GEO-THERMAL DISTRICT HEATING AIR CONDITIONING PLANT AND DISTRIBUTION SYSTEM IN VICENZA

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Abstract

A large low enthalpy geothermal water reservoir was discovered at about 2,000 m deep in permeable calcareous rocks by a Agip society oil exploration.

A geothermal well was drilled by Agip-Enel joint-venture in an area suited for the implementation of a district heating plant. The well produces 100 m /h water with low contents of salts at a temperature of 67 °C.

The project, undertaken by the Aziende Industriali Municipalizzate of Vicenza, a municipality owned company, foresees the exploitation of this hot resource by means of a complex and multifunctional energy system, including a district heating plant equipped with geothermal water storage tanks. The district heating plant will be remotely controlled from an existing multifunctional control station.

Commercial and residential buildings with 95 substations are connected to the system.

Efficiency system is about 1.85, fossil fuel saving (in case of gas working heat pump engines) is expected 3,341 tep/year, equivalent to 60% of existing system total consumptions. These values are referred to erogation conditions foreseen in the project.

INTRODUCTION

HEATING AND COOLING PROJECT

The "Vicenza" geothermal heating and cooling project was developed by "Aziende Industriali Municipalizzate", a utilities company owned by the city of Vicenza, with the purpose of distributing aproximately 39,900 kWh of heating energy a year, an amount which roughly corresponds to the energy needed to heat about 4,000 apartments in the northern sector of the town (table 1).

The project includes the installation of a power plant and a distribution system to exploit a geothermal water source drilled from underneath the city ground with the average temperature of 67 centigrades. It is predicted that a reduction in the consuption of conventional fuels both for heating and sanitary water will be achieved through a highly efficient thermo-dynamic system based on reversable heat pumps.

The system provides heating in the winter and air conditioning in the summer.

INSTALLATION - MANAGEMENT OF THE PLANT - TECHNICAL SUPPORT

The drilling phase of the project was undertaken and completed under a "AGIP-ENEL"(AGIP: State Owned Oil Company; ENEL: State Owned Electricity Company) joint-venture, partially finananced by the European Community. The drilling phase was completed in 1983 with the opening of a well (from now on referred to as "Vicenza 1"), which stands today as the first deep-drilled well within an urban precint in Italy.

This paper decribes the utilization of the geothermal water tapped from the "Vicenza 1" deep well, the feasibility study, and the contract for the design and installation of the plant.

The project design was developed by the firm "ELC-ELECTROCONSULT" of Milan, while the actual construction was contracted out to "ASTER-ASSOCIATE TERMO-IMPIANTI", another Milano-based firm.

A.I.M. Vicenza was then and still is responsible for distributing heating gas, water and electricity within the town precint and in the sorreunding area, besides providing for other public services such as public transportation and garbage collecting. It therefore acquired the task of distributing of all energy processed and produced by the plant. The undertaking of this project by AIM falls within the larger scheme of the overall municipal energy system.

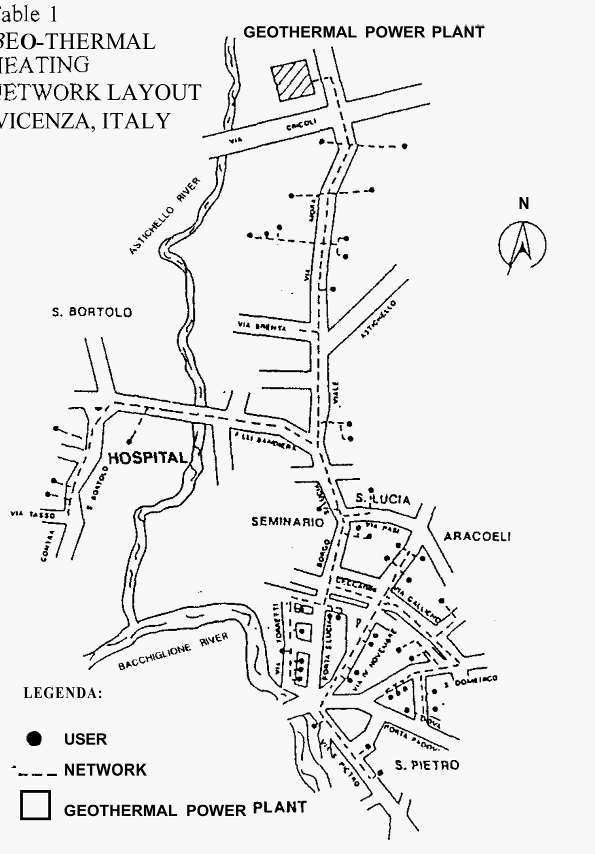
FINANCIAL MANAGEMENT

The immediate benefits provided by the project are a note-worthy reduction in conventional fuels usage, improved quality of service and the exploitation of a local, environment-friendly and self-reproducing energy source.

