Geothermics 40 (2011) 159–180

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Direct utilization of geothermal energy 2010 worldwide review

John W. Lund[a], Derek H. Freeston[b], Tonya L. Boyd[a,*]

[a] Geo-Heat Center, Oregon Institute of Technology, 3201 Campus Drive, Klamath Falls, OR 97601, USA
[b] Geothermal Institute, University of Auckland, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 23 February 2011
Accepted 11 July 2011

Keywords:
Geothermal
Direct use
Spas
Balneology
Space heating
District heating
Aquaculture
Greenhouses
Ground-source heat pumps
Agricultural drying
Industrial applications
Snow melting
Energy savings

ABSTRACT

This paper presents a review of the worldwide application of geothermal energy for direct utilization, and updates the previous survey carried out in 2005. We also compare data from 1995 and 2000 presented at World Geothermal Congresses in Italy and Japan, respectively (WGC95 and WGC2000). As in previous reports, an effort is made to quantify ground-source (geothermal) heat pump data. The present report is based on country update papers prepared for WGC2010 and other sources of data available to the authors. Final update papers were received from 70 countries of which 66 reported some direct utilization of geothermal energy. Twelve additional countries were added to the list based on other sources of information. Direct utilization of geothermal energy in 78 countries is a significant increase from the 72 reported in 2005, the 58 reported in 2000, and the 28 reported in 1995. An estimate of the installed thermal power for direct utilization at the end of 2009 is used in this paper and equals 48,493 MWt, almost a 72% increase over the 2005 data, growing at a compound rate of 11.4% annually with a capacity factor of 0.28. The thermal energy used is 423,830 TJ/year (117,740 GWh/yr), about a 55% increase over 2005, growing at a compound rate of 9.2% annually. The distribution of thermal energy used by category is approximately 47.2% for ground-source heat pumps, 25.8% for bathing and swimming (including balneology), 14.9% for space heating (of which 85% is for district heating), 5.5% for greenhouses and open ground heating, 2.8% for industrial process heating, 2.7% for aquaculture pond and raceway heating, 0.4% for agricultural drying, 0.5% for snow melting and cooling, and 0.2% for other uses. Energy savings amounted to 250 million barrels (38 million tonnes) of equivalent oil annually, preventing 33 million tonnes of carbon and 107 million tonnes of CO_2 being release to the atmosphere, this includes savings for geothermal heat pumps in the cooling mode (compared to using fuel oil to generate electricity).

Published by Elsevier Ltd.

1. Introduction

Direct-use of geothermal energy is one of the oldest, most versatile and a common form of utilization of geothermal energy (Dickson and Fanelli, 2003). The early history of geothermal direct-use has been reviewed for over 25 countries in the *Stories from a Heat Earth – Our Geothermal Heritage* (Cataldi et al., 1999), that documents geothermal use for over 2000 years. The information presented here on direct applications of geothermal heat is based on country update papers published in the World Geothermal Congress 2010 (WGC2010) proceedings and covers the period 2005–2010. Papers from 70 countries were received, 66 of which reported some geothermal direct-use with 12 additional countries added from other sources such as from WGC2005 and personal communications for a total of 78 countries – an increase of six countries from WGC2005 (Bosnia & Herzegovina, El Salvador, Estonia, Morocco, South Africa and Tajikistan). In the cases where data are missing or incomplete, the authors have relied on country update reports from the World Geothermal Congresses of 1995, 2000 and 2005 (WGC95, WGC2000, WGC2005), as well as from two *Geothermics* publications (Lund and Freeston, 2001; Lund et al., 2005), and personal communications. Data from WGC2010 are also compared with data from WGC95, WGC2000 and WGC2005.

2. Data summary

Table 1 is a summary, by country, of the installed thermal capacity (MWt), annual energy use (TJ/yr and GWh/yr) and the capacity factor to the end of 2009. The dataset on wells drilled, professional person-years and investment in geothermal projects during 2005–2009 is incomplete, but significant information can be obtained from the individual papers submitted to WGC2010. The total installed capacity, reported through the end of 2009 for geothermal direct utilization worldwide is 48,483 MWt, a 72% increase over WGC2005, growing at an annual compound rate of 11.4%. The total annul energy use is 423,968 TJ (117,778 GWh), indicating a 55% increase over WGC2005, and a compound annual growth rate of 9.2%. The worldwide capacity factor is 0.28 (equiv-

* Corresponding author. Tel.: +1 541 885 1750.
E-mail address: toni.boyd@oit.edu (T.L. Boyd).

0375-6505/$ – see front matter. Published by Elsevier Ltd.
doi:10.1016/j.geothermics.2011.07.004

Table 1
Summary of direct-use data worldwide, 2010.

Country	Capacity, MWt	Annual use in TJ/yr	Annual use in GWh/yr	Capacity factor
Albania	11.48	40.46	11.2	0.11
Algeria	66.84	2.098.68	583.0	1.00
Argentina	307.47	3906.74	1085.3	0.40
Armenia	1	15	4.2	0.48
Australia	33.33	235.1	65.3	0.22
Austria	662.85	3727.7	1035.6	0.18
Belarus	4.5	44.43	12.3	0.31
Belgium	117.9	546.97	151.9	0.15
Bosnia & Herzegovina	21.696	255.36	70.9	0.37
Brazil	360.1	6622.4	1839.7	0.58
Bulgaria	98.3	1370.12	380.6	0.44
Canada	1126	8873	2464.9	0.25
Caribbean Islands	0.103	2.775	0.8	0.85
Chile	9.11	131.82	36.6	0.46
China	8898	75,348.3	20,931.8	0.27
Columbia	14.4	287	79.7	0.63
Costa Rica	1	21	5.8	0.67
Croatia	67.48	468.89	130.3	0.22
Czech Republic	216.5	1290	358.4	0.19
Denmark	200	2500	694.5	0.40
Ecuador	5.157	102.401	28.4	0.63
Egypt	1	15	4.2	0.48
El Salvador	2	40	11.1	0.63
Estonia	63	356	98.9	0.18
Ethiopia	2.2	41.6	11.6	0.60
Finland	994	7966	2213.0	0.25
France	1345	12,929	3591.7	0.30
Georgia	26.51	689.24	191.5	0.82
Germany	2485.4	12,764.5	3546.0	0.16
Greece	134.6	937.8	260.5	0.22
Guatemala	2.31	56.46	15.7	0.78
Honduras	1.933	45	12.5	0.74
Hungary	654.6	9767	2713.3	0.47
Iceland	1826	24,361	6767.5	0.42
India	265	2545	707.0	0.30
Indonesia	2.3	42.6	11.8	0.59
Iran	41.608	1064.18	295.6	0.81
Ireland	138.45	691.91	192.2	0.16
Israel	82.4	2193	609.2	0.84
Italy	867	9941	2761.6	0.36
Japan	2099.53	25,697.94	7138.9	0.39
Jordan	153.3	1540	427.8	0.32
Kenya	16	126.624	35.2	0.25
Korea (South)	229.3	1954.65	543.0	0.27
Latvia	1.63	31.81	8.8	0.62
Lithuania	47.6	411.52	114.3	0.27
Macedonia	47.18	601.41	167.1	0.40
Mexico	155.82	4022.8	1117.5	0.82
Mongolia	6.8	213.2	59.2	0.99
Morocco	5.02	79.14	22.0	0.50
Nepal	2.717	73.743	20.5	0.86
Netherlands	1410.26	10,699.4	2972.3	0.24
New Zealand	393.22	9552	2653.5	0.77
Norway	1000	10,800	3000.2	0.34
Papua New Guinea	0.1	1	0.3	0.32
Peru	2.4	49	13.6	0.65
Philippines	1.67	12.65	3.5	0.24
Poland	281.05	1501.1	417.0	0.17
Portugal	28.1	386.4	107.3	0.44
Romania	153.24	1265.43	351.5	0.26
Russia	308.2	6143.5	1706.7	0.63
Serbia	100.8	1410	391.7	0.44
Slovak Republic	132.2	3067.2	852.1	0.74
Slovenia	115.6	1015.1	282.0	0.28
South Africa	6.01	114.75	31.9	0.61
Spain	141.04	684.05	190.0	0.15
Sweden	4460	45,301	12,584.6	0.32
Switzerland	1060.9	7714.6	2143.1	0.23
Tajikistan	2.93	55.4	15.4	0.60
Thailand	2.54	79.1	22.0	0.99
Tunisia	43.8	364	101.1	0.26
Turkey	2084	36,885.9	10,246.9	0.56
Ukraine	10.9	118.8	33.0	0.35
United Kingdom	186.62	849.74	236.1	0.14
United States	12,611.46	56,551.8	15,710.1	0.14
Venezuela	0.7	14	3.9	0.63
Vietnam	31.2	92.33	25.6	0.09
Yemen	1	15	4.2	0.48
Total	48.493	423,830	117,740	0.28

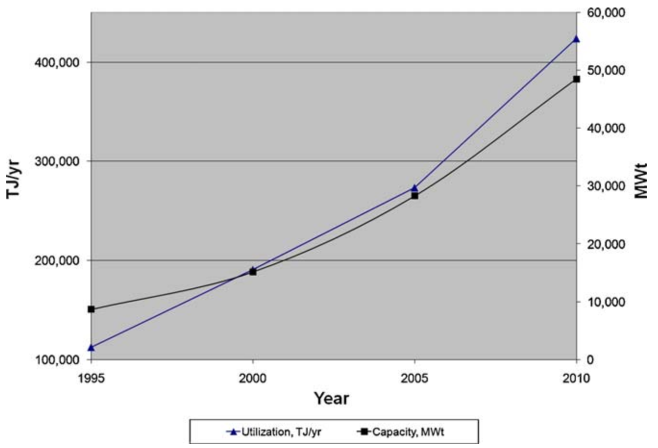

Fig. 1. The installed direct-use geothermal capacity and annual utilization from 1995 to 2010.

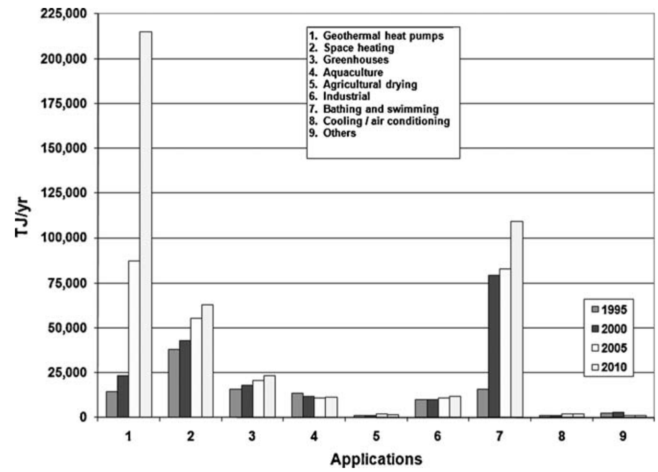

Fig. 2. Comparison of worldwide direct-use geothermal energy in TJ/yr for 1995, 2000, 2005 and 2010.

alent to 2453 full load operating hours per year), down from 0.31 in 2005 and 0.40 in 2000. The growth rate of installed capacity and annual energy use over the past 15 years is shown in Fig. 1. The lower capacity factor and growth rate for annual energy use is due to the increase in geothermal heat pump installations which have a low capacity factor of 0.19 worldwide.

The growing awareness and popularity of geothermal (ground-source) heat pumps have had the most significant impact on direct-use of geothermal energy. The annual energy use for these units grew 2.29 times at a compound annual rate of 18.0% compared to WGC2005. The installed capacity grew 2.15 times at a compound annual rate of 16.6%. This is due to better reporting and to the ability of geothermal heat pumps to utilize groundwater or ground-coupled temperatures anywhere in the world (see Table 2).

The five countries with the largest installed capacity are: USA, China, Sweden, Germany and Japan accounting for 63% of the world capacity, and the five countries with the largest annual energy use are: China, USA, Sweden, Turkey, and Japan, accounting for 55% of the world use. Japan and Germany are new members of the “top five” as compared to WGC2005. However, an examination of the data in terms of land area or population shows that the smaller countries dominate, especially the Nordic ones. The “top five” then become for installed capacity: (MW/population) Iceland, Sweden, Norway, Finland, and Switzerland; (MW/area) Netherlands, Switzerland, Iceland, Sweden and Hungary; for annual energy use: (TJ/yr/population) Iceland, Sweden, Norway, New Zealand, Denmark and Finland; (TJ/yr/area) Netherlands, Iceland, Switzerland, Hungary and Sweden. The largest increase in geothermal installed capacity (MWt) over the past five years was in: United Kingdom, Korea, Ireland, Spain and Netherlands; and the largest increase in annual energy use (TJ/yr) over the past five years occurred in: United Kingdom, Netherlands, Korea, Ireland, and Argentina. All of these increases except Argentina are mainly due to geothermal heat pump installations.

In 1985, only 11 countries reported an installed capacity of more than 100 MWt. By 1990, this number had increased to 14, by 1995 to 15, by 2000 to 23, and by 2005 33 countries. As of December 2009, there were 36 countries reporting over 100 MWt, an increase of 3 countries over 2005.

3. Categories of utilization

Table 2 divides the data from 1995, 2000, 2005 and 2010 among the various uses in terms of capacity, energy utilization and capacity factor. This distribution can also be viewed as bar charts in Fig. 2. Fig. 3 presents the 2010 data in pie-chart form in percentages. An attempt was made to distinguish individual space heating from district heating, but this was often difficult, as the individual country reports did not always make this distinction. Our best estimate is that similar to WGC2005, district heating represents 86% of the installed capacity and 88% of the annual energy use. Snow melting represents the majority of the snow melting/air-conditioning category. “Other” is a category that covers a variety of uses, details of

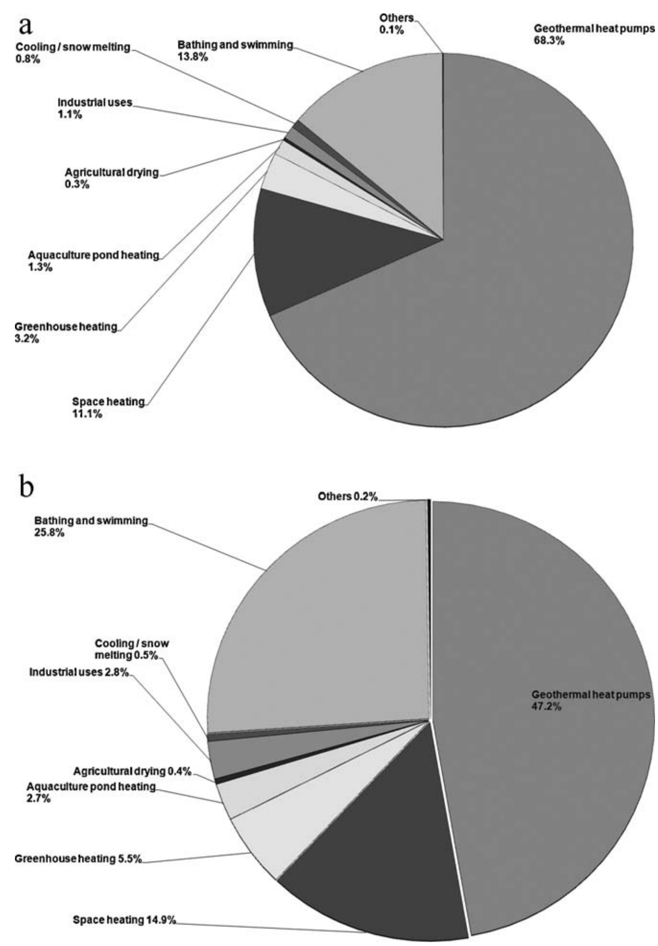

Fig. 3. Geothermal direct applications worldwide in 2010, distributed by percentage of total installed capacity (a) and percentage of total energy use (b).

Table 2
Summary of the various categories of direct use worldwide for the period 1995–2010.

	2010	2005	2000	1995
Capacity, MWt				
Geothermal heat pumps	33,134	15,384	5275	1854
Space heating	5394	4366	3263	2579
Greenhouse heating	1544	1404	1246	1085
Aquaculture pond heating	653	616	605	1097
Agricultural drying	125	157	74	67
Industrial uses	533	484	474	544
Bathing and swimming	6700	5401	3957	1085
Cooling/snow melting	368	371	114	115
Others	42	86	137	238
Total	48,493	28,269	15,145	8664
Utilization, TJ/yr				
Geothermal heat pumps	200,149	87,503	23,275	14,617
Space heating	63,025	55,256	42,926	38,230
Greenhouse heating	23,264	20,661	17,864	15,742
Aquaculture pond heating	11,521	10,976	11,733	13,493
Agricultural drying	1635	2013	1038	1124
Industrial uses	11,745	10,868	10,220	10,120
Bathing and swimming	109,410	83,018	79,546	15,742
Cooling/snow melting	2126	2032	1063	1124
Others	955	1045	3034	2249
Total	423,830	273,372	190,699	112,441
Capacity factor				
Geothermal heat pumps	0.19	0.18	0.14	0.25
Space heating	0.37	0.40	0.42	0.47
Greenhouse heating	0.48	0.47	0.45	0.46
Aquaculture pond heating	0.56	0.57	0.61	0.39
Agricultural drying	0.41	0.41	0.44	0.53
Industrial uses	0.70	0.71	0.68	0.59
Bathing and swimming	0.52	0.49	0.64	0.46
Cooling/snow melting	0.18	0.18	0.30	0.31
Others	0.72	0.39	0.70	0.30
Total	0.28	0.31	0.40	0.41

which are not frequently provided, but is known to include animal husbandry.

