Suggestion for New District Heating System Usage Tariff Assessment by Exergy

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Contents

1. Introduction - Background

District heating issues

- Current district heating system usage tariff is based on enthalpy (flow rate × temperature difference). While cost assessment is simple, it is not qualitatively evaluated.

- Differences between supply and return temperatures of water are the same, the users pay equal rate. However, from a thermo-economic point of view they are different.

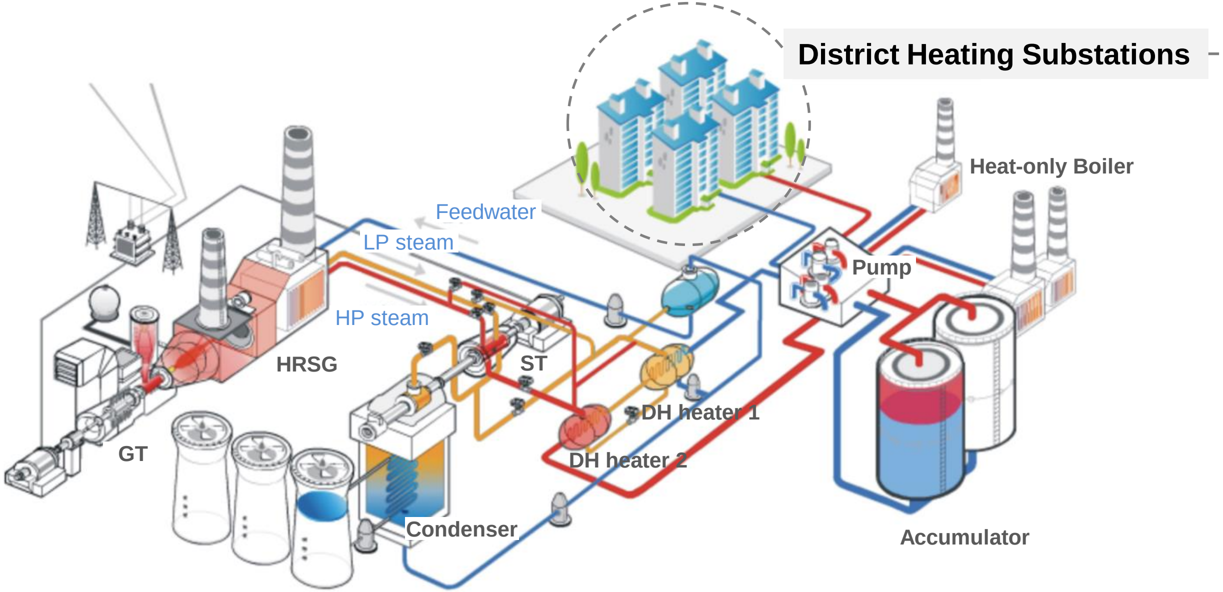
- Return temperature varies greatly among users. High return temperatures create low generation efficiency and high pumping power in plant.

- Rather than applying only quantitative factors, the proposed concept requires both quantitative and qualitative assessment.

- The objective of this research is to suggest the new concept of tariff system by exergy.

1. Introduction - District heating system in Korea

Extensive use of substations for all types of applications



District Heating Plant - Example

Source : http://www.gspower.co.kr/Cyber_Publicity/CyberPH_Tour/CyberPH_Tour.asp

[Residential]

- Heating
- DHW (Domestic hot water)

[Commercial]

- Cooling
- Heating
- DHW

[Public]

- Cooling
- Heating
- DHW

2. Design of substation and tariff structure

Typical substation design (1-stage)

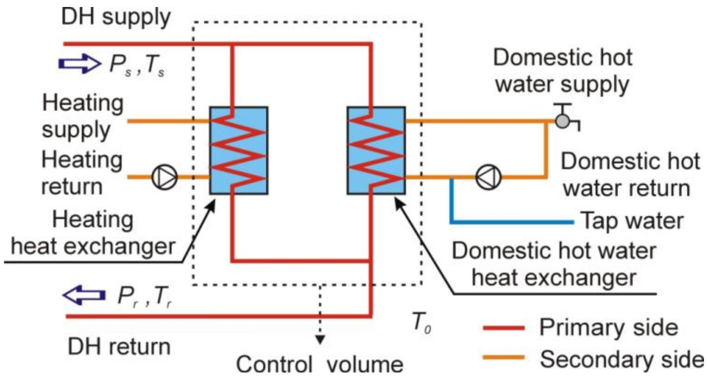


Table 1 Primary design condition of substation in Korea

Type			Temperature[℃] Supply	Temperature[℃] Return	Pressure [MPa(bar)]
Heating	Radiant		115	50	1.6(16)
	Convection/AHU			55	
Domestic Hot Water	1-stage		75	35	
	2-stage (≥150 Mcal/h)	Reheat	75	55	
		Preheat	55	35	
Absorption Chiller(Ammonia based)			95	55	