The total investment and operation budget is influenced by variablefuel costs, but overall investment in the project come close to 16,000 million lira (10 million dollars). Design and construction of the plant cost about 8,400 million lira, installation of the distribution network about 4,300 million lira, the construction of sub-stationsabout 3,300 million lira.

Recurring costs are determined by operation, maintenance, use of fuels, electricity and geothermal tax. Production income is based on the sale of heating energy, sanitary water, and cool water for air conditioning purposes.

Table 1
GEO-THERMAL HEATING NETWORK LAYOUT VICENZA, ITALY



PROJECT CHARACTERISTICS

GEOTHERMAL ENERGY

The existence of a natural geothermal reservoir underneath the Vicenza town precint came to be known through an oil prospecting undertaken by "AGIP". The well referred to as "Vicenza 1", was drilled between July and September **1983** by a joint venture AGIP-ENEL and reachs 2,150 meters of depth.

Rock formation and well characteristics are detailed in table 2. The outside structure of the well down to **1,487** meters is enclosed with metal pipes. The open well lays just underneath, at the same level as the water permeable rocks.

The static water level is **23** meters under the ground and during the production phase it goes down to **122** m. The average water exit temperature is 67 °C. The water has a low salt content (less than 0,5 g/l) and a low content of idrogen sulphide (less than 1 g/l). Water properties are such to allow safe discarge of residual fluid into the Vicenza sewage system.

SUPPLEMENTARY SANITARY WATER NETWORK

Water comes out of the "Vicenza 1" well at the costant average temperature of 67 °C, which is compatible with the requirements for hot sanitary water (h.s.w. about 50 °C). However it is clearly not warm enough for heating purposes, since the existing plants require an average temperature of 80/90 °C.

The installation of a supplementary geothermal water network will allow for independent heating of water on users' site, with no need for heat pumps. The immediate benefit is a reduction in overall consumption of electricity and other fuels.

This is a great advantage for the final-user because the sanitary water circuit is active all year long and the geothermal water can be safely discharged into the sewage pipes. There is a possibility that in the near future water may be funneled directly to users faucets with no need for heat-exchange units, provided water corrosion effects will be resolved.

Furthermore it will be possible to store geothermal water in the plant and to rationalize its consumption.

The water temperature is however insufficient for heating purposes and therefore it needs to be increased through heat pumps and boilers installed in the plant. The heat pumps are installed next to the well. This plant is the first element of a heating circuit where the water reaches a maximum temperature of 90 "C.

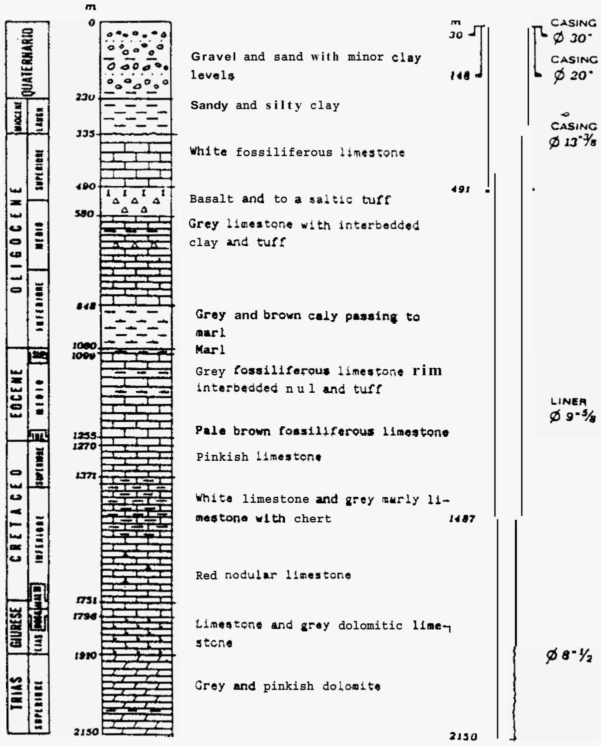


Table 2
LITHO-STRATTGRAPHIC PROFILE
WELL ROCK FORMATION VICENZA 1 WELL

The criteria used to assess the best choise of possible users distribution of users' and circuit layout are:

- Energy production in relation to location and nature of potential users,
- Energy efficiency, with emphasis on single-pipe circuits at low temperature,
- Economic and energy-efficient heat pumps motors,
- Operational costs monitoring and related financial advantages,
- Future development in terms of resource utilization and cogeneration systems.

