Ground–Med Demo Project No.4 – Benedikt, Slovenia

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ABSTRACT

Today, heat pumps are mainly used in developed areas of northern and central Europe. Recent modern, and in particular, large heat pump projects, i.e. for heating and cooling of big shopping centres, are planned to be energetically neutral and used for the interior air conditioning - heating and cooling. In such manner, the operation costs can be reduced up to 45 %, as cooling is based on a passive principle using the cold stored during winter. In order to introduce the utilisation of heat pumps in a warmer, Mediterranean climate of Europe, and reduce enormous energy consumption for cooling during summer and lower the emissions, a five-year-project termed »Advanced ground source heat pump systems for heating and cooling in Mediterranean climate« has been approved by the 7th EU Framework Programme, Theme 5 (energy). The project joins 24 companies and institutions from 13 EU countries. Slovenia is represented by Gejzir Consulting from Ljubljana.

The goal of the project is to reduce the share of electric power consumption to less than 20 % with respect to the total heat production. The pay-back of investment compared with the gas boiler of the same power must be less than seven years and the operation time at least 20 years. The project partners are obliged to develop the prototypes of heat pumps characterised by an improved capacity and more simple operation of the system.

Eight demo-sites were built in the frame of the project: »The Benedikt Culture Centre Demo Project« in Slovenia, Septemes les Vallons in France, University in Oradea, Romania, Fábrica dos Mirandas in Coimbra, Portugal, Polytechnic University in Valencia, Spain, »Solar Plant« in Barcelona, Spain, the HiRef company plant in Tribano, Italy, and the business building of the company Edrasis in Athens, Greece.

The Culture Centre Benedikt is a multi-functional building. An auditorium with 120 seats and the division for guests and employees in the ground-floor encompass an area of 240 m^2. In the attic, a meeting room and business lounge encompass 88,5 m^2. An old boiler that used extra-light oil has been replaced by a modified and improved heat pump, the model GMWW23p, which was constructed by the project partner, the company Ochsner. The existing high-temperature heating system was preserved in the original form. The system of ventilation with a heat-exchanger has been newly constructed and enables cooling or heating of the incoming air. In this manner, the existing high-temperature system has been changed into a low-temperature system.

The heat pump is connected to the system of three BHEs reaching depths of 166 m, 125 m and 98 m, respectively. The system enables active heating and cooling, and passive cooling. Because of the passive cooling, the BHEs are connected into one hydraulic loop. As a medium, pure water free of additives has been chosen. A double U-heat exchanger GEROtherm EWS 4x40 mm produced by Haka Gerodur from Switzerland has been installed in each well, and the wells were finally filled by the ThermoCem PLUS cement produced by the HeidelbergCement from Germany.

The heating of the building started in October17, 2011. During the first heating season (till October 16, 2012) the heat pump operated for 2008 hours and emitted 30 MWh of heat in the heating system. The share of energy obtained from the heat exchangers amounted to over 82 %.

1. INTRODUCTION

Planned reconstruction and remodelling of the premise of Culture Centre Benedikt encloses heating and cooling with geothermal energy using heat pump and well-heat exchangers. The existing systems of radiators, pipelines and channels will be used for heating and air-conditioning. Changed regime of heating is foreseen: the auditorium will be warmed up to 13^{0}C and at 45/40 ^{0}C temperature regime during unoccupied days. During the performance days, the auditorium will be warmed for 12 hours prior the show time using a 70/55 ^{0}C regime to attain 20 ^{0}C. The same holds for all other areas except for the office which is foreseen to be warmed to 20 ^{0}C.

Total area of the building amounts to 290,44 m^2, with ground plan dimensions of 13,70 x 21,20 m. Net area of all rooms and the auditorium amounts to 328,44 m^2.

Space heating is performed with aluminium radiators. Their dimension is calculated in accordance with the »Regulations on thermal protection and efficient use of energy in buildings«. An 8-12 hour break in heating is considered; the project temperature is –13 ^{0}C and the heating season lasts for 235 days per year. The heating system consists of two pipelines operating at the 70/55 ^{0}C regime. The boiler room contains a TAM Stadler boiler, manufactured in 1994 and has a power of 50 kW.

Air conditioning is forced. The intake of fresh air for the auditorium is in the front (façade) and is aided by two channelled electric fans of Pichler&Co trademark and of a capacity of 3 600 m^3/h. The air is blown into the space through round ceiling conduit diffusers. The air outlet is led away to the open air through the ceiling, too. The other rooms are air-conditioned through suction ventilators. The air intake is constructed by slots (slotted panels) from the neighbouring rooms.

