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Article

A new methodology for choosing the efficient and optimal option of renewable energy for local heat supply

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Abstract. One of the tendencies of the power engineering sector in Mongolia is to devise an eco-friendly new technology, and solve the problem of supplying heat from reliable sources to consumers in the centralized rural areas of the country. The soil temperature is divided into four different zones. The soil temperature starts from 1.6 meters for the 4th zone, the southern part like the Gobi provinces of Mongolia, where the soil temperature has never decreased, even in the coldest months of the year. The study compared solar collector systems and heat pump systems and proposed environmentally friendly and economically efficient heating technologies depending on the climatic zones of Mongolia.

Keywords: individual customer, heat supply, eco-friendly technology, temperature zones

1 Introduction

The climate of Mongolia is cold and dry. Large parts of Mongolia are covered by discontinuous permafrost. The extreme continental climate is accompanied by cold, and long winters, and short summers. On average 257 cloudless days can be observed in this country over a year. Moreover, Mongolia is the center of a region with high atmospheric pressure, and most precipitation occurs in summer. The lowest precipitation is observed in the south, with values ranging from 100 to 200 millimeters per year. The north has the highest rate of rainfall, which accounts for 200 to 350 millimeters per year.
Fig. 1 presents the annual mean temperatures in Mongolia from 1961 to 1990, with blue indicating relatively lower temperatures and red representing higher temperatures [1].

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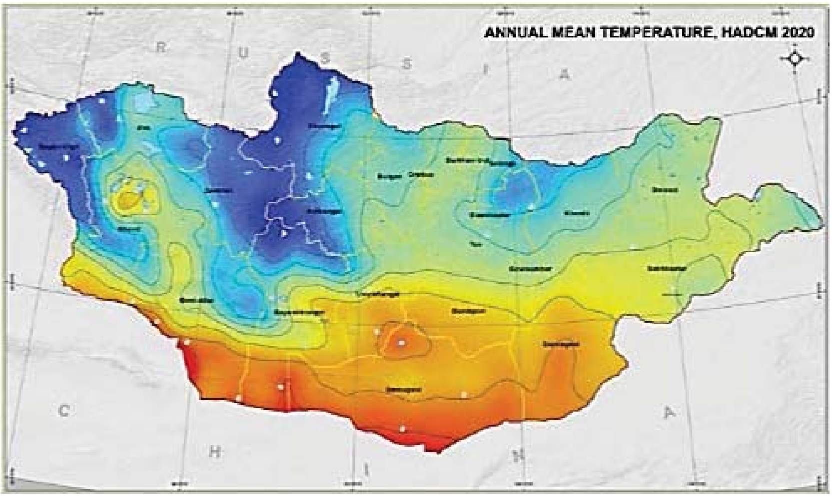

Figure 1. Annual mean temperatures in Mongolia

Mongolia has 21 aimags (provinces) and 333 soums (second-level administrative subdivision of Mongolia). In this study, 241 soums are involved. The study shows that 53 soums have centralized heating systems. The main consumers are schools, kindergartens, hospitals, hotels, post offices, local administrative offices, culture centers, banks, and other local enterprises in soums. According to the study, for most soum centers' the total heat consumption load ranges from 0.024 to 1.13Gcal/h, depending on the population, construction, and development [2, 6].

At present, only 21 heat boilers are in operation in the province centers such as Bayan-ulgii, Dornogobi, Selenge, Uvs, Khovd, Sukhbaatar, Khuvsgul, Sharin Gol of Darkhan-uul, Khanbogd of Umnugobi, Mandal, and Saikhan of Selenge, Bor-Undur and Berkh of Khentii, Ikhkhet of Dornogobi, in the 6 big provinces and cities including Nalaikh, Baganuur, Biocombinat, Khushigt valleys, and Amgalan. The furnaces imported from Russia, types such as KE, KBTC, DKBP, KB-F, and furnaces from China, including SHX, QXL, SHE, DZL are used in these power plants [3].

Private apartments' capacity areas are 25-450 m^2. Table 1 shows the annual fuel consumption of these consumers [6].

Table 1. 25 – 300 m^2 Annual Fuel Consumption

No	Heating technology	Heating area, m^2	Fuel consumption, kg
1	Traditional wall furnace	25-60	2000-4000
2		60-150	4000-8000
3		150-300	7000-25000

According to the Asian Development Bank, the "Master Plan for Energy" in 2018 has divided the population settlements into three groups. The table summarizes the heat load and provides the necessary investment (Table 2).

