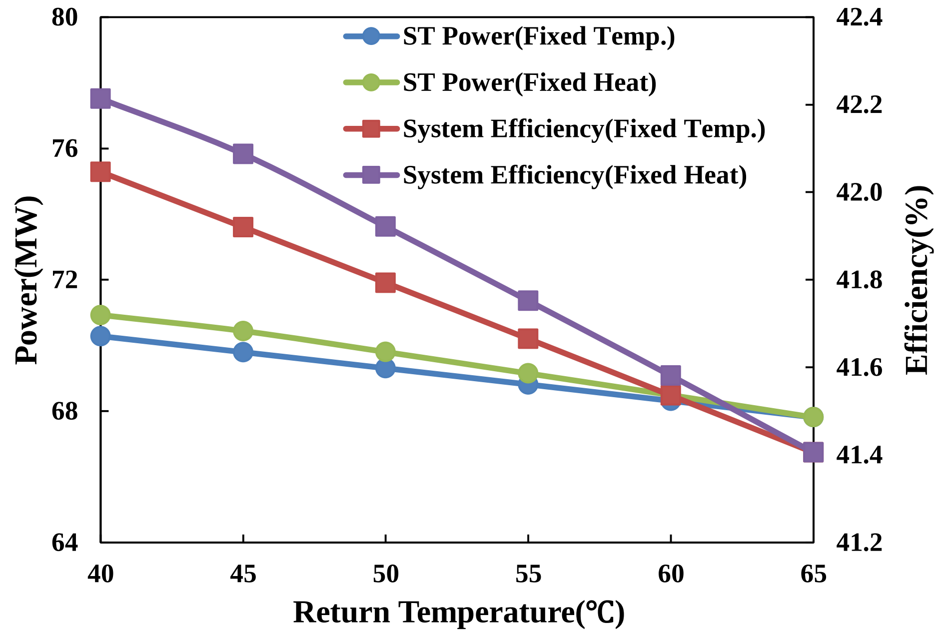
- *Catalog of CHP Technologies, U.S. Environmental protection Agency CHP Partnership, 2008*
- *A decade of progress Combined Heat and Power, U.S. Department of Energy, 2009*

More efficient operating of CHP can reducing much more energy consumptions as possible

CHP System performance variations by DH return temperature variations(System efficiency and Back Pressure variations)



Supply Temperature and Heat rate variation vs. Returning Temperature



System Power and Efficiency variation vs. Returning Temperature

CHP Performance are varied by District Heat Return Temperature variations

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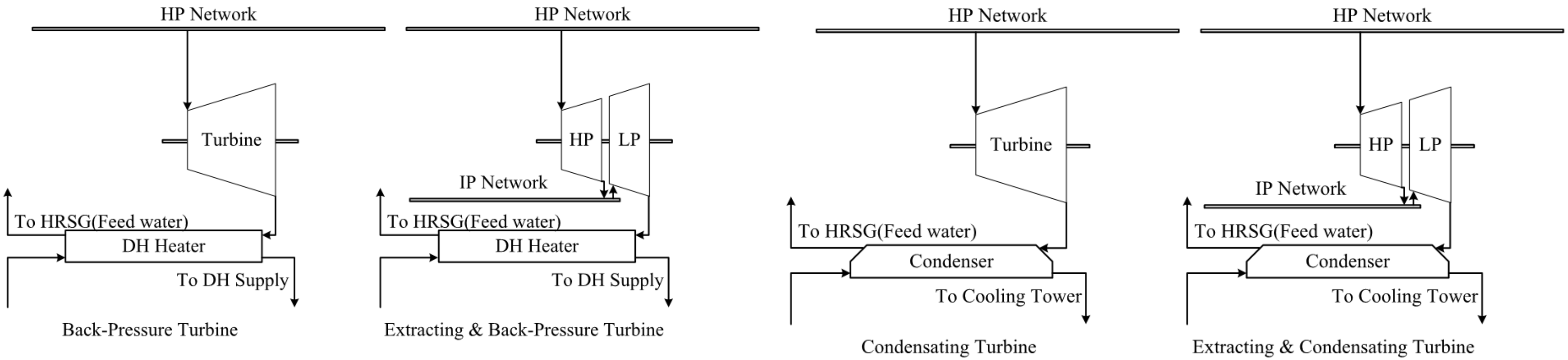
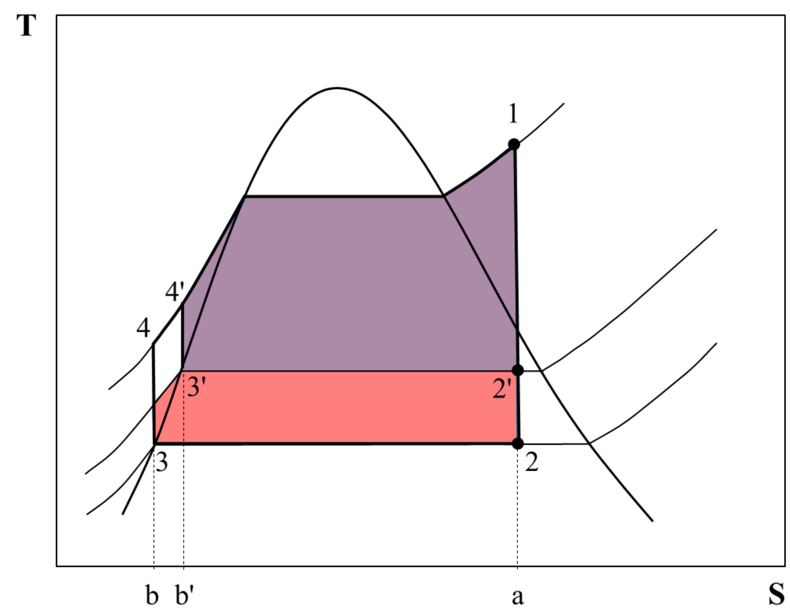
● Condensing Turbine & Back Pressure Turbine