Current tariff structure (Mcal/h)

$$C_{tot} = C_b + C_u = C_b + \alpha \times \sum \dot{m} c \Delta T \Delta t$$

- C_b (basic rate): charged by contract heating area or total heat capacity
  - · Residential: contract heating area [₩/㎡]
  - · Commercial/public: total installed capacity [₩/(Mcal/h)]
- C_u (usage rate): charged by actual heat usage

Table 2 Unit price of district heat (2016)

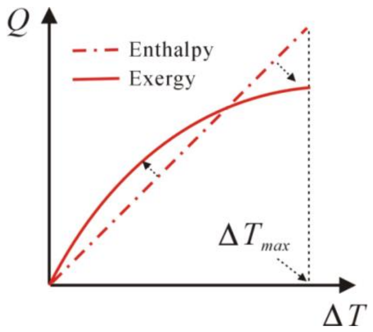
Type	C_b	α [₩/Mcal] Single	α [₩/Mcal] Graded	
Residential	52.40 ₩/㎡	66.05	Spring/Fall Summer Winter	64.73 58.25 67.99
Commercial	396.79 ₩/(Mcal/h)	85.77	Peak time(7~10AM) Non-peak time	98.65 81.48
Public	361.98 ₩/(Mcal/h)	74.90	Peak time(7~10AM) Non-peak time	86.13 71.16

* 1 cent = 11₩

3. Heat tariff assessment (1)

New concept of heat tariff assessment

- The existing charge system based on enthalpy is very simple, flow × ΔT.
- If both quantity and quality of energy are to be accounted for, it is necessary to change the tariff system based on exergy concept.
- Exergy temperature difference based on flow exergy of district heating substation is calculated as follows.
- Total amount of exergy in a certain range is equal to the total amount of heat.



$$\Delta T_x = f(\Delta T)$$

(Exergy) (Enthalpy)

$$Q = mc(\Delta T) \longrightarrow Q_x = mc(\Delta T_x)$$

$$C_u \longrightarrow C_x$$

(Enthalpy) (Exergy)

3. Heat tariff assessment (2)

New concept of heat tariff assessment

$$\dot{X} = \dot{m}(\psi_s - \psi_r) = \dot{m}c\left[(T_s - T_r) - T_o \ln\frac{T_s}{T_r} + \frac{v}{c}(P_s - P_r)\right]$$

$$= \dot{m}c\left[\Delta T - T_o \ln\frac{T_s}{T_r} + \frac{v}{c}\Delta P\right]$$

$$\Delta T_x = \left[\Delta T - T_o \ln\frac{T_s}{T_r} + \frac{v}{c}\Delta P\right]\frac{\int_0^{\Delta T_{\max}} \dot{Q}\, d\Delta T}{\int_0^{\Delta T_{\max}} \dot{X}\, d\Delta T}$$

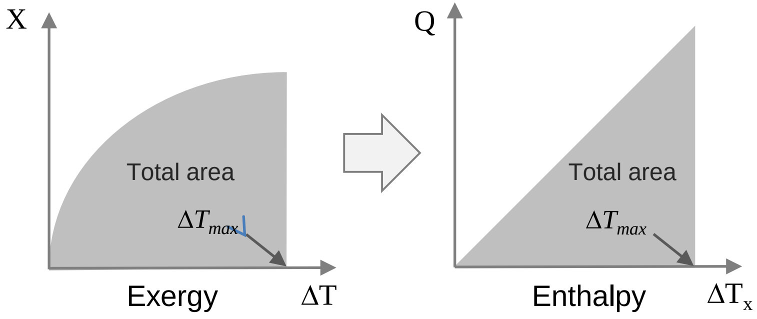
Where,

$$\int_0^{\Delta T_{\max}} \dot{Q}\, d\Delta T = \dot{m}c\frac{\Delta T_{\max}^2}{2}$$

