Tabel 1.5.1 *Principal parameters of geothermal, balneological and heat-pump installations in Poland.*

| Localization | Flow Rate [$m^3$/godz] | Temperature [$^oC$] | Installed capacity Total/Geothermal [$MW_t$] | Production [TJ/rok] |
|---|---|---|---|---|
| Geothermal Plants | | | | |
| Podhale | 670 | 86 | 54.6 / 15.5 | 264 |
| Pyrzyce | 340 | 61 | 48.0 / 15.0 | 130 |
| Mszczonów | 60 | 41 | 7.4 / 1.1 | 45 |
| Uniejów | 120 | 68 | 5.6 / 3.2 | 19.6 |
| Stargard Szczeciński | 300 | 87 | 10.0 / 10.0 | 120 |
| Total | | | **125.6 / 44.8** | **578.6** |
| Balneotherapy | | | | |
| Cieplice | 27 | 36 - 39[1] | 0.3 / 0.3 | 10.0 |
| Lądek | 50 | 20 - 44 | 0.76 / 0.76 | 15.0 |
| Duszniki | 20 | 19 - 21 | 0.05 / 0.05 | 0.7 |
| Ciechocinek | 200 | 27 - 29 | 1.9 / 1.9 | 2.8 |
| Konstancin | 9 | 29 | 0.15 / 0.15 | 0.2 |
| Ustroń | 3 | 28 | 0.06 / 0.06 | 0.6 |
| Iwonicz | 11 | 21 | 0.14 / 0.14 | 0.6 |
| Total | | | **3.36 / 3.36** | **29.9** |
| Heat Pomps | | | | |
| Słomniki | 53 | 17 | 1.8 / 0.35 | 0.25 |
| Pompy ciepła kilkaset | | 7 - 25 | >80 / >53 | >500 |
| Total | | | **>81.8 / >53.35** | **>500.25** |
| Total | | | **>210.76 / >101.51** | **>1 108.75** |

1-mixed water temperature (20-62 C)


Fig. 1.5.1 *Localization of operating geothermal (without installations utilizing soil heat) and balneological plants versus geothermal units.*

*1 - on-line geothermal plant, 2 - other planned to construct, 3 - spas using geothermal waters from springs or wells.*

## 1.5 Utilization of geothermal waters and energy in Poland

The R&D projects run in Poland since the half of 1980-ties led to the opening of five geothermal plants: in Podhale, in Pyrzyce, Mszczonów, Uniejów and Stargard Szczeciński. Moreover, several installations operate based upon groundwaters of temperatures below 25$^o$C and several hundreds of installations are in use based upon heat pumps and ground thermal energy. Geothermal energy is practically not used for recreation although climatic and hydrogeothermal conditions in Poland are similar to those in adjacent Slovakia where water centers and therapeutic pools became an important branch of national economy. Recently, projects are at various stages of design in Poland (Podhale and Central Poland), which will utilize geothermal waters for recreation.

Installations mentioned above were classified into three groups (Tab. 1.5.1). Group I includes plants utilizing waters of temperatures reaching several tens of Celsius degrees. Group II comprises balneotherapeutic installations and group III contains heat pumps systems, for which working media are groundwaters and ground of temperatures below 25$^o$C. The 25$^o$C threshold was assumed as conventional value because this is practically the maximum temperature of lower source for effectively working compressor heat pumps.

According to data for January 1$^{st}$, 2006, the installed thermal power of all geothermal plants in Poland (including heat pumps) amounted about 210 MW$_t$ and the annual heat generation was a the level of 1 108 TJ/year (tab. 1.5.1).

Total installed power in the three groups of installations exceeds 210 MW$_t$. Almost half of that figure (over 101 MW$_t$) is supplied by geothermal energy whereas the remaining about 110 MW$_t$ originates from gas, oil and electricity. These traditional energy carriers are applied to drive absorption pumps (gas), compressor pumps (electricity) and peak load sources (gas and oil boilers) as well as heat/power cogenerators (gas).

Despite the described geothermal installations several other projects are at various stages of development. In many localities studies and preliminary works are executed, which aim to utilize geothermal energy. Wide spectrum of applications is considered: from space heating through balneotherapy and recreation to agriculture, gardening and fish farming.

