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Geothermal Energy System andIts Heating Application Revisited

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Abstract
*In recent years research on direct use of Geothermal Energy(GE) for heating purpose has received much attention as it is commercially competitive with conventional energy sources.GE is the thermal energy within the earth interior. It is a renewable energy source because heat is continuously transferred from within the earth to the water recycled by rainfall. The GE is available day and night every day of the year and can thus serve as a supplement to energy sources which are only available internationally.It is more effective when used directly than when converted to electricity, particularly for moderate and low temperature geothermal resources since the direct heating of fossil fuels from which electricity is generated much more efficient. GE is broken down into three types: direct use for heating, direct use for electricity generation and indirect use by heat pumps also known as geoexchange systems or ground source heat pumps. In this paper the direct use of geothermal energy is highlighted.Example systemsare also presented to apply the efficacy of the Degree Day (DD) method for calculating total annul GE consumption of a building.*The study also shows that direct applications of geothermal heat are being effectively used in many countries all over the world and are also economical.

Keywords: *Geothermal,spaceheating,districtheating, geothermalpumps, DD method*.

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I. Introduction

Direct utilization of GEis most versatile and most common forms of utilizing geothermal energy. It is the thermal energy coming out of the molten interior of the earth towards the surface. The average rate at which the heat energy emerges is about 0.05W/m^2 while the radiant temperature gradient which causes this heat flow is about 0.03^{o}C/m. Thus, on an average the temperature of the earth increases by 30^{o}C/km if one moves inwards. GE is a renewable energy source because heat is continuously transferred from within the earth to the water recycled by rainfall. Early mine excavationsshowedthattheearthtemperature wasincreasingwithdepth,underagradientof 2-3°C/100m.Itprovidesus withanabundant,non-polluting,almostinfinite source of clean and renewable energy. The heatoriginatesfromtheEarth'scoreabout 4,000°Cat6,000kmdepthfromradioactive decay of rocks, long life isotopes of uranium, thorium andpotassium. It is reported that thetotalheatcontentoftheearthstandsinthe order of 12.6 x 10^{24} MJ and that of the crust of 5.4 x 10^{21} MJ, indeed a huge figure when compared to the total world energy demand which amounts to 6x10^{13} MJ/year thatis 100 million times lower.

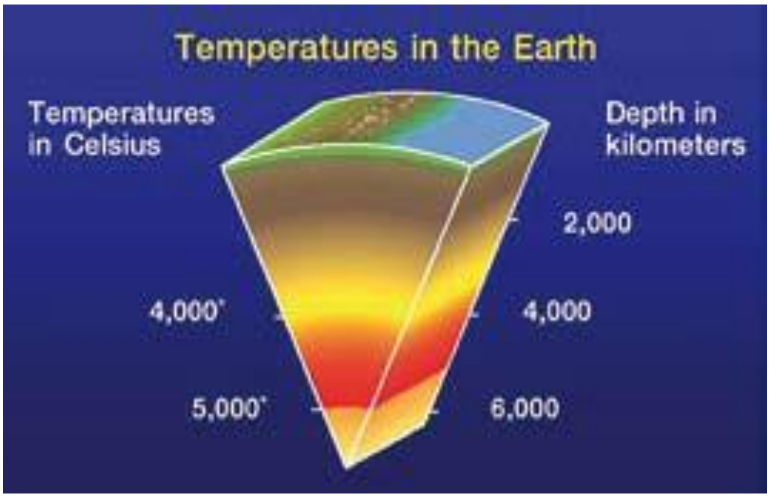

Figure 1: Temperature in the earth [2]

