Comprehensive Use of Geothermal Energy for Large Sports Complexes The Icelandic Approach

Thorkell Erlingsson, VST hf, Armula 4, IS-108 Reykjavik, Iceland
Thorleikur Jóhannesson, Fjarhitun hf, Borgartun 17, IS-105 Reykjavik, Iceland
Carine Chatenay, Fjarhitun hf, Borgartun 17, IS-105 Reykjavik, Iceland
Dr. Einar Tjörvi Elíasson, Enex hf, Grensasvegi 1, IS-108 Reykjavik, Iceland
Email: einart@enex.is

Abstract

The paper relates the ever increasing demands of youth organisations for large sport halls to be constructed to meet the training and other needs of today's modern competitive sports activities. In Iceland this trend has been very evident in the last decade and numerous large facilities of this type have been erected in small communities around the country. The use of geothermal energy for heating and tap water, in addition to the multiple activities developed in those sports facilities have made possible the running of those large sports complexes within the financial resources of small communities.

The paper goes on to give concrete examples of the design principles and operational characteristics of typical facilities of that kind.

The authors finally endeavour draw parallels with the situation prevailing in Beijing close to the location of the Olympic Games of 2008 and point out how the Icelandic approach could possibly be used there.

Keywords: geothermal, heating, ventilation, environment, savings, cascading, production

Introduction

This paper aims at introducing the Icelandic approach to the efficient use of the geothermal energy source for district heating in sports complexes.

A comparative study of a typical sports hall under Chinese and Icelandic climatic conditions brings to light the rather low energy needs of such buildings.

This leads the authors to consider ways of improving the energy use in a sports complex by planning district heating in cascade for winter and summer cases.

Moreover, one has to bear in mind that the way the energy can be used depends greatly on the way it is produced, i.e. flow and temperature range as well as production units and possible resource and system management. An introduction low temperature difference high flow and high temperature difference low flow approaches for production systems focuses on ways to improve use of energy.

But those are not the only parameters to be considered when planning geothermal district heating systems. The main parameter is the geothermal resource itself. This paper offers a scope of field parameters for both locations and points out local specifics that a district heating system has to take into account.

Definition of a sports complex

In the context of this paper, the concept of sports complex is understood to describe a small building complex that may comprise various units such as housing for athletes and visitors, sports halls, competition and leisure swimming pools, spas, health facilities and other leisure type units, which lend themselves to full utilisation of the geothermal resource through cascading.

Weather in China and in Iceland

The Icelandic standard specifies an indoor temperature of 20°C whereas the Chinese standard specifies it as 16 to 18°C. Common design temperatures are –7°C for Beijing and –15°C for Reykjavik.

The following figure compares the annual outdoor temperature curves for Beijing and Reykjavik based on data from 1991.