## 1.6 Description of geothermal installations operating in Poland

Recently, there are five geothermal plants operating in Poland, which use geothermal waters for heating purposes, i.e. central space heating systems and warm water supply. These are: Bańska-Biały Dunajec geothermal plant in the Podhale Trough and Pyrzyce, Mszczonów, Uniejów and Stargard Szczeciński geothermal plants in the Polish Lowlands.

### The geothermal plant in Bańska-Biały Dunajec (Podhale Trough)

The space heating system managed by the PEC Geotermia Podhalańska Joint Stock Co. includes three main cycles with two main energy sources:

- geothermal system with geothermal energy source;
- space heating system with peak load energy source;
- customers installations.

### Geothermal system

The principal energy source is the groundwater horizon hosted in Triassic and Eocene (so-called „Nummulitic Eocene") carbonates at depth interval 2 200 - 3 100 meters b.s. The horizon is exploited with two production wells: Bańska IG-1 and Bańska PGP-1 whereas two other wells: Biały Dunajec PAN-1 and Biały Dunajec PGP-2 are the injection ones (fig. 1.6.2).

Total discharge from production wells is 670 $m^3$/h at water temperature up to 86$^o$C, static wellhead artesian pressure over 2.7 MPa and low TDS (about 2.5 g/$dm^3$). Geothermal water is directed to plate heat exchangers of 35 $MW_t$ power where heat is transferred to secondary water circulation system. After heat exchange cooled water is transferred with disposal pipe to pumping station and injected back to the aquifer through injection wells. The power of this geothermal energy source is about 15.5 $MW_t$.

### Customers installations

Heat is delivered to customers with the pipeline system. Each customer has an individual heating unit adapted to his load, which includes space heating (sh) and warm water supply (wws). Three types of units of various parameters are in use: 15 kW sh/33 kW wws, 25 kW sh/43 kW wws and 33 kW sh/50 kW wws. Each unit has its own control system, which enables the payment settlements for supplied energy.

In 2004 the energy sale reached 264 000 GJ. Currently, the geothermal heating system includes 490 individual customers (232 in Zakopane and 258 in Bańska, Biały Dunajec and Poronin villages), 146 heavy buyers (131 in Zakopane, including 90% of hotels and 15 in Bańska, Biały Dunajec and Poronin) as well as 27 local coal- and coke-burned boilers in housing estates. Expansion of the system in 2003 allowed to reduce annual carbon dioxide emission in the area by 22 148 tonnes.

### Cascaded system of geothermal energy distribution

Such system is currently operating at the Geothermal Laboratory of the MEERI PAS in Geothermal Plant in Podhale. It enables the studies on multidirectional development of geothermal energy. Cascaded heat supply includes five stages of heat distribution based upon secondary circulation loop (fig. 1.6.3).

The first stage is the geothermal space heating system, which supplies heat and warm water to multi-storey buildings, individual houses and public service buildings. Water of highest temperatures is utilized (85 - 65$^o$C).

The second stage is a timber drying room, which heating system uses water of temperature 60$^o$C. Commonly, the recently operating timber seasoning installations use water of much higher temperatures (over 90$^o$C).

The third stage is the parapet greenhouse suitable for gardening of vegetables and decorative plants. Designed working temperature is about 45$^o$C, which requires installations of 3 times larger heating surface of radiators. In a traditional greenhouse plant has to be grown on parapets beneath which the sets of radiators are installed.

The fourth stage is the fish farm where stenothermal species are bred. Geothermal heat is used for re-heating water to temperatures about 35$^o$C. Breeding of stenothermal fish species requires the stable heat source, which would ensure optimum working temperatures of water in tanks. i.e. between 20 and 33$^o$C. Average annual fish growth varied from 167 to 210% and feeding coefficient was from 1.14 to 0.93 (i.e. from 1.14 to 0.93 kilograms of feed were used for 1 kilogram of fish body mass). These results indicate very good living conditions, perfect for African catfish (Bujakowski, 2000).