However, only a fraction of it can be utilized by human beings. Our utilization of this energy has been limited to areas in which geologicalconditionsallowafluidconsists of liquidwater or steam to transfer the heat from deep hot zones ornear the surface, thus giving rise to geothermalresources. TheheatoutflowsfromtheEarth'score,melting the rocks and forming the magma. Then, the magma rises toward the Earth's crust,carrying theheatfrombelowthroughconvectivemotions. It may flow as lava, smoothly or explosivelyat thesurface. Insomeareasitremainsbelowthe crust,heatingthesurroundingrocksandhosted waters.Someofthishotgeothermalwatermigrates upwards,throughfaultsandcracks,reachingthe reachingthe surface as hot springs or geysers, but most of it remains under ground, trapped in cracks, reaching the surface as hot springs or geysers. But most of it remains under ground, trapped in cracks and porous rocks, forming the geothermal reservoirs. Insuchlocationsthegeothermalheatflowcan reachvaluestentimeshigherthannormal [1]. Understandardconditions30°Cto50°Ctemperatureswouldbeexpectedat1kmto1.5kmdepths.Ingeothermalareasenjo yinghigherthannormal heatflows,temperaturesarelikelytoreach100°C to 150°C at similar depths. In areas close to lithosphericplatemargins,geothermalresources woulddisplayawidertemperaturerange,from 150°Ctoveryhighvalues,ultimatelyculminating at 400°C and behaves as supercritical fluid.

II.Geothermal Resources

The origin of Geothermal Resources (GR) is earth's core which is about 6500 km deep[1] [3]. The core is made up of an inner core from center and an outer core made up of very hot magma remains very high due to radioactive particle decay. The outer core is surrounded by mantle whose thickness is about 3000km. The mantle consists of magma and rock. The layer of the earth housing continents and ocean floor is called crust. The thickness of the crust is about 25 km to 55km on the continents and about 5km to 8km under the oceans. The crust is made up of tectonic plates. Volcano occurs near the edges of these plates due to closeness of magma. At some reasonable depths, the rocks and water absorb heat from the magma. These are characterized as GR. By digging wells and pumping the hot water the geothermal energy is made useful. The interior layer of the earth is depicted in Figure 2.

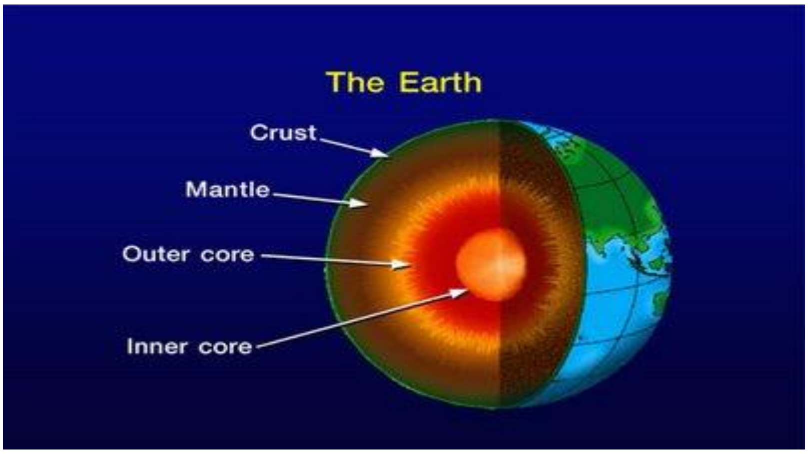

Figure 2: The interior layers of the earth [12]

III. Direct Application of Geothermal Heat

A number of residential and commercial buildings are effectively heated in winter bylow-cost geothermal heating in many parts of the world [1]. The annual amount of space heating supplied in the world is estimated to be about 360,000 TJ as of 2015. As 1 Tera Joule (TJ)=10^{12} J, this is equivalent to
36x10^{13} kJ or Btu=36x10^{8}therms where1therm=10^{5} Btu.

For space and water heating the resource temperature should be greater than 50°C.

When a district is heated by geothermal water, the rate of geothermal heat supplied to the district is determined from

$$\dot{Q}_{heat,useful} = \dot{m}C_p\,(T_{supply} - T_{return}) \quad (1)$$

Where $\dot{m}$ is the mass flow rate andC_p is the specific heat of geothermal water.T_{supply} and T_{return} are supply and return temperatures of geothermal water for the district, respectively. The amount of energy supplied for a specified period of time is calculated from:

$$\text{Energy consumption}= \frac{\dot{Q}_{heat,useful} \text{ X Operating hours}}{\text{efficiency}_{heater}} \quad (2)$$

DDmethod is used for calculating total annul geothermal energy consumption of a building. This method is also used for solar, biomass and other fossil fuel-based systems.