$$\int_0^{\Delta T_{\max}} \dot{X}\, d\Delta T = \dot{m}c\left[\frac{\Delta T_{\max}^2}{2} + T_o(T_s - \Delta T_{\max})\ln\left(\frac{T_s}{T_s - \Delta T_{\max}}\right) - T_o\Delta T_{\max} + \frac{v}{c}\Delta P \Delta T_{\max}\right]$$

$$\mathbf{Q_x = mc\,(\Delta T_x)}$$

X : Total amount of exergy[kJ]
Ψ_s: Flow exergy at supply side[kJ/kg]
Ψ_r: Flow exergy at return side[kJ/kg]
T_s: Supply temperature[K], T_r: Return temperature[K]
T_o: Ambient temperature[K]
P_s: Supply pressure[kPa], P_r : Return pressure[kPa]
Q_x: Total amount of heat[kJ]
ΔT: Enthalpy-based temperature difference[K]
ΔT_x: Exergy-based temperature difference[K]

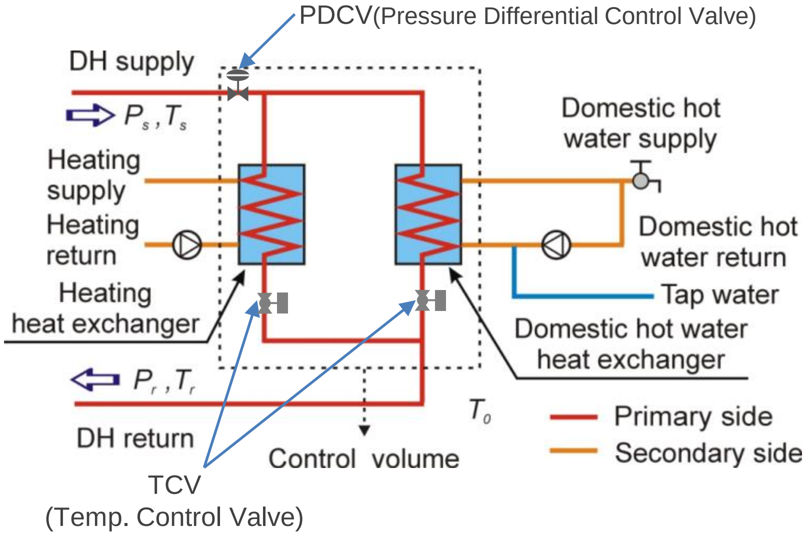


Conversion of exergy to enthalpy
(Total heat input identical)

4. Modeling approach

Model

- Control volume: Primary side includes control valves and heat exchangers



Parameter ranges

- Variables
  - Ambient temperature (T_o)
  - Supply temperature (T_s)
  - Pressure drop in substation (ΔP)
  - Maximum temperature difference (ΔT_{max})

Table 3 Parameter range for exergy calculation

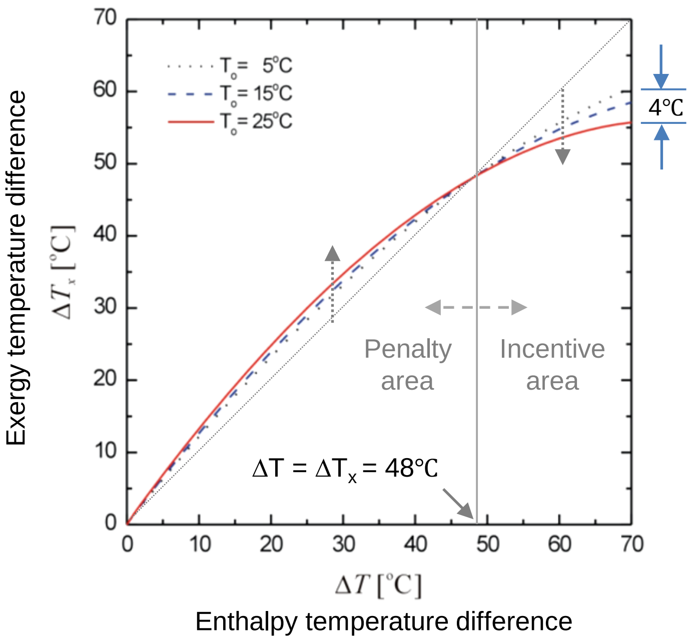
T_o [℃]	T_s [℃]	ΔP [kPa]	ΔT_{max} [℃]
5	85	50	40
15	100	100	50
25	115	150	60
-	-	-	70

: Baseline

5. Results (1)

Effect of ambient temperature (T_o)

- Conditions: T_s=100℃, ΔP=100 kPa, ΔT_{max}=70℃



- When temperature difference between supply and return temperature is 48℃, ΔT and ΔT_x are equal.

