GSHP SYSTEM FOR COMMERCIAL BUILDING

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Abstract: The number of installed ground heat source heat pump systems in Japan has been grown. However when we look at the HVAC system for the commercial buildings, so called “Packaged Air Conditioning System”, is very common. When the conventional water to water GSHP would be installed in the commercial building in the southern part of Tokyo area, the advantages of the system performance and cost reduction compared to the ASHP are small. This is a barrier to develop the GSHP market in the commercial building sector. In this paper, the concept of the novel ground source packaged air conditioning system designed for the commercial buildings with an additional cooling tower to release the excessive waste heat from the cooling is proposed. Then the performance of the combination use of ground heat exchangers and a cooling tower is investigated when there is a big imbalance of the extracted heat and the released heat into the ground. In addition, the proper cooling capacity of the cooling tower and their annual performances are evaluated for three types of buildings.

Key Words: Ground Source Heat Pump, Packaged Air Conditioner, Cooling Tower, Combined System,

1 INTRODUCTION

Energy consumptions for both the residential sector and the commercial building sector in Japan have rapidly increasing from 1990 years. Main reasons are increases of IT instruments in the rooms and requirements of more comfortable indoor environments. Obviously, increase of energy consumptions swells the CO2 emissions. Energy conversation through the passive building techniques and human activities, rise of the energy efficiency of the building facilities and adopting renewable energy resources are needed to diminish CO2 emissions. The use of the ground as the heat source and the heat sink of the heat pump is reasonable from the high efficiency and low environmental impacts pointed of view.

Here, the number of installed ground heat source heat pump systems in Japan has been grown for past few years. The leading GSHPs are still the water (brine) to water system for the residential purposes in the rather northern part of Japan. However when we look at the HVAC system for the commercial buildings, so called “Packaged Air Conditioning System”, is very common in Japan. “Packaged Air Conditioning System” is one of the typical sprit type air source heat pump (ASHP). It consists from an outdoor unit and multiple direct expansion indoor units, and these are able to be connected by the long small-diameter copper tubes for circulating the refrigerants. Energy performances of recent ASHPs have become gradually higher.

From our review, when the conventional water to water GSHP would be installed in the commercial building in the southern part of Tokyo area in Japan, the advantages of the system performance and cost reduction compared to the ASHP are small although the COP of the water to water GSHP unit could be higher than that of the ASHP. The authors have realized this is the real market barrier to develop the GSHP market in the commercial building sector.

The authors have developed the novel ground source packaged air conditioning system designed for the commercial buildings, which can operate at the highest system COP due to the primary side flow rate control. It is sure that when we would reduce the primary side flow rate, the COP of the heat pump unit would be lower and the heat transfer rate of the ground

heat exchanger would decreased. However, the needed energy consumption of the primary side circulation pump would be also much lower. This means that there could be an optimum primary side flow rate which gives the highest system COP of the GSHP system.
In this paper, the concept of the novel ground source packaged air conditioning system designed for the commercial buildings with an additional cooling tower to release the excessive waste heat from the cooling is explained. Then the performance of the combination use of ground heat exchangers and a cooling tower is investigated when there is a big imbalance of the extracted heat from the ground and the released heat into the ground. In addition, the proper cooling capacity of the cooling tower and their annual performances are evaluated for the three types of the building purposes.

