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Geothermal District Heating System in XianYang, Shaanxi, China

[1]Thorkell Erlingsson, [1]Thorleikur Jóhannesson, [2]Eldur Olafsson and [3]Gudni Axelsson

[1] Verkís hf, Ármúli 4, IS-108 Reykjavik, Iceland

[2] Enex-China Ltd, Landmark Tower, Beijing 100004, China

[3] ISOR, Grensásvegi 9, 108 Reykjavík, Iceland

te@verkis.is, tj@verkis.is, eo@enex.is, gax@isor.is

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ABSTRACT

The City of Xianyang is rich in low-temperature geothermal resources embedded in the Guanzhong basin underneath the City. The reservoir rocks are mostly sandstone layers, but major faults play a key role in the geothermal activity. Close to 30 wells, ranging in depth from 1500 to 3500 m, have been drilled in the area and production temperature is usually between 70 and 120 °C. Geothermal utilization in Xianyang has been growing rapidly in the last 10 – 15 years. With a rather high housing density (0.5 to 1.5 m² floor space per m² of land) Xianyang is well suited for district heating application.

A Joint Venture company between Iceland and China started developing geothermal space heating systems in Xanyang in the year 2003 and has now (2009) installed geothermal heating in over 1,200,000 m² of housing. The aim is to introduce geothermal heating in over 50% of the City in the next 10 years or around 8,000,000 m² of housing, thus becoming by far the largest geothermal space heating system in China.

An initial resource assessment conducted in 2005, based on rather scarce data, shows that the Xianyang geothermal system should be able to sustain the utilization planned. In order for this to be possible several resource management issues must be addressed and solved. These include: almost full reinjection, comprehensive monitoring of all wells in the area, regular resource assessment updates through reservoir modeling and common management of the resource, which is utilized by several independent companies.

Geothermal energy is one of the cleanest energy sources available. In the case of Xianyang the use of geothermal water instead of coal will reduce CO_2 emission by 40,000 tones annually for each 1,000,000 m² of houses connected.

1. INTRODUCTION

The city of Xianyang is in Shaanxi province and was founded around 350 BC. Xianyang was the capital of China more than 2000 years ago. Hot springs have been used in this area for more than two thousand years so the tradition of using geothermal water is well established. Today this area is well known among other things for its several thousand man sized terracotta warrior army located in the Mausoleum of the First Qin Emperor.

The city of Xianyang is located around 40 km nothwest of Xian, today Shaanxi capital. It is the capital of the prefecture-level division of Xianyang, an administrative area of the Shaanxi province with 5 million inhabitants shared out among 13 counties. Xianyang and its vicinity has now around 600,000 inhabitants, at the confluence of the Wei (a branch of the Yellow River) and Feng rivers. Xianyang is devoted to industrial activities, with a focus on textiles and electronics industries.

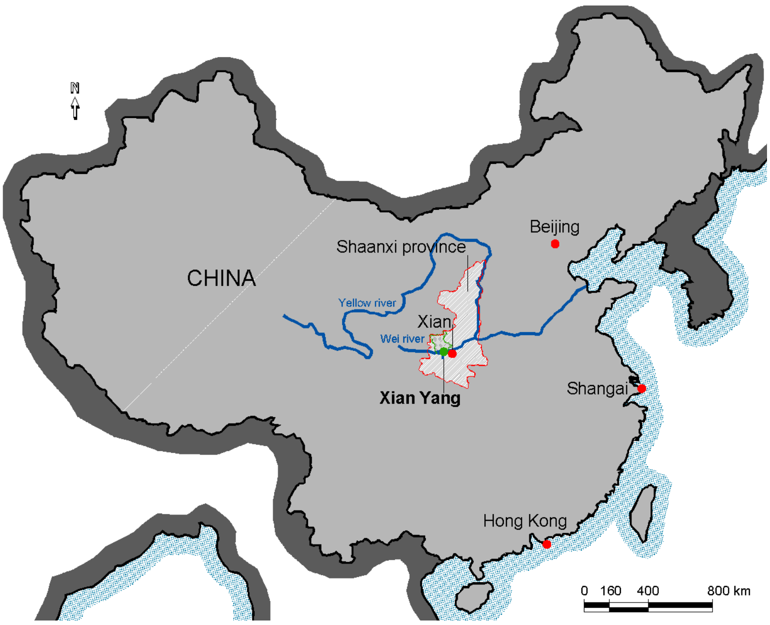

Figure 1: The figure shows China,Shaanxi provinceand Xianyang.

Using geothermal fluid for space heating in small scale has been ongoing in Xianyang for a long time. But in the year 2006 a joint venture company was established between Shaanxi Geothermal Construction Co (subsidiary of the Sinopec Group) and the Icelandic company Enex-China, with the main purpose of developing geothermal projects in the area. The name of the company is Shaanxi Green Energy Geothermal Co (SGE) and has been developing geothermal heating systems since in the area. Total heated floor area using geothermal energy as of 2009 is around 1,200,000 square meters.