Transmission and ventilator losses are calculated with accessories for the position and breaks, and in two variant heating to 13 ^{0}C and 20 ^{0}C, respectively.

Total heating power considering the losses in the pipelines amounts to 14,9 kW and 20,3 kW, with respect to the first and the second variant.

Needed cooling power for the entire building amounts to 33,5 kW; for the auditorium which experiences forced cooling it amounts to 19.211 kW.

According to the modelling of the need for heat and cool, a modified and improved heat pump of the Ochsner trademark, model GMWW23p, has been chosen. Its principal characteristics are shown in Table 1.

Table 1: Principal characteristics of the modified and improved heat pump, medel GMWW23p.

Normal operation mode (heating)

Heating power W10/W35	22,6 kW
Cooling power W10/W35	18,9 kW
Electric power consumption W10/W35	3,7 kW
Heat number (COP) W10/W35	6,1
Startup current W10/W35	7,1 A
Thermal power W10/W50	20,5 kW
Cooling power W10/W50	15,6 kW
Electric power consumption W10/W50	4,9 kW
Heat number (COP) W10/W50	4,2
Startup current W10/W50	8,8 A

Reverse operation mode (cooling)

Cooling power W18/W35	23,1 kW
Amount of waste heat W10/W18	26,5 kW
Electric power consumption W10/W18	3,4 kW
Heat number (COP) W10/W18	6,8
Startup current W10/W18	6,4 A

The heat pump GMWW23p enables active heating and passive cooling. Schematic presentation of the heat pump functioning is shown in Fig. 1.

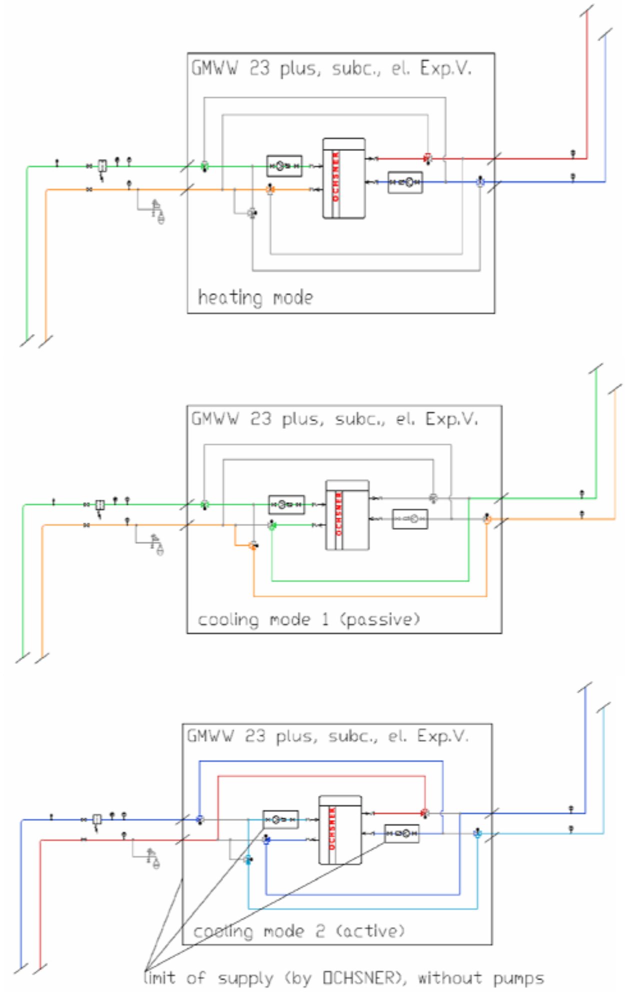

Figure 1: Schematic presentation of the Ochsner heat pump operation during the stages of active heating and passive and active cooling.

2. GEOLOGICAL SETTING

Geological data is based on previous research, mainly of thermal and mineral waters. A detailed study of mineral and thermal water was carried out in the period from 1973 – 1976 and in the year 1997. The Be-2/03 deep well was drilled in 2003/04. The research area of mineral water springs is approximately 900 m apart from the Culture Centre, and the drilling was performed about 150 m north of the premise.

Sarmatian clastic sediments occur till a depth of 220 m, and are locally interbedded by a few metres thick deposits of Quaternary alluvial silts, silty clays and clayey-silty sands with subordinate pebbles, which were deposited by local streams draining from the surrounding hills. Sarmatian sediments consist of marine sand, poorly lithified sandstone, marl, silt and poorly lithified siltstone, quartzitic (pebbly) gravel and conglomerate, and mudstone.