2 NOVEL GROUND SOURCE PACKAGED AIR CONDITIONING SYSTEM (GS-PAC)

Figure 1 shows the concept of the novel ground source packaged air conditioning system (GS-PAC) designed for the commercial buildings. It consists from a sprit type water (ground) source heat pump, primary side circulating pumps with a variable flow control unit, and ground heat exchangers. The COP of the water to water heat pump is rather higher than that of a water source packaged air conditioning unit, but system COP (SCOP) of the conventional water to water system is not so high and a left example in this Figure shows that SCOP is 3.6. On the other side, the developed one has no circulation pump in the secondary side (direct expansion) and when we can control the flow rate of the primary side by using an inverter, it is possible to obtain the higher SCOP at the lower flow rate compared to the rated one due to keeping the proper temperature difference. It is typical that the COP of the heat pump would be lower and the heat transfer rate of the ground heat exchanger would decrease when the flow rate of the primary side is reduced. However, the needed energy consumption for the primary side circulation pump would be much more decreased. This means that there could be an optimum primary side flow rate which gives the highest SCOP. In this case, SCOP of 4.5 could be achieved as shown in the right hand of Figure 1. In addition, a cooling tower combined with multiple ground heat exchangers (GHEXs) is examined in order to release the excessive waste heat from the cooling in the southern part of Tokyo in Japan. On the other side, the use of the building foundation piles as the multiple GHEX is also considered in order to reduce the initial cost.

3 USE A COOLING TOWER IN COMBINATION WITH GHEXS FOR GS-PAC

Annual performances of the GS-PAC in combination with GHEXs and a cooling tower were evaluated by using the developed design and performance prediction software by the authors.

3.1 Calculating conditions

Figure 2 shows the system configuration of the GS-PAC and Figure 3 shows the cooling and heating demand of the subject building. Table 1 is the specification of the building and GS-PAC for the calculation.
A two-storied individual small office building is assumed. The total floor are of the calculated building was 3,000 m^2 (= 1,500m^2 x 2 stories). This building has totally 54 foundation piles (6 X 9 = 54 piles). Peak demands for the cooling and the heating are 334 kW and 198 kW, respectively. The seasonal amounts of the cooling demand and the heating demand are calculated as 214 MWh and 96 MWh, respectively. To cover the cooling and the heating demand, the total coolingcapacity of 336 kW heat pump units (28 kW/unit x 12 heat pump units = 336 kW) are equipped. For this purpose, the total length of 2,700 m steel pile foundation piles (outside diameter 500 mm, each effective length 50 m/pile x 54 piles = 2,700

