DEVELOPMENT OF THE RENEWABLE ENERGY POLICY OF HYDROTHERMAL ENERGY IN USING DRINKING WATER IN SOUTH KOREA

By

KIM, Byeong Kuk

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Executive summary

Introduction

In 2017, The Renewable 3020 policy of the new government was announced to comply with the Paris Climate Change Accord to reduce Greenhouse Gas (GHG) emissions from the use of fossil fuels. Although the new government's energy conversion policy has been implemented, the electricity production proportion of renewable energy is currently at 2.2% (2016 IEA), which is insufficient for the target 20%. The share of total renewable energy is lower than other developed countries.

According to the government's 3020 Renewable Energy Implementation Plan (Ministry of Trade, Industry and Energy 2017), renewable energy, such as waste, wood fillet, etc., based on fuel combustion will be minimized and reconstituted with solar (57%) and wind (27%). As most of renewable energy sources are composed of 84% solar and wind power, it is necessary to consider the problems due to bias. However, these power sources can lower grid system reliability because of fluctuations by weather. So we need to find other renewable energy sources for energy stability.

Hydrothermal Energy (HTE) is environment-friendly energy because it does not burn fuel when it gets heat. It is also known to reduce energy cost by 20-50% compared to existing electricity and fossil fuel by being used for building cooling and heating. However, the potential of drinking water, classified as unused energy, as source of renewable energy is untapped due to lack of government support. The purpose of this research, therefore, is to investigate the possibility and advantage of drinking water as a renewable energy source in the wide-area waterworks system and to propose policies to expand Drinking Water Thermal Energy (DWTE).

Field research methods for gathering data

Based on the survey of potential energy reserve amount of drinking water, available energy by using heat pump, and environmental pollution reduction effect should be considered when using the wide-area waterworks as heat source. After investigating the DWTE reserve amount, the CO_2 reduction is compared with the use amount of fossil fuel. The stability of water heat energy is verified by comparing and analyzing water demand and energy demand. The variables for the investigation of the DWTE reserve amount are as follows: Independent variables (IV) are water and air temperature (℃), drinking water flow rate (Q), COP of heat pump (η); while dependent variables (DV) are energy reserve amount (E_R), and available calorific value (E_C, E_h). Electricity of monthly thermal load requested (user demand) for cooling and heating (P).

Analysis and findings

According to the Korea Energy Agency's Energy Statistics Handbook 2017, the heating and cooling energy consumption of households and businesses in the year 2015 is 36,439 thousand toe, which is the ton of equivalent (toe) of the amount of heat in 1 ton of crude oil, which is 10^7 Kcal. If the available DWTE is used, 3% of the total heating and cooling energy per year can be supplied and CO_2 emissions could be reduced by 3,409,000 tCO_2 using the B-C oil energy conversion factor 3.241. Over the last five years, the average growth rate of drinking water supply (1.89%) and electricity sales (1.66%) has been increasing. DWTE is very stable as renewable energy sources as the increasing trend of supply, the pattern of demand, and deviation of the supply amount per year are similar to the electricity sales trend. The flow rate deviation is stable throughout the year 2015 at 16%, which is similar to the 15% deviation of the electricity sales volume.

However, the limitation when using drinking water should be investigated. Some studies claim that bacterial growth increases as temperature increases during drinking water distribution which can also pose health risks to the users. The health problem of using drinking water is controversial because there is a possibility of biofilm formation, and if the stability is clarified more and more research will be done in the future, drinking water will become abundant renewable energy source which can be applied more easily than any other energy sources.

Policy or Administrative Recommendations

To diversify the limited renewable energy sources and strike a balance between the supply and demand of electricity, the central government should recognize unused HTE captured by heat pumps using drinking water as a renewable energy source. In order to meet the goals of 3020 Renewable Energy Implementation Plan and reducing CO_2 emission, it needs to amend renewable energy law and regulation for government support policy such as Renewable Heat Obligation (RHO) system.

Local government should give opportunities to reduce energy consumption costs for residents and building owners by energy consumption consulting and supporting the infrastructure through local-area waterworks modernization project. The U.S. Department of Energy (DOE) determined how to achieve greater energy efficiency in buildings through the Building Energy Codes Program. The program provides technical support for adoption and compliance strategies. DWTE should be a long-term infrastructural solution.

For the development of Drinking Water Energy Saving (DWES) model, it is necessary to build a cooling model using drinking water of wide-area waterworks, verify the effect through test-bed, and conduct environmental research. K-water should develop an efficient cooling and heating DWES model *(Hybrid model: Heat pump with ATES or Thermal Energy Storage, TES*) using drinking water by utilizing a wide-area waterworks pipe line. In addition, by utilizing remote monitoring control and remote meter reading system facilities, if the Energy Transfer Station (*ETS: energy demand adjustment and energy conversion of heating-cooling*) system and District Cooling–Heating System (DCHS) connected with Drinking Water Distribution System (DWDS) is constructed, drinking water distribution and DWTE operation is possible.

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Development of the renewable energy policy of Hydrothermal Energy in using drinking water in South Korea

1. Introduction

In 2017, The Renewable 3020 policy of the new government was announced to comply with the Paris Climate Change Accord to reduce Greenhouse Gas (GHG) emissions from the use of fossil fuels. In addition, it is time to change energy sources which cause the deterioration of heat island phenomenon, increase of fine dust, reduction of nuclear power plants, the increase of data centers due to the 4th industrial revolution. Although the new government's energy conversion policy has been implemented, the electricity production share of renewable energy is currently at 2.2% (2016 IEA), which is insufficient for the target 20%. The proportion of total renewable energy is lower than other developed countries as shown in Fig. 1.

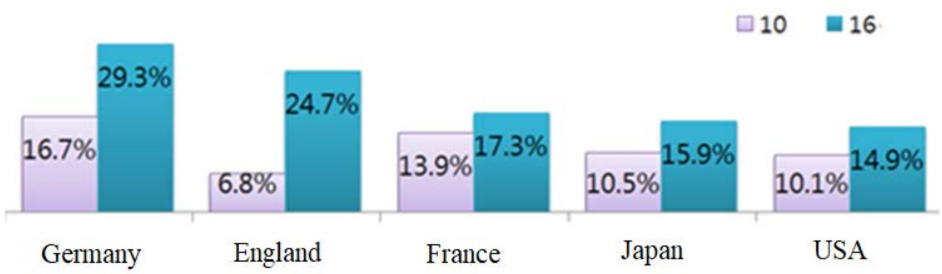

Fig. 1. Proportion of renewable energy generation (2010→2016)

Source: (Ministry of Trade, Industry and Energy, 2017)

According to the government's 3020 Renewable Energy Implementation Plan (Ministry of Trade, Industry and Energy 2017), renewable energy, such as waste, wood fillet, etc., based on fuel combustion will be minimized and reconstituted with solar (57%) and wind (27%). As renewable energy sources are composed of 84% solar and wind power, it is necessary to consider the problems due to bias. Renewable energy has the advantage of solving environmental problems and safety problems of existing power generation sources, but its disadvantage is on the low generation efficiency and the serious effects of weather conditions on the volatility of electric power. Wind power and photovoltaic power generation are typical examples. These renewable energy sources have limitations in controlling the output as needed. Korea is currently not using the grid because of the small scale of wind and photovoltaic power generation. However, wind and solar power generation will increase in the future and transport power using the same grid as conventional power sources but this can cause a problem of lowering system reliability of the grid due to output fluctuation. As an alternative to these two problems, I would like to introduce the advantages of Hydrothermal Energy (HTE), especially using drinking water that is more stable and conservable than other renewable energy sources.

