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Geothermal Direct Use and Its Contribution to CO_2 Emission Saving in China

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ABSTRACT

Geothermal energy utilization in China will reach 117,224 GWh/yr in 2010 and 351,672 GWh/yr in 2020, according to the Mid-Long Term Development Plan for Renewable Energy released by the National Development and Reform Commission in 2007. China has a long history of geothermal direct use, which has been developed rapidly since the 1990s. China has been atop of the list of countries utilizing geothermal energy with direct use of 12,605 GWh/yr in 2005 and 18,900 GWh/yr in 2007. China has rich medium-low temperature geothermal resources, and currently, about 3,000 geothermal wells have been completed to provide more than 445.7 Mm^3 of hot water for direct use. This is comprised of 65.2% balneology, 18.0% space heating, 9.1% agriculture and aquaculture, and 7.7% industrial applications (evaporating, drying, distillation, sterilization, washing, de-icing, salt-extraction, oil-recovery, milk pasteurization, leather industry, chemical extraction, etc.). In this paper, some new technologies are discussed, CO_2 emission savings by geothermal direct use are analyzed, and the direct use of geothermal heat is introduced in large cities such as Beijing, Tianjin and Shenyang.

1. INTRODUCTION

China is rich in geothermal resources, which are categorized as high, medium, and low temperature resources. High temperature geothermal resources are suitable for power generation, while medium and low temperature geothermal resources are suitable for various direct uses.

China has used geothermal resources since early times mainly for direct uses, such as hot springs and bath spas. The large-scale development and utilization of geothermal resources started in 1949. Some 160 hot spring sanatoria were founded progressively in the 1950s and 1960s in China. In the 1970s, geothermal resource development and utilization grew rapidly with the world petroleum crisis. Since the 1990s, with the thrust of the market economy, geothermal development and utilization have grown further.

According to the statistics of the Geothermal Professional Committee of the China Energy Research Society, China has been at the top of the list of countries utilizing geothermal energy. With a total direct use of 12,605 GWh/yr in 2005 and 18,900 GWh/yr in 2007, the rate of geothermal development has increased by about 10% annually in recent years. In terms of the absolute production numbers, the 10 leading countries in geothermal direct use in 2005 are shown in Figure 1 (CGSB, 2006). At present, about 3,000 geothermal wells distributed in both plain and basin areas have been completed in China to provide with more than 445.7 Mm^3 of hot water for direct use.

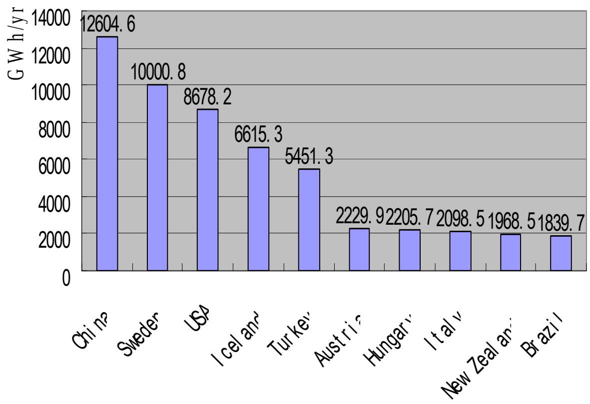

Figure 1: The 10 leading countries in geothermal direct use in 2005

2. THE CLASSIFICATION OF THE GEOTHERMAL DIRECT USE IN CHINA

Hot spring water and medium to low temperature geothermal resources have been used comprehensively for energy in China since 1970s. The direct use of medium and low temperature geothermal energy in China is mainly focused on space heating, medical care, bathing, tourism, aquaculture, greenhouse cultivation, irrigation, industrial production, and production of mineral water. At the same time, the cascaded use of geothermal resources in technology and the storage of thermal energy in underground aquifers have been developed. The proportional utilization of each direct use purpose is shown in Figure 2 (CGSB, 2006). At present, the direct use of geothermal energy is divided as follows: 65.2% balneology, 18.0% space heating, 9.1% agriculture and aquaculture, and 7.7% industrial applications, such as evaporating, drying, distillation, sterilization, washing, de-icing, salt-extraction, oil-recovery, milk pasteurization, leather industry, chemical extraction, etc.

