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DESIGN OF SMALL GEOTHERMAL HEATING SYSTEMS AND POWER GENERATORS FOR RURAL CONSUMERS IN MONGOLIA

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ABSTRACT

Some of the rural consumers in Mongolia have no reliable electricity and heating. Geothermal energy is one of the renewable, clear and economical energy resources in the world. The usage of geothermal energy is developed in Iceland, and there is a long experience in its use for heating and electrical production. Geothermal energy offers the possibility to supply electricity and heating for consumers close to geothermal resources in Mongolia.

1. INTRODUCTION

According to geothermal studies, Mongolia has about 42 small hot springs. The geothermal resources in Mongolia are not widely used for heating and not for the supply of electricity. Now there is a good possibility to develop geothermal energy usage in Mongolia. The first stage of geothermal energy application should focus on heating and possibly production of electricity using known geothermal resources. The present study deals with this and is presented in three main parts:

1. Design of geothermal heating system for the Tsenher soum centre;
2. Feasibility study for electrification of the Shargaljuut area using geothermal water;
3. Possibility of Ger (nomadic family house) heating and electrification using geothermal water.

The hot springs in Shargaljuut and Tsenher have higher surface temperature and flow rate than other hot springs in Mongolia and the consumers are close to these hot springs. Hence, these hot springs are suitable for heating and electrical production for the nearest soum centres. The Kalina geothermal power scheme is suitable for a low-temperature geothermal field such as the Shargaljuut hot springs. The Shargaljuut hot springs could produce 790 kW of electricity using a Kalina power plant. The potential electricity production is more than enough for the present electrical demand of the Shargaljuut area which is 589.5 kW. Future investigations in this area may lead to more geothermal water flow rate, and temperatures higher than the present 92˚C. If the Shargaljuut area could produce 1-3 MW of electricity, supplying power to the Bayankhongor aimag centre would be a viable option for the future. The surface temperature in the Tsenher hot spring is 86˚C, so it can be used for suppling geothermal heating systems. The geothermal heating system uses hot water of about 80˚C. Geothermal water can also be used to supply heat and electricity for Gers using a geothermal floor heating system. In addition, a new technology thermoelectric generator could supply the small electric demands of a Ger.

2. DESIGN OF A GEOTHERMAL HEATING SYSTEM FOR THE TSENHER SOUM CENTRE IN MONGOLIA

The Tsenher soum has a potential as a rest area for transit guests and tourists. This soum centre is located 20 km from the Tsenher hot spring and 30 km from the aimag centre of Arkhangai in the central part of Mongolia, far from the capital city Ulaanbaatar. The Tsenher soum centre is located at the main road between the central and western parts of Mongolia. In the last year the Government of Mongolia decided to extend the transportation main road system, so here will be the transport connection between the western and eastern parts of Mongolia as well. This main road is named the Millennium Road. Presently, around 2500 inhabitants are living in the Tsenher soum centre. There is a good opportunity to transport hot water from the hot spring and supply heat to the buildings, as well as hot water for swimming pools for tourists and guests.

2.1 Weather conditions

The load of heating systems is closely related to the influences from the heat dynamics of the buildings. These influences can be divided into two groups: The influence from the outdoor climate and those originating from sources inside the buildings. The latter group consists of heat from light, machines, persons and radiators (including the control systems). The group involving the outdoor climate is composed of (arranged in assumed decreasing importance for heating systems): Air temperature, short wave radiation (the sun), wind speed and direction, and precipitation.

Air temperature and solar radiation are the most important factors affecting building dynamics. Hence weather data was obtained for these factors. The weather data was collected and calculated from the meteorological compilation of Arkhangai Aimag (Meteorological Institute of Mongolia, 1990) and the METEONORM V4.0 program (Remand and Lang, 1999). Meteorological data, except for solar radiation, is from the meteorological compilation of Arkhangai Aimag for the Tsenher soum, while the solar radiation is calculated by METEONORM. The annual mean wind speed is not so high, only 2.8 m/s, and gusts are 14-19 m/s, occurring on the average 13 times per year. Annual average precipitation is 332 mm. In the cold period between November and March precipitation is only 26.4 mm . The average monthly air temperature for the Tsenher soum is shown in Figure 1.

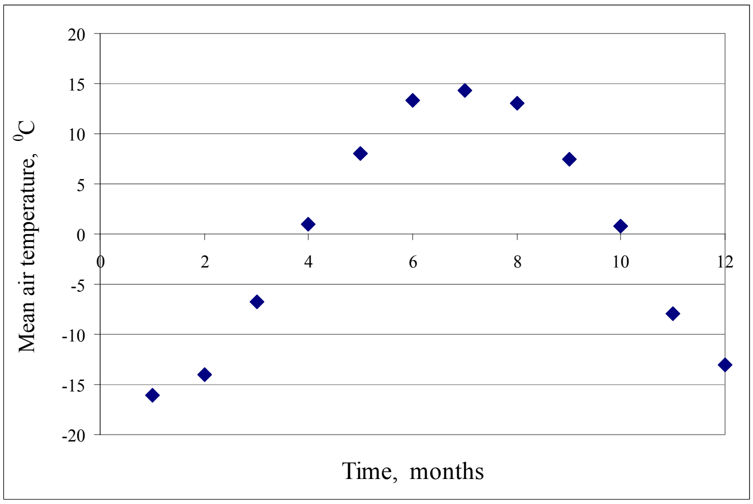

FIGURE 1: Monthly average air temperature for the Tsenher soum

The METEONORM V4.0 program includes data for all the meteorological stations worldwide for the year 1961-1990 (Remand and Lang, 1999). The weather data calculated for the Tsenher soum is shown in three figures. Firstly, the hourly data for outside air temperature (Figure 2). The result of the temperature profile shown in Figure 2 shows the lowest temperature of -31.6˚C in the Tsenher soum. Secondly, hourly values for annual global solar radiation on the horizontal surface (Figure 3). Finally, Figure 4 shows the outdoor temperature duration curve, and it shows that the outdoor temperature is below 20˚C for 8546 hours, almost the whole year.

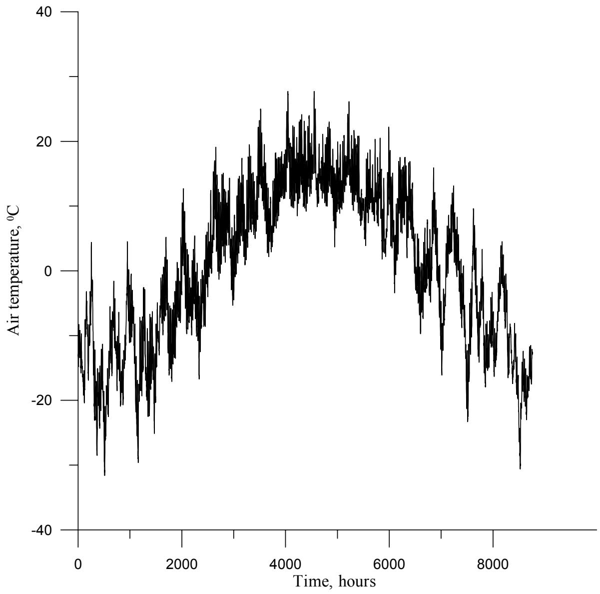

FIGURE 2: Air temperature profile for the Tsenher soum

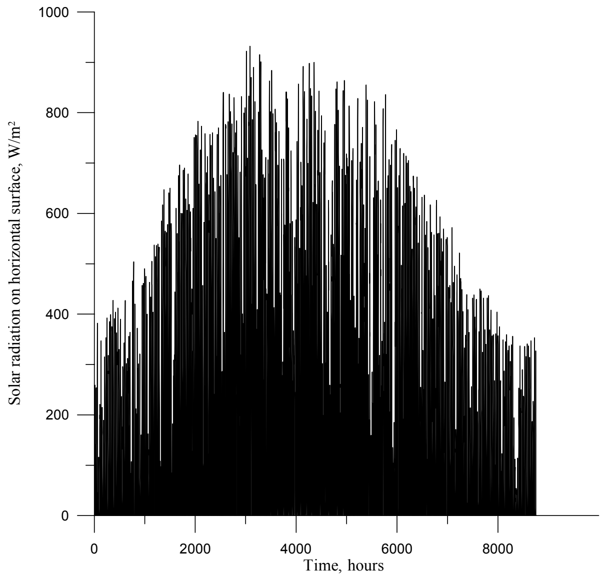

FIGURE 3: Global solar radiation profile for Tsenher soum

2.2 Geothermal heating systems models

In geothermal heating systems water is usually taken directly from low-temperature geothermal areas. Hot heating water is collected into storage tanks. From the storage tanks the water is then transmitted to the consumers to heat up the buildings and for use as tap water. Hot water temperature is about 80˚C and it cools down to about 40˚C in the radiators. Heat duty transferred to buildings is controlled by the mass flow of water (Nappa, 2000). Figure 5 shows a schematic of a geothermal heating network.

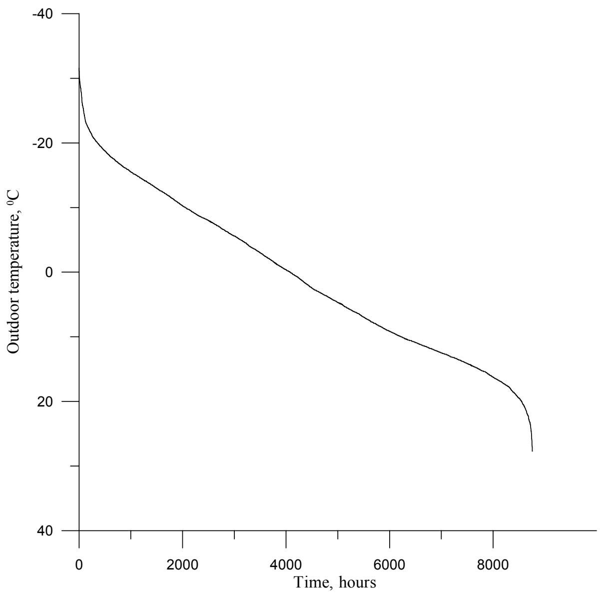

FIGURE 4: Outdoor air temperature duration curve

Radiator. The radiator is considered to be a heat exchanger between the heating water and the air of the room. The relative heat duty of a radiator can be written as:

$$\frac{Q}{Q_0} = \left(\frac{\Delta T_m}{\Delta T_{mo}}\right)^{3/4} \tag{1}$$

Logarithmic temperature difference ΔT_m is defined as:

$$\Delta T_m = \frac{(T_s - T_i) - (T_r - T_i)}{In\left(\frac{T_s - T_i}{T_r - T_i}\right)} = \frac{(T_s - T_r)}{In\left(\frac{T_s - T_i}{T_r - T_i}\right)} \tag{2}$$

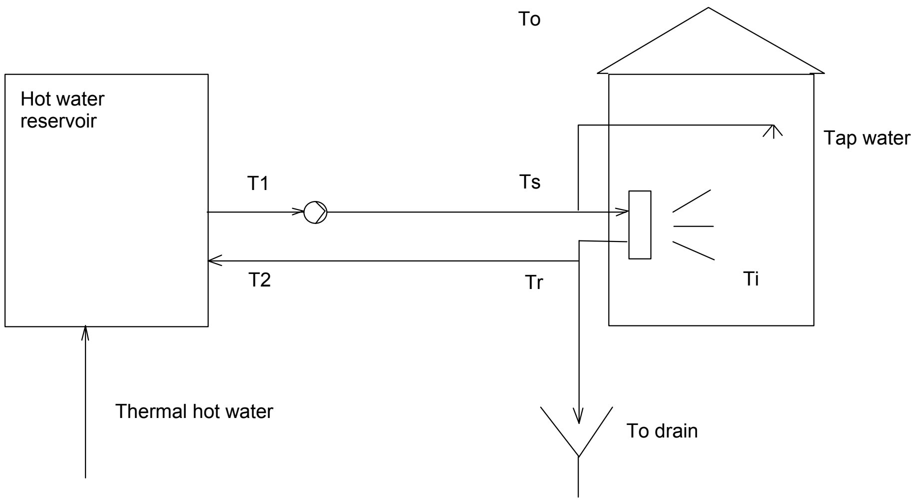

FIGURE 5: Simple model of a geothermal heating network

Inserting Equation 2 into Equation 1, it becomes:

$$\frac{Q}{Q_0} = \left(\frac{(T_s - T_r)}{In\left(\frac{T_s - T_i}{T_r - T_i}\right)} \frac{In\left(\frac{T_{s0} - T_{i0}}{T_{r0} - T_{i0}}\right)}{(T_{s0} - T_{r0})} \right)^{3/4} \tag{3}$$

Water heat duty. The heat duty, which the heating water gives away, when going through the radiators is:

$$Q = c_p m (T_s - T_r) \tag{4}$$

Relative heat duty can be calculated on the water side:

$$\frac{Q}{Q_0} = \frac{m}{m_0} \frac{T_s - T_r}{T_{s0} - T_{r0}} \tag{5}$$

Building heat loss. Heat loss from the buildings can be defined as:

$$Q_{loss} = k_l (T_i - T_0) \tag{6}$$

where the building heat loss factor k_l is taken as a constant.