Example system [1]: For the DD calculation
Highest outdoor temperature =50°F
Lowest outdoor temperature =30°F
Average outdoor temperature =40°F
DD for that day for a balance point temperature of 65°F
DD= (1 day) (65-40)^0 F=25°F-day =600° F-hour

Geothermalheatisusedforspaceheatingmostlyinadistrictheatingscheme.Normally,hotgeothermalwaterisnot directlycirculatedtothedistrictduetoundesirablechemicalcompositionandcharacteristicsofgeothermalbrine.Acommo nop e r a t i n g modeforageothermaldistrictheatingsystemisshowninFigure 3.Heatexchangersareusedtotransfertheheatofgeothermalwatertofreshwaterandthisheatedfreshwaterissenttothedistrict .Thisheatissuppliedtothebuildingsthroughindividualheatexchangers.

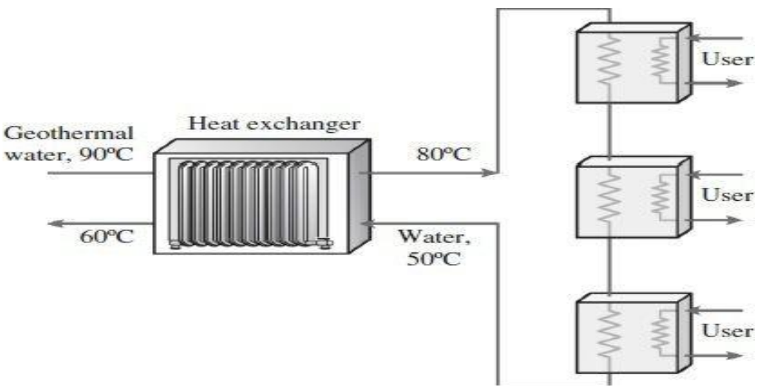

Figure 3:Acommonoperatingmodeforgeothermaldistrictspaceheatingsystems [1]

Now, when heating DDs are available for a given location, the amount of energy calculate energy consumption for the entire winter season can be determined from

Energy consumption=$\frac{K_{overall}}{efficiecy_{heater}} DD_{heating}$ (3)

where $K_{overall}$ is the overall heat transfer coefficient of thebuilding.

The amount of Fuel consumption corresponding the energy consumption can be determined from

Fuel consumption=$\frac{energy\ consumption}{Heating\ value\ of\ fuel}$ (4)

If the heating is performed by a heat pump then $efficiecy_{heater}$ needs to be replaced by a Coefficient of Performance (COP) of the heat pump. In that case energy is consumed in the form of electricity.

Electricity consumption =$\frac{K_{overal\ l}}{COP_{heating}} DD_{heating}$ (5)

For calculating cooling energy, electricity consumption =$\frac{K_{overall}}{COP_{cooling}} DD_{cooling}$ (6)

The DD method serves as a valuable tool for gaining intuitive understanding of annual geothermal energy consumption.Worldwide use of geothermal energy. Global geothermal power generation amounted to **16** GWs, only a handful of countries have surpassed the 1GW milestone [5].

Utilization of DDs to figure energy use:

When properly used, DDs allow toanticipate monthly utility costs and provide with an effective means of comparing current energy consumption rates with similar periods in years past. DDs essentially take the weather out of the equation to compare energy consumption and give a better understanding of systems' efficiency and spot opportunities to cut back and save some money.To understand the working of DDs, using a baseline temperature of 65 degrees, it is necessary to figure out the average temperature of a given day and the difference between that figure and 65 degrees is to be calculated.

Direct use typical geothermal system with heat exchanger is shown in Figure 4.

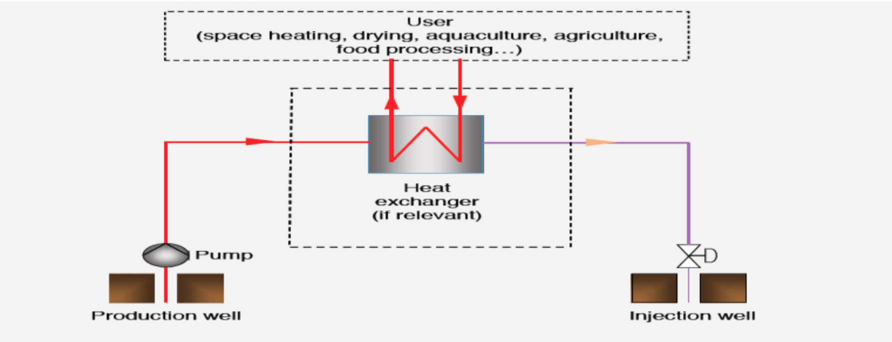

Figure 4: Direct use typical geothermal system

Example system 2:

in a a hot August day might have a high temperature of 90 degrees and a low of 72 degrees, with the day's average temperature totaling 81 degrees (the median of the day's high and low temperatures). In this example, your home's equipment consumes 16 DDs to cool the home, which is the difference between the average temperature of 81 degrees and the baseline temperature of 65 degrees.