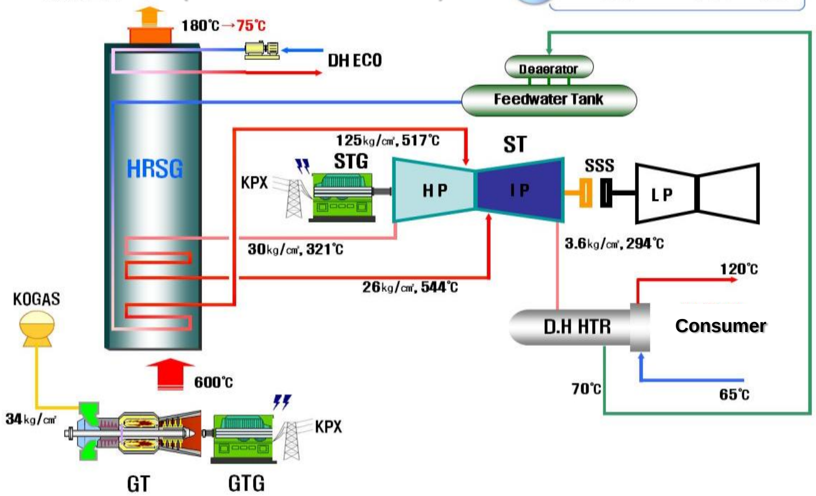
● Back pressure type

- Don't required condenser(Cost ↓)
- Single(Double) pressure system
- Narrow range Control Heat & Power ratio
- More easy control system than Condenser type
- Power generation can varied when the return temp. are varied

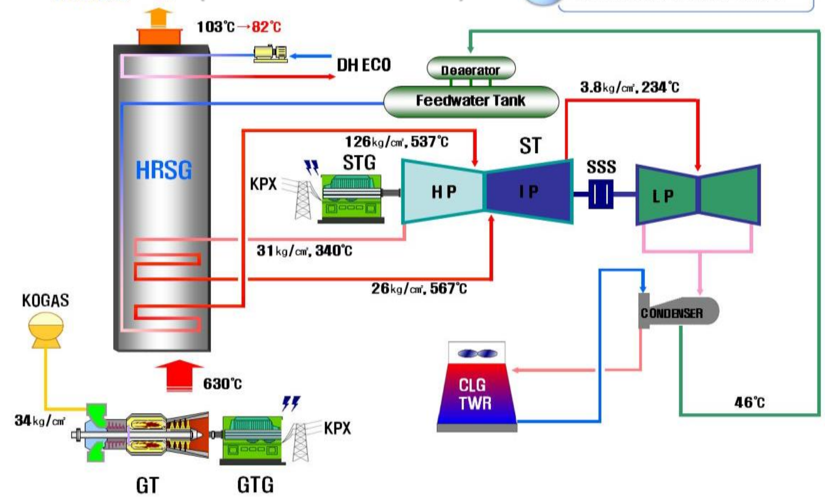


● Mode Operations

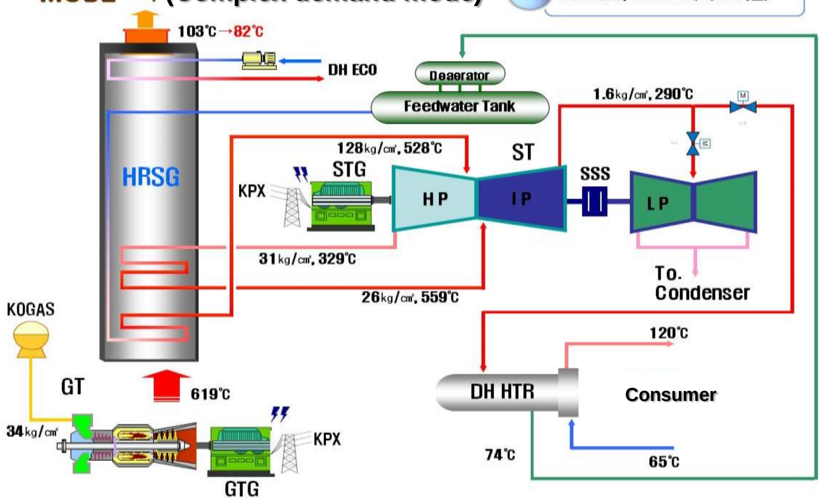
MODE -I (Heat Demand mode) 494.0MW, 392.6Gcal/h(-12℃ 기준)



MODE – III (Elec. Demand mode) 515.5.0MW, 0.0Gcal/h(32℃ 기준)