From hydrogeological aspect, the sediments are water-saturated but still poorly permeable.

Geothermal gradient is high and was measured at the mineral water study site (in the years 1976, 1983, 1985 and 1986), as well as in the geothermal well under semistable conditions (January 05, 2004). The measurements performed in the well BS-/76 are regarded the most reliable. They were obtained during drilling works in the winter season, and using cold drilling fluid when the well was in a hypothermal condition. The data is shown in Table 2.

Table 2: Temperature measurements in the well BS-2/76 under stable conditions (Kralj, 2009).

Depth (m)	BS-2/76 (°C)
5	15,3
10	15,4
20	15,7
30	16,2
40	17,0
50	18,0
60	19,1
70	20,1
80	21,0
90	22,0
100	22,8
110	23,6
120	24,7
130	25,7
140	26,6
150	27,4
160	28,0
170	28,7
180	29,5
190	30,2
200	31,0

Measured geothermal gradient amounts to over 8 °C, and the temperature at a depth of 100 m amounts to 22,8 °C, and in a depth of 200 m, it already rises to 31,0 °C. Thermal conductivity of the flooring amounts to 1 600 W/m,K, thermal conductivity of the soil to 2,4 MJ/m^3,K, and geothermal heat flow to 0,2 W/m^2.

2. WELL-HEAT EXCHANGERS

2.1 Optimisation of the field of heat exchangers

Modeling of the above shown parameters lead to the conclusion that the optimal operation can be provided from two 200 m deep well-heat exchangers being 12 m apart, and located along the longer wall of the building. A double U well-heat exchanger GEROtherm EWS having the dimensions of 4x40 mm, produced by a Swiss manufacturer Haka Gerodur, has been mounted in the well, and filled with a cement-mass ThermoCem PLUS, manufactured by the company HeidelbergCement from Germany. The cement-mass does not contain high amounts of cromate and is characterized by good conductivity (λ≈2,0 W/mK). A long-term model of the impact of the well-heat exchanger operation on the surrounding area for a period of 20 years is shown in Fig. 3. From the prediction diagram, a drop of about 0,5 °C is foreseen in the next 20 years in the area immediately surrounding the well-heat exchangers, what means according to the present knowledge that at a distance of 0,5 m from the well-heat exchangers there would be no influence of exploitation any more.

2.2 The construction of the field of well-heat exchangers

In March and April 2011 drilling works and the mounting of well-heat exchangers have been completed. Unfortunately, owing to severe technical problems of the drilling team, the well-heat exchanger reached a depth of only 166 m in the first well. A response-test has been performed in the well immediately after the well construction, and the tests have proven the accuracy of geological data and even shown somewhat better results. In the company Geoteam, a new computer modelling based on the new in situ obtained data has been elaborated, and it has shown that the total required length of the well-heat exchangers amounts to about 380 m. To minimize the risk, it has been decided to build three or four well-heat exchangers to fulfil the required total length foreseen in the new model. For that reason, the distance between the wells has been reduced to 6 m. The second well reached 98 m, and the third 125 m. Another computer modelling has been carried out showing that the field of three well-heat exchangers will suffice the needs of the planned energy demand.

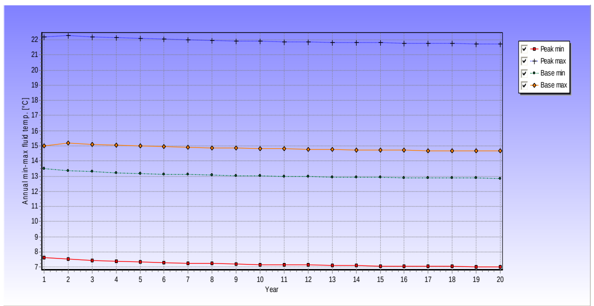

Figure 2: The change in temperature of circulating fluids in the well-heat exchanger for a period of 20 years (Report Geoteam GmbH).

3. CONSTRUCTION OF HEATING SYSTEM AND HEAT PUMP INSTALLATION

Immediately after the termination of drilling works the system of well-heat exchangers has been connected and drawn in the building, and earthworks accomplished. The construction of heat pump by the company Ochsner delayed and it has been shipped just in June. In a few days the whole heating system has been completed and the first testing run performed on June 27 2011. As often occurs in the development projects we also faced some minor technical problems in the start of operation, but they were eliminated till the beginning of the heating season. Since October 17 2011, the system has experienced flawless operation. In this year the installation of measuring equipment is planned in order to accomplish the stated objectives of the project.

As the existing high-temperature heating system has been preserved a solution for additional heating mode had to be found. That has been achieved by installation of slotted panels in the system of air conditioning which enables heating or cooling of the incoming air. The scheme of the system is shown in Fig. 3.