2. GUANZHONG BASIN

The Xianyang geothermal resources are found at depth in the Guanzhong sedimentary basin, which covers an area of about 20,000 km^2 and extends east-west through the central part of Shaanxi province. Geothermal resources are also found under Xi'an, the capital of the province, 40 km east of Xianyang. The Guanzhong basin is a Cenozoic fault-block basin with a depth ranging from 3000 to 7000 m. The geothermal reservoirs in the basin under Xianyang (and Xi'an) are mostly found in Tertiary sandstone formations. The main formation groups that have been tapped are found between approximately 500 and 3500 m depth, ranging in temperature from 70 to 120°C. Below them is a formation having still higher temperatures, which has been tapped by a few wells in Xi'an. There are also indications that carbonate sedimentary rocks exist at depth north of the North Wei River Fault in Xianyang.

Some of the big faults and fractures, criss-crossing the Guanzhong Basin play a key role in the geothermal activity. In Xianyang the North Wei River Fault is believed to play the biggest role as reflected in geothermal gradient data and thermal spring locations. Active faults and fractures may provide channels for the up-flow of hot water from greater depth as well as create greater permeability around them. Other faults may, however, act as vertical aquitards.

The geothermal water in the Xianyang system is believed to originate as rain that fell on the northern slopes of the Qinling Mountains in the south from several thousand to 30,000 years ago (Qin *et al.*, 2005). Part of the recharge may also originate in the so-called North Mountains in the north. It should, in addition, be pointed out that this long residence time may be interpreted as resulting from slow and relatively small-scale recharge. The implications for future large-scale utilization are that continuous long-term pressure (water-level) draw-down is to be expected.

3. GEOTHERMAL CONDITIONS AND POTENTIAL

An initial resource assessment of the Xianyang resources was conducted in 2005, based on rather scarce data (Fjarhitun Consulting Engineers and Iceland GeoSurvey, 2005). Close to twenty geothermal wells have been drilled in Xianyang city since 1993 - 1994. These wells have demonstrated that the potential of the geothermal resources under the city is considerable, reflected in free-flowing wells with high discharge and temperatures of about 70 – 120°C. During 1994 – 2004 the geothermal water production in Xianyang increased steadily. The cumulative production during the period amounted to 11 million m^3, with the annual production having reached 2 million m^3 in 2004. Since then the yearly production has continued to increase.

A statistical analysis of well information available in 2005 revealed a clear correlation between temperature and well depth (see Fig. 2) and an average short-term productivity index of 0.9 (l/s) per meter of water level draw-down. No correlation with location relative to the North Wei River Fault seems to exist.

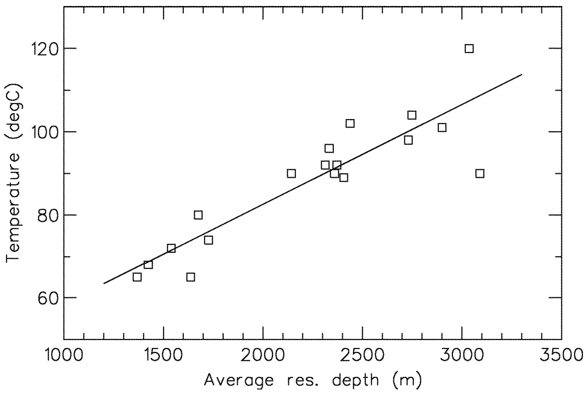

Figure 2: Correlation between average depth of producing layers (average reservoir depth) and well-head temperature for the first eighteen geothermal wells in Xianyang.

The 2005 preliminary resource assessment included simple modelling of the whole Xianyang geothermal system. The model was used to calculate reservoir pressure predictions for various future utilization scenarios. Fig. 3 shows one example, predictions for pressure (presented as water level) changes in two areas for a continuation of production as it was in 2004.

The principal result of the 2005 assessment was that the Xianyang geothermal system should be able to sustain the planned increase in geothermal utilization provided full reinjection is integrated in the long-term management of the resource. Significant interference is expected, however, from geothermal utilization in different parts of the City, which will mutually decrease the utilization potential of individual wells. Therefore, reinjection should be unconditionally applied in any new geothermal developments in Xianyang.

The results of the model calculations are uncertain, however, because of a limited data. Therefore, it is imperative that monitoring of the geothermal wells in Xianyang be improved and that planned development be conducted in steps. Careful monitoring, and consequent data-analysis and modelling during each step, will drastically improve the accuracy of all predictions and potential estimates, before an overinvestment in wells and surface equipment has taken place.

Two main problems may be foreseen with reinjection in Xianyang. First, the danger of cooling of near-by production wells. This should be easily avoidable if reinjection well locations, and depths, are correctly planned, which requires detailed and careful testing and research. At any rate, the energy content of the Xianyang geothermal system is more than sufficient to sustain the rate of production envisioned, with full reinjection. The second problem is associated with the fact that sandstone reinjection is sometimes delicate because of the danger of clogging up of the reservoir formation next to a well. A technical solution has been developed for comparable reservoir conditions in Europe, which involves thorough filtering before reinjection and keeping the fluid completely oxygen-free (Seibt *et al.*, 2005).