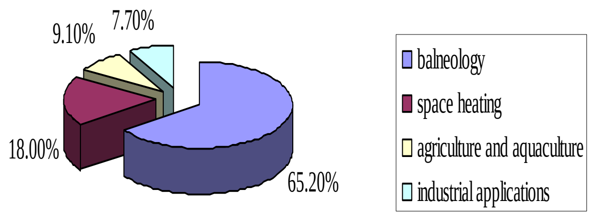

Figure 2: The proportional utilization of each type of direct use of geothermal energy

2.1 Geothermal Space Heating

The development and utilization of medium and low temperature geothermal water (60-100°C), hot tail water, and shallow geothermal energy are concentrated in metropolises, such as Beijing, Tianjin, Xi'an, Zhengzhou and Anshan. This phenomenon also occurs in oil cities such as Daqing in the Helongjiang province and Bazhou, Gu'an and Niutuo in the Hebei province.

2.1.1 Conventional Geothermal Space Heating

Space heating is concentrated in the northern cities, such as Tianjin, Beijing, Xi'an and Daqing, where 60-100°C hot water is pumped directly to the buildings. The rapid growth of the area of space heating by low and medium temperature geothermal water in the years from 1990 to 2007 is shown in Figure 3, along with the reduction of CO_2 and NO. The heating area was 1.9 Mm^2 in 1990, 8 Mm^2 in 1999, 11 Mm^2 in 2000, 12.7 Mm^2 in 2005 and 17 Mm^2 in 2007 (Zheng, 2008). Geothermal waters with temperatures of 60-100°C were used.

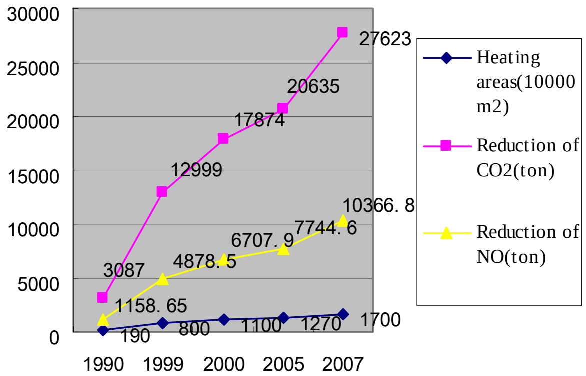

Figure 3: Space heating with low and medium temperature geothermal water and the reduction of CO_2 and NO in the years from 1990 to 2007

In 2007, the total area of geothermal district heating was 17 Mm^2 in China, including 12 Mm^2 in Tianjin, 1.64 Mm^2 in Xianyang and 1 Mm^2 in Xi'an city in the Shaanxi province, and about 2 Mm^2 in Beijing in the Hebei province. Conventional radiators or floor heating systems are typically used, and geothermal cascade utilization is carried out in order to meet an increased market demand. Geothermal waters with temperatures higher than 80°C are first used in radiator systems, and the returned water is used for floor heating. Finally, heat pumps are used to extract more heat from the secondary return water for additional space heating.

2.1.2 Ground Source Heat Pump in China

If the temperature of the geothermal resource is too low for direct application, ground source heat pumps (GSHPs) can be used. Although research on GSHPs began in the 1950s and 1960s in China, its actual application began in the end of the 1990s. Due to its high efficiency, energy savings, CO_2 emission reduction, and the fact that it is almost suitable everywhere, GSHPs have experienced a rapid growth in recent years. According to the statistics of the Report on China Ground-Source Heat Pump (2008), the GSHP market began to boom in 2005. Up to the end of 2007, GSHPs were installed to heat a building area of about 80 Mm^2. The rapid growth of GSHP activities in China since 1998 is shown in Figure 4 (Xu, 2008).

