Geothermal heat in a heat pump use

A Pavlova[1,2], J Hansen[2], H Obermeyer[2], I Pavlova[3]

[1]Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany
[2] Society for sensing and locating, Südbeckenstr. 20 a, D-76189 Karlsruhe, Germany
[3] Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
E-mail: pavlovaiv@tpu.ru

Abstract The considered innovative technology proposes to use alternative energy sources for the process efficiency in low-height construction**.** The world economy depends on price rises for energy sources and the danger of environmental pollution increases. Geothermal energy is the basic resource saving and environmentally safe renewable heat source that is characterized by inexhaustibility, permanent all the-year-round use, universal prevalence of resources and the ability to replace considerable volumes of traditional energy carriers. The expediency and power efficiency to apply a heat pump with the use of geothermal heat is proved for low-height construction.
Keywords: geothermal heat, power saving, renewable energy sources, heat pump

1. Introduction

The project dimensions a geothermal heat pump for the single family house located at 8 Mozart street, Karlsruhe, 76133.

The large amount of fossil energy sources are known to have serious impact on the environment. Such impact is the pollutant increase in the atmosphere, for example sulphur dioxide and nitrogen oxide, that occurs in the process of combustion. Also the oil and gas restricted reserves make it difficult to use the fossil energy sources for energy supply. The energy production must be aimed at renewable energy sources to solve these problems in future.

It is considered that geothermal energy is located below the earth's surface in the form of warmth. Such energy belongs to the renewable energy, i.e. the energy from permanent sources that are inexhaustible by human reckoning. It is possible to use the geothermal energy to heat a building at low temperatures of the subsurface layers (subsurface geothermics). There are many advantages of geothermics private use along with the environmental condition improvement: space saving, availability, flexible use, cost-effective energy. The heat pump technology is applied in private heating, along with the geothermal energy use.

The heat pump is not a combustion engine in contrast to the conventional heat producers. It uses free environmental energy (from water, air or geothermal energy) and converts the lower temperature heat into higher temperature one. There are many kinds of heat pumps. Two the most suitable types to heat the given house are presented in the project: a groundwater-source heat pump and heat pump with geothermal probes.

2. Heat pump types

The heat pump technology works on the following principle. The stored geothermal heat as useful heat is transferred from the lower temperature reservoir to the higher temperature heating system. The heat always flows from the higher temperature to lower one according to the second law of thermodynamics. A heat pump should bring the received energy (using high-quality energy) at the required temperature level. Such natural environments as soil, water, and air can be used as a heat energy reservoir.

One of the heat pump types is a groundwater-source heat pump. Ground water heat is used as a regenerative energy source in the groundwater-source heat pump. This heat pump needs two wells: a transport and absorbing well (Figure 1). The transport well is used to pump ground water to the pump heat exchanger. The thermally changed ground water drains again in the same groundwater bed through the absorbing well. The groundwater-source heat pump is suitable for plots of land with the small groundwater depth and sufficient amount of high-quality ground water.