- The higher is the ambient temperature, the larger is the temperature difference between enthalpy and exergy due to increased exergy loss.

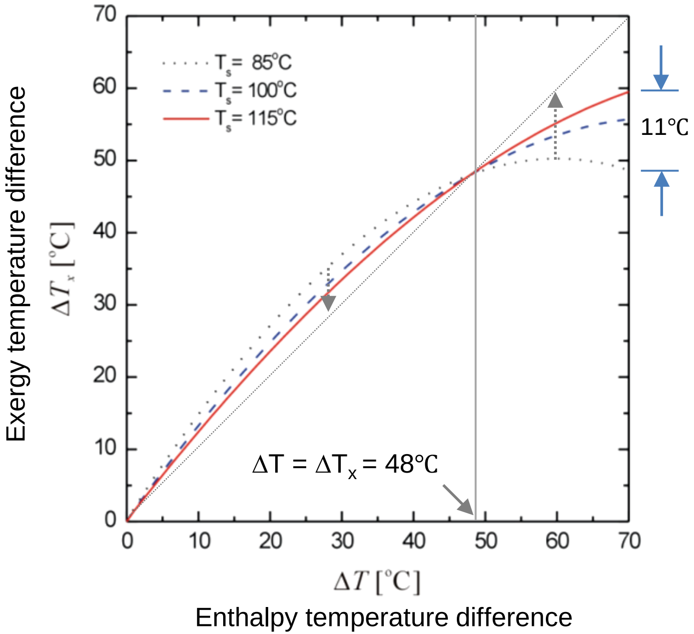
- The maximum gap of exergy temperature differences with the ambient temperature is about 4℃ at ΔT of 70℃.

- When compared with winter season condition, ΔT_x is larger than ΔT during summer season.

5. Results (2)

Effect of supply temperature (T_s)

- Conditions: T_o=15℃, ΔP=100 kPa, ΔT_{max}=70℃



- When temperature difference between supply and return temperature is 48℃, ΔT and ΔT_x are equal.

- When supply temperature increases, ΔT_x approaches ΔT. It means the temperature difference in winter is smaller than in summer.

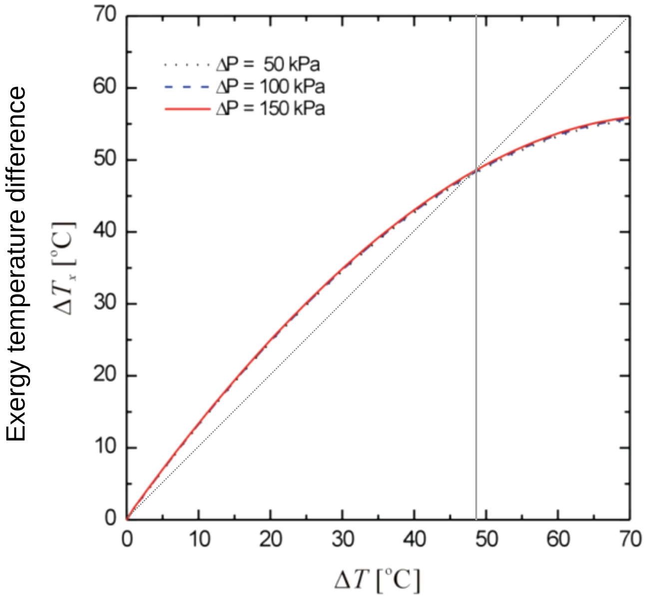
- When ΔT is higher than 48℃, the difference between ΔT_x and ΔT increases. At ΔT=70℃ the maximum gap of ΔT_x with supply temperature is more than 11℃.

- For all cases, ΔT_x is most sensitive when supply temperature is 85℃.

5. Results (3)

Effect of pressure drop (ΔP)

- Conditions: T_o=15℃, T_s=100℃, ΔT_{max}=70℃



Enthalpy temperature difference

- Changes in ΔP do not affect ΔT_x.