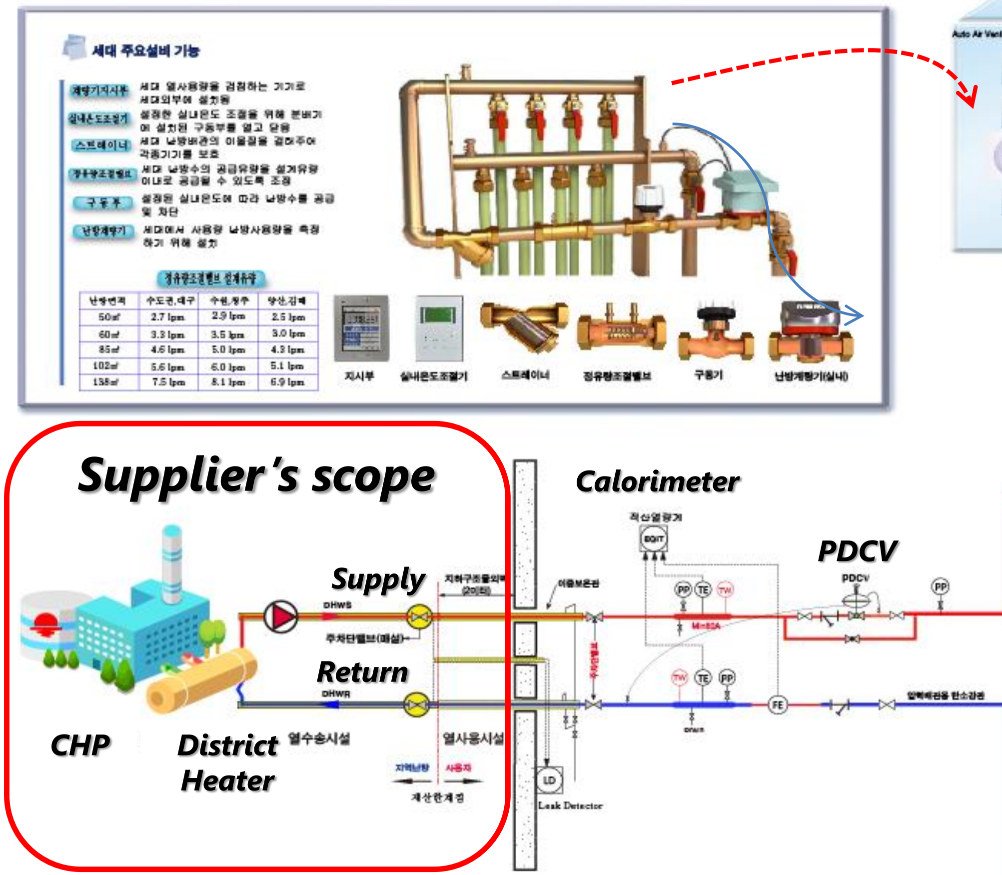
MODE – V (Complex demand mode) 518.3MW, 302.8Gcal/h(5℃ 기준)

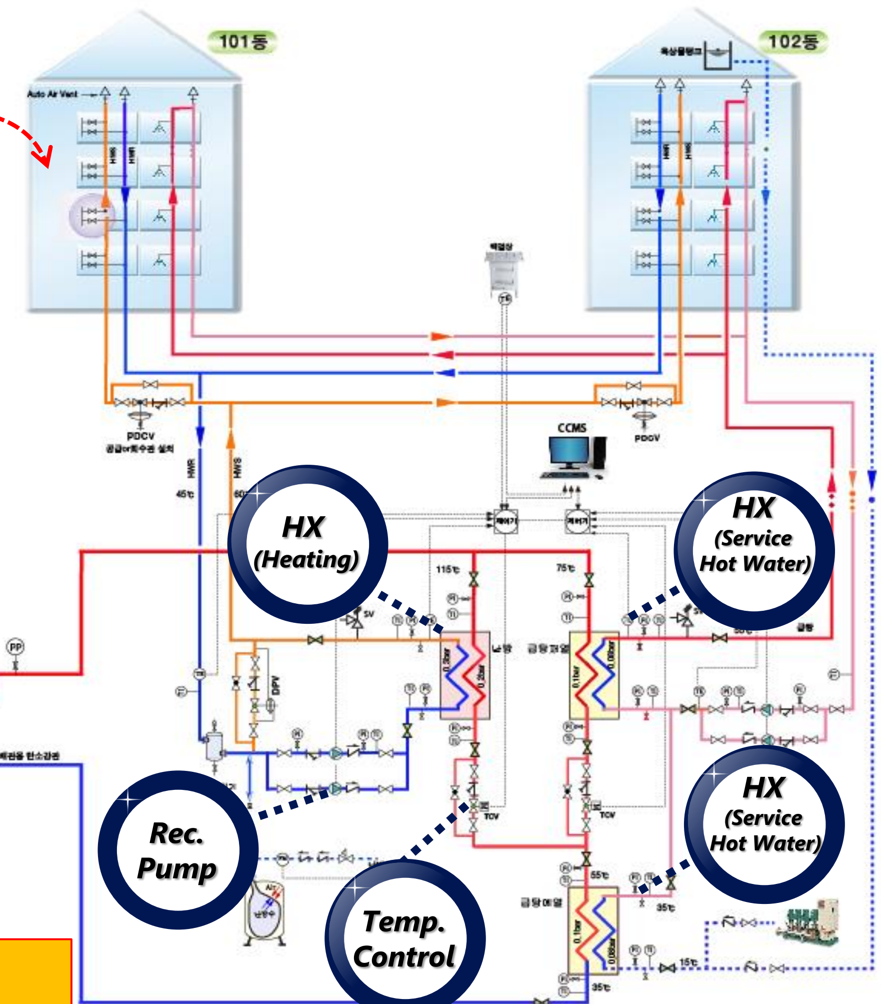


● Benefits of Mode Operations

- ➢ ***Wide range control* of Heat-Electricity ratio**
- ➢ ***Possible to respond* for seasoning heat/electricity demands**
- ➢ **Possible to *maximize revenue***
- ➢ ***Securing Reliability* of Heat & Power generation**