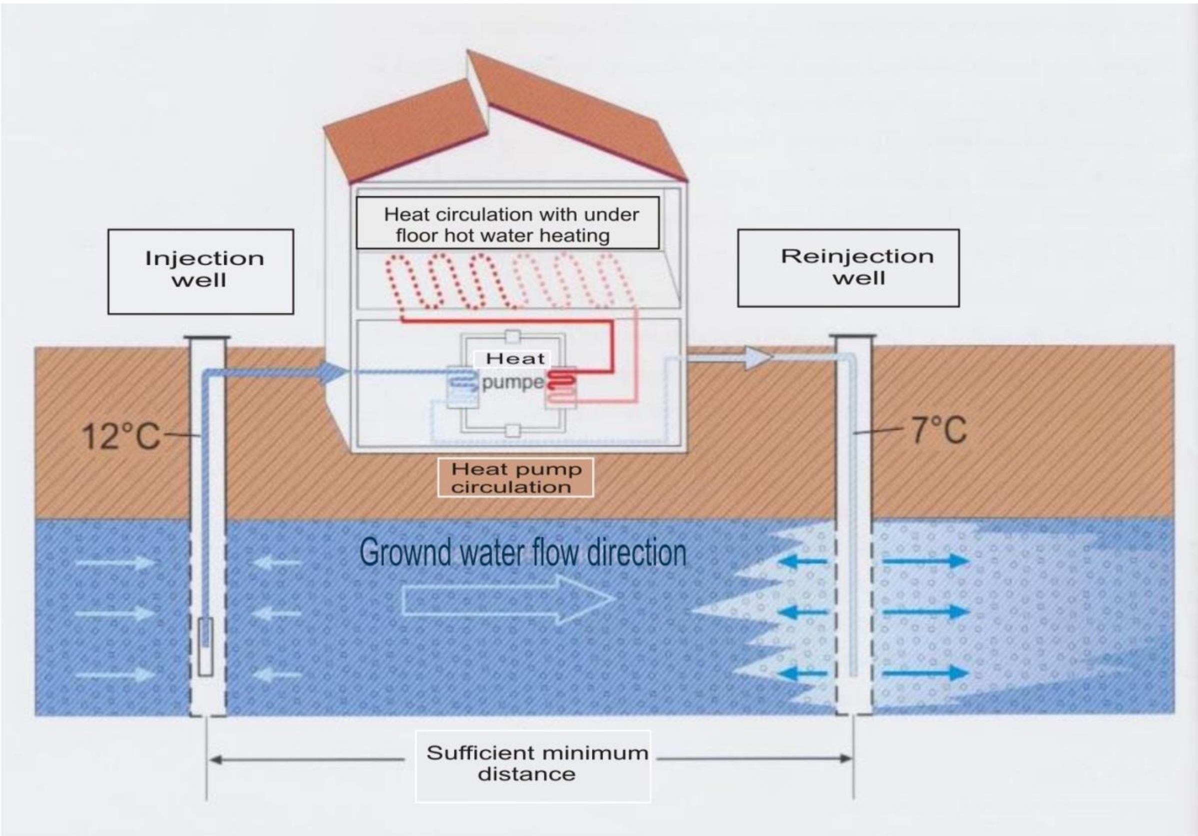

Figure 1. Groundwater-source heat pump

The second heat pump type, which is considered in the dimensioning, is the heat pump that takes the required energy out the earth by means of a geothermal probe and transfers it to the pump heat exchanger through heat-transfer liquid (brine water) (Figure 2). The geothermal probe is a closed pipe system with circulating heat-transfer liquid that is placed vertically in the subsoil. This heat pump can be designed very space-saving and, therefore, be suitable for small plots of land.