3.1. Geothermal heat pumps

Geothermal (ground-source) heat pumps have the largest energy use and installed capacity, accounting for 68.3% and 47.2% of the worldwide capacity and use, respectively. The installed capacity is 33,134 MWt and the annual energy use is 200,149 TJ/yr, with a capacity factor of 0.19 (in the heating mode). Although, most of the installations occur in North America, Europe, and China, the number of countries with installation increased from 26 in 2000, to 33 in 2005, and to 43 in 2010. The equivalent number of installed 12 kW units (typical of US and Western European homes) is approximately 2.76 million. This is more than double the number of units reported for 2005, and four times the number reported for 2000. The size of individual units; however, ranges from 5.5 kW for residential use to large units of over 150 kW for commercial and institutional installations.

In the United States, most units are sized for peak cooling load and are oversized for heating, except in the northern states; thus, they are estimated to average only 2000 full-load hours per year (capacity factor of 0.23). In Europe, most units are sized for the heating load and are often designed to provide the base load with peaking by fossil fuel. As a result, these units may be in operation up to 6000 full-load hours per year (capacity factor of 0.68), such as in Nordic countries. Unless the actual number of full-load hours was reported, a value of 2200 h (and higher for some of the northern countries) was used for energy output (TJ/yr) calculations, based on a report by Curtis et al. (2005).

The energy use reported for the heat pumps was deduced from the installed capacity (if it was not reported), based on an average coefficient of performance (COP) of 3.5, which allows for one unit of energy input (usually electricity) to 2.5 units of energy output, for a geothermal component of 71% of the rated capacity [i.e. (COP − 1)/COP = 0.71]. The cooling load was not considered as geothermal as in this case, heat is discharged into the ground or groundwater. Cooling, however, has a role in the substitution for fossil fuels and reduction of greenhouse gas emissions and is included as discussed in Section 6.

The leaders in installed units are the United States, China, Sweden, Germany, and the Netherlands.

3.2. Space heating

Space heat has increased 24% in installed capacity and 14% in annual energy use over WGC2005. The installed capacity now totals 5394 MWt and the annual energy use is 63,025 TJ/year. As stated previously about 86% of the installed capacity and 85% of the annual energy use is in district heating (24 countries). The leaders in district heating annual energy use are Iceland, China, Turkey, France and Russia, whereas, Turkey, Italy, United States, Japan and Georgia are the major users in the individual space heating sector (a total of 27 countries).

3.3. Greenhouse and covered ground heating

Worldwide use of geothermal energy used for greenhouse heating increased by 10% in installed capacity and 13% in annual energy use. The installed capacity is 1544 MWt and 23,264 TJ/yr in energy use. A total of 34 countries report geothermal greenhouse heating (compared to 30 for WGC2005), the leading countries for annual energy use being: Turkey, Russia, Hungary, China and Italy. Most countries did not distinguish between covered greenhouses versus uncovered ground heating, and only a few reported the actual area heated. The main crops grown in greenhouses are vegetables and flowers; however, tree seedlings (USA) and fruit such as bananas (Iceland) are also grown. Developed countries are experiencing competition from developing countries due to labor costs being lower – one of the main costs of operating these facilities. Using an average energy requirement, determined from WGC2000 data of 20 TJ/year/ha for greenhouse heating, the 23,264 TJ/yr corresponds to about 1163 ha of greenhouses heated worldwide – a 16.3% increase over 2005.

3.4. Aquaculture pond and raceway heating

Aquaculture use of geothermal energy has slightly increased over WC2005, reversing a downward trend from WGC1995; however, it is still lower in comparison to WGC1995. The increase over the past five years has been 6% for the installed capacity and 5% for annual energy use. The installed capacity is 653 MWt and the annual energy use is 11,521 TJ/yr. Twenty-two countries report this type of use, the main ones in annual energy use being USA, China, Iceland, Italy, and Israel. These facilities are labor intensive and require well-trained personnel, which are often hard to justify economically, thus the reason why the growth is slow. Tilapia, salmon and trout seem to be the most common species, but tropical fish, lobsters, shrimp, and prawns, as well as alligators are also being farmed. Based on work in the United States, we calculate that 0.242 TJ/yr/tonne of fish (bass and tilapia) are required, using geothermal waters in uncovered ponds. Using the reported energy use of 11,521 TJ/yr, an equivalent 47,600 tonnes of annual production is estimated that represents a 5.0% increase over 2005.

3.5. Agricultural crop drying

Thirteen countries report the use of geothermal energy for drying various grains, vegetables and fruit crops compared to 15 for WGC2005. Examples include: seaweed (Iceland), onion (USA), wheat and other cereals (Serbia), fruit (El Salvador, Guatemala and Mexico), Lucerne or alfalfa (New Zealand), coconut meat (Philippines), and timber (Mexico, New Zealand and Romania). A total of 125 MWt and 1635 TJ/yr are being utilized, a decrease from WGC2005, mainly due to the shutting down of an onion and garlic dehydration plant in Nevada, USA.

3.6. Industrial process heat

This is a category that has applications in 14 countries, down from 15 in 2005 and from 19 in 2000. These operations tend to be large and of high-energy consumptions. Examples include: concrete curing (Guatemala and Slovenia), bottling of water and carbonated drinks (Bulgaria, Serbia and the United States), milk pasteurization (Romania), leather industry (Serbia and Slovenia), chemical extraction (Bulgaria, Poland and Russia), CO_2 extraction (Iceland and Turkey), pulp and paper processing (New Zealand), iodine and salt extraction (Vietnam), and borate and boric acid production (Italy). The installed capacity is 533 MWt and the annual energy use 11,745 TJ/yr, a 10% and 8% increase over 2005 respectively. As expected, because of almost year-around operation, heat use for industrial processes has the highest capacity factor of all direct uses (0.70).

3.7. Snow melting and space cooling

There are very limited applications in this area, with pavement snow melting project in Argentina, Iceland, Japan, Switzerland and the United States. A total of about two million square meters of pavement are heated worldwide, the majority of which is in Iceland. A project in Argentina uses geothermal steam for highway snow melting in the Andes to keep a resort community open during winters, and in the United States, with most of the pavement snow melting on the Oregon Institute of Technology campus and in the City of Klamath Falls, Oregon. The power required varies from 130 to 180 W/m^2 (United States and Iceland). The installed capacity is 311 MWt and the annual energy use is 1845 TJ/yr, an increase over 2005. Space cooling is reported in five countries, amounting to 56 MWt and 281 TJ/yr. Heat pumps in the cooling mode are not included as they return heat to the subsurface, and thus do not use geothermal energy.

3.8. Bathing and swimming

Figures for this use are the most difficult to collect and quantify. Almost every country has spas and resorts that have swimming pools heated with geothermal water (including balneology), but many allow the water to flow continuously, regardless of use. As a result, the actual usage and capacity figures may be high. In some cases where use was reported, no flows or temperature drops were known; in these cases 0.35 MWt and 7.0 TJ/yr were applied to estimate the capacity and energy use for typical installations. In other cases, 5 L/s and a 10 °C temperature change were used (0.21 MWt) for the installed capacity and 3 L/s and 10 °C temperature change (4.0 TJ/yr) were used for the annual use, based on communications with the authors. Undeveloped natural hot springs are not included.

In addition to the 67 counties (up from 60 in 2005) that reported bathing and swimming pool use, we are also aware of developments in Malaysia, Mozambique, Singapore and Zambia, although no information was available. The installed capacity is 6700 MWt and the annual energy use is 109,410 TJ/yr, up 24% and 32% respectively over 2005. We have also included the Japanese-style inns (onsens) that utilize hot spring water for bathing, as we included these figures in 2000 and 2005 (Lund and Freeston, 2001; Lund et al., 2005). The largest reported annual energy uses are from China, Japan, Turkey, Brazil and Hungary.

3.9. Other uses

This category includes 42 MWt and 955 TJ/yr, and is lower compared to 2005. These values were reported by seven countries, and include animal farming, spirulina cultivations, desalinations and sterilization of bottles.

4. Capacity factors

Average capacity factors were determined for each country (Table 1) and for each category of use (Table 2). They vary from 0.09 to 1.00 (though the latter is in question) for the countries and from 0.18 to 0.72 for the categories of use. The lower values refer to countries in which geothermal heat pumps usage predominates, as indicated by the 0.19 in Table 2, whereas the higher numbers are for countries with high industrial use (New Zealand) or continuous operation of pools for swimming and bathing (Iran).

The worldwide capacity factor dropped from 0.40 in 2000 to 0.31 in 2005 to the current 0.28. Again, this is a result of the increase in geothermal heat pump usage. Capacity factors for the various categories of use remained approximately constant when compared to 2005.

The capacity factor is calculated as follows: [(annual energy use in TJ/yr)/(installed capacity in MWt)] × 0.03171. This number reflects the equivalent percentage of full load operating hours per year (i.e., CF = 0.70 is 70% full load hours or 6132 equivalent hours/yr).

5. Country reviews

5.1. Africa

5.1.1. Algeria

The most popular use of geothermal springs is for balneotherapy. These hot springs are mainly located in the northern part of the country, used by about ten public resorts. During the last few years, a significant interest has been shown for other uses of geothermal energy. Three sites have been selected for geothermal aquaculture projects. Currently, fish farms in Ghardaia and Ouargla are using the Albian geothermal water of the Sahara to produce about 1500 tonnes/yr of Tilapia fish. A third, site, at Ain Skhouna, located near Saida produced 200 tonnes of Tilapia during 2008. A small geothermal heat pump project has been development in the region at Saida for heating and cooling of a school. These various applications of geothermal water are: 1.4 MWt and 45.1 TJ/yr for individual space heating; 9.8 MWt and 308 TJ/yr for fish farming; 55.47 MWt and 1744.2 TJ/yr for bathing and swimming; and 0.17 MWt and 1.38 TJ/yr for geothermal heat pumps; for a total of 66.84 MWt and 2098.68 TJ/yr (Fekraoui, 2010).

5.1.2. Djibouti

The country is in an early exploration stage for geothermal resources and thus, there is no geothermal use at present. The government's main interest is in developing geothermal for electric power generation in the Asal field. No direct-use projects are mentioned (Houssein, 2010).

5.1.3. Egypt

No data were submitted for WGC2005 or WGC2010. A paper by Idris (2000) and personal communication with its author in 2000 indicated that there are several spas with bathing facilities in Egypt. The estimates in Lund et al. (2005) of 1.0 MWt and 15 TJ/yr are assumed to be valid.

5.1.4. Ethiopia

Teklemariam and Kebede (2010) provide details on geothermal fields and on development for power generation, but little data on direct-use. They list seven bathing and swimming facilities using geothermal energy, mainly in Addis Abba. These include the Sheraton, Filowh, Ghion, and Hilton hotels, the National Palace, Greek Community, and St. Joseph School. Based on this paper and on calculations made by one of the authors (Lund), the installed capacity is estimated at 2.2 MWt with an annual use of 41.6 TJ/yr.

5.1.5. Kenya

Oserian Development Company Ltd (ODLC) constructed a 2.0 MWe binary plant in Olkaria Central to utilize fluid from a well leased from KenGen. The plant, which will provide electrical power for the farm's operation, was commissioned in July 2004. ODLC, who grows cut flowers for export, is also utilizing steam from a 1.28 MWt well to heat fresh water through heat exchangers, enrich CO_2 levels and to fumigate the soils. The heated fresh water is then circulated through greenhouses. The advantage of using geothermal energy for heating is that it results in drastic reduction in operating costs. The capacity of the geothermal use is 16 MWt and the annual energy use is 126.62 TJ/yr (Simiyu, 2010).

5.1.6. Morocco

Geothermal direct use in the country is mainly limited to balneology, swimming pools and potable water bottling. Reconstruction of swimming pools has made some progress in the last years and the number of newly built outdoor pools has increased as well. The number of bottling companies has increased during the last five years from two to five private enterprises. The product is mainly for the local market. The geothermal region in the extreme northeast part of Morocco appears promising for geothermal development with well temperatures as high as 95 °C. (Zarhloule et al., 2010). No data were provided for the geothermal use, thus, one of the authors (Lund) estimated the following for 12 pools: 5.02 MWt and 79.14 TJ/yr for bathing and swimming.

5.1.7. Rwanda

The country is currently evaluating its high and medium enthalpy geothermal resources that exist in the northwestern part of the country. Their main interest is in electric power generation, especially since 40% of their electricity comes from hydropower – which has been reduced due to low rainfall. No direct-use projects are reported (Rutagarama and Uhorakeye, 2010).

5.1.8. South Africa

Eighty-seven thermal springs with temperatures ranging from 25 to 67.5 °C have been documented in the country. Of these springs, 31 have been developed for direct-use mainly as family leisure and recreational resorts. Very few utilize the water for health or spa purposes. In the past these springs have been used for salt recovery, as health spas, for medicinal purposes and use of the mud for healing. Unfortunately, since coal is abundant and relatively cheap, little attention has been devoted to research on renewable energy sources. Also, in view of the low temperatures of thermal springs, no effort has been made to develop the geothermal resources. Tshibalo et al. (2010) list the various uses of the springs along with the resource temperature and mineral content. However, no estimates of the geothermal energy use were made, thus one of the authors of this report (Lund) has made the following estimate: 6.01 MWt and 114.75 TJ/yr for bathing and swimming.

5.1.9. Tunisia

The use of geothermal energy in the country is limited to direct application because of the low enthalpy resources, which are located mainly in the southern part of the country. For thousands of years, geothermal water has been used in bathing and many of the geothermal manifestations in the country have the name of "Hammam" or bath, which reflects the main use of geothermal water over the centuries. Now, most of the resources are utilized for irrigation of oases and heating greenhouses. The government's policy in the beginning of the 1980s was oriented towards the development of the oasis section which is supplied with geothermal water for irrigation. About 31,500 ha of oases are irrigated after cooling the water in atmospheric cooling towers. In 1986, the government started using geothermal energy for greenhouse farming, which is considered a promising and economic development. The results are that now there are 217 ha of greenhouses (up from 111 ha in 2005), and by the end of 2016 this is planned to be increased to 315 ha. The geothermal use in Tunisia is 76% for agriculture, 19% for water drinking, and 5% for industry and tourism. The geothermal use in the Kebili area, for example, is 70.8% for oasis, 27.0% for greenhouses, 1.0% for Hammams, 0.8% for tourism and pools, and 0.3% for animal husbandry and washing. The greenhouses in the country raise tomatoes (52%), cucumbers and snake melons (21%), melons (18%), watermelons (3%), and others (6%) for a total production of 22,000 tonnes in 2009 (Ben Mohamed, 2010). No data were provided on geothermal use thus, one of the authors (Lund) used data from WGC2005 (Lund et al., 2005) and estimated the following: an increase to 42.5 MWt and 335 TJ/yr for greenhouse heating; with the other uses remaining constant at: 0.9 MWt and 23 TJ/yr for bathing and swimming; 0.4 MWt and 6 TJ/yr for others (mainly animal husbandry); for a total of 43.8 MWt and 364 TJ/yr.

5.1.10. Uganda

Exploration for geothermal energy in the country has been in progress since 1993. Three areas, Katwe, Buranga and Kibiro are in advanced stages of surface exploration. The current focus is to develop the geothermal resource for power generation. No direct-use is reported, however, the preliminary investigations indicate that subsurface temperatures would be suitable for small scale electricity production and direct uses (Bahati et al., 2010).

5.2. The Americas

5.2.1. Central American and the Caribbean Islands

A number of countries in Central America and the Caribbean have geothermal power plants; however, as detailed below, only five countries and a few of the Caribbean islands report any geothermal direct use.

5.2.1.1. Caribbean Islands. Since 2004, geothermal exploration has accelerated in the region. In 2004 and 2005, the Organization of American States (OAS) funded a program that included geologic, geochemical, and geophysical studies on Nevis, reinterpretation of geophysical data on St. Lucia, and detailed geologic and geochemical work on the Wotton Waven, Dominica area. Additionally, OAS provided geothermally relevant legal and institutional assistance to these three nations. Utilization of thermal fluids has not increased significantly in the islands since 2005, therefore, it is limited to low temperature balneological facilities built on Nevis, St. Lucia and Grenada. A geothermal power plant is operating on Guadeloupe (under France), and there are plans to produce geothermal power on Nevis and Dominica. At present, the installed capacity is 0.103 MWt and the annual energy use is 2.775 TJ/yr for bathing and swimming (Huttrer, 2010).

