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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS

COVER: Geothermal Map of California

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THE GEOTHERMAL MAP OF CALIFORNIA

Susan F. Hodgson
California Department of Conservation
Division of Oil, Gas and Geothermal Resources
Sacramento, CA

The new "Geothermal Map of California," drawn at a scale of 1:1,500,000, is the most comprehensive geothermal map every made of the state. Digitally produced with a PC-based geographic information system, the map was created by the Division of Oil, Gas and Geothermal Resources, and the California Geological Survey, under the California Department of Conservation.

The map includes digital layers for a wide range of geothermal data, including boundaries of Known Geothermal Resource Areas from the U.S. Bureau of Land Management; commercial, low-temperature geothermal projects from the Geo-Heat Center, Oregon Institute of Technology (see the illustration); thermal springs and low-temperature geothermal wells from the California Geological Survey; geothermal fields, power plants and high-temperature production wells, and plugged and abandoned wells from the California Division of Oil, Gas and Geothermal Resources; and electrical generation data from the California Energy Commission.

It is interesting to see where all the geothermal features lie. Although the state's best-known volcanoes–Mt. Shasta and Mt. Lassen–are in the northernmost area, the geothermal resources in general–both developed and underdeveloped–are more scattered. The shaded relief map overlying the large state map shows where they occur in respect to the mountain ranges and valleys. Mostly, the resources are found in the border area surrounding the central Great Valley, leaving much of the state without any geothermal features whatsoever.

Another fact becomes clear. Except for thermal springs, most geothermal features on the map are clustered to such a degree that five inset maps and an additional small, state map are needed to illustrate them. The small state map includes low-temperature wells and low-temperature projects, such as aquaculture, district heating, greenhouses, industrial uses, resorts and pools, and space heating.

A black and white version of the small, state map showing direct-use applications, was drawn for this article. Although this version is in black and white as opposed to color, a look will illustrate how often the low-temperature projects and low-temperature wells are found together. Even though the Geo-Heat Center's list of California's low-temperature geothermal projects had not been updated in several years, a sample of 99 was used. It is clear that several projects and project types often exist at a single site.

On the following page is a list of direct-use sites in California extracted from the back of the map sheet. Additional information on direct-use sites in California can be obtained from the Geo-Heat Center website: http://geoheat.oit.edu.

The thermal springs in the state–there are 299–are dispersed more widely than any of the other geothermal features (except perhaps for some of the low-temperature commercial projects related to the springs). Data about each thermal spring are organized in a chart printed on the back of the map. These include the name of the spring, the latitude and longitude, the county, the highest recorded temperature in ^{o}C, the flow rate in liters per minute, and the historical uses, such as water-supply augmentation, baths, pools, space heating, district heating, irrigation, aquaculture, greenhouse and heat exchanger applications, bottled water, idle and abandoned projects, and undeveloped springs.

Of course, California uses its high-temperature geothermal resources, as well, generating a great deal of electricity from them. In fact, more electricity from geothermal resources is generated in the United States than any other country, and most of it comes from California–about 2,429 megawatts of installed capacity in 1998 (California Energy Commission figures). The states of Hawaii, Nevada and Utah also generate small amounts.

Today in 2003, about 10 percent of the electricity in Northern California and about 5 percent of he electricity in the whole state are generated from geothermal hot water and steam. The map shows where the generation occurs-the locations of the geothermal fields, the wells with high-temperature resources, and the power plants with their names.

Plainly, many kinds of geothermal resources are important to California and many have important commercial uses. The resource variety and the resource locations are both critical, and they are clearly and artistically depicted here in full color.

TO ORDER A MAP

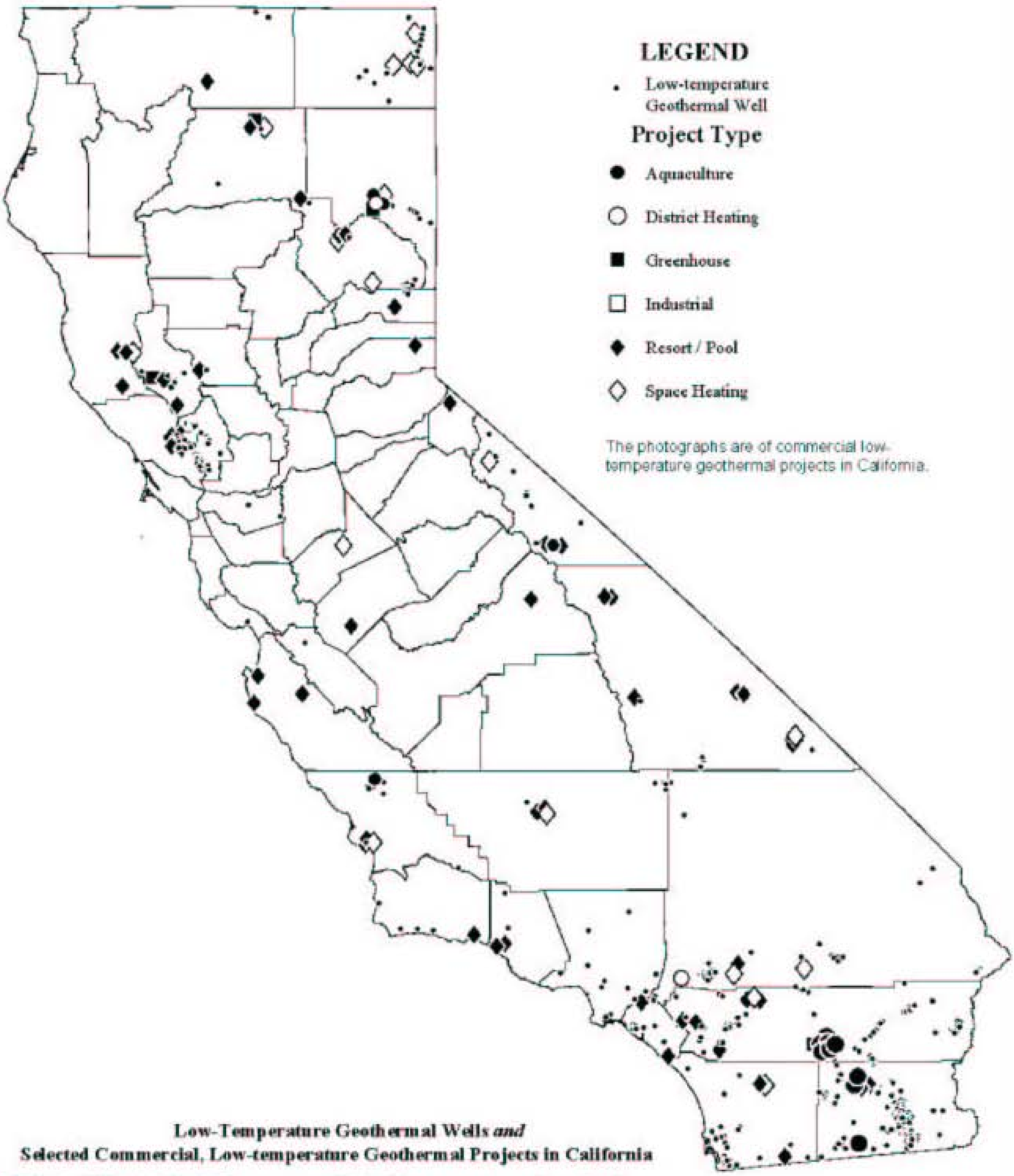
The "Geothermal Map of California" sells for $3, flat or folded, with handling and shipping included. To order a map, contact the California Division of Oil, Gas and Geothermal Resources, 801 K Street, MS 20-20, Sacramento, CA 95814-3530. Phone: (916) 445-9686.