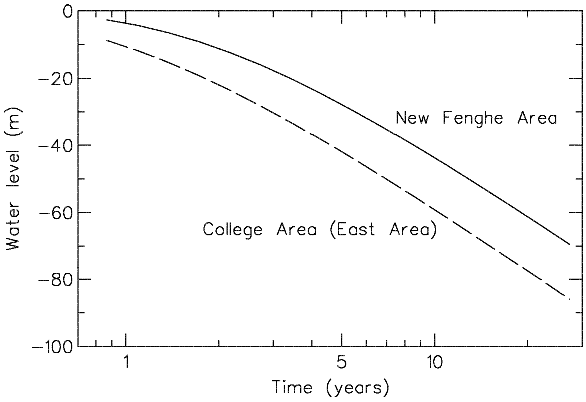

Figure 3: Estimated water level decline in two parts of Xianyang due to production from the 18 wells existing in Xianyang in 2005. An average yearly combined future production of 100 l/s is assumed. An additional annual water-level drop of roughly 20 – 40 m may be expected Note that the time scale is logarithmic.

Huang (2009) studied water level changes during 2005 – 2009 in three of the wells operated by SGE. His results indicate a continuous water level decline of the order of 2 – 4 m/year. This is comparable to the prediction results presented in Fig. 3.

4. GEOTHERMAL SPACE HEATING

Space heating is probably the largest consumer of energy in all colder countries (including northern part of China), ahead of transportation and industry, consuming around 40% of the total energy consumption. Private households use over 80% of the required final energy for heating rooms and water but less the 20% is used for electrical devices and lighting.

Energy used for heating each unit area of floor in older Chinese residential buildings has been calculated to be almost double of similar houses in the new areas in China. Today coal is the main source of fuel for central heating systems and will continue to be so for the foreseeable future in China. Changing the heat source from coal to geothermal and also simply by improving insulation in houses is a method that will reduce the CO_2 emission immensely and improve life for people.

4.1 Weather Data

Weather data for the city of Xian, a city close to Xianyang, were obtained from the Chinese Typical year Weather Data for Architectural Use, based on a 1982-1997 period of record with data obtained from the US national Climate Data Centre. Figure 4 shows the outdoor temperature curve built on the basis of those data.

Outdoor design temperature is an essential parameter to assess the peak load. This value was chosen based on the ASHRAE fundamentals from 1997; it is the mark under which the actual outdoor temperature should not be expected to fall under more than 1% of the annual time. On this base, a design outdoor temperature of -5°C was chosen.

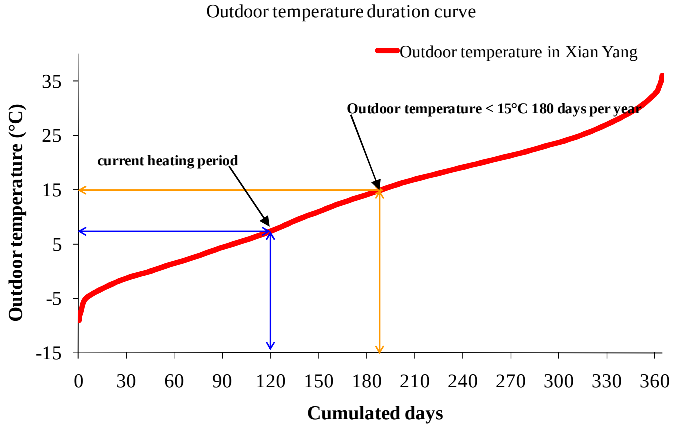

Figure 4: Outdoor temperature duration curve.

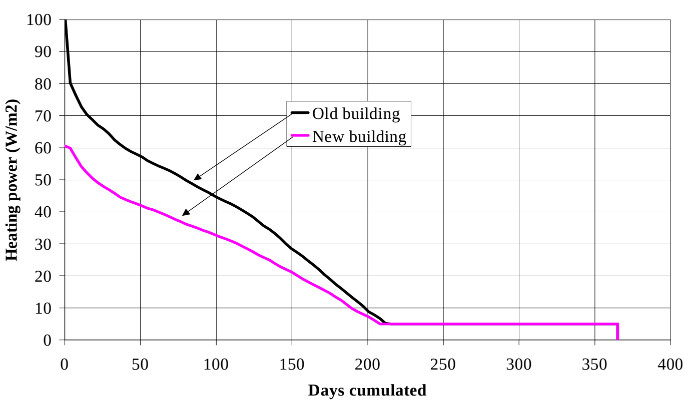

Figure 5: Load duration curves for new and old buildings.

4.2 Heat Load and Energy Calculation

To determine the energy requirements of the area, two separate models were evaluated; one for older buildings with poor insulation and another for new buildings that confirm with more recent Chinese building standards. In addition, two different models were used for the evaluation, a static model and a dynamic one.

The results from these calculations are shown in Table 1.

Table 1: Calculated Peak load and Energy demand for new and old buildings in Xianyang.

LOAD	*Old houses*	*New houses*
Peak load W/m²	92	55
Potable Hot water W/m²	5	5
Total peak load W/m²	97	60
ENERGY		
Energy for heating kWh/m²	166	96
Energy for PHW kWh/m²	26	26
Total Energy Demand kWh/m²	192	122

The annual coal used for heating water for space heating was investigated. The energy consumption was approximately 35 kg of coal per m² of housing. The raw energy derived from burning coals is approximately 29 MJ per kg of coals, or 8 kWh/kg. Thus, the raw heat produced, solely for space heating, amounted to 280 kWh/ m^2 (35 kg/ m^2 x 8 kWh/kg).