Both heating and cooling degree days use the same baseline of 65 degrees, so you can use this technique to predict your monthly energy consumption in both winter and summer. Adding up all the degree days you use in a given month will help you compare energy consumption to the levels of past months, which in turn will allow you to figure out how much your utility bill will be ahead of time. Alternatively, DD calculations show the true energy efficiency of heating and cooling equipment, regardless of variations in the weather.

If the heating and cooling costs are too high for example atPaschal, geothermal have a wide range of products and accessories that can help toreduce energyconsumption and save money onmonthly utility bills. To take advantage of comprehensive energy-savings program, HVAC equipment installation with superior energy-efficiency ratings geothermal equipment is necessary to save some money.

Study shows that the five countries with the largest direct-use, without geothermal heat pumps, in installed capacity are: China, Turkey, Japan, Iceland and Hungary, accounting for 76.0% of the world capacity.

Summary of direct-use data by region and continent is shown in Table1 to table 8.

Table 1: Summary of direct-use data worldwide by region and continent, 2019

Region/Continent (#countries/regions)	MWt	TJ/year	GWh/year	Capacity Factor
Africa (11)	198	3,730	1,036	0.597
Americas (17)	23,330	180,414	50,115	0.245
Central America and Caribbean (5)	*9*	*195*	*54*	*0.687*
North America (4)	*22,700*	*171,510*	*47,642*	*0.24*
South America (8)	*621*	*8,709*	*2,419*	*0.445*
Asia (18)	49,079	545,019	151,394	0.352
Commonwealth of Independent States (5)	2,121	15,907	4,419	0.238
Europe (34)	32,386	264,843	73,568	0.259
Central and Eastern Europe (17)	*3,439*	*28,098*	*7,805*	*0.259*
Western and Northern Europe (17)	*28,947*	*236,745*	*65,762*	*0.259*
Oceania (3)	613	10,974	3,048	0.568
Total (88)	**107,727**	**1,020,887**	**283,580**	**0.300**

Table 2: Worldwide leaders in the direct-use of geothermal energy including geothermal heat pumps.

MWt		TJ/year	
China	(40,610)	China	(443,492)
United States	(20,713)	Unites States	(152,810)
Sweden	(6,680)	Sweden	(62,400)
Germany	(4,806)	Turkey	(54,584)
Turkey	(3,488)	Japan	(30,723)

Table 3: Worldwide leaders in the direct-use of geothermal energy in terms of population(per1,000).

MW/population		TJ/population	
Iceland	(7.00)	Iceland	(99.10)
Sweden	(0.67)	Sweden	(6.22)
Finland	(0.42)	Finland	(4.23)
Switzerland	(0.26)	Norway	(2.34)
Norway	(0.21)	New Zealand	(2.12)

Table 4: Worldwide leaders in the direct-use of geothermal energy per land area (per 100 km^2).

MWt		TJ/year	
Switzerland	(5.32)	Iceland	(32.62)
Netherland	(4.14)	Switzerland	(32.18)
Iceland	(1.93)	Sweden	(13.86)
Sweden	(1.48)	Hungary	(11.94)
Austria	(1.31)	Austria	(10.30)

Table 5: Worldwide leaders in the direct-use of geothermal energy in terms of the largest increase (%)

MW/population		TJ/population	
Ukraine	(18,642)	Ukraine	(4,181)
Spain	(748)	Spain	(1,040)
Australia	(487)	Yemen	(567)
Yemen	(400)	Australia	(339)
China	(127)	Kenya	(330)

Table 6: Worldwide leaders in the direct-use of geothermal energy without geothermal heat pumps

MWt		TJ/year	
China	(14,160)	China	(197,281)
Turkey	(3,480)	Turkey	(54,413)
Japan	(2,407)	Iceland	(33,590)
Iceland	(2,368)	Japan	(29,958)
Hungary	(952)	New Zealand	(9,729)

Table 7: Worldwide leaders in the installation and use of geothermal heat pumps

MWt		TJ/year	
China	(26,450)	China	(246,212)
United States	(20,230)	United States	(145,460)
Sweden	(6,680)	Sweden	(62,400)
Germany	(4,400)	Germany	(23,760)
Finland	(2,300)	Finland	(23,400)

Table 8: % Mwt and %TJ/year of the continents Africa, America, Asia, Europe Oceania.

