The Analysis on Energy Saving Effect of STES-HGCHE in Office Building's Central AC System in Taiwan

Peng Li[1] and Hsien-Te Lin[2]

Abstract**--**In Taiwan, power consumption of air conditioning (AC) accounts for 9.7% of total electricity generation capacity. How to reduce AC power consumption is an important issue worthy to be studied. Based on the climatic condition of Taiwan, this paper focuses on the application potential of seasonal thermal energy storage-hybrid ground coupled heat exchanger (STES-HGCHE) in central air conditioning system of office buildings. Finally in ideal condition, according to the simulation of eQuest3-65 and calculation of a computer program coded by authors, STES-HGCHE can realize 5.86% reduction of energy consumption and electricity bill saving of 7.48% due to the different electricity prices of peak and off-peak time in the simulated office building in Tainan, a city in south Taiwan, and 3.21%, 4.71% respectively in Taipei, a city in north Taiwan. However the return on investment and the compact of underground water need further study.

Keywords**--**STES, HGCHE, Ground Coupled Heat Exchanger, Seasonal Thermal Energy Storage

I. Introduction

IN 2013, Taiwan spent 12.9% of that year's GDP, about 65 Billion USD, on importation of energy which accounted 97.58% of energy supply of the year [1]. In the same year, all central air conditioning (AC) units in Taiwan consumed 24.54 Billion KWH electronic power which accounted 9.7% of annual total electric generation [2]. If the power consumption of central AC units can be reduced or their efficiency can be improved, it will help Taiwan to realize energy saving, cut a part of energy importation and improve energy security.

Central AC Units are widely used in office buildings, hospitals, shopping malls and large scale public spaces. This paper will focus on energy saving effect of seasonal thermal energy storage-hybrid ground coupled heat exchanger (STES-HGCHE) in office building's central AC system in Taiwan, and will take two cities, Tainan in the south and Taipei in the north, as examples.

II. Principle and Operation Modes of STES-HGCHE

In office buildings of Taiwan, the loads of AC are composed mainly of the summer's cooling loads. In winter, there is no heating load needed. If ground coupled heat exchanger (GCHE) is integrated into central AC unit, the rejected heat will be discharged into the earth persistently and cause the temperature of the earth around the GCHE raising continuously, which will finally let the GCHE lost its function of energy saving.

To solve this problem and balance the unbalanced loads between summer and winter, STES-HGCHE is designed and integrated into central AC unit.

HGCHE is a combination of cooling tower and GCHE. Its main function is to utilize the GCHE to provide colder water for central AC unit in order to improve its cooling efficiency. The cooling tower is used to realize the heat rejection in case that the temperature of the earth goes up beyond the limitation which will cause the GCHE malfunction.

STES is a strategic arrangement on running of HGCHE. In winter, when the air dry bulb temperature （DBT） is under certain critical point, the HGCGE runs independently in order to discharge the accumulated heat in the earth into air. STES can lower the temperature of the earth and guarantee the running of HGCHE in next summer period. In Taiwan, traditionally winter mainly includes Jan., Feb. and Dec., and summer includes the other months. However, for central AC unit in office buildings of Taiwan, there is no clear boundary between winter and summer because the AC system is running

[1] Ph.D. Student, Dept of Architecture, National Cheng-Kung University, Taiwan. Email: N78023016@mail.ncku.edu.tw
[2] Chair Professor, Dept of Architecture, National Cheng-Kung University, Taiwan

on every work day of the year.

Different critical temperature assignment will bring different effect of energy saving. This is also a focus of this paper.

Fig. 1 shows how STES-HGCHE is integrated in to central AC system.

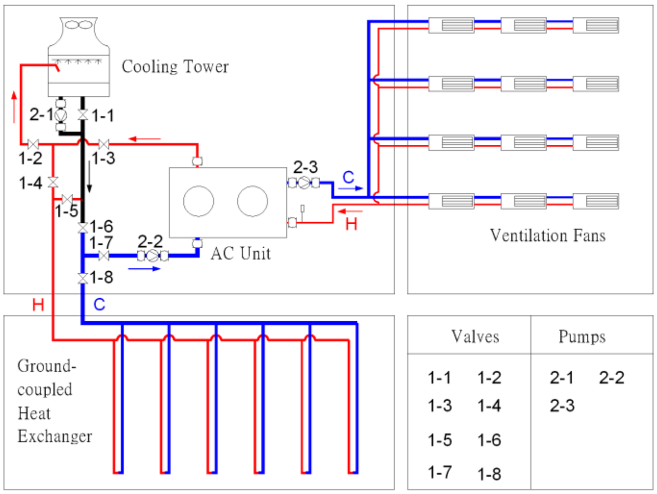

Fig. 1 STES-HGCHE System Diagram

According to different circumstances, STES-HGCHE can run in several modes. Table 1 shows three most adopted modes and gives the status of valves and pumps under different mode.

