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Feng Zhou
zhoufeng@bjut.edu.cn

Jie Chen

Guoyuan Ma

Zhongliang Liu

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Energy-saving Potential Study on Telecommunication Base Station Free Cooling with a Thermosyphon Heat Exchanger in China

Feng ZHOU[1], Jie CHEN[1], Guo-yuan MA[1]*, Zhong-liang LIU[1]

[1]Beijign University of Technology, College of Environmental and Energy Engineering,
Bejing, China
(Phone: 86 10 67391613, Fax: 86 10 67391613, E-mail: magy@bjut.edu.cn)

* Corresponding Author

ABSTRACT

The energy consumption of air conditioning for a telecommunication base station (TBS) in China can be significantly decreased when an air to air thermosyphon heat exchanger is used for free cooling in low atmosphere temperature days. The model for the typical TBS in China was established and the air conditioning energy consumption was analyzed for the cities with climatic data in China. Taking the sandwich steel panel envelope with the thickness of 50 mm for an example, the energy consumption of an air conditioner combined with a thermosyphon heat exchanger in a TBS and the energy-saving potential for using ambient energy were calculated, and were shown on the map of China by different colors according to the energy-saving rates. The static payback periods were also presented. The results demonstrate that the operation mode of the combined system of an air conditioner and a thermosyphon heat exchanger for controlling the indoor temperature can bring enormous energy-saving potential for a TBS in different Chinese cities except the southern areas.

1. INTRODUCTION

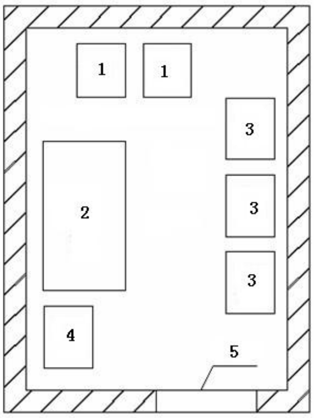
In recent years, numbers of telecommunication base stations (TBS) are built up with the fast development of the telecommunication industry. In order to ensure IT equipment works well, the air conditioner in the TBS runs for almost a whole year. The energy consumption is enormous, and the cost is main economic burden of the company. Therefore, the energy saving of the TBS is very improtant for the telecommunication industry.

Among all air conditioning energy-saving techniques of the TBS, direct air ventilation system and split air to air heat exchanger using ambient energy (Wang *et al*., 2009; Schmidt *et al*., 2003; Gillan *et al*., 2002), variable frequency air conditioner, air flow management, and air conditioner operation optimization (Deng *et al*., 2009) were adopted mostly. The thermosyphon heat exchanger was studied specially, the heat exchanging efficiency was high, and the thermosyphon effectiveness for single pipe could reach to 98% (Xie, 2011). Wang *et al*. (2009) evaluated the data center air conditioning energy-saving reform in Langfang economically, and found that using ambient energy cooling the data center can save power more than 30%. Zhou *et al*. (2011) studied the energy-saving characteristics of an internet data center with a thermosyphon heat exchanger experimentally. They found that energy consumption of the thermosyphon heat exchanger was only 41% of that of the air conditioner, and energy can be saved about 40% for a whole year. In this paper, using the building energy consumption software of DeST-c as a tool, the TBSs located in the cities in China with climatic data records were simulated hour by hour according to the performance of the thermosyphon heat exchanger developed by us. The energy-saving amount and potential of the thermosyphon heat exchanger used in a TBS was analyzed.

2. ENVIRONMENTAL REQUIREMENTS & ENERGY CONSUMPTION IN A TBS

According to People's Republic of China Telecommunication Industry Standard YD/T1624-2007, the temperature for a first grade TBS should be 10 to 25℃, and the humidity should be 30 to 70% (MII, 2007). And Information Technology (IT) equipment works for 8760 hours in a year, the heat load keeps almost constant with the information quantity. So the air conditioning has to run for a whole year.