The last, fifth stage includes with heated soiled tunnels, suitable for vegetables growing. Water of temperature 30 - 40$^o$C is directed to pipe system. The main heat radiator is a grid of plastic tubes embedded within soil at 30 - 40 centimeters depth. Supplementary system of eight tubes is mounted about 50 centimeters above soil surface. Two tubes are located along house walls and others along its axis. Such heating system enables significant extension of plant growing season. Under hard climatic conditions of Podhale region all-year vegetables growing is possible (tomatoes, cucumbers, paprika, various lettuces, radish), excluding maintenance and soil regeneration (Bujakowski, 2000). Next stage of designed cascade system will be the swimming pool.

### The geothermal-gas plant in Pyrzyce

Pyrzyce is a small town (some 14 000 residents) in northwestern Poland, located 40 kilometers south from Szczecin. Geothermal plant was opened in February, 1996 and the heat supply system was ready on June 10th, 1997 (Maliszewski, 1997; Sobański et al., 2000). The plant replaced 68 local boilers.

Geothermal installation includes several modern solutions. Similarly to the Podhale plant, this system comprises both the geothermal and the peak-load energy sources but here the absorption heat pumps were applied together with primary and secondary heat exchangers in order to enhance heat removal (fig. 1.6.4).

### The geothermal water intake works at the following parameters:

- reservoir - Liassic sandstones;

- depth to reservoir top - 1 489 [m];
- thickness of groundwater horizon - 147 [m];
- reservoir temperature - 64 [$^o$C];
- TDS - 121 [g/dm$^3$];
- number of production wells - 2;
- number of injection wells - 2;
- discharge - 340 [m$^3$/h];
- thermal power of geothermal installation - 15.0 [MW$_t$];
- distance between production and injection wells - 1.5 [km].

**Basic parameters of power plant and heat distribution system are as follows:**

- 2 low-temperature, gas-burned boilers - 20.0 [MW];
- 2 flue-gas coolers with steam condensers - 2.2 [MW];
- 2 gas-burned boilers (working temp. about 160$^o$C) - 16.0 [MW];
- 2 flue-gas coolers with steam condensers - 1.8 [MW];
- primary heat exchanger - 7.2 [MW];
- secondary heat exchanger combined with the APG - 7.6 [MW];
- working medium: water - 95/40 [$^oC$];
- hot water flow rate - 340 [t/h];
- length of pipeline system - 15 [km];
- maximum pipe diameter - 450 [mm].

Total thermal energy production in 2004 amounted about 130 000 GJ/year and carbon dioxide emission was reduced by about 82 000 t.

### The geothermal plant in Mszczonów

The geothermal water intake (the Mszczonów IG-1 well) reveals the following parameters:

- reservoir - Lower Cretaceous sandstones;
- depth to reservoir top/bottom - 1 602/1 714 [m];
- thickness of groundwater horizon - 112 [m];
- reservoir temperature - 41 [$^oC$];
- discharge - 60 [m$^3$/h];
- TDS - 0.5 [g/dm$^3$] (fresh water).

Geothermal plant is capable to supply sufficient energy to the district heating system until air temperature is over -5$^o$C. At lower temperatures water must be additionally heated with the gas boiler. Moreover, geothermal water is utilized as potable water.

The systems is similar to that operating in Pyrzyce (fig. 1.6.5). Thermal water is produced from the Mszczonów IG-1 well supplied with deep well pump. Due to low cohesiveness of Lower Cretaceous reservoir sandstones the installation has been equipped with solid particle separators and sand-fraction removal station. The well-head was equipped with standard control unit for measuring discharge, well-head temperature and depth to water piezometric surface.

Total installed power of the plant reaches 7.4 MW$_t$, which includes: absorption heat pump (2.7 MW$_t$) and supplementary, low-temperature, gas-burned boilers working at low air temperatures. Heat pump cools geothermal waters to about 25$^o$C. Estimated power from geothermal reservoir is about 1.1 MW$_t$ and the annual energy production in 2004 was about 45 000 GJ.

Geothermal plant in Mszczonów replaced three municipal, coal-burned boilers, which were releasing annually 15 t of nitrogen compounds, 60 t of sulphur compounds, 9 700 t of carbon dioxide and 145 t of fly ash. The plant improved the living conditions in the town by reduction of fly ash and sulphur compounds emission to zero, nitrogen compounds emission to 1 t/year and carbon dioxide emission by four times.