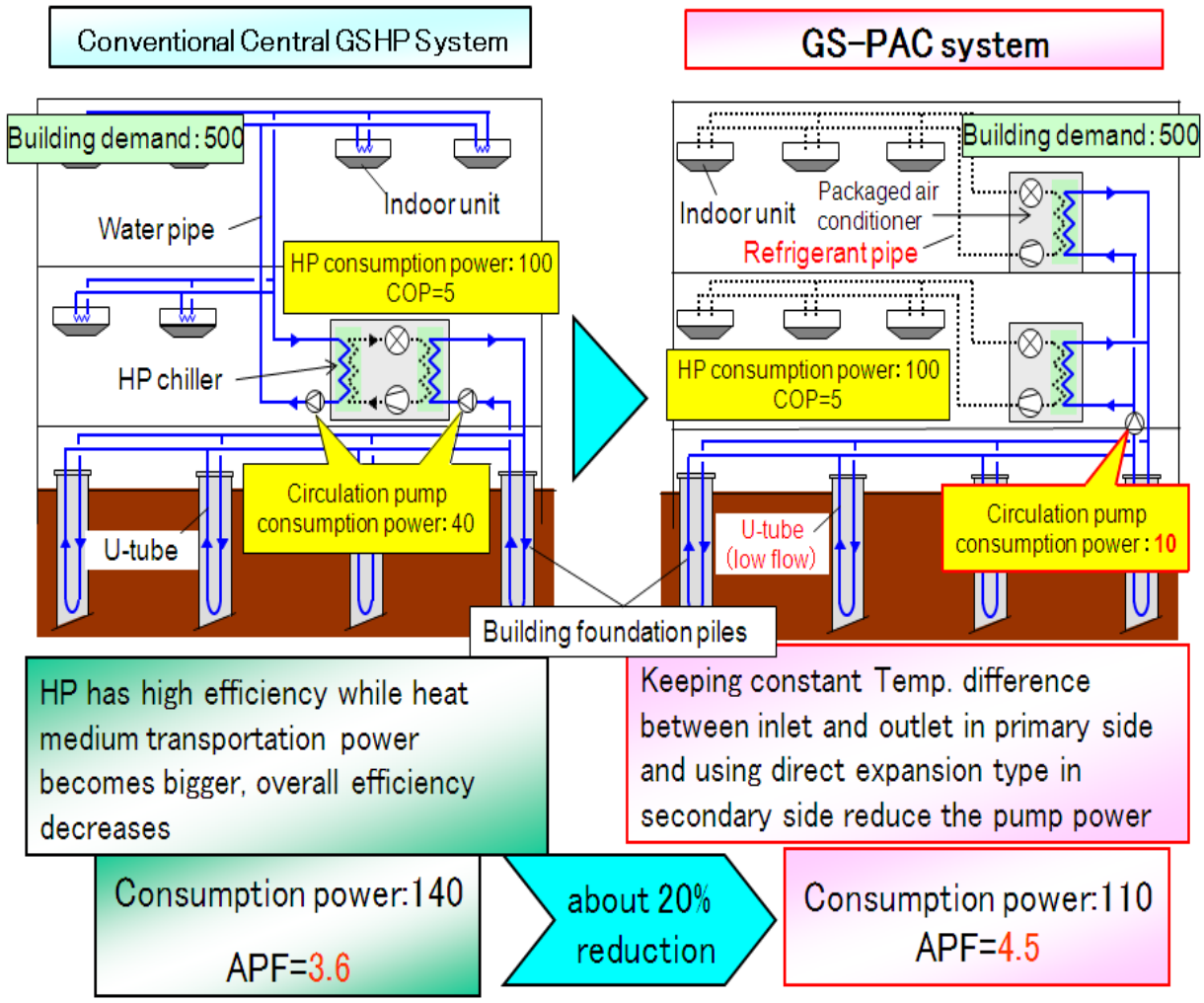


Figure 1: the concept of GS-PAC

m) are prepared. To make them as the ground heat exchangers, water is filled in the hollow steel pile and two HDPE tubes of 25 mmϕ in outside diameter are inserted into each pile. 12 circulating pumps which have a rated circulation capacity of 96 liters per minute each are equipped with the inverter control units. In this calculation the constant temperature difference between the return and the supply side is maintained by varying the flow rate of the primary side. This system is assumed built in Tokyo area, so that the natural ground temperature is given at 16.5 ^{o}C. The effective thermal conductivity and the heat capacity of the ground are 1.5 W/(m·K) and 3,000 kJ/m^3, respectively.
The calculation is conducted every hour of the year according the hourly cooling and heating demand for the representative day of each month, simulated by the simplified load calculation software, TEF-FS supplied from HPTCJ.

The following approximation which was derived from the actual performance data in the calculation is applied to calculate COPs of GS-PAC for the simulation.

$$COP = f(T_{1in},\ G_w,\ Q_2/Q_{2max},\ T_r) \quad (1)$$

Here, T_{1in}: return fluid temperature from the GHEXs to the GS-PAC [^{o}C]
G_w: circulating flow rate of the primary side [l/min]
Q_2/Q_{2max}: ratio of current cooling/heating output to maximum capacity [kW/kW]
T_r: room air temperature (26 ^{o}C for the cooling and 20 ^{o}C for the heating) [^{o}C]