HTE is environment-friendly energy because it does not burn fuel when it gets heat. It is also known to reduce energy cost by 20-50% compared to existing electricity and fossil fuel by being used for building cooling and heating. Consumption of heating and cooling energy is expected to increase due to high temperature phenomenon and the number of cooling days in winter due to climate change. In HTE, water temperature difference between water and atmosphere in different seasons can be used to heat or cool buildings by using combinations of available techniques such as heat pump.

The types of HTE sources are shown in Fig. 2. HTE contributes to the reduction of GHG with clean energy that does not directly burn fuel, and it can remove the damage of cooling tower noise, vibration, etc.,. It can also eliminate heat island phenomenon by using no outdoor fan.

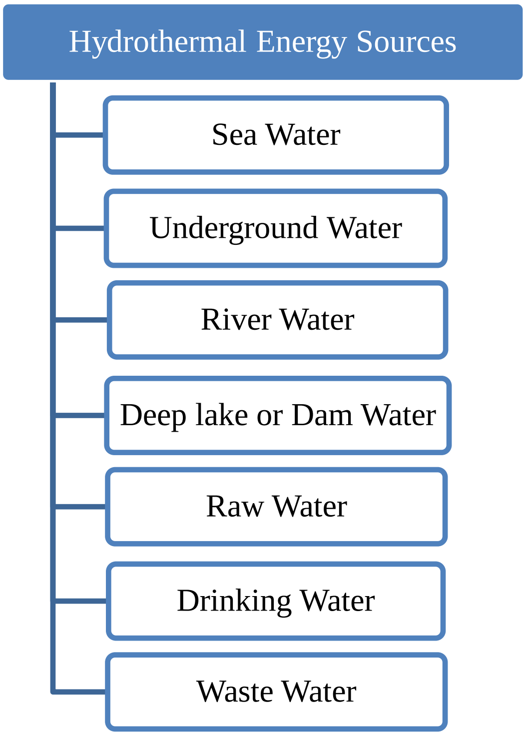

Fig. 2. Types of Hydrothermal Energy Sources

Source: (By author, 2018)

The wide-area waterworks can utilize the pipeline facilities already invested in the existing infrastructure, so it is possible to develop a large amount of HTE at a low cost in the urban city with high energy demand.

One of the reasons why the water thermal energy industry, which has many advantages, is not activated is related to Korea's renewable energy policy. In developed countries, river water, groundwater, waste water, etc. are classified as renewable energy, but in South Korea, according to New and Renewable

Energy Law, they are defined as facility that produces energy by converting the surface heat of seawater. As a result, undefined water sources other than the surface water of seawater are classified as unused energy, and the implementation of HTE as a renewable energy is low due to lack of support from the government. The purpose of this study is to investigate the possibility and advantage of drinking water as a renewable energy source in the wide-area waterworks system and to propose policies to expand Drinking Water Thermal Energy (DWTE).

A. Key Issues / Problems

a. **(Limits of energy policy)** The government regulation against the utilization of the hydrothermal energies not based on scientific evidence. Therefore unutilized HTE is not recognized as a source of renewable energy.

The New Energy and Renewable Energy Development, Utilization and Promotion Act limited surface water as water heat source. The legal standard for HTE is limited to the energy obtained by converting the surface heat of water using a heat pump. The HTE is limited to the energy obtained by converting the heat of the surface layer of seawater, and it does not utilize water energy sources as shown in Fig. 2.

On the other hand, in the case of geothermal energy (groundwater) using heat pumps, government policies support supply expansion through the mandatory use of renewable energy in public buildings, housing support projects, building support projects, local supply projects, and efficient project for the utilization of agricultural (gardening) energy.

b. **(Problems of massive introduction of variable renewable energy)** As in the 3020 Renewable Energy Implementation Plan, stability of electricity may be lowered if renewable energy power mix is biased toward wind and solar energy.

Since the power generation output of a renewable energy source is highly dependent on uncontrollable natural conditions (solar radiation, air volume), power supply required by the load can be limited. Capacity is considerably smaller than that of conventional thermal power generation and nuclear power generation, and local connection is extremely localized. Moreover, the introduction of renewable energy into the existing system can cause irregular fluctuation and imbalance of generated power, the partial systemic effect, the reverse effect of partial generation, since the power generation of new renewable energy sources can be supplied not only to the load but also to the power system (Lim and Bae 2018). As mentioned in the 8th Basic Plan for Supply and Demand of Electricity, the deviation of base power caused by wind power and solar photovoltaic power generation not only leads to large range of unstable energy supply and demand, but also fluctuation of frequency. Therefore the Energy Storage System (ESS) and Liquefied Natural Gas (LNG) Facilities are additionally required.

c. **(Problems of Regional energy imbalance)** It is important for Korea to maintain the stability of the power system, because it has a highly unbalanced energy production and consumption between regions. It is easy to see the seriousness of energy imbalance by looking at the electricity independence rate (the electricity generation and electricity sales volume). In case of electricity independence rate in 2017, Incheon was the highest at 2.762(276%), while Seoul was only 0.019(1.9%), as shown Fig. 3.

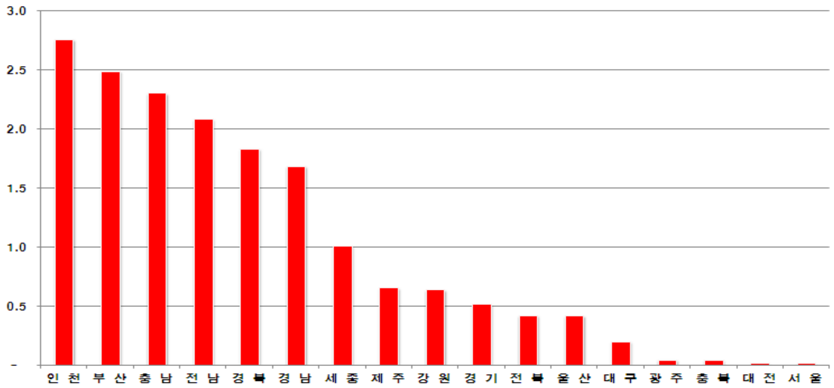

Fig. 3. The electricity independence rate (2017)

Source: (Electric Power Statistics Information System, 2018)

Electricity generated by municipalities with high electricity independent ratio is sent to local governments with low electricity independence ratio through transmission network. In the area where the transmission system is connected in this process, property rights and human risks are being raised by the installation of high voltage transmission lines and power transmission towers (Lee 2011).

As shown in Fig. 4 and Fig. 5, wind and solar photovoltaic power generators are installed in suitable areas. As the wind and solar photovoltaic power generation ratio increase, the problem of energy imbalance between regions also persists, and due to an increase in cost of transmission and distribution facilities and a decrease in power efficiency, the effect of renewable energy will be reduced.

Fig. 4. Solar power map

Fig. 5. Wind power map

Source: (Electric Power Statistics Information System, 2018)

B. Literature Review

a. **(The principle of Heat Pump)** Before we consider of hydro-thermal energy, it is necessary to understand the basic principles of heat pumps in order to reflect on the category of renewable energy, such as drinking water heat pump. As shown in Fig. 6, the heat pump is a device that utilizes the heat Q_H emitted from the condenser in heating and hot water supply.