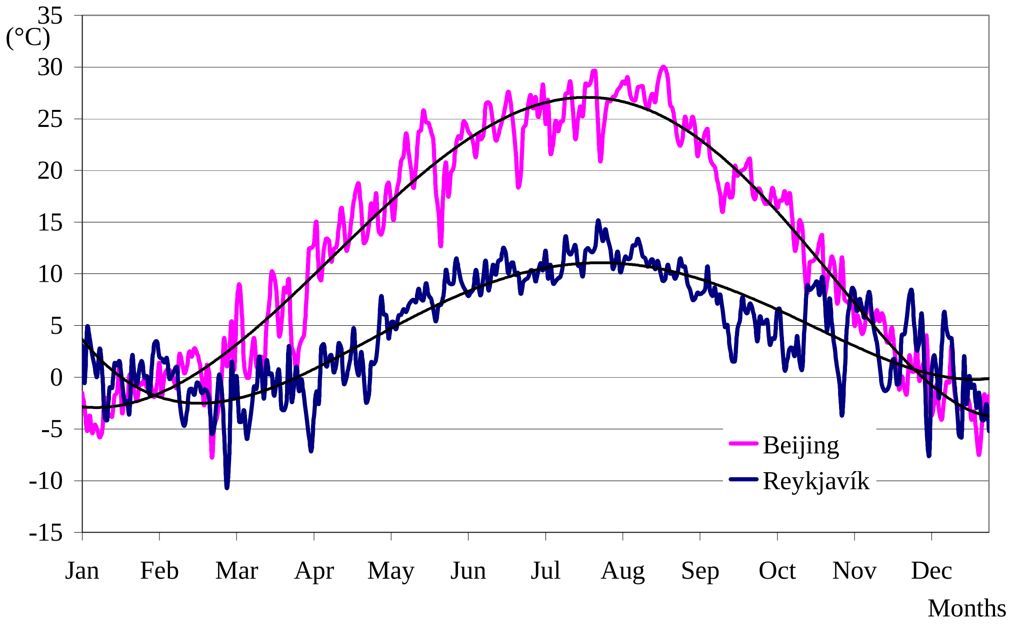

Fig 1.: Outdoor temperature data for Beijing and Reykjavik, 1991

It is evident from this diagram that Reykjavik's outdoor temperature is most of the time below 15°C. In Beijing, however, the outdoor temperature is below 15°C from October to April.

Case study: sports hall

Design premises. The sports hall studied in this paper is around 10.000 m^2 and can accommodate up to 1 000 spectators and players. It has facilities such as lockers, showers and toilets that are heated with a radiator system 80°C/40°C/20°C (supply /return /indoor temperatures). The sports hall itself is maintained at a temperature of 15°C by means of a ventilation system working with fresh air when there is a need for clean air and recirculation of the air when the building is not in use.

Peak-load. Preliminary calculations indicate a heating peak load requirement under design conditions (empty building) of 44 W/m^2 for Reykjavik and 33 W/m^2 for Beijing. This peak-load value is rather low due to the fact that such a building is maintained at lower temperature than normal buildings. Moreover, the ratio form/volume of such a building is efficient and bringing about lower heat losses.

Tap water. In assessing hot tap water demand, it is assumed that there are about 25 players training at the same time for a period of two hours. Therefore, it is reasonable to assume that 25 persons take a shower with a mix of 60°C hot water and cold water for about 10 minutes every two hours when the hall is open. According to Icelandic standards, the average need for hot tap water is thus about 3 W/m^2.

Cooling demand. Because the building can accommodate many people, and since the level of lighting requirement for such activities is rather high, it is necessary to take into account the cooling needs brought about by to these factors. When the building is in full use, people and lighting can together cause 30 W/m^2 heat generation. From this it can be inferred that there is almost no need for heating, except to satisfy the need for ventilation and clean air when there is a competition on in the building,.

Load duration curve. A model was built up based on the above premises. Dynamic simulations were made using BSIM, a software written by the Danish Building Research Institute. The resulting model is able to produce load duration curves for space heating, taking into account the sun load and the internal load. In addition, it provides an estimate of the expected energy consumption per square meter of building.

Presented below are the load duration curves for a model simulated for the Reykjavik (Iceland) situation and the Beijing (China) one.