The size and the telecommunication equipment distribution of a TBS in China are similar. And the actual heat load and parameters are adopted for the theoretical model for a TBS in order to compare the theoretical results and experimental data conveniently. Taking a real TBS in Beijing for example, the dimension of the TBS is 3.75 m (length) × 2.8 m (width) × 2.9 m (height). The building envelope is made of sandwich steel panel, of which the heat transfer coefficient is 0.848 W/(m^2·K). The heat transfer coefficients of the roof and the floor are 0.819 W/(m^2·K) and 0.295 W/(m^2·K), respectively. As shown in Figure 1, the major equipments in the TBS include three telecommunication cabinets, two air conditioners (one work, one spare), twenty-four storage battery units, and one power supply box. The air conditioner with rated cooling capacity of 3.2 kW is type KFR-32 GW/Y made by some company. For the TBS, a thermosyphon heat exchanger is developed. The rated air volume is 1,000 m^3/h, the rated heat exchange capacity is 2 kW, and the rated fan power is 120 W.



1 Air conditioner; 2 Storage battery unit; 3 Telecommunication cabinet; 4 Switching power supply; 5 Door.

Figure1: Plan view of the TBS

The input power of the telecommunication cabinet is equal to the heat dissipation rate at steady state, in which the thermal storage variation can be neglected. The electromagnetic wave energy sent by the TBS is little, which can be ignored. So the heat energy transformed from the input power is mainly dissipated through air convection and surface radiation, which results in the temperature increase in the TBS. In the TBS, a telecommunication cabinet's rated power is 684 W, the rated power of the transmission equipment is about 10 W, the rated power of the high frequency switching power supply is about 50 W, and the heat dissipated from storage battery units is very little (Guo *et al*., 2008). Accordingly, the total power of the TBS can be obtained as follows: 684 W × 3 + 10 W + 50 W, which sums to 2.112 kW. And the actual heat dissipation of a typical TBS is 2.112 kW(Tian *et al*., 2009).

3. WORKING MECHANISM AND SIMULATION ANALYSIS

The structure and heat exchanging mechanism of the thermosyphon heat exchanger are shown in Figure 2. The heat exchanger consists of numbers of thermosyphon. The clapboard is set in the middle, which divides the heat exchanger into two parts. One part is the indoor air flow section, the other part is the outdoor air flow section. The indoor air and the outdoor air are delivered by low power fans. Then the air in the TBS can be cooled by the outdoor air when they are isolated, which avoids the indoor air pollution and keeps indoor cleanliness and humidity constant.

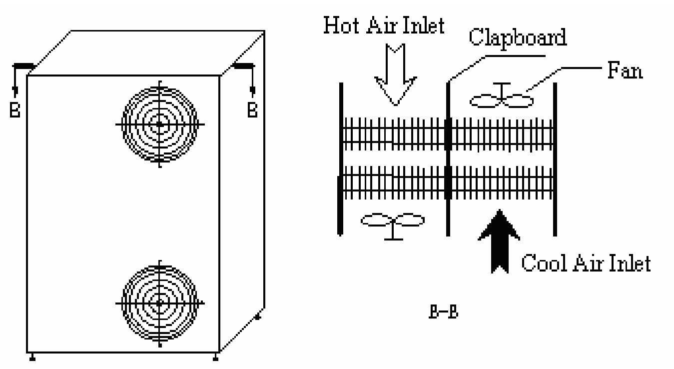


Figure2: The prototype structure and heat exchanging mechanism

The combined operation modes of thermosyphon heat exchanger and air conditioner is shown in Table 1. The thermosyphon heat exchanger starts to work in spring, autumn and winter when the indoor temperature is more than the outdoor temperature, and the air conditioner running time and energy consumption are reduced. When the indoor temperature is less than the outdoor temperature, only the air conditioner works. The energy-saving effect of the thermosyphon heat exchanger varies with the temperature difference between the indoor and outdoor of the TBS. In this paper, the investigated thermosyphon heat exchanger starts to work when the start-up temperature difference (indoor and outdoor temperature difference) is not less than 3℃. And the energy-saving effects of different cities with climatic data records in China are compared.