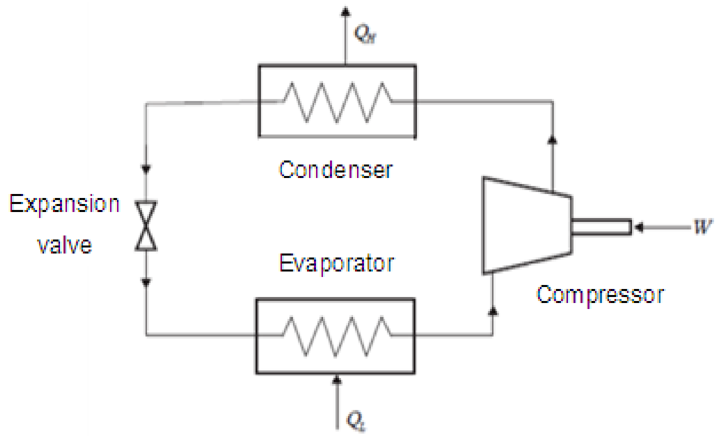

Fig. 6. Composition of refrigeration cycle

Source: (Hong and Lee, 2015)

It is called heat pump because it absorbs heat Q_L in a low temperature evaporator and extracts heat from a high temperature condenser like a pump that pulls water in a low place to a high place. On the other hand, if it is used in the evaporator to absorb the heat Q_L and lower the ambient temperature, it becomes a general freezer. In other words, the heat pump and refrigerator are exactly the same from the cycle viewpoint. In winter, Q_H is used for heating, and in summer, Q_L is used for cooling. This heat pump can be used for heating and cooling without installing a separate heater. When the energy conservation law is applied to the refrigeration cycle, the sum of the heat Q_L absorbed by the evaporator and the work W supplied by the compressor becomes the heat Q_H emitted from the condenser.

$$Q_L + W = Q_H$$

(1)

The performance of the refrigerator and the heat pump is expressed by a coefficient of performance (COP), as follows:

A performance coefficient as a refrigerator is COP = Q_L/W (2)

A performance coefficient as a heat pump is $COP_H = Q_H/W$ (3)

The COP is an indicator of the cooling and heating capacity acquired relative to the input power. Substituting formula (1) into formula (3) gives the following relation.

$$COP_H = Q_H / W = (Q_L + W) / W = COP + 1$$

When $COP_H = 3$ (COP = 2), in which the compressor supplies 1 kW of power, the evaporator absorbs 2 kW of heat from the surroundings (air or ground) and emits 3 kW of heat from the condenser. For reference, COP or COP_H is generally expressed dimensionless.

When the efficiency of the electric heater is 100%, 1 kW of electricity is supplied to obtain 1 kW of heat, but the heat pump obtains 3 kW of heat, which is a high efficiency energy device. In addition, because it absorbs heat in air, land, and river water, it is natural energy, a renewable energy device. However, in the current law, geothermal heat extracted from the ground is defined as renewable energy, while air and water heat sources are just natural energy (Hong and Lee 2015).

b. **(Drinking Water Thermal Energy Case) According to** De Pasquale et al. (2017), DWTE as a cold source in cities constantly flows throughout the distribution network. This resource has tremendous potential in terms of available thermal energy. Hoek et al. (2018) researched the "Sanquin (Blood bank, pharmaceutical company) - Waternet (Amsterdam public water cycle company)" case which the yearly needed cooling is 15,523 MWh. By using 500m^3/hr of drinking water flow and average temperature difference of 7.5℃ during winter, 17,250 MWh can be produced through the heat exchanger. The electricity consumption reduced from 1,725 MWh/a to 172.5 MWh/a and the reduction of GHG emissions mitigated 869 ton CO_2-eq/a. Systems using drinking-water cooling were found to have a 17% lower Total Cost of Ownership (TCO) than systems using conventional cooling systems.

C. Research Questions

a. ***Do the other countries and organizations utilize hydrothermal energy as renewable energy?***

(EU) Heat pump is included in renewable energy in accordance with "2008 renewable energy guidelines". **(Germany)** "Heat Regeneration Renewable Energy Promotion Act" specifies the use of heat pumps as a means of achieving renewable energy by 2020 and recognizes heat pumps as renewable energy based on SPF 3.3~4.0. **(England)** According to the Renewable Energy Association (REA) policy, heat pumps (water source heat pump) are recognized as renewable energy, and Renewable Heat Incentive (RHI) also includes hydrothermal sources. **(Japan)** "Special Action for the Promotion of New Energy Use" specifies the temperature difference energy with water as the heat source including sea water, river water etc. **(International Energy Agency, IEA)** It specifies that heat is extracted from air, water, and ground except for the use of heat pumps in the renewable energy field.

b. ***Are there negative environmental impacts when using Drinking Water Thermal Energy?***

In Amsterdam's "Sanquin-Waternet" case, Hoek et al. (2018) found out that preliminary research at laboratory scale showed that the microbiological drinking water quality, measured by Total Cell Concentrations (TCC), Adenosine Tri Phosphate (ATP), Legiionella spp. and Aeromonas spp., was not affected by cold recovery. The systems were operated for a period of eight months from May to December in 2016. The effects on microbiological water quality and biofilm formation were studied by constructing three Drinking Water Distribution Systems (DWDSs) as shown in Figure. 7. These preliminary laboratory experiments were carried out similar with "Sanquin-Waternet" case. The operated temperature below 15℃ and operational heat exchanger was set at 24℃. The System 1 represents thermal energy recovery system, System 2 represents a non-operational heat exchanger as a control group, and System 3 represents reference without a heat exchanger. All systems used drinking water for experiment.

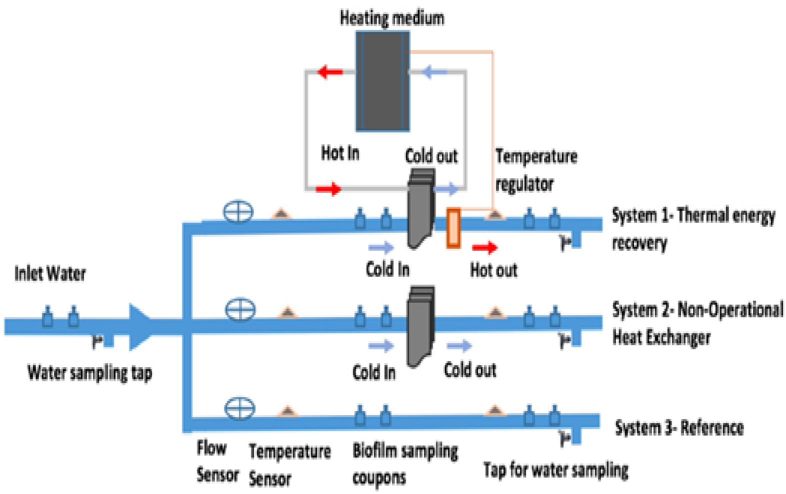

Fig. 7. Laboratory scale drinking water distribution systems

Source: (Hoek et al., 2018)

(Effect on microbiological drinking water quality and biofilm formation) Fig. 8 shows the Total Cell Concentrations (TCC) and Adenosine Tri Phosphate (ATP) concentrations in the bulk water phase in the laboratory scale DWDSs. The results of System 1 (operational heat exchanger) and System 2 (non-operational heat exchanger) show similar microbiological water quality between Before Heat Exchanger (BHE) and After Heat Exchanger (AHE), and the System 3 (reference system).