TABLE I

RUNNING MODES OF STES-HGCHE

Mode	Condition	Description
No.1	AC is on. STES is off. Cond.: AWBT<= Te	Cooling tower +central AC unit
No.2	AC is on. STES is off. Cond.: AWBT> Te	GCHE +central AC unit
No.3	AC is off. STES is on. Cond.: ADBT<=*Tc*	Cooling tower +GCHE

Mode	Status										
	Valves								Pumps		
	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	2-1	2-2	2-3
No.1	ON	ON	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON
No.2	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	ON	ON
No.3	OFF	ON	OFF	ON	OFF	ON	OFF	ON	ON	OFF	OFF

AWBT: air wet bulb temperature.

ADBT: air dry bulb temperature.

Te: earth temperature. In Taiwan, the average earth temperature keeps about 24 to 26℃ at the depth of 10 to 100 meters [3]. However, if STES is introduced, the earth temperature nearby HGCHE will become unstable and fluctuate around a new temperature level.

Tc: critical air dry bulb temperature. Different Tc will cause different effect of energy saving.

To run the STES-HGCHE and central AC unit in combination of modes listed in Table 1 will make it balanced the earth thermal energy around HGCHE. Clearer to say, the heat accumulated into the earth in summer will be equal to the heat discharged from the earth in winter, which is the very key point that lets the whole system run year by year with high sustainability.

Another fact that can improve the efficiency of STES-HGCHE is the discontinuous running of central AC unit. In most office buildings of Taiwan, the AC systems only provide cold water or air between 8:00-18:00 each work day. That is to say, there are a large fragment of time during a day that can be used for the recovery of earth temperature by thermal transmission inside the earth around HGCHE, which will make the the whole system run with high sustainability.

III. THE ANALYSIS OF ENERGY SAVING EFFECT

According to our calculation and simulation, *Tc* is the key parameter that can affect the effect of energy saving. Different regions have different optimal *Tc* to let the whole system to realize maximal energy saving potential.

In theory, under the same loop speed in HGCHE, the lower the *Tc* is and the bigger the difference of the earth temperature between summer and winter is, the better the effect of energy saving will be. But in fact, assigning a lower *Tc* means fewer hours can be used for STES, which will ask more power and higher loop speed to exchange heat in a shorter period. When loop speed exceeds certain point and heat exchange time is confined in short period, the effect of heat exchanging between HGCHE and the earth will be depressed largely. Thus, properly calculated *Tc* will be a key point for the whole system.

According to the latest typical meteorological year (TMY) data of Taiwan, TMY3 [4], the hours equal or below possible *Tc* of Tainan and Taipei are calculated. The results are showed in Table 2 and Fig. 2.

TABLE II

HOURS EQUAL OR BELOW POSSIBLE *Tc*

Month		Critical Dry Bulb Temp. (℃)							
		13	14	15	16	17	18	19	20
1	TN	37	92	162	271	406	496	554	609
	TP	112	147	229	356	515	628	694	714
2	TN	53	95	117	149	178	234	282	338
	TP	141	167	196	246	309	394	441	482
3	TN	—	7	43	68	83	112	153	208
	TP	34	62	106	162	230	286	326	396
4	TN	—	—	—	—	—	—	—	—
	TP	—	—	—	—	4	26	83	143
5	TN	—	—	—	—	—	—	—	—
	TP	—	—	—	—	—	—	4	27
6-9	TN	—	—	—	—	—	—	—	—
	TP	—	—	—	—	—	—	—	—
10	TN	—	—	—	—	—	—	—	7
	TP	—	—	—	—	—	—	—	12
11	TN	—	—	—	1	10	17	49	93
	TP	—	7	14	27	38	79	160	234
12	TN	38	56	69	111	155	223	325	423
	TP	76	94	115	187	297	399	470	547
Total (H)	TN	128	250	391	600	832	1082	1363	1678
	TP	363	477	660	978	1393	1812	2178	2555
ADBT (℃)	TN	11.9	12.7	13.4	14.2	14.8	15.5	16.1	16.7
	TP	11.5	12.0	12.7	13.7	14.5	15.2	15.8	16.3
AWBT (℃)	TN	9.8	10.8	11.5	12.2	12.8	13.4	14.0	14.5
	TP	10.3	10.8	11.5	12.3	13.0	13.6	14.1	14.6