### The geothermal plant in Uniejów

Geothermal resources in the Uniejów area were assessed for the first time in 1978 with the Uniejów IG-1 well drilled by the State Geological Institute. Next two wells: Uniejów AGH-1 and AGH-2 were completed in 1990 - 91 as a part of joint project run by the Institute of Fossil Fuels, Faculty of Exploration Geology, University of Mining and Metallurgy in Kraków and the State Geological Institute. Well-head temperature of geothermal water is 68$^o$C. Reservoir rocks are Lower Cretaceous sandstones occurring at 2 000 meters depth. Discharge is 68 m$^3$/h at the artesian pressure 2.6 bars. Water is low in TDS (8 g/dm$^3$) and reveals chloride-sodium/fluorine/boron composition.

Total power of the plant reaches 5.6 MW in which 3.2 MW is generated from geothermal waters. If air temperature drops below -5$^o$C the heating system is supported by oil-burned boilers of total power 2.4 MW. Water produced with deep well pump at the rate 90 - 120 m$^3$/h is piped to filtration unit and then to the two central heat exchangers and two warm water heat exchangers. Cooled water is pumped back to the reservoir through injection wells.

Heat distribution system comprises pipeline network of cumulative length 10 kilometers constructed with pre-insulated pipes and equipped with controlling devices and valves. Heat-generation plant and distribution systems are controlled and monitored by integrated computer system, which facilitates the control and diminishes energy losses.

The Uniejów Geothermal Co. has completed 180 connections from which 30 are heavy buyers who share 80% of total heat consumption. These are apartment buildings, school, nursery, offices, banks and private companies. The remaining connections supply heat to individual customers. The heating system started in September, 2001. Geothermal energy constitutes about 70% of total generated heat. Since July, 2002 studies have been run on utilization of geothermal water for therapeutic purposes. If positive results are obtained a healing center will be developed in the Uniejów commune, which should reduce the running costs of geothermal plant.

### The geothermal plant in Stargard Szczeciński

In early 2005 geothermal installation was opened in Stargard Szczeciński town. First drilling started in September, 2001 and was completed in April, 2002 at the depth of 2 670 meters where geothermal reservoir was discovered and assessed in Lower Jurassic formation. Recently, two geothermal wells are in operation: vertical, production GT-1 well and directional, injection GT-2 well (drilled at $39^o$ deviation), both spaced by 11 meters. Geothermal water is pumped to the surface at the rate of 300 $m^3/h$ and at wellhead temperature $87^oC$.

The designed, full annual heat production will be 300 000 GJ. Primary heat exchangers power is about 10 $MW_t$. Heat is transferred with 200-meters-long pipeline to the P.E.C. Ltd. - a heat-generation company owned by local municipalities, which supplies heat to the customers using its own pipeline system.

Exploitation of geothermal heating system will allow to save about 15 - 17 thousands tons of fine coal per year, which will significantly reduce environmental pollution in the area.

### Geothermal installation in Słomniki

In 2002 geothermal installation has started operation in Słomniki near Kraków. Installation is supplied by shallow artesian groundwater horizon located at depths 150 - 300 m b.s. Fresh water of temperature $17^oC$ flows at pressure about 0.4 MPa and at the rate of about 50 $m^3/h$. Groundwater is transferred to heat pumps from which energy is supplied by pre-isolated pipeline to school, to apartment and municipal buildings, and to individual buyers. Cooled water is utilized by municipal potable water supply system. Heat pump (320 $kW_t$) is localed in a station, which supplies energy to the housing estate. Other heat pumps are installed in three houses. Total power of the system is 1.8 $MW_t$.

Geothermal installation in Słomniki is typical of small housing estates comprising apartment buildings and individual houses. Also hydrogeological conditions of shallow groundwater reservoir are typical of vast areas in Poland. If succeeded, this installation can be the model solution for many small towns in the country.

## 1.7 Usability prospects of geothermal brines from Paleozoic and Mesozoic formations in the Polish Lowlands for balneotherapy and recreation purposes

Geothermal water resources connected with Paleozoic and Mesozoic formations in the Polish Lowlands basin are not only the source of heat but also represent valuable brines that may be used for example for production of medicinal and cosmetic salts. For such a purpose the brines of Cl-Na, Cl-Ca and Cl-Mg type are most suitable. Locally in the area of Polish Lowlands there occur also valuable brines of $SO_4$-Na type. The brines from practically all the aquifers of the Polish Lowlands basin contain specific elements of iodine, bromine and iron.