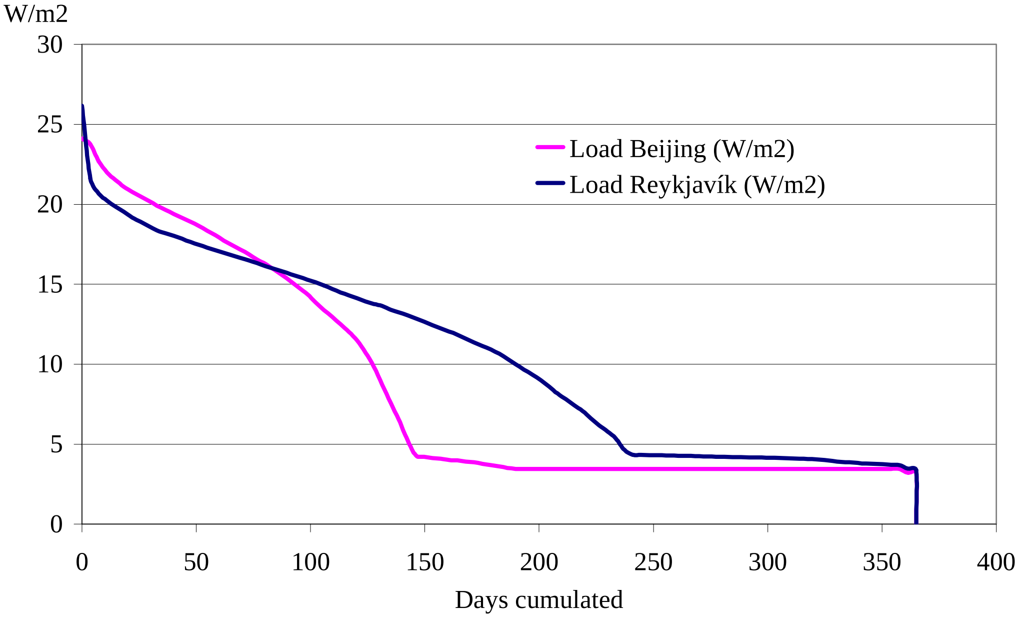

Fig.2 Load duration curves for sport hall in Reykjavik and Beijing

One can see that the heating period is about 240 days a year, i.e. 8 months for Reykjavik and 140 days a year or 4 to 5 months for Beijing. There is in addition a constant need of 3 W/m^2 for hot tap water over the year. The maximum load of 25 W/m^2 reached in the dynamic simulation is below the value calculated in the static model under design conditions. This is mainly due to the evolution of outdoor conditions, occupation and light load in the building.

Temperature duration curves. As shown on the following figure, the indoor conditions are still acceptable in winter time. Figure 3 below depicts how the outdoor/indoor temperature pair develops for each location.

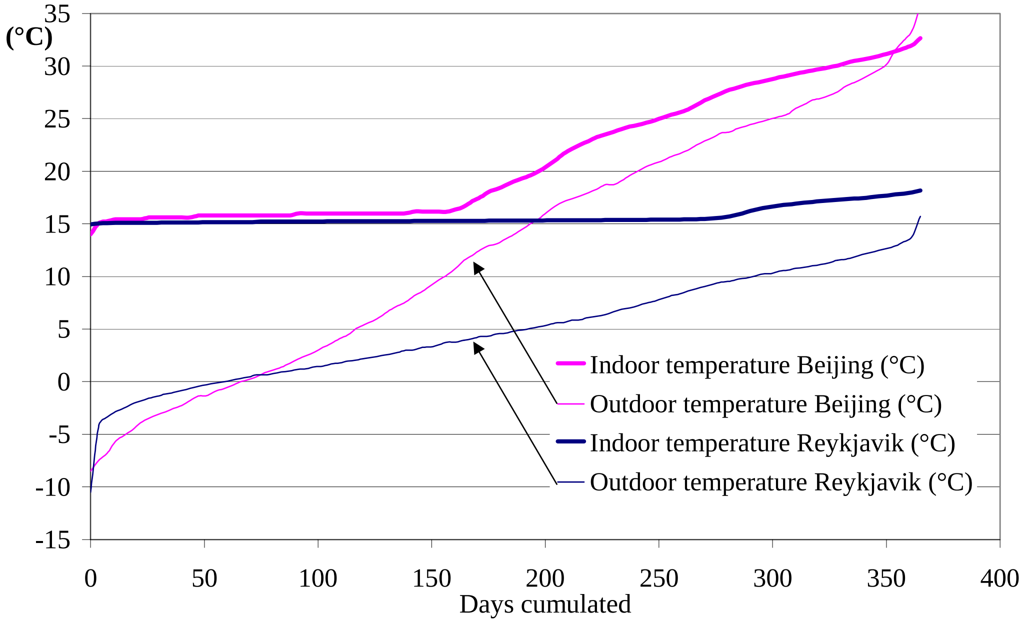

Fig.3 Temperature comparison for sport hall in Reykjavik and Beijing.

This figure reinforces the assessment regarding heating periods for such building in Beijing and Reykjavik. After the heating period, during which the system maintains an indoor temperature of 15°C, there is an intermediate period when there is no need for any special device to maintain an acceptable indoor temperature - see previous comment regarding free cooling in the chapter *Design premises*.

One can see in this figure that a sports complex located in Reykjavik has no need for special cooling devices whereas the same building located in Beijing would require cooling for about 100 days a year, or 3 to 4 months a year. It is therefore assumed that there is need for cooling when the indoor temperature exceeds 25°C and the outdoor temperature is above 20°C.

Solution to cooling demand. When public comes into the building, there is usually a need for clean air. If the outdoor temperature is below 20°C, the use of ventilation makes it possible to cool down the building, or at least to maintain it to a correct level of temperature, i.e. below 25°C. This clean air is taken directly from the outside without pre-heating and has two effects, namely cleaning the air and cooling the building.

