

# DIRECT USES OF GEOTHERMAL ENERGY 1995

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## ABSTRACT

The worldwide application of geothermal energy for non-electric use is reviewed. This paper attempts to update the previous survey carried out in 1990 by the same author and presented at the International Symposium in Hawaii. For each of these updates since 1975, the recording of data has been similar but not exactly the same and, for this latest update, an effort has been made to collate additional information on heat pumps and investments in geothermal for the past two decades. A preliminary version of this paper was published in the Proceedings of the World Geothermal Congress held in Florence in May 1995 (Freeston, 1995), which was prepared on the basis of draft manuscripts and information provided to the organizing committee prior to the meeting. However, some of these papers were modified on publication in the proceedings, and it was thought necessary to update this paper, particularly the tables, after the publication of the final manuscripts in the Proceedings of the Congress.

What is evident from the papers received, is that there is a large potential for the development of low- to moderate-enthalpy direct use across the world which is not currently being exploited due to financial constraints and the low prices of competing energy. An estimate of the installed thermal power at the end of 1994 (1990 in brackets) from the current returns is 8,664 MWt (8,064 MWt) utilizing 37,050 kg/s (31,800 kg/s) of fluid, and the thermal energy used is 112,441 TJ/y (61,747 TJ/y).

## INTRODUCTION

An update for both electric and non-electric use of geothermal energy worldwide was initiated by the World Congress 1995 Organizing Committee as a follow on to the those carried out in 1985 and 1990. From experience of the last survey, the data forms sent to individual countries were slightly modified and additional material requested, namely geothermal investments for the past two decades, in an attempt to obtain a wider and more accurate perspective of the worldwide direct use scene. The data, in tabular form, requested for this direct-use update included: information on projects on-line at December 1994, together with a summary of geothermal direct uses, geothermal heat pumps, wells drilled since 1990, as well as allocation of professional personnel to geothermal activities and investments in geothermal for the past two decades. These tables were to be attached to a country-update paper describing direct-use activity in the particular country. In all, there was 57 responses; unfortunately, not all countries responded in a similar manner for a variety of reasons. Some had only a limited amount of data available, others had difficulty in putting together flows

and temperatures for particular projects, and some were only able to submit part data in letter form. Some countries, however, produced the information as requested in the correct format which made the transfer to the summary form easy to compute. As mentioned above, a preliminary analysis based on the draft manuscripts was presented at the World Congress in May, and this paper is a reevaluation of the papers as printed in the Proceeding of the Congress. Unfortunately, not all the draft papers were returned for inclusion in the Congress Proceedings, and some tables which had been attached to the drafts were omitted from the final published paper. Where it is helpful, the author has included in the analysis and discussion this "draft" data.

The assumptions used in analysis were similar to that used in the previous surveys with the methods of calculation listed at the top of the tables issued, namely:

Installed thermal power (MWt) =  $m \text{ (kg/s)} \times (t_i - t_o) \text{ (}^\circ\text{C)} \times 0.004184$   
Energy Use (TJ/y) = Annual average flow rate (kg/s)  $\times (t_i - t_o) \text{ (}^\circ\text{C)} \times 0.1319$   
Where  $m$  = max. flow rate,  $t_i$  = inlet temperature and  $t_o$  = outlet temperature

The Japanese bathing figures, which were 98% of the Japanese geothermal direct use, dominated the 1990 survey, (30% of the total thermal power, 25% of the annual energy use), so it was decided to exclude bathing from the analysis. However, it is acknowledged that this activity is an important use of thermal fluids. Both swimming pools and other aspects of balneology, however, have been included where they were identified. The Japanese numbers used in Freeston (1990) were then modified to allow a fairer comparison of the growth of the worldwide use of geothermal energy over the past five years. It is also interesting to note that a number of countries from this latest survey are showing a significant decrease in use (e.g., Bulgaria, Hungary, Turkey, Romania, etc.). This is probably due to improved data collection methods used for this latest survey. Heat pumps have been included as a separate item for the first time in the summary of uses, and they make a significant contribution to the totals. However from the data received, it is not obvious how much of the energy allocated to heat pumps is used for the various categories listed. Indeed, heat pumps are used for most of the direct heat applications; so, it likely that there is some duplication of numbers and the totals will be inflated. In future surveys, it will be necessary to allocate applications to the heat pump data to avoid this duplication.

Table 1 shows that the installed thermal power is estimated at 8,664 MWt (1990 = 8,064 MWt) and the energy use is 112,441 kJ/kg (1990 = 98,464 kJ/y) with the average load factor based on these latter two numbers being 0.41 (0.39), implying a small increase in efficiency of use over the

**Table 1. Summary of Data Collected from Draft Country-Update Papers and Tables**

Country	Flow Rate kg/s	Power MWt	Energy TJ/y	Average Load Factor*	Cost 85-94 US\$ x 10 <sup>6</sup>	Person Years 1994
Algeria	550	100	1657	0.5	0.0	27
Argentina	0.0	0.0	0.0	0.0	4.4	56
Austria	173	21.1	200.0	0.3	0.0	0.0
Belgium	57.9	3.9	101	0.82	0.5	1
Bulgaria	258.5	133.1	778.5	0.19	0.82	23
Canada	40	1.68	47	0.88	1.9	5
China	8,628	1,915	16,981	0.28	0.0	0.0
Denmark	44.3	3.5	45	0.4	5.5	7
Fiji	0.0	0.0	0.0	0.0	0.5	0.3
France	2,889	599	7,350	0.39	580	24
Georgia	1,363	245	7,685	1.0	35	38
Germany	316	32	303	0.3	0.0	0.0
Greece	261	22.6	135	0.19	3.0	50
Guatemala	12	2.64	83	1.0	0.0	15
Hungary	1,714	340	5,861	0.54	0.0	0.0
Iceland	5,794	1,443	21,158	0.57	240	100
Israel	1,217	44.2	1,196	0.86	0.0	0.0
Italy	1,612	307	3,629	0.37	54	250
Japan	1,670	319	6,942	0.69	0.0	0.0
Macedonia	761	69.5	509.6	0.23	26.7	9
New Zealand	353	264	6,614	0.79	0.0	56
Poland	298	63	740	0.37	60	67
Romania	792	137	2,753	0.64	60	27
Russia	1,240	210	2,422	0.37	0.0	0.0
Serbia	892	80	2,375	0.94	0.0	4.0
Slovakia	353	99.7	1,808	0.57	0.0	0.0
Slovenia	581	37	761	0.65	73.5	13
Sweden	455	47	960	0.0	0.0	1
Switzerland	120	110	3,470	1.0	177	7
Turkey	700	140	1,987	0.45	0.0	0.0
USA	3,905	1,874	13,890	0.23	68.4	15
<b>TOTALS</b>	<b>37,050</b>	<b>8,664</b>	<b>112,441</b>	<b>0.41*</b>	<b>1,391</b>	<b>795.3</b>

1990-1995 period. However, the energy use figure could be inflated because there were a number of countries that did not distinguish between maximum (for power determination) and annual average (for energy flow rates), and others which had very high load factors for some uses which seem unreasonable. The latest installed thermal power figure gives an average growth rate over the past five years of about 7.5% or 1.5% per year which is very much less than the 12% per year recorded in the 1990 survey; however, these figures should be used with caution because of a number of factors highlighted in the previous discussion. What can be said is that the 1985-1990 period was a rapid-growth period; whilst during this latter five years, growth has been slow mainly due to financial constraints and competition from more conventional and cheaper fuels.

Table 1 also shows the personnel and investment numbers collected. For both these columns, it is difficult for some countries to separate those working electrical applications and those involved with direct uses. In the investment table, the split between electrical and direct-heat utilization was requested; where that has been presented, the total allocation to R&D and field development, etc., has been divided on a basis of the percentage of direct use to total utilization expenses to obtain an overall figure of US\$1,325 million. The personnel column numbers involve the total employed on geothermal, both electrical and direct use. At this time this author, on the assumption that in many countries, one work

force caters for both disciplines, has used the total number quoted per country (795.3). It is of interest to use these numbers, for those countries that have submitted the appropriate data, and to obtain an average cost/MWt and persons/MWt. The investments for the five years 1985 - 1990 are \$US2.7 million/10 MWt, and for 1994 only, 1.5 person/10 MWt professional person years of effort. However, the variation around these averages is high. For the cost/MWt, they vary from 0.04 for the USA to 1.88 for Slovenia; whilst for the personnel, the variation is from 0.1 for the USA to 10.6 for Poland.

Figure 1 shows the distribution of the annual energy utilization by use. Bathing here refers mainly to swimming in thermal mineral pools and pools heated by geothermal fluids. Snow melting and air conditioning (1%) have been put together--they each represent about 0.5%. Space heating (34%), which includes both district heating and the supply of domestic hot water, is the largest use of geothermal fluids with some big district heating systems in operation. Heat pumps utilize 13% of the total--the major countries being Switzerland and USA.

Industrial uses represent 9% of the total, with New Zealand and Iceland being the major countries utilizing geothermal fluids in this way with high load factors of 0.8 and 0.6 respectively. Fish and other animal farming account for 12% with China and USA having the major energy utilization. Typical load factors for this use are in the range 0.3 to 0.7.