5.2.1.2. Costa Rica. Various studies have been completed in the country to look at moderate- and low-temperature geothermal resources and their potential use. Even though the studies produced some favorable results, there has been no development of these resources. The main reason is the mild climate which does not require the artificial heating of greenhouses and buildings. Currently, the use of these resources is limited to mountain hotel pools dedicated to ecological tourism. The Ministry of Agriculture and Instituto Costarricense de Electricidad (ICE) has completed a technical study for the installation of a pilot plant for the drying of vegetables (onions) and grains (rice, beans, etc.) that will operate in the southern sector of the present power plant site at Miravalles. It will use some of the discharge water from the power plants (Mainieri Protti, 2010). The estimated installed capacity is 1.0 MWt and the annual energy use is 21.0 TJ/yr based on Lund et al. (2005).

5.2.1.3. El Salvador. The country update report (Herrera et al., 2010) makes no mention of geothermal direct-use. However, a recent visit to the country by one of the authors (Lund) revealed that there were some limited developments of greenhouse heating, fish farms and fruit drying. During a tour of the Berlin geothermal field, samples of dried pineapples, apples, bananas, coconuts, etc. were made available as "Procesco de deshidratado Natural Geotermico" and called "Geo Fruit or Funda-Geo" which are processed in Berlin for local consumption. A minimum value of 0.5 MWt and 10 TJ/yr is assumed for each of greenhouse heating and fish farming, and 1.0 MWt and 20 TJ/yr for agricultural drying, for a total of 2.0 MWt and 40 TJ/yr.

5.2.1.4. Guatemala. Geothermal energy in the past has been used for medicinal purposes, agriculture, and domestic use. The areas of Totonicapan, Quetzaltenango, and Amatitlan are popular tourist attractions known for their thermal bath houses and spas. These are estimated at a total of 0.21 MWt and 3.96 TJ/yr. The construction company, Bloteca, was the first to successfully apply a direct use application of geothermal steam in the curing process of concrete products (Mérida, 1999). In 1999, a fruit dehydration plant, Agroindustrias La Laguna, was built to use hot water from a well in the Amatitlan geothermal field in the drying process. A downhole heat exchanger was installed in the well, along with an enhancer tube in order to increase the performance of the heat exchanger. The company produces dehydrated pineapple, mango, banana, apple, and chili peppers. No values for the energy used are provided in the paper, thus, the data from WGC2005 will be used (Lund et al., 2005). The concrete drying facility is reported at 1.6 MWt and 40.4 TJ/yr and the fruit drying facility is reported at 0.5 MWt and 12.1 TJ/yr (Mérida, 1999; Manzo, 2005). The total for the country is thus 2.31 MWt and 56.46 TJ/yr. The operations at Amatitlan serve as direct-use examples than can be applied to other Central American countries (Asturias and Grajeda, 2010).

5.2.1.5. Honduras. A number of swimming pools are reported to be using geothermal energy: however, no estimates of energy use were made. Attempts are being made to visit these remote sites and determine the energy data (Lagos and Gomez, 2010). Castillo and Salgado (2000) and Lund et al. (2005) reported three pool sites (Tamara, Gracias 1 and Gracias 2) that were being heated by geothermal water. A total of 0.7 MWt of installed capacity and 17.0 TJ/yr of utilization were reported. Recent communications from Lagos (2009) indicated that the two major pool sites are estimated at 1.933 MWt – thus, one of the authors (Lund) estimates the annual energy use at 45.0 TJ/yr.

5.2.1.6. Nicaragua. The geothermal resources in the country have been developed for electric power generation. No country update paper was submitted and no direct-use is reported in other published papers (see e.g., Ruiz Cordero, 2009).

5.2.2. North America

5.2.2.1. Canada. In recent years Canada has steadily embraced heat pump technology. It is estimated that up to 50,000 residential and 5000 commercial systems are currently installed (Thompson, 2010). The cost of installing these units, especially in building retrofits, is often prohibitive for the average consumer; however, federal and local subsidies have lightened the financial burden. The growth rate is estimated at 13% per year, with recent rates being as high as 50%. Heat pump technology has also been used in abandoned mines, starting as early as 1989 in the Springhill Mine of Nova Scotia where the heating and cooling provides savings estimated C$45,000/yr in energy costs. The City of Yellowknife in the Northwest Territories commissioned a study in 2007 to use water from an abandoned gold mine with a heat pump to provide district heating to the community, saving an estimated C$13 million/yr. There are also 12 western hot springs used to heat swimming pools with individual flow rate of 6–32 l/s and total installed capacity of 10–15 MWt (Lund et al., 2005). Since, no specific data were available on the various Canadian geothermal uses, we estimate the following for heat pumps using a COP in the heating mode of 3.5, 3000 full load heating hours per year, an average residential size of 12 kW, and commercial size of 100 kW, resulting in a total of 1100 MWt and 8487 TJ/yr. For the mine water the estimate is 11 MWt and 26 TJ/yr (Jessop, 1995), and for the 12 western swimming pool, 15 MWt and 360 TJ/yr. This gives a total of 1126 MWt and 8873 TJ/yr.

5.2.2.2. Greenland (Kalaallit Nunaat). The island is under the jurisdiction of Denmark, but with home rule, and thus for this paper is considered part of North America. Warm springs were mentioned around 1300 A.D. near Ravensfjord, by Ivar Bardarson, now known as the island of Unartoq. He describes their annual temperature fluctuations and their therapeutic properties. He writes: "In these islets there is a lot of warm water. In winter it is so hot that no one endures it, but in summer it is suitable for bathing. There, many people have got holistic treatment and good healing and remedy of illnesses." More recently, numerous warm springs have been located at Scoresbysund and Disko. The warm springs at Unartorssuaq (Engelskmandens havn) are the only ones located near an inhabited area. They are about 2 km outside of the capital Qeqertarsuaq (Godhavn), and thus, could be used for space heating in the community. However, little can be determined about the subsurface resources and the potential for utilization until exploratory drilling is undertaken. There is no current geothermal use on the island (Hjartarson and Armannsson, 2010).

5.2.2.3. Mexico. Geothermal energy in the country is almost entirely used to produce electricity, since its direct uses are still under development and currently remain restricted to bathing and swimming facilities with recreational purposes and some with therapeutic uses (reported at 20 locations). Almost all of the resorts have been developed and are operated by private investors, yet there are isolated facilities operated by federal, state or municipal government. These public facilities are usually operated through tourism offices, or in some cases, through federal institutions like the national social security institute (IMSS). Comision Federal de Electricidad (CFE) has developed some direct uses of geothermal resources at the Los Azufres geothermal field, including a wood-dryer, a fruit and vegetables dehydrator, a greenhouse and a system for heating of its offices and facilities in this field. A mushroom growing facility at Los Humeros geothermal field has been closed. The use of geothermal heat pumps is minimal, and underdeveloped with no information available. District and individual space heating is little used in Mexico due to the mild temperatures throughout the year in most of the country. The various direct use applications include: 0.460 MWt and 4.397 TJ/yr for individual space heating; 0.004 MWt and 0.059 TJ/yr for greenhouse heating; 0.007 MWt and 0.101 TJ/yr for agricultural drying; and 155.347 MWt and 4018.229 TJ/yr for bathing and swimming; for a total of 155.818 MWt and 4022.786 TJ/yr (Gutiérrez-Negrin et al., 2010).

5.2.2.4. United States of America. Most of the direct use applications have remained fairly constant over the past five years, however, geothermal heat pumps have increased significantly. A total of 20 new projects have come on-line in the past five years and a number of projects have closed. Agricultural drying has decreased the most, due to the closing of the onion/garlic dehydration plant at Empire, Nevada. Two district heating projects have also shut down; the Litchfield Correctional Facility in California (due to competing natural gas prices) and the New Mexico State University (due to maintenance problems) system. There has been a slight increase in snow melting, cooling and fish farming, with a major increase in industrial process heating due to two biodiesel plants (Oregon and Nevada), a brewery (Oregon), and a laundry (California) coming on line. The number of installed geothermal heat pumps has steadily increased over the past 15 years with an estimated 100,000 to 120,000 equivalent 12 kWt units installed this past year. Present estimates are that there are at least one million units installed, mainly in the mid-western and eastern states. Over 50% were installed in 10 states (Florida, Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, New York, Ohio and Pennsylvania) (EIA, 2008). Approximately 70% of the units are installed in residences and the remaining 30% in commercial and institutional buildings. Approximately 90% of the units are closed loop (ground-coupled) and the remaining open loop (water-source). It is presently a US$2–3 billion annual industry in the country. The largest installation currently under construction is for Ball State University, Indiana where 4100 vertical loops are being installed to heat and cool over 40 buildings using geothermal heat pumps. The various applications are as follows: 139.89 MWt and 1360.6 TJ/yr for individual space heating; 75.10 MWt and 773.2 TJ/yr for district heating; 2.31 MWt and 47.6 TJ/yr for air conditioning (cooling); 96.91 MWt and 799.8 TJ/yr for greenhouse heating; 141.95 MWt and 3074.0 TJ/yr for fish farming; 22.41 MWt and 292.0 TJ/yr for agricultural drying; 17.43 MWt and 227.1 TJ/yr for industrial processing; 2.53 MWt and 20.0 TJ/yr for snow melting; 112.93 MWt and 2557.5 TJ/yr for bathing and swimming; and 12,000 MWt and 47,400 TJ/yr for geothermal heat pumps. The total is 12,611.46 MWt and 56,551.8 TJ/yr (Lund et al., 2010).

5.2.3. South America

5.2.3.1. Argentina. Development of geothermal resources increased in the last few years with the discovery of new thermal areas linked to sedimentary basins that belong to the hydrothermal conductive system, along with advanced research of high enthalpy thermal fields. This has allowed the development of new therapeutic-recreational complexes that generate income for different regions of the country. During the last five years, 11 new projects were started and are now in the exploration stage for direct-use. These projects are being considered for recreational therapeutic facilities and to supply drinking water to nearby towns. At present there are 64 bathing and swimming developments, two greenhouse sites, two fish farms, one snow melting site, and three space heating sites (Pesce, 2010). A summary of the installed capacity and annual energy uses for the various sites were provided, however, several uses had to be estimated from combined uses by one of the authors (Boyd). The various applications of geothermal direct use are: 22.25 MWt and 295.82 TJ/yr for individual space heating; 20.44 MWt and 269.95 TJ/yr for greenhouse heating; 19.9 MWt and 252.92 TJ/yr for fish farming; 2.00 MWt and 15.14 TJ/yr for snow melting (at Copahue in the Andes); 91.36 MWt and 2169.74 TJ/yr for bathing and swimming; 1.62 MWt and 44.62 TJ/yr for other uses (water consumption); and 149.90 MWt and 858.55 TJ/yr for geothermal heat pumps. The total for the country is 307.47 MWt and 3906.74 TJ/yr.

5.2.3.2. Brazil. A significant number of low temperature resources (<90 °C) have been identified in the continental area, but the potential for high temperature geothermal systems appears to be restricted to the Atlantic islands of Fernando de Noronha and Trindade. Most of the springs that account for the potential are located in the west central Brazil (in the states of Goiás and Mato Grosso) and in the south (in the state of Santa Catarina). The potential for large scale exploitation of low temperature geothermal water for industrial use and space heating is considered to be significant in the central part of the Paraná basin (situated at southern and southeastern Brazil), where cold winter seasons prevail under subtropical climate conditions. The various applications of direct use are: 0.9 MWt and 15.4 TJ/yr for fish farming, 4.20 MWt and 77.0 TJ/yr for an industrial wool processing plant; 355 MWt and 6530 TJ/yr for bathing and swimming, for a total of 360.1 MWt and 6622.4 TJ/yr (Hamza et al., 2010).

5.2.3.3. Chile. Geothermal energy in the country has been only utilized for recreational purposes. Current use in spa and swimming pools, accounts for all the capacity. However, there are many private thermal spas and resorts in the geothermal area, for which quantitative information regarding their use of geothermal resources is not available. In some spas, shallow wells have been drilled to obtain hot water, while in others hot water is collected and piped to the buildings pools, through shallow drains and plastic hoses. There are about 15 thermal facilities for which quantitative information is unavailable. A total of 20 bathing and swimming sites have been identified amounting to 9.11 MWt and 131.82 TJ/yr (Lahsen et al., 2010).

5.2.3.4. Columbia. No country update report was filed for this country as nothing has changed since the last report according to Claudia Alfaro (personal communication September, 2009). Thus, the figures from WGC2005 are (see Lund et al., 2005): 14.4 MWt and 287 TJ/yr for bathing and swimming at 41 sites.

5.2.3.5. Ecuador. The utilization of geothermal resources in the country is restricted to direct uses only i.e., bathing resorts, balneology and swimming pools. Recently, the first use of space heating at the private Termas Papallacta Spa Resort Hotel has been commissioned, but no data are available. In addition, several projects for fish hatcheries are waiting funding for development. Thus, the data from WGC2005 (Lund et al., 2005) have not changed and the installed capacity is 5157 MWt and annual energy use of 102,401 TJ/yr, all for bathing and swimming (Beate and Salgado, 2010).

5.2.3.6. Peru. No report on use of geothermal resources was made available for WGC2010. Based on personal communication with G. W. Huttrer in 2000, we assume that the figures given by Lund et al. (2005) of 2.4 MWt and 49 TJ/yr for 7 spas have not changed during the last five years.

5.2.3.7. Venezuela. No report on the use of geothermal resources was made available for WGC2010. Personal communication with Urbani (2009) indicated that there has been no change since 2005. Thus, the figures of 0.7 MWt and 14 TJ/yr estimated for several small spas is used (Lund et al., 2005).

5.3. Asia

5.3.1. Bangladesh

This is a new country to appear on the list of geothermal countries. However, a current paper by Guha et al. (2010), gives no detailed numbers that can be used to add to the database. With current population of about 150 million and increasing at the rate of about 2% per year, the demand for electricity and energy resources is rising at about 10% per year. The rise in demand is related to irrigation needs in the rural areas and air conditioning in the urban areas. A number of abandoned wells and a recent survey have given an insight into the geothermal potential related to the major tectonic structural regions. Bangladesh is looking for development partners, donors, private investors, etc. to assist in the development of these resources.

5.3.2. China

The Chinese government, since 2006 has encouraged the development of geothermal energy, along with other renewable energies (Zheng et al., 2010a,b). Geothermal district heating capacity has continued to increase at about 10% annually (52% since reported in 2005) to 1291 MWt and 14,798.5 TJ/yr, and there has been a large increase in heat pump capacity from 383 MWt (2004/5) to 5210 MWt and 29,035 TJ/yr in 2009. Geothermal district heating in Tianjin utilizing geothermal water is now servicing some 1 million people using 26.4 million m^3 annually saving 1.17 million tonnes of standard coal equivalent and reducing 2.78 million tonnes of CO_2 emissions. The return water from the district heating system is reheated with GHP for use in floor heating of other buildings. Bathing, agriculture, and fish farming have continued to be major uses of geothermal waters. There has been a rapid development in the use of GHPs across the country. Renewable energy accounted for about 26% of the total heating and cooling requirements of the 2008 Olympic venues in Beijing and served as a good demonstration of the use of these forms of energy. Chinese and Australian experts signed an agreement in 2007 to undertake a survey of likely sites for the development of Enhanced Geothermal Systems. A program of work was established in 2009 and it is hoped to have an in depth study in 2010 of suitable sites. Other uses in the country include: 147 MWt and 1687.9 TJ/yr for greenhouse heating; 197 MWt and 2170.8 TJ/yr for fish farming; 82 MWt and 1037.5 TJ/yr for agricultural drying; 145 MWt and 2732.6 TJ/yr for industrial process heat; and 1826 MWt and 23,886.0 TJ/yr for bathing and swimming. The total is 8898 MWt and 75,348.3 TJ/yr.

5.3.3. India

Chandrasekharam and Chandrasekhar (2010) discusses the geothermal potential of the country and the current use of its resources. As of December 2009, 265 MWt are installed all for bathing and swimming with an annual use of 2545 TJ/yr. No other uses of geothermal direct heat are recorded, including a zero entry for GHP. Currently, the building sector utilizes 33% of thermal power and the food processing industry 13%, generated by coal fired plant these activities could easily be serviced by geothermal if the environment was right for the conversion. However, there appears to be little incentive for the conversion to geothermal heat. One of the major difficulties is having trained manpower to undertake these developments.

5.3.4. Indonesia

Although, the major focus has been on the development of electricity generation by geothermal energy, a group of researchers in government sponsored research and technology agency (BPPT) had begun to investigate methods to apply geothermal energy to the agriculture sector, particularly to sterilize the growing medium used in mushroom cultivation. The process started five year ago and is still at the research stage (Darma et al., 2010). Other uses of geothermal fluids include palm sugar processing, copra drying, tea drying and pasteurization and some fish farming. These activities are spread over about six areas totaling about 200–300 tonnes/h of fluid. No heat pump installations are used to date as they appear to be uneconomical at this time due to the availability and abundance of high enthalpy fluids. Lund and Freeston (2001) cited 2.3 MWt and 42.6 TJ/yr as the usage for bathing and swimming and are assumed to remain unchanged. Surana et al. (2010) indicate additional direct use installations in the country, including bathing and swimming, mushroom growing, palm sugar production, copra and cocoa drying, aquaculture, and space heating. Unfortunately, no data on capacity and annual energy use were provided, and thus cannot be estimated for this report.