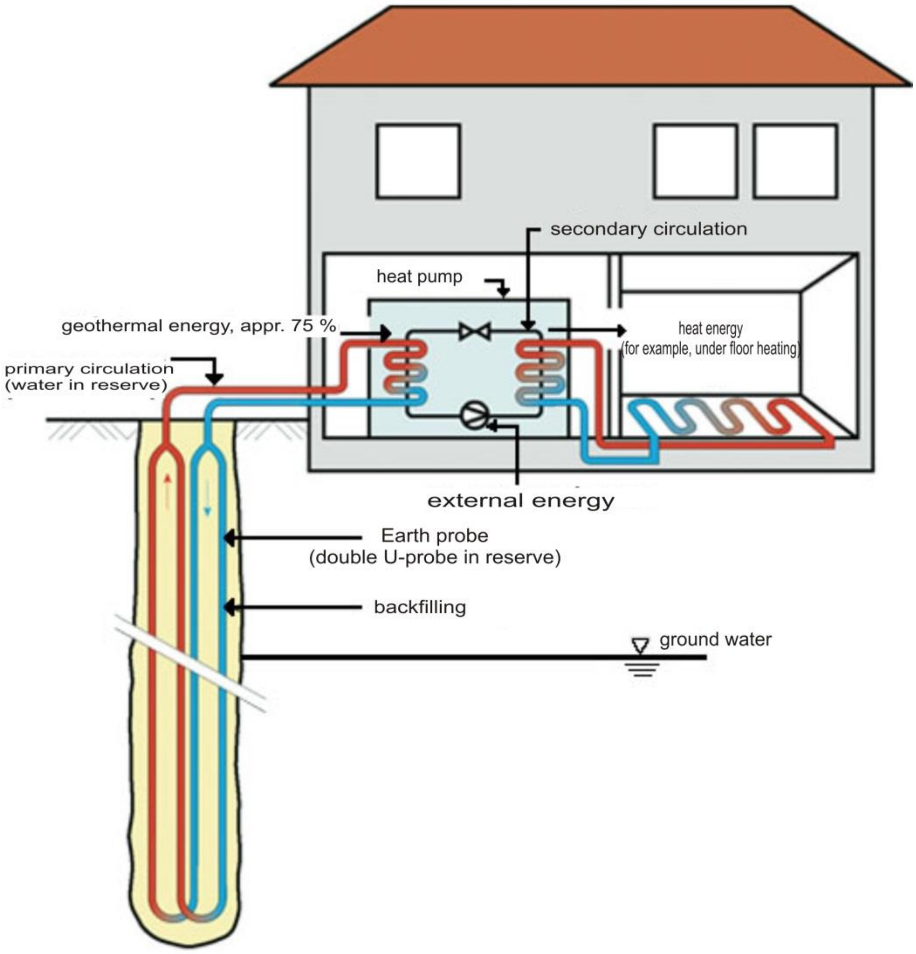

Figure 2. Brine-water heat pump

3. The heat pump dimensioning

- **Heat consumption**

The heat pump dimensioning has been carried out for the single family house located at 8 Mozart street, Karlsruhe. The first stage of the dimensioning was to calculate the house heat consumption.

The considered house consists of three heated floors (including a usable roof floor) and an unheated cellar. The ceiling height is 3.07 m for the ground floor, 3 m for the first floor, and 2.5 m for the usable roof floor. The overall heated area is 418 m² and overall volume is 1210 m³. The more exact data are presented in the following tables.

Table 1. The ground floor area and volume

Room	**Area, m²**	**Volume, m³**
Room 1	15.75	48.35
Room 2	11.90	36.53
Room 3	22.00	67.54
Room 4	8.75	26.86
Room 5	27.00	82.89
Room 6	15.60	47.89
Room 7	16.00	49.12
Room 8	4.62	14.18
Room 9	3.08	9.45
Room 10	10.59	32.51
Floorboard	19.98	61.33
Bathroom	5.47	16.79
WC	2.82	8.65
Overall:	163.56	502.12

Table 2. The first floor area and volume

Room	**Area, m²**	**Volume, m³**
Sitting Room	12.87	38.61
Utility Room	13.65	40.95
Study	12.61	37.83
Kitchen	8.32	24.96
Living Area	27.00	81.00
Dining Room	13.44	40.32
Bedroom	19.10	57.30
Floorboard	25.86	77.58
Bathroom 1	5.60	16.80
Bathroom 2	4.25	12.75
WC	1.00	3.00
Overall:	143.70	431.10

Table 3. The usable roof floor area and volume

Room	**Area, m²**	**Volume, m³**
Study	9.12	22.80
Bedroom 1	22.5	56.25
Bedroom 2	8.96	22.40
Bedroom 3	14.00	35.00
Living Area	17.88	44.70
Room 1	13.05	32.62
Room 2	20.66	51.65
Bathroom	3.20	8.00
WC	1.60	4.00
Overall:	110.97	277.42

The house standard heating load has been calculated according to the EU norm of German Institute for Standardisation EN 12831. According to the norm, the standard heating load is the sum of transmission heat loss, ventilation heat loss and the additional required heat supply for all heated rooms. The house standard heating load is 22.733 W according to the calculation. The data are shown in the following table.