Relative heat loss is obtained as:

$$\frac{Q_{loss}}{Q_{loss0}} = \frac{T_i - T_o}{T_{i0} - T_{o0}} \tag{7}$$

Pipe heat loss. Some heat loss will be in the pipe connecting the pumping station and the buildings to be heated. The amount of the loss can be calculated by using the pipe heat transmission effectiveness parameter. The transmission effectiveness τ is defined by the following equation (Valdimarsson, 1993):

$$\tau = \frac{T_s - T_g}{T_l - T_g} = e^{\frac{U_p}{mc_p}} \tag{8}$$

The reference value, τ, can be calculated from the reference flow conditions:

$$\tau_0 = \frac{T_{s0} - T_g}{T_{l0} - T_g} = e^{\frac{U_p}{m_0 c_p}} \tag{9}$$

The parameters U_p and C_p are assumed to be constant all over the system.

Combining Equations 8 and 9 the transmission effectiveness can be obtained as:

$$\tau = \tau_0^{\frac{m_0}{m}} \tag{10}$$

Combining Equations 8 and 10, the supply temperature to the house can then be calculated as:

$$T_s = T_g + (T_1 - T_g)\tau = T_g + (T_1 - T_s)\tau_0^{\frac{m_0}{m}} \tag{11}$$

If the heating network circulates water, the return temperature at the pumping station is obtained from Equation 12.

$$T_2 = T_g + (T_r - T_g)\tau = T_g + (T_r - T_s)\tau_0^{\frac{m_0}{m}} \tag{12}$$

Building energy storage. When the heating for the building is turned off, the building does not cool down immediately. The building has heat capacity and it stores energy. The building energy storage model is:

$$\frac{\partial T}{\partial t} = \frac{1}{C} Q_{net} = \frac{1}{C}(Q_{\sup p} - Q_{loss}) = \frac{1}{C}(m \cdot c_p \cdot (T_s - T_r) - k_l \cdot (T_i - T_0)) \tag{13}$$

All time derivatives are set equal to zero in the steady-state model.

Steady-state approach. When the heating systems are assumed to be in steady-state, no heat is accumulated in the buildings. Return temperature can then be calculated by combining Equations 3 and 7.

$$\frac{Q}{Q_0} = \left(\frac{(T_s - T_r)}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} \frac{\ln\left(\frac{T_{s0} - T_{i0}}{T_{r0} - T_{i0}}\right)}{(T_{s0} - T_{r0})} \right)^{3/4} = \left[\frac{T_i - T_o}{T_{io} - T_{o0}} \right] \tag{14}$$

From Equation 14, T_r can be calculated with iteration. The fastest convergence of a fixed point iteration is obtained, when solved for T_r, found inside the logarithm, (Valdimarsson, 1993). The equation for the n+1 iteration value is then

$$T_{r,n+1} = (T_s - T_i) \cdot e^{-z} + T_i \tag{15}$$

where z is

$$z = \frac{T_s - T_{r,n}}{T_{s0} - T_{r0}} = \ln\left[\frac{T_{s0} - T_{i0}}{T_{r0} - T_{i0}}\right] \cdot \left(\frac{T_{i0} - T_{o0}}{T_i - T_o}\right)^{4/3}$$

When outdoor temperature data is given, T_i is assumed to be constant and supply temperature is known, then $T_{r,n+1}$ can be found iteratively from Equation 15.

In steady-state, the heat loss from the building is the same as the heat supplied:

$$Q_{\sup p} = Q_{loss} \tag{16}$$

$$mC_p(T_s - T_r) = k_1(T_i - T_o) \tag{17}$$

Mass flow is obtained directly from Equation 17.

$$m = \frac{k_1(T_i - T_o)}{C_p(T_s - T_r)} \tag{18}$$

The factor k_i can be calculated from the reference conditions:

$$k_1 = \frac{m_o c_p (T_{s0} - T_{r0})}{(T_{i0} - T_{o0})} \tag{19}$$

2.3 Geothermal heating system equipment

This chapter provides an overview of the various components that are used in most geothermal direct-use projects and is mainly based on Lund (1996). Four main types of equipment are described in more detail: well pumps, piping, heat exchangers and space heating equipment. Standard equipment is used in most direct-use projects, provided allowances are made for the nature of geothermal water and steam. Temperature is an important consideration; so is water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. In many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal water, except perhaps the lowest temperature water. Care should be taken to prevent atmospheric oxygen from entering district heating water; for example, by proper design of storage tanks. The isolation of geothermal water by installing a heat exchanger may also solve this and similar water quality derived problems. In this case, a clean secondary fluid is then circulated through the user side of the system as shown in Figure 6.

The primary components of most low-temperature direct-use systems are downhole and circulation pumps, transmission and distribution pipelines, peaking or back-up plants, and various forms of heat extraction equipment (Figure 6). Fluid disposal is either surface or subsurface (injection). A peaking system may be necessary to meet maximum load. This can be done by increasing the water temperature or by providing tank storage (such as is done in most of the Icelandic district heating systems). Both options mean that fewer wells need to be drilled. When the geothermal water temperature is low (below 50˚C), heat pumps are often used. The equipment used in direct-use projects represents several units of operations. The major units will now be described in the same order as seen by geothermal water produced for district heating.

2.3.1 Downhole pumps

Unless the well is artesian, downhole pumps are needed, especially in large-scale direct utilization systems. Downhole pumps may be installed not only to lift fluid to the surface, but also to prevent the release of gas and the resultant scale formation. The two most common types are: lineshaft pump systems and submersible pump systems.

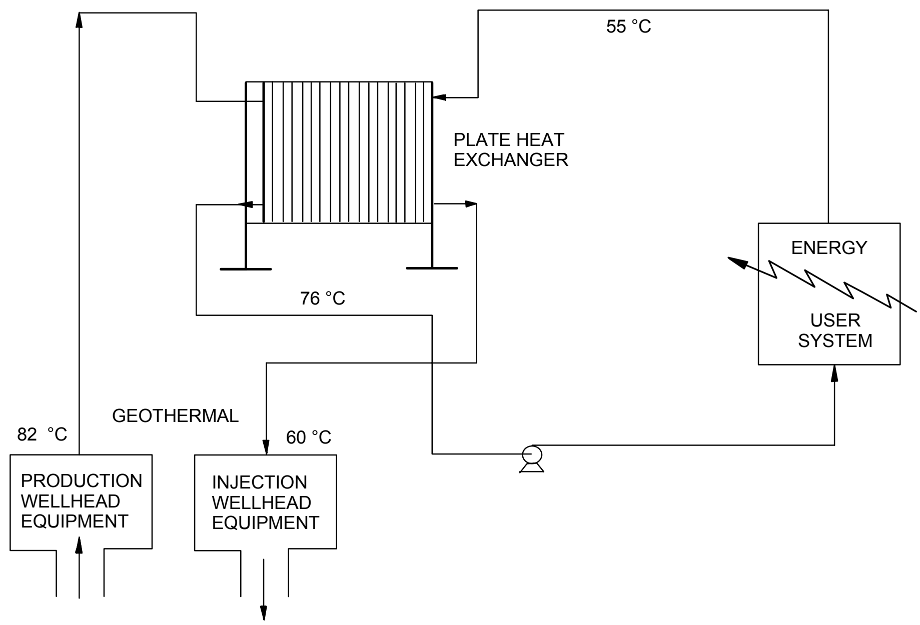

FIGURE 6: Geothermal direct utilization system using a heat exchanger

The lineshaft pump system (Figure 7a) consists of a multi-stage downhole centrifugal pump, a surface mounted motor and a long drive shaft assembly extending from the motor to the pump. Most are enclosed, with the shaft rotating within a lubrication column which is centred in the production tubing.

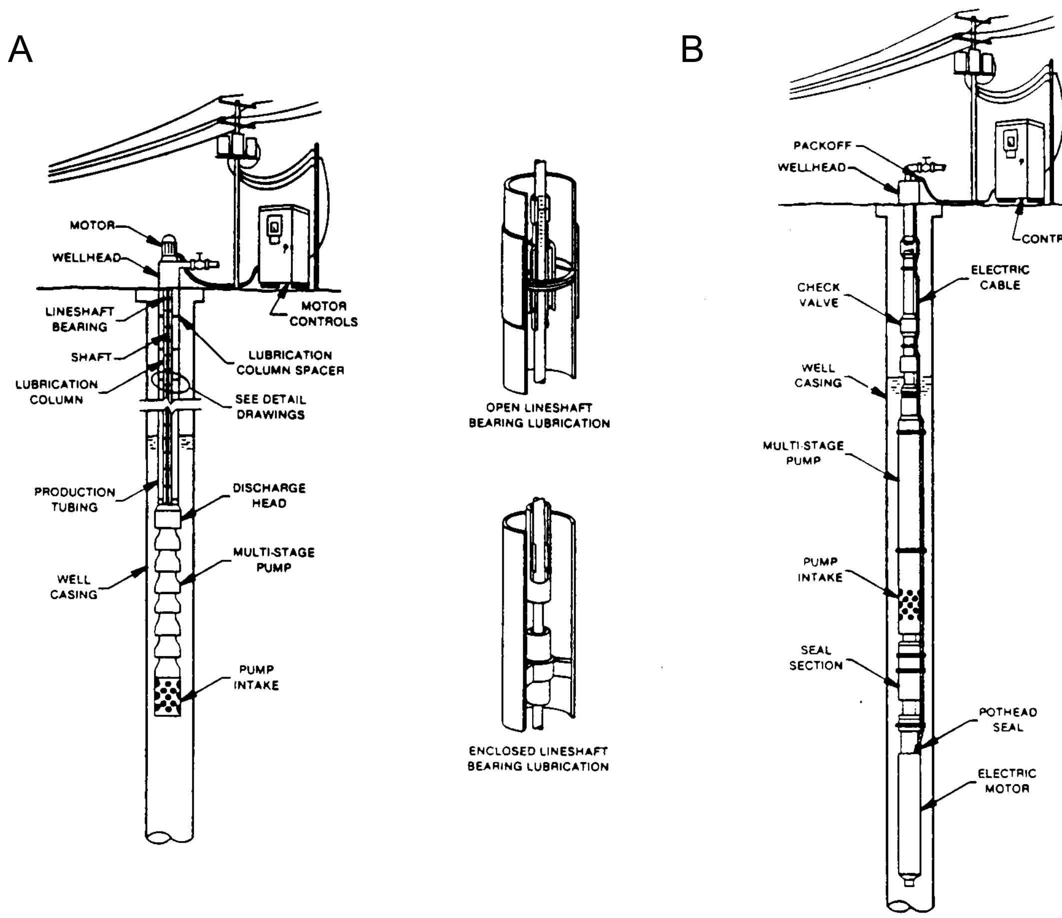

FIGURE 7: Downhole pumps (a) lineshaft pump details, and (b) submersible pump details

This assembly allows the bearings to be lubricated by oil, if the hot water does not provide adequate lubrication. A variable-speed drive set just below the motor on the surface can be used to regulate flow instead of just turning the pump on and off.

The electrical submersible pump system (Figure 7b) consists of a multi-stage downhole centrifugal pump, a downhole motor, a seal section (also called a protector) between the pump and motor, and electric cable extending from the motor to the surface electricity supply.

Both types of downhole pumps have been used for many years for cold water pumping and more recently in geothermal wells (lineshafts have been used on the Oregon Institute of Technology campus in 89°C water for 36 years) (Lund, 1996). If a lineshaft pump is used, special allowances must be made for the thermal expansion of various components and for oil lubrication of the bearings. The lineshaft pumps are preferred over the submersible pump in conventional geothermal applications for two main reasons: the lineshaft pump costs less, and it has a proven track record. However, for setting depths exceeding about 250 m, a submersible pump is required.

2.3.2 Piping

The fluid state in transmission lines of direct-use projects can be liquid water, steam vapour or a two-phase mixture. These pipelines carry fluids from the wellhead to either a site of application, or a steam-water separator. Thermal expansion of pipelines heated rapidly from ambient to geothermal fluid temperatures (which could vary from 50 to 200°C) causes stress that must be accommodated by careful engineering design.

The cost of transmission lines and the distribution networks in direct-use projects is significant. This is especially true when the geothermal resources is located at great distance from the main load centre; however, transmission distances for hot water of up to 60 km have proven economical in Akranes, Iceland (Georgsson et al., 1981), where asbestos cement pipes insulated with rock-wool and covered with earth were used successfully (see Figure 8 later).

Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks, especially if the fluid temperature is over 100°C. Other common types of piping material are fibreglass reinforced plastic (FRP) and asbestos cement (AC). The latter material, used widely in the past, cannot be used in many systems today due to environmental concerns; thus, it is no longer available in many locations. Polyvinyl chloride (PVC) piping is often used for the distribution network, and for un-insulated waste disposal lines where temperatures are well below 100°C. Conventional steel piping requires expansion provisions, either bellows arrangements or by loops. A typical piping installation would have fixed points and expansion points about every 100 m. In addition, the piping would have to be placed on rollers or slip plates between points. When hot water pipelines are buried, they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipes in many geothermal district heating systems. Although expensive (generally over $300/m), tunnels and trenches have the advantage of easing future expansion, providing access for maintenance, and a corridor for other utilities such as domestic water, waste water, electrical cables, phone lines, etc.

Supply and distribution systems can consist of either a single-pipe or a two-pipe system. The single-pipe is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is recirculated so the fluid and residual heat are conserved. A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir.