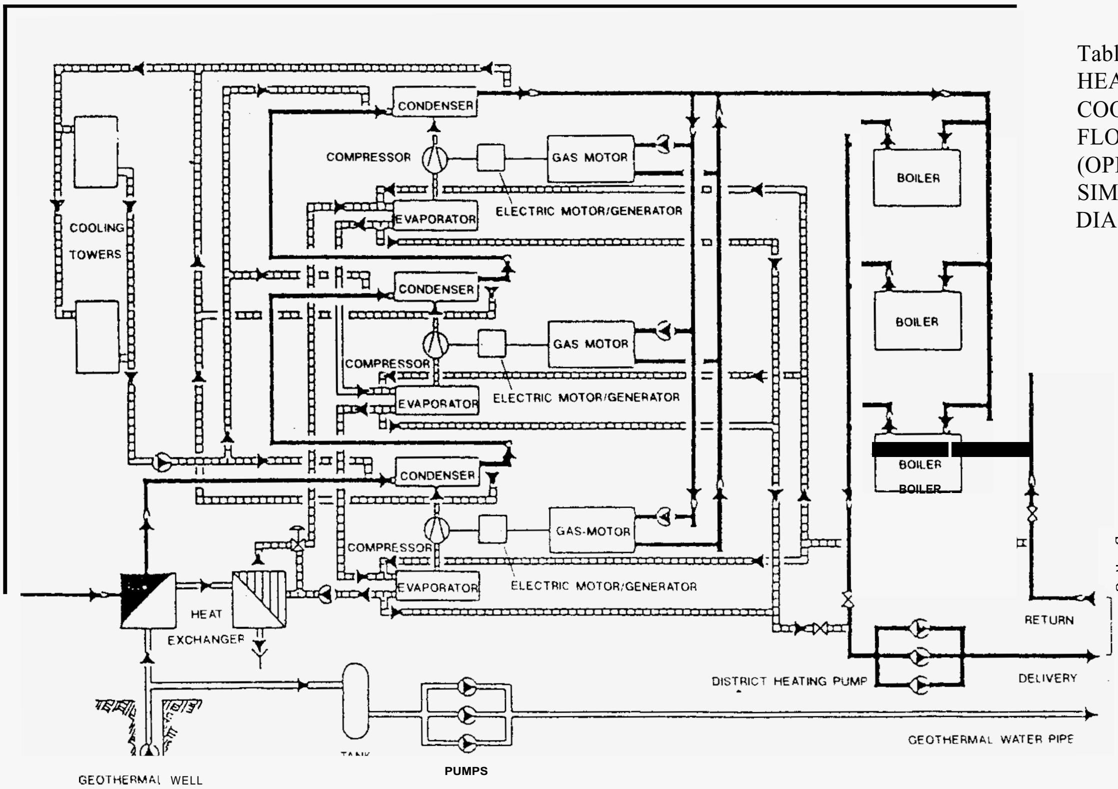


Table **3**
HEATING AND COOLING PLANT FLOWCHART (OPERATION SIMPLIFIED DIAGRAM)

DISCHARGE TEMPERATURE OF THE GEO-WATER

It has been calculated that the variation in temperature discharge will go from a minimum of 20 °C during off seasons and 25 °C during the coldest periods. The difference between normal heating balance in the pipes (about 60 °C) and the peak temperature for heating purposes (90 "C), is such to guarantee an economically efficient use of the energy source. The expenditure of energy necessary for further decreasing the temperature is however not economically satisfactory, in the sense that is is not payed off by the heat produced.