Introduction
Research Background



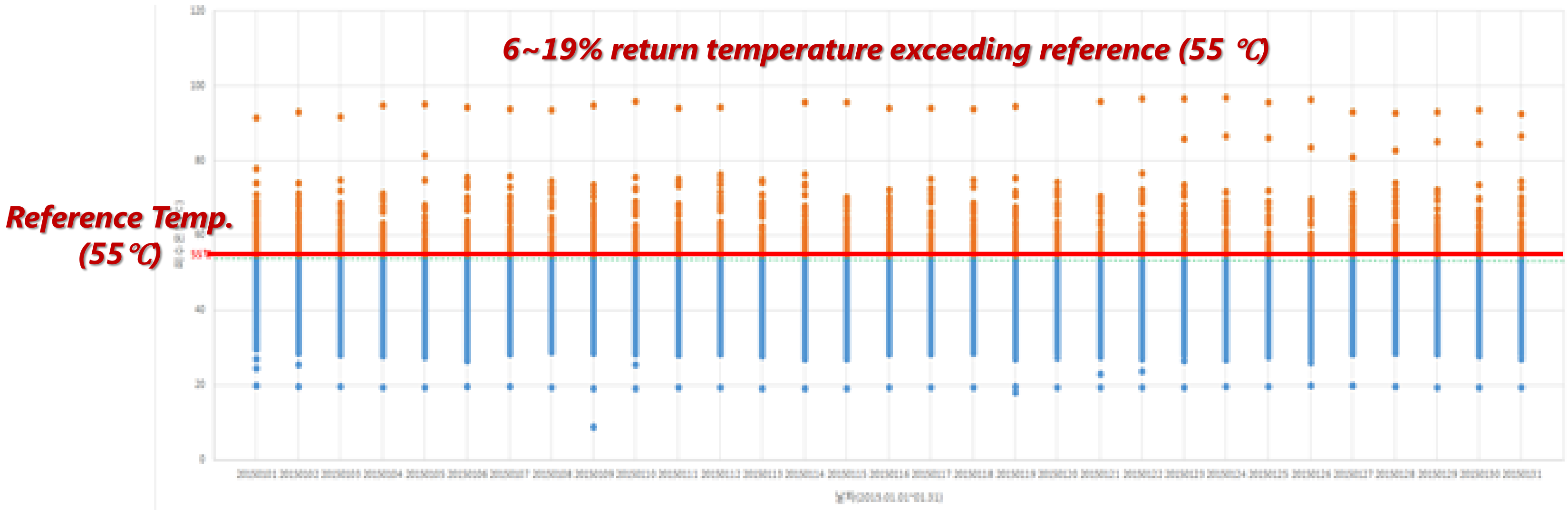


- Customer side is not KDHC scope and many problems have been happened in customer side
- KDHC supplying heat to 1.3million households and 2,100 buildings (13,000 substations)

● User return temperature operation status
(for 508 users in KDHC A branch, over 55 ℃ return temperature)

Month	1	2	3	4	5	6	7	8	9	10	11	12
%	16.8	11.4	12.8	11.9	11.4	12.4	12.6	13.3	11.0	9.8	9.9	11.4

● Jan 2015 Daily user return temperature distribution
(A branch, 508 users)



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- **Analysis of the change of heat source performance and opportunity cost according to user return temperature**

- Step1 : Analyzing on the effect that return temperature of each substation influence to total return temperature
  - Mathematically summarize the effect on the total return temperature rise for the reference return temperature(55℃)