Table 1: Combined operation modes of thermosyphon heat exchanger and air conditioner in the TBS

Start-up condition	Operation mode	Air conditioner heat transfer	Thermosyphon heat exchanger heat transfer
<3℃ Start-up temperature difference	Only air conditioner	A	
≥3℃ Start-up temperature difference, but $Q_{THE}<Q_{AC}$	Thermosyphon heat exchanger prior to air conditioner	B_1	B_2
≥3℃ Start-up temperature difference, and $Q_{THE}\geq Q_{AC}$	Only thermosyphon heat exchanger		C
Total heat load		$A+B_1$	B_2+C

Note: Q_{THE} is the heat transfer rate of the thermosyphon heat exchanger; Q_{AC} is the heat transfer rate of the air conditioner.

In the TBS, the air conditioner usually works in cooling mode for a whole year. But in cold region minor in China the air conditioner sometimes works in heating mode when the heat dissipation through the building envelope is very much.

Basing on the energy-saving evaluation standard of conventional civil buildings , the simulation evaluation indexes of the thermosyphon heat exchanger are built up as shown in Equation (1) ~ (5), which include cooling/heating load, energy-saving rate, annual electricity saving amount, and static payback period. Considering the administrators of a TBS are generally less than three persons, only the heat dissipation through building envelope and cooling/heating load of the air conditioning are calculated in the simulation model. And the heat losses caused by ventilation, lights and door on-off in a TBS are ignored.

(1) Cooling/heating load of the air conditioning

When the air conditioning works in cooling mode, the cooling load is:

$$Q = Q_2 - Q_1 \qquad (1)$$

where, Q is the cooling load of the air conditioning in the TBS, kWh; Q_1 is the heat dissipation through building envelope of the TBS (+, from indoor to outdoor, -, from outdoor to indoor), kWh; Q_2 is the telecommunication equipment's heat dissipation of the TBS, kWh.

When the air conditioning works in heating mode, the heating load is:

$$Q = Q_1 - Q_2 \tag{2}$$

(2) Energy-saving rate

The air conditioning heat rate is conversed into electricity consumption amount for simulation analysis, and the cooling COP and the heating COP of an air conditioning are considered as 2.6 and 3.2, respectively. The temperature effectiveness of the thermosyphon heat exchanger can be calculated according to the formula fitted from experimental data. Then the energy-saving rate can be obtained as follows:

$$\eta = (1 - \frac{Q_{2c}/2.6 + Q_{2h}/3.2 + P_e}{Q_{1c}/2.6 + Q_{1h}/3.2}) \times 100\% \tag{3}$$

where, η is energy-saving rate when the thermosyphon heat exchanger is used; Q_{1c} is the annual air conditioning cooling load without the thermosyphon heat exchanger, kWh; Q_{2c} is the annual air conditioning cooling load with the thermosyphon heat exchanger, kWh; Q_{1h} is the annual air conditioning heating load without the thermosyphon heat exchanger, kWh; Q_{2h} is the annual air conditioning heating load with the thermosyphon heat exchanger, kWh; P_e is the annual electricity consumption amount of the thermosyphon heat exchanger, kWh.

(3) Annual electricity saving amount

$$ES = C_1 - C_2 \tag{4}$$

where, ES is the annual electricity saving amount, kWh; C_1 is the annual electricity consumption amount without the thermosyphon heat exchanger, kWh; C_2 is the annual electricity consumption amount with the thermosyphon heat exchanger, kWh.

(4) Static payback period

$$P = I / (ES \times \alpha) \tag{5}$$

where, P is the static payback period, year; I is the initial investment (which is 7,000 RMB in this paper), RMB; ES is the annual electricity saving amount, kWh/year; α is the commercial electricity price (which is usually 0.8), RMB/kWh.

