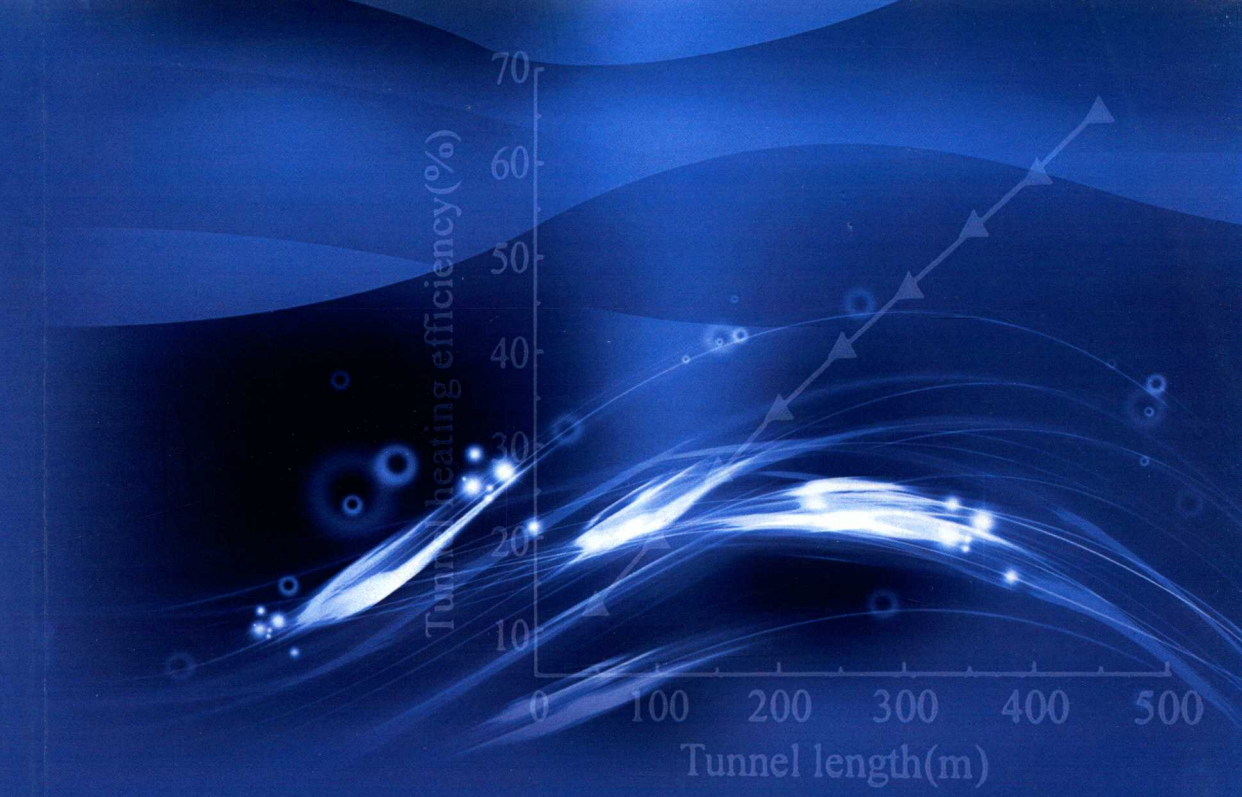

Air through Tunnel and Air Source Heat Pump

地道风与空气源热泵

李永安 · 著

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Foreword

With the development of social economy and growth in the living standard, Heating Ventilation and Air Conditioning (HVAC) energy consumption has held a larger and larger proportion in national energy consumption, and thus more attentions are drawn to HVAC energy conservation of countries in the world.

In 1960s—1970s, the activity of tunnel digging was conducted to be prepared against war and natural disaster nationwide. The soil heat transfer obtains the delay features, therefore, the air inside the tunnel is warm in winter and cool in summer, and generates huge energy.

Applying air source (also known as air energy) heat pump principle in combination with air characteristics in tunnels, author of the original work and his research team took the responsibility to conduct the research project of *Air Source Heat Pump Based on Air through Tunnel of Ministry of Housing and Urban-Rural Development*, which implemented deep research and exploration to the characteristic of air through tunnel in winter and summer as well as the air source heat pump based on air through tunnel, which put forward the energy conservation technology of air source heat pump and air through tunnel coupling, and made approvable contribution to the promotion of green energy-saving building industrial development. This book, translated and published the research achievement of the author of original work.