ADBT: Average Dry Bulb Temperature; TN: Tainan;

AWBT: Average. Wet Bulb Temperature; TP: Taipei;

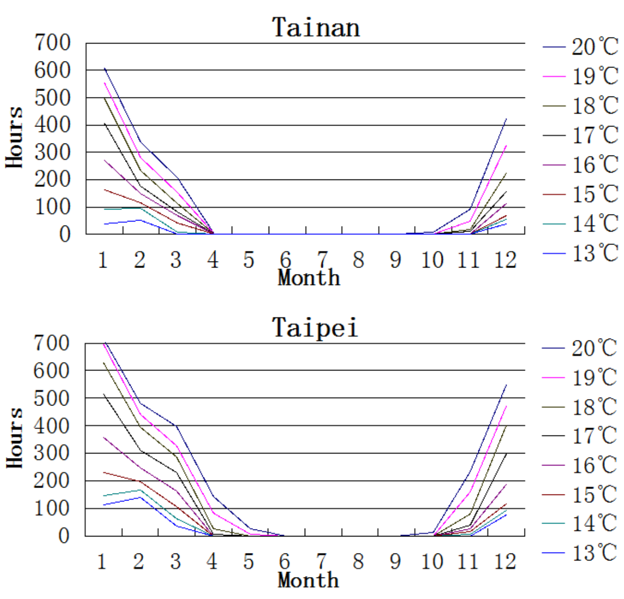

Fig. 2 Hours Equal or Below Possible *Tc*

Power Consumption of central AC system includes the consumption of AC unit, fans, cooling tower, chilled water pump and condenser water pump. Each part takes different portion in different buildings. For example, according to the description of one paper [5], in one office building, the AC unit takes 49.5% of total power consumption of whole central AC system, pumps take 14%, fans take 33.3% and cooling tower takes the rest 3.2%.

Composition of power consumption in AC system with STHS-HGCHE is different with normal AC system. Table 3 gives a clear description on the composition in both systems. If the total annual consumption of AC system with STHS-HGCHE is less than normal AC system, the effect of energy saving of STHS-HGCHE will be proved effective.

TABLE III

COMPOSITION OF AC POWER CONSUMPTION

Normal AC System		AC System with STHS-HGCHE	
Sumer	Winter	Sumer	Winter
AC unit		AC unit	
Fans		Fans	
Cooling Tower			Cooling Tower
Chilled Water Pump		Chilled Water Pump	
Condenser Water Pump		Condenser Water Pump	Condenser Water Pump

IV. CALCULATION AND SIMULATION OF STHS-HGCHE

In order to make sure whether the STHS-HGCHE can realize energy saving, a computer model showed in Fig. 3 was created for simulating the power consumption of a whole year. The model is an 8F office building with 5574 square meters area and assigned an AC running schedule according to the regulation of government [6]. The software used in simulation is eQuest3-65.

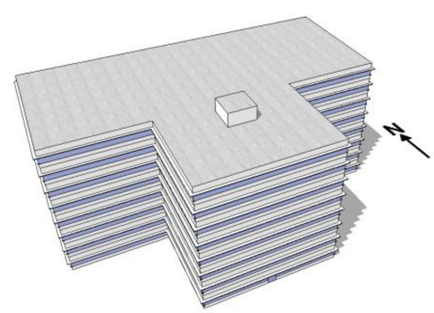

Fig. 3 The Computer Model, 8F Office Building

Besides the simulation, a short paragraph of computer program code was written to make a clear calculation of the AC running data of the calculated year hour by hour.

For purpose of comparison, this model was simulated and calculated in both Tainan and Taipei.

Table 4 shows the total power consumption of the model with normal AC system.

TABLE IV

TOTAL POWER CONSUMPTION OF THE BUILDING

Total Power Consumption with Normal AC System By eQuest									
Hours		Power Consumption（×1000KWh）							
		TL	ME	Central AC System					
				Unit	Fan	ChWP	CdWP	CT
Tainan	2510	291	234.8	387.3	234.9	33.9	46.4	33
	Percentage(%)			52.66	31.94	4.61	6.30	4.49
Taipei	2510	291	234.8	292.8	158.5	30.3	41.9	23.1
	Percentage(%)			53.57	29.00	5.54	7.67	4.23

TL: Task lights.

ME: Miscellaneous Equipment.

ChWP: Chilled Water Pump

CdWP: Condenser Water Pump.

CT: Cooling Tower.

When the temperature of the earth is lower than air web bulb temperature, the HGCHE can be used to replace the cooling tower in order to provide condenser water with lower temperature. According to the research [7], 1℃ reduction of the condenser water can lower 3.33% power consumption of AC unit.