Table 4. The house standard heating load

Floor	**Transmission heat loss, F_T, W**	**Ventilation heat loss, F_V, W**	**Additional required heat supply, F_{RH}, W**	**Standard heating load, F_{HL}, W**
Ground floor	4,974.65	3,042.73	1,472.04	9,489.43
First floor	3,193.86	3,031.17	1,293.3	7,518.33
Usable Roof Floor	3,070.42	1,478.59	998.73	5,725.23
Overall:	11,238.94	7,729.98	3,764.07	22,733

The additional hot water consumption is 1,250 W for five people. The overall house heat consumption is 23,983 W, which is the sum of the standard heating load and hot water consumption.

Another house standard heating load has been calculated according to the oil fuel consumption and is 34,914.4 W.

The heat pump dimensioning has been carried out for both load values.

- **Groundwater-source heat pump**

This heat pump directly uses groundwater as a heat source. This is the most effective heat source because the groundwater annual average temperatures are the highest. The average groundwater temperature is 13.9 ^{o}C in this case.

It is necessary to check whether the plot of land is located in the groundwater protection area because the groundwater-source heat pump construction and operation is prohibited in some water protection areas. The following map created by the Baden-Württemberg State Office for the Environment, Measurements and Nature Protection shows the water conservation areas in and around Karlsruhe. The house in 8 Mozart street is located in the Weststadt (the district in the west of Karlsruhe) outside the water protection area (Figure 3).

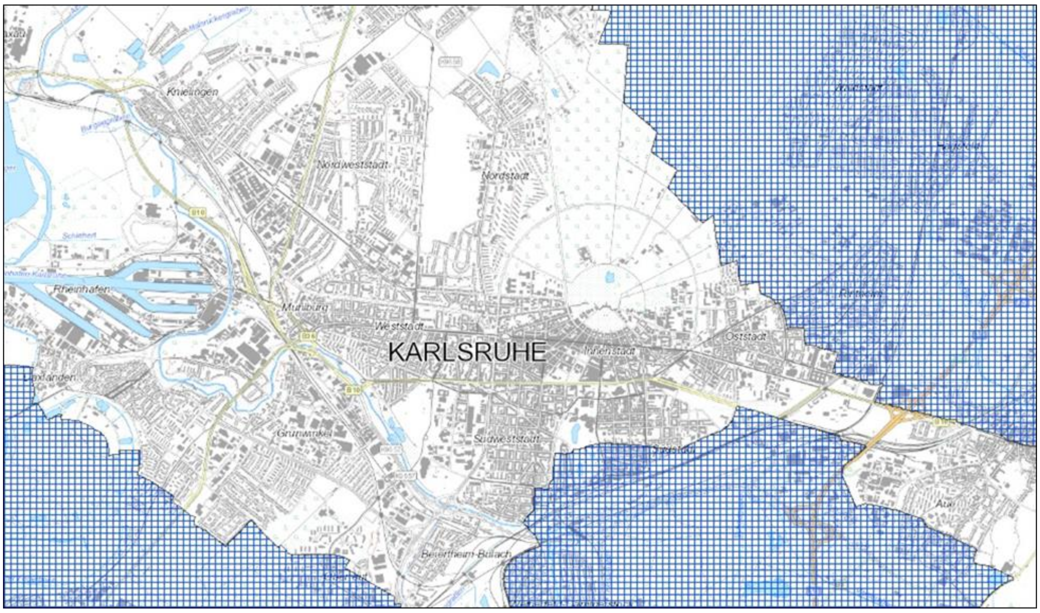

Figure 3. Water protection areas in Karlsruhe and surroundings

The ground water suitable chemical properties are an important condition to use ground water for the groundwater-source heat pump. The ground water should contain no sediments such as iron, manganese, and some other chemical elements. The limiting concentration should not be over the limit values for these elements. The data of the annual ground water catalogue (2000 - 2014) created by the Baden-Württemberg State Office for the Environment, Measurements and Nature Protection have been taken from the well closest to the house to study the ground water chemical composition. It can be clearly seen that some elements exceed the limit values, nevertheless, the excess is not critical. The data are shown in the following table.