This process is similar for Beijing and Reykjavik but reaches its limits in Beijing in summer time when the outside temperature is above 20°C, thus making it impossible to maintain the building cool without using an additional device. Cooling could in that case be achieved for instance by using geothermal fluid as a source for heat pumps.

Energy consumption. One has to keep in mind that climatic conditions in Reykjavík are more severe than in Beijing. *Table 1* summarizes the main power and energy data deduced from the simulations for Beijing and Reykjavik.

Table 1. Power and energy comparison for sport complex in Beijing and Reykjavik.

	Beijing	**Reykjavik**
Peak load power (W/m^2)	24,1	26,1
Average load (W/m^2)	8,6	10,5
Energy (kWh/m^2/year)	74,8	91,7

A similar simulation has also been made for a normal housing. It shows amongst other things that the yearly energy requirement for housing in Beijing is 30% higher than for sports halls i.e. about 100 kWh/m^2.

Operation of large sports facilities in Iceland

Multiple uses. To improve the financial viability of sports halls, Icelandic sports hall owners have in the design and construction of halls adapted the principle of making them suited to a whole range of other uses that ensure their full occupancy throughout the year.

Examples of uses are of course miscellaneous club sports, table tennis, badminton, basketball, handball, and football. It is as well used for competitive indoor sport training, e.g. athletics, running, jumping, dancing etc. Art exhibitions, trade exhibitions, amateur and professional theatre performances, musical concerts etc. also feature strongly.

Running cost. In Icelandic towns and communities outside the capital area which have constructed large sports complexes, the small population (<3.000 inhabitants) forces the owners, which are municipalities and/or local sports clubs, to adapt a special multipurpose operation for ensuring financial viability of the undertaking.

For a small community, the dominating unit in the operation, and therefore in the running costs of such a sports complex, is the sport hall itself. The size of sports halls is mainly dictated by the size and space demand of the sport that the hall is to be used for. Whether the number of spectators during competition is 1.000 or 10.000 does not critically affect the hall size.

The description above clearly shows that the stand-alone energy demand for heating of large sports halls is relatively small even though it is slightly higher when there is a fair sized cooling load present. This is therefore not the critical cost factor in the operation such buildings.

Nevertheless, it is important to ensure that district heating uses energy as efficiently as possible. The next part of this paper focuses on the Icelandic approach for efficient geothermal resources energy use within a district heating for a sports complex.

Cascade use of energy

When planning a district heating system, it is of great importance to focus on the efficient use of the energy. The goal is therefore to optimize heat recovery from geothermal fluid at the user end and at the production end.

Winter conditions. With medium temperature energy resource, the geothermal fluid enables hot water at about 70°C to be obtained for the district heating distribution system. When distributing this fluid to the users, via substations, it is possible to provide heating using radiators with supply 70°C and return temperature 40°C. This rather low temperature level of the return flow is still exploitable in floor heating systems down to 33-35°C. At the same time, domestic hot water at temperature 40-65°C is usually included in the distribution system. There are many reasons for including tap water in a geothermal district heating system, the main one being that it makes it possible to get the best out of the geothermal production wells throughout the year.

As a variant, it is also possible to consider providing water at 70°C to buildings for radiator system only and then to use the return water in other buildings for floor heating only, each building having the same type of domestic hot water system.

Similar systems could as well be used in large buildings opened to the public such as sports halls, concert theatres, auditorium as well as in office buildings or hotels. Since such buildings are designed to receive quite a lot of people, clean air is needed, and therefore part of the radiator system would be replaced by a ventilation system using a similar range of temperature.

Return water from the buildings previously described is at a level of 35°C and can still be used down to 20°C before it is re-injected into the geothermal reservoir. In the context of a sports complex, it is of interest to consider the case where rather a low indoor temperature of 15°C is required, as for example within a sports hall. A floor heating system with hot water from 35°C down to 20-25°C would be suitable for such buildings.

Sport halls and public buildings might sometimes need cooling even during cold periods. Cooling devices could be integrated into the ventilation system and designed to use energy as described in the summer condition case.

The following Figure 4 shows a typical winter case for cascade use in district heating.