5.3.5. Iran

Saffarzedeh et al. (2010) cite a small improvement in the utilization of geothermal fluids for bathing with a capacity of 41.583 MWt and 1063.72 TJ/yr annual utilization; 2005 figures were 30.1 MWt and 752.3 TJ/yr. New resorts have been constructed and older ones renovated resulting in increased flows and capacity driven by joint ventures from the private and public sectors. Ground source heat pumps have been installed as demonstration projects in five different regions of the country in order to evaluate the efficiency under different climatic conditions. The installed heat pump capacity is 0.025 MWt and the annual energy use is 0.46 TJ/yr. The total is 41.605 MWt and 1064.18 TJ/yr.

5.3.6. Israel

No country update paper has been received from Israel. Thus, assuming the direct-use in the country has not changed, the estimates from WGC2005 (Lund et al., 2005) are used. Geothermal energy is used for spas, greenhouses and aquaculture as follows

(Levitte and Greitzer, 2005): 27.6 MWt and 512.0 TJ/yr for greenhouse heating; 31.4 MWt and 989.0 MWt for fish farming; and 23.4 MWt and 692 TJ/yr for bathing and swimming; for a total of 82.4 MWT and 2193 TJ/yr.

5.3.7. Japan

The direct use of medium- and low-enthalpy geothermal water is mainly located in the areas around the high-enthalpy geothermal areas where hot spring resources are abundant. Otherwise, the use of shallow geothermal heat pump systems in available nationwide. These latter installations account for only 0.3% of the direct-use, and thus have limited use in the country. Although many hotels and Japanese-style inns utilize hot spring water, this bathing utilization has been excluded in past reports and was only estimated for WGC2005, mainly because it is difficult to evaluate the actual use. However, to be consistent with reports from other countries and the world-wide summary, the numbers for bathing and swimming are included in this report. The total capacity without bathing has not changed much from WGC2005. Bathing now accounts for about 90% of the utilization in the country for direct-use. Since 2002, 141 new direct-use facilities has been added to the database, while 136 facilities were removed of which 58 facilities were dismantled or stopped operating due to economic problems, switching to oil or corrosion/scaling problems. The various applications are as follows: 77.37 MWt and 969.49 TJ/yr for space heating; 36.92 MWt and 451.73 TJ/yr for greenhouse heating; 7.91 MWt and 141.86 TJ/yr for fish farming, 1.24 MWt and 30.92 TJ/yr for industrial applications; 152.54 MWt and 516.27 TJ/yr for air conditioning and snow melting (assuming a 30–70% split as for WGC2005); 1810.19 MWt and 23,519.81 TJ/yr for bathing and swimming; and 13.36 MWt and 67.86 TJ/yr for geothermal heat pumps. The total is 2099.53 MWt and 25,697.94 TJ/yr (Sugino and Akeno, 2010).

5.3.8. Jordan

Saudi and Swarich (2005) reported no new development in the country using geothermal energy for direct-use for WGC2005. Thus, our data is based on the situation described in Lund and Freeston (2001). It appears that at least six sites have installation for direct-use, mainly for bathing and swimming. The estimated capacity is 153.3 MWt and annual energy use is 1540 TJ/yr.

5.3.9. Korea (South)

Direct-use statistics on 13 major hot springs show discharge temperatures higher than 42 °C, some of which have been used for more than a thousand years. Many of these hot springs are used for space heating of small hotel buildings and for greenhouses. There has been a large increase in greenhouse heating use in rural areas due to financial support for a special rural subsidy program. Recently, some private universities installed large heating systems without government subsidy in order to reduce operating costs of heating and cooling on campus. Geothermal or ground-source heat pump installation has rapidly increased over the past four years, with a large increase in 2009 due to an active rural subsidy program. Most installations in the country are mainly for office and public buildings and relatively large buildings such as dormitories, university campuses and hospitals. Geothermal heat pumps are found in over 700 locations throughout the country and are typically in the 300 to 100 kW size for a total of over 3000 units. The various applications are: 8.66 MWt and 53.43 TJ/yr for individual space heating; 2.21 MWt and 31.28 TJ/yr for district heating; 0.17 MWt and 1.33 TJ/yr for greenhouse heating; 32.56 MWt and 507.61 TJ/yr for bathing and swimming; and 185.7 MWt and 1361 TJ/yr for geothermal heat pumps. The total for the country is 229.3 MWt and 1954.65 TJ/yr (Song et al., 2010).

5.3.10. Mongolia

No country update report was received for WGC2010. Based on data from Bignall et al. (2005) and estimates by Lund et al. (2005), it is assumed that the geothermal use has not changed over the past five years. Hot springs in the country are utilized for heating, bathing and medical treatment, with three hot springs currently located in popular tourist attractions. Data were only available from one area, Shargaljuut. Based on the previous data and estimates mentioned above, the various applications are: 1.4 MWt and 44.0 TJ/yr for individual space heating; 2.4 MWt and 74.0 TJ/yr for greenhouse heating; and 3.0 MWt and 95.2 TJ/yr for bathing and swimming; for a total of 6.8 MWt and 213.2 TJ/yr.

5.3.11. Nepal

Geothermal development has been taking place on a very small scale with the increased participation of local government and the limited financial resources. Increased popularization of geothermal springs has led to more visitors. The local people have been able to boost their business and as a result, taken the initiative to building road infrastructure with the assistance of local government bodies. The main use has been for bathing and swimming at 25 locations. There is also some small use for boiling eggs in restaurants and for direct drinking of the water to cure gastroenteritis disease; however, these two uses are not quantified and are included in the bathing and swimming numbers: 2.717 MWt and 73.743 TJ/yr (Ranjit, 2010).

5.3.12. Philippines

Direct-use of geothermal energy in the country is very limited. Two agricultural drying plants using geothermal heat were located at Palinpinon and Manito. The Palinpinon project used steam from the Southern Negros Geothermal Projects (Palinpinon I geothermal power plant) where coconut meat and copra were dried (Chua and Abito, 1994). Both of these drying plants have been closed because of uneconomic operations. The main resorts using geothermal heat are at Laguna, Batangas, Palawan, Sorsogon, and Agco. The various applications are: 1.63 MWt and 26.93 TJ/yr for agricultural drying (the majority at the Palinpinon plant) before the plants shutdown in 2001; thus, only bathing and swimming are counted for a total of 1.67 MWt and 12.65 TJ/y (Ogena et al., 2010).

5.3.13. Saudi Arabia

There are ten thermal springs in the country. Of these, six are in Gizan (southwest near the Yemen border) and four in Al-Lith area (west-central on the Red Sea). None are being exploited at present (Rehman, 2010).

5.3.14. Tajikistan

A number of uses of geothermal water are described in the paper by Normatov (2010); however, no estimates of the installed capacity or annual energy use were made. Fourteen sites are listed using geothermal fluids for balneology and health resorts, two for drinking and bottling the water, and two for other uses. Seven locations are listed that have potential to be developed for balneology and for health resorts. The six main health resorts using geothermal water are listed at Garm-Chashma in the Pamir Mountains, and Hodzha-Obigarm, Tamdikul, Hovatag, Obi-Garm and Yavroz in central Tajikistan. Based on these uses an estimate was made (assuming 5 l/s and 10 °C "ΔT" for peak use and 3 l/s and 10 °C "ΔT" for annual use) of 2.93 MWt and 55.40 TJ/yr for bathing and swimming (which includes balneology).

5.3.15. Thailand

No country update papers were submitted for either WGC2005 or WGC2010. Based on communications from Praserdvigai (2005), an estimate is made of direct use at a 0.3 MWe binary plant at

Fang in Chiang-Mai province. A small crop-drying facility and air-conditioning unit are utilizing the exhaust from the power plant. The distribution of use is 0.04 MWt and 0.3 TJ/yr for crop drying and 2.5 MWt and 78.8 TJ/yr for bathing and swimming, for a total of 2.54 MWt and 79.1 TJ/yr.

5.3.16. Turkey

Turkey has extensive geothermal resources that have been utilized for heating of residences, district heating, greenhouse heating, and for spas. There are a total of 260 spas in the country using geothermal water for balneological purposes. There is also a liquid carbon dioxide and dry ice production factory integrated with a power plant at Kizildere. Greenhouse heating has increased substantially in the last three year with installations in six major area covering 230 ha. Tourism is also an important industry with over 12 million local and 10,000 foreign visitors benefiting from the balneological aspects of hot springs and spas. Geothermal heat pump applications include the Metro Meydan M1 Shopping Center in Istanbul and the Terme Maris Facility in Dalaman. The geothermal heating is equivalent to supplying energy to 201,000 residences. The various applications are: 219 MWt and 2417 TJ/yr for individual space heating; 792 MWt and 7386.4 TJ/yr for district heating; 483 MWt and 9138 TJ/yr for greenhouse heating; 552 MWt and 17,408 TJ/yr for bathing and swimming; and 38 MWt and 536.5 TJ/yr for geothermal heat pumps. The total for the country is 2084 MWt and 36,885.9 TJ/yr (Mertoglu et al., 2010).

5.3.17. Vietnam

No country update paper was received; however, the current development in the country has been described in Ngoc et al. (2010). The authors described an experimental facility at the Hoi Van geothermal source in Binh Dinh province that is used for drying bananas, coconuts, and medicinal herbs. Its usage is estimated at 0.5 MWt and 11.83 TJ/yr. Also, a salt factory uses an estimated 1.4 MWt and 21.6 TJ/yr geothermal energy at the Hoi Van producing 7000 tonnes/yr of iodized salt from evaporation. Other geothermal resources providing hot water for balneological and medical treatment that attracts tourism are estimated at 29.3 MWt and 58.9 TJ/yr. These estimates are based in part, on data from Cuong et al. (2005) and Lund et al. (2005) and add to a total of 31.2 MWt and 92.33 TJ/yr.

5.3.18. Yemen

No country updates were submitted for WGC2005 and WGC2010, thus, the figures from 2000 (Lund and Freeston, 2001) will be assumed to still be valid. These are 1.0 MWt and 15 TJ/yr for bathing and swimming.

5.4. Europe

5.4.1. Albania

The basis for most of the work in the country is from the “Atlas of Geothermal Resources in Albania” (Frasheri et al., 2004). More recently, a report (Frasheri et al., 2008) has described the potential for direct-use: spa-hotels with hot pools, greenhouse and aquaculture installations. The geothermal energy resources for direct-use include natural springs and deep wells with thermal water of temperature up to 65.5 °C, and ground with a temperature of 16.4 °C (using geothermal heat pumps). At present, the only direct geothermal use is for bathing and swimming with an installed capacity of 9.57 MWt and an annual energy use of 8.53 TJ. Geothermal heat pumps use is 1.914 MWt and 31.93 TJ/yr with 105 installed units. This gives a total of 11.48 MWt and 40.46 TJ/yr (Frasheri, 2010).

5.4.2. Austria

Only seven deep boreholes were drilled in the country over the past year, all of which were used to supply heat for balneological purposes. No other geothermal projects were undertaken in Austria since 2005 due to lack of public support and low feed-in tariffs for electric power (7.3 cents/kWh). However, the number of ground source heat pumps has shown a steady increase with the estimated number of units at 50,000 having a capacity of 600 MWt and producing 800 GWh/yr. As in most countries, the data on geothermal heat pumps are hard to obtain as only groundwater wells are registered with the authorities. Future projects are expected in the Vienna basin near the capital and in the Austrian Molasse Basin. Geothermal heat pump use is expected to increase with more than 50% of the new family houses to have units installed. The various direct-uses include: district heating (50.03 MWt and 602.4 TJ/yr); greenhouse heating (1.80 MWt and 29.0 TJ/yr); industrial process heat (2.15 MWt and 31.3 TJ/yr); bathing and swimming (8.87 MWt and 185.0 TJ/yr); and geothermal heat pumps (600.0 MWt and 2880 TJ/yr) for a total of 662.85 MWt and 3727.70 TJ/yr (Goldbrunner, 2010).

5.4.3. Belgium

No country update report was received for Belgium, thus data from WGC 2000 and WGC2005 will be utilized along with some updated material on geothermal heat pumps (Lund et al., 2005; EurObserv’ER, 2009). Since only an abstract was submitted in 2005, data from WGC2000 was used (Berckmans and Vandenberghe, 1998). Geothermal energy used in the country is focused on shallow applications with the geothermal heat pump market growing significantly over the past few years, with the open-loop type being the most common. Most applications are in the eastern provinces. Aquifer thermal energy storage is also being utilized in a number of locations. The total estimated installed capacity and use are: space heating 2.1 MWt and 53.8 TJ/yr; greenhouse heating 0.9 MWt and 22.1 TJ/yr; aquaculture 0.3 MWt and10.1 TJ/yr; agricultural drying 0.5 MWt and 13.1 TJ/yr; and swimming pool 0.1 MWt and 8.1 TJ/yr. The estimated number of geothermal heat pumps based on 2008 data is 9500 units (up from 5000 in 2005), with an installed capacity of 114.0 MWt. Using 1500 full load heating hours per year and a 3.5 COP in the heating mode, the energy use is estimated at 439.77 TJ/yr. Thus, the total capacity and use in the country are 117.90 MWt and 546.97 TJ/yr.

5.4.4. Bosnia and Herzegovina

Geothermal research and development in the country has increased over the past five years, however, only five new wells were drilled. Direct-use of geothermal energy has been implemented at 23 locations, with individual space heating being the largest use of the energy (44.9%), followed by spas and recreation centers (39.2%); greenhouses at 15.5% and fish farming at one location using 0.4%. Geothermal heat pumps are installed at three locations. There are 20 spas including nine recreational centers. Individual space heating is used in five locations. Greenhouses using geothermal waters for heating grow flowers and vegetables for the domestic market and for export to Croatia. A planned project is for drilling five wells for district heating in Bijeljina in the Pannonian Basin. The direct uses are for individual space heating: 6.73 MWt and 114.08 TJ/yr; for greenhouse heating; 1.51 MWt and 39.41 TJ/yr; for fish farming; 0.09 MWt and 1.1 TJ/yr; for bathing and swimming; 13.21 MWt and 99.62 TJ/yr; and for geothermal heat pumps; 0.1555 MWt and 1.15 TJ/yr; for a total of 21.696 MWt and 255.36 TJ/yr (Miošić et al., 2010).

5.4.5. Bulgaria

The country is rich in geothermal water within the temperature range of 20–100 °C with the main geothermal activity concentrated in the southern part of the country due to the higher water temperature and low water salinity. The information in the paper is based mainly on state-owned and only partially municipality-owned geothermal fields, and on existing permits and concessions. The main geothermal direct-use in the country is for balneology (prevention, treatment and rehabilitation, bathing and swimming pools), space heating and air-conditioning, greenhouse heating, geothermal heat pumps, direct thermal water supply, bottling of potable water and soft drinks. The cultivation of microalgae and production of iodine paste and methane extraction have been terminated. The installed capacity for direct use, excluding geothermal heat pumps, is about 30% less as compared to five years ago. The geothermal direct use is: 9.28 MWt and 128.56 TJ/yr for individual space heating, 6.7 MWt and 65.5 TJ/yr for air conditioning, 5.99 MWt and 88.68 TJ/yr for greenhouse heating, 48.78 MWt and 768.32 TJ/yr for bathing and swimming, 6.92 MWt and 32.83 TJ/yr for other uses, and tentative values of 20.63 MWt and 286.23 TJ/yr for geothermal heat pumps, for a total of 98.30 MWt and 1370.12 TJ/yr (Bojadgieva et al., 2010).

5.4.6. Croatia

Direct utilization in the country is mainly for heating swimming pools and spas along with recreational centers, as well as space heating. There are 20 spas and 5 geothermal fields above 100 °C that use geothermal energy. The five high temperature geothermal fields are being considered for combined heat and electrical energy production and may be started soon. The estimated total direct-use is 34.78 MWt and 253.05 TJ/yr for individual space heating and 32.70 MWt and 215.84 TJ/yr for bathing and swimming, for a total of 67.48 MWt and 468.89 TJ/yr (Jelić et al., 2010).

5.4.7. Czech Republic

No country update paper was received for this country. Therefore, data from WGC2005 has been utilized (Myslil et al., 2005) assuming no changes. The direct use of thermal water in spas and swimming pools dates back several hundred years. There are 11 major spas and thermal springs in the Czech Republic, the most famous being Karlovy Vary (Karlsbad) and Marianske Lazně (Marienbad). According to official information, more than 14,000 geothermal heat pumps have been installed for residences and almost 1000 for commercial/institutional buildings. The main expansion of geothermal heat pump installations started in 2000. The overall capacity of geothermal heat pumps installed in 2008 was 55 MWt (approximately 4000 installations), the average capacity being 14 kWt. By 2008, the total energy use for the heat pump installations was 1200 TJ/yr (333 GWh/yr) (personal communication, Stibitz, 2010). Using an average COP of 3.5 and 2200 full load operating hours per year, the installed capacity is 212 MWt. The estimated capacity for the spas is 4.5 MWt, with an energy use of 90 TJ/yr (Lund, 1990). The total for the country is 216.5 MWt and 1290 TJ/yr.