2.2 The Geothermal Utilization in Agriculture

Geothermal energy is also widely used in agriculture, mainly for greenhouse cultivation and aquaculture.

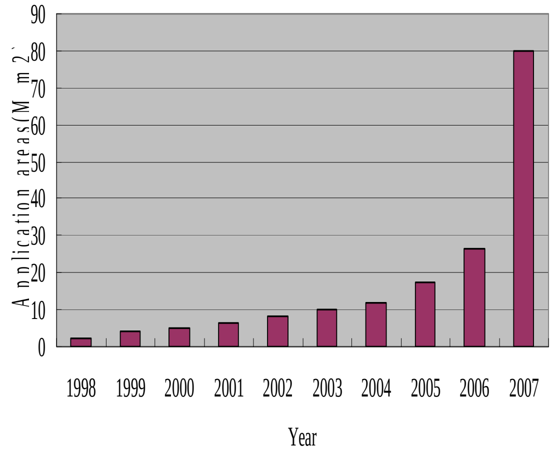

Figure 4: The rapid growth of GSHP activities in China

2.2.1 The Geothermal Greenhouse Cultivation

Geothermal greenhouses have replaced the rough cultivation of the past in the countryside of northern China. It sustains the production of a variety of high quality vegetables during all growing seasons. Due to providing necessary nutrition to plants, geothermal water not only makes crops ripen earlier, but it also leads to an increase in production irrigated by geothermal water. Geothermal water is mainly used for planting melons and other fruits, vegetables, edible fungus, flowers in northern China, and seedings in southern China. According to the statistics, there is currently a total of 1.33 Mm^2 of greenhouse in the country. This is mainly in northern China, and 0.47 Mm^2 is in the Hebei province alone.

At present, the geothermal energy used for greenhouse plants is equivalent to that of 0.215 Mt of standard coal every year, accounting for 3.4% of the total exploitation of geothermal resources.

2.2.2 The Geothermal Aquaculture

Geothermal aquaculture has experienced a widespread increase in southern China, due in part to the high value of valuable exported species that are thus supplemented. It was developed earlier in Beijing, Tianjin, Fujian and Guangdong, and is now available to more than 20 provinces (regions and cities).There are currently about 300 cultivation farms with a total fish pool area of 4.45 Mm^2 in the country, mainly in southern China in Guangdong and Fujian provinces. The consumption of the geothermal water in the aquaculture is about 5.7% of the total in the country.

2.3 Geothermal Utilization for Health Care and Touring

Medicinal treatment using hot spring is widespread in China. Because geothermal fluid has a high temperature and contains special chemicals, gases, a small amount of biological active ions, and some radioactive substances, it has an obvious medical effect on the adjustment of human organs. According to statistics, there are 420 places that utilize geothermal water for medical treatment in over 20 provinces of China.

Hot spring bathing is one of the traditional activities favored by ancient Chinese civilization. According to incomplete statistics, there are about 1,600 public hot spring bathing houses and swimming pools in the country. These account for the largest share of geothermal direct use in China. In recent years, hot spring resorts have evolved rather quickly, especially in coastal areas in the Guangdong and Fujian provinces and in large cities like Beijing, Tianjin, and Xi'an.

According to the reported percentage of exploited geothermal water used for bathing in Beijing, it is estimated that the national consumption of geothermal water for bathing is about 138 Mm^3 every year. 716.45 MW of geothermal energy is used to provide bathing for 688 million people every year, which displaces the equivalent annual use of 771,000 tons of standard coal.

2.4 The Geothermal Utilization in Industry

Medium and low temperature geothermal water is also used for industrial purposes, such as evaporating, drying, distillation, sterilization, washing, de-icing, salt-extraction, oil-recovery, milk pasteurization, leather production and chemical extraction.