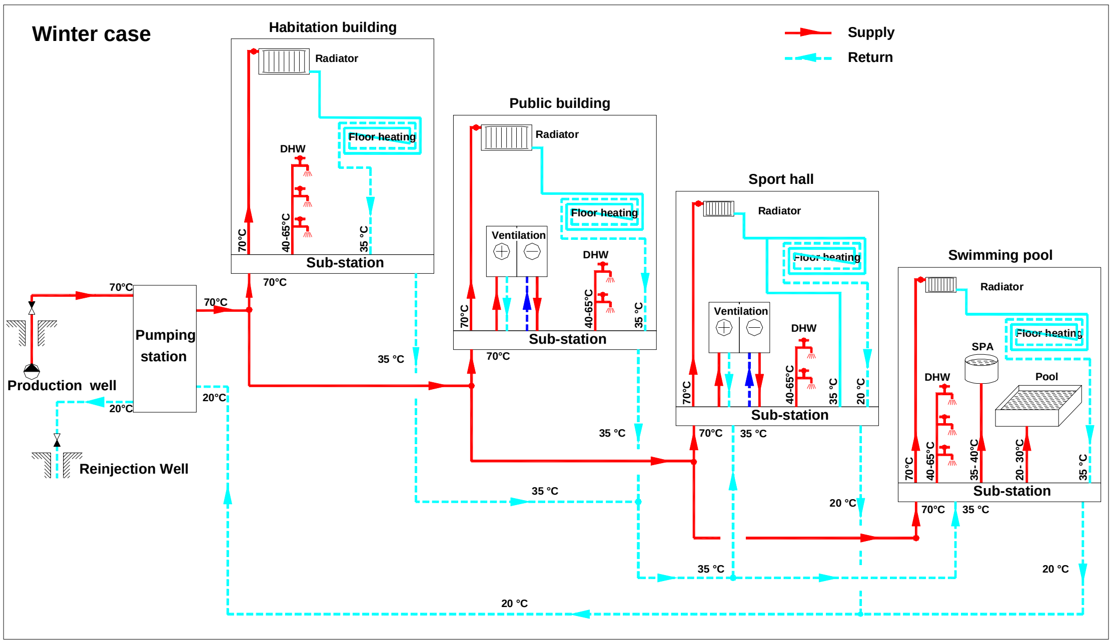

Fig 4. Winter case: cascade use in a sport complex for a medium geothermal field.

Summer conditions. During summer, buildings often need cooling due to high load from people and equipment. It is therefore possible to contemplate cooling those complexes using heat pumps in the substations.

Absorption heat pumps can provide cooling using a hot fluid. They are suitable for medium temperature energy fields and are moreover silent and very friendly to the environment.

It could be possible to use geothermal hot water available from the district heating system as a driving fluid to provide 10-17°C cold water using a cooling fluid of 16-25°C. This cooling fluid could be the cold ground water available in large quantities under the city at a temperature level of 16°C and used as a sink within the system.

It is also possible to consider using the outside air as a cooling source.

The following drawing (Figure 5) depicts a typical case for cascaded use in district heating for summer time use.