The map is by Susan F. Hodgson and Leslie G. Youngs, and the cartography is by Roberto A. Coronel.

DIRECT-USE SITES IN CALIFORNIA

NAME	COUNTY	TEMP ºC (ºF)	FLOW RATE L/MIN (GPM)	USE
Grover Hot Springs	Alpine	60 (140)	400 (106)	B, H
Wilbur Hot Springs	Colusa	60 (140)	80 (21)	B
Mercy Hot Springs	Fresno	48 (118)		B
Keough Hot Springs	Injyo	59 (138)	2000 (528)	B
Tecopa Hot Springs	Inyo	42 (108)	757 (200)	B, C
Nevares Springs	Inyo	40 (104)	1325 (350)	A
Miracle Hot Springs	Kern	50 (122)	49 (13)	A, B
Delonegha Hot Springs	Kern	44 (111)	30 (8)	B
Democrat Hot Springs	Kern	46 (115)	57 (15)	B
Placer Claim Springs	Kern	40 (104)	9.5 (2.5)	B
Howard Hot Springs	Lake	46.3 (115)	55 (14.5)	B
Bassett Hot Springs	Lassen	79 (174)	200 (53)	A, B
Zamboni Hot Springs	Lassen	40 (104)	95 (25)	B, C
"Trilby Spring"	Mendocino	28 (82)		B
"Pool Spring"	Mendocino	29 (84)		B
Vichy Springs	Mendocino	29 (84)		B, J
SX Ranch Spring	Modoc	26 (79)	19 (5)	A, E
Little Hot Spring	Modoc	73.5 (164)	300 (79)	E
Fales Hot Springs	Mono	61 (1402	1000 (264)	B
Tassajara Hot Springs	Monterey	60 (140)	189 (50)	B
Paraiso Springs	Monterey	43 (109)	57 (15)	B, E
Brockway Hot Springs	Placer	55 (131)	600 (158)	B
Warm Springs at Twain	Plumes	38 (100)	19 (5)	B
White Sulfur Springs	Plumes	27 (81)	95 (25)	B, C
Murrieta Hot Springs	Riverside	54 (129)		B
Agua Caliente Spring	Riverside	41 (106)		B, C
Warner Hot Springs	San Diego	56 (133)	500 (132)	B, C
Agua Caliente Springs	San Diego	37 (99)	56 (15)	B, C
Newsom Springs	San Luis Obispo	36 (97)	57 (15)	B
Montecito Hot Springs	Santa Barbara	48 (118)	300 (79)	A
Hunt Hot Springs	Shasta	56 (133)	27 (7)	B
Big Bend Hot Springs	Shasta	82 (180)	340 (90)	B
Campbell Hot Springs	Sierra	42 (108)	284 (75)	B
California Hot Springs	Tulare	45 (113)	500 (132)	A, B

A - Augmenting water supply B - Direct-use in baths/pools C - Space heating D - District heating E - Irrigation
F - Fish farming H - Heat exchanger in use J - Bottled water



Low-Temperature Geothermal Wells *and*
Selected Commercial, Low-temperature Geothermal Projects in California

• In 1993, the California Geological Survey prepared a list of low-temperature geothermal wells in California. Low-temperature wells have water 68 °F to 212 °F and the locations are shown on the map.

◆ In 1996, the Geo-Heat Center identified 99 commercial, low-temperature geothermal projects in California and prepared a map with some of the locations. For more information, contact the Geo-Heat Center at the Oregon Institute of Technology, 3201 Campus Drive, Klamath Falls, OR 97601.
(541) 885-1750; or http://geoheat.oit.edu

THE ECONOMICS OF CONNECTING SMALL BUILDINGS TO GEOTHERMAL DISTRICT HEATING SYSTEMS

Kevin Rafferty
Geo-Heat Center

INTRODUCTION

Recently renewed interest has been expressed in district heating as a potential application for low temperature geothermal fluids. To some extent this has been driven by a publication (Boyd, 1996) in which 271 communities were identified as being co-located with geothermal resources. Beyond that, the availability of a software tool (WSU, undated) which can be used for evaluating the economics of distribution systems for district heating, has made the process of feasibility study more convenient.