In addition, there are nearly 50 natural mineral water using geothermal water in China. They are mainly located in the Beijing, Tianjin, Anhui, Guangdong, Guangxi, Chongqing, Guizhou, Yunnan, Shaanxi and Qinghai provinces. Geothermal water with mineralization below 0.6g/L and temperature below 50°C is mainly used.

3. THE GEOTHERMAL DIRECT UTILIZATION IN CHINA

According to the statistics of the Geothermal Professional Committee of the China Energy Research Society, China utilized geothermal energy for the direct use of 12,605 GWh/yr in 2005 and 18,900 GWh/yr in 2007. The rate of geothermal development in recent years has increased by about 10% annually. Geothermal energy utilization will reach 117,224 GWh/yr in 2010 and 351,672 GWh/yr in 2020, according to the Mid-Long Term Development Plan for Renewable Energy released by the National Development and Reform Commission in 2007, as shown in Table 1. Geothermal direct use in the metropolis of Beijing is as follows.

Table 1: The geothermal energy utilization with direct use in China

Year	2005	2007	2010	2020
Utilization(GWh/yr)	12,605	18,900	117,224	351,672

3.1 The Geothermal Direct Utilization in Beijing

Geothermal energy is used for various direct purposes in Beijing, including space heating, domestic hot water heating, greenhouses, fish farming, and health and recreation spas, as shown in Figure 5. Multi-purpose use is very common, and a combination of space heating and domestic hot water supply is often used. In 2005 (Liu, 2008), the geothermal water production was 7.7 Mm^3, and there were 91 geothermal users in Beijing. This includes 20 for space heating (totaling 1.2 Mm^2 of floor area), 68 for domestic hot water supply, 33 for hotels, 38 for recreation, and 14 for greenhouses (totaling 0.38 Mm^2 of floor area) and fish farming (totaling 0.15 Mm^2 of ponds).

The history of traditional geothermal space heating has lasted more than 30 years in Beijing. Beijing is the pioneer city for GSHPs in China, and in recent years, their application has grown rapidly. Up to the end of 2007, there were 479 projects totaling 10.52 Mm^2 of building area installed with GSHPs in Beijing, and this sector is growing at a rate of 150% annually. The GSHP heating area in Beijing is currently the second largest in the country. According to the 11th Five-Year Plan, a building area of 30 Mm^2 will be air-conditioned using GSHPs by 2010.

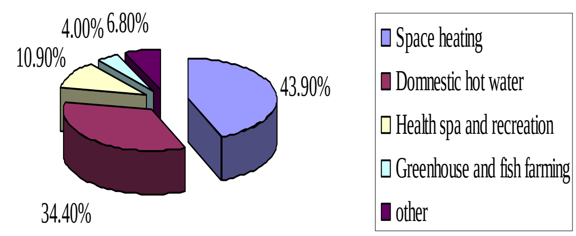

Figure 5: Percentage of each kind of geothermal utilization in Beijing

3.2 The Geothermal Direct Utilization in Tianjin

Tianjin was the first city which comprehensively used geothermal resources in the country. Tianjin geothermal field is a typical low-temperature system that is located in the middle-lower reaches of the Haihe River System on the North China plain. Because it is a coastal city in northern China, its key industries were textiles and dyeing, and geothermal groundwater was exploited for printing and dyeing. This was the beginning of utilization of geothermal resources.

The district heating system in Tianjin was developed recently. In the 1970s, there were practically no district heating facilities in buildings. When district heating was developed in the 1980s, geothermal water with a temperature above 80°C became the best choice for space heating in the city. Due to widespread distribution, high temperature (bedrock reservoirs are mostly higher than 80°C), and large yield, Tianjin reached an area of 12 Mm^2 in 2007. Geothermal heating was developed vigorously there, and it became the leading geothermal space heating utility in the country. The geothermal heating area in Tianjin accounts for more than 70% of the total heating area in the country developed over the past 10 years.