The quantity of thermal insulation of transmission lines and distribution networks will depend on many factors. In addition to minimizing the heat loss of the fluid, the insulation must be waterproof and water tight. Moisture can destroy the value of any thermal insulation, and cause rapid external corrosion. Aboveground and overhead pipeline installations can be considered in special cases. Considerable insulation is achieved by burying hot water pipelines. For example, burying bare steel pipe results in a reduction in heat loss of about one-third as compared to aboveground in still air. If the soil around the buried pipe can be kept dry, then the insulation value can be retained. Carbon steel piping can be insulated with polyurethane foam, rock wool or fibreglass. Belowground, such pipes should be protected with a polyvinyl (PVC) jacket; aboveground, aluminum can be used. Generally 2.5 to 10 cm of insulation are adequate. In two-pipe systems, the supply and return lines are usually insulated; whereas, in single-pass systems, only the supply line is insulated.

At flowing conditions, the temperature loss in insulated pipelines is in the range of 0.1-1°C/km, but in uninsulated pipes, the loss is 2-5°C/km for a approximately 5-15 l/s flow in a 15 cm diameter pipe. It is less for larger diameter pipes and for higher flow rates. As an example, less than 2°C loss is experienced in the aboveground 29 km long and 80-90 cm wide steel pipeline with 10 cm of rock wool insulation that runs from Nesjavellir to Reykjavik in Iceland. The flow rate is around 560 l/s and takes seven hours to cover the distance. Un-insulated pipe costs about half of insulated pipe and thus, is used where temperature loss is not critical. Pipe material does not have a significant effect on heat loss; however, the flow rate does. At low flow rates (off peak), the heat loss is higher than at greater flows.

Several examples of aboveground and buried pipeline installations are shown in Figure 8. Steel piping is shown in most cases; but FRP or PVC insulation can be used in low-temperature applications. Aboveground pipelines have been used extensively in Iceland, where excavation in lava rock is expensive and difficult; however, in the USA, belowground installations are most common to protect the line from vandalism and to eliminate traffic barriers.

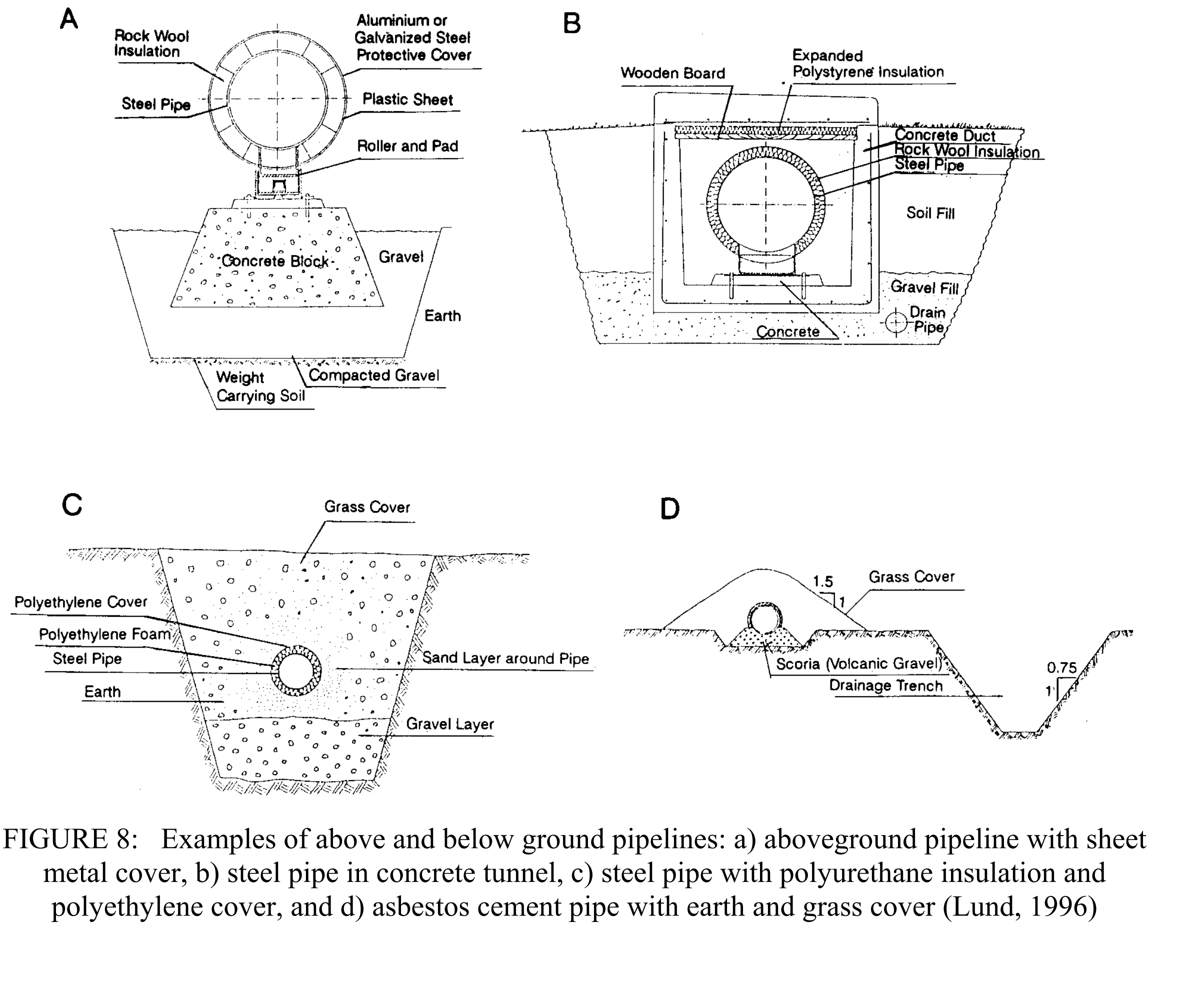

FIGURE 8: Examples of above and below ground pipelines: a) aboveground pipeline with sheet metal cover, b) steel pipe in concrete tunnel, c) steel pipe with polyurethane insulation and polyethylene cover, and d) asbestos cement pipe with earth and grass cover (Lund, 1996)

2.3.3 Heat exchangers

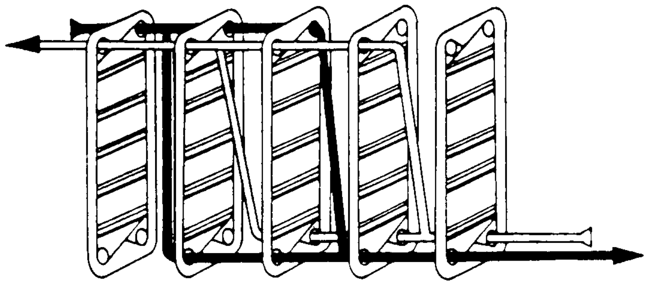

FIGURE 9: Plate heat exchanger (Lund, 1996)

The principal heat exchangers used in Examples of above and below ground pipelines: a) aboveground pipeline with sheet metal cover, b) steel pipe in concrete tunnel, c) steel pipe with polyurethane insulation and polyethylene cover, and d) asbestos cement pipe with earth and grass cover (Lund, 1996) geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods (Figure 9). The counter-current flow and high turbulence achieved in plate heat exchangers provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when additional load is added, and cost about 40% less. The plates are usually made of stainless steel; although, titanium is used when the fluids are especially corrosive. Plate heat exchangers are commonly used in geothermal heating situations worldwide.

Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size.

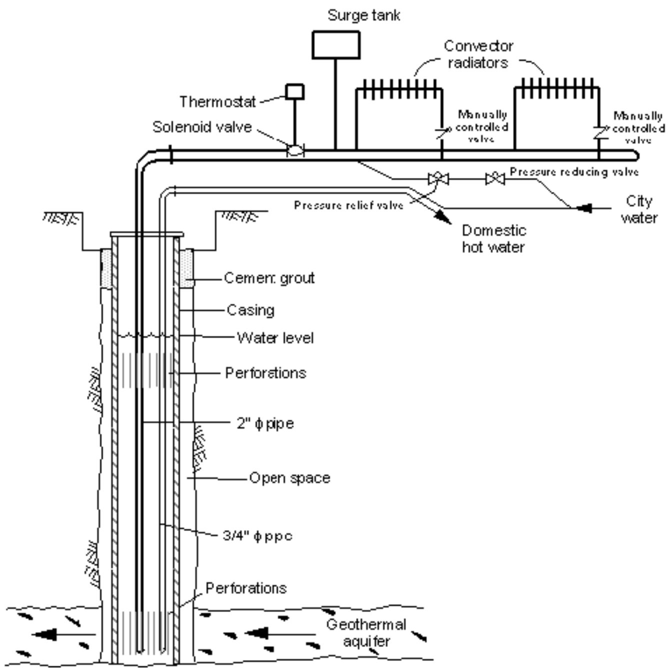

FIGURE 10: Downhole heat exchanger (typical of Klamath Falls, OR) (Lund, 1996)

Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads such as the heating of individual homes, a small apartment house or business. The exchanger consists of a system of pipes or tubes suspended in the well through which secondary water is pumped or allowed to circulate by natural convection (Figure 10). In order to obtain maximum output, the well must be designed to have an open annulus between the well bore and casing, and perforations above and below the heat exchanger surface. Natural convection circulates the water down inside the casing, through the lower perforations, up into the annulus, and back inside the casing through the upper perforations (Culver and Reistad, 1978). The use of a separate pipe or promotor has proven successful in older wells in New Zealand to increase the vertical circulation (Dunstall and Freeston, 1990).

2.3.4 Convectors

Heating of individual rooms and buildings is achieved by passing geothermal water (or a heated secondary fluid) through heat convectors (or emitters) located in each room. The method is similar to that used in conventional space heating systems. Three major types of heat convectors are used for space heating: 1) forced air, 2) natural air flow using hot water or finned tube radiators, and 3) radiant panels (Figure 11). All three can be adapted directly to geothermal energy or converted by retrofitting existing systems.

2.4 Consumer description

Population groups in Mongolia. The total population of Mongolia is 2,650,952 (est. July 2000). The annual population growth rate is now 1.45%. The size of the country 1,564,619 km^2, 52% of the population lives in the capital city Ulaanbaatar and aimag centres, 48% of population lives in rural areas. There are 21 aimag centres and 314 soums.

Building types. The most common building material until in the 1970's was brick. Then concrete assembled building took over as the most common building type. The overall heat transfer coefficient *U* for a concrete assembled building is equal to 1 W/m^2 °C. Overall heat transfer coefficient *U* of buildings built before 1970 is the same as the European standard. A very low percentage of the city population lives in private buildings. The walls of a building are usually made of wood and a mixture of sand and cement. A wall could be made of a number of materials in a number of layers. Usually it is constructed of 15-20 cm of wood, and a mixture of sand and cement on both sides of the wooden wall. On the inside, the wall is covered by a plaster plate. The thickness of the plaster plate is 5-8 mm.

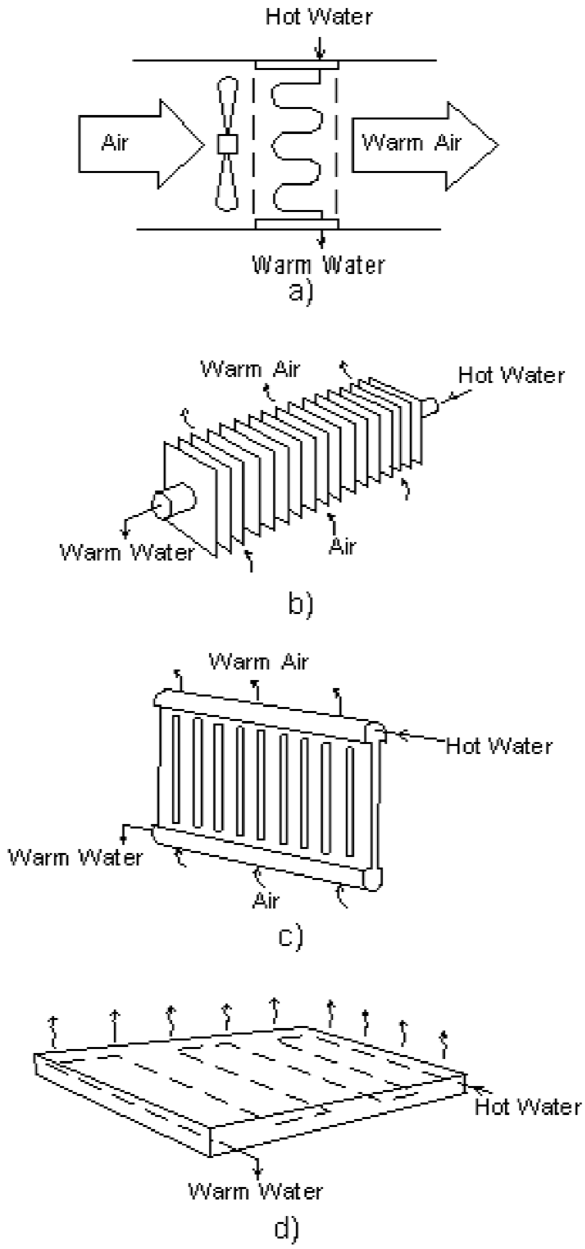

FIGURE 11: Convectors: a) forced air, b) material convection (finned tube), c) natural convection (radiator), and d) floor panel

Present heating systems in the capital city and aimag centres. District heating is a common heating system in the cities of Mongolia. The capital city Ulaanbaatar and the industrial aimag centres, Erdenet, Darkhan, Choibalsan and Dalanzadgad have a thermal power plant supplying heat in the winter season. The water supply temperature is 70-150°C, and the return temperature is 70-90°C. A temperature control system is placed in the central heating plant. Changes in supply temperature depend on the weather conditions. The heating season in Mongolia starts 15th October and ends on 15th April, when the heating system is turned off. The radiators used to heat buildings are made of cast iron.