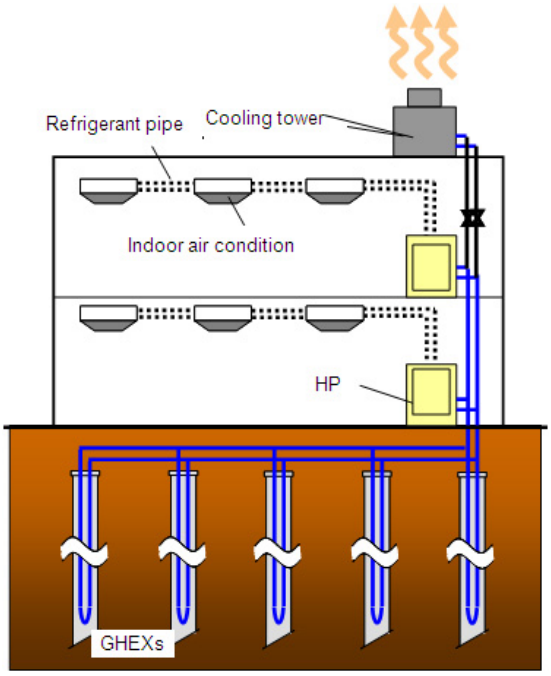


Figure 2: GS-PAC configuration

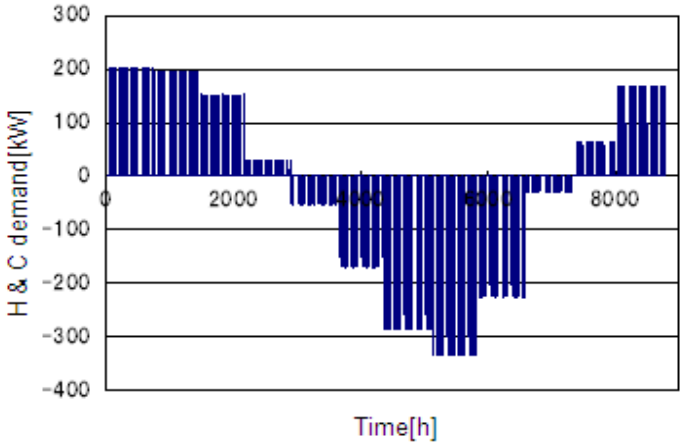


Figure 3: Cooling and heating demand of the subject building

Table 1: the specification of the building

Building		office building, 3,000m² (1500m² × 2 floors)
Demand	peak	cooling: 334kW、heating: 198kW
	seasonal amount	cooling: 214MWh、heating: 96MWh
GHEX		steel pipe pile (effective length 50m、500mmφ) × 54 piles
		HDPE O.D. 25mm φ, double U-tube
Heat pump		water-cooled build-multi-HP 28kW × 12
Circulation pump		Flow rate: 96L/min × 12 pumps
		constant temp. difference control between inlet and outlet (⊿T=5℃)
Ground		natural temp:16.5℃、heat capacity:3000kJ/m^3
		effective thermal conductivity:1.5W/(m・K)

From table 1, the annual amount of the cooling demand is bigger than that of the heating one and it is clear that the amount of heat release into the ground is much bigger. This fact means that a cooling tower should be taken into the account in order to release the excessive waste heat and to prevent yearly increase of the ground temperature. In this study a closed type cooling tower is used.

3.2 Evaluation of the performance in combination use of GHEXs and a cooling tower

The annual performances factor (APF, annual average system COP) with/ without a cooling tower are examined.

3.2.1 Combination of GHEXs and cooling tower

When the combination use of GHEXs and a cooling tower is designed, the following three methodologies can be applied.

[1] Serial connection 1 (Ser.1) [GS-PAC → Cooling Tower → GHEXs → GS-PAC]
[2] Serial connection 2 (Ser.2) [GS-PAC → GHEXs → Cooling Tower→ GS-PAC]
[3] Parallel connection (Pal) [GS-PAC → GHEXs → GS-PAC]
Cooling Tower →