The total production rate and heating area in Tianjin from 1995 to 2007 is shown in Figure 6. By the end of 2007, there was a total of 314 geothermal wells in Tianjin, 36 of which were reinjection wells. Hot water production was 25,838,000 m^3/yr, and reinjection reached a volume of 4,093,000 m^3/yr, with a reinjection rate of about 15.8 %. Geothermal space heating covered about 8% of the total heating area in winter (Wang, 2008). About 114 geothermal wells were used for space heating, mainly supplying the urban area (Tanggu and Wuqing Districts, etc.). Every year, about 100,000 families and 850,000 people enjoyed geothermal hot water for domestic purposes.

3.3 The Geothermal Heat Pump in Shenyang

Shenyang is the capital of Liaoning province, a main industry city in northeastern China, where the space heating season lasts six months (from October 15th to April 15th). Shenyang did not begin its GSHP activities early but did attempt to spread its market. Shenyang was recognized as the Demonstration City by the China Construction Ministry in 2006 for its effort to popularize GSHPs.

In August 2006, Shenyang authorized its Particular Blueprint for Geothermal Source Heat Pump Application in the Period of the 11th Five-Year Plan in Shenyang and the Administrative Measures for Construction and Operation of

Geothermal Source Heat Pump System in Shenyang, based on the investigation of the GSHP technology and its application across China. Both were issued as government orders, which stated that GSHPs will in principle be installed in all buildings of within 455 km^2 areas of the third ring, of which about 409 km^2 areas with suitable ground water and about 46 km^2 with Bore Heat Exchangers (BHEs). Additionally, some favorable policies were issued, such as charging a fee for civilian electricity usage and no fee for water resource. Furthermore, some administrative organizations were established in city, district and county governments of all levels. In December 2006, the Associate of Geothermal Source Heat Pump and Expert Research Group were founded in Shenyang, by which a series of scientific research projects were executed. Such projects concern the addition of technical specifications, reinjection of underground water, sedimentation, underground water environment survey, etc.

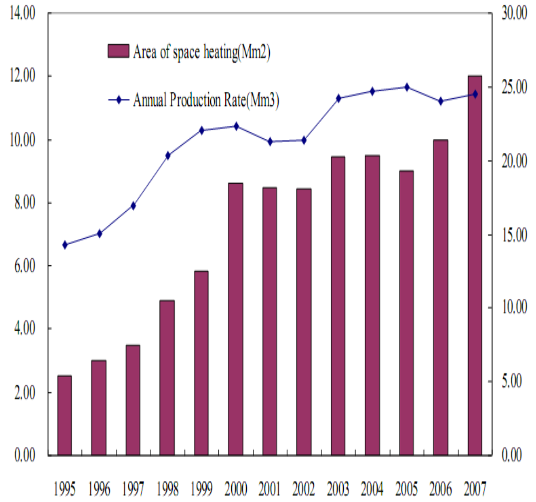

Figure 6: The Growth of Geothermal Production Rate and Space Heating Area 1995-2007 in Tianjin

The GSHP heating area was about 1.8 Mm^2 before 2004, 3.1 Mm^2 in 2006, and 18 Mm^2 at the end of 2007. The GSHP heating area in Shenyang is the largest in China. According to the 11th Five-Year Plan, this area will be increased to 65 Mm^2, which takes up 32.5% of the total heating spaces in Shenyang (Zheng et al., 2008).

4. THE CONTRIBUTION TO CO_2 EMISSION SAVING BY GEOTHERMAL DIRECT USE IN CHINA

The Chinese government and local governments issued many policies to encourage the exploitation and utilization of renewable energy resources to meet the demand of energy savings and environment protection. In 2005, the Chinese government called for the conservation of resources and the environment, and they set goals to reduce energy consumption by 4% and emission by 2%.

As shown in Table 1, China has utilized geothermal energy with direct use of 12,605 GWh/yr in 2005, and 18,900 GWh/yr in 2007. Geothermal energy utilization will reach 117,224 GWh/yr in 2010 and 351,672 GWh/yr in 2020.