Before calculation, some assumptions are made.

1. The return water temperature of cooling tower is 4℃ higher than air web bulb temperature.

2. The return water temperature of HGCHE is 4℃ higher than ground temperature.

3. The heat exchanging efficiency of HGCHE is 70%.

4. The power consumption of pumps in HGCHE is directly proportional to loop speed.

5. In order to let the HGCHE work properly, the STES stage runs in advance of summer.

After the calculation, it can be seen that the temperature of the earth will increase constantly in STES-HGCHE system. Fig. 4 can show this phenomenon clearly. When the temperature of the earth goes up to the point B, it means that, at the rest time of that year, the STES-HGCHE can not provide colder water than cooling tower. And in Taipei, point B comes sooner than in Tainan because of the different meteorological conditions.

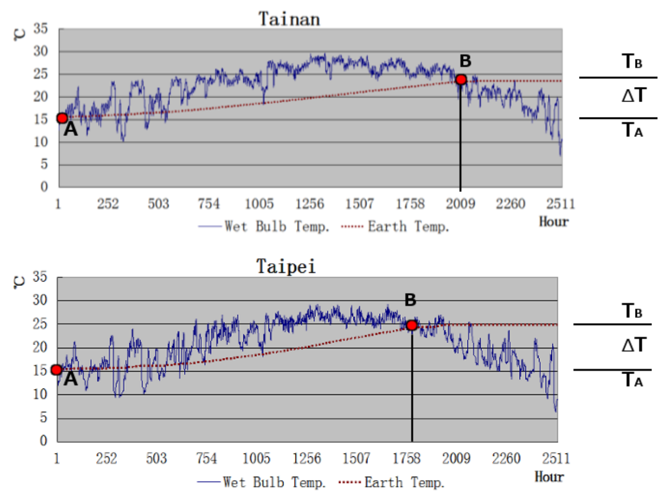

Fig. 4 The Temp. Changes in A Year Period in STES-HGCHE System (*Tc*=15℃)

The *ΔT* is the difference between T_A, the temperature of earth in point A, and T_B, the temperature of earth in point B.

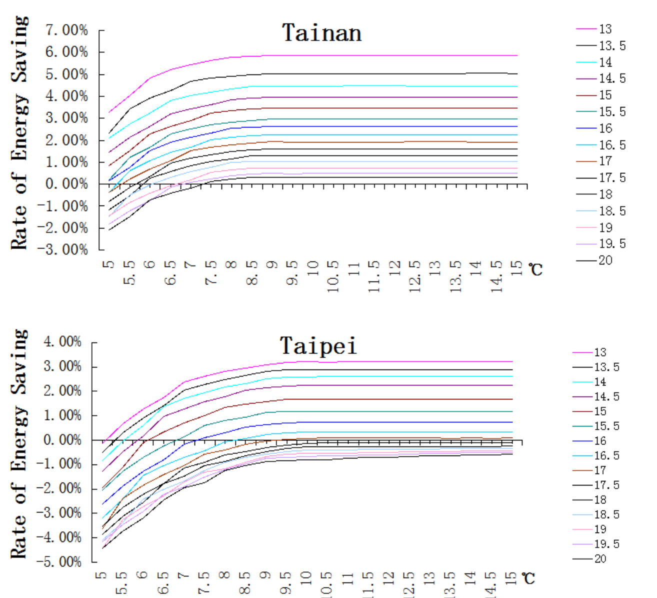

Fig. 5 Energy Saving Potential (Vertical Axis) in Different *Tc*(Curves) and *ΔT*(Horizontal Axis)

Fig. 5 shows that the lower *Tc* is, the higher the rate of energy saving is. In certain range, the larger the *ΔT* is, the higher the rate of energy saving is. However, the effect of STES-HGCHE in Tainan is better than in Taipei.

Table 5 and Fig. 6 show the maximal rate of energy saving of STES-HGCHE in different *Tc* and corresponding rate of electricity bill saving and *ΔT*.