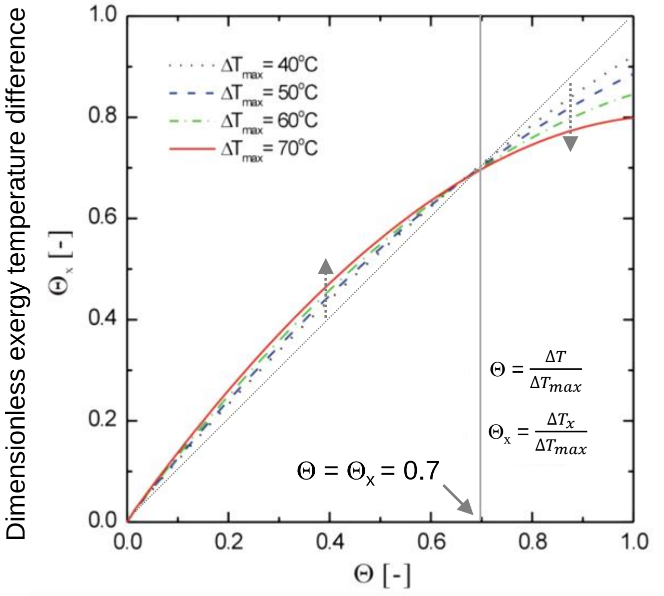
- ΔT_x is almost equal to ΔT for different ΔP.
  ·$\Delta T = \Delta T_x$=48℃ at 50 kPa
  ·$\Delta T = \Delta T_x$=48℃ at 100 kPa
  ·$\Delta T = \Delta T_x$=49℃ at 150 kPa

- Friction losses in heat exchangers, pipes, and valves can be negligible for ΔT_x calculation because the district heating water is incompressible.

5. Results (4)

Effect of max. temperature difference (ΔT_{max})

- Conditions: T_o=15℃, T_s=100℃, ΔP=100 kPa



Dimensionless enthalpy temperature difference

- When ΔT_{max} = 40℃, then $\Delta T = \Delta T_x$ = 28℃.
  When ΔT_{max} = 70℃, then $\Delta T = \Delta T_x$ = 48℃.
- The smaller ΔT_{max}, the closer ΔT_x to ΔT.
- Depending on the range of ΔT_{max}, the rate of increase and reduction can vary greatly.
- To apply new tariff to users, ΔT_{max} range should be evaluated along with building types, operation conditions of district heating plant.
- It can be a basis for establishing the limit of return temperature.

5. Results (5)

Practical application for a consumer in Korea

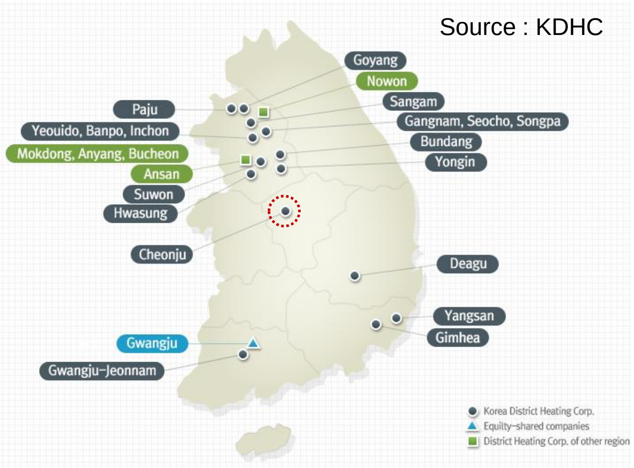


Table 4 Information of a consumer

Category	Contents	Remarks
Location	Cheonju	Latitude 36.4
User type	Commercial	24h operation
Heating area	1,700㎡	
Heating capacity	1,020 Mcal/h	Heating: 200 Mcal/h DHW: 820 Mcal/h

Table 5 Daily data of energy consumption(winter)

t [h]	m [ton/h]	ΔT [℃]	ΔT_x [℃]	Q [Mcal]	Q_x [Mcal]
1	5.29	47.1	**47.4**	249.2	251.0
2	6.44	51.5	**50.7**	331.7	324.6
3	5.41	56.8	**54.5**	307.1	294.4
4	2.67	62.5	**58.3**	166.8	157.5
~	~	~	**~**	~	~
21	4.62	60.8	**57.2**	280.7	263.2
22	5.79	50.6	**50.0**	293.0	290.2
23	4.62	48.1 -	**48.1**	222.3	221.4
24	4.86	42.0	**43.2**	204.0	211.9
Total				6004.3	5735.8

Daily charge (only usage cost)