Table 2. Soum's population and capacity

No	Population	Number of soum's	Output, MW	Produce, GW·h/year	Year	Investment /USD/
1	up to 1000	156	0.6	2.1	2020	2872000
2	up to 1001-2000	130	2.4	8.4	2020	6424000
3	up to 2001 – 5000	36	4.0	14.0	2020	2880000
	Total	322		24.5		12176000

The study of the soum's heating load was completed and its capacity was classified as below (Table 3):

Table 3. Soum's capacity, Gcal/h

Lists of the provinces	The number of soum's involved in the study	Capacity, Gcal/h				
		0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	Higher than 0.8
Arkhangai	16	1	10	2	1	
Bulgan	16	5	7	3	1	
Gobi-Altai	15	4	10	1		
Gobi-Sumber	4	1	3			
Darkhan-Uul	4	1	2	1		
Dorno-Gobi	12	6	5			1
Dornod	12	5	4	2		1
Dund-Gobi	10	6	4			
Orkhon	1			1		
Uvurkhangia	17		7	6	3	1
Umnu-Gobi	14	2	11			1
Sukhbaatar	12	8	4			
Tuv	26	8	16	1	1	
Uvs	16	2	4	5	4	1
Khovd	11	7	3		1	
Khuvsgul	23	7	10	5	1	
Khenti	17	9	5	1	2	
Total	226	72	105	28	14	5

The present study shows that most soum centers' heating loads range from 0.2 to 0.4 Gcal/h or 232-456.2 kW/h. Thus, as mentioned earlier in this study, the soum center does not need centralized heating systems because it will result in energy inefficiency. Instead of the centralized heating system, the localized heating system is beneficial for these soums.

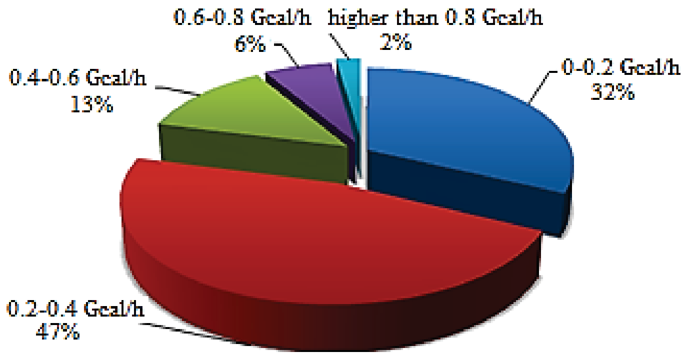

Figure 2. Soum's capacity

2 Methodology

The Gobi Desert is seen as a region with high renewable potential with an overall solar and wind potential, of around 2.6 TWh [8].
Solar collectors can be used for small-scale hot water supply, residential heating, central heating, and large-scale solar power plants [7].
The technical and economic performance of a heating system with solar collectors depends on several basic conditions, including:

- The local climate and weather conditions;
- Amount of energy to be processed (solar radiation level, number of sunny days per year, etc.);
- Private investment costs for solar collectors;
- Own cost of energy and fuel costs.

In Central Asia, 1 square meter of land perpendicular to the sun's rays generates 800-1000 watts or 1 kW of energy per hour [2].

According to the solar collector test calculation method by the National Standards Institute of America, the total energy released from the collector is determined by the following equation:

$$Q_u = F_R A \cdot [I_T(\tau\alpha) - U_L(T_i - T_a)] \quad (1)$$

Here: F_R –Heat transfer coefficient from the collector; A – collector area, m^2; I_T –the total solar radiation flow density in the flat collector, W/m^2; τ ability to filter out the transparent part of the solar radiation; α–solar radiation absorption ability of the collector plate; U_L–collector heat loss coefficient, W/(m^2·K); T_i–temperature of the liquid entering the collector, °C; T_a –Ambient temperature, °C. The test results express the collector efficiency.

$$\eta = \frac{Q_u}{AI_T} \quad (2)$$

B.Anderson formulated the solar radiation power sufficient for a solar collector as follows:

$$H_a = (0.96)I\tau\alpha \tag{3}$$

Here: I–the total amount of solar energy delivered to the solar collector, W/m^2;

The specific power of a water heater can be determined by the following formula, based on the given conditions.

$$Q = qc_p B[(P_S\theta_S I_S + P_D\theta_D I_D)/U + T_0 - T_{BX}] \tag{4}$$

Here: q–specific heat consumption, kg/m^{2}s; c_p–constant pressure heat capacity, J/(kg·K); P_S, P_D –Solar collector location coefficient for direct and diffuse radiation; θ_s, θ_D - Optical characteristics of direct and diffuse radiation solar water heaters; I_s–flow density of solar irradiance, W/m^2; I_D–solar diffuse radiation flux density, W/m^2; U–heat transfer coefficient of a solar collector, W/m^2·K; T_0–ambient temperature, °C; T_{BX} –Solar collector inlet temperature, °C.