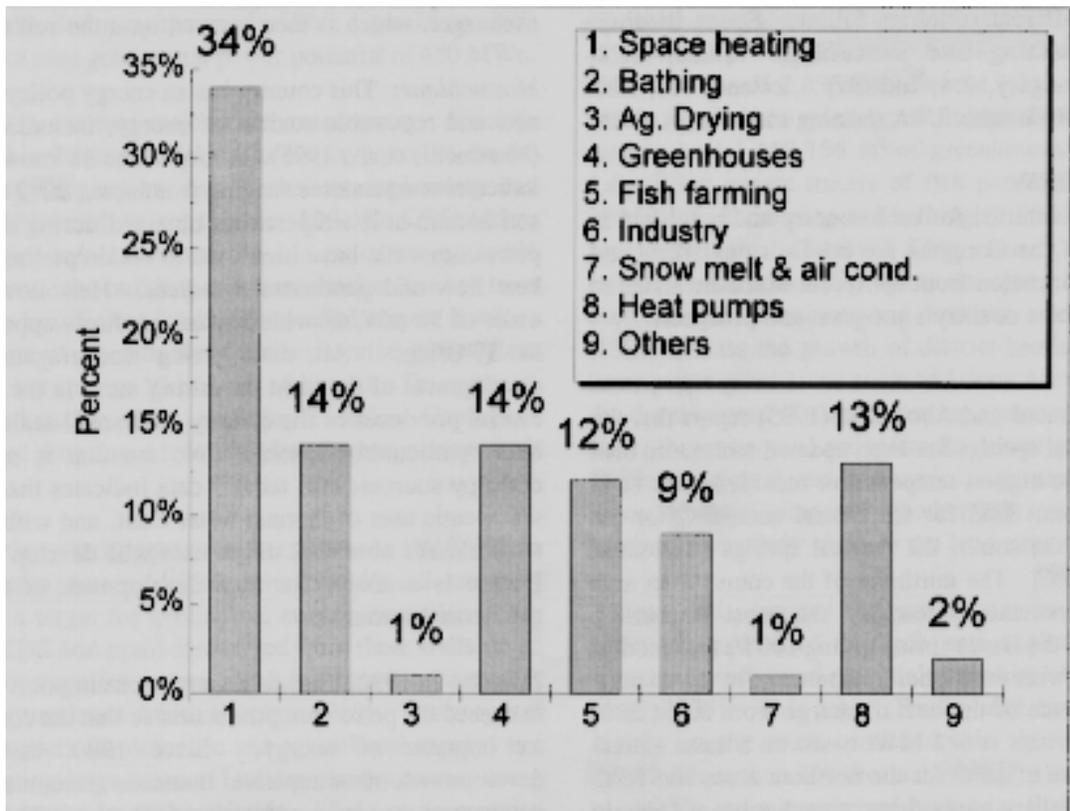


Figure 1. Summary of worldwide energy use of direct heat. Data is based on returns from 25 countries. Total = 115,659 TJ/y.

Table 2 gives the average load factors for each of the categories. This is based on the total energy and installed power for each use as returned in the summary table. As mentioned elsewhere in the text, some country data gives load factors equal to or greater than one.

**Table 2. Load Factors**

Space Heating	0.47
Bathing and Swimming	0.46
Agriculture and Drying	0.53
Greenhouse Heating	0.46
Fish & Farming	0.39
Industrial	0.59
Snow Melting	0.25
Air Conditioning	0.37
Heat Pumps	0.25

The load factor will be influenced by a number of things including local climate, process use and commercial interests; so, the average values above, indicate typical values only. Snow melting for example is used in adverse climatic conditions which will be in use for a limited period of the year, so has a low value; whilst, it can be expected that industrial use will have a higher load factor because industrial operations, in general, will be operated for longer periods. Examples from different countries follow: **Space heating:** Iceland, 0.45; **Bathing and swimming:** China, 0.28; **Greenhouses:** Hungary, 0.4; **Industry:** Iceland, 0.6, New Zealand, 0.8; **Heat pumps:** USA (heating mode only), 0.18.

## COUNTRY REVIEW

The reports submitted for each country and published in the Proceedings of the Congress are briefly summarized and any additional information from the recent literature added to give an overview of a country's program and prospects.

### Africa

*Algeria:* Fekraoui and Abouriche (1995) report that the inventory of thermal springs has been updated with more than 240 identified. The highest temperatures recorded were 66°C for the western area, 80°C for the central and 96°C for the eastern areas. In the south, the thermal springs have mean temperatures of 50°C. The northeast of the country, an area of 15,000 km<sup>2</sup>, remains potentially the most interesting geothermally, with the Barda spring giving 100 l/s and another spring in the area, with the highest temperature in the country of 96°C. An estimate of the heat discharge from about 30% of the country's springs is 642 MWt based on a mean annual outdoor temperature of 18°C for the northern areas and 30°C for the central or Sahara area. Some greenhouses at Ouargla and Touggourt in the central region are reported to be using

60°C geothermal water for heating. Bellache, et al. (1995) states that the geothermal potential in these regions is sufficient to heat 9,000 greenhouses, with a flow of 3,421 l/s. The same authors have also carried out a study recommending further use of the country's geothermal resources to improve food production. They use greenhouses outside of the conventional periods when the climate requires heated greenhouses to enhance growth, which is during the severe climatic conditions from October to March. No mention is made of the proposed residential heating projects mentioned in the 1990 update as to whether these have been commissioned. The tables of data included with the report are incomplete; however, there are average flow rates and energy use for six of the localities amounting to 258 kg/s and 793 TJ/y respectively. Using these numbers as a basis, it is estimated that for the total of eleven localities used for bathing together with the amounts quoted for greenhouse usage, the total flow would be about 550 kg/s and an energy utilization 1,657 TJ/y, which with a load factor for bathing of say 0.5 gives a thermal power of about 100 MWt.

*Kenya:* Freeston (1990) reported on warm and hot springs being used for livestock drinking water and other uses; however despite there being potential available, little use has been made of the low-enthalpy resources to date in Kenya. One project on soil sterilization for the Oserian flower farm located adjacent to the Olkaria geothermal field is reported by Melaku, et al. (1995). A hot-water spray system uses fluid from an existing well, which was not suitable for electric power production, to heat clean water in a plate heat exchanger, which is then sprayed onto the soil to sterilize it.

*Mozambique:* This country has an energy policy to encourage new and renewable sources of energy, including geothermal (Martinelli, et al., 1995). A map of the 38 known hot springs indicates temperatures ranging from about 20°C to over 90°C, and bottom-hole temperatures obtained during the logging of petroleum wells have been used to obtain preliminary data on heat flow and geothermal gradient. Heat flows are of the order of 50 mW/m<sup>2</sup> with thermal gradients approximately 15 to 39°C/km. All data giving encouragement for the development of the most promising areas in the northern and central provinces of the country with small-scale power plant being particularly suitable. No mention is made of low-enthalpy sources; but, tabular data indicates that bathing and therapeutic uses of thermal water exist, and with the range of temperatures obtained, direct uses will develop as and when finance is available for total development of the country's geothermal resources.

*Tunisia:* In 1992, Tunisia's energy consumption was expected to exceed the petroleum production so that the country became an importer of energy. Since 1980, assessment and development of alternative domestic resources, including geothermal, has been undertaken. There are 70 identified hot springs, 230 shallow wells and 350 deep petroleum well that

have been used to assess the potential for the utilization of geothermal energy for agricultural and industrial uses (Ben Dhia and Bouri, 1995). Ten areas have been identified where low- to moderate-temperature fluids, to about 150°C, are known to exist at shallow depths to make them useful as alternate sources of energy. However, not all parts of the country are assessed at the same level, and for the last three years geothermal research has focused on the northern part. The object being to assess its geothermal potential. However, no new utilization projects seem to have been started. The cooling tower and greenhouse projects mentioned in the 1990 report appear in the latest update without any apparent expansion.

*Uganda:* This country appears for the first time in these surveys. Unfortunately, a draft paper was received; but, the final manuscript did not arrive for publication, so the data is based on the draft. A geothermal exploration project, funded by the government of Uganda, UNDP, OPEC and the government of Iceland ran between March 1993 to April 1994 (Mboijana, 1995). Its primary objective was to select from three prospects in western Uganda, which are on the western branch of the East African rift system--one for further geophysical exploration and exploratory drilling. The three prospects had been identified by studies carried out earlier during some initial surveys in the 1950s to 1970s. The recent study, phase 1, which employed geologic and geochemical methods, gave reservoir temperatures in the range 120°C to 200°C. The second phase is to use the data from phase 1 and create a geothermal model, which will serve to identify suitable sites for detailed geophysics. In 1981, Uganda was estimated to have a total geothermal power potential of 450 MWe.

*Zambia:* There are two major geothermal energy developments in Zambia (Money, 1994). The Kapisya project, on the shores of Lake Tanganyika, has 15 shallow exploratory and production wells used to supply two 100 kW ORC turbo-generators which have been installed, but are currently unable to operate because the building of a transmission line has been delayed due to insufficient funds. The second project involves the development of a health resort and a potential power plant at Chinyunyu hot springs 50 km east of Lusaka. This project, being undertaken by JICA and the Zambian Geological Survey, has not progressed from the planning stage due to lack of funds.