Evaluations of geothermal district heating (GDH) systems often focus heavily on the resource, central mechanical facilities and distribution piping. While it is true that these components do constitute the bulk of the capital costs for the system and without careful design of these components a system cannot brought to fruition, it is equally true that a system cannot be successfully developed without customers. In the world of simulation, virtual customers can be expected to connect to any system the modeler creates. Real customers however require a reasonable economic incentive to connect. In the small building size range typically found at most of the co-located sites, the economics associated with connecting to a geothermal district heating system may include some substantial economic hurdles for building owners.

The term “district energy” is often used in describing these systems. It is a useful term for marketing purposes and to describe systems in which both heating and cooling (and electricity in some cases) are delivered to the customer. Low temperature geothermal resources are capable of supporting only district heating and this is the term that will be used in this paper.

In many cases, the heat rate required to provide the potential customer with favorable economics may be far lower than what the system operator can afford to offer. This has been the case with some existing geothermal district heating systems. Few of these systems have achieved full subscribership (in 10 to 15 years of operation) and some are operating at less than 50% capacity with potential customers located adjacent to existing distribution lines unconnected to the system. In order to attract customers, geothermal district systems serving a small building customer base must offer rates substantially lower than competing heating fuels or other incentives to create the necessary customer economics. A feasibility study which fails to address the customer economics issues cannot provide an accurate picture of the prospects of the system.

THE ADVANTAGES OF LARGE BUILDING CUSTOMERS

In some cases, there has been the tendency to assume that rate structures used in large conventionally fueled district systems (typically located in large cities serving large [>50,000 ft^2] buildings) would also be effective in small geothermal district systems. In the larger systems, rates are often in excess of the energy cost that would be incurred in generating the heat with a boiler in the customer’s building. District systems can employ these high rates due to other savings large building owners receive when using district heating. One of the largest of these is the elimination of boiler operating personnel associated with large boilers. If the boiler room was staffed with only one individual per shift and 3 shifts per day, this savings alone would amount to between $100,000 and $200,000 per year. The average combined space and water heating energy consumption for a 200,000 ft^2 office building would amount to just 66,800 therms (EIA,1998). At a gas rate of $ 0.75 per therm this amounts to $50,100 per year - only 25 to 50% of the boiler operator costs. In addition to the personnel savings, large building owners may also realize insurance savings resulting from the elimination of the boiler operation on site. If the boiler is eliminated completely, additional floor space rent may be possible from rental of the boiler room area as well. Beyond the heating savings, many large district systems supply chilled water for space cooling in addition to the steam or hot water for heating. The savings from use of district chilled water normally dwarf those associated with heating service due to the greater cost of electricity compared to heating fuels. Together, these issues permit district systems serving large buildings to charge very high rates for their product.

The issue of retrofit costs is also a much smaller hurdle in large buildings due to their more common use of hot water based heating systems. Converting buildings of this type to using district supplied heating media is much less costly than small buildings since no retrofit of terminal equipment (the individual units which actually deliver heat to the space such as furnaces, unit heaters, heat pumps, etc.) is required.

SMALL TOWNS, SMALL BUILDINGS

In the context of the 271 sites, it is useful to consider the size of the population centers associated with them and the type of buildings which are likely to be encountered there. Though they have come to be referred to as “cities” (Bloomquist and Lund, 2000), the original reference more correctly refers to them as communities. Cities is a term that implies a certain level of population and infrastructure and in the case of the 271 locations identified in Boyd (1996) this term is probably not an accurate characterization. Of the 271 sites, 43% have a population of less than 500 and 71% are less than 5000. Of the 45 with the highest populations, 10 already have geothermal district systems installed and 13 others have other forms of geothermal development in place - indicating that they are aware of geothermal development but have chosen to pursue applications other than district heating. It seems reasonable to conclude that geothermal district heating development associated with the 271 collocated sites will likely occur in small to very small towns.

Given the size of these communities, most prospective customers for any district heating systems that might be developed there would certainly be in the small size range since few towns in the 5000+/- population size range have many buildings (if any) larger than 10,000 ft^2. As a result, the costs of converting small buildings to hot water heating and the relationship between these costs and the savings to be had from connecting to a district system is a pivotal issue in the context of the development of GDH systems.

HEATING SYSTEMS USED IN SMALL-TO-MODERATE SIZE BUILDINGS

In existing buildings, the magnitude of the retrofit costs incurred by the customer to convert the heating system to use the hot water supplied by the district system is heavily influenced by the type of heating equipment in place. As mentioned above, systems already based on hot water are the simplest to connect since in most cases, no modification is necessary to the individual terminal units (the equipment actually supplying heat to the space). Unfortunately, most small buildings do not use hot water based heating systems. Figure 1 provides a summary of heating system types for small and moderate sized buildings. It is apparent from the figure that in the small building category, approximately 85% of the

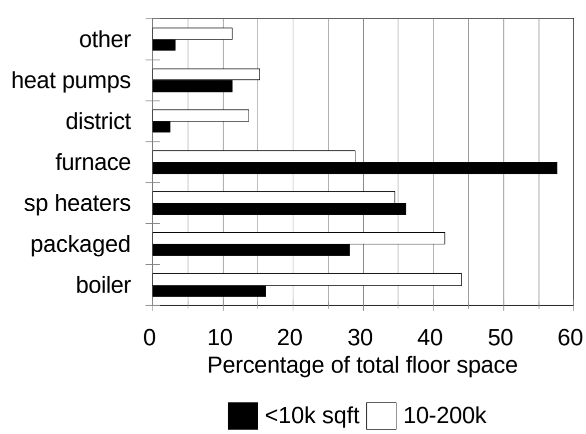


Figure 1. Heating equipment by building size (EIA, 1995).

floor space in these buildings is heated by other than hot water based systems. In fact, the percentage may be higher than this assuming that some of the boiler systems would be older steam systems rather than hot water. The situation in moderate sized buildings (10,000 ft^2 to 200,000 ft^2) is somewhat better in that some 43% of the total floor area in these buildings is served by a boiler system.