The value of B is determined by the equation as follows.

$$B = e^{\frac{-U}{gc_P}} \tag{5}$$

In the calculation method, for flat plate solar collector standards, the instantaneous energy efficiency is determined by the following formula:

$$\eta_K = \eta_0 - \frac{K_K}{I_K}(T_{TH} - T_B) \tag{6}$$

Here: $K_к$ –coefficient of heat loss efficiency of the collector, W/(m^2·K); T_B – outside air temperature, °C; η_0 –efficiency indicator of optical calculation of solar collector efficiency; T_{TH}–temperature of the heat carrier entering the solar collector, °C; $I_к$ – the total solar radiation density falling on the surface of the solar collector, W/m^2;

The total amount of energy delivered to the collector at that moment is:

$$Q_K = F_K[I_K\eta_0 - K_K(T_{TH} - T_B)] = m_K c_P F_K(T_{TK} - T_{TH}) \tag{7}$$

Here: F_K –surface area of the solar collector, m^2; m_k –specific mass flow rate of the heat carrier in the solar collector, kg/(m^{2}s); T_{TK} – Temperature of the heat carrier from the collector.

MJ/(m^2·day) Specific efficiency of flat-plate solar collectors, monthly average, MJ/(m^2·day)

$$q_K = E_K\overline{\Phi}\eta_0 \tag{8}$$

Here: $E_к$ –, Average monthly solar energy received per day MJ/(m^2·day); $\overline{\Phi}$ -The value of the degree of solar energy utilization in a flat solar collector, as a monthly average.

In buildings using active solar thermal systems, the collector area is determined and the optimal size of the area is selected.

It is considered economically viable to provide a certain percentage of the heat load for hot water supply and heating systems with solar energy, while the remaining portion must be provided by an additional energy source.

To calculate the solar energy contribution from the total monthly heat load (f), the solar collector and monthly heat load can be determined as a dimensionless complex of X and Y.

$$X = \frac{AF'_R U_L (T_{ref} - \overline{T}_a)\Delta t}{L}; \quad Y = \frac{AF'_R \overline{(\tau\alpha)} \overline{H}_T N}{L} \tag{9}$$

Here: A –solar collector area, m^2; F'_R –heat transfer efficiency coefficient taking into account the effects of heat exchange; U_L –total heat loss coefficient of the collector, W/(m^2·K); Δt –number of seconds in a month; T_{ref} – base temperature, °C; $\overline{T_a}$-Average monthly outdoor temperature, °C; L–full monthly heat load, J; $\overline{H_T}$-The total amount of solar radiation on the inclined solar collector is the average monthly, J/m^2; N –number of days in a month; $\overline{\tau\alpha}$ - transferred absorption ability on a monthly average; X –ratio of the full monthly heat load to the collector's monthly heat load at base temperature; Y –The ratio of the full heat load to the heat absorbed by the collector in the middle of the month.

Then, the internal f for the liquid and air heat carriers is determined.

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3$$

$$f = 1.04Y - 0.065X - 0.159Y^2 + 0.00187X^2 + 0.0095Y^3$$

In this method, the formula for determining f used in the former Soviet Union is used as below:

$$f = \frac{\sum \left(1 - \frac{Q^M_{ADD}}{Q^M_L}\right) Q^M_L}{\sum Q^M_L} \tag{10}$$

Here: Q^M_{ADD}–Monthly value of heat load to be provided by additional heat source, GJ/month; Q^M_L –monthly value of heat load, GJ/month.

From all of the above, when calculating the optimal number of solar collectors, on the local climate and weather characteristics, the external air temperature and the amount of solar radiation are taken into account. Using the methods described above, and they compared with the numerical data confirmed by experiments.