*Other Countries:* In **Egypt**, four thermal wells (50-75°C) in the northwestern desert, drilled primarily for oil are considered to be a target for geothermal energy extraction. The fresh water (TDS 464 ppm) discharged from these wells is fed from the Nubian aquifer system which is located in the eastern Sahara desert, northeast Africa (Boulas, 1989). The proposal is to use the waters for domestic and agricultural supply, and also for irrigating large areas of land by pumping water using electricity generated from these fluids. These wells can also be used for supplying hot water to greenhouses for the production of vegetables and fruits. There is no further information on progress on the developments mentioned in Freeston (1990) in

**Djibouti or Madagascar;** although, Battistelli, et al. (1991) reports on some reservoir engineering studies at the Asal field in Djibouti.

#### Asia

*China:* Ren, et al. (1990) reported in Table 2B, utilization of geothermal energy for direct heat 1989, a total average flow rate of 7,294 kg/s which, with the temperatures provided, Freeston (1990) estimated a total energy utilization of 5,527 GWh at an average load factor of 29%. The latest survey, Tang Nighua (1994) shows a reduction in the average amount of fluid used to 5,996 kg/s. This is mainly the result of a reduction in flow rates utilized in Tianjin, Shandong and Shanxi provinces, and despite some small increases in flow rates recorded for Jiangzi and Xinjiang provinces. Tang Nighua (1994) also quotes an annual energy use of 16,981 TJ/y from an installed capacity of 1,914 MWt, an overall average load factor of 0.28. The numbers are, therefore, essentially the same as 1990, indicating little or no change in the utilization of geothermal energy for direct heat in the past five years. For completeness in this report, the uses of geothermal fluid is outlined in Ren, et al. (1990), which are not detailed in this latest report, are used to recalculate the breakdown of the power and energy use for 1995. Assuming there is no change in the percentage distribution as quoted by Ren, et al. (1990), it is noted that Wang, et al. (1995) has utilized these 1990 figures in his 1995 paper. Ren, et al. (1990) states there are 49 projects using thermal water for industrial processing such as dyeing, drying fruit and vegetables, paper and hide processing, air conditioning and pre-heating boiler feed water, etc., with a net annual energy consumption estimated for 1995 of 1,443 TJ/y. Space heating, mainly in north China, uses a 1995 estimate of 2,836 TJ/y, where 1,313,800 m<sup>2</sup> of heating area is supplied by geothermal fluids. Geothermal fluids are used to heat 1,159,156 m<sup>2</sup> of greenhouses (1,223 TJ/y) and 1.6 million square meters of fish ponds (3,617 TJ/y) in 17 provinces. Swimming and bathing (7,852 TJ/y) make up the balance to a total of 16,981 TJ/y. Huang and Zheng (1995) refer to some specific projects on space heating, industrial uses, medical treatment and tourism, and Zheng and Cao (1995) discuss the growth of district heating in China. This latter paper gives some costs and demonstrates that, although the development of district heating systems in China has been slow, there are good prospects for future geothermal systems as environmental and economic constraints are changed in favor of developing the geothermal resources for district heating particularly close to the load centers.

*India:* This country did not appear in the 1990 survey; however, a detailed research and exploration program to assess the geothermal potential started in 1973-74 (Pandey and Negi, 1995). This paper (Pandey and Negi, 1995) is based mainly on the work carried out in the last seven or eight years. More than 300 thermal springs with temperature 30°C to 100°C, and a number of high heat flow areas, have been identified. Some thermal springs have deep reservoir temperatures beyond 200-250°C. Some estimates of power potential from these thermal areas range from 2,000 MWe to 10,000 MWe. Exploitation

of wells drilled for hydrocarbons in sedimentary basins are also considered to be suitable for development projects with temperatures measured of 100 - 150°C at 1.5 to 3 km deep in the Cambay graben. Use of the country's resources for electric power production is at an early stage as no serious deep drilling to prove reservoirs has been undertaken. Direct utilization is also in its infancy with a number of projects having been started. The government of Himanchal Pradesh has finalized plans for direct utilization of geothermal heat in selected areas for tourism and health resorts. In general, however, the country lacks the infrastructure to rapidly develop its large geothermal resources.

*Japan:* Sekioka and Toya (1995), in their presentation of the geothermal direct use in Japan, emphasize the small scale of most of the systems in Japan, and the lack of detailed measurements to make a full analysis. However, the data presented is of sufficient quality to enable an overview of the utilization of geothermal fluids in the country. The number of geothermal direct-use facilities analyzed is 208 with the majority of them in the Hokkaido and Tohoku districts which have a cold climate, and Kyushu which has a large number of geothermal resources. Many of the load centers are close to resources; 81% of systems are within 1,000 m of the resource. Well depths range from about 100 m to over 2000 m with the majority of wells, 60%, drilled to less than 500 m. The installed thermal power from all 208 facilities is about 319 MWt of which 182 MWt is for space heating, and about 52 MWt for greenhouse heating. The average load factor for all systems is 69% with a high load factor of 81% for space heating and a low of 8% for air conditioning in an installation at Akita prefecture. The data produced in this paper show substantial increases in the installed capacity and energy use over the past five years; however, this is due to better reporting rather than an evolution of direct uses in Japan. Sekioka and Toya (1995) do not include the fluid and energy used in bathing which has been a dominant factor in previous surveys. In 1990, the mass flow, installed thermal power and annual energy use allocated to bathing was 31,213 kg/s, 3,321 MWt and 31,428 TJ/y (8,730 GWh) respectively. Since there is no update on these figures, it is proposed, for the purposes of analyzing the world direct use utilization, to follow the lead of the authors and to ignore the numbers associated with bathing. For the future, combining binary plant with direct uses is planned. The New Energy and Industrial Development Organization (NEDO) is developing 100 kWe and 500 kWe binary-cycle generators and has identified 63 existing geothermal and hot spring wells having potential outputs within this range to give a possible total of 15,527 kWe; which together with a production of 11,251 kWe from 12 existing wells, would give a total of 23,778 kWe available utilizing these small-scale binary plant. In addition, the discharge temperature and flow rate from these plants, 76°C and 125 ton/h is suitable for geothermal direct uses.

*Korea:* A total of 276 sites has been identified for low-temperature direct use in North and South Korea (Han, 1995). Reservoir temperatures for 69 hot springs in South

Korea are 6 in the range 25 to 78°C. In North Korea, 28 springs are tabled with reservoir temperatures 35 to 78°C. Most of these springs are utilized for public or private baths and hotels with many sanatoriums for medical treatment of illness. Swimming pools for athletic training have been developed in the Onyang hot spring area, and greenhouses growing fresh vegetables and potted plants exist in the Kyungbook and Choonngnam provinces. Fish farming in the southern parts of Korea raise shrimps, turtles, eels, snails and snakes. Space heating projects are under investigation in Masan and Chagweon areas, and a feasibility study of the geothermal potential of Cheju Island is underway.

*Philippines:* The geothermal program is centered around the development of electrical energy from its geothermal resources which for a while in the early part of the decade came to a stop as there were no new developments, due in part to the structure of the industry (Gazo, 1994; Javellana, 1995). However, a number of key events provided a stimulus for development and the 1990 objectives have been largely met. A major direct-heat project was undertaken with UNDP help, utilizing waste brine from the Palinpinon 1 power development. The demonstration crop-drying facility was commissioned in 1994 to hot dry coconuts, and a variety of fruits and fish. The project has a high-social content and it is anticipated that similar plants will be established at geothermal projects elsewhere in the Philippines. Plants producing ice are also planned for installation in Manito, Albay using brine from several exploration wells not included in the Bac-Man 1 and 11 geothermal steam pipe network (Gazo, 1994).

*Thailand:* Since 1990, Fang is the only geothermal field that has been fully developed for multipurpose utilization (Ramingwong and Lertsrimongkol, 1995). This includes generating electricity, drying and cooling processes, and tourism. A deep drilling project was undertaken at Fang with the objective of defining the potential of a deep reservoir. The results indicated that the prospect of having a high-enthalpy reservoir in the area was low. It was also concluded that it is necessary to develop deviated drilling techniques if the current reservoirs are to be fully utilized. The San Kampaeng project has been postponed after two unsuccessful deep wells; but, a new prospect in the Pai district, Mae Hong Son province, is undergoing the pre-feasibility stage. No data is given to allow estimates of installed capacity, etc.