Continent	Countries	%MWt	%TJ/year
Africa	11	0.2	0.4
Americas	17	21.7	17.7
Asia	19	45.6	53.4
Europe*	38	31.9	27.4
Oceania	3	0.6	1.1

* Includes CIS Countries (Georgia, Russia and Ukraine)

Categories of utilization:

Curves in Figure 5 depict1995, 2000, 2005, 2010, 2015 and 2020 among the various uses in terms of capacity (MWt), energy utilization (TJ/yr) and capacity or load factor (C.F.). This distribution can be viewed as a bar chart in Figure5 for the top 6 energy uses. 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. The best estimate is that district heating represents 91% of the installed capacity and 59% of the annual energy use. Snow melting represents the majority (>90%) of the snow melting/air conditioning category. “Other” is a category that covers a variety of uses, details of which are not frequently provided, but is known to include animal husbandry, cultivation of spirulina, and carbonation of soft drinks [11].

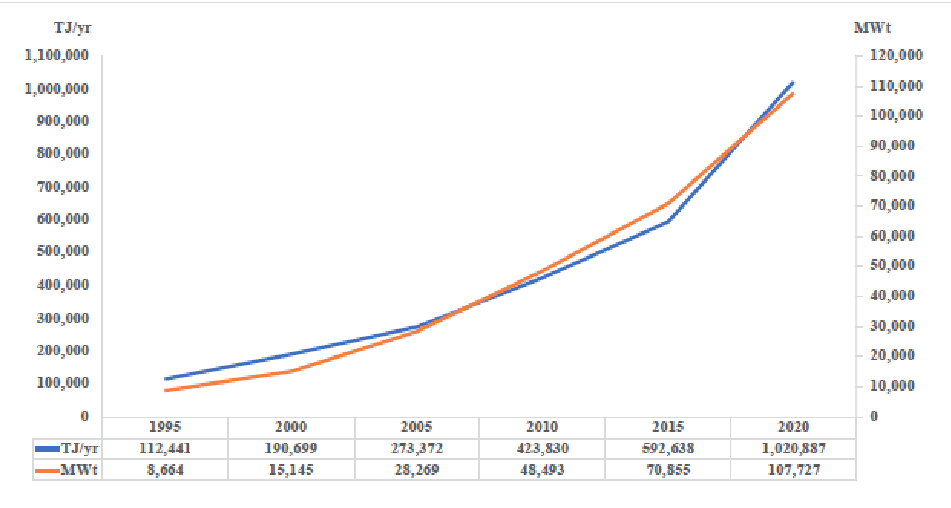

Figure 5: The installed direct – use geothermal capacity and annual utilization from 1995-2020 [11]

IV. Conclusion

A DD is a combination of time and temperature difference. The basic idea behind it is to give an indication of how much heating or cooling a building might be needed. DDs are just an estimate of heating and cooling needs. One point of confusion for many people is that "DDs" sound like a unit of time though it is not. That is why we can have 5 DDs in one day and well more than 365-DDs in a year. Atlanta, Georgia has about 3,000 heating degree days each year (65° F base temperature). There is a broad range of geothermal direct use applications, the most common being bathing and space heating either in a centralized system – district heating – or with decentralized units such as ground source heat pumps. In this research it is observed that direct use of geothermal energy for district heating purposes is the largest form of utilizing GE. Its utilization depends on the depth of the resource, the temperature found, the geological settings, the resource type, closeness to energy demand etc. The discussions on DDs are just an estimate of heating and cooling needs and mentioned in this research to look at some of the reasons that is why it need to keep them in the proper perspective. A DD is a combination of time and temperature difference. The intension is to carryout research on geothermal cogeneration of GE in a forth coming paper.

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