448$ →

428$

Save 4.5%

5. Results (6)

Practical application for a consumer in Korea

Table 6 Daily data of energy consumption (spring)

t [h]	m [ton/h]	ΔT [℃]	ΔT_x [℃]	Q [Mcal]	Q_x [Mcal]
1	0.83	50.9	**49.8**	42.2	41.4
2	1.05	51.8	**50.4**	54.4	52.9
3	2.16	49.5	**49.0**	106.9	105.7
4	3.50	53.0	**51.1**	185.5	178.8
~	~	~	**~**	~	~
21	2.21	55.8	**52.7**	123.3	116.4
22	1.65	56.4	**53.0**	93.1	87.4
23	1.63	54.1	**51.7**	88.2	84.3
24	1.62	56.4	**53.0**	91.4	85.8
Total				2671.9	2562.5

Table 7 Summary of daily tariff with season

Tariff		Enthalpy [₩]	Exergy [₩]	Difference [%]
Winter	C_b	13,490	13,490	-
	C_u	514,989	491,960	4.5
	C_{tot}	528,479	505,450	4.4
Spring	C_b	13,490	13,490	-
	C_u	229,168	219,785	4.1
	C_{tot}	242,658	233,275	3.9

* 1 cent = 11₩

Daily charge (only usage cost)

199$ →

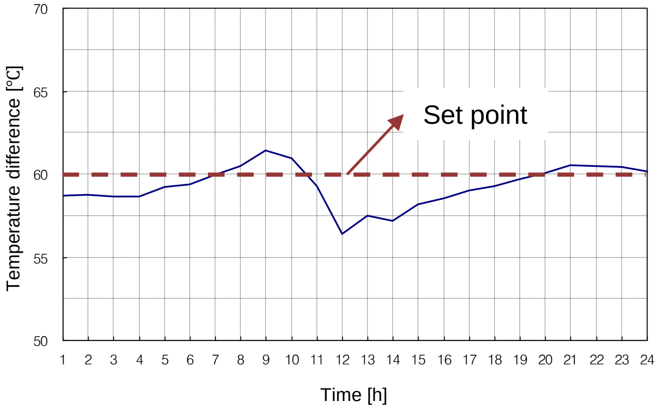
191$

Save 4.1%

5. Results (7)

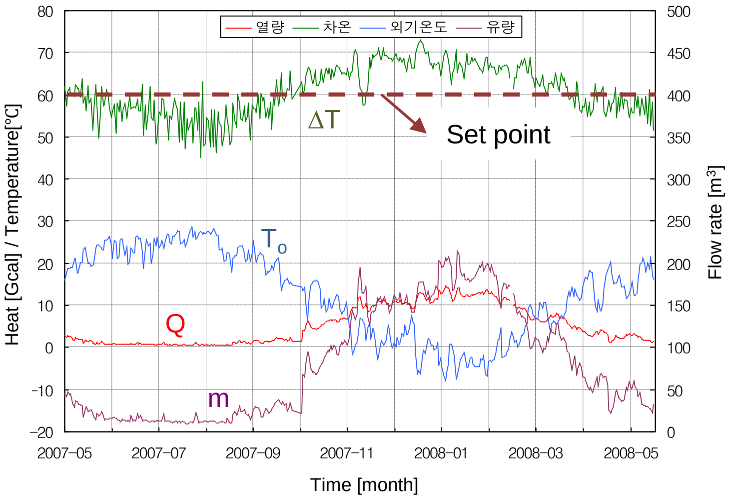
Comparison of daily and annual consumption

Daily heat usage data (example)



- Day time: Penalty
- Morning/Night: Incentive

Annual heat energy consumption data (example)



- Winter, Fall: Incentive
- Spring, Summer: Penalty

6. Conclusion

1. When assessing district heating system heat tariffs, exergy rather than enthalpy should be better to reflect energy and economic value.

2. Supply temperature and maximum temperature difference(ΔT_{max}) have a dominant effect on exergy. When setting ΔT_{max}, the actual operation conditions of a district heating plant must be evaluated.

3. As a result of applying the new tariff system to an actual district heating user, the daily average charge is reduced by more than 4% in winter and spring.

4. New tariff assessment by exergy can be applied to different rates by time, seasons, and consumer characteristics. Therefore, it is a reasonable charge system in terms of plant efficiency compensation for suppliers as well as incentive or penalty for users.

5. In the future, additional research will be necessary into a variety of scenarios, such as a flexible rate system that provides incentives in the range of lower return temperature or penalties for higher return temperature.

Thank you

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