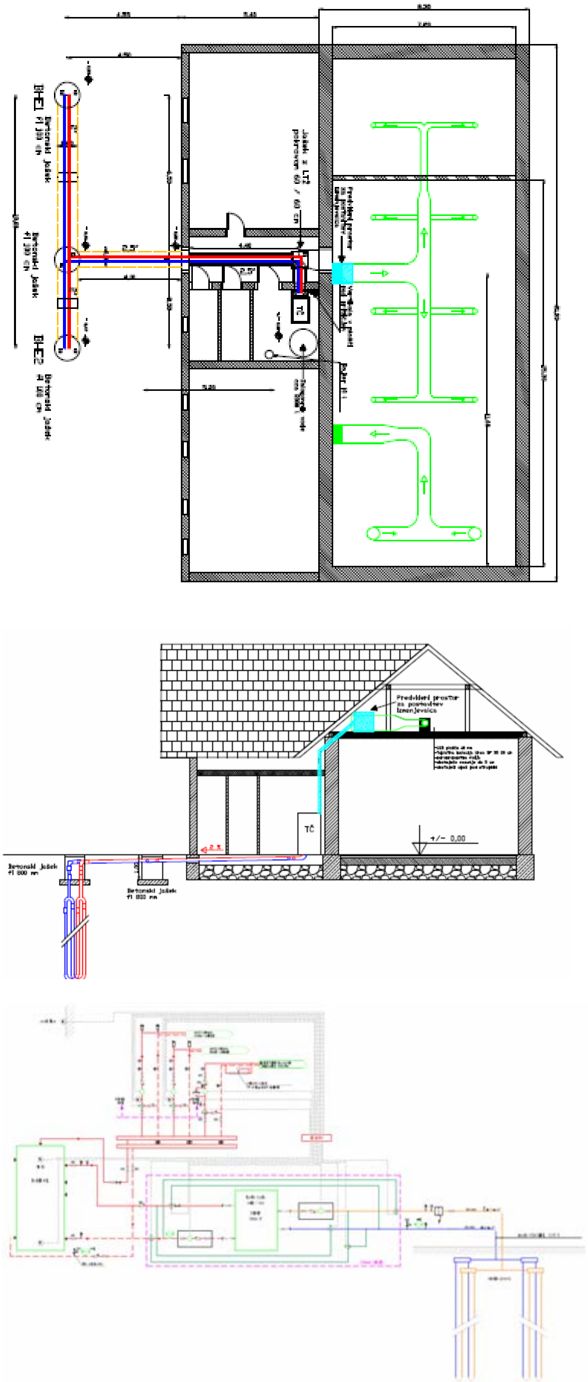

Figure 3: Schematic representation of construction and connection of the well-heat exchangers with the heat pump, and installation of the third branch of the heating system connected to the system supplying fresh air to the auditorium (Kralj, 2009).

4. MONITORING OF PRODUCED HEAT

The heat pump started with operation on October 17 2011. Energymeters UH50-x50 manufactured by Landis+Gyr have been installed on October 16 2012. Since then, the amount of heat produced from the system of well-heat exchangers as well as the heat transmitted into the heating system have been recorded and measured. From October 16 2012 until April 11 2013, 25.425 kWh of heat have been produced from the system of well-heat exchangers for the purpose of heating of the Culture Centre Benedikt, and 33.363 kWh of heat have been distributed into the system, demonstrating the ratio between the heat produced from the earth and the heat emitted in the heating system amounts to 3,2:1, and the SPF_h is 4,2 for the measuring period. Table 3 shows the data.

Table 3: Produced geothermal heat and the heat distributed in the heating system.