Here, a cooling tower of 162 kW in cooling capacity is selected and it was always used in combination with GHEXs during the cooling operation though cooling demand is low in these calculations.
Calculated APFs according to the operation years were shown in Figure 4. The annual amounts of released heat from the cooling tower were also presented. From the results there is not much difference between all of APFs and they are around 5.1. However, APFs fall in any cases according to the elapsed years in spite of they are really affected by the amount of released waste heat from the cooling tower. In the case of no cooling tower (No), APF decreases from 5.08 to 4.75 linearly in five years.
On the other hand, when a cooling tower is combined with the GHEXs, APFs seems to be stable though they decline in a few years. When the value of APF is 5.1, we understand that the amount of the released heat from a cooling tower is 80 MWh. This is 31 % of the total amount of the waste heat of the cooling, which is 256 MWh. In the comparison between Ser1, Ser2 and Pal., the effect of the cooling tower in the case of Ser. 1 keeps good, so that APFs in that case also keeps highest. This result can conclude that the serial connection 1 [GS-PAC→Cooling Tower →GHEXs →GS-PAC] is reasonable for the combination.

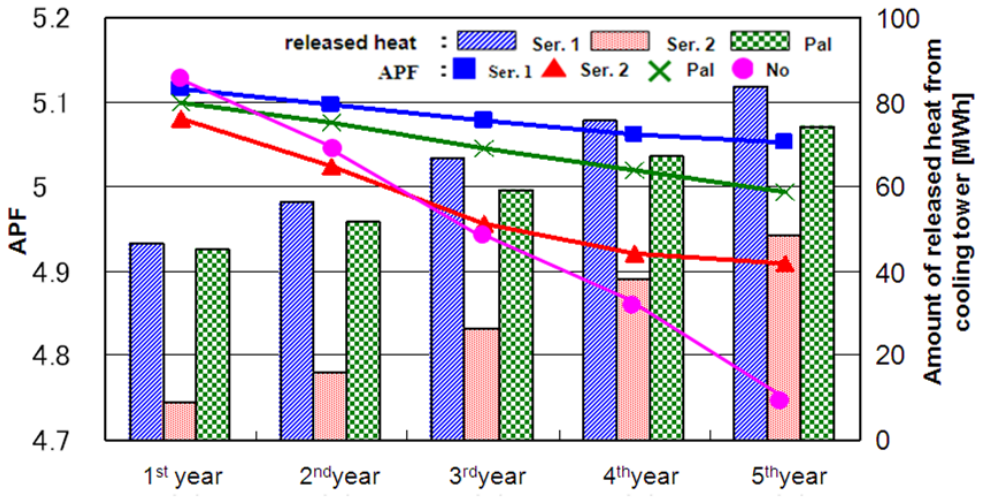


Figure 4: the annual amounts of released heat from the cooling tower

3.2.2 Monthly operation of the cooling tower

The methodology of the monthly operation of the cooling tower is examined during the cooling season from May to October as shown in Table 2. The Case0 means that it has no cooling tower and only GHEXs are used for the heat release. In the Case1 it has small size of cooling tower (its cooling capacity is 162 kW) and it is always combined with GHEXs in the series connection 1. In the Case2 and the Case3, the heat absorption capacity of the ground is intended to preserve until appearance of the peak demand to expect higher performance. So, a cooling tower operates alone to release the waste heat of the cooling at the beginning and at the end of cooling season. Their cooling capacities are set at 216 kW and 270 kW, respectively according to the maximum released heats. Calculated results are shown in Figure 5. The best solution appears in the Case1. In the Case2 and Case3, heat releasing from only GHEXs is tough for the peak demand. In addition a bigger cooling tower consumes larger power to drive the cooling tower even cooling demands are low, so that APFs are lower than that of Case1.