Geothermal waters from Cretaceous and Upper Jurassic aquifers are most suitable for recreation i.e. swimming and bathing whereas waters from Lower Permian formations maybe used in balneotherapy.

The waters from Devonian, Carboniferous, Lower & Upper Triassic, Lower & Middle Jurassic reservoirs may be utilized both for recreation, bathing and balneotherapy. Those brines characterize of high content of bromine, sometimes also potassium and magnesium (Bojarski, 1996). Hydrogeological data acquired hitherto show that the reserves of high-salinity brines in the Polish Lowlands basin are sufficient to start industrial production of bromine, potassium, magnesium and iodine.

Balneotherapy as well as water recreation using subsurface geothermal brines creates promising and attractive line of tourist business. Tourism may profit by multifunctional and ecological (reducing air-pollution) use of deep geothermal waters including heating the hotels, guest and rest houses, swimming pools and entire health and water resorts. Therefore, exploration and utilization of geothermal waters from deep wells promotes the development of regionally balanced tourism.

Searching for subsurface geothermal brines in Poland has been neglected for a long time. However, the idea of their utilization has been developed from 19th century and there are 37 quite popular and traditional spas in Sudetic and Carpathian mountains as well as along Pomorze-Kujawy segment of Mid-Polish High (striking NW-SE) where mineral and geothermal waters from wells and springs are used. Still, those water sources in Poland seem to be insufficient so that great many Polish tourists prefer to visit geothermal spas in Slovakia, Hungary, Czech and Austria. This proves for a great demand for balneotherapy and water recreation of that type in our country.

Poland has at disposal large resources of geothermal waters usable for balneologic and recreation purposes specifically in the area of the Polish Lowlands, Sudetes Mts., Carpathian Mts. and Carpathian Foredeep.

The Polish Lowlands area of North European Paleozoic Platform embracing northwestern and central Poland as well as East-European Precambrian Platform („Old Platform") extending east of Teisseyre-Tornquist deep fault zone were analysed in order to apprise the prospects of utilization of Paleozoic and Mesozoic geothermal waters for balneology and recreation (Paczyński & Płochniewski, 1996).

Reasoning from scientific literature and the results of hitherto hydrogeological and petroleum geology research as based on well data (Fossil Fuels Dept., AGH University of Science and Technology, Cracow & Polish Geological Institute PIG, Warsaw Database) the evaluation of prosperous geothermal water zones usable for balneotherapy and recreation purposes has been carried on. Specifically the evaluation presented here comes from such hydrogeological data as salinity, temperature and chemical composition (also specific components) of subsurface brines. This is primary selection and classification of hydrogeothermal zones useful for the above purposes to turn attention for the prospects of deep brines utilization and to realize the size their unexplored potential reserves that occur over considerable area of the Polish Lowlands.

Once positive promise for subsurface geothermal brines exploration and utilization is decided then more detailed feasibility study and analytical project has to be completed according to appropriate decrees of Polish Ministry of Health (2.11.2002), Ministry Council (27.02.2006) and the due Law (1.09.2005).

In the Atlas presented here the subsurface waters of salinity not exceeding 70 $g/dm^3$ and temperature less than about 60$^o$C are classified as usable for recreation purposes. Swimming and bathing needs waters of salinity not more than 35 g/dm$^3$ and temperature from 24$^o$C to 30$^o$C. Therefore, deep subsurface brines usually of higher salinity and temperature have to be mixed with fresh surface waters to meet the above requirements (Paczyński & Płochniewski, 1996; Ponikowska, 1995).

The description of hydrogeothermal zones presented here usable for balneotherapy and recreation purposes considers also their geological and geographical location and physiographic characteristic of well sites. The hydrogeological well sites with indications on nearby rivers, lakes forests etc. are usually mentioned from north to south and from west to east. The distances in kilometers are mostly given by road.

Exploration of subsurface reservoirs of geothermal brines not only for heating but also for balneotherapy and recreation creates great opportunity for environmentally friendly and balanced development of touristic regions in the Polish Lowlands.