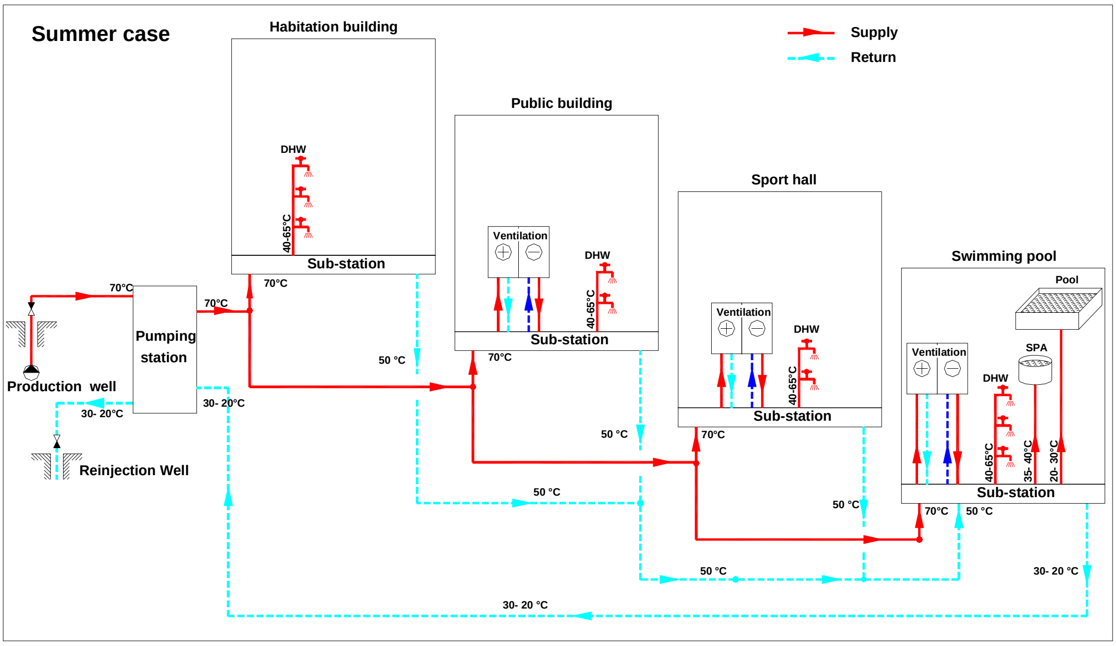

Fig 5. Summer case: cascade use in a sport complex for a medium geothermal field.

There are other uses suitable for this return fluid, such as in swimming pools, for snow-melting, greenhouses or fish farming. Those cases are quite typical and could easily be adapted to both the winter and summer case.

Optimal area. It is considered that the housing comprises apartments of about 120m^2 with 3.25 inhabitants in each. Then, an area with about 1.000 inhabitants would be required to run a sports hall of 10.000 m^2 using the return temperature in cascade.

The following table introduces the pre-requisite for optimisation of energy use.

Table 2. Requirements for efficient use of energy in a sport shall in Beijing

	Habitation building	Sport hall
T_{supply} (°C)	70	35
T_{return} (°C)	35	20
T_{indoor} (°C)	18	15
Need(W/m^2)	50	33 *
Area (m^2)	40.000	10.000

*: See chapter *Case study: Sports hall in Beijing*.

Production system

Low temperature difference high flow approach. A typical pumping station for district heating based on the low temperature difference high flow approach includes peak load boiler and an electrical heat pump. The hot water is distributed to the users at temperatures of 55-45°C for supply and return. In order to make the best use of the geothermal field, a re-injection temperature of 20°C is assumed.

In the actual system, there is no special emphasis on efficient cascaded use of energy within the district heating distribution system. Actually, such system is designed to provide hot water only for radiator system designed for 55°C/45°C/18°C (supply /return /indoor temperatures).

Figure 6 shows a typical pumping station scheme for this approach.

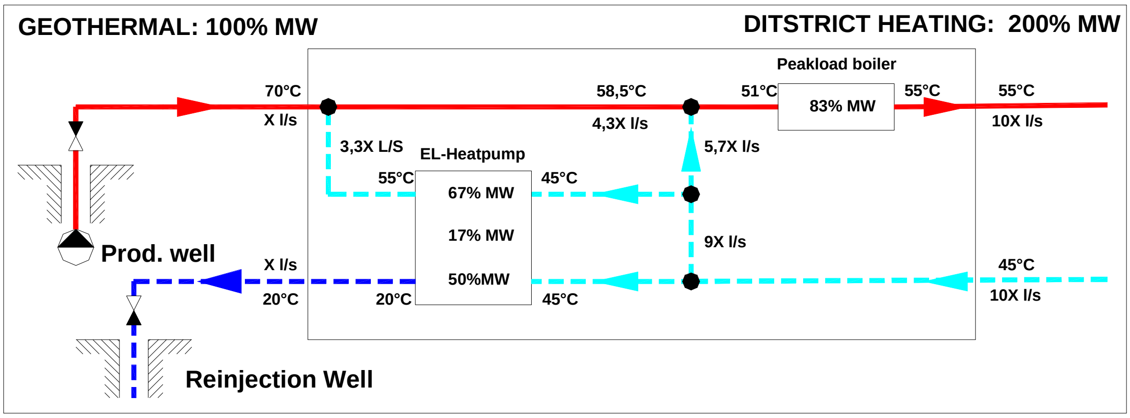

Fig.6 Pumping station scheme for low temperature difference high flow approach.

If power input from the geothermal field is 100%, then there is a power need for 83% from peak load boiler and 17% from heat pumps to provide the equivalent power of 200% to the users under peak load conditions. Such a district heating system requires 3 sources of energy: geothermal, electrical for the heat pump and gas for the peak load boiler.