Table 2: the methodology of the monthly operation of the cooling tower

	capacity of cooling tower	May	June	July	Aug	Sep	Oct.
CASE0	0	GHEX only					
CASE1	162kW	combined GHEX and cooling tower					
CASE2	216kW	cooling tower only		combined	GHEX only	combined	cooling tower only
CASE3	270kW	cooling tower only		GHEX only		cooling tower only	

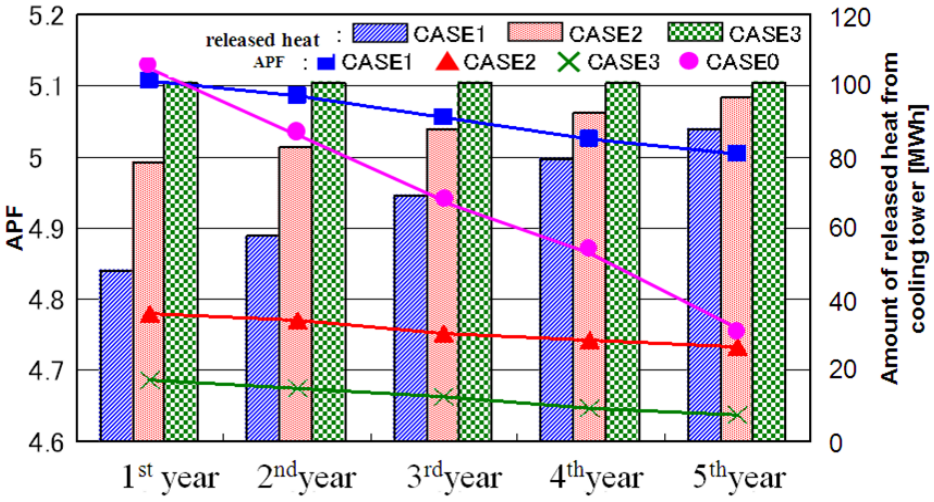


Figure 5: calculated results

3.2.3 Bypass control of the cooling tower

From the result of the previous session, it is realized that the continuous combination use of GHEXs and a cooling tower shows the highest performance. However, cooling tower still works even during the low cooling demand period. Therefore it is possible to improve the APF to bypass the cooling tower according to the secondary side fluid temperature to the cooling tower, T_{ctin}.
Figure 6 presents the changes of the APF at the fifth year according to T_{ctin}. The proper size of

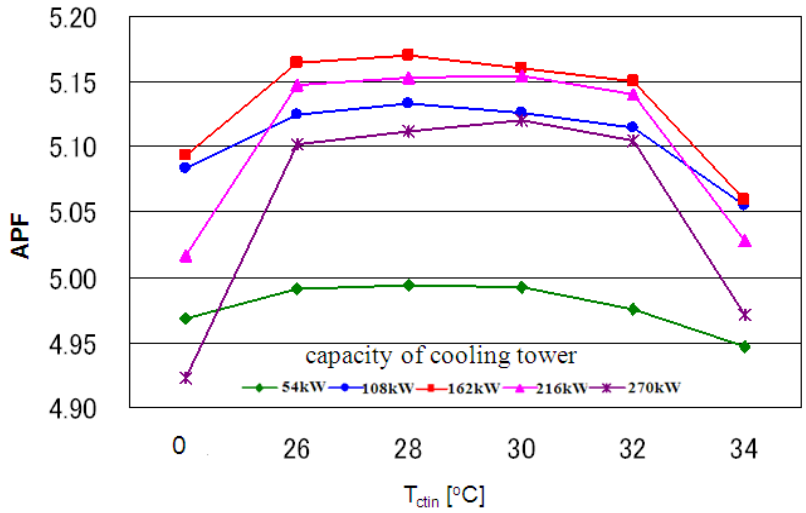


Figure 6: the changes of the APF at the fifth year according to T_{ctin}

the cooling tower is also examined in this figure. When the bypass control is introduced, APFs are higher in all cases. The highest APF appears when the cooling capacity of the cooling tower is 162 kW at preset temperature for bypass of 28 °C. However, APFs show almost the same value when the bypass preset temperature is changing from 26 °C to 30 °C.
To reduce the heat release impact to the atmosphere and to prevent the heat island effect, the preset temperature for bypass of 30 °C is reasonable.