*Others:* In **Iran**, a geothermal exploration project was commenced in 1975, and Fotouhi (1995) reports that the northern region of Sabalan has potential with estimated temperatures of 140 - 251°C. It is recommended that an exploration well be drilled in the Meshkin-Shar zone. **Malaysia** has done very limited work on its geothermal resources; however since 1987, some detailed investigations, which include water chemistry and resistivity traversing, have been carried out in the Andrassy area (Lim, 1994). **Nepal** has identified 23 geothermal springs with surface temperatures in the range 21 to 71°C. At present, the spring water is largely confined to bathing and washing activities, (Ranjit, 1995). The

people of Juma use the water for medical purposes and tourists are attracted to the area; similarly, the local people of Bajhang observe a festival at their geothermal site once a year, and a guest house and temple have been built in the thermal spring area at Darchula to attract visitors undertaking mountaineering activities. A complete inventory of all the geothermal resources is underway; but, a definite program on their utilization has yet to emerge. From 1992 to 1994, the Geological Survey of **Vietnam** has undertaken a preliminary assessment of the geothermal potential of some hot water resources in the south of the country. Thach Tru, in the Modoc district of Quang Ngai province, has been selected for detail study (Le Vinh Hong, 1995). A reservoir temperature of 160 to 180°C is indicated; but, for electricity generation to be economic, it would be necessary to produce fluid from 500 m. However, an exploration well is considered justified.

## **THE AMERICAS**

### Central America

The majority of the countries in Central America have developed or are developing their geothermal resources for electrical power generation. Costa Rica, El Salvador and Guatemala have all submitted update reports which detail their electrical capacity and potential; but, only **Guatemala** gives information on direct heat projects. Palma and Garcia (1995) tabulate four small projects in Zunil and Amatitlan: two for bathing, one for industrial process heat, and one for agricultural drying at Zunil using production from a slim hole to dry fruits and vegetables. Total installed thermal power is 2.64 MWt and energy use of 83.11 TJ/yr. The Platanares geothermal field in **Honduras** has been studied since 1987. A recent publication (Di Pippo and Goff, 1994), has assessed the field so far explored, as being capable of supporting 7 MWe with a load center adjacent to the field--a mining company, able to absorb the energy.

### North America

*Canada:* Geothermal research and development during the years 1990 - 1994 has been at a very low level, as government has withdrawn funding and private industry has not been willing to take over (Jessop, 1995). With the exception of a direct-use development at Springhill, Nova Scotia, no geothermal project, no geothermal project was within reach of profitable development. This development uses water from a flooded coal mine, which is raised in temperature by heat pumps to supply four industries and Carleton University with space heating. This project uses six heat pumps with a total nominal output of 800 kWt utilizing the mine water at 9.5°C as a heat source (Jessop, 1995). Jessop (1995) also describes two other projects where wells have been drilled and feasibility studies completed without progress to utilization. From their worldwide review of the literature, Fridleifsson and Freeston (1994) reported that seven geothermal projects were ongoing when the federal government ceased funding geothermal energy research in 1986. Of these, six were utilizing warm waters for heating agricultural buildings, swimming pools and deicing projects. Heat pumps are in use on two projects--one for heating and cooling a 14,000 m<sup>2</sup> factory and the other as

mentioned above. At Pebble Creek, on the north slope of Mount Meager (British Columbia), a project to install 10 MWe condensing turbines is underway followed by a working plant of 100 MWe, progress will depend on funds becoming available (Jessop, 1995). At the South Meager geothermal reservoir preparations are in hand to drill a large-diameter deep well following extensive resource evaluation (GRC, 1994).

*Mexico:* No direct heat update was submitted; however, it is known that there are a number of direct heat projects in the country. Lund and Rangel (1995) describe the design and operation of a fruit drier at Los Azufres and an industrial park using Cerro Prieto residual heat and solid by-products which was proposed in 1989. Legal and economic implications of this 580-hectare industrial park were being reviewed (Lund, 1991). Attempts to use the silica for bricks and soil stabilization were being researched. An industrial laundry was under construction using waste brine from two wells at 180°C to heat clean water for washing laundry from U.S. hotels and hospitals, employing 200 people. Projects using geothermal fluids for greenhouses and refrigeration plant at Cerro Prieto and Los Azufres were under consideration; but, no further details are available for these studies.

*United States:* Since 1990, there were 18 new or expanded projects representing an increase in thermal capacity of 51 MWt and annual energy utilization of 524 TJ/y (Lienau, et al., 1995). Geothermal heat pumps represent the largest growth sector during the period adding an estimated 627 MWt and 2,223 TJ/y to these figures. Sixty-two wells were drilled for direct utilization to an average depth of 250 m and the numbers of professional staff employed in the industry fell by 70%, mainly due to reductions in funding from both state and federal sources. There has also been a shift from public to private funding of direct-heat projects. In Lund, et al. (1990), two district heating schemes were reported as under construction: Mammoth Lakes and Bridgeport. These systems have not been built; but, exploratory wells have been drilled. There are no new geothermal district heating systems started; but, both Klamath Falls and San Bernardino have expanded their systems. All categories of use have seen steady growth with the largest occurring in space heating, greenhouses and industrial plants. A significant development in the industrial sector was the establishment of a second onion and garlic dehydration plant in Nevada. To expand utilization of low-temperature resources, ten state resource teams reviewed and updated their resource inventories within the temperature range 20 to 150°C. Many, of which, have potential to supply a load within 8 km of the resource, in addition to greenhouse, aquaculture, etc., locally. This assessment project has resulted in a catalogue of 8,977 thermal wells and springs for these 10 western states, an increase of 82% compared to the assessment in 1983, and priority sites have been identified. Lienau, et al. (1995) gives details of new plant developments with forecasts of particular growth in the geothermal heat pump industry. They conclude that the potential for geothermal direct use in the U.S. is very large; however, the large resource base is underutilized. However, there are impediments to

development, which include lack of information about the resources and the infrastructure for development, high risk and low cost of gas coupled with consumer lack of knowledge.

### South America

Only two reports were received of direct-heat developments in South America.

*Argentina:* Geothermal resource surveys have been carried out in eleven areas throughout the country (Pesce, 1995). Six of these were studied further to the feasibility stage of which two, Bahi Hlanca (Buenos Aires) and Rio Valdez (Tierra del Fuego) were low-enthalpy resources. At Rio Valdez, 13 springs have been located with an average temperature of 38.5°C. The reservoir fluids are at temperatures between 88 and 98°C. It is anticipated that the fluids could be used for space heating (as the area has long cold winters), wood drying, processing wool, food refrigeration, etc. The Biahia Blanca area has reservoir temperatures in the range 55 to 85°C at depths of 530 to 1000 m. The raising of shrimps using this resource is under study. Pesca (1995) shows 34 sites using thermal fluids, mainly for bathing with temperatures between 26 and 65°C. Twenty wells have been drilled mostly for direct utilization between 1949 and 1991; although, three of these wells are for the 670 kW binary plant at Copahue. Fifty-six professionals are employed in the industry which has spent US\$ 9.17 million of public money in the past 10 years of which US\$ 1.1 million has gone into direct-heat utilization. No details are given which would enable the utilization of geothermal fluids to be evaluated.

*Chile:* Investigation of the country's geothermal resources began in 1967 concentrated on two areas: El Tatio and Puchuldiza (Gonzalez, 1995), and in 1977, a country-wide, but divided into regions, geothermal inventory was started which continued into the 80s. Later in 1993, a detailed reconnaissance of resources in central Chile was made. This confirmed the possibilities for geothermal development. Low-enthalpy resources are abundant along the eastern boundary of the central valley, which are areas of high population. Medium- and high-enthalpy resources are located along the mountain chain of Los Andes Cordillera, where mining centers are sited. Permeability studies were done on three hot spring areas with the economics favoring a cascade type of exploitation. El Tatio has been the primary area of investigation with 13 wells drilled between 1969-1974 for which, despite the exploration work, the total energy potential of the field is unknown. New governmental legislation is being written which, it is hoped, will stimulate geothermal development.

*Others:* High-temperature resources have been identified by drilling in Bolivia, Columbia, Ecuador, Peru and Venezuela; but, there is little new information on their current use and plans, and the status of any low-temperature fields since that published in Freeston (1990). With reference to the **Bolivian** project, Delgadillo (1994) reported that six wells were drilled with UNDP and Italian government help, of which five are

producers in the Sol de Manana field, which together with an additional well are sufficient to install up to 25 MWe. Currently, funding is being pursued to install two 4-MW units. In **Peru**, the government is considering legislation to allow private investment in the governments electric power industry (Koenig, 1994). Since the early 80s, exploration at a regional level has led to a detailed geochemical study of the El Pilar-Casanay **Venezuela** prospect where a water-steam shallow reservoir has been located with temperature of 200 - 220°C, and a deep liquid-dominated reservoir with temperatures of the order 250 - 300°C (D'Amore, et al., 1994).