HEATING AND COOLING PLANT

The plant has been designed to produce heating in the winter and air conditioning in the summer, through use of dual-power heat pumps. The same pumps operate with motors that can be fueled both by natural gas or by electricity. The plant was built near the geothermal well and has the following components:

- water-to-water heat pumps that run on electrically or gas-powered engines,
- supplementary boilers (3x5 Gcal/h),
- heat-to-electricity unit to interface between the geothermal water and the water in the district heating distribution pipes.
- Cooling towers connected to the heat pumps with refrigeration equipment for the summer months.
- Collection and pumping systems both for heating and cooling, pumping and storage of geothermal water.

The plant flowchart is reproduced in table 3. The sanitary water circuit requires about one sixth of the overall well capacity, the remaining 5 sixths are required for the operation of the heating distribution circuit, both through direct exchange or through the heating pumps. The heating pumps are installed one next to the other and the geothermal water goes through different cooling cicles in evaporators. The water funneled into the heating pipes is heated by condensers. The two flows operate therefore side by side but in opposite directions.

As the water comes out of the heat pumps at peak thermal use, it is heated to reach the thermal output temperature required by the system. At lower level of usage and return temperature, the water inthe heating pipes is heated through a direct heat exchange with the geothermal water. A substantial contribution to the distribution capacity is also given by the "heat-recovery units" installed on the gas-powered motors.

Table 4
HEAT DURATION CURVE
OF THE DISTRICT HEATING SYSTEM

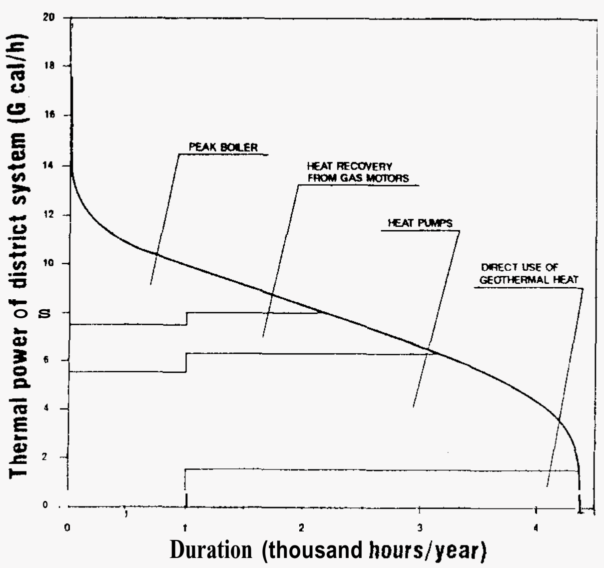


Table 5
GEOTHERMAL DISTRICT HEATINE AND AIR CONDITIONING PLANT TECHNICAL DATA
(The values are referred to output conditions as estimated in the project)

1) Thermal power installed in plant	Gcalh	**22.05**	**(26.2** MW)
2) Heat pump **T.** power	Gcal/h	**5.05**	**(6.5** MW)
3) Gas motor recoverring T. power	Gcal/h	**2**	**(2.3** MW)
4) Gas fired boiler installed T. powe	Gcal/h	**15**	**(17.4 MW)**
5) Heat supply	Gcal/year	**34,300**	**(39,900** kWh/year)
6) Domestic hot water supply	Gcal/year	**5,540**	**(6,400** kWh/year)
7) District heating temperature (delivery/return) peak level operation	°C	**90/65**	
8) District heating temperature (delivery/return) **50%** thermal level operation	°C	**75/50**	
9) Geothermal tanks	m^3	**200**	
10) Cooling power	Mfrig/h	**2.5**	
11) Cooling network temperature (delivery/return)	°C	**6/12**	

The heat pumps winter output **is** balanced by the cooling energy required during the summer by one of the major user of the system. The pipes are used for distribution of cold water during the summer as well. The reversable heat pumps allow for an extended operation schedule of the system, with related economical benefits.

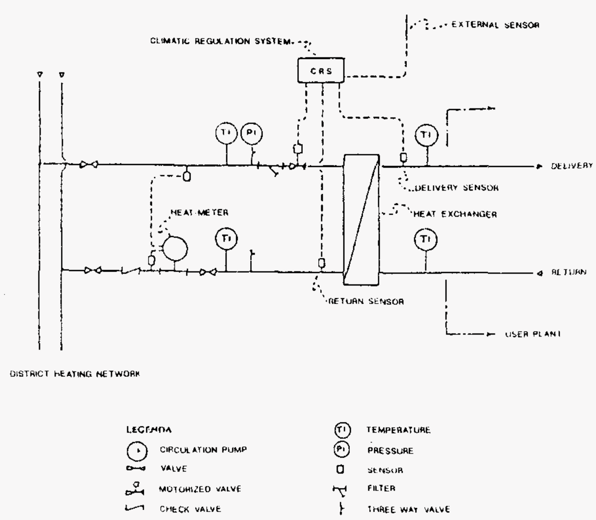
Table 4 is a reproduction of the duration curve of the thermal power. It also shows the heat origin of all the equipment as determined by project specifications, while table 5 is a summary of principal technical features of plant design.