The installed power made available by the boiler stations was 132 W/ m^2, a value that far exceeds the demand since it is 30% higher than the peak demand calculated, or 97 W/ m^2. Since the efficiency is highest when burners run at 60-70% of maximum capacity, this gives us reason to believe that the efficiency of coal burning in the studied area in boiler stations is high. Up to 80% efficiency can be expected under such circumstances.

Assuming that this is the case in the boiler stations, i.e. a coal burning efficiency of 80% is taken into account and an estimated 10% heat loss from the distribution network, the resulting annual energy consumption for space heating is 200 kWh per m^2. This fits reasonably well with our calculations in Table 1.

By renovating old buildings in cold areas (better insulation, window improvement, heating system improvement and implementation of a suitable tariff system) the energy consumption can be reduced by up to 50%. The added building cost is of the range of 5 to 10% depending on buildings and is very cost effective over the lifecycle of the building. Renovation would also reduce the coal consumption and hence the CO_2 emission. Renovation of old housed heated with coal can save almost as much coal and CO_2 emission as changing the heating systems in new houses from coal to geothermal heating.

4.3 House Heating System

In most cities in China and many places in the world a single piping system has been used for in-house radiator systems. The main principle is that water is led up to the highest floor and the radiators are connected in series so that the return water from a high level radiator is led to the next floor supply below. A throttle valve is sometimes installed parallel to the radiator to ensure that the water runs through the radiators on each floor. The result is that the supply water to radiators situated on lower levels will be colder than the supply water to radiators higher up in the building. This means that radiators on the lower levels must be installed larger than the radiators higher up. The overall temperature drop can be measured from top to bottom of each building. A common temperature drop is from 90°C to 70°C during periods of maximum heat load for an average apartment building; see present system in Figure 6.

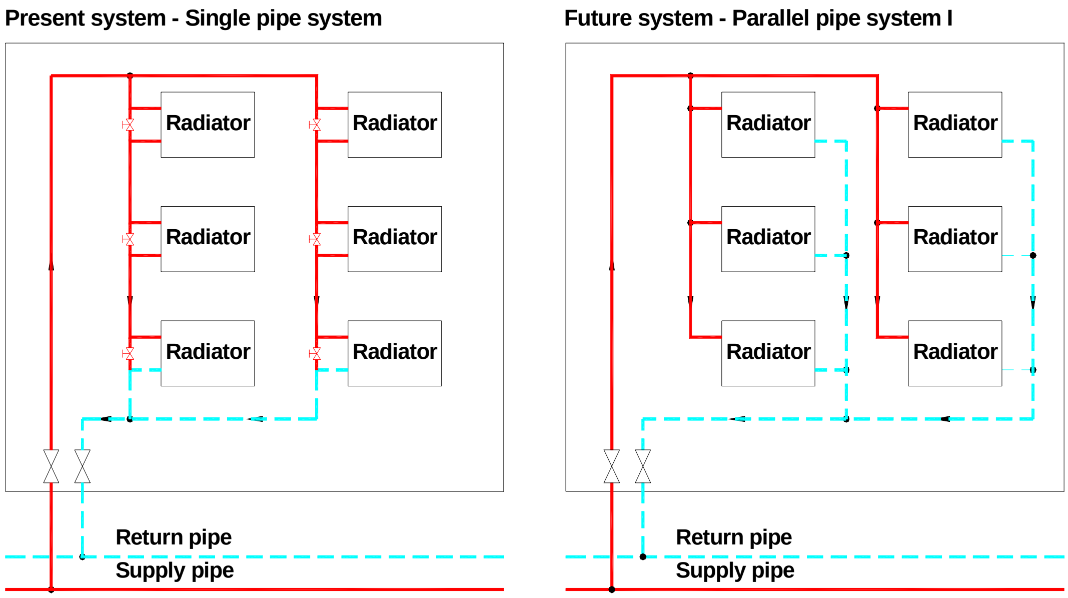

Figure 6: Typical pipe arrangement of present system in coal heated buildings and recommended changes. Proposed pressure control at house connection not shown.

The advantage of a series loop arrangement is that the installation of the heating system is easy and therefore the installation cost is low. The disadvantage is the complex design of the heating units. This is caused by the fact that the average water temperature lowers progressively from the first unit connected to the last causing the heat output to fall. This calls for adjustments of each unit in the circuit. In addition, if the water flow is controlled, comfort cannot be maintained in separate spaces.

The present radiator systems are not suited to low temperature usage, mainly because radiators are too small and the quality is poor. Also due to the fact that the lower floor radiators have to be very large since the water running through them has already cooled considerably. Therefore a pressure balanced parallel system is recommended. In this type of system a similar temperature drop is experienced in every radiator in the building.

To be able to use low temperature fluid, i.e. 70/35°C the overall size of a radiator must be large. Radiators installed to use 70°C supply water with a 35°C return temperature will be about 60% larger than 90-70°C.

Due to the large temperature difference (35-40°C) between the supply and return water, the flow rate is lower and it is possible to reduce the size of the distribution network and in-house piping system.