Heat pump (HP) technology: To extract low-potential heat from the soil, metal-plastic pipes are placed vertically in a well 1.2–1.5 m deep, at a depth of 20–100 m, or spirally in a well 2–4 m deep. The maximum annual heat gain from the soil surface is 50–70 kW·h/m^2 [9].

Calculation of horizontal collector for heat pump: To extract low-potential heat from the soil, there are several parameters for each length of pipe: i.e.soil depth, soil water resources, soil structure, etc. affect

With a horizontal collector, the heat capacity from the ground is approximately 20 W/m. For example: sand dry clay soil–20, moist clay soil–25, clay soil containing a lot of water–35 W/m, soil water 80 W/m [11].
The temperature difference between the supply and return heat carrier is usually 3°C. The distance between the pipelines is assumed to be 0.7–0.8 m. The length of one well is 30...120 m, the distance between wells is 5 m.
Heat pumps are selected based on, first, the availability of a low-potential heat source, and second, the heat demand. The heat consumption, or load, is calculated directly using the method of calculating the heat loss of the building depending on the outside air temperature, and this will be the load of our heat pump.
This study has adopted the calculation method developed by J. Kantor, Wales University, England, to determine the possibility of using heat pump technology in Mongolia, depending on the climatic zoning [10]. (Fig. 3.)

Vertical collector: To provide heat to the building, geothermal heat is collected through vertical collectors and fed to a heat pump. The vertical collector consists of 2 pairs of PE heat transfer plastic pipes 4xØ32x3.0 mm with a diameter of Ø150 mm. There are 40 vertical collectors, the depth of the well is 103 m, and the seal is checked before inserting the PE pipe into the well. Each pipe exiting the well is welded to the main line using a special welding machine. The heat carrier is R22, and two pairs of PE thermal insulation pipes are installed in the hole and sealed with a special substance to the ground surface. The vertical collector heat pipes should be connected every 5 m with special clamps [11]. (Table 4.)

Horizontal orientation of the collector: Between the borehole and the building, the collector is connected horizontally to the main line at a depth below the freezing depth. Each collector is insulated, wrapped with waterproofing, foil, and sand insulation before being inserted into the building. (Table 5.)

The number of inlet lines to be installed in the building is 4 supply and 4 return, a total of 12 PE pipes. After the heating line is assembled, it is tested with gas at a pressure of not less than 1.8 MPa.

The heat storage tank is designed to be heated by an additional electric heater and a vacuum collector with heat pipes. The heat pump is self-adjusting.

The results of comparing the above calculations with other heating options for the same object are shown in Table 6.

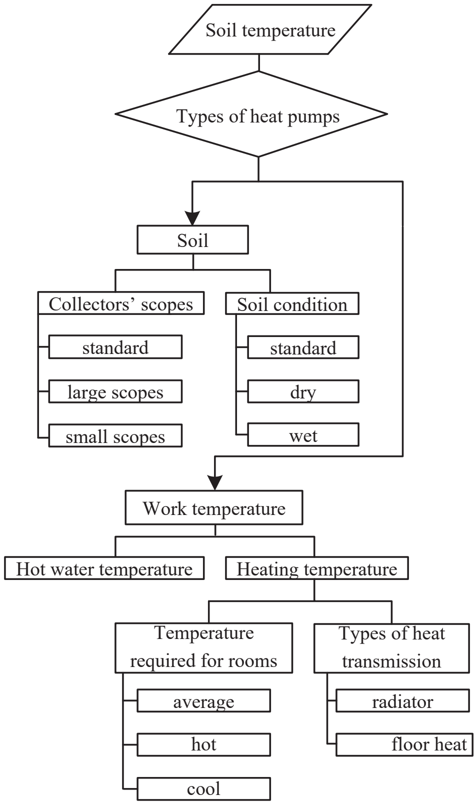

Figure 3. Calculation algorithm of heat pump technology

Using the above methodology, a calculation was made to provide geothermal heat for a kindergarten building in Bayantsagaan soum, Tuv aimag.