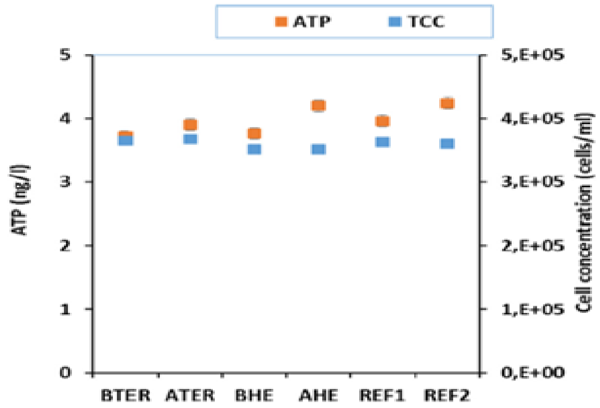

Fig. 8. Microbiological water quality in DWDS 1 (BTER: before thermal energy recovery; ATER: after thermal energy recovery), DWDS 2 (BHE: before heat exchanger; AHE: after heat exchanger) and DWDS 3 (REF 1: at start of DWDS; REF 2: at end DWDS)

Source: (Hoek et al., 2018)

Regarding the positive sample of micro-organisms, Legionella spp., and Aeromonas spp., the water quality was also stable in the three DWDSs, as shown in Fig. 9 and 10.

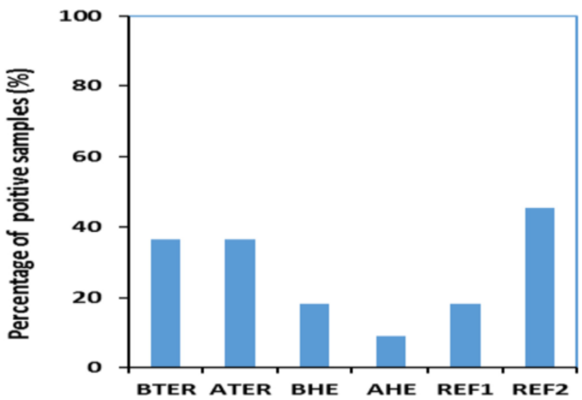

Fig. 9. Positive Legionella spp. samples in bulk water in DWDS 1, DWDS 2 and DWDS 3

Source: (Hoek et al., 2018)

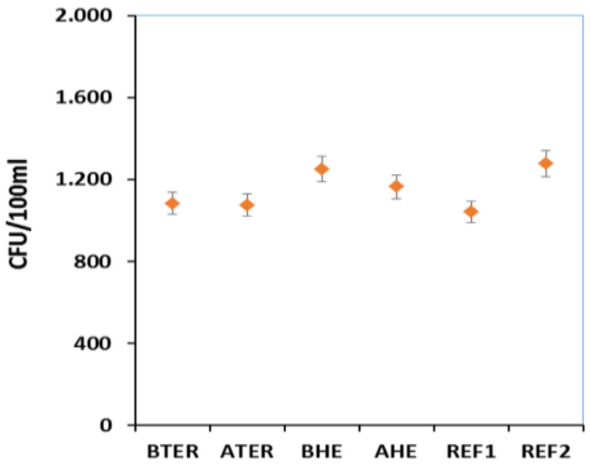

Fig. 10. Aeromonas spp. in bulk water in DWDS 1, DWDS 2 and DWDS 3

Source: (Hoek et al., 2018)

Fig. 9 and 10 shows that Legionella and Aeromonas did not increase when compared to before and after heat exchanger passage, and system 1 (operating heat exchanger) did not increase either.

In contrast, higher cell numbers and biological activity were detected in biofilm formed after cold recovery compared to the biofilm before cold recovery (2.5 times higher TCC and ATP, Fig. 11). It may have been affected by the drinking water treatment without chlorine. Therefore, further research is needed to identify biofilm formation after cold recovery and to reveal the potential role of biofilm growth on microbial water quality.

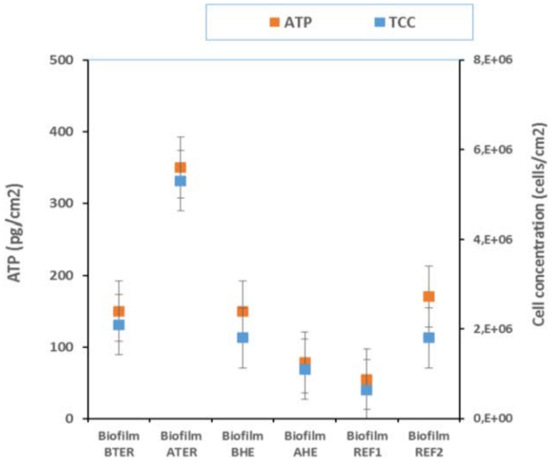

Fig. 11. Biofilm development in DWDS 1, DWDS 2 and DWDS 3

Source: (Hoek et al., 2018)

2. Field research methods for gathering of data

After estimating HTE amount in using drinking water, analyze the saving fossil fuel energy and CO_2 reduction. In order to establish a pilot project for using unutilized energy, it is necessary to first make a database of information on the available regional wide-area water works site. Based on the survey of potential energy reserve amount of drinking water, available energy by using heat pump, and environmental pollution reduction effect should be considered when using the wide-area waterworks as heat source. After investigating the water thermal energy reserve amount, the air pollution reduction rate is compared with the amount of fossil fuel used. The stability of water heat energy is verified by comparing and analyzing water demand and energy demand.

The variables for the investigation of the DWTE reserve amount are as follows: Independent variables (IV) are water and air temperature (℃), drinking water flow rate (Q), COP of heat pump (ꞃ); while dependent variables (DV) are energy reserve amount (ER), and available calorific value (EC, Eh). Electricity of monthly thermal load requested (user demand) for cooling and heating (P).

A. Hydrothermal Energy reserve amount (E_R)

According to *"An Estimation of Regional Quantity of Unused Energy of River Water and Its Energy Saving Potential"* (Huh and Kim 1998), in the case of using drinking water as a heat source the flow rate, the variables to be investigated are wide-area waterworks water temperature, flow rate, available temperature difference. The calculation equation of the reserve energy is as follows.

$$E_R = \Delta t \times Q \times C \tag{4}$$

In this case, E_R is the energy reserve (Tcal / year), Δt is the utilization temperature difference (℃), Q is the drinking water flow rate (㎥ / year) and C is the specific heat (Mcal / ㎥ · ℃). Using this standardized formula calculate unused energy reserve and availability. It is also applied to the drinking water of wide-area network system.

B. Available Flow Rate (Q)

The total quantity of drinking water supply which is used as HTE is acquired from K-water data of WIS. In the case of available flow rate, the drinking water supply is slightly changed in a day, so the time unit for estimation decides month, the water quantity (Q) uses the monthly flow rate from 2013 to 2017. Table 1 summarizes the wide-area network water supply of purification plants which are operated by K-water. The accounted water rate is not considered to be different from region to region. The table shows that the supply amount of drinking water is increasing every year.

Table. 1. Supply of drinking water of purification plants in K-water from 2013 to 2017 (Unit: Thousand ㎥)

Year	2013	2014	2015	2016	2017
Total	2,846,554	2,855,884	2,940,350	2,996,424	3,072,549
JAN	240,414	236,945	241,355	245,996	245,062
FEB	212,220	213,615	221,861	235,166	224,479
MAR	232,803	235,766	245,880	243,651	252,759
APR	224,365	227,887	235,547	239,060	247,135
MAY	239,330	240,201	248,727	249,664	262,819
JUN	238,409	241,692	251,496	251,379	265,382
JUL	250,149	257,497	262,666	263,026	279,758
AUG	255,330	249,062	260,577	268,116	273,529
SEP	238,845	236,386	246,609	250,099	257,365
OCT	241,487	242,840	247,586	254,015	251,413
NOV	235,366	232,642	234,916	246,109	251,894
DEC	237,836	241,351	243,130	250,143	260,954

Source: (Korea Water Resources Corporation, WIS, 2018)

C. Utilization Temperature difference (Δt)

In the case of HTE, a heat pump is used to supply heat. The temperature difference between the inlet and the outlet of the heat exchanger is considered to be the actual available quantity of heat. Generally, the temperature difference between the inlet and outlet of the heat exchanger is about 3 to 5 ℃ (Jung 2018).