5.4.8. Denmark

No pronounced temperature anomalies exist (reported) in this area so that the temperatures in the country are in the low-enthalpy range. Two large district heating plants using heat pumps have been built in the country. The first was established in 1984 at Thisted and later expanded to produce 200 m^3/h of 44 °C saline water from 1250 m depth resulting in 7 MWt of installed capacity. The second is in Copenhagen and started in 2005. It uses 73 °C saline water at 235 m^3/h from 2560 m depth with an installed capacity of 14 MWt. When including the heat for the absorption heat pumps which is recovered as district heat, the two plants have an installed capacity of 44 MWt and annual energy use of 800 TJ. Additional projects are being investigated for district heating at Sønderborg, Hjørring, and other communities. The plants at Thisted and Copenhagen are being considered for expansion. A number of small heat pump projects have been installed, estimated at 20,000 units in a horizontal configuration with a capacity and annual energy use of 160 MWt and 1700 TJ/yr. Some groundwater is also being used for cooling and heating at industrial locations. The total geothermal capacity is 200 MWt and the annual use is 2500 TJ (Mahler and Magtengaard, 2010).

5.4.9. Estonia

No country update paper was received from this country; however, an estimate of geothermal heat pump capacity is presented in EurObserv'ER (2009). For 2008, the number of installed units was 4874 with an installed capacity of 63.0 MWt. Using a COP of 3.5 and 2200 full load operating hours annually, the estimated use is 356 TJ/yr. No other geothermal use has been recorded.

5.4.10. Finland

No country update paper was received from this country, however, estimates were made based on 2008 data (personal communications, Jarmo, 2009 and 2010) for geothermal heat pumps – the only geothermal use in the country. Approximately 7500 geothermal heat pumps units were sold in 2008, or about 40% more than 2007 with a total energy supply of 1–2 TWh/yr. By 2008, a total of 46,257 units were installed with a capacity of 994 MWt. The number of full load hours annually is estimated at 3340 with an average COP of 3.0. The annual net energy used is then 7966 TJ (2213 GWh/yr).

5.4.11. France

The development of geothermal resources in the country has seen several phases. A major development phase was initiated at the beginning of the 1980s based on low enthalpy resources from sedimentary basins, followed by a period of inactivity during the 1990s, and then a recently revival of activity of all kinds based on a policy by the government for energy management and development, especially renewable energy (French Energy Law in 2005 and the large consulting process "Grenelle de l'environnement" in 2007). The goal of the latter act is to have 535 ktoe/year of geothermal heating by 2012, and 1300 by 2020 composed of district heating (about 40%), large heat pumps (about 20%), and individual geothermal heat pumps (about 40%); the total use in 2006 was 220 ktoe/yr. A "renewable heating and cooling fund" was set up by the finance law 2009–2011, which supports renewable heating and cooling projects. The use of geothermal heat pumps started in the 1980s, and now provides 20,000 units for heating individual houses. Most geothermal heat pump units are either direct expansion or water-source type with 74% new and 26% retrofit installations. Geothermal district heating supplies heat to 150,000 dwellings mainly in the Paris and Aquitaine basins. At present the direct-uses include: district heating (300 MWt and 4900 TJ/yr), greenhouse heating (9 MWt and 155 TJ/yr), fish farming (19 MWt and 212 TJ/yr), bathing and swimming (17 MWt and 162 TJ/yr), and geothermal heat pumps (mainly individual homes) (1000 MWt and 7500 TJ/yr), for a total of 1345 MWt and 12,929 TJ/yr. Fish farming, greenhouses and bathing uses are mainly located in the Aquitance Basin or other regions outside of Paris (Boissier et al., 2010).

5.4.12. Germany

Presently, there are 163 geothermal direct-use installations in the country. The installations comprise district heating, space heating in some cases combined with greenhouses and thermal spas. Most of the district heating plants are located in the Northern German Basin, the Molasse Basin in Southern Germany, or along the Upper Rhine Graben. Three geothermal power plants at Landau, Neustadt-Glewe, and Unterhaching also provide water for district heating. In addition to these large installations, there are numerous small- and medium-size geothermal heat pump units located throughout the country. Under the prevailing economic and political conditions, multiple or cascaded uses are employed to help improve the economic efficiency of the direct use. For this reason, many installations combine district or space heating with greenhouses and thermal spas. No figures are given for greenhouse heating. Numbers for geothermal heat pump installations are difficult to determine, however, estimates from sales statistics indicated that there were 148,000 units operating in 2008 and a 20% increase estimated for 2009 for a total of 178,000 units (13% water-source and 87% ground-coupled). The capacity and energy use for the various applications are: 1.2 MWt and 2.9 TJ/yr for individual space heating, 209.3 MWt and 1054.4 TJ/yr for district heating; 44.9 MWt and 1339.2 TJ/yr for bathing and swimming; and 2230 MWt and 10,368 TJ/yr for geothermal heat pumps, for a country total of 2485.4 MWt and 12,764.5 TJ/yr (Schellschmidt et al., 2010).

5.4.13. Greece

The first half of the present decade was characterized by a diversification of direct applications with new uses such as aquaculture, spirulina production, outdoor pool heating, water desalination, and fruit and vegetable dehydration. However, in the past few years there has been a rapid expansion of geothermal heat pumps, such that the increase in direct use installed capacity since WGC2005 has been almost solely attributed to geothermal heat pumps. There have been some reduction in use, mainly with the greenhouses and desalination plant on Kimolos Island being taken out of operation, and the 2.0 MWt project for heating and cooling several public buildings in Langadas (Thessaloniki) has been abandoned. The fate of a novel desalination project on Milos Island is still unclear, despite the completion of eight production and injection wells. Space heating is used only in two spa buildings, in a hotel in Milos, in several individual houses, and in a high school. Approximately 21 ha of greenhouses are heated, mainly for vegetable and cut flower growing, with 27 greenhouse units in the country run by 21 operators. Soil heating, especially for asparagus, has increased significantly and is now 17 ha. There are more than 60 thermal spas and bathing centers in operation. A tomato dehydration unit has been operating since 2001 producing more than 1000 kg of dehydrated tomatoes per day. Geothermal water is used for frost protection for a number of aquaculture ponds during the winter. Approximately, 350 geothermal heat pump applications are located in the country with about 65% being of the open loop configuration. The figures for the various direct uses are: 1.5 MWt and 16.5 TJ/yr for individual space heating; 34.8 MWt and 340 TJ/yr for greenhouse heating; 9.0 MWt and 71.5 TJ/yr for fish farming; 0.3 MWt and 1.8 TJ/yr for agricultural drying; 39.0 MWt and 238 TJ/yr for bathing and swimming; and 50.0 MWt and 270 TJ/yr for geothermal heat pumps. The total for the country is 134.6 MWt and 937.8 TJ/yr (Andritsos et al., 2010).

5.4.14. Hungary

Surface manifestations have been known in the country since ancient times. Exploration for thermal waters began in 1877 and during the 1950s and 1960s hundreds of geothermal wells were drilled, mainly for agricultural utilization. More recently, the use of geothermal energy has decreased substantially due to the global recession; however, promising projects are being investigated for both power production and direct-uses. Balneology was the earliest use of thermal waters, with 289 thermal wells and 120 natural springs presently used for sport and therapeutically purposes. Agricultural use is one of the important applications of geothermal waters in the country with 193 operating wells supplying heat for 67 ha of greenhouses. Animal farms use thermal water in more than 52 cases to raise chickens, turkeys, calves, pigs and snails. At present more than 40 townships with more than 9000 flats are heated in district heating projects. Thermal waters are also used in secondary oil production with 5400 m^3/s of hot water being injected into oil reservoirs for enhanced oil recovery. In addition, gathering pipes in a heavy oil producing oilfield are heated with geothermal waters. Geothermal heat pumps have had the largest growth in the country since 2005, with more than 4000 units installed. The various uses are: 23.7 MWt and 232 TJ/yr for individual space heating; 94.9 MWt and 930 TJ/yr for district heating; 196 MWt and 2388 TJ/yr for greenhouse heating; 4 MWt and 44 TJ/yr for fish farming; 2 MWt and 17 TJ/yr for animal farming; 10 MWt and 123 TJ/yr for agricultural drying; 12 MWt and 159 TJ/yr for industrial process heating; 272 MWt and 5356 TJ/yr for bathing and swimming; and 40 MWt and 518 TJ/yr for geothermal heat pumps. The total for the country is 654.6 MWt and 9767 TJ/yr (Toth, 2010).

5.4.15. Iceland

Due to its location, the country has very favorable conditions for geothermal development. The geothermal resources are utilized for both electricity generation and direct heat applications. Geothermal energy provides 62% of the nation's primary energy supply with space heating, the most important direct-use, providing 89% of all space heating in the country. The largest geothermal district heating system is in Reykjavik where 197,404 people are served with an installed capacity of 1264 MWt and peak load of 924 MWt. Two other large district heating systems are located on the Reykjanes peninsula which serves about 20,000 people and the Akureyri system in northern Iceland serving about 23,000 people. There are 135 swimming pools in the country that use geothermal heat and are generally open throughout the year. Snow melting has been recently increased to where 820,000 m^2 of sidewalks and parking areas are heated throughout the country, with most in Reykjavik. Most of the heat energy for direct use comes from the return water from space heating systems. Industrial uses include the seaweed drying plant at Thorverk; carbon dioxide production at Haedarendi; and fish drying by 18 small companies, producing about 15,000 tonnes of dried cod heads for export. The diatomaceous earth drying plant at Kisilidjan has been closed. Other industrial applications using geothermal heat are salt production, drying of imported hardwood, retreading of car tires, wood washing, curing of cement blocks, and steam baking of bread at several locations. After space heating, heating of greenhouses is the oldest and most important use of geothermal energy. Crops include vegetables (55%) and flowers (45%), with an estimated 17.5 ha in operation at present. Fish farming had increased to around 10,000 tonnes in 40 plants by 2006, with salmon the main specie; however, arctic char and cod production are increasing rapidly. Geothermal energy installed capacity and annual use are: 1380 MWt and 17,483 TJ/yr for district heating; 40 MWt and 677 TJ/yr for greenhouse heating; 67 MWt and 1835 TJ/yr for fish farming; 65 MWt and 1642 TJ/yr for industrial process heat; 200 MWt and 1448 TJ/yr for snow melting; 70 MWt and 1256 TJ/yr for bathing and swimming; and 4 MWt and 20 TJ/yr for geothermal heat pumps (2 large units in Akureyri); for a total of 1826 MWt and 24,361 TJ/yr (Ragnarsson, 2010).

5.4.16. Irish Republic

Geothermal energy exploitation in the country has expanded rapidly over the last few years, despite low geothermal gradients (<25 °C/km) and limited geothermal resources. There are 42 warm springs in the country between 13 and 24.7 °C. The emphasis is on exploitation of low temperature resources for space heating, using heat pump technology. However, a major new development is the first deep drilling project to reach warmer water at depth for district heating projects, with an exploration well drilled to over 1.3 km in the western suburbs of Dublin. Approximately 8000 geothermal heat pump units have been installed, with most in the 15 kW size, but a number of larger units in the 100–450 kW range are serving public and institutional/commercial buildings. The largest installation is a 3 MW open loop system at the Athlone City Center Retail Complex. The domestic market primarily uses closed loop systems, whereas the commercial market prefers the open loop using ground water. At present 1.45 MWt and 7.91 TJ/yr are used for bathing and swimming, and 137 MWt and 684 TJ/yr are used for geothermal heat pumps, for a total of 138.45 MWt and 691.91 TJ/yr (Allen and Burgess, 2010).

5.4.17. Italy

Geothermal direct-use has increased by a factor of 1.2 in the past five years to 867 MWt and 9941 TJ/yr. This larger contribution, in terms of installed power, is mainly due to the increased development of geothermal district heating and the number of single household installations in northern Italy. Both heating and cooling have been developed using geothermal energy, mainly by a large increase in geothermal heat pumps (both open and closed systems). Much of the growth has been in response to the interest from the community, as well as due to the decrease in the cost of systems. For centuries, Italians have largely used thermal waters for bathing, medical cures and relaxation, and the industry is still an important part of geothermal use, accounting for 32% of the annual energy use. A number of district heating systems using geothermal energy are operating in the country with Ferrara being the most important. Several geothermal district heating systems are also operating in the Tuscany region. Greenhouse heating and fish farming are also important parts of direct use applications, amounting to 13% and 16% respectively of the annual energy use. The largest greenhouse operation uses “waste” water from the Mt. Amiata power plant in Tuscany. Large geothermal heat pump installations (2–5 MWt) have played an important role in Italy. Installation of geothermal heat pumps has increased 15% in 2009. The installed capacity and annual energy use for the various applications are: 92 MWt and 1769 TJ/yr for individual space heating; 118 MWt and 963 TJ/yr for district heating; 111 MWt and 1329 TJ/yr for greenhouse heating; 100 MWt and 1632 TJ/yr for fish farming; 28 MWt and 130 TJ/yr for industrial applications; 187 MWt and 3157 TJ/yr for swimming and bathing; and 231 MWt and 961 TJ/yr for geothermal heat pumps. The total is 867 MWt and 9941 TJ/yr (Buonasorte et al., 2010).

5.4.18. Latvia

No country update paper was received from Latvia, thus the data will be based on Lund et al. (2005), EurObserv’ER (2009), and personal communication with I. Skapare (2005). The following use of geothermal energy were reported in 2005: two balneology facilities at Jurmala and Lieapaja for a total of 0.53 MWt and 9.50 TJ/yr; a fish farm at Dobele for 0.23 MWt and 6.44 TJ/yr; individual space heating for 0.38 MWt and 8.90 TJ/yr; and district heating of 0.17 MWt and 4.75 TJ/yr. In 2005, geothermal heat pumps were reported at four locations for a total of 20 units, which is more than the number reported in EurObserv’ER (10 units). Thus, we will use the 2005 report which gives an installed capacity of 0.321 MWt and 2.22 TJ/yr. The total for Latvia is then 1.63 MWt and 31.81 TJ/yr.

5.4.19. Lithuania

In June of 2004 the State Commission confirmed that the plant capacity for the Klaipeda geothermal demonstration plant on the west coast of the country was 35 MWt, of which 13.6 MWt was from geothermal energy. Four absorption heat pumps (at 4.5 MWt each) extract energy from 39 °C geothermal water which is boosted to 175 °C by three natural gas hot water boilers (16.2 MWt each). The heat energy is then supplied to the local district heating system. The installed geothermal capacity for the Klaipeda plant is 18.0 MWt (now operating at 13.6 MWt) producing 105.80 TJ/yr. In addition there are a number of smaller geothermal heat pumps units in single family houses throughout the country adding 34.0 MWt and 305.72 TJ/yr. The total for the country is 47.6 MWt and 411.52 TJ/yr (Zinevicius and Sliaupa, 2010).

5.4.20. Macedonia

The use of geothermal waters in the country is from seven projects and six spas; however, there has been little change since WGC2005. All were completed before and during the 1980s. The majority of the geothermal energy use is for district heating followed by greenhouse heating. No figures were given for spa heating, thus these numbers are estimated. Greenhouses are located in Istibanja (6 ha), Kocani (18 ha), and Bansko (3 ha). In addition, space and district heating is carried out in Bansko, Kocani and Negorci. There is renewed interest in revitalizing the Strumica project at Bansko, mainly consisting of greenhouses. The energy use for the various applications are: 0.84 MWt and 6.60 TJ/yr for individual space heating; 42.55 MWt and 518.37 TJ/yr for district heating; 2.79 MWt and 61.14 TJ/yr for greenhouse heating; balneology and hot water heating is recorded from WGC2005 by the same authors at 1.0 MWt and 15.3 TJ/yr. The total for the country is 47.18 MWt and 601.41 TJ/yr (Popovska-Vasilevska et al., 2010).