Table 4. In the case of a vertical collector

Estimated outside air temperature for heating	Average heating temperat ure	Heating duration	Heat transfer medium temperature (supply/return)	Vertical collector depth,	Thermal unit power of vertical collector, W/m
-30 ^{0}C	-8,7	233 days	65^{0}C/55^{0}C	Ø150m*77pcs	25

Table 5. In the case of a horizontal collector

Estimated outside air temperature for heating	Average heating temperature	Heating duration, days	2nd circuit heat carrier temperature (supply/return)	Heat storage tank	Additional electric heater for heat storage tank
-30 ^{0}C	-8.7	233	65^{0}C/55^{0}C	1000 *l*	12 kW

Table 6. Economic comparison of heating systems

Performance	Variants of combined heating systems			
	System with solar collectors	"Soil-Water" heat pump combined heating system (with horizontal collector)	"Soil-Water" heat pump combined heating system (with vertical collector)	Electric heater heating system
heat to be produced kW/h (days)	21	33.8		144...432
Heat to be distributed, kW/h (days)	45.2	32.2		136...410
Investment, thousand MNT	23.063	59366.3	119823.48	1400
Total expense, thousand MNT	2.3	15414.2	14947.01	1540
1 kW hour the cost to generate heat, thousand MNT	55.28	67.11	65.55	77
1 kW.hour selling price of heat, MNT/kW·h	62.17	92.35	123.75	92.4
Payback period, years	4.5	7	9	1.8
Internal rate of return, % (IRR)	9.1	5.5	7	9.5

Mongolia is a landlocked country, surrounded with mountains and far from the sea. The climate is very changeable, as it is cold in the winter, and cool in the summer. In addition, there is a big difference between day and night time.

Our country's weather condition is very harsh, and it is different from other countries lying in the same latitude. From the north to the south of the country, the harsh climate gradually drops down and the average temperature constantly rises. The coldest month of the year in Mongolia is January.

The average temperature spread zone of January was shown in Fig. 4.

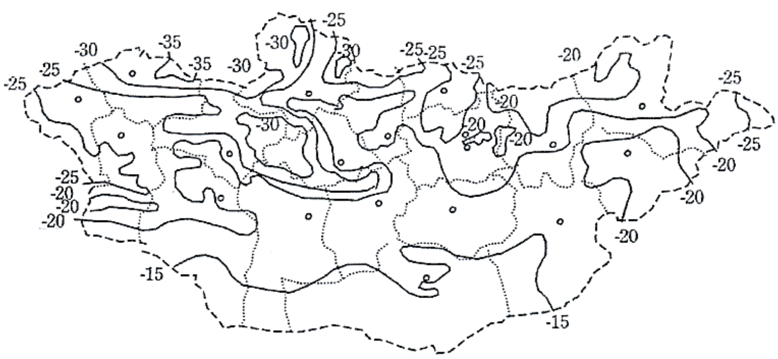

Figure 4. The average temperature spread zone of January

The duration of the average temperature range is higher 10 in March and April. However, in Sainshand and Zamin-Uud, located in the 45 to the south of the north latitude, duration is up to 5 months. This defines the seasonal duration of the heat consumption of the customers [5, 9].

As a result of the study, eco-friendly technology solution to the heat supply of the individual consumer in different regions was developed by dividing Mongolian territories into four different zones. Outside air temperature calculation, which is defined by the average temperature of five coldest days of the areas, is used for calculating consumer's heat load. This can be defined as follows [4]:

$$t_{out}^{T} = 1{,}6\bar{t}_2 - \Delta T \tag{11}$$

where: $\bar{t}_2$ - is the average temperature of the coldest month; ΔT- correction (Fig. 5).