However, in this paper, in order to estimate the actual available HTE, the amount of unutilized energy reserve is based on the temperature difference between air and drinking water.

$$\Delta t = t_{inlet} - t_{outlet} = t_{water} - t_{air} \tag{5}$$

Due to fluctuation of temperature, monthly average water temperature of purification stations is used from K-water data of WIS and the monthly average air temperature is provided by the Korea Meteorological Administration (KMA) from 2013 to 2017, as shown in Table 2 and Table 3. The drinking water temperature is acquired from three selected watershed-based purification plants, Suji (Han River), Gosan (Geum, Yeongsan, Sumjin River) and Sacheon (Nakdong River), which have the maximum water supply. The air temperature regions which provide drinking water from selected purification plants, are Suwon, Jeonju and Jinju.

Table. 2. Drinking water average temperature (Unit: ℃)

Year	2013	2014	2015	2016	2017	Average Temp.
JAN	3.5	4.3	4.4	4.7	5.1	4.4
FEB	3.6	4.6	4.5	3.3	4.4	4.1
MAR	6.9	7.3	6.6	5.7	7.3	6.8
APR	11.2	12.2	11.0	10.5	12.7	11.5
MAY	15.4	15.6	16.6	16.1	18.2	16.4
JUN	19.2	19.6	21.9	22.4	21.6	20.9
JUL	21.1	20.3	23.6	21.9	24.0	22.2
AUG	23.7	21.7	25.1	24.9	21.8	23.4
SEP	22.9	22.4	22.1	21.3	20.5	21.8
OCT	20.5	18.9	18.8	19.0	18.7	19.2
NOV	14.6	13.7	14.5	13.9	13.1	14.0
DEC	7.4	7.4	8.8	8.4	6.3	7.7

Source: (Korea Water Resources Corporation, WIS, 2018)

Table. 3. Air average temperature (Unit: ℃)

Year	2013	2014	2015	2016	2017	Average Temp.
JAN	-1.9	0.4	0.5	-0.8	-1.5	-0.7
FEB	0.7	3.2	1.9	2.0	0.0	1.6
MAR	6.7	8.0	6.8	7.5	5.7	6.9
APR	10.5	13.5	13.2	14.1	13.2	12.9
MAY	18.2	18.6	18.6	18.8	18.4	18.5
JUN	23.2	22.4	22.2	22.6	22.4	22.6
JUL	26.6	25.3	24.8	26.0	26.5	25.8
AUG	27.8	24.3	25.7	27.3	25.5	26.1
SEP	21.9	21.5	21.3	22.3	21.2	21.6
OCT	16.0	15.3	15.4	16.1	15.4	15.6
NOV	7.2	8.8	10.4	8.0	5.7	8.0
DEC	1.3	-0.4	3.7	2.9	-1.4	1.2

Source: *(Korea Meteorological Administration, 2018)*

Considering that the increase in bacteria due to the rising temperature of drinking water may adversely affect the health of the user, Netherlands has limited the drinking water temperature after the heat exchanger to below 25℃ for Drinking water quality (Hoek et al. 2018). Therefore, in this paper the outlet drinking water temperature is limited below 25℃ for protecting growth of biofilm in pipe. The available temperature difference can be calculated from formula (5) as shown in Table 4. Figure 12 shows the available temperature difference trend in a year. Cooling energy can be used from March to August and heating energy from September to February.

Table. 4. Temperature difference: Drinking Water - Air (Unit: ℃)

(+): Available Temp. for Heating, (-): Available Tempe. for Cooling

Water-Air Temp. Diff.	Origin	Modify	Limitation
JAN	5.1	5.1	
FEB	2.5	2.5	
MAR	-0.2	-0.2	
APR	-1.4	-1.4	
MAY	-2.1	-2.1	
JUN	-1.6	-1.6	
JUL	-3.7	-2.83	Below 25
AUG	-2.7	-1.55	Below 25
SEP	0.2	0.2	
OCT	3.5	3.5	
NOV	6.0	6.0	
DEC	6.4	6.4	

Source: (By author, 2018)

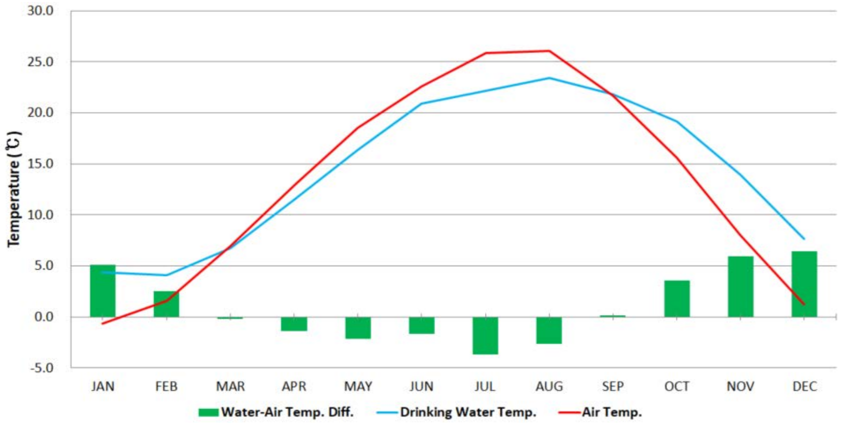

Fig. 12. Temperature difference between Drinking water and Air

Source: (By author, 2018)

D. Available calorific value (E_C, E_h)

The available calorific value can be defined as the calories given in Formula (6) and (7). Heating is for 6 months from September to February and cooling is 6 months from March to August. The heat pump of COP is different from each other during cooling and heating. Furthermore, the amount of available HTE can vary greatly depending on the condition and performance of the heat pump. Therefore, the heat pump of COP should be considered by the current level of technology and applied with the suitable value for small district heating systems and for large district heating system. The available amount of heat pump heat source can be defined as follows, assuming that heat pump is used for cooling and heating. The COP value of heat pump is used from average COP_h (3.46) and COP_C (5.25) of the water-to-water system pilot plant using wide-area network raw water in Seongnam water purification plant (Cho et al. 2016).

Availability of Heating: $Eh = E \times (\frac{COPh}{COPh-1}) = \Delta t \times Q \times C \times (\frac{COPh}{COPh-1})$ (6)

Availability of Cooling: $Ec = E \times (\frac{COPc}{COPc+1}) = \Delta t \times Q \times C \times (\frac{COPc}{COPc+1})$ (7)

3. Analysis and findings

A. Amount of Reserve energy (E_R) and Available energy (E_A)

As the amount of drinking water supply in the wide-area waterworks has increased by 1.89% on average over the last five years (2013 to 2017), the amount of energy reserve has been calculated based on the amount of supply in 2017 as shown in Fig. 13. The drinking water energy reserve amount can be defined as the annual calories given in formula (4), (6) and (7) as shown in Table 5. The available energy using Heat Pump (HP) system is generated about 19% higher than extracted from drinking water when electricity required for the subsidiary facilities is not considered.