Date	Time	Heat BHEs kWh	Heat distr. kWh	T out °C	T in °C
16.10.2012	12:00	0	0	10,70	
24.10.2012	10:45	507	609	10,80	
7.11.2012	14:00	2.079	2522	11,70	
14.11.2012	12:00	2833	3451	9,10	
21.11.2012	18:00	3611	4394	9,70	
25.11.2012	15:00	3999	4866	9,10	
30.11.2012	15:00	4472	5440	7,00	
6.12.2012	9:00	5159	6289	-1,00	
11.12.2012	16:00	5958	7321	-0,90	
18.12.2012	16:00	7337	9.184	4,80	
31.12.2012	9:30	9426	11990	-0,60	20,3
2.1.2013	16:00	9776	12458	0,60	19,9
9.1.2013	13:00	10731	13699	3,70	19,5
18.1.2013	11:40	12382	15883	2,70	19,2
25.1.2013	14:00	13551	17445	1,20	19,8
25.1.2013	21:45	13611	17525	-4,30	19,8
1.2.2013	10:18	14823	19179	3,60	19,2
2.2.2013	11:18	14988	19397	6,80	19,3
11.2.2013	14:00	16592	21548	2,8	19,5
16.2.2013	15:30	17495	22767	5,30	19,4
1.3.2013	14:00	19744	25799	6,30	19,7
8.3.2013	16:00	20777	27167	15,90	20,4
10.3.2013	18:00	20863	27268	9,80	17,6
14.3.2013	18:00	21128	27579		15,9
18.3.2013	17:00	21646	28234	3,90	15,8
22.3.2013	14:00	22088	28793	8,80	17,1
29.3.2013	15:00	23574	30930	6,60	20,7
4.4.2013	19:30	24527	32181	8,80	19,7
5.4.2013	15:30	24669	32365	7,50	20,1
11.4.2013	18:00	25425	33363	16,70	19,2

From Marc 01 to April 11, 2013, the testing of heating system efficiency under various entry water temperatures in the heating system has been carried out. For that reason, the temperature curve in the heat pump program defined at the outdoor temperature of -15 °C and +20 °C has been changing. The temperature defined at the outdoor temperature of -15 °C has been changing in the interval of 5 °C (from 35 °C to 65 °C) with the temperature defined at the outdoor temperature of +20 °C keeping constant at +20 °C. The data is shown in Table 4. The results are expected – with higher entry temperatures in the heating system more additional energy is required, and consequently the efficiency decreases. The objectives for < 20 % additional energy have been greatly exceeded only at low-temperature regime (heating curve +35 °C at -15 °C outdoor temperature and +20 °C at +20 °C outdoor temperature). The data is shown in Table 5. In order to change to exclusively low-temperature regime in the Culture Centre Benedikt at low outdoor temperatures, the whole pipeline system in the heating system should be replaced as the diameter is too small and does not allow a sufficient flow of heating fluid.

Table 4: Produced geothermal heat and the heat distributed in the heating system at various entry temperatures in the heating.

HEATING CURVE
50 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
01.03. 14:00		19.744	25.799			
08.03. 16:00	170	20.777	27.167	1.033	1.368	**4,08**

HEATING CURVE
35 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
08.03. 16:00		20.777	27.167			
14.03. 18:00	146	21.128	27.579	351	412	**6,75**

HEATING CURVE
40 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
14.03. 18:00		21.128	27.579			
18.03. 17:00	95	21.646	28.234	**518**	**655**	**4,78**

HEATING CURVE
45 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
18.03. 17:00		21.646	28.234			
22.03. 14:00	93	22.088	28.793	442	559	**4,78**

HEATING CURVE
65 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
22.03. 14:00	0	22.088	28.793			
29.03. 15:00	169	23.574	30.930	1.486	2.137	**3,28**

HEATING CURVE
60 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
29.03. 15:00		23.574	30.930			
05.04. 15:30	168,5	24.669	32.365	1.095	1.435	**4,22**

HEATING CURVE
55 °C (-15 °C outside T.) .... 20 °C (+20 °C outside T.)

Date 2013	Time (hour)	Energy Ground (kWh)	Energy Heating S. (kWh)	Energy Diff. Ground (kWh)	Energy Diff. Heat. S. (kWh)	**SPF_h**
05.04. 15:30		24.669	32.365			
11.04. 18:00	146,5	25.425	33.363	756	998	**4,12**

Table 5: Efficiency dependence on the entry temperature of the heating system.

HEATING CURVE	SPF $_{(Heat)}$
35 °C (-15 °C outside T.) .. **20 °C** (+20 °C outside T.)	**6,75**
40 °C (-15 °C outside T.) .. **20 °C** (+20 °C outside T.)	**4,78**
45 °C (-15 °C outside T.) .. **20 °C** (+20 °C outside T.)	**4,78**
50 °C (-15 °C outside T.) .. **20 °C** (+20 °C outside T.)	**4,08**
55 °C (-15 °C outside T.) .. **20 °C** (+20 °C outside T.)	**4,12**
60 °C (-15 °C outside T.) . **20 °C** (+20 °C outside T.)	**4,22**
65 °C (-15 °C outside T.) . **20 °C** (+20 °C outside T.)	**3,28**

3. CONCLUSIONS

The Demo-project Benedikt has proven that the existing industry of heat pumps disposes with technology that already enables the production of low-temperature geothermal heating systems with heat pumps that require less that 20 % of additional heat.

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