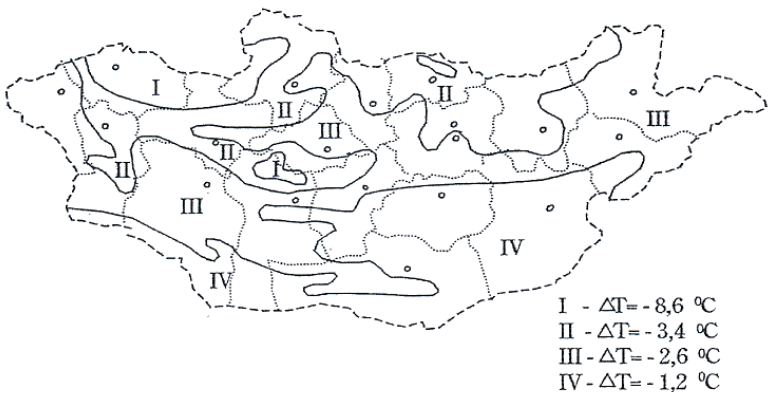

Figure 5. Heat calculation temperatures in zones

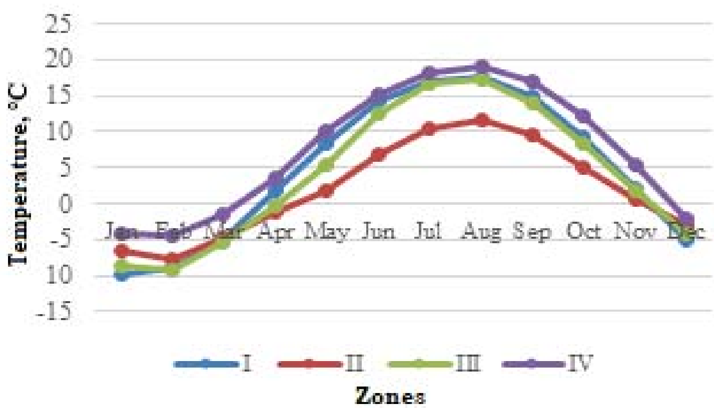

Figure 6. Average underground temperature of Mongolia (at 0.8 meter), °C

The most efficient heat sources are solar and geothermal energy for individual consumers in the areas including the southern part of our country (4th zone) that are to the south from 44° of the North Latitude. This is economical as well as multi-beneficial. These areas include the following provinces: southern parts of Gobi-Altai, Bayankhongor, Dorno-gobi, and whole areas of Umnugobi aimag.

Electrical boilers, geothermal and solar energy are also another possibility for heat supply in the specific areas such as northward areas from the 45° of the North latitude and western areas to the 46° of the North latitude and some northern areas of the 47° north latitude (3rd zone).

However, solar energy technology, electrical boilers, and heat pumps have a chance to operate in the second zone. These areas are located in the southern parts from the 48° of the northern latitude and eastern and western parts of the provinces in the 50 of the north latitude. Heat pump technology is available in the Tsenkher hot spring resort, which is located 25 km from the province. The surface temperature of the springs is 86°C. It is possible to use heat pump technology if there is a geothermal energy source is found in certain places. Although a geothermal heat pump uses the surface layer of the earth's farina as a heat source, the temperature range is very different. Thus, we can use wastewater or low-potential heat as a source for heat pumps.

However, this study indicates that solar energy sources are lower, and the duration of the heat supply season is longer than in other provinces. Therefore, using small-sized furnaces and electrical sources are a good way to heat for consumers in the northern parts of the country (1st zone), including Khuvsgul, Uvs and Selenge province.

3 Result

1. As a result of the study, we divided Mongolian territory into 4 different zones. Moreover, we gave some suggestions for using an eco-friendly new, technology of heat supply for individual consumers of the country.
2. The study considered solar collector systems and heat pump systems. The study showed that for the kindergarten building in Bayantsagaan soum, Tuv aimag, which was taken as an example, the cost of producing 1 kWh of heat is 55.28 MNT. For a heat pump system, it is 65-67 MNT, and for electricity it is 77 MNT.
3. The payback period for the initial investment is 4.5 years for solar collector systems, 7-9 years for heat pump technology, and 1.8 years for electricity. Therefore, for consumers with independent district heating systems, it has been determined that using renewable energy, either alone or in combination with other heat sources, is of great economic and ecological importance. This finding is in accordance with the weather climate and seasonal characteristics of the region.
4. The study showed that the use of low-power stoves and electricity for heat supply is economically uneconomical in the northern part of Mongolia (region I), given the low solar energy resources and long heating season in Khuvsgul, Uvs, and Selenge aimags.
5. The choice of heating technologies depending on the region of Mongolia is proposed in Fig. 7.

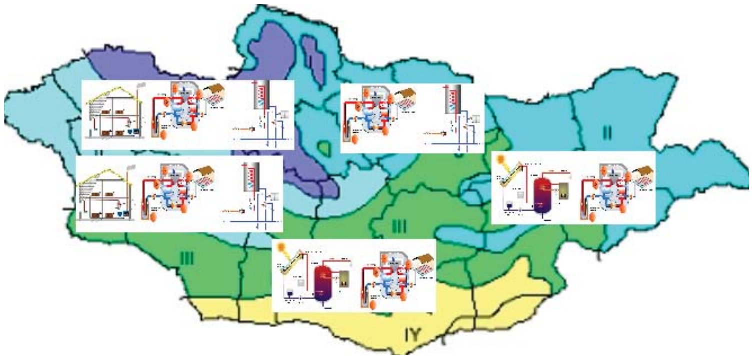

Figure 7. Recommended heating technologies depending on climatic zones

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