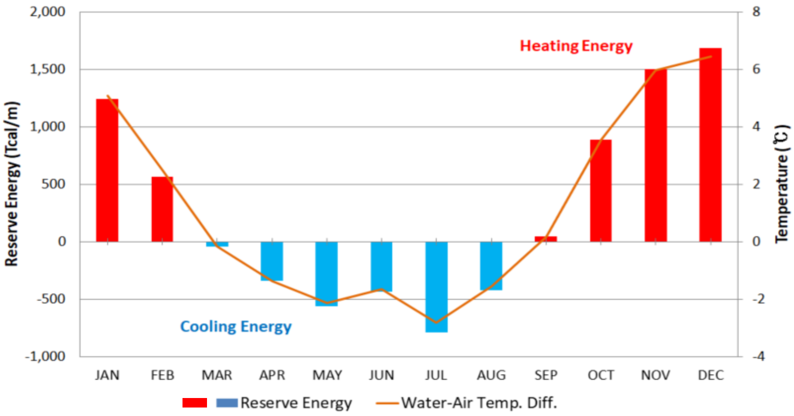

Fig. 13. The reserve energy of Cooling and Heating

Source: (By author, 2018)

Table. 5. Drinking Water Thermal Energy reserve and available amount in the wide-area waterworks by managing K-water (Unit: Tcal/year)

Reserve energy amount (E_R)	
Heating	5,926
Cooling	2,600
Total	8,526
Available energy amount (E_A)	
Heating	8,335
Cooling	2,184
Total	10,519

Source: (By author, 2018)

B. Heating and cooling energy usage (t toe) and CO_2 emission (tCO_2)

According to the Korea Energy Agency's Energy Statistics Handbook 2017, the heating and cooling energy consumption of households and businesses in the year 2015 is 36,439 thousand toe, which is the ton of equivalent (toe) amount of heat in 1 ton of crude oil or 10^7 Kcal. If the available DWTE is used, 3% of the total heating and cooling energy per year can be supplied and CO_2 emissions could be reduced by 3,409,000 tCO_2 when B-C oil energy conversion factor 3.241 is used.

C. The similarity between Energy Demand and Hydrothermal Energy

Over the last five years, the average growth rate of drinking water supply (1.89%) and electricity sales (1.66%) has been increasing, as shown in Fig. 14. As shown in Fig. 15, the consumption of water supply and electricity sales trend increases in summer and winter and decreases in spring and autumn. The flow rate deviation is stable throughout the year at 16%, which is similar to the 15% deviation of the electricity sales volume. Figures 14 and 15 show that DWTE is a very stable renewable energy source, since the trend of supply increase, the pattern of demand, and deviation of the supply amount per year are similar to the electricity sales trend. When using DWTE as a renewable energy source during the winter from December to February, there is relatively low water demand compared to the peak demand. Therefore, it is necessary to design the HTE system with considering peak demand.

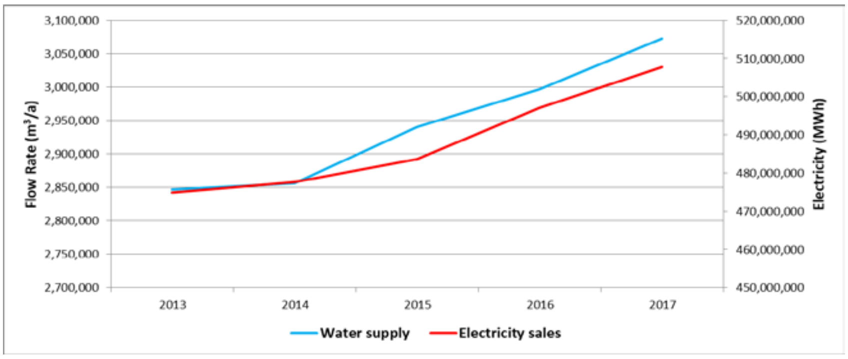

Fig. 14. Annual amount of Water supply and Electricity sales

Source: (By author, 2018)

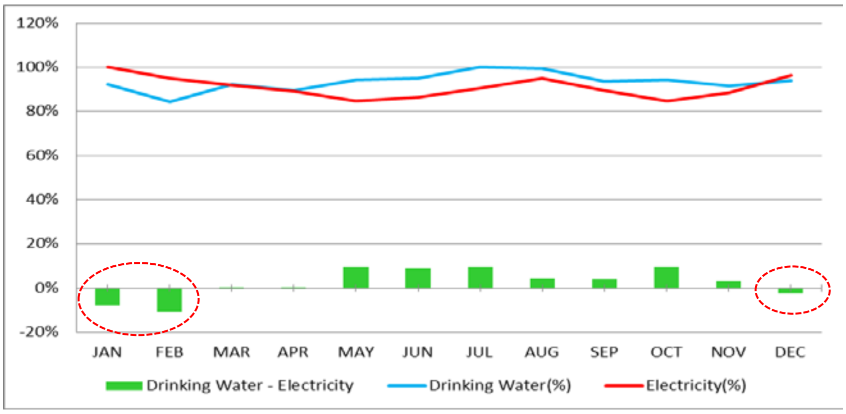

Fig. 15. Monthly amount of Water supply and Electricity sales

Source: (By author, 2018)

As a result of the regression analysis of the water supply and electricity sales amount (power) considering the time effect, the regression model shows that the Adj R-squar is 0.89, which means that power can explain the 89% fluctuation of the flowrate. And the flow rate and power have a statistically significant positive correlation (p-value <0.001), which means that the flowrate increases by 5.644 units (in flow rate units) when 1GW increases as shown table. 6. This is a result of the simple regression model which does not consider time series data, seasonality and autocorrelation between variables, and it is necessary to analyze more accurately by adding unobserved factor between flow rate and power.

Table. 6. Result of the regression analysis of the water supply & electricity sales

. reg flowrate power_M i.mon

Source	SS	df	MS
Model	9.3454e+09	12	778783236
Residual	897685871	47	19099699.4
Total	1.0243e+10	59	173611605

Number of obs	=	60
F(12, 47)	=	40.77
Prob > F	=	0.0000
R-squared	=	0.9124
Adj R-squared	=	0.8900
Root MSE	=	4370.3

flowrate	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
power_M	5.644114	.4690931	12.03	0.000	4.70042	6.587808

Source: (By author, 2018)

D. The comparison between Drinking Water Thermal Energy and other Hydrothermal Renewable Energy sources

Previous studies were conducted on the use of HTE sources such as river water, seawater and sewage that can be used as water heat energy. In the case of river water, the amount of unutilized energy is about 192,100 Tcal/year, and available amount is estimated 1,630 Tcal/year considering the environmental impact. The amount of unutilized energy of seawater energy is about 27,160 Tcal/year for 7 surveyed areas (Incheon, Busan, Ulsan, Gangneung, Gunsan, Mokpo, and Seogwipo) and the available amount is 20,280 Tcal/year. Lastly, the unutilized energy of the sewage is about 16,120 Tcal/year, and the available amount is 34,360 Tcal/year (Park 2002). As shown in Table 7, the drinking water has a sufficient amount of available energy by comparing the energy amount among thermal energy resources.

Table. 7. The energy comparison of Drinking water and other hydro-thermal resources (Unit: Tcal/year)

Water Resource	Reserve	Available
River	192,100	1,630
Sea	27,160	20,280
Waste	16,120	34,360
Drinking	8,526	10,519

Source: (Park, 2002 and by author, 2018)

Moreover, the major advantage of DWTE other than HTE resources is that DWTE can reduce initial costs and can be immediately implemented due to the use of existing wide-area waterworks infrastructure facilities. Since the distance from the heat and cool source to the heat demand is not long and water is clean, the initial construction cost and the maintenance cost are less than the river water, sea water and waste water. The advantages and disadvantages of using a drinking water supply system as a heat source for a heat pump are shown in Table. 8.