4 DESIGN PROCEDURE AND CASE STUDIES

4.1 Proposed design procedure

In the actual projects, the length and the number of building foundation piles are fixed. The authors propose the design procedure to determine the proper cooling capacity of the cooling tower combined use with GHEXs as follows. In this time the use of the developed simulation tool is on the premise.

[1] It should be confirmed by the calculation that the minimum primary side fluid temperature is kept above 2 °C without a cooling tower at the first winter season when the calculation is started from the heating period.

[2] The operating simulation is done for five years with the cooling tower. In this time the cooling capacity of a cooling tower should be selected in order that the maximum secondary side fluid temperature is below 35 °C. Because the performance of the unit is guaranteed by the manufacturing companies below this temperature.

[3] The bigger cooling tower needs bigger power consumption. Therefore the oversized cooling tower makes APF lower. Finally, the proper size of the cooling tower is selected to keep the highest APF under these critical temperature conditions.

4.2 Case studies

Selected building purposes and their cooling and heating demands per unit floor area are presented in Table 3. In Table 4, numbers of the case studies are given according to the purpose of the building, the total floor area and the pile length. The proper cooling capacities are examined for the various cases shown in Table 3 and Table 4 according to the proposed design procedure.

Table 3: building purposes and their cooling and heating demands

Building purpose	Cooling		Heating	
	Peak [W/m^2]	Annual [MWh/(m^2・year)]	Peak [W/m^2]	Annual [MWh/(m^2・year)]
office	111	71	66	32
department store	98	123	38	14
hotel	47	60	21	38

4.2.1 The approximate proper size of the cooling tower

First, the approximate proper size of the cooling tower is examined. The imbalance of the estimated amount of extracted heat from the ground and the estimated amount of released heat into the ground without the cooling tower is taken into account. In addition, equivalent cooling operating hours compared to the rated cooling capacity is considered. Consequently, the excess heat release rate [kW], which is defined by the imbalanced amount of heat [kWh] divided by equivalent cooling operating hours [h] is taken as a variable.
Figure 7 shows the relationship between proper sizes of the cooling tower which takes the highest APF under the given conditions and the excess heat release rate defined above in various cases. It is found the proper size of the cooling tower is in proportion to the excess heat release rate. We can determine the approximate proper size of the cooling tower from this figure. On the other hand, the cooling tower is not needed when the excess heat release rate is less than 50 kW.

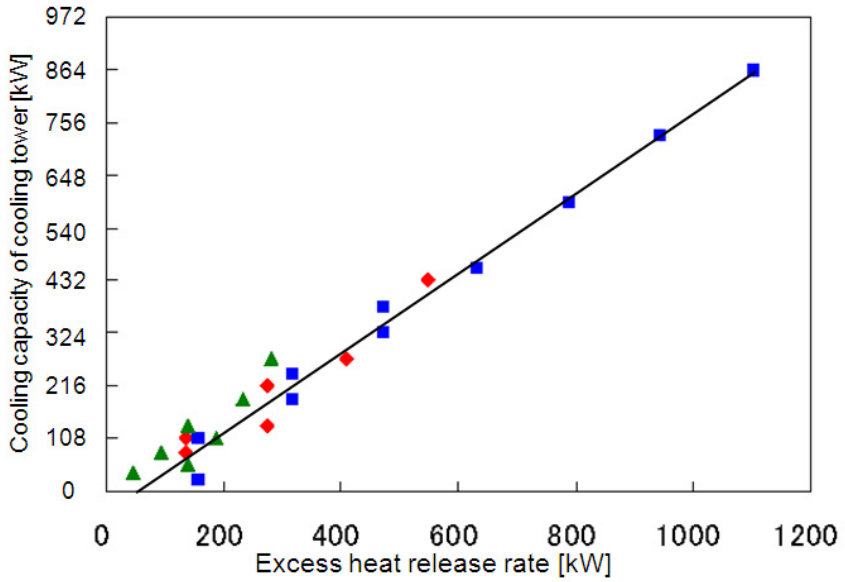


Figure 7: the relationship between proper sizes of the cooling tower

4.2.2 Calculating results and discussions

The calculated results on the fifth years of the amount of extracted heat from the ground and the amount of released heat into the ground, seasonal performance factors (SPFs) and APFs are shown in Table 4. As the same discussion in the session 4.2.1, a bigger size cooling tower is needed when the cooling demand is greater than that of the heating demand in order to obtain the higher APF. However, it is found the enlargement effect of the GHEX capacity is