As a result, it is clear that in the small building category, the majority of the buildings use other than hot water heating systems. For systems of this type, conversion to hot water heating involves at a minimum: installation of hot water coils at all terminal units, hot water supply and return piping, sheet metal modifications to existing duct work to accommodate the installations of the coils, new controls and associated fittings and components. Details of this equipment and costs are provided in the retrofit section of this paper.

RETROFIT OF SMALL BUILDING HEATING SYSTEMS

Retrofit of existing non hot water based heating equipment to use hot water heat involves substantial modifications. The extent of the retrofit modifications is dependant upon the type of equipment.

Given the type of equipment installed in these buildings (Figure1), converting terminal equipment falls into two categories - applications where a coil must be installed in the distribution duct work (existing furnaces, packaged equipment, heat pumps) and applications where a hot water unit heater must be installed to replace existing fossil fired or electric unit heaters. Interestingly, in these small buildings the cost of the retrofit is more a function of the number of individual units which must be retrofit than it is of the total heating capacity required. This arises from the fact that the only component directly tied to the heating output is the coil or unit heater and the cost of this component constitutes only about 5 to 15% of the total retrofit costs. Beyond that doubling the capacity of a coil or unit heater only involves an incremental cost of about 40%.

Figure 2 provides a diagram of a simple, one coil retrofit of a building that might be served by a gas furnace or rooftop packaged unit. This retrofit design approach assumes that an isolation heat exchanger is not required at the customer building. The use of the customer heat exchanger would substantially increase (approx 33%) the cost of the retrofit since it would require the addition of a circulating pump, expansion tank, domestic water cross-connect (for pressurization), additional controls, etc. The “open”type customer connection shown here minimizes retrofit cost and is an arrangement used by several operating GDH systems.

Table 1 provides a breakdown of the retrofit costs for the system. Depending upon the design of the district system, a circulating pump may be required to provide flow through the customers system and/or a meter may be required for measuring the customers consumption. These costs are shown separately.

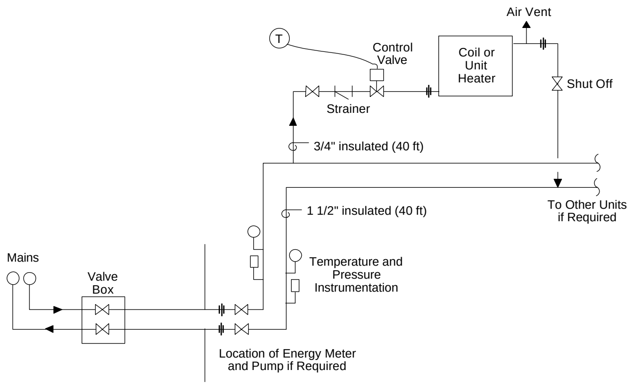


Figure 2. Simple one-coil retrofit design.

Table 1. Retrofit Costs for Small GDH Customer

Outside lines, main tap, valve box	1800
wall cut, 11/2" bldg pipe, fittings	1550
coil, 3/4" pipe, controls sheet metal	2040
10% contingency	540
Total (single heating unit - ducted)	5930
Total (single unit heater)	6280
add for booster pump if necessary	660
add for Btu meter if necessary	1130
add for ea additional coil	3080
add for ea additional unit heater	3160
add for building heat exchanger if req'd	2020
add for domestic hot water retrofit (100kBtu/hr)	1660

Costs for each additional coil or unit heater are indicated as well. The basic piping used for the building in this case would accommodate up to a 500,000 Btu/hr load at a 40^{o}F Δt. Additional costs for the coils and unit heaters are based on a capacity of 100,000 Btu/hr per unit.

Using these figures, an automotive repair shop with 3 unit heaters would have a retrofit cost of $6280 + 2(3160) = $12600 to retrofit the heating system for the use of a hot water heating medium. If a booster pump and energy meter were also required, this total would be $14390.

A small office with two roof top heat pumps would incur a retrofit cost of $5930 + 3080 = $9013.

CUSTOMER SAVINGS

For the small building customer, decisions concerning connection to a district system are influenced by both retrofit costs and savings which accrue to the owner from connection to the system. In these smaller buildings (10,000 ft^2 and less), the additional non-energy savings discussed in the large building section of this paper are unavailable. The small heating equipment does not require operating personnel, space required for the equipment is of little or no consequence to the owner and insurance is unaffected since most customer agreements require that the building owner have a standby system available. As a result, the only savings to be had from the connection to the district system are those arising from reduced heating costs assuming the absence of any other incentives.

The savings the building owner receives from connecting to a district system is determined by the difference between the districts rate for the heat, the owner's existing cost of heating. For fossil fuel fired heating systems, there is a savings to the owner even if the district prices it's heat at the same as that of the competing fuel. This arises from the fact that fossil fired heating equipment has an efficiency associated with it. Depending upon the age and quality of the unit, between 5 and 35% of the heating value in the fuel is lost up the flue. Beyond the savings associated with the inefficiency of the conventional heating equipment, there is an additional savings associated with whatever difference may exist between the district rate and the conventional fuel rate (in equivalent dollars per million Btu). Most current geothermal district heating systems use rates which are lower than the most commonly used competing fuels--some as little as 70% of natural gas. Table 2 presents some example costs for heat based on current (March 2001) utility rates in Klamath Falls OR.