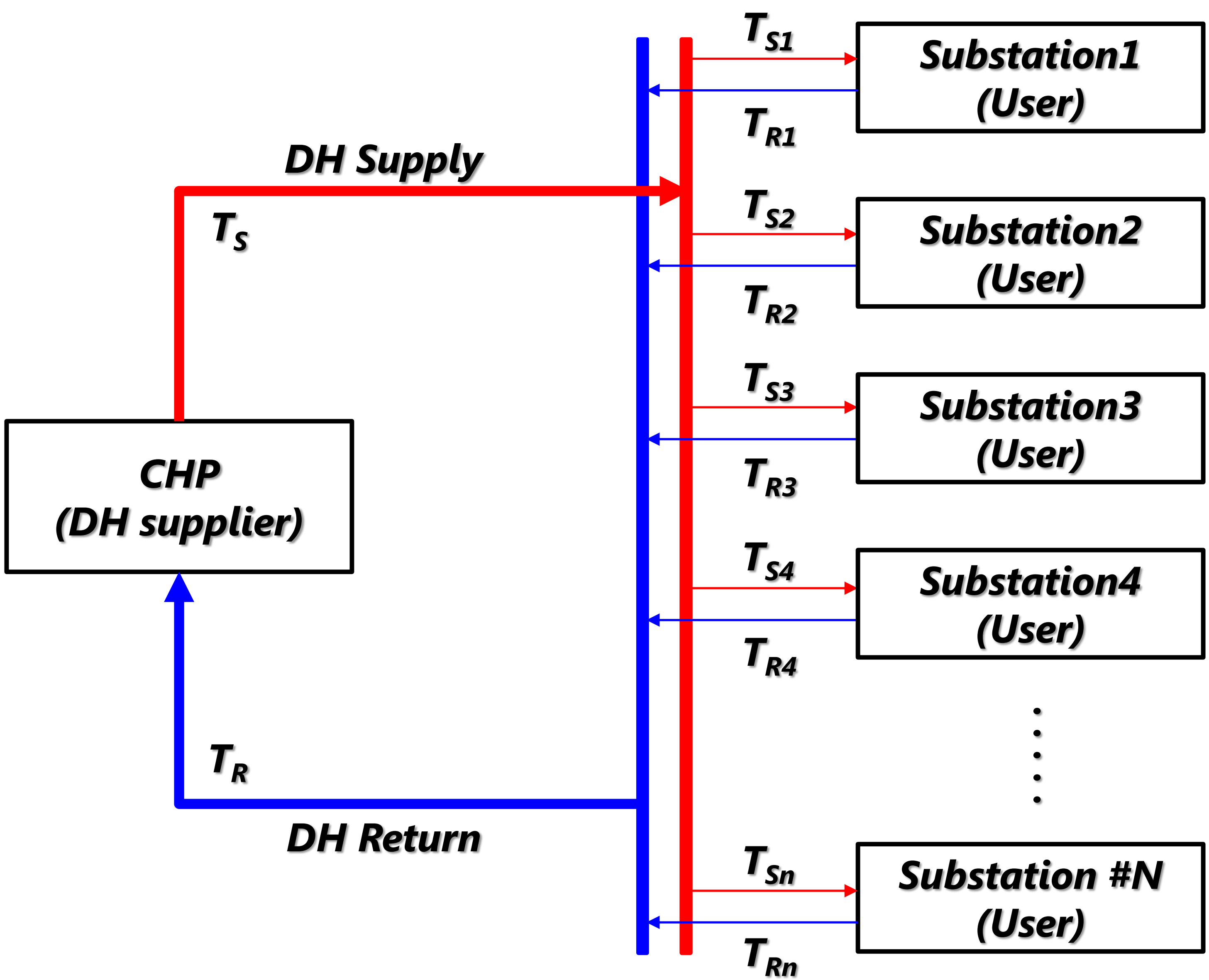
- Step2 : Estimate cost of power generation opportunity loss in heat source with total return temperature change
  - Commercial CHP Plant simulation Using commercial simulation program(GateCycle)

- Step3 : Analysis of effect of return temperature of individual users on cost of lost electricity production opportunity of CHP
  - Utilizing the operating data of A branch of Korea District Heating Corporation
  - 508 Substations (additional cost analysis of 115 users with a return temperature of 55 ℃ or higher)

System modeling

System Modeling

Conceptual diagram of total return temperature calculation



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Basic Equation

➢ Heat production : $Q = cm\Delta T$

c: specific heat of DH supply water
m: mass of DH supply water
$\Delta T=(T_S-T_R)$: Temperature difference between supply and return

Assumptions

$$Q - Q_{loss} = Q' = \sum_{i=1}^{n} Q_i$$

- Q ', excluding Qloss from Q, is equal to the sum of the Qi which are used by the individual user.
- Q_{loss} is not related to the result when analyzing the effect of individual user's return temperature on total return temperature.

The derived equation #1

$$Q = cM(T_S - T_R) = cm_1(T_{s1} - T_{r1}) + \cdots + cm_n(T_{sn} - T_{rn}) \quad M = \sum_{i=1}^{n} m_i$$

$$= c\sum_{i=1}^{n} m_i(T_{si} - T_{ri})$$

$$\therefore T_R = \frac{c\sum_{i=1}^{n} m_i(T_{si} - T_{ri})}{M}$$

T_{si}: i-th substation Supply temperature

T_{ri}: i-th substation return temperature

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- **The derived equations #2 when the return temperature of the i-th user is changed to 55℃**

$$Q_i = cm_i(T_{si} - T_{ri}) = cm_{55i}(T_{si} - 55) \qquad \therefore m_{55i} = \frac{m_i(T_{si} - T_{ri})}{c(T_{si} - 55)} = \frac{Q_i}{c(T_{si} - 55)}$$

$$cM\grave{}_{55i}(T_S - T\grave{}_{Ri}) = cm_1(T_{s1} - T_{r1}) + \cdots + \frac{cQ_i}{c(T_{si} - 55)}(T_{si} - 55) + \cdots + cm_n(T_S - T_{rn})$$

$$(T_S - T\grave{}_{Ri}) = \frac{m_1(T_{s1} - T_{r1})}{M\grave{}_{55i}} + \cdots + \frac{Q_i}{cM\grave{}_{55i}} + \cdots + \frac{m_n(T_{sn} - T_{rn})}{M\grave{}_{55i}}$$

$$= \frac{m_1T_{s1} + \cdots + m_{i-1}T_{si-1} + m_{i+1}T_{si+1} + \cdots + m_nT_{sn}}{M\grave{}_{55i}} + \frac{Q_i}{cM\grave{}_{55i}}$$

$$- \frac{m_1T_{r1} + \cdots + m_{i-1}T_{ri-1} + m_{i+1}T_{ri+1} + \cdots + m_nT_{rn}}{M\grave{}_{55i}}$$

$$\therefore T\grave{}_{Ri} = T_S - \frac{\sum_{i=1}^{n} m_i(T_{si} - T_{ri}) - m_i(T_{si} - T_{ri})}{M\grave{}_{55i}} + \frac{Q_i}{cM\grave{}_{55i}}$$

The T_{Ri} value is affected by the return temperature of the rest users.