The heat content of fossil fuels and the CO_2 emissions that result from burning fossil fuels are shown in Table 2 (Rybach, 2008). Such emissions can be avoided when geothermal energy is used instead of fossil fuels.

As 1 kWh is equivalent to 3.6×10^6 J, it is concluded that the potential annual CO_2 emission savings by geothermal direct use in China will reach 39.67 Mt in 2010, as shown in Table 3.

Table 2: Heat content and CO_2 emission of traditional fossil fuel (Data from Swiss Federal Office of Energy, 2008)

Fuel	Heat content (GJ/t)	CO_2 emission (t CO_2/TJ)	CO_2 emission (t CO_2/t fuel)
Coal	28.1	94.0	2.64
Oil light	42.6	73.7	3.14
Natural gas	46.5	55.0	2.56

Table 3: Potential CO_2 emission savings by geothermal direct use in China

Year	2005	2007	2010	2020
Utilization (GWh/yr)	12,605	18,900	117,224	351,672
CO_2 emission (M t/yr)	4.27	6.40	39.67	119.01

4.1 The Calculation Formula for the Reduction of CO_2 Emission by GSHPs Compared with air source heat pumps (ASHPs)

Due to geological conditions, there are widespread low-temperature geothermal resources in most provinces of China that are already widely used for space heating, balneology, fish farming and greenhouses during the cold winter months and for tap water in the summer. The potential fossil fuel displacement by geothermal direct use is very large, as space heating is a significant part of the energy budget in China. GSHPs are among the most important direct uses of geothermal energy for space heating.

GSHPs have been widely used in China for the last ten years. With the support and promotion of the government, GSHP projects have been initiated in 31 provinces all over China. According to the statistics of the Report on China Ground-Source Heat Pump, the areas heated by geothermal heat pumps used for house heating reached 26.5 Mm^2 in 2006, 80 Mm^2 in 2007, and it will reach 240 Mm^2 in 2010 (Xu, 2008). Although geothermal district heating accounted for a very small part of the winter space heating market in China, it contributed to the reduction of CO_2 emission in the country.

With heat pump systems, the use of fossil primary energy sources can be avoided. However, since heat pumps are usually driven by electric components, the origin of the electricity and the corresponding CO_2 emissions must be considered.

GSHP installations need no fossil fuel, do not use combustion processes to generate heat, and thus do not produce air polluting substances. This is the advantage of the GSHP systems. Due to its high COP, this represents the “savings” of fossil fuels – and the corresponding CO_2 emission reduction.

During the 1950's and 1960's, when air source heat pumps came into vogue, electricity was being generated in central station fossil fuel plants with efficiencies approaching 30%. Air source heat pumps (ASHP) of the time delivered SPF's (COPs) (seasonal performance factors) typically ranging between 1.5 and 2.5. While it is shown in Table 4 that at the point of delivery to the building, 60% of the energy is extracted from the air, only 75% of the original energy used to generate the electricity is recovered as useful heat. Thus, while renewable energy from the air has been used to deliver thermal energy efficiently, no net gain has resulted. The second column of Table 4 demonstrates today's figures. New co-generation or combined cycle generating plants can deliver electricity with efficiencies exceeding 40%. Ground source heat pumps currently demonstrate COP's in excess of 4. This results in an apparent "efficiency" of 160%, with 75% of the final energy originating underground. More importantly, there is an excess of 60% above the original energy consumed to generate the electricity (Lund, et al., 2005).

Table 4: Energy and Efficiency Comparisons

	Old (air source + old fossil fuel)	Old (air source + new fossil fuel)	New (ground-source + new fossil fuel)
Electrical generation efficiency	0.3	0.4	0.4
COP or SPF	2.5	2.5	4
Delivered energy/Consumed energy	0.75	1	1.6
Delivered Renewable Energy	60%	60%	75%
"Excess" Renewable Energy	-25%	0	60%

According to a new calculation method based on a new theory created by B.D. Hong and E.R. Slatick of US Department of Energy, one carbon atom combines with 2 oxygen atoms to become one molecule of CO_2,. Considering the net carbon contents in coal and the burning efficiency, burning one ton of coal releases about 2.2002 – 2.3861 tons of CO_2, 1.7% of SO_2, 0.6% of NOx and 0.8% suspended dusts (Zheng et al., 2008).