5.4.21. Netherlands

Originally, the object of drilling energy wells in the country was to store solar energy for space heating in winter. Later, this application broadened to the storage of thermal energy (both heat and cold) from other sources and to include geothermal heat pumps. The R&D of the early applications in the 1980s was focused on large scale applications such as commercial buildings rather than residential houses. Almost all of these early projects used ground water wells to store and extract thermal energy. In the late 1990s, borehole heat exchangers began to play a more important role in conjunction with geothermal heat pumps. At present, most of the geothermal heat pumps projects are using vertical borehole heat exchangers, with over 25,000 of these in operation. Most are small scale applications such as for single family houses or small office and commercial buildings. Systems in family homes are designed for the heating load, whereas in commercial/office building the design is for both heating and cooling. Most projects use aquifer storage for both heating and cooling, with heat pump capacities in the 50–100 kWt range, and using ground water flow rates at less than 10 m^3/h (as no permits are need up to this rate). In the Netherlands about 1200 large systems are installed with heat pump capacities around 1000 kWt, in some cases (e.g., in Amsterdam) extracting over 250 m^3/h from a single well. Direct groundwater cooling is also practiced with the larger projects. The estimated capacity and use of geothermal heat pumps in the country is 175 MWt and 1012.6 TJ/yr for the smaller units (average 7 kWt) and 1219.3 MWt and 9407.2 TJ/yr for the larger units (average 1006 kWt) for a total of 1394.30 MWt and 10,419.80 TJ/yr. In recent years, development of deep geothermal energy projects has been undertaken in addition to the shallow applications. The first deep well became operational in 2008 (6 MWt, later increased to 8 MWt). A second well was drilled in 2009 (6 MWt). In March 2010 two new deep wells were started and the number of license applications for deep wells rose to over 60. In 2010 energy use was 5.83 MWt and 89.7 TJ/yr for district heating and 10.13 MWt and 189.9 TJ/yr for greenhouse heating. The total for the country is 1410.26 MWt and 10,699.40 TJ/yr (Van Heekeren and Koenders, 2010).

5.4.22. Norway

Recent policy in Norway is to reduce the dependence on hydropower by restricting demand and increasing energy diversity. To plan, coordinate, and promote research and development within geothermal energy in Norway, the "Norwegian Centre for Geothermal Energy Research" (CGER) was established in 2009 with 19 partners from universities, colleges, research institutes and industry. The center aims to facilitate the exploitation of geothermal energy as a national energy source and as an international business objective. At present, the geothermal energy use in the country is mostly in the form of geothermal heat pumps (GSHP). The total number of installations is estimated at 30,000 with an installed capacity of 1000 MWt. More than 90% of these installations are vertical boreholes with single U-shaped pipes in open groundwater-filled boreholes. Today, about 350 large GSHP systems for public, commercial buildings or multi-family dwellings are installed, including some of the largest GSHP with borehole heat exchangers (BHE) in Europe. These installations are borehole thermal energy storage (BTES) systems providing a balanced combination of both heating and cooling. One of the largest systems comprising 228 boreholes of 200 m depth provides heating and cooling to the new Akershus University Hospital (137,000 m^2). It is planned to expand the system to 350 boreholes. The total installed capacity of GSHP is 1000 MWt producing 10,800 TJ/yr of heat energy (Midttømme et al., 2010).

5.4.23. Poland

Poland is characterized by low-enthalpy geothermal resources found mostly in the Mesozoic sedimentary formations. For many centuries warm springs have been used for balneotherapy in several spas. At present, five geothermal heating plants are in operation, the largest in the Podhale region in southern Poland with an installed geothermal capacity of 41 MW and producing 267 TJ/yr. Seven new bathing centers opened in the past five years. Other types of geothermal use include greenhouse heating, wood drying, fish farming (three are at the Podhale MEERI PAS Geothermal Laboratory as R&D projects), playground heating and salt extraction from geothermal water. Geothermal heat pump installations have increased by at least 50% over the past five years with three large absorption units in two heating plants (water-source units), and over 11,000 units in individual buildings (ground-coupled units, both vertical and horizontal). The various uses include district heating of 68.0 MWt and 393 TJ/yr; greenhouse heating, 0.5 MWt and 2.0 TJ/yr; fish farming 0.5 MWt and 2.0 TJ/yr; bathing and swimming 8.67 MWt and 55.2 TJ/yr; and geothermal heat pumps at 203.10 MWt and 1044.5 TJ/yr; others (salt extraction and playground heating) 0.28 MWt and 4.4 TJ/yr; for a total of 281.05 MWt and 1501.1 TJ/yr (Kepinska, 2010).

5.4.24. Portugal

High temperature geothermal resources in Portugal are limited to the volcanic islands of the Azores where electric power has been produced since 1980. Low-temperature geothermal resources are exploited for direct use in balneotherapy, small space heating systems, and geothermal heat pumps. In 2008, private investors obtained concession rights for exploration of geothermal resources for a total area of 2655 km^2, and plan to develop small scale EGS generation projects in the future. District heating projects are operating at Chaves in northern Portugal and S. Pedro do Sul, in central Portugal. There is a single greenhouse project in S. Pedro do Sul covering 2 ha, for raising tropical fruits (mainly pineapple). About 30 spas are operating in the country, but most are only open in the summer. Several dozen small geothermal heat pump installations are operating throughout the country, but unfortunately, this application is not yet recognized as a geothermal resource by the Portuguese administration. The data on the various geothermal uses are: 1.5 MWt and 12.9 TJ/yr for district heating; 1.0 MWt and 13.8 TJ/yr for greenhouse heating; and 25.3 MWt and 358.6 TJ/yr for bathing and swimming. No estimates were made for geothermal heat pumps; thus we estimate 24 installations at 12 kW, a COP of 3.5 and 1500 full load operating hours per year, gives 0.3 MWt and 1.1 TJ/yr. This gives a total for the country of 28.1 MWt and 386.4 TJ/yr (Cabeças et al., 2010).

5.4.25. Romania

The main geothermal resources in the country are found in porous and permeable sandstones and siltstones (such as in the western plains), or in the fractured carbonate formations (such as at Oradea and Bors and Beius in the western part, Olt Valley and North Bucharest in the southern part of the country). The total capacity of the more than 100 existing wells producing water at temperatures from 40 to 115 °C is about 480 MWt; however, only about 148 MWt from 80 wells are currently used. Thirty-five (35) of these wells are used for balneology and during the last five years seven geothermal wells have been drilled in the country with National financing, with some to depths of 1500–3000 m producing up to 90 °C water. There are two main companies in Romania currently exploiting geothermal resources: Transgex S.A. and Foradex S.A., have been given long term concession for practically all known geothermal reservoirs. Transgex, the most active company, is looking at developing district heating projects in a number of communities. The University of Oradea has established a Geothermal Research Center which provides geothermal training and research. The current direct utilization in the country includes: 13.28 MWt and 164.83 TJ/yr for individual space heating; 58.95 MWt and 531.72 TJ/yr for district heating; 4.18 MWt and 20.78 TJ/yr for greenhouses (8 locations); 4.50 MWt and 9.70 TJ/yr for fish farming (one location); 1.40 MWt and 12.70 TJ/yr for agricultural drying; 0.75 MWt and 6.84 TJ/yr for industrial process heat (4 locations); 64.68 MWt and 489.16 TJ/yr for bathing and swimming; and an estimated 5.5 MWt and 29.70 TJ/yr for geothermal heat pumps, giving a total of 153.24 MWt and 1265.43 TJ/yr (Rosca et al., 2010).

5.4.26. Serbia

The most common use of geothermal energy in the country is for balneology and recreation. Archeological evidence indicates similar uses by the Romans in the locations of the present spas such as Vranjuska, Niska, Vrnjacka and Gamzigradska. Today there are 59 thermal water spas in the country used for balneology, sports and recreation and as tourist centers. Thermal waters are also bottled by nine mineral water bottling companies. Space heating and electric power generation from geothermal energy is in the exploration stages. There are presently 25 wells in use within the Pannonian Basin, and with uses for heating greenhouses (4 wells), heating pig farms (3 wells), industrial process such as in leather and textile factories (2 wells), space heating (3 wells) and 13 wells for various uses in spas and for sport and recreation facilities. Outside the basin, geothermal water is used for space heating, greenhouse heating (raising flowers), a poultry farm, a textile workshop, a spa rehabilitation center and a hotel. Three other spas and rehabilitation centers also use geothermal heat, including heat pumps of 6 MWt, which uses water at 25 °C, and in the carpet industry. The various applications include: 20.9 MWt and 356 TJ/yr for space heating; 18.5 MWt and 128 TJ/yr for greenhouse heating; 6.4 MWt and 128 TJ/yr for fish and animal farming; 0.7 MWt and 10 TJ/yr for agricultural drying; 4.6 MWt and 58 TJ/yr for industrial process heating; 39.8 MWt and 647 TJ/yr for bathing and swimming; and 9.9 MWt and 83 TJ/yr for geothermal heat pumps. The total for the country is 100.8 MWt and 1410 TJ/yr (Martinovic and Milivojevic, 2010).

5.4.27. Slovak Republic

Geothermal direct-use is distributed in eight counties in the country with Nitra County (southwest of the center of the country) having the highest number of locations (19), and Trnava Country (western Slovakia) having the highest amount of thermal energy used. The smallest number of facilities is in Kosice Country (eastern Slovakia) with five locations reported; however, this area has the highest potential for geothermal use in the country, including the generation of electricity. Greenhouse heating is reported in 11 locations, two of which receive heat at the end of a cascaded system. Vegetables and cut flowers are the main products grown in these greenhouses. There are 19 installations using geothermal energy for individual space heating and two locations for district heating. The main district heating system is for heating of blocks of flats and a hospital in Galanta. There are 59 locations using geothermal water for swimming pools, both outside and inside. The combined utilization (cascaded use) of the energy is for greenhouse heating, district heating and finally for bathing – in Topolniky and Podhajska. Two locations use geothermal energy for fish farming. There are also nine locations using geothermal heat pumps with a total of 16 units installed. The various direct-uses include: 16.7 MWt and 381.1 TJ/yr for individual space heating; 10.8 MWt and 232.0 TJ/yr for district heating; 17.6 MWt and 461.1 TJ/yr for greenhouse heating; 11.9 MWt and 271.0 TJ/yr for fish farming; 73.6 MWt and 1708.5 TJ/yr for bathing and swimming; and 1.6 MWt and 13.5 TJ/yr for geothermal heat pumps. The total for the country is 132.2 MWt and 3067.2 TJ/yr (Fendek and Fendekova, 2010).

5.4.28. *Slovenia*

Geothermal direct-use is implemented at 28 locations in the country; this includes four new sites that have come on line and which are located in the northeastern part of the country. Direct use was discontinued at three sites due to poor economics. There are 20 thermal spas and health resorts, and five recreation centers (four of which are part of a hotel complex). Space heating is implemented at 14 locations, mainly at thermal spas, with air conditioning (cooling) at one location. There are two district heating projects, at Murska Sobota for about 300 dwellings and in Lendava where several buildings are heated in the downtown area and snow melting is planned for the future. There are a number of greenhouse locations, one growing flowers for the domestic market of 4.5 ha, one of 1 ha growing tomatoes and one of 3 ha growing orchids. The leather factor at Vrhnika is closed. A total of about 4410 heat pump units are installed in the country, about half open loop systems (50%) extracting 128 TJ/yr from shallow ground water, and the others are closed loop, mostly horizontal (46%) extracting 94 TJ/yr, with 4% being vertical closed loop installations (22 TJ/yr). About 20 TJ/yr of heat is rejected to the ground in the cooling mode, presumably by vertical systems. Space heating and bathing with swimming are the largest direct-uses in the country, followed by fast growing geothermal heat pumps; however one of the obstacles to their use is the higher tariff imposed for electricity for these units. The various uses include: 22.9 MWt and 317.8 TJ/yr for individual space heating; 3.29 MWt and 44 TJ/yr for district heating; 0.13 MWt and 2 TJ/yr for air conditioning (cooling); 13.6 MWt and 94.6 TJ/yr for greenhouse heating; 25.8 MWt and 313.2 TJ/yr for bathing and swimming; and 49.9 MWt and 243.5 TJ/yr for geothermal heat pumps. The total for the country is 115.6 MWt and 1015.1 TJ/yr (Rajver et al., 2010).

5.4.29. *Spain*

In the 1970s to early 1990s more than seventy geothermal projects were undertaken; however, in the past 10 years only four or five projects were instituted. Recently, new activity is focusing on very low-temperature resources and the development of geothermal heat pump facilities. Geothermal heat pumps are being installed in all areas of the country. In addition, with the possibility of finding locations with favorable geological characteristics, the potential for enhanced geothermal systems (EGS) is being investigated, especially in Cataluña and Galicia. Also low-temperature geothermal resources are being considered for district heating and cooling, especially north of Madrid. The Andalusian Energy Agency has started a study for the evaluation of the geothermal resources and reserves in their territory, and a group of organizations are looking at the potential in Catalonia. The installed capacity and annual energy use for the various applications are: individual space heating of 3.51 MWt and 76.21 TJ/yr; greenhouse heating of 14.93 MWt and 92.42 TJ/yr (estimated at 10 ha – Lund et al., 2005); and 120 MWt estimated for geothermal heat pumps, though the actual data are very poor and not specific. We then estimate, using a COP in the heating mode of 3.5 and 1500 full load heating hours per year, that the annual energy use is approximately 462.92 TJ/yr. In addition, in 2005, the reported value for swimming and bathing was 2.6 MWt and 52.5 TJ/yr; we assume these facilities are still in use (Lund et al., 2005). The total for the country is 141.04 MWt and 684.05 TJ/yr (Sanchez-Guzman and Garcia-de-la-Noceda, 2010).

5.4.30. *Sweden*

Heat pumps are the main geothermal use in the country, with the Lund district heating project being the largest geothermal plant producing about 250 GWh/yr and has been doing so for 25 years. The majority of the heat pumps are small and typically used in single houses. There are currently around 230,000 installations with about 25,000 units installed annually. Bedrock-soil-water is the most common source for heat pumps using geothermal energy with about 12 TWh of energy use or about 15% of the national heat demand. A number of systems use underground thermal energy storage (UTES), either as *aquifer thermal energy storage* (ATES) or *borehole thermal energy storage* (BTES). The former was implemented in the mid 1980s and current there are approximately 100 plants using this system, mainly large scale with average capacity of 2.5 MWt. Water wells are used and serve both as production and injections well, with the flow direction being reversed from summer to winter. The BTES systems consist of a number of closely spaced boreholes, normally 50–200 m deep. These are equipped with borehole heat exchangers, with the holes filled with ground water and not grouted. It has been shown that water filled boreholes are more efficient than grouted ones. These are typically used for combined heat and cooling of commercial and institutional buildings. For geothermal use in the country the following is listed: 140 MWt and 828 TJ/yr for individual space heating; 90 MWt and 504 TJ/yr for UTES; and 4230 MWt and 43,969 TJ/yr for other geothermal heat pump systems; for a total of 4460 MWt and 45,301 TJ/yr, all as geothermal heat pumps. In addition, the UTESs add 90 MWt and 612 TJ/yr for cooling (Bjelm et al., 2010).

5.4.31. *Switzerland*

The use of geothermal energy for direct-use has increased substantially, mainly with the installation of geothermal heat pumps (GHP). GHP numbers have increased at rates up to 17% per year, with borehole heat exchangers-coupled systems dominating. Novel applications such as using warm tunnel waters and energy piles have been developed. In just 2009 alone, over 2000 km of borehole heat exchangers (BHE) were drilled. The majority of the BHEs have been installed in new buildings, but the number of retrofits is increasing. The second largest use of geothermal energy is with thermal spas and wellness facilities. The proportion of the various uses in terms of energy use is 73.9% for BHE and horizontal loops, 13.6% for balneology, 10.4% using shallow groundwater, 1.0% using geostructures (energy piles), 0.6% using deep aquifers which includes using tunnel water. With about one GHP installed on the average every square km, this is the highest concentration in the world. One geothermal district heating system is located in Riehen, Canton Basel city. A recent change in governmental policy was the introduction of a feed-in tariff and a risk coverage system in 2008. There is now a clear trend of installing more and more large GHP systems with several 100 BHEs. The geothermal use by the various categories is: 2 MWt and 14.7 TJ/yr for individual space heating; 3 MWt and 33.5 TJ/yr for district heating; 1.4 MWt and 11 TJ/yr for air conditioning; 0.1 MWt and 0.3 TJ/yr for snow melting; 34.9 MWt and 1045.4 TJ/yr for bathing and swimming; 2.4 MWt and 7.7 TJ/yr for using tunnel water; and 1017.1 MWt and 6602 TJ/yr for GHP. The total for the country is 1060.6 MWt and 7714.6 TJ/yr (Rybach and Sgnorelli, 2010).

5.4.32. United Kingdom

The exploitation of geothermal resources in the country continues to be minimal. There are no proven high temperature resources and limited development of low and medium enthalpy resources. The main area of UK activity in the last five years has been in the rapid growth of ground source heat pump installations. The City of Southampton Energy Scheme remains the only exploitation of low enthalpy geothermal energy in the UK for district heating starting operation in 1987. It has been expanded to become a combined heat and power scheme for 3000 homes, 10 schools and numerous commercial buildings. The famous hot springs at Bath have long been a tourist attraction among the Roman architecture of the ancient city. Now the baths, together with four adjacent buildings, have undergone a major refurbishment, and have been reopened in 2008 and are now fully operational. The level of activity with geothermal heat pumps is estimated to be in the range of 3000–5000 installations per year. A few of these installations are large scale open loop systems (~500 kW to 2 MWt), the majority are closed loop (domestic) systems in the range of 3.5–15 kW heating only, with approximately 750 units at commercial/institutional sites and 4500 units at residential sites with full load operating hours per year of 1500 and 1800 respectively. The non-residential, closed loop systems, range in sizes from tens of kWs to several MWs of heating and cooling. The main driver for the geothermal heat pumps activity has been the realization that these can offer significant reductions in overall carbon emissions compared to traditional methods of heat delivery. The various applications are: 2.761 MWt and 72.545 TJ/yr for district heating; 0.251 MWt and 7.914 TJ/yr for greenhouse heating; 2.11 MWt and 15.88 TJ/yr for bathing (Bath); and 181.50 MWt and 753.40 TJ/yr for geothermal heat pumps. The total is: 186.62 MWt and 849.74 TJ/yr (Batchelor et al., 2010).