PIPE LINES AND SUB-STATIONS

The end-users are connected to the plant by a 7,400 m long double pipe network, both for heating and cooling, and by a 6,000 m supplementary single line network for sanitary water. The two lines run parall. The hot water funneled through the pipes is used in substations located at the users' site. This is where the thermal exchangewith the building water system takes place.

A technical description of a standard heating sub-station is found in table 6. The two-way regulation system is set to minimize the temperature in the pipes.

Table 6
HEATING SUBSTATION - DIAGRAM



The geothermal water is distributed directly to those users that have a centralized sanitary water treatment equipment. The standard sub-station design in table 7 require the use of a heat-exchanger geothermal-water-to-drinkable-water. The temperature in the secondary circuit is regulated around **48** °C in order to minimize heat loss.

MONITORING, MEASUREMENT AND REGULATING CRITERIA

A.I.M. Vicenza is in charge of distributing such public services as water, electricity and heating gas. The distribution networks are monitored by a centralized electronic control center. The geothermal plant and network will be connected to this system for monitoring and operational supervision. The plant itself operates on an automated control center. This minimizes local and around-the-clock supervision and personnel costs. The automated operation system allows for two types of setting:

- most efficient use of geothermal water
- most efficient use of energy for operation of compressors in the heat pumps.

Both criteria can be used for the operation of the heat pumps, for a more economic and energy efficient operation of the system, notwithstanding the amount of production power used.

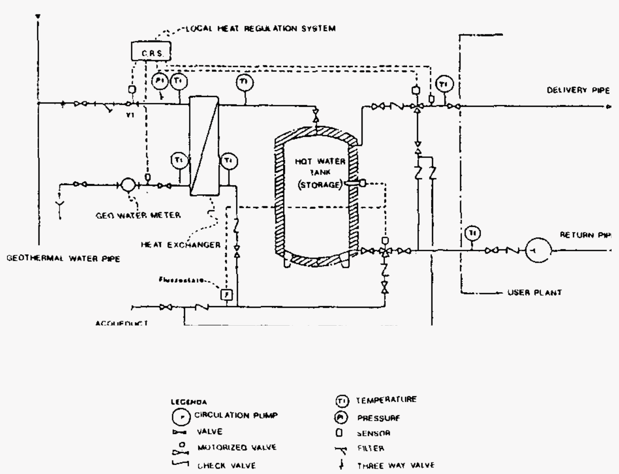
The sub-stations located at the end-user site (for heat and preparation of sanitary water), are themselves equipped with an indipendent regulation system, with local panel and controls.

Future developments will include direct connection to the centralized remote control computer for operational monitoring and transmission of quantity of energy consumed.

The electronic transmission of such factors as temperature and other status indicators will allow for a more precise regulation of temperatures in the system, proportionally to the amount of energy required by users. Other future develompents include remote operation on the sub-station for some of the most critical users and the programming of the overall system output as related to the geothermal resource.

The users' substations are equipped with local control switches that operate on the primary circuit and are set to minimize return temperatures of the heating pipe line. The remote control center will regulate in-coming temperatures in the pipes at the lowest level required by the most critical users (that is the one that requires the highest temperature). This balancing criteria has the purpose to reduce the thermal output in the pipe line as much as possible and to decrease energy consumption of the heat pumps. The transmission of major status indicators both from the plant and from sub-stations to a single centralized control center will make it possible to rationalize overall operations, monitoring and printing/storing of operational data.

Table 7
SANITARY WATER SUBSTATION - DIAGRAM



EFFICIENCY AND ENERGY SAVING

ENERGY OUTPUT

The geothermal heating system substitutes conventional heating systems, where heat is produced in furnaces of boilers located at the users' site. Therefore these conventional systems are the backdrop for determining the energy efficiency of the geothermal network.