4. RESULTS AND DISCUSSIONS

According to the climatic data of different cities in China from DeST-c software and the base room temperature of a TBS, the energy-saving potential is analyzed between air conditioner and combined system of air conditioner and thermosyphon heat exchanger while the thermosyphon heat exchanger runs when the start-up temperature difference is not less than 3℃. Taking the sandwich steel panel envelope with the thickness of 50 mm for example, the results of typical cities in China are shown in Table 2.

The combined operation mode of thermosyphon heat exchanger and air conditioner in Table 1 is adopted in the data analysis of Table 2. When the start-up condition of the thermosyphon heat exchanger is not met, the air conditioner affords the loads, and the cooling and heating loads can be summed up from hourly loads in working time. When the start-up condition of the thermosyphon heat exchanger is provided but the heat transfer rate of the thermosyphon heat exchanger can not afford the total cooling load, the thermosyphon heat exchanger and the air conditioner work together. And the former works prior to the latter. When the start-up condition of the thermosyphon heat exchanger is provided and the heat transfer rate of the thermosyphon heat exchanger can afford the total cooling load, only the thermosyphon heat exchanger works. And the thermosyphon heat exchanger load is summed up from hourly loads in running time.

Table 2: The annual energy consumption of combined system for a TBS in China

Provinces	Only A/C		THE prior to A/C			Only THE		Load and ESR			
	RT (h)	**A/C load (kWh)**	**RT (h)**	**A/C load (kWh)**	**THE load (kWh)**	**RT (h)**	**THE load (kWh)**	**Total A/C load (kWh)**	**Total THE load (kWh)**	**ESR**	**SPP (year)**
Tibet	282	569.6	1072	757.1	1181.1	7406	8795.3	1326.7	9976.4	64.9%	3.1
Qinghai	403	839.4	947	705.1	1013.9	7410	7916.2	1544.4	8930.1	60.4%	3.6
Yunnan	996	2026.3	3136	2259.6	3230.7	4628	6324.0	4285.9	9554.7	51.5%	3.2
Shanxi	1571	3286.6	1544	1264.2	1466.6	5645	6198.3	4550.9	7664.8	44.4%	4.2
Jilin	1173	2433.5	1329	1079.6	1279.0	6258	5522.2	3513.1	6801.2	43.0%	5.1
Guizhou	2053	4240.4	2175	1731.4	2053.9	4532	5845.3	5971.8	7899.1	41.9%	3.9
Heilongjiang	1173	2445.4	1218	933.4	1224.1	6369	5259.9	3378.8	6484.0	41.7%	5.5
Liaoning	1628	3387.9	1359	1130.7	1271.5	5773	5611.2	4518.6	6882.6	40.9%	4.9
Xinjiang	1553	3266.0	1244	1003.2	1189.9	5963	5466.2	4269.2	6656.1	40.3%	5.2
Hebei	2603	5520.3	1315	1089.3	1265.7	4842	5627.5	6609.6	6893.2	36.8%	4.6
Jiangsu	2790	5881.0	1476	1271.9	1324.6	4494	5483.6	7152.9	6808.2	35.4%	4.6
Guangxi	4839	10187.2	1923	1571.3	1812.3	1998	2868.9	11758.5	4681.2	21.0%	6.6
Guangdong	5043	10604.8	1670	1373.7	1547.4	2047	2972.7	11978.6	4520.1	20.4%	6.8
Hainan	6011	12407.3	2131	1708.4	1940.2	618	938.5	14115.8	2878.7	11.9%	11.3

Note: RT is Running Time, A/C is Air Conditioner, THE is Thermosyphon Heat Exchanger, ESR is Energy-Saving Rate, SPP is Static Payback Period.

According to Table 2, the energy-saving rates and payback periods of the combined system for a TBS in typical cities in China are shown in Figure 3, in which the energy-saving rates of the cities are arranged from high to low.