Table 2. Comparative Rates for GDH and Competing Fuels

Fuel	Cost of heat ($/1,000,000 Btu)
Natural gas @0.75 $/therm, 75% eff.	10.00
Natural gas @0.75 $/therm, 93% eff	8.07
Fuel oil @ 1.55 $/gal, 70% eff	5.82
Propane @ 1.40 $/gal, 75% eff	20.74
Heat Pump @ .065 $/kWh, 2.0 COP	9.52
Electric resistance @ .065 $/kWh	19.04
GDH @ 100% of Nat Gas (70%eff)	7.50
GDH @ 90% of Nat Gas (70% eff)	6.75
GDH @ 80% of Nat Gas (70% eff)	6.00
GDH @ 70% of Nat Gas (70% eff)	5.25

The table uses natural gas as the basis and this is common in areas where this fuel is available. Obviously, in areas where it is not, comparisons would be made to the most commonly used fuel.

It is apparent that even at a GDH rate of 100% of that of natural gas, the potential GDH customer still enjoys a 25% savings due to the inefficiency of his older natural gas heating system. Of course the total savings a customer would achieve would be a function of the difference in rates and the total energy consumption of his building on an annual basis.

Heating energy consumption varies by building use, construction, climate, hours of operation and other variables. The U.S. Energy Information Administration publishes averages values for building energy consumption. Table 3 summarizes these values for a variety of different commercial building types. The values appear in units of Btu/ft²/yr, commonly referred to as the Energy Utilization Index or EUI.

Table 3. **Commercial Building Heating Energy Consumption (Btu/ft²/yr) (EIA,1998)**

Building Type	Space Heating	Water Heating
Office	24.3	8.7
Mercantile/Service	30.6	5.1
Lodging	22.7	51.4
Public Assembly	53.6	17.5
Food Service	30.9	27.5
Warehouse	15.7	2.0
Food Sales	27.5	9.1
Public Safety	27.8	23.4

A check of the smaller buildings connected to the Klamath Falls GDH system agrees well with this data, indicating a range of 25,000 to 65,000 Btu/ft²/yr for heating energy.

The question remains however, can sufficient savings be generated based on the existing heating costs and typical commercial building energy usage to create sufficient motivation for small business owners to connect to a GDH system

To evaluate this issue Figures 3 through 5 were developed. Figure 3 evaluates the economics of the smallest customers - 1000 ft² building typical of a small storefront in a downtown area. For this customer, it has been assumed that only a single unit will require retrofit (such as a single furnace, heat pump, unit heater, roof top unit, etc.). Two different building energy use rates are considered - 30,000 Btu/ft²/yr and 60,000 Btu/ft² yr. This range of EUI's encompasses all of the small building types in the EIA data and also reflects the range of values found in the Klamath Falls building stock. A total of eight curves appear in the figure. The solid line curves reflect the lower building EUI of 30,000 Btu/ft² yr and the dotted lines the higher (60,000) value. In each case the four curves represent customer savings using GDH of 25%, 32.5%, 60% and 52.5% compared to the existing annual costs with conventional heat. Retrofit cost used to make the payback calculations appearing in this figure were based on the data in Table 1. It was assumed that no circulating pump, energy meter, building heat exchanger or domestic hot water retrofit was required and a rounded off value of $6000 was used as reasonably representative of either the coil or unit heater type retrofit for a single heating unit. This represents a very conservative assumption with respect to the costs a building owner may encounter as the addition of the components assumed to be unnecessary would nearly double the retrofit cost.

Payback requirements necessary to trigger action on energy measures have been characterized by others (Spain, 2000; ComEd, 2000; Univ of Michigan, 2001; Rafferty, 1996) as being less than 5 years (less than 3 years in most cases).

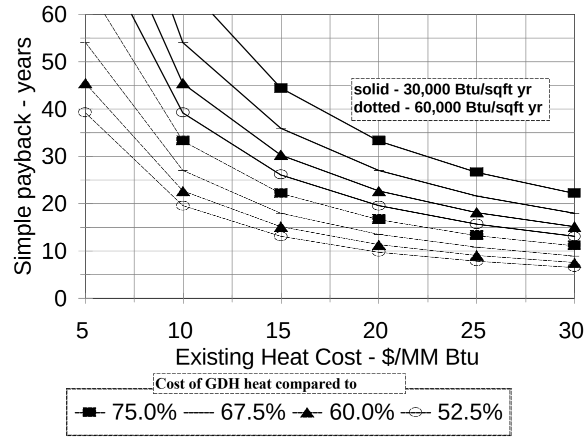


Figure 3. ***Customer economics - 1000 sq ft.***

Using the 5 year figure, it appears that in the smallest building size as depicted in Figure 3, there are no circumstances under which it could be expected that owners would find connection to a GDH system attractive.

Figure 4 provides similar information for a building of 5000 ft² assuming two existing heating units would have to retrofit. Again table 1 values are used as the basis for retrofit cost and a rounded off value of $9000 (basic 1 unit retrofit of $6000 plus an additional unit at $3000) was used. This case is slightly more positive as far as the prospects for connection are concerned but only in those cases where high building energy use exists combined with the prospect of a GDH rate that results in greater than 50% savings for gas users or a minimum 25% savings for propane and electric resistance users.