New buildings in Xianyang where geothermal heating is implemented should be equipped with modern parallel radiator connections of suitable size, enough to deliver 50-60 W/m^2 for 70°C supply water and 35°C return water and maintaining a room temperature of at least 18°C. Also widely used in new houses in Xianyan is the floor heating system with supply temperature of 45°C and return temperature of around 35°C. Such floor heating system is ideal for geothermal systems where the return temperature should be as low as possible. The radiator and floor heating systems in new houses in Xianyang are working fine for the geothermal system but the old houses are still a problem.

4.4 Heat Central and Distribution System

The Joint Venture Company has now the right to develop geothermal heating systems in two north areas of the city (yellow and green area on map figure 7) in addition to a new area in the south part of the city (brown area on map figure 7). These areas cover less than half of the city area.

The geothermal heating system has gradually expanded in the city, starting in the year of 2003. In the year 2006 the Joint Venture was formally established with the main focus on developing geothermal space heating in Xianyangt. At that time only very small area was heated with geothermal water in the city.

The design of the heating system in Xianyang is such that the city is divided up in to areas with 500,000 to 1,000,000 m² of houses in each area. One Heat Central (pumping station) is located in each area and a loop of distribution pipes from the heat central connected to the existing coal boiler units or new houses, see Figure 8 and 9. The function of the Heat Central is to be the connecting point between the various sources of energy and the users. It receives energy in the form of geothermal fluid from the geothermal wells and transmits it to the users via a heat exchanger and pumping system. Since the district heating system covers the end users needs for space heating and domestic hot water, the geothermal energy production system will be in use all year around. The intention is to pump all the geothermal fluid into the ground again. Experiments are being conducted on Site but actual re-injection has not yet started.

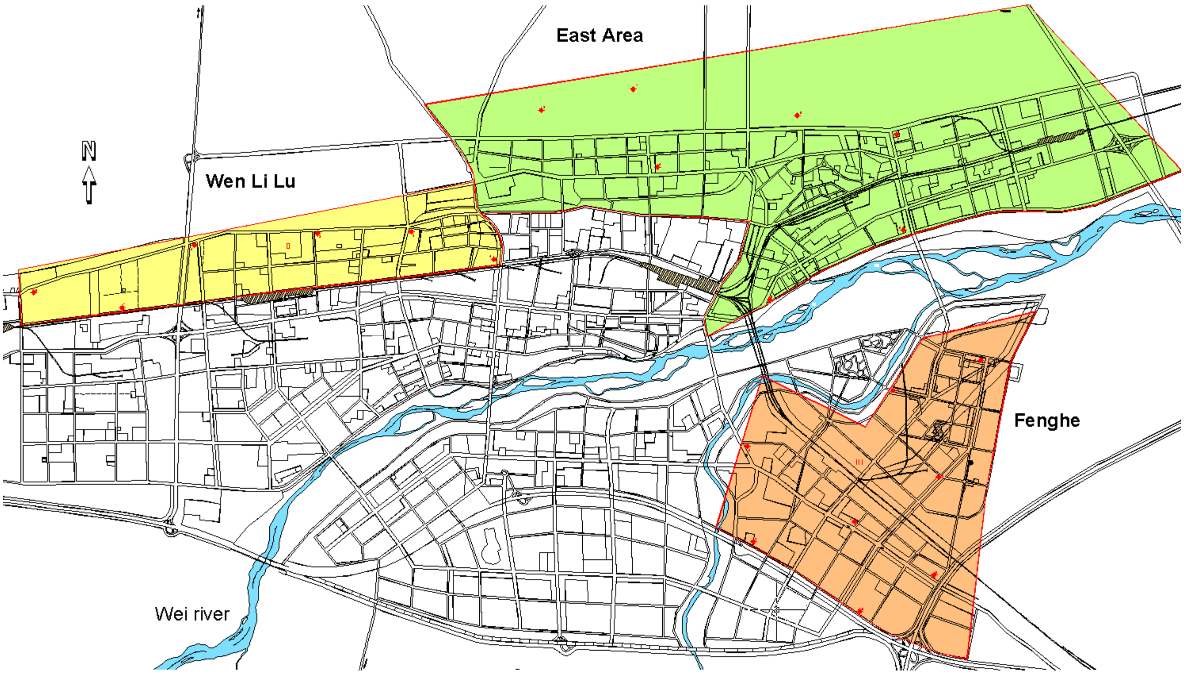

Figure 7: The areas in Xianyang where the Joint Venture Company has the right to develop geothermal heating systems.