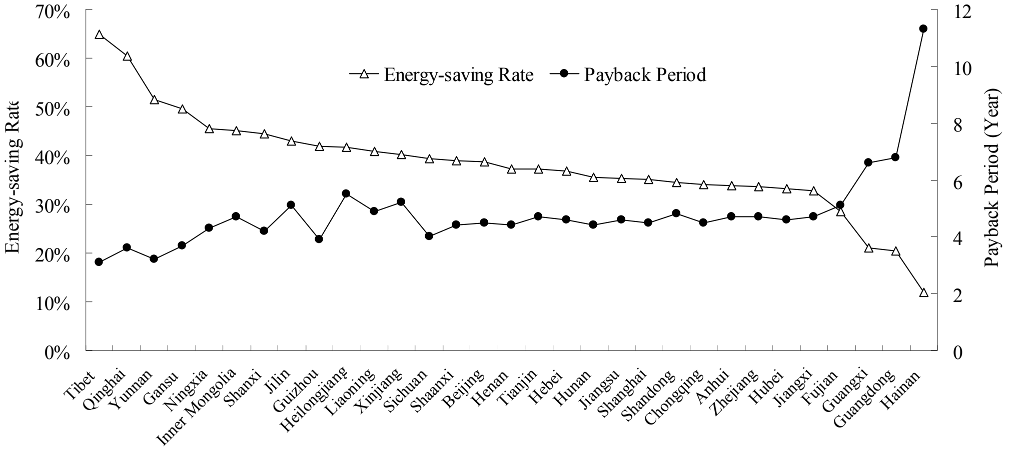


Figure 3: The energy-saving rate and payback period of the combined system for a TBS in China

As shown in Figure 3, the energy-saving rates of most cities are in the range of 30% to 50%. The highest is 64.9% in Tibet, the followed is 60.4% in Qinghai, and the values are not over 25% in Guangxi, Guangdong and Hainan. The reason is that Tibet and Qinghai lie in severe cold area and cold area respectively with rich ambient energy, which can be used by the thermosyphon heat exchanger and the running time for the air conditioner can be reduced.

However, Guangxi, Guangdong and Hainan lie in the south of China, where the average temperature of the coldest month in a year is over 9℃. The running time of the thermosyphon heat exchanger is not much and the energy-saving rate is low.

The payback period of the thermosyphon heat exchanger increases with the decrease of energy-saving rate. When the energy-saving rate decreases from 64.9% to 11.9%, the payback period increases form 3.1 years to 11.3 years. The payback periods of most cities are in the range of 4.2 to 4.5 years, but the values in Jilin, Heilongjiang, Liaoning and Xinjiang fluctuate differently. The energy-saving rates in other cities basically keep coincident with the payback periods, even though there is small change. In Guangxi the payback period increases rapidly with the decrease of the energy-saving rate.

The impact factors of the payback period for the thermosyphon heat exchanger include annual electricity-saving amount, initial investment, electricity price, etc. Generally, the higher the energy-saving rate, the shorter the payback period. Otherwise, the lower the energy-saving rate, the longer the payback period. The energy-saving rate is the key factor, but not the only factor for the payback period. In Jilin, Heilongjiang, Liaoning and Xinjiang, the energy-saving rates are relative high, but the payback period is long. The reason is that the annual average temperature is too low, and the yearly air conditioner cooling load is a little. So the total annual electricity-saving amount is not much, and the payback period is long. Whereas in Guangxi, Guangdong and Shanghai the low energy-saving rate caused by reduction of annual electricity-saving amount results in the long payback period.

It is mentioned that, the equipment price will decrease with the application and popularization of the thermosyphon heat exchanger, and the initial investment will get reduced. Meanwhile, the power cost will go up because of the clean energy policy and the energy saving policy in China, which will cause the increase of the electricity price. In a word, the above factors will shorten the payback period further, and the thermosyphon heat exchanger will have a bright application future.

According to the climatic regions in "Thermal design code for civil building" (MC, 1993), the energy-saving distribution map of the thermosyphon heat exchanger in China is plotted basing on the energy-saving rates of over 200 cities. The map is shown in Figure 4.