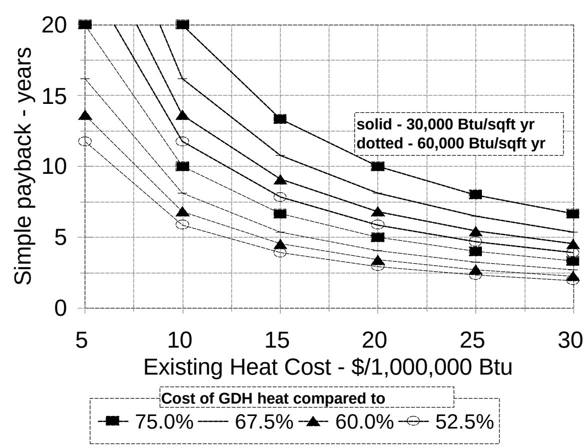


Figure 4. ***Customer economics - 5000 sq ft. Retrofit of 2 units required.***

Figure 5 provides information for buildings of 10,000 ft² floor area. Due to the much larger building and total energy use and the lower retrofit costs per square foot (4 units assumed to require retrofit @ $15,000), the customer economics are the most favorable of the building sizes

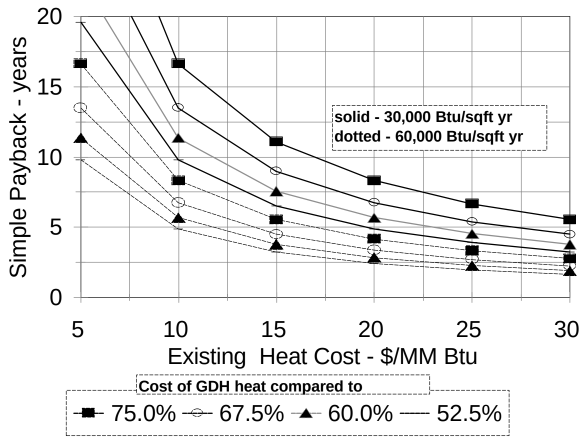


Figure 5. ***Customer economics - 10,000 sq ft. Retrofit of 4 units required.***

considered here. For buildings at the low end of energy use (30,000 Btu/ft^2 yr) the economics of connecting to a GDH system appear only to be favorable in situations where the highest cost fuels are currently used (electric resistance and propane) and where the district rate results in a 50% or more cost savings. For buildings of a higher energy use index, the 5 year payback criteria could be met by gas users if the GDH system offered rates of approximately 50% that of natural gas.

CONCLUSIONS

Of the 271 population centers co-located with low temperature geothermal resources, over 70% have populations of less than 5000 people. Towns of this size typically do not have a substantial number of buildings in the large size range - the size range in which the economics of connecting to GDH system is often positive. As a result, if new GDH systems are to be developed in these small towns, a substantial portion of the potential customer buildings will be in the small size range.

Buildings in this size range, because they do not typically use hot water based heating systems, require fairly substantial retrofit work to their existing heating systems to accommodate the hot water heating medium. The costs associated with this retrofit work are such that, in buildings of less than 10,000 sq ft of floor area, the economics of retrofit of the buildings may not provide sufficient incentive to the owner to connect to the GDH system in many cases.

In the smallest buildings (<5000 ft^2), only in cases where the prospective GDH system is capable of offering heating costs which are substantially lower (40% to 50% lower) and where the building has high energy use and where the owner is using a high cost fuel (electric resistance or propane) can there be a reasonable expectation of connection. For those owners using higher cost fuels (propane and electric resistance) and having high energy use buildings, the prospects for favorable economics are present in buildings greater than 5000 ft^2. It is likely however that conversion to a more efficient or lower cost fuel heating system could be more attractive than connection to a district system in many cases. The prospects for competing with natural gas appear unfavorable in all cases. Clearly, other incentives (beyond energy cost savings) are required for the connection of small buildings to district systems.

These conclusions were based upon designs which resulted in minimum retrofit cost to the customer and the most optimistic assumptions as to what would constitute an attractive payback. In situations where the design would require a customer heat exchanger, a booster pump, an energy meter, domestic hot water retrofit (Table 1) or payback period requirements are shorter than 5 years, prospects for connection of small buildings will be less favorable than discussed in this paper.

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USE OF GEOTHERMAL ENERGY FOR TOMATO DRYING

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INTRODUCTION

Dehydration (or drying) of fruit or vegetables is one of the oldest forms of food preservation methods known to man. The process involves the slow removal of the majority of water contained in the fruit or vegetable so that the moisture contents of the dried product is below 20%. In the Mediterranean countries the traditional technique of vegetable and fruit drying (including tomatoes) is by using the sun, a technique that has remained largely unchanged from ancient times. However, on an industrial scale, most fruit is dried using sun (or sometimes solar drying), while most vegetable are dried using continuous forced-air processes.

Dried fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used, which depends on the type of food and the type of characteristics of the final product (Mujundar, 1988; Nijhuis, et al., 1998):

1. Sun drying. It is limited to climates with hot sun and dry atmosphere with strong winds. Typical areas with such climates are most of the Mediterranean regions, and most of the Aegean islands. Solar drying can be also used.
2. Atmospheric dehydration by passing heated air over the food to be dried.
3. Sub-atmospheric dehydration
4. Freeze-drying, for added value products, such as coffee.
5. Electromagnetic drying (e.g. microwave drying).
6. Drying using the osmotic phenomenon.

The two last methods have been tried experimentally for the dehydration of fruits and vegetables, but no commercial installation is in place. Although vegetable drying aims primarily at food preservation, food drying also lowers the cost of storing, transportation and packaging. Industrial drying is usually carried out with the second method in batch or continuous processes. Continuous processes include tunnel, fluidized bed, continuous belt and other driers. Tunnel driers are the most flexible and efficient dehydration systems and they are widely used in drying fruits and vegetables. Geothermal energy is a possible energy source for heating the drying air.