Present heating system and heat request in soum centres. The installed capacity of the heating systems in the soum centres is 0.8-3.0 MW, and estimated peak heat load is 0.4-2.0 MW. The heating station is located in the central part of the soum centre. Hot water is supplied from a steam boiler to the consumers by underground insulated pipelines. All consumers have heating control systems.

The total population of the Tsenher soum centre is 2500. The main buildings in the soum centre are the school house, dormitory, hospital and administration buildings. There are 800 pupils in the school. The heat loss from this building is 300-450 kW. About 70 pupils are living in the dormitory, with a heat loss of 100-150 kW. The hospital is for only 15 persons, and the heat loss of the building is 100 kW.

Type of heating equipment. The building radiators used in Mongolia are the same as the Russian standard radiator (GOST 8690-75). Technical characterization and a figure of the sectional cast-iron radiator is shown in Table 1 and in Figure 12.

TABLE 1: Technical characterization of heating equipment, sectional cast-iron radiators (GOST 8690-75)

Type of heating equipment	**Size of heating surface, A [m²]**	**Nominal heat flow, Q_{nhnf}, [W (kkal/h)]**	**Structural size, [mm]**				**Weight [kg]**
			T	**t1**	**t2**	**t3**	
MC-140-108	0.244	185(159)	500	588	140	108	7.62
MC-140-98	0.240	174(150)	500	588	140	98	7.4
M-140 AO	0.299	178(153)	500	582	140	96	8.45
M-140A	0.254	164(141)	500	582	140	96	7.8
M-90	0.2	140(120)	500	582	90	96	6.15
MC-90-108	0.187	150(129)	500	588	90	108	6.15

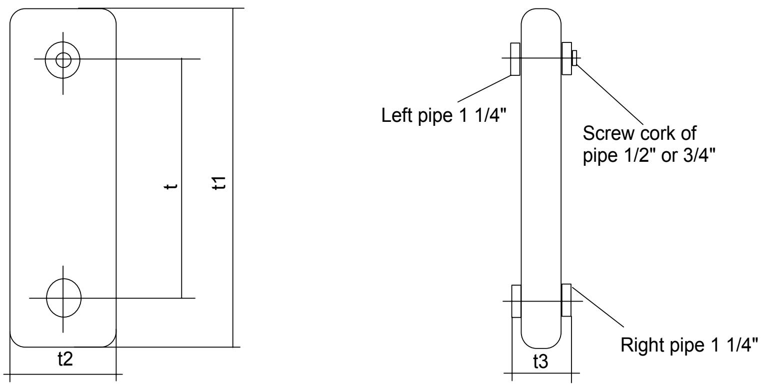

FIGURE 12: Sectional cast-iron radiator

2.5 Design of a geothermal heating system for the Tsenher soum centre

Tsenher soum is at an elevation of 1600 m above sea level, the location is 47˚26' latitude and 101˚45' longitude. The Tsenher hot spring is located 15 km southwest of Tsenher soum centre, at location 47˚20' latitude and 101˚39' longitude, at an elevation 1860 m above sea level. Figure 13 illustrates a topographical map of this area, and clearly shows the elevation difference between these two places, with the Tsenher hot spring lying 260 m higher than the Tsenher soum.

2.5.1 Transmission piping

Piping is very important equipment for geothermal heating systems. Until 1998 it was common to use Asbestos Cement (AC) pipes. Concern about the carcinogenic nature of asbestos has resulted in an impact on the availability of AC pipes (Lund, et al., 1998). Ductile iron pipelines are suitable for buried transmission piping system. Ductile iron piping is cost competitive with asbestos cement material. In addition, it is commonly in use in water supply systems, which results in wider familiarity with its installation practices. However, ductile iron pipe is the heaviest material of those covered here. As a result, additional handling costs are to be expected in comparison to the lighter weight materials. Table 2 outlines costs for installation of pre-insulated distribution piping. Included are 11 cost categories: saw cutting of existing pavement, removal of pavement, hauling of pipe (local), trenching and backfill, pipe material, bedding, installation and connection of piping, valves, fitting, traffic control, and paving.

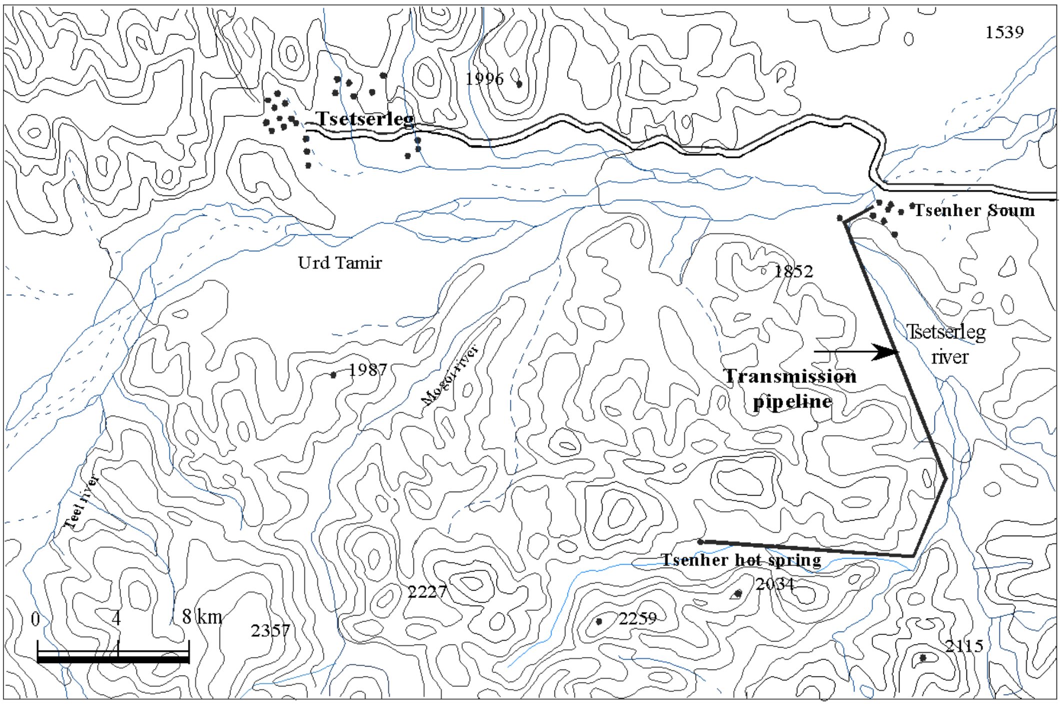

FIGURE 13: Topographic map for Tsenher soum and vicinity

TABLE 2: Cost summary ($/m) of pre-insulated ductile iron distribution piping (DUC – Ductile iron (carrier), PVC - Polyvinyl chloride (jacket))

Carrier/Jacket	Size (m)	Cost ($/m)
DUC/PVC	0.10	154.89

Several examples of aboveground and buried pipeline installations are shown in Figure 8. Buried or aboveground pipe installations are options in the system design that require evaluation. Aboveground installations are more subject to damage and vandalism. Buried piping systems, the most common type of transmission pipe line, are aesthetically more pleasing than aboveground installations and are deemed far superior from the standpoint of immunity to accidental or intentional damage. Therefore, the buried pipe installation of transmission piping is chosen, see Figure 8c.

2.5.2 Pressure drop in transmission piping

The pressure drop, Δp, may be expressed in terms of a friction factor, f (Holman, 1989):

$$\Delta p = f \cdot \frac{L}{D} \rho \frac{V^2}{2} \tag{20}$$

where f = Friction factor;
L = Length of transmission pipe (m);
D = Pipe inner diameter (m);
ρ = Density of geothermal water (kg/m^3);
V = Velocity (m/s) of geothermal water in the piping, $V = \frac{4 \cdot Q}{\pi * D^2}$

The modified Colebrook equation relates the friction factor f to the pipe inner surface roughness ε, the pipe inner diameter *D,* and Reynolds number *Re*:

$$f = \frac{1.325}{\left(\ln\left(\frac{\varepsilon}{3,7D} + 5,74 \cdot Re^{-0.9}\right)\right)^2} \tag{21}$$

We can write the Reynolds number

$$Re = D \cdot \frac{V}{\nu} \tag{22}$$

and the kinematic viscosity can be calculated from the dynamic viscosity by:

$$\nu = \frac{\mu}{\rho} \tag{23}$$

The relative roughness ε / D in 4" diameter ductile iron piping equals 0.00045. Hence the friction factor f equals 0.016.

The temperature of the geothermal water in the Tsenher hot spring is 86˚C, and surface flowrate is 10 kg/s. The properties of water at 86˚C are

ρ	= 970.2 kg/m^3	k	= 0.673 W/m˚C
μ	= 3.47 × 10^{-4} kg/m s	Pr	= 2.16
C_p	= 4.195 kJ/kg˚C		

The properties of the transmission piping are:

L	= 20000 m,	D	= 0.1 m

Figure 13 shows the route of the geothermal water transmission piping between Tsenher geothermal field and Tsenher soum centre. The route of the transmission piping is along the valley of the river. The geothermal water can reach the consumers by gravity flow in the transmission pipe, as the altitude difference between these two places is 260 m. The calculated pressure drop equals 245600 Pa or 25 bar in 20 km length piping, which corresponds almost exactly to the altitude difference of 260 m.

2.5.3 Temperature drop in the transmission piping

The supply water temperature to the consumers can be calculated by the following equation:

$$T_s = T_0 + (T_w + T_o) \cdot \exp\left(\frac{-U_{\_pipe} \cdot L}{m \cdot C_p}\right) \tag{24}$$

The heat transfer coefficient U_p can be defined:

$$U_p = \frac{1}{R_{ins.} + R_{ground}} \tag{25}$$

where R_{ins} , R_{ground} are determined as follows:

$$R_{ins.} = \ln\left(\frac{\frac{r_o}{r_i}}{2\cdot\pi\cdot k_{ins.}}\right) \qquad R_{ground} = \ln\left(\frac{\frac{2\cdot D}{r_i}}{2\cdot\pi\cdot k_{ground}}\right) \tag{26}$$

where k_{ins} = Thermal conductivity of insulation material, for glass wool 0,038, W/m˚C, (Holman, 1989);
k_{ground} = Thermal conductivity of ground, 1 W/m˚C (Holman, 1989);
D = Buried depth of pipe to its centre (m);
r_i = Inside radius of transmission pipe (m);
r_o = Outside radius of transmission pipe (m).

Heat transfer coefficient U_p for 0.1 m diameter pre-insulated transmission pipeline is equal to 0.6255 W/m˚C. Equation 21 is used to calculate the supply temperature, T_s, of the water at design soil surface temperatures T_0 = –25˚C. Figure 14 shows supply water temperature as a function of the distance from the hot spring.

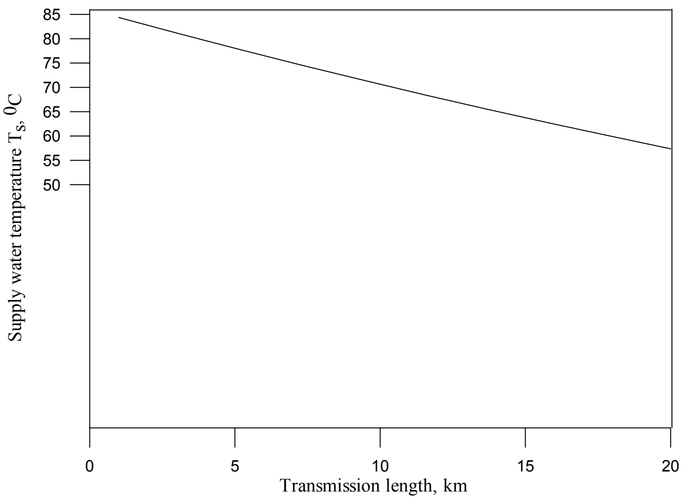

FIGURE 14: Temperature drop in hot water transmission line

2.5.4 Design of geothermal heating system for Tsenher soum centre

As mentioned in Chapter 2.4, the installed capacity of the heating system in the soum centre is 0.8-3.0 MW, and estimated peak heat load is 0.4-2.0 MW. It is summarized as follows: In the school building heat loss is 450 kW, the dormitory has heat loss of 150 kW and the hospital building has heat loss of 100 kW. The additional administration buildings, kindergarten building, and cultural centre buildings have a total heat loss of 200 kW. Therefore, the total heat required in the Tsenher soum centre is 900 kW.

2.5.5 Radiators

Installed radiator data is as mentioned above in Chapter 2.4

T_{s_inst} = 90˚C T_{r_inst} = 70˚C T_{i_inst} = 20˚C

The calculated geothermal supply water temperature is less than the design supply temperature for the existing radiators. Therefore, we must add radiator sections in order to increase the radiator size. It is easier to add radiator sections than to change the whole radiator system. Equation 22 defines how many sections we need.

$$increase = \left[\left(\frac{T_{s\_inst}-T_{r\_inst}}{\ln(T_{s\_inst}-T_{i\_inst})/(T_{r\_inst}-T_{i\_inst})}\right)\cdot\left(\frac{\ln(T_{s0}-T_{i0})/(T_{r0}-T_{i0})}{T_{s0}-T_{r0}}\right)\right]^{\frac{4}{3}} \tag{27}$$

where T_{s0} = Design supply water temperature in geothermal heating system, 80˚C;
T_{i0} = Design inside temperature in geothermal heating system equals T_{i_inst};
T_{r0} = Design return water temperature in geothermal heating system, 50˚C.