### **EUROPE**

*Albania:* There was no report from Albania at the 1990 meeting; so, the data presented, which has been collected in the last three years, represents a new geothermal country. The country has both hydro energy, with 1,427 MWe installed in seven plants, and 20 oil and gas reservoirs producing about 649.8 kt of oil in 1993, down from an average 1.2 Mt in previous years. The oil is used in domestic and industrial plant, and a thermal plant of 160 MWe. Coal is also available in significant quantities. Alternative sources of energy are being studied in view of the decline of oil, gas and coal resources in the country in recent years. The recent geothermal study has collected data which has included heat flow studies, natural thermal water springs, and water basins that have anomalous temperatures (Frasheri and Bakalli, 1995). The investigation of the fields is based on temperature measurements carried out in 120-deep oil and gas wells located in the Ionian and Kruja zones, and the Preadriatic depression, and in 15 bores in the ophiolitic belt in the Mirdita zone. Temperatures vary from a minimum at 100 m of 12°C to 105.8 C at 6,000 m. In the central part of the Preadriatic depression where there are many boreholes, the temperature reaches 68°C at 3,000 m. The thermal springs, which are situated mainly in the regional tectonic fractures, have temperatures ranging from 21 to 58°C. Maps of temperatures at 2,000 m, thermal gradients and spring locations are included in the paper. The authors conclude that there are geothermal resources that can be used, and a detailed evaluation of the energy available needs to be done as soon as possible.

*Belgium:* Due to the low-energy prices, no major developments of Belgium's geothermal energy have taken place in the last five years (Berckmans and Vandenberghe, 1995). The main development in geothermal research was initiated by the European Community in 1993 under the JOULE II program. This led to a review in 1994 of the geothermal resources of Belgium. The results are to be published in 1996 of the Atlas of Geothermal Resources of Europe. These results have indicated that the Dinantian in the Hainaut basin, the Buntsandstein and deeper lying areas of the Dinantian in the Campine basin have the best potential for future development. Technology and regional economic parameters, together with the nature of the aquifer, warrant further evaluation. In the north, the chalk reservoir is used to heat a swimming pool in the summer at the town of Herentals;

whilst, another pool at Turnbout is heated through the year. At Dessel close to Turnbout, fish are produced. In the south, the local regional development company runs a geothermal installation which includes heating to a school, a swimming pool, a sport facility and residential buildings, from a well having a temperature of 70°C. In the second stage, the water is cooled from 50 to 40°C to heat a 4,000 m<sup>2</sup> greenhouse which after further cooling to 30°C, is used to heat waste muds at Wasmuel. The total installed thermal power is 3.9 MWt with an energy use of 101 TJ/y. It is estimated that since 1975, US\$ 10.7 million have been spent on geothermal projects; however, only US\$ 0.5 million since 1985, mainly on research. These figures are based on the tables provided with the draft manuscript and which do not appear in the Congress Proceedings.

*Bulgaria:* The heat potential estimated for the thermal waters discovered in Bulgaria amounts to 488 MWt, one third of which can be obtained with the use of heat exchangers and two thirds using heat pumps. Temperatures in the range 32 to 42°C are not included as according to law, these waters are reserved for balneological use (Bojadgieva, et al., 1995). The thermal water utilization in Bulgaria is related mainly to balneological uses (7.6%), the rest (49.5%) is labelled as free capacity indicating that the estimated full potential of 488 MWt has not been utilized. The average duration of the heating season in Bulgaria is 180 days; so, load factors are moderate, many systems having heating and ventilating capacity. However, estimations based on all projects indicate that the price of one GJ of produced energy from geothermal resources is 2 to 4 times lower than for fossil fuels and the payback period is 2.5 to 8 years. Drilling costs are not included as all sites use existing wells. Fifteen wells have been drilled since 1990 ranging in depth from 300 to 2,000 m with 24 person years of effort in 1994 and 0.82 million US\$, of mainly public money, expended on geothermal research and development during the last ten years. The figures that appear in Bojadgieva, et al. (1995) for thermal power (133 MWt) and annual energy (788 TJ/y) are not consistent with the numbers used in the 1990 report, 293 MWt and 2,2772 TJ/y respectively. For this analysis, the 1995 numbers are used.

*Croatia:* There are two regions in the Republic of Croatia that have geothermal potential; although, only in the north, which belongs to the Pannonian sedimentary basin where the average geothermal gradient of 49°C/km is of significance (Cubric and Jelic, 1995). Several geothermal reservoirs, discovered during hydrocarbon exploration have been extensively tested; however, only three areas (Bizovac, Ivanic, and Zagreb) have been exploited with a total installed thermal power of 15 MWt. At Bizovac, the thermal water is used for balneology and some space heating with fluid extracted from two reservoirs at 1,800 m and 1,600 m. Wellhead temperatures are 96 and 85°C with flows of 5 and 3 kg/s respectively. At Ivanic, the water (2 kg/s), at a WHT of 62 C, is used for balneology, and at Zagreb two areas of the reservoir, the very permeable area of which is estimated to be about 10 km<sup>2</sup>, have been exploited. Reservoir temperature is 55 - 82°C between 500 - 1,000 m deep. At

Balto site, the planned thermal power is 7 MWt, whilst at Mladost, 6.3 MWt with an additional 0.86 MWt of heat pump. The energy is used for space heating and swimming pools. Data is also given in the paper of potential sites, particularly in the northern part of the country. It is estimated that 815 MWt is available for development from known resources; but like many countries, financial and other constraints, the northern cities are close to a natural gas pipeline, limiting the interest and development of these fields.

*France:* Over the past thirty years, the French have specialized in the development of geothermal energy using low-enthalpy resources for urban heating (Demange, et al., 1995). Today geothermal energy is used for heating and hot water production of around 200,000 heating units. Forty projects are located in the Paris basin with another 14 operations in the Aquitaine region, some of which are used for agriculture. In addition, there is a 4.5 MWe electric power station operating in Martinique and around a thousand operations exploit shallow aquifers with heat pumps for heating and air conditioning. Most of these installations were built between 1981 and 1986. Demange, et al. (1995) discuss in their paper the French experience in maintenance, remote monitoring and optimizing, developing of geothermal heat networks, and their work on reservoir behavior. Since 1986, when most of the 55 geothermal doublet wells in the Paris region had been completed, three successive 3-year R&D programs have been implemented, focusing on reservoir behavior with the objectives of understanding the resource and managing its exploitation. The last two programs to be completed in 1995 have been centered on the Dogger reservoir where at the scale of the Paris basin, an understanding of the phenomena that defines the reservoir condition has been attempted. In the last three years, the geothermal doublet has been researched to explore the concept of life-time and its characteristics. Since 1975, US\$ 1,320 million has been spent on research, development and utilization of the geothermal resources of which US\$ 640 million has been spent between 1985 and 1994. This includes HDR research and US\$ 30 million on electrical utilization. The tables attached to Demange, et al. (1995) show a total mass flow of 2,889 kg/s, which is similar to the 1990 number, and an annual energy use greater than 5,522 TJ/y. Table 4 gives a summary of direct heat use and the authors note that more than 30,000 heat pumps are used, providing heat for space heating, greenhouses, swimming pools and air conditioning. For the purposes of the worldwide scene, this author has calculated the installed thermal power using average load factors obtained from survey, and has used the numbers quoted in Table 4, acknowledging that the heat pumps are used for space heating, greenhouses, etc., as detailed in the footnotes to the table, as discussed in the authors' introduction.

*Georgia:* The geothermal fields in Georgia are in the carbonate rocks of the intermontane trough to the west and fissured volcanic, and sandstones of the Adjara-Trialety folded system in the east of the country (Buachidze, 1995). In the far west, the Gagra balneological resort uses 30 kg/s of 47°C

thermal water, and at the Sukhumi-Dranda field balneology facilities, a flower greenhouse and the airport use the fluid. To the southeast, the Kindghi-Okhurei fields supply hot water to hot beds and greenhouses over an area of 15 hectares. Further eastwards, there is another major field at Zugdidi-Tsaishi. Here, the hot water is used for a paper mill as well as heating the town of Zugdidi. Again in the southeast, four further fields are used for balneological purposes and protection of the citrus crop in inclement weather. In west Georgia, another popular resort at Tskaltubo uses thermal water; whilst, at Tbilisi field on the eastern edge of the Adjara-Trialety folded system, the thermal water is tapped at 1.5 to 4.0 km giving temperatures about 65°C. The total installed thermal power is 245 MWt with a total energy use of 7,685 TJ/y. Process heat has 30 MWt installed with greenhouses 70 MWt, and space heating and fish farming 66 and 64 MWt respectively. Since 1991, no development has taken place; but, it is estimated that since 1975, US\$ 152 million has been spent on research, development and utilization of geothermal fluids, all public money, of which US\$ 35 million was spent from 1985 to 1990.

*Greece:* Geothermal research that started in 1970 has revealed geothermal potential, both high- and low-enthalpy, in numerous fields around the country. During the last five years, related-exploration activities were focused mainly on the low-enthalpy fields of Thrace and Macedonia, and in the field of Soussaki in central Greece (Fytikas, et al., 1995). At Magama (Thrace), a new, very promising geothermal field has been identified by 21 exploration and 3 production wells. Country-wide geothermal development has resulted in approximately 160 acres (65 ha) of geothermally heated greenhouses in operation, approximately 80 acres (32.5 ha) of which were commissioned in the past five years. From the data presented, 261 kg/s of fluid are used solely in heating greenhouses giving a total estimated installed capacity of 22.6 MWt with total energy utilization of 135 TJ/y and an average load factor of 0.19. This represents a small increase from that reported in 1990. Demonstration heat pumps (18.3 kW) have been installed near Athens and are tabulated using heat sources of 18 and 20°C. In addition, it is reported that for the period 1982-1992, 0.4 million US\$ had been invested in direct-heat uses, which when proportioned to include some of the research and development costs gives 3 million US\$. The professional personnel for 1994 was 50 person-years of effort.