Table **8** illustrate the operating energy outcome of the system when the pumps operate on gas.

The most remarkable data is the **high** value of heat discharge given by the sum of heat produced by the pumps and the heat exchanger- it equals 70% of the energy necessary for heating purposes -and the considerable savings in conventional fuels.
Gas-operated motors contribute to overall savings of about ***60%*** (3,300 tep/a) as referred to conventional systems and electricity-operated motors guarantee up to 50% savings (2,850).

Table 8 - ENERGY OUTPUT HEAT PUMPS (GAS MOTORS)

		HEAT		H.S.W.	C	T
NET HEAT DEMANDE	Gcal/a	33,600		5,100	2,450	41,150
EXISTING SYSTEM						
Efficiency (1)	%	76		67	69	74
Consumptions	Gcal/a	44,515		7,580	3,570	55,665
GEO System						
Distr. efficiency	%	98		92	98	
Tot. heat supply	Gcal/a	34,300		5,540	2,500	
Geoheat direct use	Gcal/a	4,440	(13%)	-		
Heat pump supply	Gcal/a	19,630	(57%)	-		
Engines recovery	GcaVa	5,730	(17%)	-		
Boiler supply	Gcal/a	4,500	(13%)	-		
CONSUMPTIONS						
Gas boilers	Gcal/a	4,500				
Gas engines	Gcal/a	33,600				
Elec. heat pumps (2)	Gcal/a			-	1,725	
Elec. pumps (2)	GcaVa	4,500		115	-	
TOTAL CONSUMPTIONS	Gcal/a	20,415		115	1,725	22,250
EFFICIENCY AND SAVING						
Total efficiency						1,85
Fossil fuel savings	Tep/a					3,341
Percent. savings	%					60

Elec = Electricity
HEAT = Heating
H S W = Hot Sanitary Water
C = Cooling
T = Total heat and cooling demand

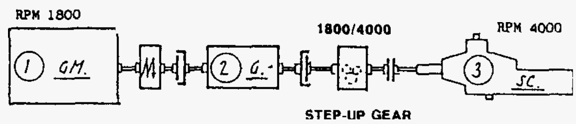
(I) Average efficiency, the average boiler efficiency is 72%, while the average hospital boiler efficiency is 80%
(2) The conventional thermoelectric power station specific consumption for electrical energy production is 2,300 kcal/kWh

HEAT PUMPS OPERATION - WINTER TIME

Table 9 shows the operating diagram of the pumps during the winter time. The pumps operate on the gas-powered motor, and energy is re-used through the endothermic engine.

Table 9
WINTER OPERATION

TANDEM GROUP



(1) Gas motor
(2) Electric motor/Generator
(3) Screw compressor

Plant operation: 1 - on
2 - off
3 - on

Heat exchanger for combustion fluid cooled by aqueduct water: on.

Cas-engine and hear oil-engine recovering exchanger operating into the district heating network: on.

Cooling towers: Off.

Table 10 - PEAK LEVEL OPERATION

Plant lay-out:	Plant operations:
gas engines 1,800 rpm	Peak 17,500,000 kcal/h = 20 MW
electric motors/generators: stand by	300 hours/year
heat-pumps engines with copper	Delivery temperature Td = 90 °C
evaporators (double screw compressors)	Return temperature Tr = 65 °C
boilers	District heating flow = 700 m³/h

Gas-Engines — PCI = 9.45 kWh/Nm

eng. n.	R.P.M.	mech. power kW	gas consump. Nm /h	spec. consump. kWh/kWh	air consump. kg/h	cooling recov. kWt	fumes recov. kWt (100°)
1	1,800	468	144,6	2,82	2,383	502	238
2	1,800	502	153	2,88	2,547	516	254
3	1,800	524	158,5	2,86	2,654	524	264

Electric Motors-Generators

eng. n.	R.P.M.	tens. Voltage V	freq. frequency Hz	absorbed power kWe	effic. %	generated power kWe	effic. %
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0

Heat Pumps

eng. n.	R.P.M.	evap. power kWt	Tea °C	Tua °C	eng. netpw kWa	cond. power kWt	Tea °C	Tua °C	C.O.P. -
1	4,000	1,304.8	29.18	19.42	448	1,752.8	65.17	65.15	3,91
2	4,000	1,696.2	41.86	29.18	481,8	2,178	67.15	69.83	4,52
3	4,000	2,157.7	58.00	41.86	495	2,652.7	69.83	73.26	5,35

Boilers

eng. n.	eng. net pw kWt	Tea °C	Tua °C	effic. %	gas cons. Nm³/h	air cons. Nm³/h	aux. abs power kWe
1	5,814	76.08	83.22	90			
2	5,514	83.22	90	90			
3							

Heat Exchanger HE 201

kWt 139,5
Tea 65 °C
Tua 65.17 °C

Other heat is recuperated through steam heat and from the engine oils cooling system.