Radiator size increase calculated from Equation 27 is shown in Table 3 and Figure 15.

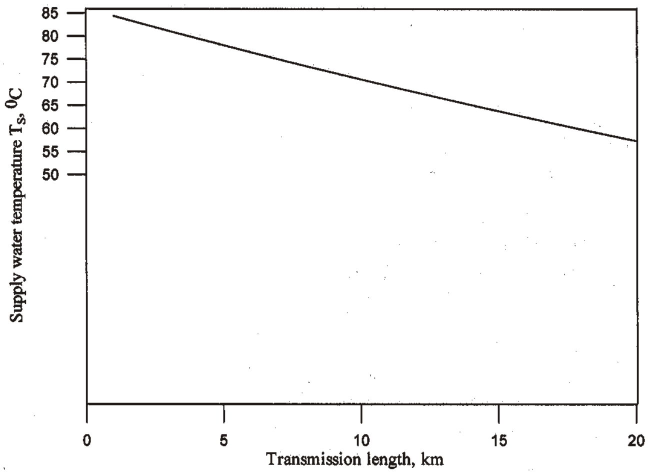

FIGURE 15: Relationship between T_s and radiator size increase

TABLE 3: Increase in radiator size

Increase in radiator size	Supply water temperature (˚C)
1.527	80
1.57	77.78
1.616	75.56
1.665	73.33
1.717	71.11
1.773	68.89
1.834	66.67
1.899	64.44
1.969	62.22
2.045	60

2.5.6 Supply and return water temperature calculation for geothermal heating systems

Above we have determined the design of the transmission piping and the radiator system for a geothermal heating system instead of a boiler heating system. Now we define the needed supply water temperature and geothermal water mass flow for the whole geothermal system in the Tsenher soum.

The return water temperature of the geothermal heating systems is calculated by the following equation:

$$\left(\frac{T_i - T_o}{T_{i0} - T_{o0}}\right) = \left(\frac{(T_s - T_r)}{\ln((T_s - T_i)/(T_r - T_i))} \cdot \frac{\ln((T_{s0} - T_{i0})/(T_{r0} - T_{i0}))}{(T_{s0} - T_{r0})}\right)^{\frac{4}{3}} \qquad (28)$$

where T_{i0} = Design inside temperature (boiler system), 20˚C;
T_{o0} = Design outside temperature (boiler system), -25˚C;
T_{s0} = Supply water temperature (boiler system), 90˚C;
T_{r0} = Return temperature (boiler system), 70˚C;
T_s = Design supply water temperature (geothermal system), 82.5˚C;
T_i = Design inside temperature (geothermal system), 20˚C;
T_o = Design outside temperature (geothermal system), -25˚C;
m_o = Mass flow (geothermal system), 1 l/s.

Equation 28 gives us the return water temperature T_r. We can find the mass flow in the geothermal heating systems by the following equation:

$$\frac{m}{m_o} \cdot \frac{T_s - T_r}{T_{s0} - T_{r0}} = \frac{T_i - T_o}{T_{i0} - T_{o0}} \qquad (29)$$

The calculation results are shown in Table 4 and Figures 16-18.

TABLE 4: Calculation results for T_o, T_s and m

Outside temperature (˚C)	**Supply temperature (˚C)**	**Mass flow, m (kg/s)**
-25	82.29	38.24
-21.11	80	22.56
-17.22	77.58	15.28
-13.33	75	11.07
-9.44	72.21	8.33
-5.56	69.17	6.40
-1.67	65.8	4.97
2.22	61.98	3.85
6.11	57.52	2.95
10	52.07	2.20

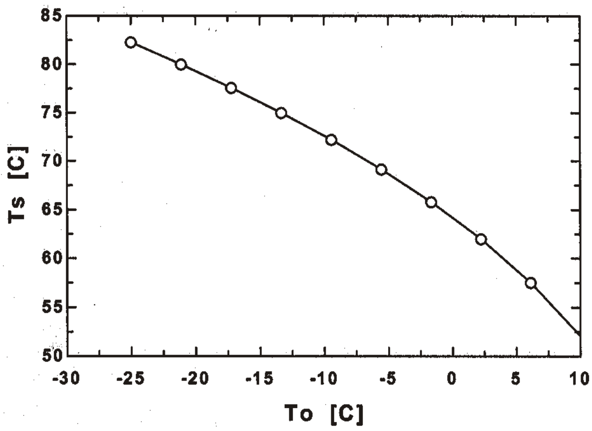

FIGURE 16: Relationship between T_s and T_0

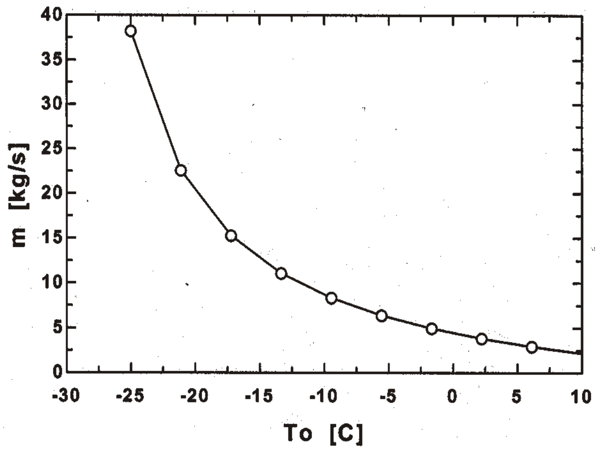

FIGURE 17: Relationship between m and T_0

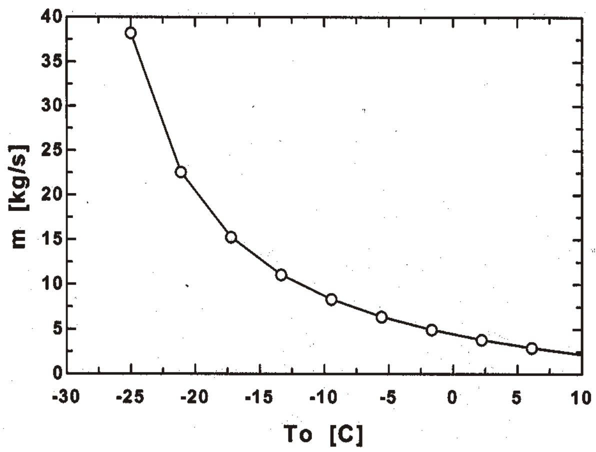

FIGURE 18: Relationship between m and T_s

Table 4 shows us a strong relationship between the supply water temperature, the hot water mass flow and the outside air temperature. The outlet water temperature in the hot spring is 86˚C, and the maximum flowrate is 10 kg/s. At -9.4˚C outside temperature, 8.3 kg/s hot water are required according to Table 14. At this outside temperature the water supply temperature in Tsenher soum is 72.21˚C. At -13.33˚C, 11.07 kg/s are required, which is more than what is available from the hot spring. It means that without drilling for more water we can supply Tsenher soum with geothermal heating down to about -10˚C outside air temperature. In order to supply enough water for the design outside air temperature of -25˚C, we will need four times more geothermal water than is available. In order to be able to supply geothermal heat under the design conditions, we need to drill one or two geothermal wells in the area. Else it is possible to use an additional small capacity boiler if the outside air temperature is less than -10˚C.

3. FEASIBILITY STUDY FOR ELECTRIFICATION OF SHARGALJUUT AREA IN MONGOLIA USING GEOTHERMAL WATER

A 2 MW capacity Kalina power plant has recently been taken into operation in Húsavík town, N-Iceland. The following study is based on the design for this power plant. It is estimated that the present population of the Shargaljuut area totals around 2,500 people and the demand for electricity in the area is around 200 kW. The nearest aimag centre, Bayankhongor, is 58 km from the Shargaljuut hot spring and if further investigations confirm the availability of larger geothermal power potential (1-3 MW), supplying power to Bayankhongor would be a viable option for the future (Worley International, 1995). Now this aimag centre is supplied with electricity from a diesel generator.

3.1 Present situation of electricity supply in Mongolia

The main source of electricity in Mongolia is a coal power plant with an installed capacity of 764 MW, which supplies 40% of the total area and 50% of the population. According to recent estimates, 7 aimags, 197 soums, and 200,000 nomadic families are not supplied by the central power supply line. These are supplied with electricity from isolated diesel generators (Tacis services, 2000).

The main player in the electricity sector in Mongolia is the Energy Authority of Mongolia, which manages three systems:

-The Central Energy System (CES)
-The Western Energy System (WES), and
-The power plant in the aimag centre of Choibalsan

The historical electricity balance of the country is shown in Table 5.

TABLE 5: Historical electricity balance in Mongolia

Year	1975	1980	1985	1990	1993	1995
Total installed capacity (MW)		430	758	935		970
Gross generation (GWh)	848.3	1531.7	2843.2	3347.3	2703.2	2628.7
Imports (GWh)		263	153	228	198.2	381.2
Exports (GWh)			53	76	53.8	28.6
Total consumption (GWh)	848.3	1794.1	2943.2	3499.9	2847.7	2981.3

The most important transmission network of the country is that of the CES. The CES transmission system consists mainly of 220 kV overhead lines. In some cases, the system has been extended to cover isolated aimags. Due to the very large distances involved, this has resulted in very long feeders with significant losses. Only a fraction of the country is covered by the existing transmission system (Figure 19). Thus, 7 out of the 18 aimags of Mongolia are supplied with electricity through isolated diesel plants (and in one case coal-fired CHP). Electricity supply data for each aimag Centre in 1995 is shown in Table 6.

TABLE 6: Aimag centres electricity supply for 1995

Aimag centres	Generation (GWh)	Peak load (MW)
Hovd	8.8	3.2
Uliastai	11.5	n.a.
Altai	6.0	2.6
Murun	12.1	3.3
Bayankhongor	7.9	2.8
Dalanzadgad	7.5	1.9
Baruun-Urt	6.6	2.4
Choibalsan	67.0	13.3

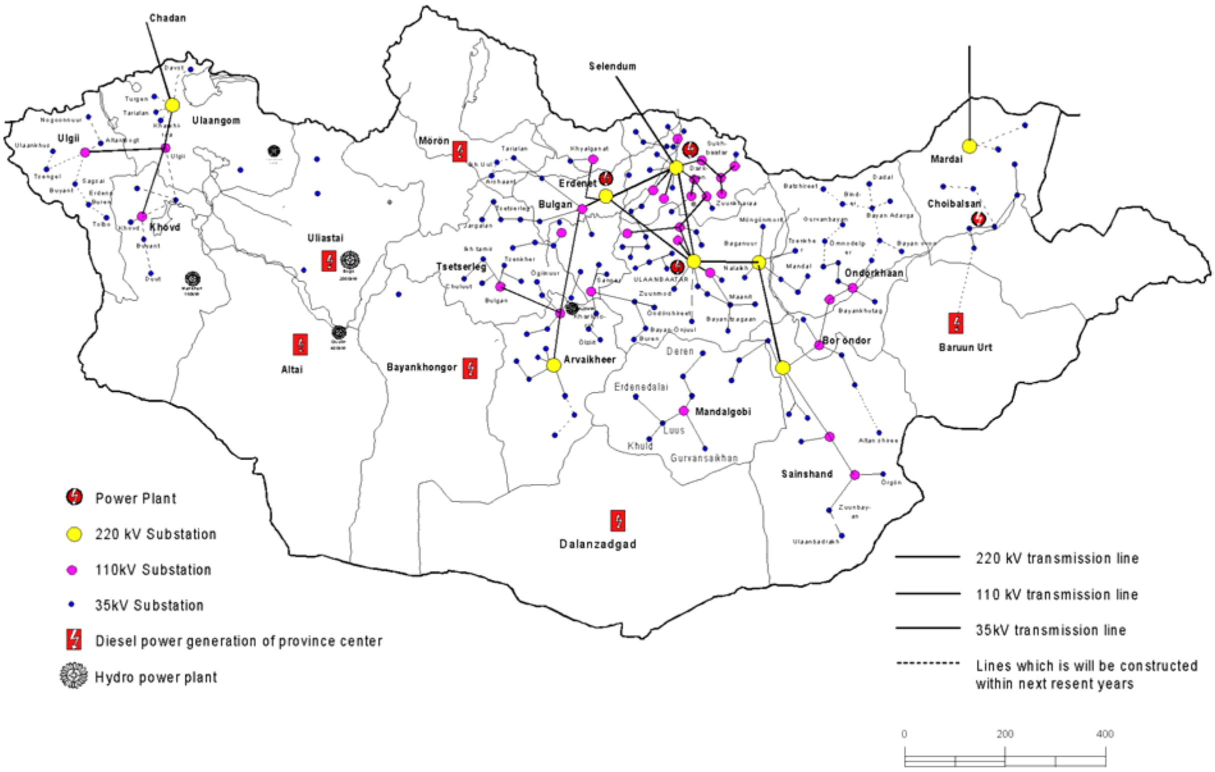

FIGURE 19: Scheme of the Mongolian centralized energy supply

3.2 Electrification by geothermal water in Shargaljuut area

Mongolia, with a 1,564,619 km^2 total territory and a total population of 2,373,500 exhibits significant challenges in the electricity supply sector, imposed by a number of reasons, the most important of them being the limited coverage of the country by the electricity network, the dependence on oil for the electrification of remote areas, the (degradation) of the existing equipment and the very severe climatic conditions in most parts of the country.