Thus, the calculation formula for the reduction of CO_2 emissions can be described as follows:

$$CES = (2.2002 \sim 2.3861) \times ECS \qquad (1)$$

where *CES* is CO_2 emission savings (t/yr), and *ECS* is equivalent coal savings per year (t/yr).

The equivalent coal savings can be calculated as follows:

$$ECS = OCC_{GSHP} - OCC_{ASHP} \qquad (2)$$

where OCC_{GSHP} is Original Coal Consumption (OCC) to generate electricity for GSHPs (t/yr), and OCC_{ASHP} is OCC to generate electricity for ASHPs (t/yr).

OCC to generate electricity can be calculated as follows:

$$OCC = \frac{E_c}{E_e \times COP} \qquad (3)$$

where E_c is equivalent coal of the delivered energy (J/yr), E_e is the efficiency of coal electricity generation, and COP is the Coefficient of Performance.

The equivalent coal of delivered energy can be calculated as follows:

$$E_c = \frac{C_i \times t}{7 \times 4.1868 \times 10^6} \qquad (4)$$

where C_i is the installation capacity (W), and *t* is the operation time of the heat pump (s).

The capacity of installations can be calculated as follows:

$$C_i = I_e \times A \qquad (5)$$

where *Ie* is the energy indicator (W/m^2), and *A* is the heated building area (m^2).

4.2 The Calculation Result and Analysis

A space heating time of 120 days at 17 hours per day in winter and a cooling time of 90 days at 10 hours per day in summer were assumed. It was further assumed that the COP was 4.0 for GSHPs and 2.5 for ASHPs, the energy indicator was 55 W/m^2 for heating and 65 W/m^2 for cooling, and building areas were 26.5 Mm^2 in 2006, 80 Mm^2 in 2007, and will be 240 Mm^2 in 2010. The equivalent coal savings (ECS), CO_2 (CES), SO_2 (SES) and NO_x (NES) and dust (DES) emission savings (t/yr) were thus calculated according to Equations 1, 2, and 3 for 2006, 2007 and 2010, while taking the heating mode priority to provide only the base load with peaking by fossil fuel.,The results of these calculations are shown in Table 5.

Table 5: Comparative potential reductions of emissions contributed by the utilization of GSHPs and ASHPs in China

	A Mm^2	**ECS t**	**CES t**	**SES t**	**NES t**	DES t
2006	26,5	197,383	434,282	3,356	1,184	1,579
2007	80	595,872	1,311,038	10,130	3,575	4,767
2010	240	1,787,818	3,933,557	30,390	10,725	14,301

5. CONCLUSIONS

China is at the leading country in the direct utilization of geothermal energy. Up to the end of 2007, the geothermal energy utilization reached 18,900 GWh/yr, and about 3,000 geothermal wells had been completed to provide with 445.7 Mm^3 of hot water for direct use. The geothermal energy utilization is forecasted to reach 117,224 GWh/yr in 2010 and 351,672 GWh/yr in 2020 in China.

China has utilized geothermal resources comprehensively since the 1970s. At present, the total direct use of geothermal energy includes 65.2% for balneology, 18.0% for space heating, 9.1% for agriculture and aquaculture, and 7.7% for industrial applications.

Geothermal energy is a renewable and environmentally benign energy source that has been utilized in many parts of

China for decades, especially for space heating. A potential estimation reveals that if the building area heated by GSHPs reaches 240 Mm^2 in China at the end of 2010, the increasing development of GSHPs will contribute 1,787,818 t/year coal savings compared with ASHPs, which means that 3,933,557 t/yr CO_2, 30,390 t/yr SO_2, 10,725 t/yr NO_x and 14,301 t/yr of suspended dusts emissions could be saved.

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