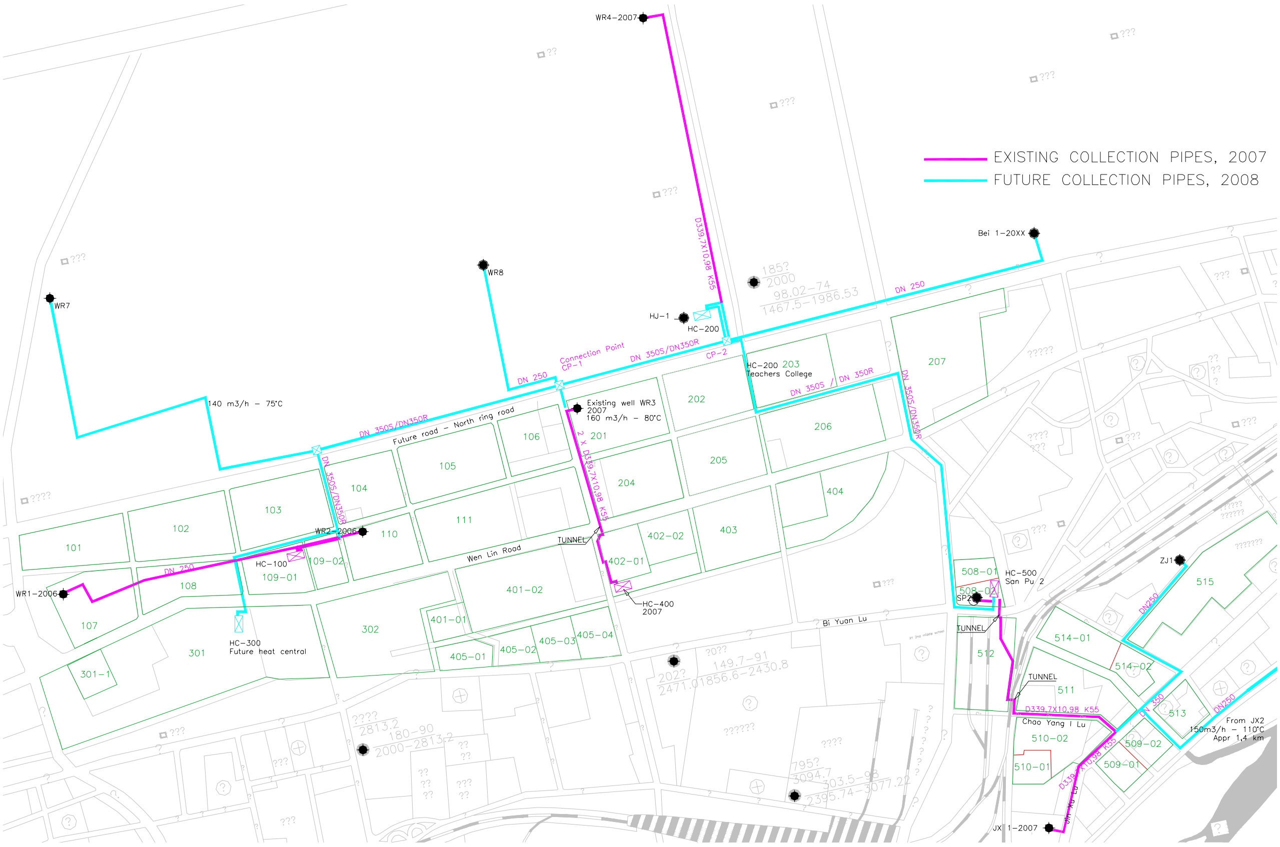

Figure 8: Current and planned collecting system in north-western area.

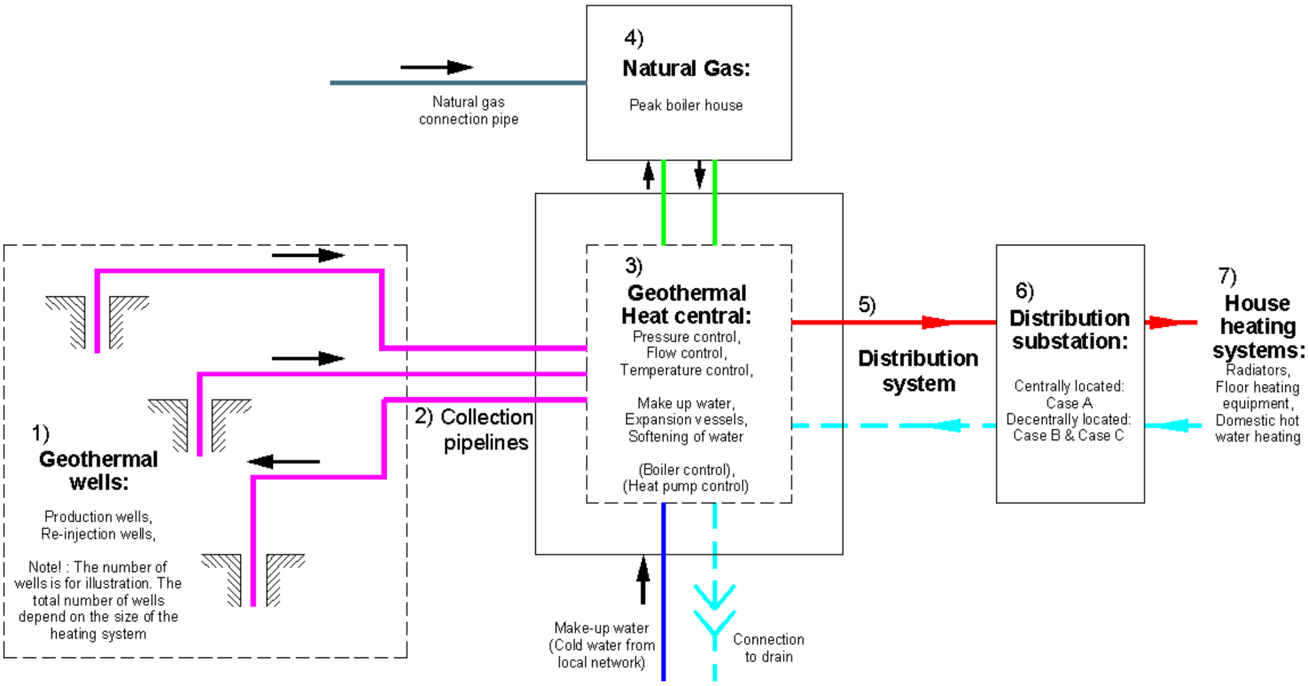

Figure 9: Schematic drawing showing the geothermal heat central and the connecting points.