The translation work of this book is supported and instructed by Professor Li Yong'an, author of the original work, and assisted by some colleagues, whereby the translator expresses grateful thanks to them all.

If some mistakes or improper parts are found due to the limited knowledge level of the translator, you are very welcome to share criticism and correction.

Xing De'an
May, 2015
in Jinan

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Chapter 1 Introduction

1.1 Current situation of energy source in China

Energy is the material foundation to the survival of mankind. For a long time, the main energy used in China is fossil energy, but it is stated by the data in *BP World Energy Statistics* in 2006 that the global proved oil production can serve more than 40 years, and natural gas and coal reserve can supply 65 and 155 years, respectively. The international energy agency analysis in 2005 deemed that, the worldly energy demand shall increase 60% till the year 2030. In the meantime, it also pointed out that the CO_2 emission will also increase. Therefore, energy saving and environmental protection is a major task faced by the current human.

With the rapid growth of China's economy, our country has become the world's powerful energy production and consumption country. By 2001, China's energy consumption has reached 11.4% of the world's total energy consumption, and China has become the world's third largest energy producer following the United States and Russia's and the world's second largest energy consumer after the United States. In 2003, for example, China's fresh water and primary energy use have respectively become the first and second in the world. Thus the resulting water pollutant and SO_2 emissions are both in the world's first place. In the environment of rapid economic growth, China's energy industry is faced with dual pressure of economic growth and environmental protection. Fire coal and coal processing and mining produce a large number of pollutants, causing serious air pollution and water pollution. The current level of energy exploration, development and utilization of China determines that the problem of dependence on oil cannot be solved in a short term, and the new energy development and utilization technology is not yet mature, which shall lead to short energy supply, at the same time, the environmental pollution caused by irrational energy structure in China, has become a major problem restricting China's economic and social development.

Energy industry, as the foundation of the national economy, is very important to the social and economic development and the improvement people's living standard. Energy industry in China obtains relatively backward technical management and technical level,

with the features of low energy efficiency and per capita energy consumption, and energy shortage and waste coexistence, causing sharp contradiction between supply and demand. Since 1997, our country has turned into energy importer from energy exporter, and with the further growth of the economy in our country, the demand for energy shall further increase. It is predicted from current level that, by the year 2020, China's energy consumption shall reach 1,500 Mtoe (million tons of oil equivalent) which is more than twice of that in 1995, therefore, China is faced with very severe energy situation.

In general, the energy resources status and characteristics in China mainly are:

1. Abundant total resources, low per capita quantity

The fossil energy and renewable energy resources are relatively rich in our country, which is dominated by coal. In 2006, the coal resource reserve is 1.034 5 trillion tons in our country, the remaining proven recoverable reserves account for about 13% of the world, listing the third in the world. Unusual fossil energy reserves, such as oil shale, coalbed methane obtain large potential. Water resources theory reserves shall convert into an annual capacity of 6.19 trillion KWH, economically developable annual energy output reaches about 1.76 trillion KWH, equivalent to 12% of the world's water resources, listing the first in the world.

Currently, the energy consumption of China (calculated as per the kilo oil equivalent/GDP) has exceeded 10% of the world's total energy consumption, far higher than the industrial developed country, listing the second in the world, which is about 5 ~ 9 times of that of US, Japan, UK, and France, while the energy resource holding quantity of China holds a small proportion of the world's average level. Overpopulation and relatively insufficient resources make our country far below the world average per capita energy capacity. Coal and water resources per capita is equivalent to 50% of the world's average level, oil and natural gas resources per capita is only about 1/15 of the world average. At the same time, the cultivated land resources per capita is only less than 30% of the world's average, and the development of biomass energy is constrained.

2. Unreasonable energy structure

China's energy structure is given priority to coal, with low proportion of clean energy. Coal accounts for about 70% of energy consumption, while oil accounts for 22.0% of energy consumption; as the most important fundamental energy in China, coal obtains a proportion of 69%, while the gas obtains 2.6%, new energy and renewable energy sources 7% such as hydropower, nuclear power, wind power and solar

energy. Figure 1. 1 is the structure of world's and China's primary energy consumption in 2005. It can be seen from the Figure that the percentage of China's coal consumption in the total energy consumption is greatly higher than the world average, which is about 2. 5 times of the world average, while the proportion of oil, natural gas, hydropower and nuclear power is relatively low, especially the utilization of renewable energy is much lower than the world average.