Rural electrification in Mongolia. Currently, 197 Soum Centres in Mongolia are not connected to any electricity grid. From these, about 50 are expected to be connected to the grid in future years, while there is not any such plan for the remaining 150 Soum Centres. The main problems, which were identified concerning the soum centres electricity supply, are as follows:

- Lack of resources of rural population, and thus not adequate consumption of electricity.
- Most of the electricity generating equipment is over 20 years old, manufactured in Russia. In addition to low efficiency, this also causes frequent failures and difficulties in repair due to lack of spare parts.
- The supply of fuel; transportation of fuel for the diesel generators over the long distances to the Soum Centres increases costs by about 10%.

Furthermore, the lack oil resources in Mongolia creates a dependence on foreign oil imports.

Renewable energy technologies present a number of advantages for the electrification of remote areas in Mongolia:

- They favour the exploitation of local resources, thus reducing the import dependence as well as the transportation problems associated with fuel oil.
- They remain economic and may operate efficiently on a small scale.

- They utilise simple technology, with possibilities for some local production (geothermal turbine components, solar panel and wind turbine components).
- Due to their capability for implementation on a small scale, but also with world-wide awareness of their environmental advantages, they may prove easier to finance than conventional, large scale electricity supply technologies.

The Shargaljuut area has geothermal water as one of its renewable energy resources. Thus, Shargaljuut area has the possibility of supplying electricity from the geothermal water of Shargaljuut hot springs.

3.3 Chemical content of the Shargaljuut hot spring

Chemical composition of surface spring waters at Shargaljuut is reported (Worley International, 1995) as follows:

K+Na	83.7 ppm
Ca	0.4 ppm
Mg	1.2 ppm
Fe	0 ppm
Cl	14 ppm
SO_4	75 ppm
HNO_2	61 ppm
NO_2	24 ppm
Ph	8.4
Surface Temp.	92˚C
Flowrate	25 l/s

3.4 Kalina cycle

A Kalina cycle is principally a modified Rankine cycle. The transformation starts with an important process change to the Rankine cycle - changing the working fluid in the cycle from a “pure” component (typically water) to a “mixture” of ammonia and water (Saad, 1997).

The modifications that complete the transformation of the cycle from Rankine to Kalina consist of proprietary system designs that specifically exploit the virtues of the ammonia-water working fluid. These special designs, either applied individually or integrated together in a number of different combinations, comprise a family of unique Kalina cycle systems. This is somewhat analogous to the Rankine cycle which, in fact, has many design options such as reheat, regenerative heating, supercritical pressure, dual pressure etc., all of which can be applied in a number of different combinations in a particular plant.

Each Kalina cycle system in the family of designs has a specific application and is identified by a unique system number. For example - “Kalina Cycle System 5” (KCS5) is particularly applicable to direct (fuel) fired plants, “Kalina Cycle System 6 (KCS6) is applicable to gas turbine based combined cycles and “Kalina Cycle System 11(KCS11) is applicable to low-temperature geothermal plants.

The Kalina cycle does not require technological breakthroughs in equipment design. There is only a lack of experience with an ammonia-water working fluid in the power industry. As such, knockout risks associated with the Kalina cycle are minimized. It is important to point out that the Kalina cycle’s combined higher efficiency and lower cost advantages should make possible the exploitation of new energy resources. There is an abundant supply of low-temperature geothermal energy sources and waste heat process streams that are not economically feasible to develop using current technologies. The claims of the Kalina cycle technology have been supported by a 2 MW power plant in Húsavík, Northern Iceland. This plant utilizes geothermal water at 125˚C from a geothermal well. Kalina cycles are covered by approximately 30 patents in the US and internationally, which are hold by Exergy Inc., California (Exergy Inc., 2001).

A mixture of fluids has been proposed to substitute steam in a Kalina cycle, where a mixed working fluid variable composition is used to provide a better match between the temperatures of hot and cold flows (Korobitsyn, 1998). The composition of the fluid is changed in the cycle at different points. In most Kalina cycle studies a mixture of water and ammonia has been used. The ammonia in the mixture begins to vaporise first, and as it boils off, the liquid mixture ammonia concentration decreases, and the boiling temperature of the liquid mixture increases. This reduces the temperature mismatch between the topper's waste heat and the fluid in the boiler, and allows an efficiency rise in the bottoming cycle. Figure 20 shows a schematic diagram of heat utilization in a vaporizer in the Kalina cycle (Mlack, 1996 and 2001).

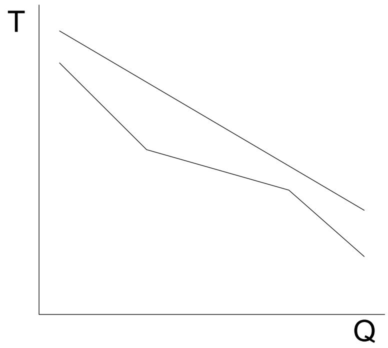

FIGURE 20: Heat utilization line in the Kalina cycle

A basic Kalina cycle consists of a heat recovery vapour generator (HRVG), a steam-ammonia turbine, and the distillation condensation subsystem (DCSS), as shown in Figure 21. In the DCSS the stream from the turbine is cooled in the recuperator, and then mixed with a lean solution of ammonia in order to raise the condensing temperature. The resulting basic solution is condensed in the absorber and brought to the recuperator under pressure. Part of the flow is sent to dilute the ammonia-rich stream coming from the separator. The main flow passes the recuperator and is flashed in the separator. The vapour is mixed with the basic solution, condensed and pressurized before entering the vapour generator.

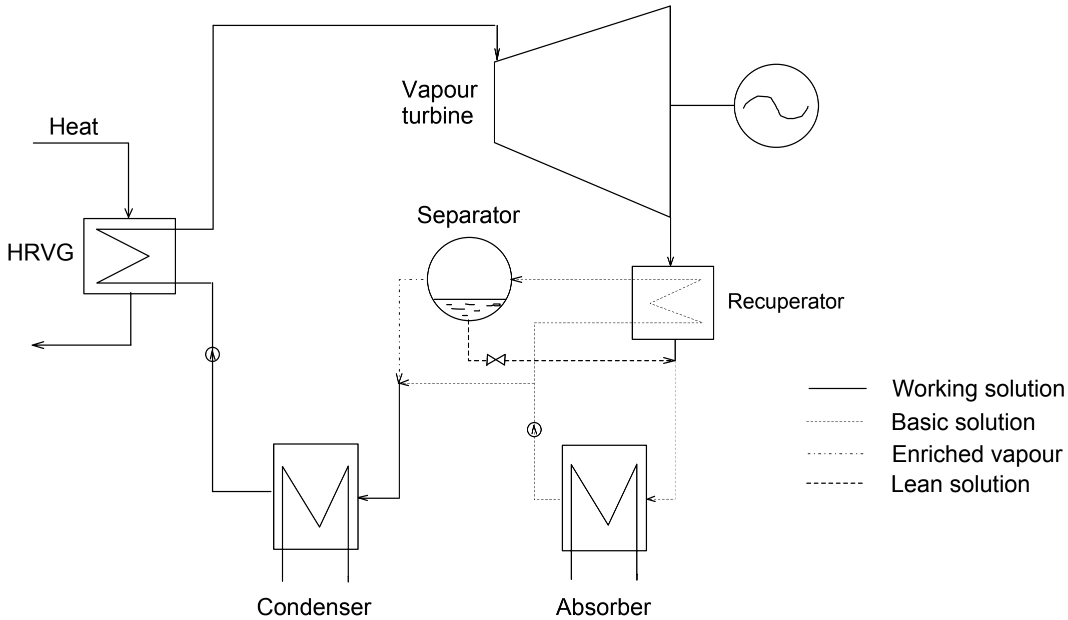

FIGURE 21: Flow scheme of the Kalina cycle

3.5 Design of a Kalina power plant in Shargaljuut

A Kalina power plant in the Shargaljuut is based on the flow scheme shown in Figure 22. This is the same flow scheme as in the Húsavík power plant. All calculations were carried out with the Engineering Equation Solver (EES) program (Klein and Alvardo, 2001). Program input variables are:

x_bl	= 0.87	Ammonia - water mixture, %
P_high	= 20	Pressure on the high pressure side, bar
P_low	= 5	Pressure on the low pressure side, bar
T_high	= 92+273.1	Water inflow temperature, K

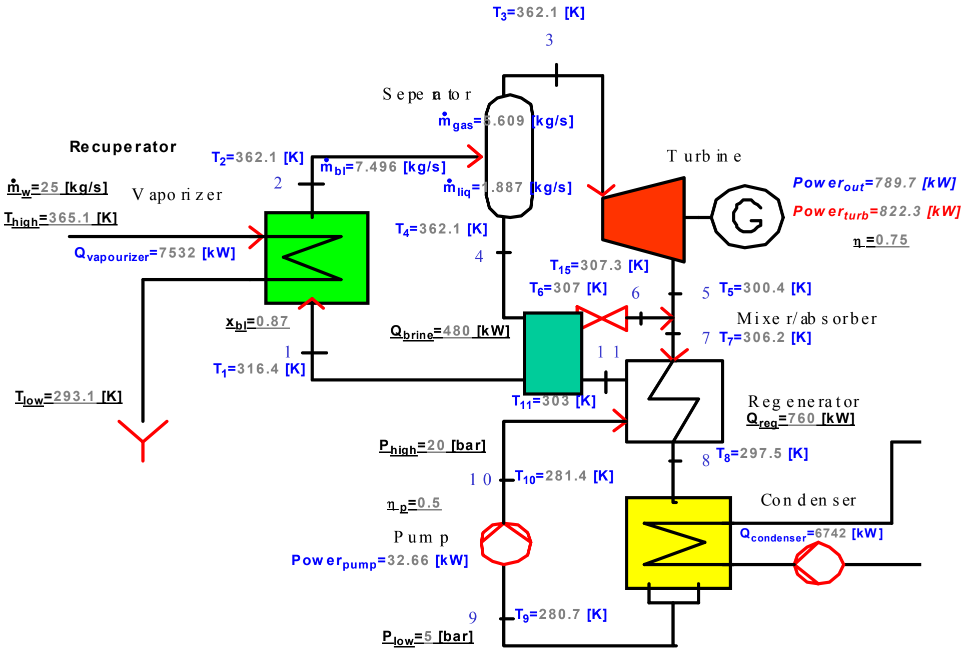

FIGURE 22: Block diagram for a Kalina power plant in Shargaljuut

T_low	= 20+273.1	Water outflow temperature, K
m_dot_w	= 25	Water flow rate, kg/s
eta	= 0.75	Turbine efficiency, %
eta_p	= 0.5	Pump efficiency, %
Q_brine	= 480	Recuperator heat exchange rate, kW
Q_reg	= 760	Regenerator heat exchange rate, kW

The calculation results are shown in the following block diagram (Figure 22) and Figures 23-26. The diagram shows all calculated variables, such as each component's inlet and outlet temperatures, ammonia concentration in the mixture, turbine electricity production and pump power demand.

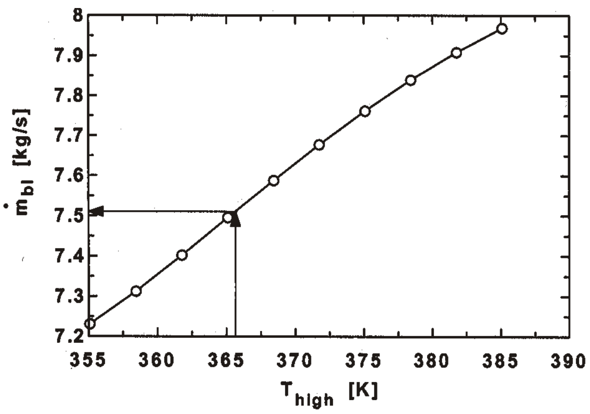

FIGURE 23: Relationship between geothermal water temperature and ammonia water mixture rate

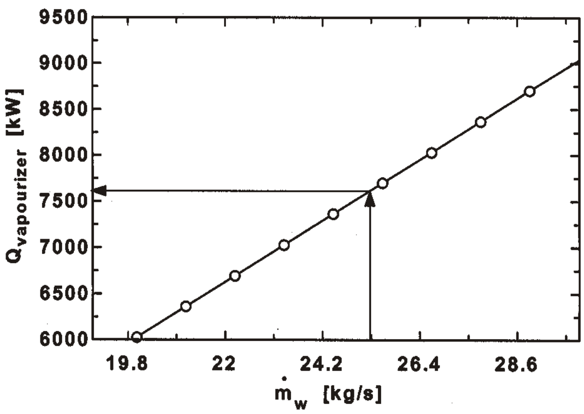

FIGURE 24: Relationship between inlet thermal power and geothermal water flow rate

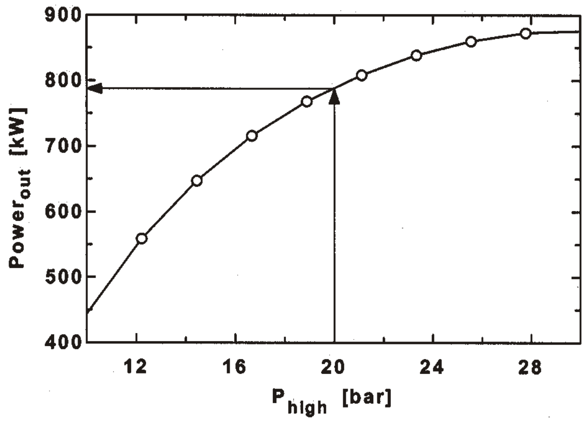

FIGURE 25: Relationship between pump pressure and electricity production

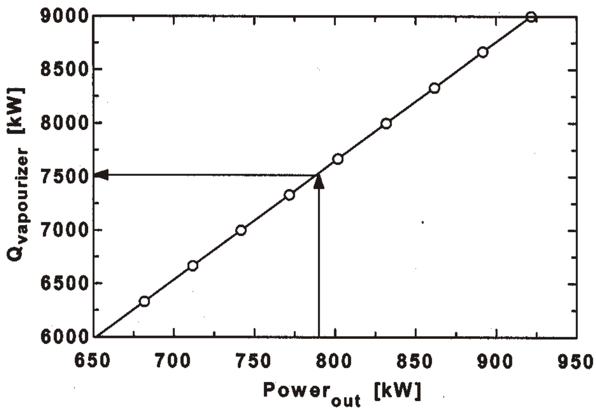

FIGURE 26: Relationship between inlet thermal power and electricity production

The Shargaljuut hot springs geothermal water could produce **790 kW** electricity using a Kalina power plant. The produced electricity is enough to supply the electric demands of the Sharagljuut area and it is possible to increase electric demands by **590 kW.** If the geothermal water flow rate in this area could be increased, and higher temperatures than 92°C temperature found, by investigations and drilling, the Kalina power plant could produce the 1-3 MW needed for Bayankhongor aimag as well.