different. When APFs are compared in the case1-1 and in the case1-2, the APF rises 0.31 from 4.76 to 5.07 according to double in the total length of GHEXs. However, APFs are distributed within 4.75 to 5.32 in all cases. These are very high. This means that the combination use of GHEXs and a cooling tower gives a good chance for a sustainable operation and a good performance of the GS-PAC system which has the imbalance of the extracted heat from the ground and the released heat into the ground. On the contrary the maximum heat release rates show quite big varieties. This fact describes it is necessary to make the proper design of GSHP system by using this kind of simulation tools.

Table 4: extracted heat from the ground and the amount of released heat into the ground, seasonal performance factors (SPFs) and APFs

CASE			1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3
Building purpose			office building			department store			hotel		
Total floor area		m^2	3000	3000	6000	4500	4500	9000	4500	4500	9000
GHEX	each pile length	m	25	50	50	25	50	50	25	50	50
	total pile length	m	1350	2700	2700	1350	2700	2700	1350	2700	2700
	total length/area	m/m^2	0.45	0.9	0.45	0.3	0.6	0.3	0.3	0.6	0.3
Proper cooling tower capacity		kW	216	135	432	378	324	729	135	54	270
heating	seasonal amount of extracted heat	kWh/m^2	25	26	25	11	11	11	30	31	30
	peak heat extraction rate	W/m^2	51	53	51	31	31	31	16	17	16
	COP	-	4.62	5.10	4.66	4.39	4.63	4.45	4.57	5.02	4.59
	SPF	-	4.44	4.88	4.48	4.14	4.35	4.18	4.35	4.76	4.39
Cooling	seasonal amount of released heat	kWh/m^2	37	58	36	24	37	22	37	54	36
	seasonal amount of released heat by cooling tower	kWh/m^2	46	25	48	119	106	122	32	15	33
	peak heat release rate	W/m^2	57	87	52	26	43	26	31	47	31
	peak heat release rate of cooling tower	W/m^2	81	49	84	93	76	93	25	10	26
	COP	-	5.71	5.80	5.69	6.11	6.11	6.08	6.51	6.43	6.50
	SPF	-	4.90	5.15	4.87	5.09	5.15	5.02	5.50	5.75	5.50
APF		-	4.76	5.07	4.75	4.98	5.06	4.92	4.99	5.32	5.01

5 CONCLUTIONS

First, it is found that the continuous combination use of GHEXs and a cooling tower gives higher performance when there is a big imbalance of the extracted heat from the ground and the released heat into the ground. In this time, the highest APF always appears in the case of Serial connection 1 [GSHP → Cooling Tower → GHEXs → GSHP]. To improve the APF, the bypass control is effective and preset temperature for bypass from 28 ^oC to 30 ^oC gives the higher APF. To reduce the heat release impact to the atmosphere to prevent the heat island effect, the preset temperature for bypass of 30 ^oC is reasonable.
Second, the design procedure of GSHP used in combination with GHEXs and a cooling tower was proposed. In addition, the proper cooling capacities are examined for the three types of the building purposes. It is found that proper size of the cooling tower is in proportional to the excess heat release rate defined by the imbalanced amount of heat [kWh] divided by equivalent cooling operating hours [h]. APFs are distributed from 4.75 to 5.32 in all cases and these are high. This means that the combination of GHEXs and a cooling tower gives a good chance for a effective and sustainable operation of the GSHP system which has the imbalance of the extracted heat from the ground and the released heat into the ground.

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