Table. 8. The advantages & Disadvantages of Drinking Water Thermal Energy

	Advantages
Stability	- Dinking Water mass flow is more stable than waste, river water during year
safety	- No need of additional drillings of aquifer and the risk of ground water pollution - Fouling problems of the heat exchanger are much less than waste water
Abundance	- Average growth rate of drinking water supply has been increasing - Abundant supply of quantity, non-depleting sources
Low cost	- The distance from the heat & cool source to the demand is not long and the using water is so clean → The initial construction cost and the maintenance cost are less than other hydrothermal energy sources
Applicability	- Can be immediately implemented due to the use of existing wide-area waterworks
	Disadvantages
Health risk	- Increased bacterial growth as temperature increases during drinking water distribution can pose a health risk to the user
Complaint	- Displeasure due to rise and fall of temperature after heat exchange - Public opposition to use of drinking water
Variability	- Differences in the amount of available DWTE according to heat pump COP

Source: (By author, 2018)

4. **Policy or Administrative Recommendations**

A. **The amendment of renewable energy law, regulation and support policy - Central government**

In order to get maximization of advantages, renewable energy law and regulation for government support policy should be amended and the dissemination of unused DWTE is needed. In order to meet the goals of 3020 Renewable Energy Implementation Plan and reduce CO_2 emission, to expand the diversity of limited renewable energy sources and to stabilize supply and demand of electricity the unused DWTE captured by heat pumps, should be classified as renewable energy source. For DWTE dissemination, it is necessary to introduce the Renewable Heat Obligation (RHO) system, which is currently pending. In a similar case, the geothermal energy has been expanded after the implementation of the Renewable Portfolio Standard (RPS) system. RHO is a system that requires a certain percentage of thermal energy consumption of buildings to be supplied with renewable thermal energy. As in Europe and Japan, policy support and subsidies are needed for local energy development utilization and heat utilization promotion using heat utilization model projects.

In order to get minimization of advantages, COP label system of heat pump should be introduced. Because available DWTE is dependent on heat pump performance as shown in formula (6) and (7). Even at the same flow rate, the amount of energy available varies depending on the COP. The COP labeling should be introduced to ensure the lowest performance and highest efficiency.

B. **Local government and stakeholders corporation**

HTE using temperature difference for cooling & heating is a long-term infrastructural solution. It should be financed with public funds, and the risks should be socialized. The socio-economic viability depends on the commitment of both the supplier and the customer of the HTE. In order to get maximization and minimization of advantages, it is necessary to actively support policies of local governments from urban planning stage, and to coordinate with the facility owners such as building, factory, data center, etc., households and other relevant organization in the area where unused DWTE exist by using drinking water pipe.

The U.S. Department of Energy (DOE) determined how to achieve greater energy efficiency in buildings through the DOE Building Energy Codes Program. This program provides technical support for adoption and compliance strategies. In other words, the DOE supports early-stage research and validation of energy performance improvements in existing and new residential buildings to save energy, energy cost and avoid CO_2 emission. Building energy codes represent a significant savings opportunity for U.S. home and business owners. This system should be introduced in South Korea. Local government should give opportunities to reduce energy and cost for residents and building owners by energy consumption consulting and supporting the infrastructure through local-area waterworks modernization project. It could encourage residents and building owners to voluntarily participate in Drinking Water Energy

Saving (DWES) program. Also, it could reduce public opposition to use of drinking water.

C. **Development of Drinking Water Energy Saving model – K-water**

For the development of DWES model, it is necessary to build DWES model. We need to refer to the model of "Sanquin-Waternet" case which is a cooling model of heat pump & Aquifer Thermal Energy Storage (ATES) using drinking water pipe line as shown Fig. 16.

The project by Amsterdam water utility, Waternet to make thermal energy available from their drinking water network, has been awarded a Bronze award at the World Water Congress & Exhibition of the International Water Association (IWA) 2018 in Tokyo, Japan. This project could save about 1,900tonnes of carbon dioxide a year, which, according to the city of Amsterdam, is the annual energy usage for up to 1,800 households.

Fig. 16. Laboratory scale drinking water distribution systems

Source: (Hoek et al., 2018)

The principle of this project is that during winter, cooling capacity can be delivered directly by drinking water. In addition, groundwater is pumped from beneath the ground and cooled through the heat exchanger. This cooled groundwater is stored in the ATES. In the summer, as drinking water is not cold enough for the required temperature, the heat exchange procedure is stopped. However, cool groundwater of ATES that has been stored during winter can be utilized for cooling in summer as shown in Fig. 17, 18, and 19.

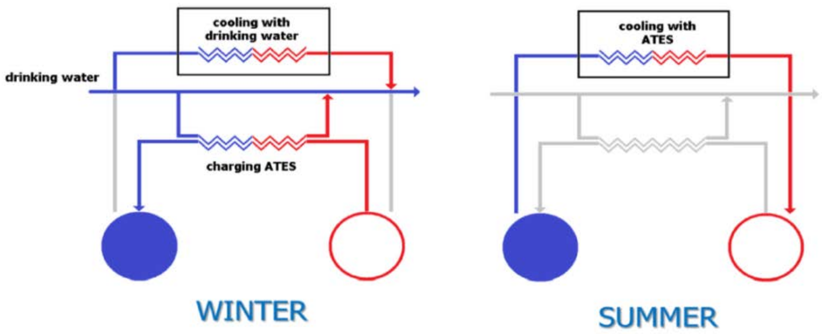

Fig. 17. Process of cooling with Drinking water under winter and summer

Source: (Hoek et al., 2018)

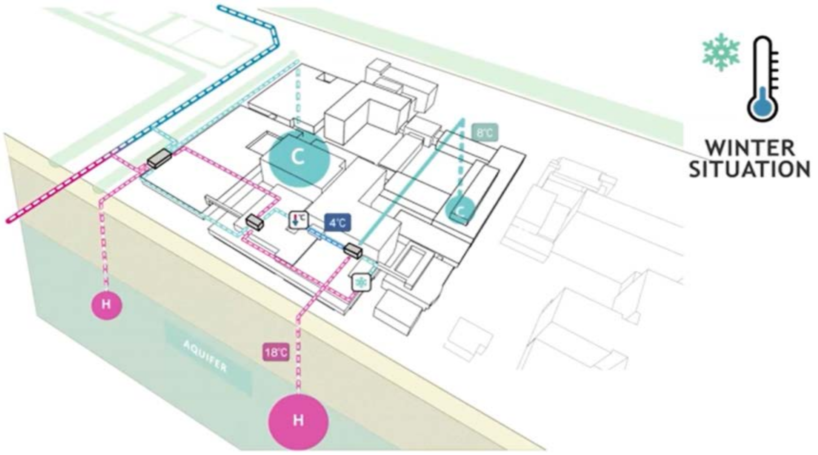

Fig. 18. Process of cooling with DW under winter situation

Source: (Hoek et al., 2018)

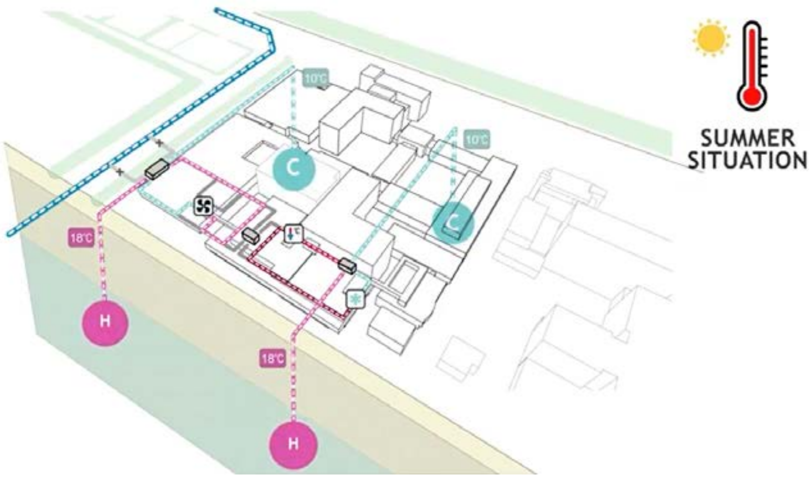

Fig. 19. Process of cooling with ATES under summer situation

Source: (Hoek et al., 2018)

Extracting cold from a nearby water pipeline is a new, relatively cheap and simple alternative: heat exchanger technology is widely available, distances to water pipelines are typically quite short (in contrast with deep lakes), heat exchangers in drinking water require less maintenance than in surface water, and the constant stream of drinking water guarantees delivery of cold (as long as the outside temperature is below the design threshold). The environmental effects are beneficial. Downstream drinking water will be warmer in the winter, reducing energy expenses in the households. The principle is also replicable to extract summer heat from drinking water, and can be applied whenever a drinking pipeline passes near an existing ATES system, or a location where seasonal storage is possible (City-zen 2017),. By using the ATES system with heat pump, the efficiency of thermal energy system increases up to 90%.