4. POSSIBILITY OF GER HEATING AND ELECTRIFICATION USING GEOTHERMAL WATER

4.1 Nomadic family life style

As a nomadic nation, the Mongols have thousands of years of history and experience in raising livestock. The life of the Mongols depended almost totally on those animals. They ate the meat and the milk, even distilled wine from the sour cream; they made clothes from the skin and made the felt of the yurts from the wool; their transportation were the big animals like horse, ox and camel. So the Mongols are very fond of the livestock and can recognize every single one. Mongols only raise five kinds of livestock and only these animals are considered as livestock ("mal" in Mongol language) by them. They are horse, sheep, ox, camel and goat. The Mongols call them "tavun hushuu mal".

Ger (Figure 27) is the main house for rural herdsman and will be for the agricultural inhabitants in the coming forseeable years. Ger fulfils a very important role for the nomadic family. These simple but very functional tents can easily be dismantled and moved, yet are warm and comfortable. The Ger is heated with firewood or animal dung burned in a stove standing in the centre.

Nowadays 30% of the population in Mongolia live in modern apartments (residents) and 70% live in Gers and small buildings, Ger is a house for the rural population as well as city and town residents because there is a lack of modern apartments Ger fulfills a very useful purpose in isolated rural areas. There are several advantages of the Ger. It is light weight, easy to transport and install, warm to live in. It can stand natural calamity such as quicken, with good sunlight and good ventilation.

Most Gers are designed in similar way, but they can have different wall dimension: 4 walls, 5 walls, 6 walls. Figure 27 shows the general design of Mongolian Ger. The Ger with 5 walls are in common usage in Mongolia. The size of floor for this Ger is 36.3 m^2, inner volume is 47 m^3, light transmission and air convection top parts measure 2.27 m^2, ratio of the basic diameter of Ger D and the diameter of light transmission top part D_T equals D/D_T= 4. Diameter D_T is the same as the height of the door Hg (D_T= Hg). The ratio between the height of the supports and wall is 1.5 (H_p/H_{CT}=1.5). The data on the Ger is shown in Table 7.

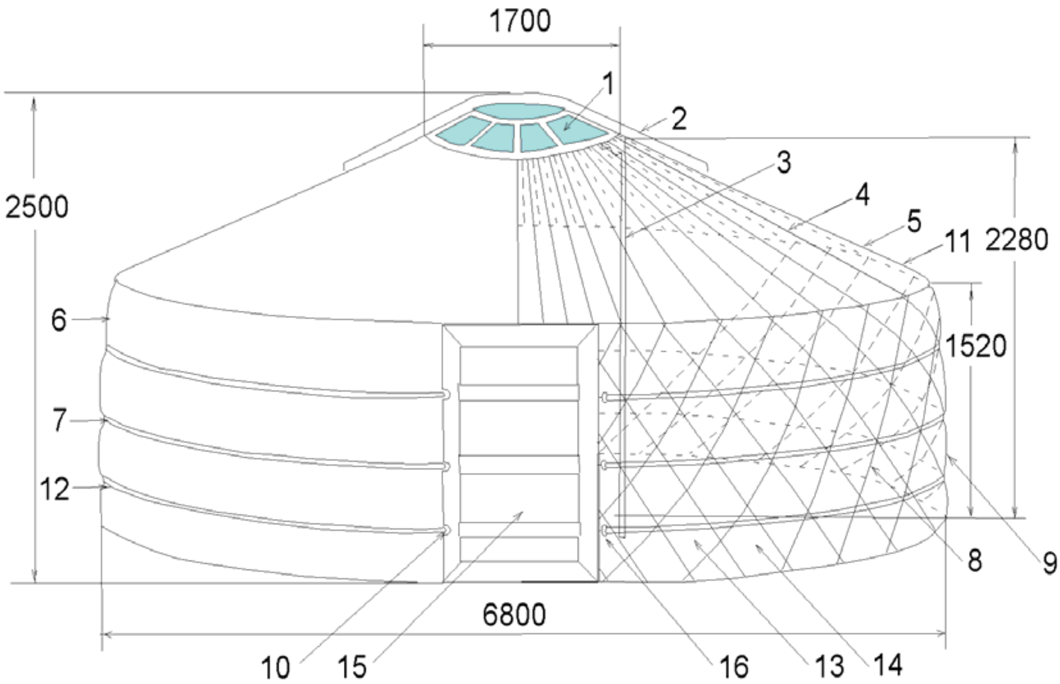

FIGURE 27: The general design of Mongolian Ger. 1. Top air ventilation and lighting through sunshine wheel opening part, named "toono"; 2. Felt cover for window; 3. Roof support; 4. Wooden part of roof named "uni"; 5. Several rev (two rev felt and between them paper); 6. Internal circle curtain isolated by cotton fabric; 7. Rope encircles walls; 8. Walls consist of several wooden lattices named "hana"; 9. Several coverings (two coverings "esgii" and paper insulation); 10. Wall ropes tighten and encircle felt cover; 11. Outside textile (white cotton fabric) covers of Ger; 12. Outside rope girdle of Ger; 13. Floor made of board wood; 14. Sand foundation; 15. Door made of board wood; 16. The holdings for rope

TABLE 7: The main dimensions of a typical Ger

	Unit	Dimension
Size of Ger	Diameter of foundation D, m	6.80
	Diameter of top part D_T, m	1.70
	Height of post H, m	2.28
	Height of wall H_{CT}, m	1.52
	Height of Ger H^1, m	2.50
Size of main elements of Ger	Dimension of each wall, m^2	1.52×3.06= 4.65
	Dimension of total wall, m^2	23.25
	General size of a cover on top, m^2	20.96
	Dimension of a door, m^2	1.38

The top and upper parts of the Mongolian Ger are different from the Kazakh Ger.

4.2 Heat requirements of the Ger

The heat transfer from the Ger to its environment can be calculated using the following equation (Emeish, 2001):

$$q = UA\,(T_i - T_0) \tag{30}$$

where U = The overall heat transfer coefficient of the wall;
A = Area of the wall;
T_i = Inside design temperature;
T_o = Outside design ambient temperature.

For our case the overall heat transfer coefficients and different area elements of the Ger are shown in Table 8.

TABLE 8: Overall heat transfer coefficients of different elements of a typical Ger

Elements	Material	Area (m^2)	Thickness (m)	U value (W/m^2°C)
Wall	Wooden lattice covered by felt	23.25	0.15	0.35
Roof	Wooden supports covered by felt	36.32+1.135/2	0.15	0.35
Floor	Wood and concrete	36.32	0.1 and 0.55	0.92
Window (toono)	Wooden framework and glass	1.135/2	0.005	6.2
Door	Wood and felt	1.38	0.03 and 0.05	0.94

The area of the window equals half of its total area as half of the window is covered by felt. Therefore, half of the window area is added to the roof area.

In the following calculation design the inside temperature and outside ambient temperature were chosen as the standard Mongolian design conditions, at 20˚C and -25˚C. Now we can calculate the heat loss of the Ger from Equation 30 which at design conditions leads to Equation 31.

$$q_{ger} = (U_{wall} \cdot A_{wall} + U_{roof} \cdot A_{roof} + U_{windows} \cdot A_{windows} + U_{door} \cdot A_{door}) \cdot (T_i - T_o) \quad (31)$$

The results indicate a peak heat requirement of **1318 W**.

4.3 Geothermal water needed for heating the Ger

In the *floor heating system*, steel pipes were mostly used before, but now only plastic pipes with high heat endurance are used. Much progress has been made in the production of plastic pipes with high heat endurance and they will most likely cost less in the future compared with other types of pipes. These pipes are laid 150-450 mm apart, depending on the diameter of the pipe used and how big a surface is to be heated. Least distance from floor surface to pipe is 40 mm. Designs have become better and there is much interest in utilizing 40-60˚C hot water for heating (VEO, 2000). Figure 28 shows the 3 types of

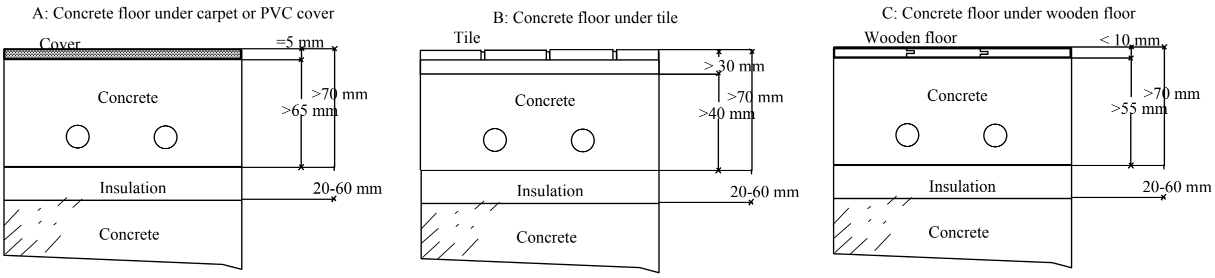

FIGURE 28: Different floor types for a Ger; *Type A:* At least 30 mm of plastic insulation is laid over the whole floor. On the insulation is laid a steel mat where PEX pipes are fastened. Then there is the concrete floor. The distance from a pipe to the surface of the floor is 30-90 mm; *Type B:* Like A, except the concrete is thinner or 30-50 mm. On top of the cover is for example 2.5 mm cork; *Type C:* Like A, except now the concrete is thinner or 30-50 mm. On top of the cover is for example 13-23 mm wooden floor

floor designs.
Table 9 shows heat flow from the heated floor (the three types) and mean water temperature. The mean water temperature is a calculated mean of supply and return water temperatures. Columns marked I indicate floor material with hard and smooth surface, for example PVC floor covering, cork or wood; columns marked II, indicate soft hairy surface, for example carpet.

TABLE 9: Heat flow and mean water temperature in floor heating systems

		Floor type							
		A		B			C		
t_r (˚C)	t_g (˚C)	t_v (˚C)	(W/m^2)	t_r (˚C)	I (W/m^2)	II (W/m^2)	t_r (˚C)	I (W/m^2)	II (W/m^2)
16	20	23	39	25	39	31	27	39	31
	22	26	61	30	61	48	32	61	48
	24	32	86	35	86	68	41	86	68
	26	36	110	40	110	88	49	110	88
	28	41	137	46	137	109	57	137	109
	30	46	164	52	164	131	65	164	131
18	20	21	18	22	18	14	23	18	14
	22	25	39	27	39	31	30	39	31
	24	29	62	32	62	49	36	62	49
	26	34	86	37	86	69	44	86	69
	28	38	112	43	112	90	51	112	90
	30	43	138	49	138	110	59	138	110
20	22	23	18	24	18	14	25	18	14
	24	27	40	29	40	32	32	40	32
	26	32	63	34	63	50	39	63	50
	28	36	87	39	87	70	46	87	70
	30	40	112	45	112	90	53	112	90
	32	45	139	51	139	111	62	139	111
22	24	25	18	26	18	14	27	18	14
	26	29	40	31	40	32	32	40	32
	28	34	64	36	64	51	41	64	51
	30	38	88	42	88	70	48	88	70
	32	43	114	47	114	91	56	114	91
	34	48	140	53	140	112	64	140	112
	36	53	168	59	168	134	72	168	134
24	26	27	19	28	19	15	29	19	15
	28	31	40	33	40	32	36	40	32
	30	36	64	38	64	51	43	64	51
	32	40	89	44	89	71	50	89	71
	34	45	115	50	115	92	58	115	92
	36	50	142	55	142	114	66	142	114

Pipe: Wirsbo-Pex 20x2 mm; Distance between pipes: 250 mm
t_r = Room temperature; t_g = Mean temperature of surface of floor;
t_v = Mean temperature of hot water.