Today there are already 4 Heat Centrals up and running with almost 1,200,000 m² of houses connected to them and heated with geothermal water.

4.5 Peak Load – Additional Source of Energy

Four Heat Centrals are constructed with planed peak load of 15 to 20 MW thermal power in each central.

Two to three wells are connected to each Heat Central providing around 60-70% of the peak power needed using gas boilers and/or heat pumps for the remaining 30-40% of the peak power. On the other hand the geothermal energy provides around 90% of the energy needed but the gas boilers only around 10% of the energy, see Figure 10.

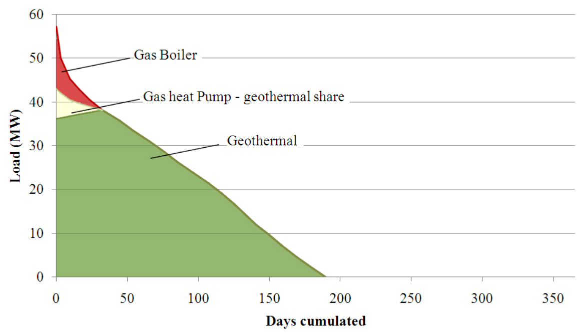

Figure 10: Load duration curve and peak facilities.

Both gas boilers and electrically driven heat pumps are used for the peak load depending on the energy availability in each case. Also some experiment is being done using different type of peak load.

The intention is to connect the heat centrals together with pipes so energy and power can be distributed in the most economical way. The connection will also increase the availability and running security. The connection has not yet been completed but is on the schedule.

At the end of the 2008-2009 heating period, the district heating system was connected to 7 wells able to provide up to 140 l/s of geothermal fluid with temperature ranging from 70°C to 100°C. The system composed of 5 heat centrals of which only 4 are equipped with peak gas boilers with 24 MW installed capacity. Some heat centrals were additionally equipped with electrically driven heat pumps with 15 MW installed thermal power. Once the district heating system is fully developed, about 40% to 50% of its total installed capacity is expected to be covered by the geothermal system.

4.6 Metering Methods

The billing for heating energy in China today is mostly based on a square meter price per year and has nothing to do with energy consumed or energy wasted. This billing method does not encourage the consumers to extract as many degrees °C out of the supply water, which is a fundamental issue in geothermal heating, nor does it promote energy saving or any house improvement such as added insulation, double glassing or keeping windows shut in cold periods. This must be changed in order to implement additional house improvement and energy saving.

Where geothermal resources are utilized, it is of utmost importance to consider seriously the condition of the resource when designing and operating district heating networks. Choosing the right metering method is very often crucial in achieving satisfactory resource utilization. The reason is simple: The users always have to pay for their heat (in the end). With the right metering method, the users are motivated and encouraged to participate in building a system that utilizes heat correctly, for the benefit of themselves at the same time as it benefits the whole district heating network and its users.

Flow meters are used successfully in many places where geothermal energy has been in use for long time such as in Iceland and it is expected that the use of flow meters should work properly in Xianyang as well. If kept in mind that the geothermal field contains very old water which has a slow natural renewable rate, the conditions for using flow meters are improved. The use of flow meters is therefore strongly recommended, especially since the construction sites will be dense. Standard heat metering is not an appropriate solution because it lacks the driving force of squeezing as many degrees °C from the delivered supply water. Some sort of a penalty mechanism for high return temperature must be built in the system.

It is strongly emphasized that choosing an applicable metering method is extremely important to reach a goal of running an economical and practical (geothermal) district heating utility.

5. CONTRIBUTION TO SUSTAINABLE DEVELOPMENT

The use of the geothermal energy in Xianyang will replace the current use of coal boilers used for space heating. This will improve the local air quality and reduce the burning of coal. The reduction of air pollution due to geothermal production of heat for space heating and for heating of domestic hot water is one of the main advantages of a geothermal district heating system. Values in Table 2 are set forth as estimates of real pollution quantities for typical space heating systems using different source of heating. The values for coal boilers largely depend on coal and boiler quality, burning temperatures etc., and may differ quite a bit, especially in NO_x and SO_2.

Table 2: Methods of heating, comparison of typical emission values per produced kWh heat. (jansson, 1986; Bolland, 2002; US Department of Energy, 2008; Interstate Natural Gas Association of America , 2008) (*Varies greatly with different sulphur content in unburned coals.)