Table 5. Ground water chemical properties

	Fe [mg/l]	**Mn [mg/l]**	**pH**	**O_2 [mg/l]**	**LF [mS/m]**	**NO_3 [mg/l]**	**SO_4 [mg/l]**	**Cl [mg/l]**
Average value for 14 years	0.342	0.054	7.207	1.183	66.383	7.003	81.362	34.025
Limit values for special steel heat exchanger	<0.2	<0.1	>7.5	<2	1-50	<100	>1	<300

The drinking water supply is the top priority among the other purposes of ground water use. Consequently, the area hydrogeological situation is always very important while heat pump dimensioning. The use of the upper groundwater bed near surface with free water level is quite smooth. The distance between the groundwater bed and ground surface is approximately 5 m for the given house (Figure 4).

The upper groundwater bed thickness under the plot of land is approximately 30 m. The impermeable horizon starts between the first and second groundwater beds at approximately 35 m. One may drill not lower than 35 m in order not to touch the second groundwater bed.

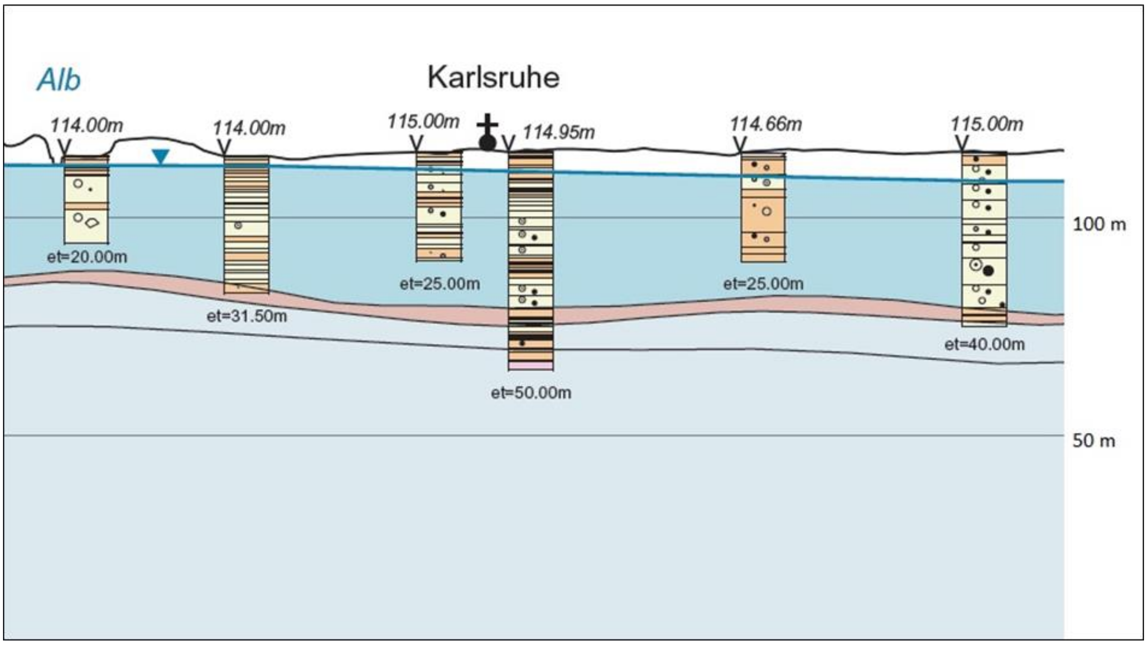

Figure 4. Geologic profile of Karlsruhe

Two heat pumps have been dimensioned for two different heating load values. The Heliotherm HP28S 40W-WEB heat pump with the heat supply of 38,050.0 W has been taken for a heating load of 23,983.0 W. The Heliotherm HP32S45W-WEB heat pump with the heat supply of 42,560.0 W has been taken for a heating load of 34,914.4 W.

The rated consumption is 5-6 m³/hr for the required heating load. Table 6 shows the calculated data.