5.5. Commonwealth of independent states

5.5.1. Armenia

No country update report was received, nor was one received for WGC2005. The data reported here is based on a report by Henneberger et al. (2000) and personal communication with Henneberger (2009). Geothermal water from an operating well is bottled and sold as mineral water, and also used to heat a nearby guesthouse. Two wells produce CO_2 one for a bottling plant and the other for a dry-ice factory. These wells also supply hot water to the Ankavan Sanatorium, a facility dedicated to the treatment of stomach ailments. Using numbers from Lund et al. (2005), it is estimated that the capacity is 1.0 MWt and the use (mainly for bathing and swimming) is 15 TJ/yr.

5.5.2. Belarus

Starting in 1997 the first small heat pump systems were installed in the country. Today, around 100 geothermal heat pump installations are in operation in the country including heating of private cottages, a railroad station, frontier and customs points, waterworks and sewage treatment building mostly in the Minsk District in and around the main towns and cities. Around 20 of these installations are supplying space heating for industrial buildings. All of these installations use water taken from shallow boreholes with typical temperatures of 8–10 °C. One source uses river water. Another 12–15 heat pump installations are under construction. In the beginning of 2010 a geothermal station was put into a test operation with an installed capacity of around 1 MWt for heating of a greenhouse complex. The total installed capacity is estimated to be 4.5 MWt with an average COP of 3.5. Using 3840 full load operating hours per year (email communication from Zui, 2009), the corresponding annual energy use would amount to 44.43 TJ/yr (Zui, 2010).

5.5.3. Georgia

Among thermal water deposits available on the territory of Georgia, the main thermal aquifer is in Tbilisi. Currently, the water low in minerals (45–50 °C) is used in the central area of the capital by the Tbilisi Balneological Health Resort and the hygienic bath houses. The high temperature water (57–74 °C) in the Lisi and Sburtalo area of Tbilisi is used for hot-water supply and for the heating of residences and offices. In addition, there are farming and other complexes under construction at Lisi Lake. Future plans are to install a central distribution system in Tbilisi so as to eventually supply all of the city with geothermal heated water for heating. For the whole of Georgia the various applications are: 13.57 MWt and 360.09 TJ/yr for individual space heating; 8.74 MWt and 239.79 TJ/yr for district heating; 2.20 MWt and 59.36 TJ/yr for greenhouse heating; and 2.00 MWt and 30.00 TJ/yr for bathing and swimming. The total is 26.51 MWt and 689.24 TJ/yr (Melikadz et al., 2010).

5.5.4. Russia

Direct use of geothermal resources is mostly developed in the Kuril-Kamchatka region, Dagestan and Drasnodar Krai, mainly for district and greenhouse heating. To date, 66 thermal water and steam-and hydrothermal fields have been exploited in Russia. Half of these are in operation providing approximately 1.5 million Gkal (Gcalories) of heat annually (Povarov and Svalova, 2010). Approximately half of the extracted resource is used for space heating, a third for heating greenhouses, and about 13% for industrial processes. There are also approximately 150 health resorts and 40 factories bottling mineral water. Heat pumps are at an early stage of development in Russia. An experimental facility was set up in early 1999 in the Philippovo settlement of the Yaroslavl district. Eight heat pumps are used for a 160-pupil school building. There are also some buildings using heat pumps in Moscow (Svalova, 2010). A district heating project is being proposed for Vilyuchinsk City on Kamchatka (Nikolskiy et al., 2010). Unfortunately, no specific data were provided on direct-use geothermal, thus it was suggested that we use the data from WGC2005 (Svalova, personal communication, 2009). Based on data from Kononov and Povarov (2005) and modified by Lund et al. (2005), the breakdown of the various applications is: 16.5 MWt and 328 TJ/yr for individual space heating; 93.5 MWt and 1857 TJ/yr for district heating; 160 MWt and 3279 TJ/yr for greenhouse heating (estimated at 46.5 ha); 4 MWt and 63 TJ/yr of fish and cattle raising; 4 MWt and 69 TJ/yr for agricultural drying (wool washing, paper production and wood drying); 4 MWt and 63 TJ/yr for swimming and bathing; 25 MWt and 473 TJ/yr for industrial processes; and 1.2 MWt and 11.5 TJ/yr for geothermal heat pumps – mainly in Kamchatka, consisting of 100 units. The total for the country is then 308.2 MWt and 6143.5 TJ/yr. The installed capacity figures are confirmed in a paper by Butuzov et al. (2010).

5.5.5. Ukraine

No country update paper was received from this country, thus, the data from WGC2005 will be utilized, assuming no changes (Lund et al., 2005). According to the report in 2005, the direct-uses in the country are for individual space heating (3.5 MWt and 36.3 TJ/year); and district heating (7.4 MWt and 82.5 TJ/yr). Two of these applications are associated with power plants in co-generating schemes (1.8 MWt). Most of the uses were installed between 1978 and 1998 with only one project coming on line in 2002. The total is 10.9 MWt and 118.8 TJ/yr (Khvorov et al., 2005).

5.6. Oceania

5.6.1. Australia

Australia's only geothermal district heating system, at Portland in Victoria, was decommissioned in 2006 for environmental reasons (spent water was being discharged into a surface stream). However, geothermal energy is increasingly being recognized as a cheap source of energy around the country. A number of public swimming pools are using geothermal water in the Perth Basin in Western Australia, including the suburbs of Claremont, and at Christchurch and Craigie, and at the sporting arena "Challenge Stadium", along with it being used for domestic hot water in the arena. At Robe in South Australia barramundi are grown in tanks using 29 °C water. Here 22 local people are employed with annual revenue of AU$2 million. A similar facility is located in Victoria at Werribee. At Warrnambool geothermal water is used for washing down and sterilizing an industrial meat processing facility. Spas using geothermal water are located at Warrnambool and at Rye on the Mornington Peninsula south of Melbourne. This latter facility is undergoing a major expansion for accommodations, agriculture, greenhouses, space heating, and balneology in a cascaded process using 45 °C water. Throughout the rest of the county a number of recreational swimming and bathing centers are located from Hastings, Tasmania in the south to Innot Hot Springs in Queensland. A total of 12 sites are listed. However, the energy use by all these facilities is difficult to determine, and thus, is estimated in some cases. The Geoscience Australia building in Canberra is the country's largest ground source heat pump installation with 2500 kW of installed power. Other geothermal heat pump units are installed in New South Wales, Canberra, Tasmania, Victoria, South Australia, Queensland and Northern Territory. The various applications are: 2.3 MWt and 43.5 TJ/yr for fish farming; 7.03 MWt and 61.6 TJ/yr for bathing and swimming; and 24 MWt and 130 TJ/yr for geothermal heat pumps. The total for the country is 33.33 MWt and 235.1 TJ/yr (Beardsmore and Hill, 2010).

5.6.2. New Zealand

Direst use applications are found in both the North and South Islands. The most common application for the lower temperature resources is for bathing (over 50 commercial sites identified), with space and water heating to a lesser extent, and occasional direct use for frost protection and irrigation. Higher temperature resources found in the Taupo Volcanic Zone are used for greenhouse heating, prawn farming, kiln drying of timber (at Kawerau, Ohaaki and Taupo), and for special tourism development (Rotorua and Wairakei). The Kawerau facility for pulp and paper manufacturing, now accounts for 56% of the national geothermal direct-use. It is also the largest industrial use in the world and is currently being expanded further to adjacent industrial users. Geothermal heat pumps are only just taking off in the country. There are now multiple companies in the country that can supply the necessary services for both residences and commercial users. The majority of the applications appear to be water source installations. Most installations are in the more climatically extreme conditions of South Island, especially Queenstown, though there are installations in Auckland in the luxury housing market. Commercial buildings owners are recognizing that geothermal heat pumps should be considered, and an initial project has been installed at the Dunedin airport (South Island). The various applications are; 19 MWt and 181 TJ/yr for space heating; 24 MWt and 379 TJ/yr for greenhouse heating; 17 MWt and 273 TJ/yr for fish farming; 224 MWt and 6104 TJ/yr for industrial process heat; 74 MWt and 1733 TJ/yr for bathing and swimming; 28 MWt and 843 TJ/yr for other uses (irrigation, frost protection, geothermal tourist park); and 7.22 MWt and 39 TJ/yr for geothermal heat pumps. The total for the country is 393.22 MWt and 9552 TJ/yr (Harvey et al., 2010).

5.6.3. Papua New Guinea

Geothermal resources on the Island of Lihir are exploited to generate electricity for the gold mines, now at 56 MWe (Melaku and Mendive, 2010). Lihir Gold Ltd. continues to drill on the island and plans to expand their use of geothermal energy as more resource is proven. On New Britain Island, however, low-enthalpy heat is used to boil megapod eggs and the megapod (local fowl) use the hot ground to incubate their eggs, which are harvested by the locals – creating something of a tourist attraction. During World War II, at Rabaul on the north end of the island, the Japanese used the hot springs for bathhouses, and used oil drums split lengthwise to evaporate sea water for the salt using a combination of hot springs and solar heat. The current direct-use geothermal heat is estimated for bathing and swimming at 0.1 MWt and 1.0 TJ/yr.

6. Energy savings

Geothermal, a domestic source of sustainable and renewable energy, replaces other forms of energy use, especially fossil fuels. For many countries, geothermal energy leads to a reduction in their dependence on imported fuel, and for all countries, it means the elimination of pollutants such as particulates and greenhouse gases. An attempt is made here to quantify the fossil fuel savings, using an efficiency factor of 0.35 if the competing energy is used to generate electricity and 0.70 if it is used directly to produce heat, such as in a furnace.

Using the 423,830 TJ/year of energy consumed in direct geothermal applications by 2010 (see Table 1), and estimating that a barrel of fuel oil contains 6.06×10^9 J, and that the fuel is used to produce electricity, the savings would be 200.0 million barrels of oil or 30.0 million tonnes of oil annually. If the oil were used directly to produce energy by burning it for heating, then these savings would be 100.0 million barrels or 15.0 million tonnes. The actual savings are most likely somewhere in between these two values. Note that 200 million barrels is almost three days of worldwide oil consumption.

Using figures developed by Lawrence Livermore Laboratory for the U.S. Department of energy (Kasameyer, 1997) and by private consultants Goddard and Goddard (1990) the following savings would be realized for carbon, CO_2, SO_x and NO_x. Compared to using electricity, the carbon savings would be 14.65 tonnes/TJ from natural gas, 62.6 tonnes/TJ for oil or 72.7 tonnes/TJ from coal, for a total carbon production savings of 6.22, 26.54 or 30.82 million tonnes, respectively. Similarly, using 193 kg/MWh (53.6 tonnes/TJ), 817 kg/MWh (227.0 tonnes/TJ), and 953 kg/MWh (264.7 tonnes/TJ) for carbon dioxide emissions when producing electricity from natural gas, oil and coal, respectively, the savings in CO_2 emissions would be 22.72, 96.24, and 112.22 million tonnes, respectively. The savings in SO_x and NO_x producing electricity from natural gas, oil and coal would be 0.0, 0.59 and 0.64 million tonnes, and 5.90, 17.67, and 017.67 thousand tonnes, respectively. If heat were produced by burning these fuels, the carbon, CO_2 and SO_x and NO_x savings would be half of these values. Again, the actual savings would be somewhere in between these values since a mix of fossil fuels would be used for heating and electricity generation.

If savings in the cooling mode of geothermal heat pumps are considered, which is not geothermal, then this is equivalent to an additional annual savings of approximately 50.0 million barrels (7.5 million tonnes) of fuel oil, and 6.6 million tonnes of carbon pollution from burning fuel oil to produce electricity, assuming that the annual energy used in cooling is approximately half that used in the heating mode (+25%). The above figures are summarized in Table 3.

Table 3
Worldwide savings in energy, carbon and greenhouse gases using geothermal energy including geothermal heat pump cooling (figures in millions) in terms of fuel oil (TOE = tonnes of oil equivalent).

	Fuel oil		Carbon	CO_2	SO_x	NO_x
	bbl	TOE	TOE	TOE	TOE	TOE
As electricity	250.0	37.5	33.2	106.9	0.74	0.022
As direct heat	125.0	18.8	16.6	53.4	0.37	0.011

7. Total investment in geothermal

Approximately US$10 billion was invested in geothermal projects by 46 countries during the period 2005–2009 for both direct-use and electrical power. The average was US$210 million/country, with the countries investing over US$500 million being USA, China, New Zealand, Turkey, Philippines and Mexico. The following are the regional investments:

- 33% in Asia by 7 countries
- 4% in Africa by 5 countries
- 21% in Europe by 24 countries
- 27% in the Americas by 8 countries
- 15% in Oceania by 2 countries

Of those countries reporting on investment in geothermal, 28% was for direct-use projects in 29 countries, 22% was for electric power projects in 8 countries, and the remaining 50% was for R&D and for field development. The leaders in direct-use project investments were China, Switzerland, Korea, Ireland and Turkey. In electric power plant investment, the leaders were New Zealand, Turkey, United States, Mexico and Kenya.

8. Person-years of professional personnel working in geothermal

Approximately 45,600 person-years in 43 countries of professional effort was allocated to geothermal development (restricted to personnel with university degrees) during the period 2005–2009 for both direct-use and electrical power (no distinction was made between the two). The average was 1060 person-years/country (212 persons/year/country over the five-year period), with countries allocating more than 1000 person-years being Germany, Philippines, USA, Japan, Netherlands, New Zealand and China. The following are the regional allocations:

- 28% in Asia by 7 countries
- 1% in Africa by 5 countries
- 51% in Europe by 21 countries
- 16% in the Americas by 8 countries
- 4% in Oceania by 2 countries

9. Wells drilled for geothermal

Approximately 2089 wells were drilled in 37 countries during the period 2005–2009 for both direct-use and electric power. Shallow heat pump wells are not included in these figures. The average was 56 wells/country, and the countries drilling more than 100 wells being: USA, China, Turkey, Iceland, Korea, India and New Zealand. The following are the regional allocations:

- 40% in Asia by 6 countries
- 2% in Africa by 4 countries
- 20% in Europe by 16 countries
- 29% in the Americas by 9 countries
- 9% in Oceania by 2 countries

Table 4
Distribution of geothermal energy by continent.

Continent	#countries	%MWt	%GWh/yr
Africa	7	0.3	0.7
Americas	15	30.1	19.0
Asia	16	28.7	34.9
Europe[a]	37	40.0	43.1
Oceania	3	0.9	2.3

[a] Includes CIS countries west of Urals.

Of the total number of wells drilled, 44% were for direct-use, 36% were for electric power, 20% were for combined use, and <1% were for "other". The leading countries in terms of drilling direct-use wells were: China, Turkey, Korea, Iceland and Hungary.

10. Well depths drilled for geothermal

Approximately 2391 km of wells were drilled in 36 countries during the period 2005–2009 for both direct-use and electric power (no distinction was made between the two). Shallow heat pump wells are not included in these figures. The average was 1.14 km/well, and the countries drilling more than 100 km during this period were: China, USA, Iceland, Mexico, Korea, Turkey and Germany. The following are the regional drilling depth percentages of the total:

- 44% in Asia by 6 countries
- 3% in Africa by 4 countries
- 24% in Europe by 15 countries
- 26% in the Americas by 9 countries
- 3% in Oceania by 1 country

11. Concluding remarks

As in 1995, 2000 and 2005, several countries stand out as major consumers of geothermal fluids for direct uses; however, in most countries development has been slow. This is not surprising as fossil fuels are a major competitor; the development has been curtailed due to the recent downturn in the world economy; and the initial high investment costs. Many countries have; however, been doing the necessary groundwork, conducting inventories and quantifying their resources in preparation for development when the economic situation is better and governments and private investors see the benefits of developing a domestic renewable energy source. The distribution of geothermal use by continents of the world is shown in Table 4.

With the increased interest in geothermal heat pumps, geothermal energy can now be developed anywhere, for both heating and cooling. Low-to-moderate temperature geothermal resources are also being used in combined heat and power plants (CHP), where hot waters with temperatures below 100 °C are first run through a binary (Organic Rankine Cycle) power plant and then cascaded for space, swimming pool, greenhouse and/or aquaculture pond heating, before being injected back into the aquifer. CHP projects certainly maximize the use of the resources and improve the economics, as has been shown in Iceland, Austria and Germany.