Table 10 shows projected operating characteristics, at peak level (17.5 Gcal/h=20 MWt), guaranteed by the company that built the plant. Table 11 shows a chart of winter peak level operation.

Table 12 shows project data for evaporators and condensers, of the heat pumps circuits. Project data have been confirmed by actual measurements taken during plant operation.

Table 12 - TECHNICAL PROJECT DATA

	PEAK	FULL LOAD	2/3 LOAD	1/3 LOAD	1/3 LOAD
EVAPORATORS PIPELINE					
INPUT TEMPERATURE (°C)	58	58	48	47	47
OUTPUTTEMPERATURE ("C)	19,42	19,61	12,63	20.17	11,01
/ T ("C)	38,58	38,39	35,37	26,83	35,99
FLOW (m³/h) CAPACITY	115	115	115	115	115
DISTRICT HEATING					
RETURN TEMPERATURE (°C)	65	65	50	45	45
CONDENSERS PIPELINE					
INPUT TEMPERATURE (°C)	65,17	65,19	53	49.10	49
OUTPUT TEMPERATURE ("C)	73,26	74,10	65,73	61,55	59,48
/ T ("C)	8,09	8,91	12,73	12,45	10,48
FLOW (m³/h) CAPACITY	700	700	400	300	300
USEFUL HEAT POWER OUTPUT					
TO DISTRICT HEATING FROM HEAT PUMPS (kWt)	6,583	6,565	5,924	4,343	3,658