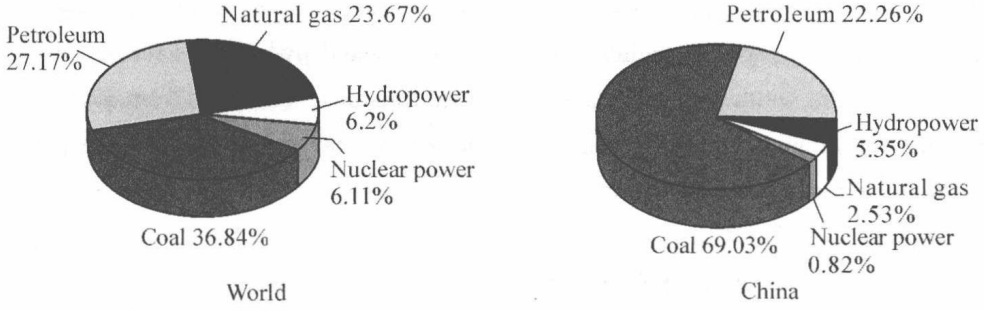

Fig. 1. 1 Comparison of China's and world's primary energy consumption structure in 2005

The high proportion of coal in energy consumption structure of China leads to current severe environment pollution caused by coal burning in our country. Each year, the national SO_2 emission is 23. 7 million tons, and the soot and dust emission is 18. 4 million tons, and energy consumption's contribution to the above two emissions is 85% and 70% respectively. Therefore, it is imperative to improve the energy consumption structure, and vigorously develop clean and renewable energy.

3. Disharmony of energy resources, energy consumption with economic layout

Energy is widely distributed in our country, but its types and reserves are of very unequal distribution, which leads to the disharmony of energy distribution and consumption with economic layout of China. 80% energy resources are distributed in the north and west areas of China, while 60% of energy consumption is in eastern and southern coastal areas of developed economy.

4. Low energy utilization rate

China has a very low energy utilization rate, and it is one of countries with the highest energy consumption per unit GDP in the world. China's energy consumption is over three times of the world average level, and 4. 5 times of DECD countries average, and 9. 5 times of Japan. In the 2004 *Energy Policy Research Report*, it pointed out that China's energy utilization rate is only 36. 81% , far below the world average of 50. 32% . Its main reasons lie on the energy consumption structure with priority to medium-and low-quality energy, unreasonable energy use, and serious waste. Therefore, how to

improve the efficiency of energy utilization is the urgent problem at present in our country.

5. Great difficulty in energy development

Compared to the world energy resource development condition, China is faced with poor development conditions of coal resource geology, where most reserve requires underground mining and only a small quantity offers open pit mining. Oil and gas resources are in complex geological conditions, deeply buried, and requiring higher exploration and development technical level. Undeveloped hydropower resources mainly concentrate in the southwest mountains and deep canyons, far away from load center, with great development difficulty and cost. Unconventional energy resources exploration is of low degree and poor economic efficiency.

It is predicted that China's future energy supply and demand gap will be bigger and bigger. Oil import dependency (the ratio of net imports and consumption) has increased to 20% in 2000 from 6.6% in 1995, in 2005 it reached to 43.7%, and by 2020, China's oil import dependency will be as high as 60%, gas imports will reach 100 ~ 150 billion cubic meters; energy security problem in China is facing a great challenge.

1.2 Utilization of renewable energy resource

Renewable energy mainly refers to solar energy, wind energy, biomass energy, low thermal energy, water, ocean energy, tidal energy, etc. Compared with the non-renewable energy, it possesses the characteristics of richness, no environment pollution, cleanness and safety, and resource renewability. Therefore, facing the increasingly tense energy situation today, vigorously promotion of the application of renewable energy has extremely significance.

Renewable energy in China is abundant with the full available species, and has a huge potential market, and the renewable energy technology maintains a wide variety of use. By 2002, the total power generation is 48.9 Mtce through the development of small hydropower, wind power, solar energy, geothermal energy, biomass gasification, etc. If combined with biomass energy utilized in the traditional way, the amount of energy provided by renewable energy (excluding large hydropower) has exceeded the total amount of oil, natural gas production in the same year, composing an important part in the energy supply system, which has played an outstanding role to solve the energy supply problem in rural and remote areas, ease the environmental pollution caused by fossil energy consumption and the huge pressure of global climate change, and even

promote the development of national economy.