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The modified derived equations #2

$$\triangle T'_{R55(i)} = T_S - \frac{Q'}{c(\sum_{i=1}^{n} m_{55(i)} - m_{55(i)} + m_i)} - 55$$

$$= T_S - \frac{Q'}{c(\sum_{i=1}^{n} \frac{Q_i}{c\cdot(T_{si} - 55)} - \frac{Q_i}{c\cdot(T_{si} - 55)} + m_i)} - 55$$

- **When the return temperature of the i-th user is higher than 55℃,**
  - ✓ **the return temperature of other users is adjusted to 55℃ to eliminate the influence of other machine rooms(Fixed supply heat and temperature, flow rate are adjusted)**
  - ✓ **We can evaluating Only the i-th user's return temperature impact.**
  - ✓ **It can minimize the impact between the mechanical room, and It is unaffected by ever-changing supply / return temperatures**

Results

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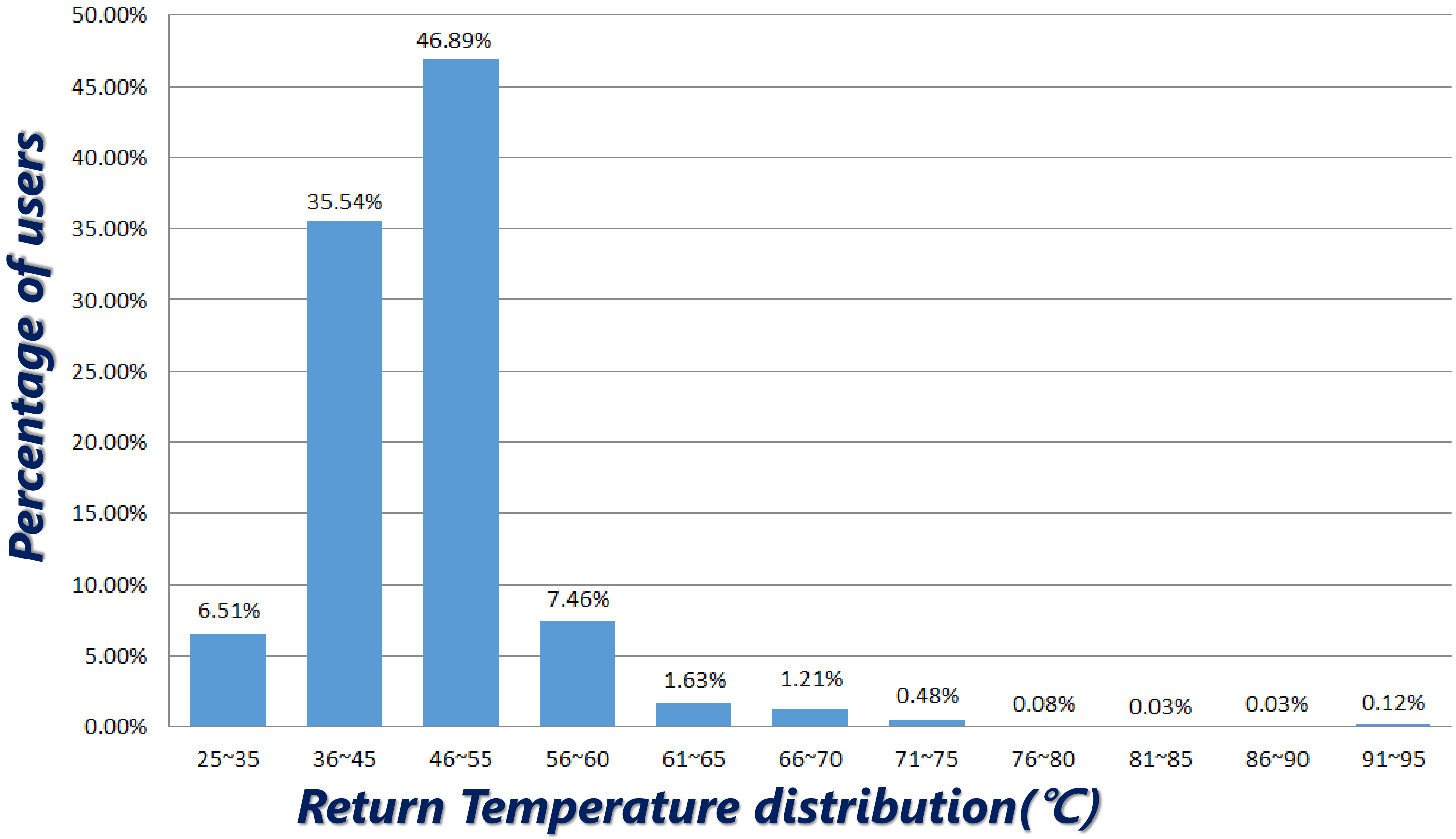
● The Raw data of substations

Date	Supply Status				Using heat by Customer (Gcal)
	Supply Temp.	Return Temp.	Flow Rate (ton)	Supply heat (Gcal)	
2015-01-01	107	50.6	234,314	13,215	13,215
2015-01-02	107	50.0	222,756	12,697	12,697
2015-01-03	107	48.8	207,869	12,108	12,108
2015-01-04	107	47.4	180,811	10,772	10,772
2015-01-05	107	46.7	167,884	10,130	10,130
2015-01-06	107	48.2	189,776	11,151	11,151
2015-01-07	107	49.5	211,651	12,180	12,180
2015-01-08	107	49.4	211,094	12,150	12,117
2015-01-09	107	48.6	198,259	11,582	11,582
⋮	⋮	⋮	⋮	⋮	⋮
2015-01-24	107	46.7	155,229	9,356	10,314
2015-01-25	107	46.8	162,003	9,756	9,756
2015-01-26	107	46.3	152,310	9,243	9,243
2015-01-27	107	47.7	179,260	10,637	10,637
2015-01-28	107	48.7	194,755	11,357	11,357
2015-01-29	107	47.9	185,850	10,975	10,975
2015-01-30	107	48.5	192,411	11,264	11,264
2015-01-31	107	49.2	204,245	11,814	11,814