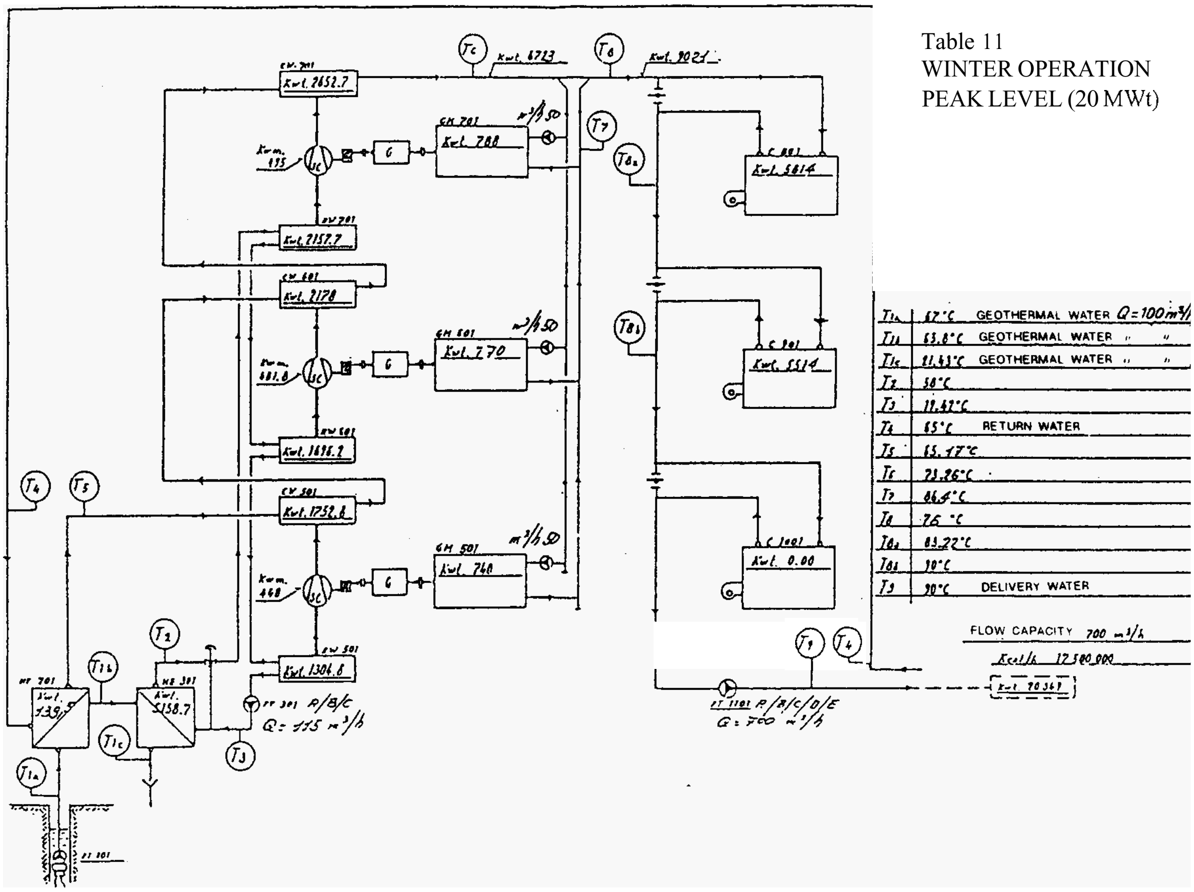


Table 11
WINTER OPERATION
PEAK LEVEL (20 MWt)

HEAT PUMPS OPERATION - SUMMER TIME

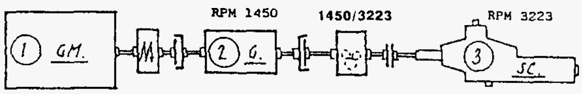
Table13 shows a diagram for summer time operation of the system,when the pumps are powered by the electrical motor.

Table 14 is a chart of operating conditions and table 15 shows technical data as guaranteed by the company that built the plant.

The system has been used so far in the summer to provide air conditioning through cold water to the Vicenza Hospital.

Table 13
SUMMER OPERATION

TANDEM GROUP



(1) Gas motor
(2) Electric motor/Generator
(3) Screw compressor

Plant operation
1 - off
2 - on
3 - on

CONCLUSIONS

The geothermal heating system in the town of Vicenza uses a self-reproducing energy source, a fluid at low enthalpy, that contributes in a significant manner to local energy needs both for heating and sanitary water. The water temperature was however too low for a normal heating system and it was therefore necessary to increase it to 80/90 °C. The higher temperature was obtained through the installation of heat pumps. The same heat pumps were designed to produce cool water for air conditioning in the summer for one of the major clients of the utilities circuits, and this resulted in the increased utilization of the system. The system went into operation in 1992. During the first year the most difficult aspect in the operation of the system was related to the necessity of fine tuning the heat pumps because of the very different operating conditions in the summer and winter months

Table 15
SUMMER OPERATION

Plant lay-out:
3 gas engines 1,800 rpm
3 electric motors/generators: stand by
3 heat-pumps engines with copper evaporators (parallel double screw compressors)
evaporative tower circuit

Plant operations:
Summer Frig/h 2,533,560 hours/year
Delivery temperature Td = 6 °C
Return temperature Tr = 12.1 °C
District heating flow = 416.5 m³/h

Gas-Engines

eng. n.	R.P.M.	mech. power kWa	gas consump. Nm³/h	spec. consump kWh/kWh	air cons. kg/h	cooling recov. kWt	fumes recov. kWt

Gas-Engines off

Electric Motors-Generators

eng. n.	R.P.M.	tens. Voltage V	freq. frequency Hz	absorbed power kWe	effic. X	gener. power kWe	effic. X
1	1,478	6,000	50	189.5	93.8	0	0
2	1,478	6,000	50	189.5	93.8	0	0
3	1,478	6,000	50	189.5	93.8	0	0

	Refrigerator Groups					Evaporative Towers			
eng. n.	R.P.M.	evap. power kWt	Tea °C	Tua °C	eng. net pw kWa	cond. power kWt	Tea °C	Tua °C	effic -
1	3,285	982	12.1	6	172.4	1,154.2	33.59	29	5.7
2	3,285	982	12.1	6	172.4	1,154.2	33.59	29	5.7
3	3,285	982	12.1	6	172.4	1,154.2	33.59	29	5.7

Boilers

eng n.	eng. net pw kWt	°C	Tua °C	effic. X	gas consump Nm³/h	air consump m³/h	aux. power kWe

Boilers off

Table 14
SUMMER OPERATION