During the tenth five-year plan, the development and utilization of renewable energy in China has brought remarkable environmental benefits. By the end of 2005, the development and utilization of renewable energy has reduced about 2.5 million tons sulfur dioxide emission, about 1 million tons nitrogen oxide emissions, about 1.3 million tons soot emissions, and about 400 million tons CO_2 emissions, conserved about 700 million m^3 water, and protected about 100 million mu forest land from damage. Table 1.1 states the situation of the development and utilization of renewable energy in China for the period 1990—2005.

Table 1.1 Development and utilization of renewable energy in China

Year	1990	2000	2005
Total of renewable energy resources	313.4(25.0)	309.4(19.2)	454.5(17.9)
Including: traditionally utilized biomass energy	262.0(20.9)	219.1(13.6)	295.6(11.6)
Large and medium hydropower	34.3(1.4)	53.1(3.3)	96.1(3.8)
New and renewable energy	17.1(1.4)	37.2(2.3)	62.8(2.5)
Total consumption of primary energy	1 250.9(100.0)	1 612.8(100.0)	2 541.7(100.0)

The traditionally utilized biomass energy in Table 1.1 refers to direct combustion of fuel wood and straw; new and renewable energy includes small hydropower, biomass gasification, liquefaction and power generation, solar energy heat utilization and photovoltaic cells, direct use of geothermal and power generation, and wind power generation. It is seen from Table 1.1 that the development and utilization of renewable energy has achieved great improvement in China. In the period from the year 1990 to 2005, the large and medium hydropower has increased 1.8 times and the new and renewable energy increased 2.7 times. The traditional use of biomass, hydropower, small water and electricity, household biogas digester, solar water heater and so on are listed the first in the world.

By the year 2006, total amount of renewable energy development and utilization of China (excluding traditionally utilized biomass energy) has reached 200 million tons of standard coal, equivalent to about 7.5% of the total amount of nationwide primary energy consumption, which has eased the imbalance between supply and demand of energy in China. Although our country has attached great importance to the development

and utilization of renewable energy, and has made great achievements, but compared with foreign developed countries, China's energy technology is relatively backward, and there is still some gap on the strength of the renewable energy development and utilization. Taking the United States as an example, till the end of 2005, its overall production of renewable energy has reached to 218 million tons of standard coal. In the primary energy consumption of the whole US, oil occupies 40%, coal 23%, natural gas 23%, 8% nuclear power, 6% renewable energy (where solar energy has accounted for 1%, geothermal 5%, biomass 47%, wind power 2%, and hydropower 45%).

Our country is vast in territory, and the renewable energy also obtains imbalanced distribution on the geographical perspective, therefore, we shall fully consider regional characteristics, adopt proper HVAC technology, adjust measures to develop renewable energy sources as per local conditions.

1.3 Traditional utility pattern of air through tunnel (hereafter referred to as "ATT")

Our country is vast in territory, and obtains a huge amount of available civil defense works; in 1960s—1970s, China built many tunnels (including air-raid shelters, caves, underground rivers, tunnels, etc.), and the ATT resource is more than abundant, with 7 million square meters tunnel area only in Shandong Province. The said tunnels are generally 10 meters or so under the ground, and experience high air temperature in winter and low temperature in summer compared with outdoor temperature, due to surface temperature wave attenuation and delay. Therefore, enormous energy is stored in tunnels.

In the early 1970s, ATT cooling technology is developed rapidly in our country, and it was the first utility of tunnel resources in China. Its basic principle is: conduct air cooling in tunnel in summer, and then convey the cooled air to the buildings on the ground through mechanical ventilation system or induction ventilation system, in order to achieve cooling purpose. It is firstly applied to the public buildings with crowded personnel and presses for air cooling, such as theaters, auditorium etc., and later, it is gradually developed to the cooling and ventilation for guest houses, office buildings and industrial buildings, such as printing house, textile mill, thermal workshop in electronics and machinery factory and other industrial workshop, and achieves good cooling effect.