TABLE V

MAXIMAL RATE OF ENERGY SAVING OF STES-HGCHE IN DIFFERENT *Tc*

Tc (℃)	Maximal Rate of Energy Saving(%)		Rate of Electricity Bill Saving(%)		*ΔT* (℃)	
	Tainan	Taipei	Tainan	Taipei	Tainan	Taipei
13	5.86	3.21	7.48	4.71	13	10
13.5	5.05	2.90	6.61	4.41	14	10
14	4.48	2.60	6.08	4.03	11	10.5
14.5	3.95	2.24	5.51	3.65	11	10
15	3.46	1.69	4.98	3.17	9.5	9.5
15.5	2.98	1.19	4.45	2.51	12.5	10
16	2.64	0.74	4.13	2.00	9	10.5
16.5	2.26	0.34	3.7	1.46	11	11
17	1.93	0.09	3.42	1.01	9	10.5
17.5	1.6	-0.10	3.09	0.81	9	13.5
18	1.3	-0.25	2.74	0.34	9.5	15
18.5	1.03	-0.32	2.48	0.27	8.5	15
19	0.73	-0.42	2.06	0.17	9.5	15
19.5	0.48	-0.49	1.66	0.10	9	15
20	0.31	-0.57	1.42	0.02	9	15

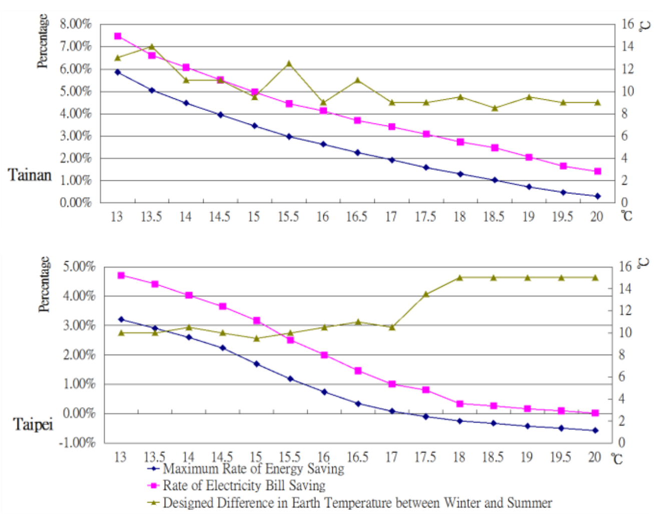

Fig. 6 Maximal Rate of Energy Saving of STES-HGCHE in Different *Tc*

V. CONCLUSION AND SUGGESTION

By computer simulation and calculation, compared with the normal AC system, STES-HGCHE can realize 5.86% reduction of energy consumption and electricity bill saving of 7.48% due to the different electricity prices of peak and off-peak time in the simulated office building in Tainan, a city in the south, and 3.21%, 4.71% respectively in Taipei, a city in the north.

In Taiwan, by making an overall consideration of the conditions of utilization of STES-HGCHE, it is highly suggested that the *Tc* should be assigned in the range from 14 to 16℃ and the *ΔT* in the range from 9 to 12.5℃ in order to realize 2.64 to 4.48% energy saving and 4.13 to 6.08% electricity bill saving.

However the return on investment and the compact of underground water need further study.

REFERENCES

[1] Bureau of Energy, MOEA. (2014). Energy Statistics Handbook 2013(pp. 10). Report of Bureau of Energy. Taipei: Bureau of Energy, MOEA

[2] Bureau of Energy, MOEA. (2014). The White Paper on Energy Technology and Industry 2014 (pp. 49). Report of Bureau of Energy. Taipei: Bureau of Energy, MOEA

[3] Taiwan Sugar Corporation Tainan Branch. (2005). Groundwater quality monitoring and analysis for Taiwan groundwater monitoring network （2/2）. Report of Water Resources Agency, Ministry of Economic Affairs. Taipei: Water Resources Agency, Ministry of Economic Affairs.

[4] Ming-Jin He, Kuo-Tsang Huang. (2013). The Development and Research on Hourly Typical Meteorological Years (TMY3) for Building Energy Simulation Analysis of Taiwan Report of Architecture and Building Research Institute, Ministry of the Interior. New Taipei City: Architecture and Building Research Institute, Ministry of the Interior.

[5] Kuo-Tsang Huang, Hsien-Te Lin. (2006). A Study on Simplified Prediction Method for Annual Air-Conditioning Energy Consumption of Office Building. Journal of Architecture(58), 131-147.

[6] The Construction and Planning Agency, Ministry of the Interior. (2011). Design and Technique Directions for Energy Saving of Building on Office（Revise reference NO.1000810233）. Direction of the Construction and Planning Agency. Taipei: the Construction and Planning Agency, Ministry of the Interior.

[7] Win-Jet Luo, Ming-Ke Chen. (2013). Energy Efficiency of Centrifugal Chillers with Constant and Variable Frequency under Different Heat Loads and Cooling Temperatures（Table-5）. 2013Green Technology Engineering and Application Conference, Paper No. GT5-016, Taichung.

http://dx.doi.org/10.15242/IICBE.C0215047