In order to get maximization of use DWTE, K-water should develop an efficient cooling and heating energy supply model (*Hybrid model: Heat pump with ATES or Thermal Energy Storage*, *TES*) using drinking water by utilizing a wide-area waterworks and local-are waterworks pipe line. In addition, by utilizing remote monitoring control and remote meter reading system facilities, if the Energy Transfer Station (*ETS: energy demand adjustment and energy conversion of heating-cooling*) system and District Cooling–Heating System (DCHS) connected with drinking water distribution system is constructed, drinking water distribution and DWTE operation is possible, as shown in Fig 20 and 21. This DWES model should focus on reducing initial construction and maintenance costs and improving energy stability.

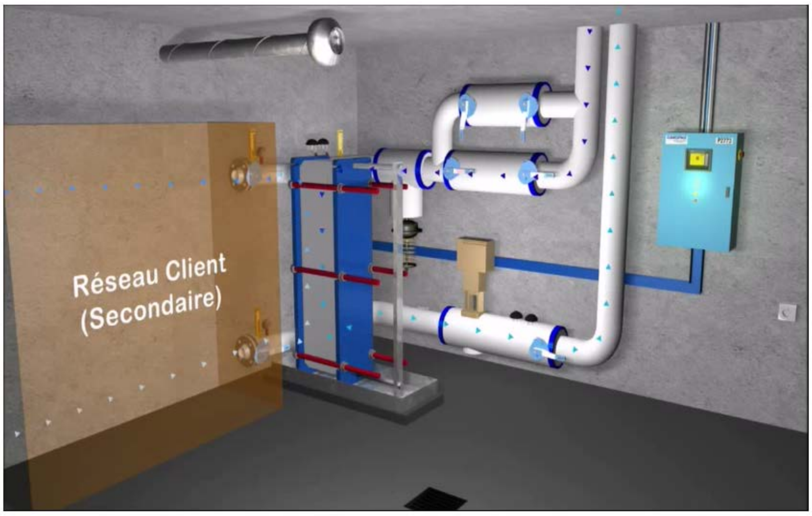

Fig. 20. Energy Transfer Station (ETS)

Source: (CLIMESPACE, n.d.)

Fig. 21. District Cooling - Heating System (DCHS)

Source: (CLIMESPACE, n.d.)

In order to get minimization of advantages, it is requisitely needed to verify the negative effect on health risk through test-bed and research biofilm formation as temperature recovery. Minimum and maximum operating temperature standard should be provided that do not cause adverse effects in health risk and unpleasant. If negative impacts are found, long-term research should be proposed to suggest solutions.

In addition, available temperature may change according to the geothermal or recovery of usage temperatures during the drinking water distribution process in pipeline. Therefore, based on the temperature standard, to solve displeasure of the public due to rise and fall of temperature after heat exchange and estimate accurate amount of available DWTE, it is necessary to estimate the water temperature through simulation of EPANET and actual measurement of wide-are waterworks distribution node. It is necessary to suggest a temperature recovery method such as ATES or TES using pumping stations and distribution reservoirs.

5. Utility and Limitations of the Proposed Research

De Pasquale et al. (2017) announced that some studies found out that increased bacterial growth as temperature increases during drinking water distribution can pose a health risk to the user. The increase in biofilm formation after cold temperature restoration requires further study to reveal the potential role of biofilm growth on microbiological water quality. The health problem of using drinking water is controversial because there is a possibility of biofilm formation, and if the stability is clarified more and more research will be done in the future, drinking water will become abundant renewable energy source which can be applied more easily than any other energy sources. The DWES project should be estimated individually to judge their availability.

The status of renewable energy lies in the replacement of fossil fuels and CO_2 reduction. Renewable thermal energy already reached high in technology, therefore if policy support is followed, it can serve as a driving force for many dissemination in a short period of time similar to geothermal energy. In addition, the drinking water which has not been previously studied, will be sufficient as an alternative source of available renewable energy and will contribute to energy saving, environmental pollution reduction and reduction of heat island phenomenon compared to existing fossil fuel use. The DWES system will play a leading role in the development and utilization of renewable energy. The DWES system contribute to the improvement of domestic technology level till world leading countries and achieve to implement the 3020 eco-friendly development policy of the new government by unused energy sources.

The results of saving energy, energy reserve and available calorific value could not be measured directly but obtained by the assumptions in the limit conditions. The result can be affected by the limit conditions such as available Q (Flow rate), Δt (Temperature difference) and COP of heat pump.

6. Conclusion

The purpose of energy policy is to achieve energy stability, and environmental protection. HTE from drinking water offers an alternative for the use of fossil fuel and contributes to the reduction of CO_2 emissions. According to the Statistics Information System of Korea Energy Economics Institute, the energy used in buildings accounts for more than 20% of the total energy demand of the country, and many of the energy supplies are provided on the basis of fossil fuels. Therefore, the building is the main target field in the National GHG Reduction Plan. Drinking water using wide waterworks pipe line available amount is abundant at 8,526 Tcal/year. It is estimated that the expected 3% of the total heating and cooling energy per year can be supplied and CO_2 emissions could be reduced by 3,409,000 tCO_2 when accordance with B-C oil energy conversion factor 3.241. The introduction of the cooling and heating supply system using drinking water has significant effects on the national economy such as mitigation of domestic energy consumption, saving space of renewable energy facilities and low energy cost of residents and saving water resources.

To do so, we must first clearly recognize the effectiveness of public interest by unused HTE. A long-term road map should be established and promoted so that the unused HTE (Using Drinking Water) system can be actively introduced into the social infrastructure during urban planning and urban redevelopment. In order to expand the public benefit of the DWES system in South Korea, the legislation should be revised to include unused HTE in the category of renewable energy sources. After that, it is desirable that various institutions support the promotion and dissemination of unused HTE as renewable energy sources.

The DWES project will be effective in different approaches to large-scale areas and local small-scale areas. First, the central government, municipal governments, and business partners should collect consensus among the large scale districts such as business, complex, data center, etc. with high cool and heat density, and conduct projects in connection with urban development. On the other hand, it maintains a wide-area network including districts that are relatively inferior from heat sources such as housing districts, rural districts, and small towns that are not economically feasible. In this case, considering large scale property and payback period, it is desirable to establish a framework as a part of the public benefit project and to maintain it in the mid- to long-term, because it is very strong in social capital such as water, electricity, and gas. Through these public services, reducing cooling and heating energy costs and welfare can be an effective support policy for low-income and elderly class of people.

Unused DWTE should be utilized by the revision of new and renewable energy law for diverse renewable energy sources. Drinking Water District System (DWDS) using DWES will be the solution for saving energy, reducing CO_2 emission, stable electricity, balance of energy mix and public welfare in South Korea.

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