*Hungary:* The numbers of active thermal wells reported in Árpási (1995) is 810, with 342 closed wells as of 31 December 1993 (i.e., a total of 1152), compared with a total of 1,045 reported in Ottlik (1990) of which Árpási (1995) quotes 138 wells were closed. The current extraction rate is 6,032 kg/s (1990 - 9,533 kg/s) nearly half of which has a temperature in the range 30-40 C. Drinking water supply utilizes 29.9% of the total, balneology 27.3%, agriculture 26% and space heating 1.3%, with typical load factors of 0.5 for space heating of buildings, 0.4 for greenhouses and hot water supply at 0.4. Thermal water production in recent years has declined from 493 Mm<sup>3</sup>/y in 1989 to 190 Mm<sup>3</sup>/y in 1993, and there is no

reinjection as all the water is discharged to surface water reservoirs. Geothermal energy accounts for 0.25% of the total energy consumption of Hungary; but, only one system was commissioned in the period 1990-1994. Since 1990, there have been no funds injected into geothermal developments. The geothermal energy utilized for agriculture and space heating is given as 1,600 TJ/y, which represents 27.3% of the total. The other 72.7% is used for balneology (1,600 TJ/y), drinking water supply (3,352 TJ/y) and others (908 TJ/y). Using the load factors in the text, an estimate of the installed power is obtained, 340 MWt, which is considerably less than the 1,276 Mwt estimated from the data supplied in 1990. It is thought that these 1995 figures are more reliable since a number of assumptions were made, which may not have been valid to generate the 1990 numbers.

*Iceland:* The principal use of geothermal energy in Iceland is for space heating with 85% of all houses heated with geothermal water (Ragnarsson, 1995). Twenty percent of the total geothermal energy production is utilized for the generation of electricity which represents 5% of the electricity consumption for the country. The total flow of geothermal fluid used is now 5,794 kg/s (4,595 kg/s in 1990) in over 30 projects with an annual energy use of 21,158 TJ/y. This represents a total installed power in 1995 of 1,443 MWt from 774 MWt in 1990. The increases appears to have come, in general, from increased flows in mainly, existing systems. For example, Reykjavik is now drawing 1,000 kg/s more than in 1990. In addition, three new industrial projects are also reported. By far, the biggest use of geothermal fluid is for district heating which accounts for 62% of the geothermal primary energy supply, with electrical energy using 20%. The biggest district heating scheme is Reykjavik which serves about 145,000 people within a volume of 37,568 m<sup>3</sup>, using 56 wells with a delivery temperature of 75°C and an installed thermal capacity of 640 MWt. One hundred twenty public swimming pools, of surface area of 23,000 m<sup>2</sup>, 350,000 m<sup>2</sup> of snow melting systems, a total area of 175,000 m<sup>2</sup> of greenhouses together with 105,000 m<sup>2</sup> of soil heating, 75 fish farms as well as the diatomite, seaweed processing and salt plant (recently closed down) and industrial plant represent the wide use of geothermal heat in Iceland. In 1994, 100 professional person years of effort were utilized in the industry, about the same as for 1990, with US\$ 249 million spent in the last 10 years.

*Israel:* This is the first time there has been a report from Israel, where investigations using logs from 340 deep drill-holes, which cover most of the country, have enabled isotherms and geothermal gradients to be established (Greitzer and Levitte, 1995). A number of springs located in the Rift valley with temperatures in the range 26 to 60°C are presently used for spa and recreation, and a few geothermal wells with temperatures of 26 to 60°C are used for agriculture, greenhouses and fish farming. In total, 1,217 kg/s of geothermal fluid are currently utilized giving about 42 MWt of installed thermal power and a total annual energy use of 1,196 TJ, which gives a very high-load factor of 84%. The major use

is bathing (44%) and fish farming (43%) with the remainder (13%) used in greenhouses where the load factor is about 50%.

*Italy:* The present use of geothermal energy for direct use is reported in Allegrini, et al. (1995). The total energy use amounts to about 2,700 TJ/y with a peak thermal power of about 240 MWt. These numbers are significantly different from those quoted at the 1990 conference where the figures used by Freeston (1990) were for an installed capacity estimated at 330 MWt. It is not known where the discrepancy occurs; but at that time, 64% of the installed capacity was for balneology use. Swimming and bathing utilizes the most energy, 74% of this 1995 total; whilst, two new district heating projects, at Ferrara and Vicenza, have come online since the last report. The Vicenza plant is discussed by Leoni (1995). Fish farming accounts for only 1.2%, the aquaculture project is discussed in Berdoncini, et al. (1995). The promotion activities carried out by the ENEL demonstration center is discussed by Burgassi, et al. (1995), and this includes initiatives ranging from mineral and chemical recovery to the use of geo-heat for agro-industrial applications. Allegrini, et al. (1995) shows that 250 professional person years of effort were utilized in 1994 compared to 220 in 1990. The numbers relate to the total employed in both the electrical and non-electrical spheres of geothermal activity. The total investment for the past 10 years is given as US\$ 1,655 million with about 0.1% on direct utilization and 27% on electrical utilization. The rest is the cost of R&D and field development, including drilling.

*Republic of Macedonia:* This is a developing country of 25,713 km<sup>2</sup> and 2.1 million people with an energy budget which is based on 50% imported liquid fuel, coal for industry and electricity, and 50% on hydro power and domestic fossil fuel, was reported by Dimitrov and Gorgieva (1995) in their draft paper and tables which were not published. Currently geothermal is supplying 141 GWh of energy with electrical energy from hydro and thermopower supplying 6,780 GWh per year. So far, no high-enthalpy fields have been discovered; but, more than 50 shallow and deep exploratory and production wells drilled to depths between 40 and 2,100 m have outlined 4 to 6 major geothermal areas including several minor fields. The total flow is 1,000 l/s, total installed thermal capacity is estimated in excess of 72 MWt with an energy use of 510 TJ/y, of which 80% is exploited in greenhouse heating at load factors of about 0.33. Maximum temperatures measured were over 80°C with estimated deep fluid temperatures in some fields of 100 to 120°C. Fifteen geothermal projects are in operation or under development in five main areas. One project at Kocani is described by Dimitrov and Dimitrova (1995). In 1994, nine professional man years of effort were utilized of which government and public utilities supplied two thirds. In 1990, the same professional effort was used; but, the most of it was from the government sector. In the last 10 years, US\$ 26.7 million from mainly public funds has been spent on geothermal R&D, field and direct-utilization developments.

*Poland:* Geothermal waters for balneology purposes have been known and utilized since historical times; but, in 1985, data analysis of several hundred oil wells in the geothermal basins allowed estimate to be made of the geothermal potential in an area of 250,000 km<sup>2</sup> and occupied by over 30 million people. A program of research and construction of a district heating plant was initiated in 1985. During the period 1987 to 1994, a number of exploration wells were drilled and an experimental plant at Podhale was constructed and the construction of a heat generating plant at Pyrzyce started (Sokolowski, 1995). The tables show a total of thermal installed power of 63 MWt (9 MWt in 1990) and an energy use of 700 to 775 TJ/y, at load factors greater than 0.8. An 18-MWt heat pump is also shown to be operating at Pyrzyce utilizing 25 C water. The largest user of geothermal energy is the 40-MWt air conditioning plant at Pyrzyce using 70°C water. Currently, 63 professional man years of effort with 19 provided by foreign consultants and aid programs are shown. Over the 1985-1994 period, it has been estimated that US\$ 60 million has been spent on the program.

*Romania:* For the 1990 survey, Freeston (1990) used data generated in the 1985 survey of Gudmunsson (1985), since none other was available at that time (i.e., thermal power 251 Mwt, flow rate 1,380 kg/s). The latest information we have is from Panu (1995), where it is stated that a total of 195 wells have been drilled since 1964, four of which were drilled in 1994. A total of 54 geothermal wells are producing 792 kg/s at temperatures ranging from 40 to 105°C, with a total installed capacity of 137 MWt and an annual energy use of 2,753 TJ/y. The paper by Sarbulescu, et al. (1995) gives some additional information and details energy utilization for greenhouses at Tomantec. Geothermal energy is used for district heating for about 3,000 dwellings, 47 ha of greenhouses, sanitary hot water for 16,000 dwellings, preparation of industrial hot water for about 10 factories and balneology uses. Some of the geothermal waters have high proportion of methane gas (80-90%), which has a heating capacity of 8,500 kcal/m<sup>3</sup>, which some consumers are now using. A number of new projects are underway. New wells are being drilled in the Santandrei area, where it is hoped that the temperatures will be sufficiently high to supply fluid to ORC generators for electricity. At Olanesti, it is expected that an artesian flowrate of 200 m<sup>3</sup>/h at a temperature about 90 - 92°C will provide heating for a hotel complex and in the north of Bucharest, a doublet giving 80 - 85°C will provide heat to tourist dwellings. Investment in geothermal over the past two decades was 259 million US\$ with 60 million being spent in the last 10 years, all from public funds. Currently, 27 professional person years of effort has been allocated to these projects.