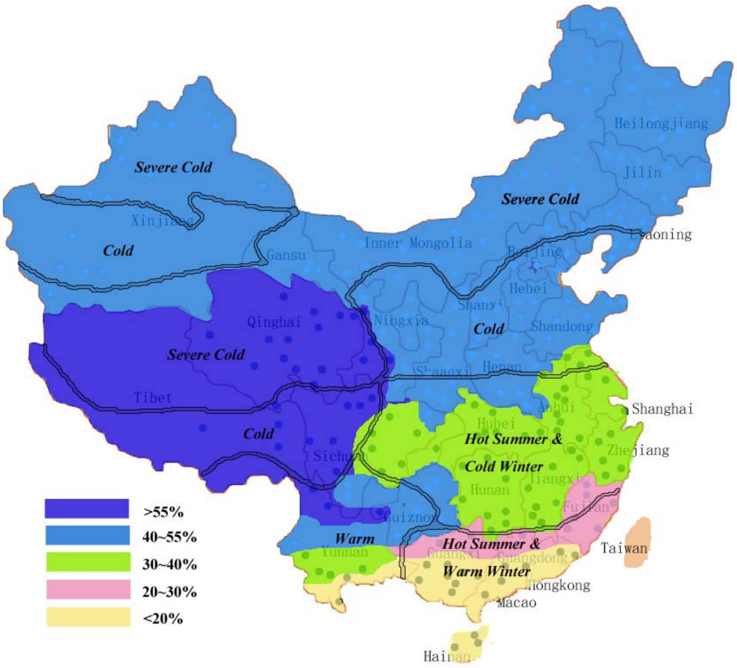


Figure 4: The energy-saving distribution map of the thermosyphon heat exchanger in China

As shown in Figure 4, the distribution map consists of five color regions with different energy-saving rates. The energy-saving rate of the most suitable region is over 55%, the energy-saving rate of the more suitable region is form 40% to 55%, the energy-saving rate of the suitable region is from 30% to 40%, the energy-saving rate of the common region is from 20% to 30%, and the energy-saving rate of the unsuitable region is less than 20%.

It is found that the most suitable region lying in the west of China includes Tibet, Qinghai, west of Sichuan, and north of Yunnan. The more suitable region lies in the northwest, the northeast and the midland of China, in which the ambient energy is rich and the thermosyphon heat exchanger can be applied in wide range. It should be noted that in Heilongjiang and Inner Mongolia the energy-saving rates show a little fluctuation, because the air conditioner in the TBS works in heating mode when the outdoor temperature is too low in winter. For most area of Yunnan and Guizhou in mild region the outdoor climatic condition is suitable for utilization of the thermosyphon heat exchanger and the energy-saving effect is obvious. For cities in hot summer and cold winter zone the energy-saving rates are not low, which belongs to the suitable region. For Guangxi, Guangdong and south of Yunnan lying in hot summer and warm winter zone, the indoor and outdoor temperature difference is small, the energy-saving rate is the lowest, and it belongs to the unsuitable region.

It is mentioned that the envelope material is the sandwich steel panel with the thickness of 50 mm in the simulation model. The energy consumption of the air conditioner is higher than that in a brick envelope TBS, because the heat transfer coefficient of the sandwich steel panel is smaller and the heat dissipation through the envelope is less. Meanwhile, the running time of the air conditioner is long in simulation model. So the total level of the energy-saving rate is high.

6. CONCLUSIONS

According to the theoretical analysis of a TBS with the thermosyphon heat exchanger in China, the conclusions are drawn as follows:

- Among all cities with climatic data records in China, the energy-saving rates of Tibet and Qinghai are relatively high, and the energy-saving rates of Guangxi, Guangdong and Hainan are relatively low. The energy-saving rate of most cities is between 30% and 50%. It is pointed out that about 88% of all the cities with climatic data records in China are suitable for the application of the thermosyphon heat exchanger, and show obvious energy saving potential.
- The payback period of the thermosyphon heat exchanger usually is 4.3 years in most cities in China. The payback period in Tibet and Qinghai is only 3.3 years. And the payback period will be shortened further when the cost of the thermosyphon heat exchanger decreases in future.

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