Moreover, the flow required for distribution to the users is 10 times the original flow from the geothermal field.

The high temperature difference low flow approach. A typical pumping station for district heating exclusively used in Iceland only needs a peak load boiler in addition to the geothermal field. The hot water is distributed to the users with temperatures 70-20°C for supply and return.

Such system is designed to enable efficient use of the geothermal energy via a cascaded system. It is designed to provide hot water for radiator system, tap water, ventilation, floor heating and swimming pools as described in the chapter *Cascaded use of energy*.

Figure 7 shows a typical pumping station scheme for the high temperature low flow approach.

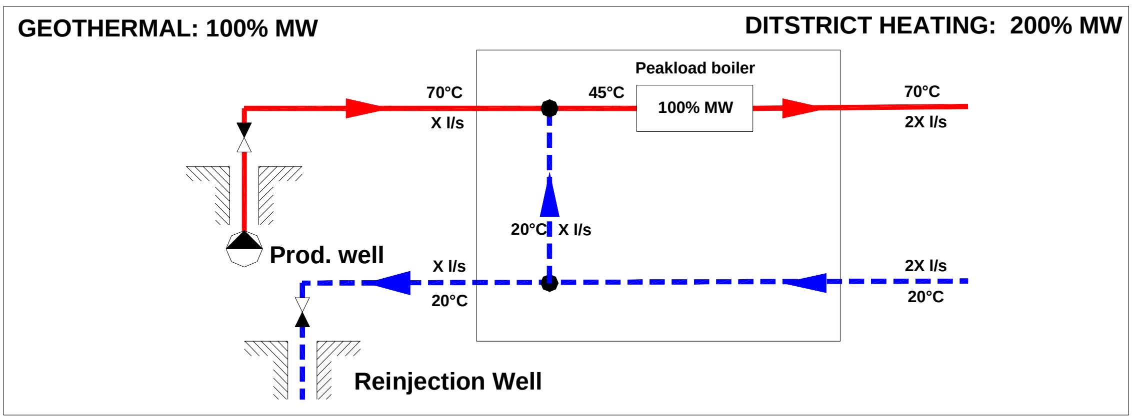

Fig 7. Pumping station scheme for high temperature difference low flow approach

If power input from the geothermal field is 100%, then there is a power need for 100% from a peak load boiler to provide the equivalent power of 200% under peak load conditions. Such a district heating system requires 2 sources of energy: geothermal and gas for the peak load boiler.

Moreover, the flow required for distribution to the users is 2 times the original flow from the geothermal field.

Comparison. One can see that the high temperature difference low flow case is a lot simpler and efficient than the low temperature high flow case is. Firstly, the flow for distribution to the users is 5 times less than the flow required in the low temperature difference high flow case. This difference is mainly due to a more efficient use of energy within the distribution system in the former approach, enabling a return temperature of 20°C that can be directly re-injected into the geothermal reservoir.

Moreover, the high temperature difference low flow approach only requires one exterior source in addition to geothermal energy, i.e. a gas peak boiler, when the low temperature difference high flow approach requires an extra electrical heat pump in order to decrease the geothermal fluid temperature to 20°C and to enable the recovery of some energy for the system.

In terms of project economy, the low temperature difference high flow is less efficient. It requires larger diameter pipes for the distribution system, the installation of a heat pump as an extra production device and larger capacity pumps for the distribution system.

Geothermal resource

It should be borne in mind, that any two geothermal resources, whether they be proximate or worlds apart, have never exactly the same characteristics as regards response to utilisation, composition and economic potential.

The most important aspect of any planned geothermal development is the geothermal resource, its energy capacity, overall characteristics and behaviour in response to the scheduled utilisation.

The Beijing geothermal resource

A very rough outline will be given here about the geothermal resource envisaged for the Olympic Games 2008 Complex. It is only presented here to enable a rough comparison with an Icelandic low temperature field typical for such applications.

General description. Beijing City is situated on top of a sedimentary basin where geothermal resources have been found at depth and utilised for a long time. Such resources exist because of a good permeability at 1-4 km depth in rock formations hot enough to heat water to exploitable temperatures.

The geothermal activity is believed to be sustained by major faults and fractures providing the main flow paths for circulating water whilst also acting as aquicludes. The water recharge to the basin is believed to be precipitation falling in the hills and mountains on the outskirts of the basin.