Table 6. Rated consumption

Heatig load, W	Pump heat supply, W	Evaporator capacity, W	Rated consumption, m³/hr
23,983.0	38,050.0	31,971.7	5.4
34,914.4	42,560.0	35,750.4	6.1

The well capacity and productivity have been calculated depending on the rated consumption (Table 7).

Table 7. Well productivity and capacity

Minimum diameters, m	Maximum penetration, m	Operational range, m	Allowed entry speed, m/s	Filter length, m	Well productivity, m³/h	Well capacity, m³/h
0.05	0.03	4.67	0.003	3	12.14	11.93

The minimum drilling depth is approximately 10 m (5 m of water level + minimum 3 m of filter length). The transport well should be deeper than the absorbing one.

The minimal distance between the transport and absorbing well should be 15 m. It is possible to keep the maximum distance between the wells of approximately 40 m at the considered plot of land. The wells should be drilled perpendicularly to the ground water flow direction. Figure 5 shows the approximate well location at the plot of land.

Figure 5. Well location

- **Geothermal probe**

The other heat pump type that has been dimensioned is a brine-water heat pump with geothermal probes. The ground is a heat source for this pump.

Two cases to supply the building with the possible required heat have been considered like by the groundwater-source heat pump dimensioning. The GeoTherm VWS 300/3 heat pump with the heat supply of 30,000 W has been taken for a heating load of 23,983.0 W. A heating load of 34,914.4 W is used for the GeoTherm VWS 460/3 heat pump with the heat supply of 45,700 W. The evaporator capacity has been calculated for both heat pumps (Table 8).

Table 8. Evaporator capacity

Heating load, W	**Pump heat supply, W**	**Evaporator capacity, W**
23,983.0	30,000	23,333.3
34,914.4	45,700	35,544.4

The drillings with the geothermal probes from 50 to 100 m in length should be carried out through three beds (Figure 6):

- the higher sandy gravel groundwater bed;
- the intermediate bed from clay and sandy clay;
- the second groundwater bed from sand and gravel.

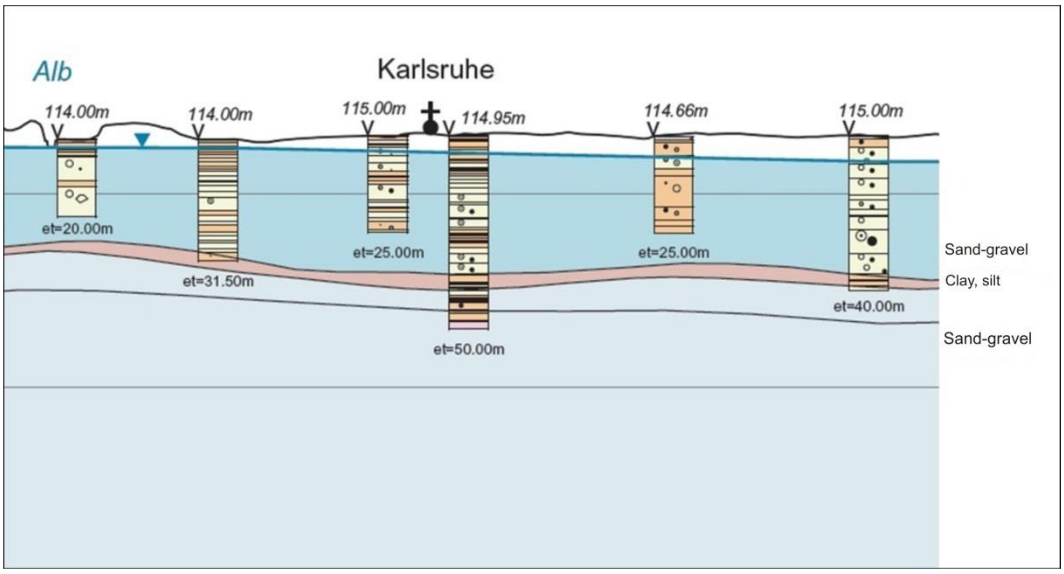

Figure 6. Geologic profile of Karlsruhe

The geothermal probe length has been calculated for the lowest and highest heat generation of the beds. It has also been calculated for two evaporator capacities (Table 9).