However, due to the fact that most of the tunnel is in polluted situation, the air

inside tunnel presents pungent odor or a little musty smell, which shall lead to serious deterioration in room air quality after cooling and discharging indoor. At the same time, it is also found through practice that harmful gases are contained in the tunnel, and radon concentration is very large. Radon is a colorless, odorless, tasteless, natural radioactive inert gas that is slightly heavier than air, originated in three natural radioactive series of rocks (soil contained). It can emit a harmful radioactive gas, whose daughter is a strong α, β, γ radioactive solid particle which is electrically charged, possesses very strong "wall attachment effect", that is, it can firmly adhere to all material surface, and form the difficult-to-erase "radioactive thin-layer". When people enter the high radon concentrated places, the inhaled radon constantly decays in the body and produces radon daughter, the particles of which shall accumulate in the respiratory system, cause large bronchial epithelial cells serious damage due to the formation of strong radiative source resulting from their short half-life period, all in-situ decay, and even induce lung cancer. In addition, it shall also cause leukemia and other respiratory diseases, and is harmful to human body.

Table 1.2 states the average concentration of radon and its daughter in underground buildings of different districts. According to the sampling investigation, the concentration of radon and its daughter in underground buildings is 5 ~ 10 times higher or even more than that in the ground buildings.

Table 1.2 Average concentration of radon and its daughter in underground buildings of different districts

Place	Kunming	Shenyang	Guizhou	Shanghai	Beijing	Wuhan	Underground karst cave		
							Zhejiang	Jiangsu	Guizhou
Radon concentration (Bq/m^3)	644.5	293.0	88.1	80.6	69.2	50.0	131.0	322.0	990.0

After the recognition of the radon harm to human body, certain measures have been taken to reduce the radon concentration in the tunnel and the indoor concentration, such as changing the ventilation way from air exhaust mode to air press-in mode; painting water-proof, radon free sealing material to the tunnel; enforcing air circular flow by a fan; increasing windowing times; adding ventilating bypass valve in ventilation system and others. However, since the underground rock, soil and building materials related to the rock and soil are the main sources of radon gas in underground construction sources,

even though the protective measures are taken, it is very difficult to reduce the radon concentration to the safe range, let along the radon has strong diffusivity and is unavoidable to enter indoor and stay in the indoor air, which brings great threat to physical and mental health of human. In addition, the ATT air conditioning system is of air drafts for air convey to building, which aggravates the radon diffusion to the tunnel in the masonry material and its sounding rocks and soils.

In the meantime, during the system application, improper tunnel utility and management and delayed elimination of ponding and sewage in tunnel cause the breeding of all kinds of microorganism and bacteria, all of which lead to the existence of other hazard substances other than radon gas, and severely worsen the indoor air environment.

ATT cooling technology, after the phase of rapid development, is gradually walking out the sight of human. Therefore, the key to ATT utility is to discover a new and healthy energy utilization mode.

Chapter 2 Characteristic of Formation Temperature Change

The original formation temperature obtains differences in deep and shallow formation, where the change of shallow formation temperature depends on the formation surface temperature change which, as for plain area, is caused by solar radiation and long wave radiation heat dissipation that lead to corresponding changes of atmospheric temperature.

Due to the formation thermal storage effect, the temperature wave, spreading to deeper formation, not only causes temperature wave attenuation and delay time relative to the ground temperature wave. In the calculation of air temperature drop (rise) through tunnel, it not only needs to know the temperature wave attenuation amplitude, and needs to know the formation temperature values at a certain computing time, as well as formation temperature wave delay situation, in order to make good use of the formation temperature changes, for the convenience of the maintenance of the minimum cooling temperature(the best cooling effect) of outdoor air through tunnel in summer and the maximum heating effect in winter.

2.1 Source of formation energy

Formation energy sources are solar radiation, geothermal, and heat release during biological processes in soil and chemical heat generated in the chemical process, etc., where the solar radiation is the most basic energy source of soil and is the key factor to soil heat flow.

2.1.1 Solar radiation energy

The sun, as a huge radiator with surface temperature of about 6 000 K, constantly radiates huge energy to the surrounding space, only a few part of which is acquired by the earth (about 20 pphm). When the sun radiation goes through the earth's atmosphere, a part of its energy is absorbed by the atmosphere and scattering, a part is reflected by cloud, and only about 50% of the sun radiation travels to the surface, this little part of which is thousands of times more than the total energy of the soil acquired