The Beijing basin has been divided into several (about ten) geothermal areas on the basis of geological and geothermal conditions. The best known areas are the Urban and Xiaotangshan areas, which have been utilised since the 70’s and 80’s, respectively

The yearly production from the Urban and Xiaotangshan fields corresponds to an average production of about 110 and 120 kg/s, respectively. This has resulted in a water level draw-down of the order of 1.5 m/year in the two fields. The reservoir rocks in the Urban and Xiaotangshan systems are mostly limestone and dolomite of the so-called Wumishan and Tieling formations.

The Shahe field. Part of the Beijing geothermal resource area is the Shahe geothermal field located in the NW-part of the city. The field has an area of about 100 km2 elongated NW-SE.

Utilisation aspects. The possible influence of production by other users outside the designated area, but inside the same Shahe field is extremely important in the context of utilising the Shahe reservoir for the Lishuiqiao project. This will indisputably constrain the maximum production from the reservoir and should therefore be taken into account.

Currently there is lack of reliable information on this use. It would be prudent and mutually beneficial to everyone concerned to set up common management of the reservoir to avoid its overexploitation and the resulting consequences.

Studies carried out by Chinese specialists (Quilong et al, 1986) and their Icelandic counterparts strongly indicate a limited resource that should be harnessed in carefully planned steps until better reservoir response data become available.

It is also considered of the utmost importance to proceed to full re-injection right from the start in the event of a serious permanent downdraught. Cold break-through may be avoided keeping future wells 1.0 to 1.5 km apart (Axelsson and Gunnlaugsson, 2000).

Typical Icelandic low temperature resource

The typical geological setting for low temperature geothermal reservoirs in Iceland is neo-volcanic where the hot geothermal fluid is mainly carried via near vertical fractures and faults.

The hot fluid is typically of potable quality, which makes its disposal to the surface or into the sea possible without re-injection back whence it came from. In certain areas, where the reservoir is limited in capacity and size will be needed within the next few years and re-injection tests are ongoing or planned to meet the eventuality of dangerous drawdown conditions. In one area re-injection is practised to mine heat from the surrounding formations whilst partially sustaining the pressure in the reservoir.

Typical water temperatures range between 70°C and 130°C and the fluid carrying reservoirs lie at 500 to 2000 m depth.

Prior to sustained withdrawal of fluid the static liquid levels in the production wells was commonly close to the surface or the wells artesian. After a few years of pumping from the wells, however, the water level has typically sunk quite low or between 50 and 200 metres. It is quite common also that the distance between the geothermal reservoir and the user location in Iceland is long or from 1 km to 20 km.

Icelandic pumping and fluid transportation technology is thus of necessity of a high standard as is the pumping control system.

Conclusions

The following points are worth considering in the planning of a district heating system for a sports complex:

(1). Sports hall buildings are a great asset for small communities because of their promotion of competitive sports activities and other associated socio-economic benefits. The fact that they don't require high levels of energy, compared to their size energy requirements and lower than for normal housing, facilitates their being run successfully as a part of a sports complex.

(2). Energy can be efficiently harnessed in a sports complex using a carefully planned user system including radiator system, tap water, ventilation, floor heating and swimming pools in cascade.

(3): A production system based on the high temperature difference low flow approach combined with cascaded use of energy, such as geothermal water combined with a boiler for peak load and supply/return temperatures of 70°C/20°C for the user is of the greatest interest. It enables the use of a simple pumping station with the smallest possible distribution pipes so reducing installation and running costs

(4): User side cooling can be considered using hot water from district heating as the primary fluid for absorption heat pumps. Ground water used as a sink or outside air could be used as a cooling fluid to produce chilled water.

(5): Geothermal fluid is to the greatest extent available all year long. It is of great interest for providing sports complexes with hot tap water and eventually cooling.

(6): Geothermal energy within any given reservoir is a limited resource that has to be carefully harnessed. To sustain future use, it is primordial to return the spent water back into the reservoir by re-injection.

(7): The Icelandic experience in these matters has been put to test and has proved its worth. Therefore, the extensive Icelandic experience in optimizing the energy use could be successfully applied to such a sports complex as the Olympic Village to be erected in Beijing.

(8): If planned as recommended above, the building and operation of the sport complex will achieve a healthy economic basis with attractive diversity, flexibility for the future and numerous socio-economic benefits.

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