Table 9. Geothermal probe length

Evaporator capacity, W	**Geothermal probe length, m, lowest heat generation**	**Geothermal probe length, m, highest heat generation**
23,333.3	534.9	428.1
35,544.4	814.9	652.1

It can be clearly seen that the geothermal probe length is from 428.1 m to 534.9 m for the lower evaporator capacity. Two calculations have been carried out to find the number of the geothermal probes: with probe minimum length 50 m and with maximum one 100 m (Table 10).

Table 10. Number of probes, the first case

Geothermal probe length, m	**Number of probes, 50 m**	**Number of probes, 100 m**
534.9	11	6
428.1	9	4

The maximum number of probes from 50 to 100 m in length is 11 and the minimum number is four for a heating load of 23.983 W.

The same calculation has been carried out for the higher evaporator capacity (Table 11).

Table 11. Number of probes, the second case

Geothermal probe length, m	**Number of probes, 50 m**	**Number of probes, 100 m**
814.9	16	8
652.1	13	7

The maximum number of probes is 16 and the minimum one is seven for a heating load of 34,914.4 W. The calculations show that the minimum overall length of probes is approximately 428 m and the maximum one is approximately 815 m for the given house.

The heat pump with geothermal probes is not cheaper than the groundwater-source heat pump due to the drilling costs.

4. Conclusion

Two heat pump types have been dimensioned in the project: the groundwater-source heat pump and heat pump with geothermal probes.

The first stage of both dimensionings has been to calculate the house standard heating load. Two values of the heating load have been calculated as a result of different calculation methods and used in further dimensioning. The suitable heat pumps have been found for both values in heat pump prospectuses.

The first dimensioning has been carried out for the groundwater-source heat pump. The following aspects have been considered by dimensioning:

- The house location (water protection areas);
- The ground water quality (chemical properties);
- The hydrogeological situation (the distance between the groundwater bed and ground surface, the groundwater bed thickness and its hydrogeological properties).

The hydrogeological research carried out by the Baden-Württemberg State Office for the Environment, Measurements and Nature Protection has been used as well as the hydrogeological maps and profiles.

The well location shown in the report has been provided by means of QGIS.

The second dimensioning has been carried out for the brine-water heat pump. Several cases with different evaporator capacity, heat generation, and geothermal probe length have been considered. Moreover, the minimum and maximum number of probes have been calculated.

The result of the dimensioning suggests that the groundwater-source heat pump is best suited for the given house.

References

[1] The house and plot of land plan.

[2] SGD-Personenkreis Geothermie der Ad-hoc-Arbeitsgruppe Geologie. Fachbericht zu Bisher Bekannten Auswirkungen Geothermischer Vorhaben in Den Bundesländern

[3] The textbook on geothermal heat and groundwater-source heat pumps. The Baden-Württemberg State Office for the Environment, Measurements and Nature Protection, the first edition, April.

[4] 2014 Heat pumps for heating and hot water production, the project engineering and installation book, Dimplex.

[5] Design documentation of air-to-water and brine-water heat pumps. Wolf.

[6] 2011 Heat pump plants, the small guide for beginners, Johannes Wegesin, the first edition.

[7] 2003 *The German Institute for Standardization* EN 2831.

[8] 2011 *Virtual Desktop Infrastructure* 4640

[9] Bleicher A[a], Gross M[ab] 2016 *Renewable and Sustainable Energy Reviews*. Geothermal heat pumps and the vagaries of subterranean geology: Energy independence at a household level as a real world experiment Vol. **64**, pp. 279-288

[10] Lund J.W. Sanner B. Rybach L. Curtis R. Hellström G. 2014 *A world overview (2004) GHC Bulletin*. Geothermal (ground-source) heat pumps. pp. 1-10.

[11] Weber J, Ganz B, Schellschmidt R, Sanner B, Schulz R 2015 *July Congress Proceedings of World Geothermal*. Geothermal energy use in Germany.