<The Operating data of substations of A Branch at January 2015>

● The Raw data distributions



<User return temperature distribution in January 2015>

- **Analysis on the effect that return temperature of each substation influence to total return temperature**

# of sub.	Heat	Flow rate (m^3)	Supply Temp.	Return Temp.	Flow rate when the return temp. adjusted to 55℃	Estimated total return temp. when only the i-th user send over than 55℃	Total Temperature difference between real and estimated
43	39.4	851.2	107	60.72	757.69	55.0191	0.0191
50	44	882.0	107	57.12	846.15	55.0074	0.0074
55	15.4	301.6	107	55.94	296.15	55.0011	0.0011
56	14.3	295.2	107	58.56	275.00	55.0041	0.0041
57	31.6	618.0	107	55.87	607.69	55.0021	0.0021
69	64	1268.2	107	56.54	1,230.77	55.0077	0.0077
79	31	612.6	107	56.40	596.15	55.0034	0.0034
82	21.8	436.2	107	57.02	419.23	55.0035	0.0035
84	13.5	411.9	107	74.23	259.62	55.0311	0.0311
106	17.2	592.7	107	77.98	330.77	55.0536	0.0536
107	8.8	175.7	107	56.93	169.23	55.0013	0.0013
113	29.3	614.2	107	59.30	563.46	55.0104	0.0104
120	6.2	126.3	107	57.92	119.23	55.0015	0.0015
123	6.2	149.8	107	65.63	119.23	55.0063	0.0063
124	0.98	25.8	107	69.16	18.85	55.0014	0.0014
125	1.17	26.5	107	62.92	22.50	55.0008	0.0008
129	32	642.5	107	57.20	615.38	55.0056	0.0056
130	33.3	656.3	107	56.26	640.38	55.0033	0.0033
144	8.5	179.8	107	59.73	163.46	55.0033	0.0033
145	22.9	494.3	107	60.68	440.38	55.0110	0.0110
148	28	539.9	107	55.14	538.46	55.0003	0.0003
149	29.1	566.3	107	55.62	559.62	55.0014	0.0014
150	112.7	2254.2	107	57.01	2,167.31	55.0178	0.0178

It looks very small difference but each substation individually influencing to total return temperature.

Results
Influence of each substation to the heat source

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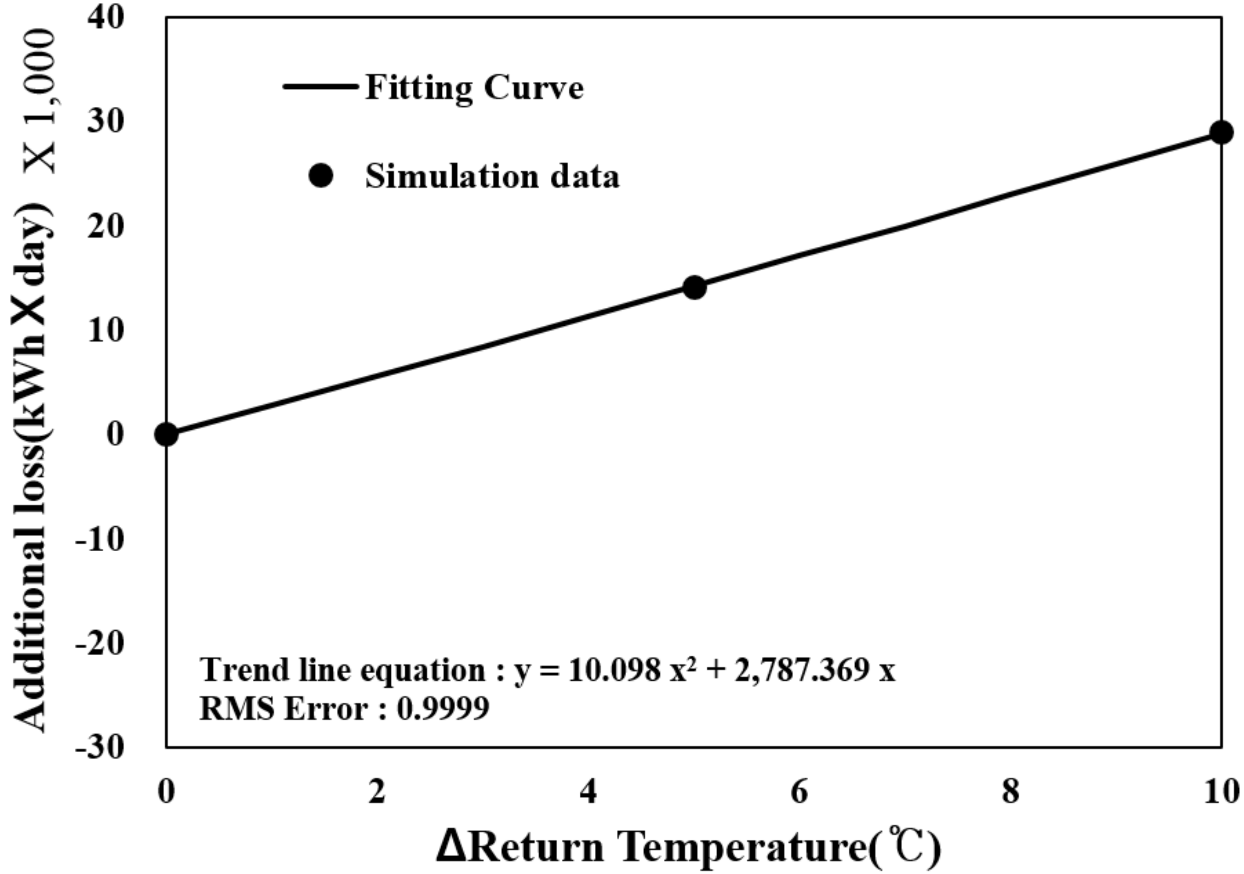
	Units	Simulation Results				
Return Temp	℃	**45**	**50**	55 (Reference)	**60**	**65**
△Return Temperature	℃	-10	-5	0	5	10
△Power Generation	kW	-983.300	-493.940	0	498.890	1,000.810
△Pump required work	kW	-136.889	-74.4783	0	90.612	203.5501
additional loss(total)	**kWh**	**-1,120.19**	**-568.418**	**0**	**589.502**	**1,204.360**
additional loss/day	**kWh×day**	**-26,884**	**-13,642**	**0**	**14,148**	**28,904**
Additional price/day	**(80won /kwh)**	**-2,150,76**	**-1,091,36**	**0**	**1,131,844**	**2,312,371**
Additional price/month	**(80won /kwh)**	**-64,522,881**	**-32,740,894**	**-**	**33,955,315**	**69,371,142**