*Russia:* Kononov, et al. (1995) presents the current state of geothermal utilization; where, apart from the small plant at Kamchatka (11 MWe), geothermal fluids are used mainly for space and district heating. Six towns and eight big settlements with a total population of about 220,000 use geothermal

district heating and a total area of geothermally-heated greenhouses is about 340,000 m<sup>2</sup>. Direct use is most widespread in the following regions of the Russian federation: North Caucasus, pre-Caucasus, West Siberia, Baikal and Kuril-Kamchatka regions. By the end of 1994, 367 geothermal wells had been drilled: 185 for production, 10 for reinjection and 86 for observation. Total flow is 1,240 kg/s producing 8,180 TJ/y from an installed capacity of 210 MWt (Authors' note: These figures imply a load factor in excess of 1.0, assuming the energy use is correct; then for a more reasonable load factor of say 0.5, the installed capacity would be about 500 MWt from a maximum flow of about 2,400 kg/s.) In Kamchatka, temperatures of 80 - 100°C are utilized for space heating in a number of settlements and the construction of an 80-km pipeline for the transmission of thermal water is underway to connect the power plant at Mutnovsky to the town of Elizovo. Of the energy use, 45% is used in district heating with 48% in greenhouse heating with just over 1.5% for industrial which includes wool washing, paper production, wood drying, etc. About 150 bath resorts and 40 bottling factories, using thermal and mineral waters, operate in the regions. At Mostovskoy, 75°C water is used in a complex system, involving greenhouses, space heating, cow sheds, pig farms, and poultry yards as well as fabrication of concrete blocks and wood drying. Finally, the resulting 20 - 30°C water is used in a swimming pool and fish farm. There are at present 14 geothermal centers involved in geothermal projects, including 26 scientific institutes, 2 universities, 5 project bureaus with planned projects costing over US\$ 600 million.

*Serbia:* A draft manuscript for Serbia was received from Milivojevic and Martinovic (1995); however, it did not reach the final manuscript stage for the Congress Proceedings. The data and comments following are based on the draft manuscript. Geothermal investigations began in 1974 and an assessment of the resources has identified four geothermal provinces of which the most promising are the Pannonian and Neogen magmatic activation provinces. More than 80 low-enthalpy systems have been identified. The most important are located at the southern edge of the Pannonian Basin. Values of the heat flow density are higher than the average for continental Europe with the highest value in the Pannonian Basin (>100 mW/m<sup>2</sup>). One hundred, fifty nine natural thermal springs have been identified with temperatures in excess of 15°C with a total flow of about 4,000 kg/s. Between 1977-1988, 58 wells were drilled in the Pannonian Basin, with an overall yield of 550 kg/s and a heat capacity above 25°C, of 48 MWt; but since 1988, only four exploration wells have been drilled. In the other provinces, 45 holes were drilled up to 1992, with a yield of 550 kg/s and a total capacity of 108 MWt. The most common use of the geothermal fluid is the traditional one of balneology. There are 59 thermal spas, and thermal waters are also bottled in nine mineral water bottling companies. The direct use for space heating is in its initial stage and very modest in relation to the potential. The total installed thermal capacity is 80 MWt with 5 MWt of heat pumps and a total energy use of 2,375 TJ/y. 1,150 TJ/y or 48% of the total are used for bathing and swimming, 24% for

space heating, and nearly, 11% for greenhouse heating. The geothermal activity is currently manned by a total of four professional person years of effort, three from the universities. For the future, the resource base data suggests that geothermal energy in Serbia could make a significant component to the national energy mix. In addition, the intensive use of thermal water in agro- and aquacultures, and in district heating systems, particularly west of Belgrade, could be of value to the Serbian energy situation.

*Slovakia:* Twenty-six geothermal fields have been identified (27% of Slovakia) as prospective areas for potential exploitable geothermal resources in Slovakia. Since 1971, 61 wells have been drilled yielding 500 kg/s of water in the temperature range 20 - 92°C (Remsik and Fendek, 1995). The total estimate of geothermal energy in all the prospects is 6,608 MWt with the eastern Slovakian basin having the highest heat flow of 120 mW/m<sup>2</sup>. Low-temperature waters (<100°C) exist in the 26 areas with 16 areas having temperatures in the range 100 - 150°C, and only five areas with temperatures greater than 150°C. In the Kosice basin in east Slovakia, medium- and high-temperature sources of geothermal energy suitable for electricity generation (25 - 30 MWe) looks to be possible. The total average annual flow rate from the current exploitation is 353 kg/s producing an annual energy use of 1,808 TJ/y. Of this, 49% is utilized in greenhouses, with a further 36% used in bathing and swimming. Space heating and fish farming are the other application of the energy. The total installed thermal power for the country is 100 MWt. (Authors note: This data and that in Table 1 was taken from the tables enclosed with the draft report which have not been published in the Congress Proceedings.) Franko (1995) describes the utilization of geothermal, present and future, in the Vysoké Tatry Mountains and with temperatures of 50°C concludes that the potential thermal power available in this region is 94 MWt. Tourist and sporting facilities, space heating, domestic and industrial are seen as future projects for the region.

*Slovenia:* Slovenia is placed between the colliding margins of the Eurasian and African plates on the western border of the Pannonian basin. Investigations started in 1982 and heat-flow density temperatures maps were published in 1991; whilst, geothermal energy resources were investigated in 1992-93 (Rajver, et al., 1995). The main geothermal parameters were established from 72 boreholes in a depth range 100 - 4,000 m. Temperatures at 4,000 m do not exceed 200°C; while, temperature gradients vary from 10 C/km to about 70 C/km. The geothermal energy potential is concentrated in the eastern part of the country. From the tables, geothermal energy utilizes 761 TJ/y from a flow from 21 geothermal localities. Thermal spas and recreation centers (56%) are the main consumers, with some output to space heating (29%), greenhouses (10%), and industrial purposes (2%). More than 400 heat pumps extracting an additional 40 TJ from the shallow groundwater are also operating. The installed thermal power is 36.5 MWt. Heat pumps provide an additional 5.5 MWt. Thirty-two wells have been drilled since 1990, and in the past 10 years, it is estimated that US\$ 73.5 million has

been spent of public funds on geothermal development. In 1994, 13 professional person years of effort were used in developing the geothermal program.

*Switzerland:* The early nineties marked a turning point in Swiss geothermal development. Deep drilling projects gave a momentum to a country-wide borehole heat exchanger (BHE) installations (Rybach and Gorhan, 1995). Since 1990, significant steps in energy policy development towards the utilization of indigenous and environmentally forms of energy have been undertaken. A governmental risk-coverage system for deep drilling (>400 m) introduced in 1987 is still effective. Fifteen million Swiss francs were awarded by federal government to cover activities 1987 - 1977. Six wells have been drilled to depths between 650 and 2,550 m since 1991 with, in general, too low flow rates for sensible utilization. However, wells drilled in the late 80s, were more successful, resulting in a geothermal doublet system of 4.7 MWt starting up in 1993 in Riehen. Shallow geothermics, 15 - 400 m deep bores, has resulted in BHEs and their derivations (energy piles, multiple BHE, combined heat extraction/storage, etc.) providing new impetus to geothermal developments in the country. More than 6,000 such systems are installed representing heating amounting to 3.2 PJ/y (Switzerland used 346 PJ for space heating in 1993). In addition to the extensive use of BHEs, Rybach and Gorhan (1995) describe other initiatives such as the use of Alpine Tunnel waters in heat pump installations (see also Rybach and Wilhelm, 1995), and a contribution to the European HDR program. The tables indicate that 218 TJ/y are utilized mainly in conventional space heating with a total installed rated capacity of 104 MWt and an annual energy use of 3,252 TJ/y. The professional person years of effort in 1994 was 7, and the total investment in the past 10 years was US\$ 177 million of which 85% was private funds.

*Turkey:* Since the 1960s when exploration studies started, 140 geothermal fields have been explored with wellhead temperatures above 40°C. The geothermal energy is used mostly in space heating, dwellings, greenhouses, thermal facilities and in balneology (Mertoglu and Basarir, 1995). Also electricity generation and the production of 40,000 tons/y of industrial food-grade CO<sub>2</sub> takes place at Kizildere. Heating accounts for 87% of the geothermal energy consumption in the country, and at present, an equivalent of 23,000 dwellings and 6,000 m<sup>2</sup> greenhouses are heated by geothermal fluids. The proven potential for geothermal direct usage in Turkey is in excess of 2,500 MWt. Currently, geothermally-heated installations total 160 MWt, with a further 121 MWt under construction, and a future growth with completed feasibility studies of 563 MWt. This last figure is for 80,500 dwellings and about 80,000 m<sup>2</sup> of greenhouses. Mertoglu and Basarir (1995) quote costs of heating in US cents for electricity, 5 c/kWh; fuel-oil, 5.6 c/kWh; natural gas, 4.8 c/kWh; coal, 3.9 c/kWh, and geothermal at 0.1-0.56 c/kWh. Also 1994 costs for heating a dwelling during the winter and domestic hot water throughout the year are US\$ 15/month with installation cost per dwelling of about 750 US\$. Unfortunately, there is no table presented in the paper that allows a good comparison of the figures

presented in 1990; neither is there a breakdown of uses. In Freeston (1990), the total installed thermal power was 246 MWt, compared to the present 160 MWt.