Key data and explanations were frequently missing from the WGC2010 country update reports used in this worldwide summary. Some data also appeared to be in error or misreported. We have attempted to correct for these errors by contacting WGC2010 authors and by making estimates for the missing data, and have pointed this out in the relevant country summaries.

Despite these discrepancies and the effort required to correct them, work on this review has proved useful, as it has allowed us to demonstrate that using low-to-moderate temperature geothermal resources in the direct heat applications, given the right conditions, is an economically feasible business, and can make a significant contribution to a country's or region's energy mix. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy.

At the time of writing this report (June, 2010), the cost of crude oil is at US$78/barrel and has been in the recent past over US$100/barrel, and natural gas prices are also on the rise. Thus, with geothermal energy becoming increasingly more competitive with fossil fuels and the environmental benefits associated with renewable energy resources better understood, development of this natural "heat from the earth" should accelerate in the future. An important task for all of us in the geothermal community is to spread the word on geothermal energy, its various applications, and the many environmental benefits that can accrue from its use.

Acknowledgements

The authors would like to thank Dr. Roland Horne for his assistance as Technical Program Chair for the WGC2010. He and his staff at Stanford University greatly facilitated the work of gathering information and editing the reports.

References

Allen, A., Burgess, J., 2010. Developments of geothermal utilisation in the Irish Republic. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0157, 9 pp.

Andritsos, N., Arvanitis, A., Papachristou, M., Fytikas, M., Dalambakis, P., 2010. Geothermal activities in Greece during 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0138, 10 pp.

Asturias, F., Grajeda, E.C., 2010. Geothermal resources and development in Guatemala, country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0156, 7 pp.

Bahati, G., Natukunda, J.F., Tuhumwire, J., 2010. Geothermal energy in Uganda, country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0112, 8 pp.

Batchelor, T., Curtis, R., Ledingham, P., 2010. Country update for the United Kingdom. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0166, 4 pp.

Beardsmore, G.R., Hill, A.J., 2010. Australia – country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0150, 11 pp.

Beate, B., Salgado, R., 2010. Geothermal country update for Ecuador, 2005–2010. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0160, 16 pp.

Ben Mohamed, M., 2010. Geothermal direct application and its development in Tunisia. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 2803, 8 pp.

Berckmans, A., Vandenberghe, N., 1998. Use and potential of geothermal energy in Belgium. Geothermics 27, 235–242.

Bignall, G., Dorj, P., Batkhishig, B., Tsuchiya, N., 2005. Geothermal resources and development in Mongolia: country update. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 0132, 7 pp.

Bjelm, L., Alm, P., Andersson, O., 2010. Country update for Sweden. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0137, 9 pp.

Boissier, F., Desplan, A., Laplaige, P., 2010. France country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0161, 9 pp.

Bojadgieva, K., Hristov, H., Hristov, V., Benderev, A., Toshev, V., Barokov, K., 2010. Bulgaria – geothermal update report. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0144, 11 pp.

Buonasorte, G., Rizzi, F., Passaleva, G., 2010. Direct uses of geothermal energy in Italy 2005–2009: update report and perspectives. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0151, 5 pp.

Butuzov, V.A., Tomarov, G.V., Shetov, V., Amerkhanov, K., Bryantseva, R.A., Butuzov, E.V.V.V., 2010. Study and construction of geothermal system of heat supply of domestic buildings and greenhouses with the use of solar energy and heat pumps. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 3415, 6 pp.

Cabeças, R., Carvalho, J.M., Numes, J.C., 2010. Portugal country geothermal update 2010. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0165, 10 pp.

Castillo, G.E., Salgado, R.M., 2000. Honduras country update paper. In: Proceedings of the 2000 World Geothermal Congress, Japan, May 28–June10, 2000, pp. 123–132.

Cataldi, R., Hodgson, S.F., Lund, J.W., 1999. Stories from a Heated Earth – Our Geothermal Heritage. Geothermal Resources Council, Davis, California, 580 pp.

Chandrasekharam, D., Chandrasekhar, V., 2010. Geothermal energy resources, India: country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0105, 11 pp.

Chua, S.E., Abito, G.F., 1994. Status of Non-Electric Use of Geothermal Energy in the Southern Negros Geothermal Field in the Philippines. Geo-Heat Center Quarterly Bulletin 15 (4), 24–29.

Cuong, N.T., Giang, C.D., Thang, T.T., 2005. General evaluation of the geothermal potential in Vietnam and the prospect of development in the future. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 0101, 8 pp.

Curtis, R., Lund, J., Sanner, B., Rybach, L., Hellström, G., 2005. Ground source heat pumps – geothermal energy for anyone, anywhere: current worldwide activity. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 1437, 9 pp.

Darma, S., Harsoprayitno, S., Setiawan, B., Hadyanto, Sukhyar, R., Soedibjo, A.W., 2010. Geothermal energy update: geothermal energy development and utilization in Indonesia. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0128, 13 pp.

Dickson, M.H., Fanelli, M., 2003. Geothermal background. In: Dickson, M.H., Fanelli, M. (Eds.), Geothermal Energy: Utilization and Technology, UNESCO Renewable Energy Series. Earthscan Publications Ltd., London, UK, pp. 1–28.

EIA (Energy Information Agency), 2008. www.eia.doe.gov, Washington, D.C.

EurObserv'ER, 2009. Barometre pompes a chaleur, Systemes solaires le journal des energies renouvelables, No. 193, pp. 60–79.

Fekraoui, A., 2010. Geothermal activities in Algeria. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0117, 6 pp.

Fendek, M., Fendekova, M., 2010. Country update of the Slovak Republic. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0139, 10 pp.

Frasheri, A., 2010. Geothermal energy resources in Albania – country update paper. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0104, 15 pp.

Frasheri, A., Çermak, V., Doracaj, M., Liço, R., Safanda, J., Bakalli, F., Kresl, M., Çanga, B., Vokopola, E., Stulc, P., Halimi, H., Malasi, E., Kapedani, N., Kuçerova, L., Jareci, E., 2004. Atlas of Geothermal Resources in Albania. Faculty of Geology and Mining, Polytechnic University of Tirana, Tirana.

Frasheri, A., Londo, A., Shtjefni, A., Cela, B., Kodhelaj, N., Pano, N., Alusaj, R., Bushati, S., Thodhorjani, S., 2008. Space Heating/Cooling Systems Borehole Vertical Heat Exchanger Heat Pump System. Faculty of Geology and Mining, Polytechnic University of Tirana, Tirana.

Goddard, W.B., Goddard, C.B., 1990. Energy fuel sources and their contribution to recent global air pollution trends. Geothermal Resources Council Transaction 14 (1), 643–649.

Goldbrunner, J., 2010. Austria – country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0134, 16 pp.

Guha, D.K., Henkel, H., Imam, B., 2010. Geothermal potential in Bangladesh—results from investigations of abandoned deep well. In: Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, April 25–29, 2010, paper No. 0172, 8 pp.

Gutiérrez-Negrin, L.C.A., Maya-González, R., Quijano-León, J.L., 2010. Current status of geothermics in Mexico. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0101, 11 pp.

Hamza, V.M., Cardoso, R.R., Gomes, A.J.L., Alexandrion, C.H., 2010. Brazil: country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0147, 13 pp.

Harvey, C.C., White, B.R., Lawless, J.V., Dunstall, M.G., 2010. 2005–2010 New Zealand country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0168, 10 pp.

Henneberger, R., Cooksley, D., Hallberg, J., 2000. Geothermal resources of Armenia. In: Proceedings of the 2000 World Geothermal Congress, Kyushu-Tohoku, Japan, May 28–June 10, 2000, pp. 1217–1222.

Herrera, R., Montalva, F., Herrera, A., 2010. El Salvador country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0141, 6 pp.

Hjartarson, A., Armannsson, H., 2010. Geothermal research in Greenland. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0158, 8 pp.

Houssein, D.E., 2010. Geothermal Resource Assessment of Asal Field, Republic of Djibouti. In: Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, April 25–29, 2010, paper No. 0154, 5 pp.

Huttrer, G.W., 2010. 2010 Country update for eastern Caribbean island nations. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0113, 9 pp.

Idris, M., 2000. Geothermal evaluation of thermal fluids at Helwan Springs, Egypt. In: Proceedings of the 2000 World Geothermal Congress, Kyushu-Tohoku, Japan, May 28 June 10, 2000, pp. 1295–1299.

Jelić, K., Golub, M., Kolbah, S., Kulenović, I., Škrlec, M., 2010. Croatia geothermal resources updates in the year 2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0143, 9 pp.

Jessop, A., 1995. Geothermal energy from old mines at Springhill, Nova Scotia, Canada. In: Proceedings of the 1995 World Geothermal Congress, Florence, Italy, May 18–31, 1995, pp. 463–468.

Kasameyer, R.,1997. Working Draft, Brief Guidelines for the Development of Inputs to CCTS from the Technology Working Group. Lawrence Livermore Laboratory, California, U.S.A., 10 pp.

Kepinska, B., 2010. Geothermal energy country update report from Poland, 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0108, 8 pp.

Khvorov, M., Shurchkov, A., Zabarny, G., 2005. The results of geothermal-energy harnessing activity in Ukraine. In: Proceeding of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 0169, 3 pp.

Kononov, V., Povarov, O., 2005. Geothermal development in Russia: country update report 2000–2004. In: Proceedings of the 2005 World Geothermal Congress 2005, Antalya, Turkey, April 24–29, 2005, paper No. 0117, 7 pp.

Lagos, C.A., Gomez, R., 2010. Honduras country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, paper No. 0148, 5 pp.

Lahsen, A., Muños, N., Parada, M.A., 2010. Geothermal development in Chile. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0118, 7 pp.

Levitte, D., Greitzer, Y., 2005. Geothermal update report for Israel 2005. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 0125, 5 pp.

Lund, J.W., 1990. Geothermal spas in Czechoslovakia. Geo-Heat Center Quarterly Bulletin 12 (2), 20–24.

Lund, J.W., Freeston, D.H., 2001. World-wide direct uses of geothermal energy 2000. Geothermics 30, 29–68.

Lund, J.W., Freeston, D.H., Boyd, T.L., 2005. Direct application of geothermal energy: 2005 Worldwide review. Geothermics 34, 691–727.

Lund, J.W., Gawell, K., Boyd, T., Jennejohn, D., 2010. The United States of America country update 2010. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0102, 18 pp.

Mahler, A., Magtengaard, J., 2010. Country update report for Denmark. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0131, 9 pp.

Mainieri Protti, A., 2010. Costa Rica country update report. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0115, 6 pp.

Manzo, A.F.R., 2005. Geothermal power development in Guatemala 2000–2005. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005, paper No. 0133, 8 pp.

Martinovic, M., Milivojevic, M., 2010. Serbia country update. In: Proceeding of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0164, 11 pp.

Melaku, M., Mendive, D., 2010. Geothermal development in Papua New Guinea – a country update report 2005–2009. In: Proceedings of the 2010 World Geothermal Congress 2010, Bali, Indonesia, April 25–29, 2010, paper No. 0159, 4 pp.

Melikadz, G., Tsertsvadze, L., Tsertsvadze, N., Vardigoreli, O., Barabadze, T., 2010. Country Update from Georgia. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0167, 7 pp.

Mérida, L., 1999. Curing blocks and drying fruit in Guatemala. Geo-Heat Center Quarterly Bulletin 20 (4), 19–22.

Mertoglu, O., Simsek, S., Dagistan, H., Bakir, N., Dogdu, N., 2010. Geothermal country update report of Turkey (2005–2010). In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0119, 9 pp.

Midttømme, K., Berre, I., Hauge, A., Musœus, T., Kristjansson, B., 2010. Geothermal energy – country update for Norway. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0171, 5 pp.

Miošić, N., Samardžić, N., Hrvatović, H., 2010. The current status of geothermal energy use and development in Bosnia and Herzegovina. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0133, 10 pp.

Myslil, V., Stibitz, M., Frydrych, V., 2005. Geothermal energy potential of Czech Republic. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005 paper No. 0177, 7 pp.

Nikolskiy, A.I., Semenov, V.V., Tomarov, G.V., Shipkov, A.A., 2010. Geothermal district heating of Vilyuchinsk City (Kamchatka). In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 3417, 9 pp.

Ngoc, N.L., Giang, C.D., Cuong, N.T., 2010. Geothermal research and current development of geothermal energy in Vietnam. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 1608, 3 pp.

Normatov, I., 2010. Geothermal water resources of the Republic of Tajikistan and a perspective on their use. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 106, 6 pp.

Ogena, M.S., Maria, R.B.S., Stark, M.A., Oca, R.A.V., Reyes, A.N., Fronda, A.D., Bayon, F.E.B., 2010. Philippine country update: 2005–2010 geothermal energy development. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0149, 10 pp.

Pesce, A.H., 2010. Argentina country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0122, 12 pp.

Popovska-Vasilevska, S., Popovski, K., Micevski, E., 2010. Macedonia – country update 2010. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0109, 7 pp.

Povarov, K.O., Svalova, V.B., 2010. Geothermal development in Russia: country update report 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0145, 4 pp.

Ragnarsson, A., 2010. Geothermal development in Iceland 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0124, 12 pp.

Rajver, D., Lapanje, A., Rman, N., 2010. Geothermal development in Slovenia: country update report 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0130, 10 pp.

Ranjit, M., 2010. Geothermal energy update of Nepal. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0146, 8 pp.

Rehman, S., 2010. Saudi Arabian geothermal energy resources – an update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0107, 6 pp.

Rosca, M., Antal, C., Bendea, C., 2010. Geothermal energy in Romania: country update 2005–2009. In: Proceeding of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0129, 9 pp.

Ruiz Cordero, J.F., 2009. Geothermal energy in Nicaragua – current situation. In: Proceedings of the Central American Geothermal Workshop, San Salvador, El Salvador, p. 16.

Rutagarama, U., Uhorakeye, T., 2010. Geothermal development in Rwanda: an alternative to the energy crisis. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0132, 6 pp.

Rybach, L., Sgnorelli, S., 2010. Country update of Switzerland. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0120, 12 pp.

Saffarzedeh, A., Porkhial, S., Taghaddosi, M., 2010. Geothermal energy development in Iran. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0126, 8 pp.

Sanchez-Guzman, J., Garcia-de-la-Noceda, C., 2010. The evolution of geothermal energy in Spain – country update (2005–2009). In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0135, 8 pp.

Saudi, A., Swarich, A., 2005. Geothermal resources of Jordan, country update report. In: Proceedings of the 2005 World Geothermal Congress, Antalya, Turkey, April 24–29, 2005 paper No. 0104, 8 pp.

Simiyu, S.M., 2010. Status of geothermal exploration in Kenya and future plans for its development. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0169, 11 pp.

Schellschmidt, R., Sanner, B., Pester, S., Schulz, R., 2010. Geothermal energy use in Germany. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0152, 18 pp.

Song, Y., Kim, H., Lee, T.J., 2010. Geothermal development in Korea: country update 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0121, 11 pp.

Sugino, H., Akeno, T., 2010. 2010 country update for Japan. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0142, 7 pp.

Surana, T., Atmojo, J.P., Suyanto, Subandriya, A., 2010. Development of geothermal energy direct use in Indonesia. In: Proceeding of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 2824, 5 pp.

Svalova, V., 2010. Mineral extraction from brines and geothermal resources complex use in Russia. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 2822, 7 pp.

Teklemariam, M., Kebede, S., 2010. Strategy for geothermal resource exploration and development in Ethiopia. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0155, 9 pp.

Thompson, A., 2010. Geothermal development in Canada: country update. In: Proceedings of the 2010 World Geothermal Congress 2010, Bali, Indonesia, April 25–29, 2010, paper No. 0116, 3 pp.

Toth, A., 2010. Hungary country update 2005–2009. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0125, 8 pp.

Tshibalo, A.E., Olivier, J., Venter, J., 2010. South Africa geothermal country update (2005–2009). In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0127, 13 pp.

Van Heekeren, E.V., Koenders, M., 2010. The Netherlands country update on geothermal energy. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0171, 3 pp.

Zarhloule, Y., Rimi, Abedlkrim, Boughriba, M., Barkaoui, A.E., Lahrach, A., 2010. The geothermal research in Morocco: history of 40 years. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0110, 6 pp.

Zheng, K., Han, Z., Zhang, Z., 2010a. Steady industrialized development of geothermal energy in China. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0136, 11 pp.
Zheng, X., Xia, B., Chen, H., Du, L., 2010b. Geothermal direct use and its contribution to CO_2 emission saving in China. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 2809, 6 pp.
Zinevicius, F., Sliaupa, S., 2010. Lithuania – geothermal energy country update. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0153, 8 pp.
Zui, V.I., 2010. Geothermal resources of Belarus and their utilization in Belarus. In: Proceedings of the 2010 World Geothermal Congress, Bali, Indonesia, April 25–29, 2010, paper No. 0170, 12 pp.