For more information on the effect of return temperature on heat source, see the 107th IDEA Conference Material

Results

Analysis of heat source power production opportunity cost



<Variation of power generation loss according to return temperature change>

Results

Analysis of each substation' additional cost by return temperature

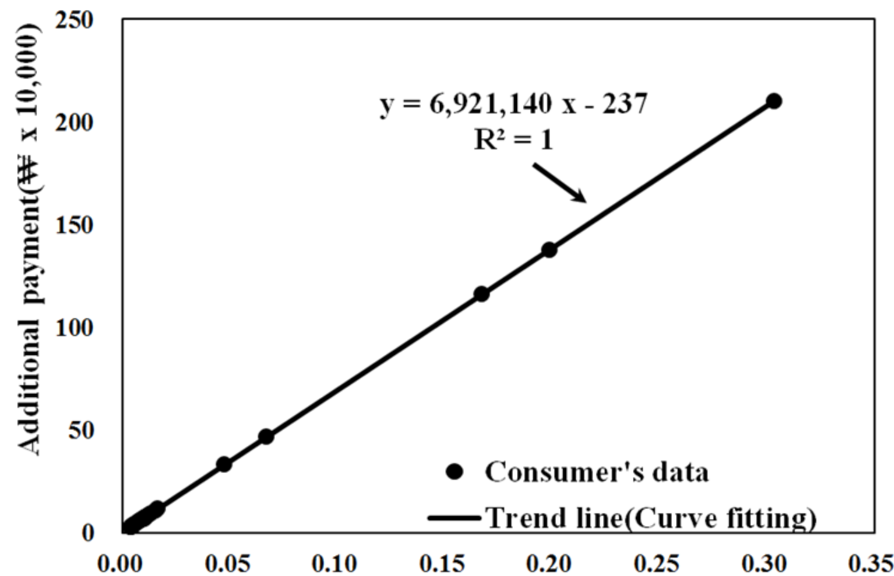
# of sub.	Average temp. difference(℃)	Opportunity loss cost(Won)	Basic cost(Won)	Increasing Rate(%)
490	0.3034	2,099,600	1,652,906	127.02%
475	0.1988	1,376,042	7,421,726	18.54%
472	0.1675	1,158,928	12,393,171	9.35%
237	0.0672	464,791	6,329,606	7.34%
478	0.0474	327,883	5,609,472	5.85%
106	0.0368	254,221	1,183,968	21.47%
84	0.0237	163,503	1,121,816	14.57%
366	0.0166	114,507	2,562,680	4.47%
388	0.0152	105,084	1,521,193	6.91%
266	0.0131	90,231	1,422,974	6.34%
150	0.0114	78,748	5,149,243	1.53%
297	0.0106	73,055	2,725,465	2.68%
274	0.0101	70,147	933,067	7.52%
175	0.0101	69,494	4,013,316	1.73%
471	0.0100	68,929	921,926	7.48%
489	0.0097	67,397	1,509,539	4.46%

<Opportunity loss cost of each substations>

Results

Analysis of each substation' additional cost by return temperature

- **If all substations sending return temp. as reference**
  - **$330/day** savings in heat source
  - About **$6,600/month** opportunity loss cost can be eliminated (considering 20 working day)
  - About **$79,200/year** opportunity loss cost can be eliminated
  - Considering 18 branches **$1.4million/year** can be saved
  - It is same as **8,400ton/year** CO_2 reduction effect



Conclusion

Conclusion

- ***During this research,***
  - ***Analyzed on the effect that return temperature of each substation influence to total return temperature***
  - ***Estimated Influence of each substation to the heat source***
  - ***Analyzed CHP's power production opportunity cost***
  - ***Analyzed each substation's additional cost by return temperature variations***

- ***If all users are good user(means that every user send return temperature as reference temperature)***
  - ***\$330/day = \$6,600/month = \$79,200/year are saved (on each branch)***
  - ***\$1.4million/year = 8,400ton/year*** CO_2 ***reduction (Considering 18 branches)***

Thank You for Your Attention!

Any Questions?

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