Calculation for floor heating:

Size of the Ger floor: 36.32 m^2;
Needed heat: 1318 W or 36.28 W/m^2 - the total heat loss minus floor heat loss;
Type of room: Ger is like a living room.

To gain maximum comfort, the floor heat should be within certain limits. Table 10 shows that the floor surface temperature of the living room should not be above 28˚C.

TABLE 10: Maximum floor temperatures

Room type	Floor surface temperature (˚C)
Kitchen, working place	25
Living and shop quarters, play schools and churches	28
Corridors, halls, porch	30
Bathroom, swimming pools, showers and wash room	32
Rooms that are seldom used (store room, garage)	35

The needed heat for the Ger at outside design temperature of -25˚C equals 36.28 W/m^2 and indoor design temperature t_r = 20˚C. Combining Table 9 and Table 10 enables us to find the mean water temperature in the 3 types of a Ger floor. For example if CII type floor (see Figure 28) is used, the surface temperature of the floor is 26˚C, the mean water temperature t_v equals 39˚C, and heat flow from the floor is 50 W/m^2. With this, we could supply heating to the Ger during a cold period.

Floor heating for a Ger has a relationship between supply water temperature and return water temperature:

$$(T_s+T_r)/2 = t_v \quad \text{or} \quad (T_s+T_r)/2 = 39\,^{\circ}C \tag{32}$$

For Ger floor heating, the minimum supply geothermal water temperature equals **40˚C**. The minimum geothermal water flow rate is **0.157 kg/s**.

4.4 Small geothermal electric generator for nomadic family appliances

The first basic appliances supplied by electricity for nomadic families are:

- Lighting 50 W
- Lighting and TV 100 W
- Lighting, TV and satellite antenna 200 W.

Therefore, the need for geothermal electric generation capacity equals this electric demand, i.e. 50-200 W. The recently developed thermoelectric converter is suitable for small geothermal resources.

The *thermoelectric converter* shown in Figure 29 essentially consists of two semiconductor blocks connected by a conductor (Saad, 1997). The conductor receives heat from a thermal source at temperature T_H, whereas the open ends of the blocks reject heat to a low-temperature reservoir at temperature T_L. The sides of the semiconductors are insulated so that heat flow takes place unidimensionally through the semiconductors. When heat is transferred to the high-temperature junction, electrons in n-type semiconductors and holes in p-type semiconductors tend to flow away from the junction. An electric potential is therefore generated, and if the circuit is completed at the low-temperature junction, an electric current flows through the load.

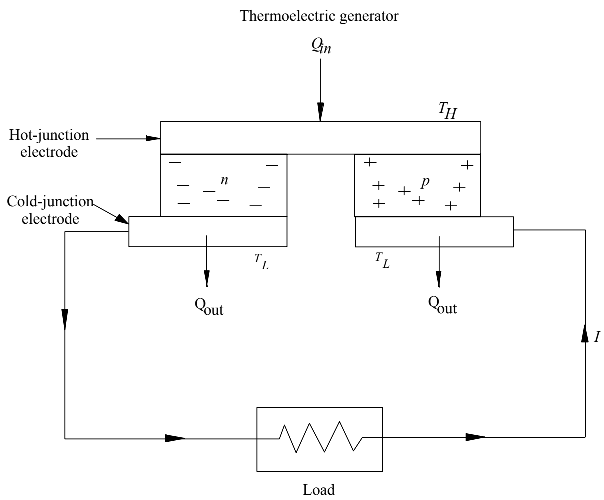

FIGURE 29: Thermoelectric generator

This system may be reversed by supplying electrical energy rather than heat. The current flow then serves to remove heat energy from one junction and to deliver heat energy to the other junction. The process of thermoelectric refrigeration represents an application of the Peltier effect.

In the Peltier effect an electric current is sent through a junction of two dissimilar materials A and B, and this results in either a heating or cooling to the junction. The rate of heating (or cooling) is proportional to the current flow and is given by the equation

$$\dot{Q} = \pi_{AB} \cdot I \tag{33}$$

where the coefficient π_{AB} is a function of temperature called the Peltier coefficient. The subscript *AB* indicates that the Peltier coefficient also depends on the two material *A* and *B*. A typical unit of π_{AB} is the volt. If current flows in the direction of the potential drop characteristic of the junction, then the temperature of the junction decreases, and a refrigerating effect occurs in the space surrounding the junction. If current flows in the direction of the junction's potential rise, the temperature of the junction increases and heat must be transferred from the junction to maintain constant temperature at the junction. Figure 30 shows the Peltier effect of *A* and *B* materials.

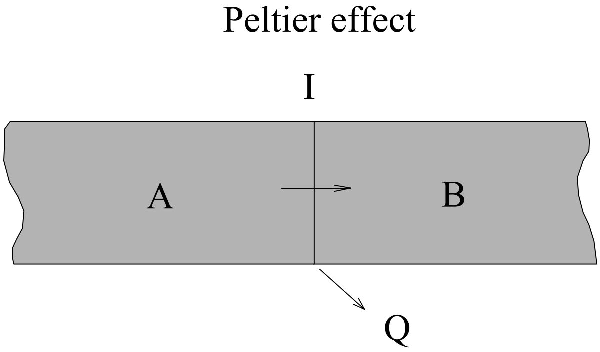

FIGURE 30: Peltier thermoelectric effect

An index used in rating thermoelectric converters is called the *figure of merit, Z,* and is defined as

$$Z = \frac{S}{\rho K_t} \tag{34}$$

where S = Seebeck coefficient;
ρ = Electrical resistivity; and
K_t = Thermal conductivity of the semiconductors.

A high figure of merit is achieved by using substances of large Seebeck coefficient, small electrical resistivity, and small thermal conductivity. Maximum values of the figure of merit are obtained when the electric and conduction losses are at a minimum, and when the two losses are approximately equal. Figure 31 shows the variations of *S* and *Z* as a function of electron density. The maximum value of *Z* is obtained with semiconductors having an electron density of the order of 10^{19} to 10^{20} electrons/cm^3. Typical values of *Z* are in the range of 1-3 × 10^{-3}/K .

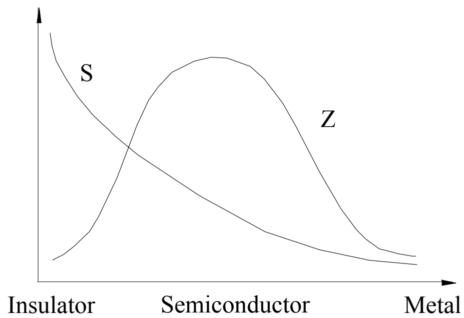

FIGURE 31: *S* and *Z* versus carrier concentration

The ideal thermal efficiency of a thermoelectric converter is

$$ideal\,\eta_{th} = \frac{P_{out}}{Q_{in}} = \left(\frac{T_H + T_L}{T_H}\right)\left[\frac{M-1}{M + \left(\frac{T_L}{T_H}\right)}\right] = \eta_{Carnot}\eta_{rel} \tag{35}$$

where M is the ratio of the load resistance to the internal resistance of the converter, or

$$M = \sqrt{1 + \frac{Z}{2}(T_H + T_L)} \qquad \text{and} \qquad \eta_{rel} = \frac{M - 1}{M + \left(\frac{T_L}{T_H}\right)}$$

The relative efficiency η_{rel} reflects the reduction in efficiency resulting from irreversible losses. The overall efficiencies of actual thermoelectric converters lie between 2 and 6 percent, which are considerably below the efficiencies of the conventional power plants. Special features, such as lights weight, small size, and simplicity, make them suitable for space vehicles even though their thermal efficiency is low.

If the thermoelectric converter is operated as a refrigerator, then

$$ideal\beta_{rel} = \frac{\dot{Q}_c}{P_{in}} = \left(\frac{T_L}{T_H - T_L}\right)\left[\frac{M - \frac{T_L}{T_H}}{M + 1}\right] = \left(\beta_{ref}\right)_{Carnot}\left(\beta_{ref}\right)_{rel} \tag{36}$$

where

$$\left(\beta_{ref}\right)_{rel} = \frac{M - \left(\frac{T_L}{T_H}\right)}{M + 1}$$

If the converter is used as a heat pump, its performance is described by

$$ideal\beta_{heatpump} = \frac{\dot{Q}_c}{P_{in}} = \left(\frac{T_L}{T_H - T_L}\right)\left[1 - 2\frac{M - 1}{T_H^2}\right] = \left(\beta_{ht\cdot p}\right)_{Carnot}\left(\beta_{ht\cdot p}\right)_{rel} \tag{37}$$

where

$$\left(\beta_{ht\cdot p}\right)_{rel} = \left(\frac{T_L}{T_H}\right)\left[1 - 2\frac{M - 1}{T_H^2}\right]$$

5. CONCLUSIONS

The main goal of this report is a design for small heating systems and electric generation for rural consumers in Mongolia.

For the Tsenher soum, the heat needed at -25˚C is four times bigger than the available geothermal resource in the Tsenher hot spring. Research to find more geothermal water in this area is necessary. It is also possible to use an additional small boiler if the outside air temperature is below -12˚C

The Shargaljuut hot springs could produce electricity up to 790 kW using a Kalina power plant. The produced electricity is enough to supply the electrical demand of the Shargaljuut area and it is possible to extend electric demands to more than the 590 kW needed presently. Future investigations may lead to availability of more geothermal water and at temperatures higher than the present 92˚C found at surface in this area. If the Shargaljuut area could produce 1-3 MW of electricity, supplying power to Bayankhongor aimag centre would be a viable option for the future.

The minimum geothermal water temperature and flow rate needed for floor heating of a Ger is 40˚C and 0.157 kg/s. In this case calculated floor properties are from a 10 mm wooden layer on top of 55 mm concrete layer and 20-60 mm insulation.

Icelandic researchers are now working to improve efficiency of thermoelectric converters up to 10%. If the research work is successful, the thermoelectric converters will become profitable. In future, it could be possible to produce electricity for Mongolian nomadic family from low-temperature geothermal water using thermoelectric converters.

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REFERENCES

Culver, G.G., and Reistad, G.M, 1978: *Evaluation and design of downhole heat exchangers for direct application*. Geo-Heat Center, Klamath Falls, OR.

Dunstall, M.G., and Freeston, D.H., 1990: U-tube down-hole heat exchanger performance in a 4-inch well, Rotorua, New Zealand. *Proceedings of the 12th New Zealand Geothermal Workshop, Auckland,* 229-232.

Emeish, M.E., 2001: *Simulation of heating systems in Jordanian buildings*. University of Iceland, M.Sc. thesis, UNU Geothermal Training Programme, Iceland, report 1, 91 pp.

Exergy Inc., 2001: *Exergy.* Web site http://exerg.com.

Georgsson, L.S., Jóhannesson, H., and Gunnlaugsson, E., 1981: The Baer thermal area of Western Iceland: Exploration and Exploitation, *Geoth. Res. Council, Transactions, 5,* 511-514.

Holman, J.P., 1989: *Heat transfer*. McGraw-Hill Book Company, Singapore, 676 pp.

Klein, S.A., and Alvardo, F.L., 2001: *Engineering equation solver*. Professional version 6.267.

Korobitsyn, M.A., 1998: *New and advanced energy conversion technologies. Analysis of cogeneration, combined and integrated cycles*, Twente University in Holland, PhD. thesis, 135 pp.

Lund, J.W., 1996: *Lectures on direct utilization of geothermal energy.* UNU G.T.P., Iceland, report 1, 123 pp.

Lund, J.W., Lineau, P.J., and Lunis, B.C., 1998: *Geothermal direct-use engineering and design guidebook.* Geo-Heat Centre, Oregon Institute of Technology, Or, 454 pp.

Nappa, M., 2000: *District heating modelling*. University of Iceland, report, 47 pp.

Meteorological Institute of Mongolia, 1990: *Meteorological compilation of Arkhangai Aimag.* Meteorological Institute of Mongolia, Ulaanbaatar.

Mlack, H., 1996: An introduction to the Kalina cycle. *Proceeding of the International Joint Power Conference, ASME Book No. H01077*.

Mlack, H., 2001: *Design and start-up of the 2MW Kalina cycle, Orkuveita Húsavíkur geothermal power plant in Iceland.* European Geothermal Energy Council, 2nd Business Seminar EGEC 2001, Altheim, Austria.

Remand, J., and Lang, R., 1999: *METEONORM, version 4.0 program*. Meteotest, CH-3012, Bern.

Saad, M.A., 1997: *Thermodynamics*. *Principles and practice*. Prentice-Hall International Limited, London, 935 pp.

Tacis Services, 2000: *Techno-economic feasibility study for electrification of Soum centres in Mongolia using renewables*. Tacis services DG1A, European Commission, report EMON 9601, 62 pp + app.

Valdimarsson, P., 1993: *Modelling of geothermal district heating systems*. University of Iceland, PhD. thesis, 315 pp.

VEO, 2000: Heating systems in Icelandic. In: *Energy days, course for technicians and consultants.* Verkvangur engineering office, course material, 10 pp.

Worley International, 1995: *Power system master plan interim report*. Asian Development Bank and Government of Mongolia, report 2095-MON, 423 pp.