Peak load power	Resulting CO_2 emissions (kg/kWh)	Resulting NO_x emission (g/kWh)	Resulting SO_2 emission (g/kWh)
Coal boilers coal	0.35	1.5	0.5*
El. heat pump coal	0.20	0.4	0.1*
Nat Gas boiler gas	0.25	0.03	< 0.01
El. boilers- coal	0.85	2.6	0.8*

In addition, traces of mercury, Hg, are contained in coal and released upon burning. The amount of mercury in natural gas is around 0.2% of the amount in coal, having a capability to reduce the emissions of mercury considerably.

Assuming the above mentioned emission values, resulting emissions for three situations are calculated and shown in Table 3. These situations are 1) 100% coal boiler, 2) 50% coal boiler, 50% natural gas boiler and 3) geothermal and natural gas boiler. The service area is assumed as 10,000 m^2 of typical new houses in Xianyang in China. Estimated energy demand is 96 kWh/m^2 per year for heating and 26 kWh/m^2 per year for domestic hot water heating, total of 122 kWh/m^2 per year

Table 3: Methods of heating, comparison of typical emission values per produced kWh heat. (Jansson, 1986; Bolland,2002; US Department of Energy, 2008; Interstate Natural Gas Association of America , 2008)

	Resulting CO_2 emissions (tons)	Resulting NO_x emissions (tons)	Resulting SO_2 emissions (kilos)
1) 100% Coal boiler	437	1.9	625
2) 50% Coal, 50% Natural gas.	344	0.9	313
3) 80% Geothermal 20% Nat. Gas peak boiler	50	0.007	0.1

According to the numbers, the CO_2 amounts are reduced with almost 90%, and other pollutants nearly disappear.

At least one source from the USA (Energy information Administration, 2008) indicates that when providing grants to reduce pollution, grants for reduced NOx, SO_2 and Hg may be 0-8 fold compared to the grants for reduced CO_2 per ton. The actual matter may differ significantly from these values, and are of course dependent on any grant acceptance.

The implementation of a geothermal district heating system would contribute to achieve a significant reduction of local and global air pollution and therefore to reduce health hazards for the population and improving their quality of life.

6. ENVIRONMENTAL AND SOCIAL BENEFITS OF USING GEOTHERMAL HEAT

Being located inland, extreme temperatures in Xianyang can go as low as -18°C in winter and as high as 40°C in summer. Housing conditions such as cold indoor temperatures can result in adverse effects on human health. The minimum ideal comfort temperature for dwelling-houses is 18°C during winter, many western countries requiring 20°C as a standard.

Heating in China is usually required to sustain 18°C indoor temperature when outdoor temperatures fall under 15°C. Outdoor temperature in Xian and Xianyang falls below 15°C during around 6 months every year.

The current coal fired district heating system in Xianyang provides hot water for space heating only 4 months a year or when the outdoor temperature is below 7°C, which means that the indoor temperature does not reach the ideal 18°C for about 1 to 2 months each year, in the fall and in the spring time when the outdoor temperature is between 7°C and 15°C.

When using geothermal resources, heating can be used whenever needed. This increases the heating services provided, and lengthens the current heating period by 2 months, to 6 months total. The increase in service is indicated in figure 3, which depicts typical energy needs and sources of supply over a time span of one year.

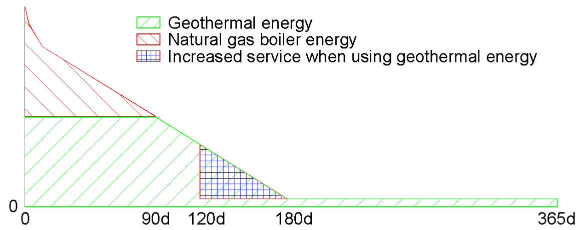

Figure 11: Typical heat load curve for Xianyang, China including energy source coverage according to Enex China conceptual design.

The implementation of a geothermal district heating system requires a new way of thinking with regards to house heating systems. Old house heating systems need to be modified and new heating systems need to include a few components and pipes that are not used in current coal house heating systems as discussed here before.

7. FUTURE PLANS

It is estimated that in the next 5 years the geothermal heating area will be expanded by 200.000 to 300.000 m² of house heating area each year and will heat around 2.500 m² in the year of 2015. This corresponds to around 130 MW peak power in heating capacity.

During the same period it is estimated that the re-injection will be fully implemented and all the residue geothermal fluid will be pumped again into the ground.

It is also expected that the billing system for heating in the area will be changed so energy or cubic meter of geothermal water will be sold instead of fixed price for heated area each year as it is today. At the same time heating systems and control in the houses will be improved and the geothermal fluid will be used in a more economical manner.

8. CLOSING REMARKS

To achieve the goal of creating a successful and modern heating system, house heating systems need to be modified to suit the geothermal heat source. This has been difficult to carry out on site, especially when upgrading current coal based house heating systems. A reason for potential problems is that the metering systems used and heating responsibility have been the responsibility of the heating company solely.

The main goals of geothermal heating systems are to utilize the temperature of the geothermal water to the greatest extend or to what is economically feasible in one step and to keep the systems simple. This can be effectively done with differential pressure control and variable flow through heat elements, controlled with thermostats.

House heating systems in the geothermal district heating system is one of the most critical component when using a geothermal heat source. If geothermal heat is used in unsuitable house heating systems, the utilization of the energy source will be poor and the resource will not be used responsibly.

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