Drying of agricultural products is probably the most important industrial application of low or medium-temperature geothermal energy (40-150ºC). Fresh or recycled air is forced to pass through an air-water converter and to be heated to temperatures in the range 40-100ºC. The hot air passes through or above trays or belts with the raw products, resulting in the reduction on their moisture content. In geothermal drying, electric power is used to drive fans and pumps. Agricultural products that are dried using geothermal energy include (Lienau, 1998; Lund, 2000): onions, garlic, various fruits (apple, mango, pear, bananas, pineapple), alfalfa, grain, coconut meat, seaweed, timber, etc. The largest dryings units, which started in the 60s and 70s, deal with drying of diatomaceous earth in Iceland and timber and alfalfa drying in New Zealand. Worldwide, the geothermal energy used for agricultural drying represents about 0.5% of the total geothermal energy use at the beginning of 2000 (Lund and Freeston, 2001). Apart from a small pilot-scale cotton drier in N. Kessani (Perfecture of Xanthi), which operated for a two-month period in 1991 and demonstrated that geothermal drying is possible, no other application of geothermal drying has been reported in Greece.

This contribution describes the first example of geothermal tomato drying in Greece and discusses the possibilities of using geothermal energy for drying traditional agricultural products in the Aegean islands.

TOMATO DRYING

Tomatoes, as other vegetables, can be dried using various methods. In any tomato drying technique the required time for drying the product depends on many parameters such as tomato variety, the soluble solids content (ºbrix) of the fresh product, the air humidity, the size of the tomato segments, the air temperature and velocity and the efficiency of the drying system. The rate of drying affects the end quality of the dried product.

In general, dried tomatoes undergo the following process steps: predrying treatments, (such as size selection, washing and tray placing), drying or dehydration, and postdehydration treatments, such as inspection, screening and packaging.

Traditional sun-drying has the advantages of simplicity and the small capital investments, but it requires long drying times that may have adverse consequences to the product quality: the final product may be contaminated from dust and insects or suffer from enzyme and microbial activity. On the other hand, industrial drying under high temperatures (~90ºC) suffers from quality losses regarding color and aroma and may lead to case hardening (the formation of a hard outer shell), impeding the drying of the interior part of the product. It is obvious that the ideal conditions for drying tomatoes are mild temperatures between 45 and 55°C, which enable the dried product to retain its nutrients (including vitamins and lycopene, the nutrient responsible for the deep-red color of tomatoes) and flavors.

DESCRIPTION OF THE TOMATO DRYING SYSTEM

The complete tomato dehydration process can be divided into three stages: a pre-drying preparation step (pretreatment), the drying step, and the postdrying treatment, as illustrated in the schematic diagram of Figure 1. The predrying treatment prepares the raw tomatoes (in our case Roma variety, probably one of the most suitable varieties for drying) for the dehydration process. This step involves initially the selection of the tomatoes, regarding their maturity and soundness. About 40-70% of the tomatoes are selected to proceed for drying depending mainly upon the climatic condition during tomato growth and harvesting. The sorting of the tomatoes into two sizes is followed: tomatoes above 90 g and tomatoes of lower weight. The raw tomatoes are then placed in crates, washed to remove dust, dirt, plant parts etc, cut into two halves and placed into stainless steel trays (mesh type, 100×50 cm^2). It is noted that blanching of the raw tomatoes is not required because of the richness of tomatoes in antioxidants substances.

The drying step is carried out in a tunnel drier. This drying system consists of the following main components (Figure 2):

1. *Finned-tube coil air-water heat exchanger* (INTERKLIMA) for heating the drying air and having a capacity of 300,000 kcal. The 'cold' air enters the heat exchanger at atmospheric conditions (20-35°C) and leaves the exchanger at an almost constant temperature of 55°C. The incoming geothermal water a temperature is 59EC, while the temperature of the water at the outlet is 51-53°C. The mean water flow rate used during the first two drying periods was about 25 m^3/h. The geothermal water has a very low TDS and its does not cause any scaling or corrosion problems (Kolios & Sarandeas, 1992). The geothermal wellhead is located about 1400 m west of the drier and the geothermal water is transmitted in non-insulated PVC pipes having diameter 110 mm.

Figure 2. *Overview of building and drier (the long, light colored box)*

2. *Fan units.* Two fan units were installed in the system, totaling a rated power of 7 kW. During the operation of the drying system in 2001-2002 only a small part (~30%) of this power was used with the

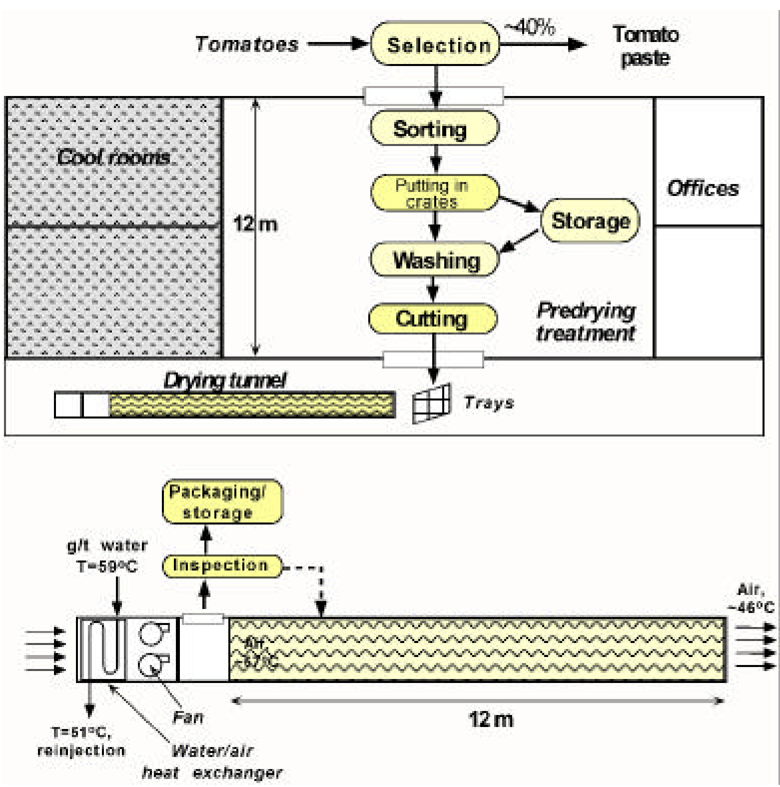

Figure 1. *Schematic diagram of the geothermal tomato drier system.*

aid of an inverter. The air flow rate in the tunnel was 10,000-12,000 m^3/h and the superficial air velocity in the tunnel (without the trays loaded with product) was 1.7 m/s. In the presence of the loaded trays that block partially the cross-section of the tunnel the air velocity increases by 20-50%, depending on the location inside the tunnel.