*Others:* Wells for the exploitation of geothermal energy in **Austria** have been drilled in the Upper Austrian Molaase basin and the Styrian basin, both of which are, bordering the Alps, since 1985 (Goldbrunner, 1995). At the end of 1995, the installed geothermal thermal power was 21.1 MWt. The largest project is at Altheim in upper Austria where 750 dwellings are heated. Wells drilled in the Styrian since 1985 are all used for bathing. Spas are of growing economic importance in southern Austria. The only field quoted for **Denmark** is at Thisted which is a sandstone reservoir with a high-dissolved solids content (150,000 mg/kg) and a reservoir temperature of 46 C (Mahler, 1995). An absorption heat pump extracts 3.5 MWt from the geothermal water when it cools 143 m<sup>3</sup>/h of thermal water from 44 to 22°C. The use is for space heating and utilizes 45 TJ/y. Additional information (not published) gave an investment for 1994 of US\$ 5.5 million and a person years effort of 7. There is no country-update paper for **Germany**; but, three papers in the conference give details of some direct heat activities and a communication from Schulz (1995) indicates 20 geothermal areas with a total utilization of about 32 MWt, which with an assumed load factor of 0.3 gives the thermal energy as 303 TJ/y. Freeston (1990) recorded that low-enthalpy geothermal energy is utilized in 15 localities with a total installed capacity of about 8 MWt. The paper by Kabus and J ntsch (1995) reports on a district heating system at Waren-Papenberg providing heat for 1,000 flats, and Sanner (1995) reviews ground-source heat pumps in Germany; whilst, J hn (1995) details the utilization of 8 MWt of geothermal heat from thermal water in Straubing by cascading through multi-uses with heat pumps, swimming pools and space heating from a production temperature of 36°C down to a reinjection temperature of 13°C. In addition, Bram (1993) reports on the German continental drilling program and Poppei, et al. (1993) reports on studies to utilize existing abandon oil and gas wells with closed-loop water systems for extracting energy in heat pump, and district heating systems. **Latvia** has recently established a geothermal database and based on these data, existing district heating networks have been evaluated for partial conversion in a pilot demonstration plant at Liepaja utilizing 420 TJ/y of geothermal energy (Eihmanis, 1995). **Lithuania** is another country in the very early stage of geothermal exploration and utilization. Favorable conditions have been found; particularly, in west Lithuania in an area of 42,444 m<sup>2</sup>, where a geothermal gradient of 4°C/100 m has been measured. The most promising technology is based on an absorption heat pump with a number of feasibility studies indicating that both technically and economically, a project would be viable. Construction of a pilot plant at Klaipeda is under consideration (Suveizdis, 1995). The geological prospects for deep geothermal energy for direct use are favorable in the **Netherlands**, which was established by making an inventory of resources during the period 1979-1984; but because of large reserves of natural gas, etc., no major geothermal developments have taken place (Walter, 1995). However, one trial well was drilled at Asten,

but was unsuccessful due to a lack of permeability. Government policy has set targets for using sustainable resources, including geothermal, and in 1993, the De Lier demonstration project, which is to be used for heating about 15 ha of greenhouses and pre-heating natural gas in a demonstration station, was studied. It is anticipated that a well doublet will be drilled in 1995, and the plant will become operational in 1996-1997. The exploitation of geothermal resources on the **Portuguese** mainland and Maderia island has resulted in a pilot geothermal generator plant of 4.9 MWe producing 20-25% of the island's requirement (Rodrigues, 1995). On the mainland, there are some low-enthalpy resources; but, limited at this stage to the heating of a hospital in the Lisbon region, no details are given. **Sweden** has had a heat pump operating at Lund since 1986, currently using four production and six reinjection wells located at depths between 600 - 800 m (Alm and Bjelm, 1995). The heat pump is rated at 47 MWt and produces 960 TJ/y of energy, from a flow rate of 455 kg/s (Bjelm and Lindeberg, 1995). In the **United Kingdom**, Batchelor (1995) states that there has been no new geothermal developments since 1990; although, the Southampton direct-use project is still operated by a private company and there is interest in ground-loop heat pump systems.

## OCEANIA

*Australia:* The Australian continent comprises sedimentary basins over a basement of precambrian and palaeozoic metamorphics, without significant fold mountains or active fault zones. Volcanic heat sources are largely confined to the newer basalts of western Victoria. Current geothermal production in Australia is in small projects dispersed across the eastern half of the continent (Burns, et al., 1995). Natural hot springs and hot artesian bores have been developed for recreational and therapeutic purposes. A district heating system at Portland, in the Otway basin of western Victoria, which is serving a building area of 18,990 m<sup>2</sup> and has done so for the past 12 years without any significant problems, also has prospects for further expansion to use the hot water directly for the development of a wool scouring plant. A geothermal well is providing hot water for paper manufacture at Traalgon, in the Goppsland basin of eastern Victoria. Power production from hot water aquifers was tested at Mulka in south Australia with a 20 kWe binary cycle. A plant at Birdsville in Queensland, commissioned in 1992, is now undergoing a four-year production trial, where a Rankine-cycle engine using Freon, produces 150 kWe from water flowing at about 30 l/s and 99 C from a 150-cm (6-in.) nominal bore drilled to 1221 m. An important Hot Dry Rock resource has been confirmed in the Cooper basin. It has been proposed to build an HDR experimental facility to test power production from deep-conductive resources in the Sydney basin near Musselbrook. The proposal is to develop a A\$60.4 million experimental, 20-MWe power plant designed around a resource volume one cubic kilometer of hot rock at a temperature of 250°C.

*Fiji:* The Fiji department of Energy has been carrying out a comprehensive resource assessment program to identify and promote the local use of renewable energy resources where they are economically viable, Autar (1995). DOE is currently involved in investigating the extent of geothermal resources, and in particular whether geothermal fields in the Savusavu and Labasa areas, the two fields with the greatest potential, are capable of exploitation for electricity generation/process heat. It is also of interest to make a comparison of generation cost from geothermal with those from the other options on Vanua Levu. Results to date have indicated that the Savusavu resource is suitable for generation of electricity; whilst, the Labasa resource can only provide process heat. The initial geoscience studies have been completed and deep drilling to provide the resources is at the planning stage. The tabular information supplied (but not printed) indicated a total investment since 1975 of US\$ 0.7 million and since 1990, the number of professional person years of effort was 6.4, of which 2.5 was from foreign consultants and in 1994, 0.3 professional person years of effort was used.

*New Zealand:* Thain and Freeston (1995) summarize geothermal developments in the country for the last five years. Restructuring of the electricity industry in 1993 and creation of the Resource Management Act (RMA) in 1991 has impacted on both the geothermal electrical and direct heat developments. The former enabled any power company to sell power to any customer anywhere in New Zealand. Promotion of private generation has generated the planning of a number of small-scale geothermal projects; however, none of them have started. Although, it is possible one or two will start in the next year or so. The regional councils have been given the responsibility of administering the RMA with respect to about 80% of the countries high-temperature resources. They have proposed that these be sustainably managed from a Macro perspective rather than attempt to manage individual systems. This has given rise to the concept of a steam-field management organization which would be responsible for ensuring the resource is utilized efficiently and equitably. Since the report of Lumb and Clelland (1990), the major direct-heat developments have taken place on the Kawerau and Ohaaki fields. At Kawerau, two Ormat power plants with a total capacity of 5.9 MWe have been installed using 170 degree separated water and a timber drying facility has been installed with a thermal power of about 3.2 MWt drying 100,000 m<sup>3</sup>/y and operating 340 days/y, 24 hrs/day, a load factor of over 0.9. At Ohaaki, the Lucerne (alfalfa) plant, and timber drying facility have been further developed to improve their efficiency (Pirrit and Dunstall, 1995). They now use a total of under 10 MWt at peak times instead of the 45 MWt quoted by Lumb and Clelland (1990). The professional personnel allocated to geothermal activities is shown as 85 man years, an increase of 16 over the 1990 figure. This probably reflects the interest shown by non-governmental groups that have come about since the restructuring of the industry.

## CONCLUDING REMARKS

As in previous surveys, some countries stand out as major users of geothermal fluids for direct use, and in these countries, developments have in general proceeded at a slow pace. This is not surprising since the price of oil and natural gas during the past five years has given developers cheaper options, and financing of projects both in developed and developing countries has been difficult to obtain. However, the prospects are there when the need arises and many new geothermal countries have been doing the basic ground work to establish databases for future exploration and exploitation. This particular survey has been limited, as explained in the text, by the quality of the data supplied. It is obvious from the results that there are a number of anomalies which have been generated, in general, by the format and content of the information requested in the tables. However, this exercise has been useful if only to demonstrate that the use of low-temperature geothermal fluids for direct use, given the right environment, is viable and economic. As oil and gas supplies dwindle, the use of geothermal energy is an alternative source of energy.

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