3. *Drying tunnel*. The14-m long rectangular tunnel (width 1 m and height 2 m) is constructed of polyurethane aluminum panels. A picture of the tray entry is illustrated in Figure 3a. The heated air flows counter-currently with regards to the trays in the tunnel. The tomato-loaded trays are placed at the entry of the tunnel and they are conveyed towards the end (where the hot air enters the tunnel) in a semi-continuous manner: approximately every 45 min a series of 25 trays with dried product are removed and 25 trays loaded with raw tomatoes are inserted at the entry and push the upstream trays toward the end. About 7 kg of raw tomatoes are placed on each tray. The profile of temperature with the height of the tunnel seems to be uniform, as deduced for temperature measurements at various heights and from the uniformity of the product drying regardless of the tray position.

4. *Measuring instruments.* The inlet and outlet temperatures of both air stream and geothermal water are continuously monitored using thermocouples. The moisture content is measured by weighing certain marked trays at various locations in the tunnel.

Figure 4. ***Detail of drying racks with tomatoes.***

The *postdehydration step* involves inspection and screening (the removal of dehydrated pieces of unwanted size, of foreign materials etc.) and packaging in glass jars with olive or sunflower oil, wine vinegar, salt, garlic and various herbs.

The solids contents of the Roma tomatoes range between 8 to 10% w/w and the moisture content of the final product is estimated to be about 10% (Figure 5). Accordingly, the weight of the processed product reduced about 10-12 times after drying. The removal of the moisture content appears to be faster at the first half part of the tunnel. The residence time of the product in the drier was 30 hours, adjusted by trial-and-error to achieve the best quality product. During that period about 4200 kg of raw tomatoes are introduced in the tunnel and the production of dried tomatoes reaches about 400 kg.

Figure 3. (a) Picture of the tunnel entry and (b) picture of the packaged product.

Figure 5. ***Final dried tomato product.***

Dehydration at 50-57ºC, i.e. at mild temperature conditions and for relatively long times, appears to retain the color and the aroma of the tomatoes, in contrast to the tomatoes dried in industrial driers (employing conventional fuels) using air temperatures higher than temperature 80ºC, shorter drying times and air recycling. Apart of the color preservation, mild drying conditions are supposed to reduce the isomerization of lycopene (Shi, et al., 1999; Zanoni, et al., 1998). Lycopene is the tomato nutrient responsible for the deep-red color of the tomatoes and it has been suggested that lycopene's antioxidant properties - the highest among those of all the dietary carotenoids - may explain its apparent ability to reduce an individual's risk of prostate and certain other cancers. It is reported that high drying temperatures lead to partial degradation of the nutrient through isomerization and oxidation reactions. Lycopene in fresh tomatoes is found as trans-isomer and isomerization converts all trans-isomers to cisisomers, which are less effective antioxidants.

During the first year of operation of the drying unit about 4 tonnes of dried product were produced, which was packaged in glass jars of various sizes. A picture of a glass jar with dried product is shown in Figure 3b. The dried product was sold in Greece and abroad as 'sun-dried' tomatoes. The geothermal energy use totaled 1 TJ, which represents about 0.5% of the total use of geothermal energy in Greece (Fytikas, et al., 2000). This energy use corresponds to ~22 TOE. In the summer and early fall of 2002, 5.5 tonnes of dried tomatoes were produced despite the rainy conditions during harvesting, which deteriorated the quality of the raw tomatoes and decreased considerably the selection rate. About 500 kg of the sun-dried tomatoes represented organic tomatoes which had to be transported to the geothermal plant from a distance of 200 km. Such a geothermal drying unit seems to be quite flexible regarding the product to be dried and many agricultural products can be dehydrated without major modifications. As an example, the unit was used successfully in May 2002 to dehydrate about 1 tonne of poorly dried figs. There are also thoughts to extend the drying period and dehydrate peppers and mushrooms. It is noted that the capacity of the unit (geothermal water, heat exchanger, air fans) is more than double of the 2001-2002 production.

POSSIBILITIES OF GEOTHERMAL DRYING IN THE AEGEAN ISLANDS

Greece, like several other Mediterranean countries, is rich in geothermal energy. In particular, in the Aegean island and coastal areas there are abundant easily accessible geothermal resources reaching almost 100ºC. A review of these resources can be found in Fytikas (2002). Islands with low and moderate temperature geothermal resources include Milos, Santorini, Kimolos, Kos, Nisyros, Evia, Chios, Lesvos and Samothraki. Consequently, there is considerable potential for meeting some of the drying requirements of several agricultural products by geothermal energy.

In Santorini Island (and in other islands in Cyclades) a special variety of small tomatoes (cherry tomatoes) is cultivated for many years. Part of the product is consumed as fresh vegetable, while another part is dried in the sun and is sold as delicatessen. Low-temperature geothermal energy can be used efficiently for dehydrating this variety of tomatoes in these islands. Geothermal drying can be partially substitute the traditional 'sun-drying' process and eliminate some of the quality problems of the dried products associated with this method. Geothermal water, with temperature as low as 60ºC, can be used to heat atmospheric air (to a temperature of 55ºC) in finned tube air heater coils (air-water heat exchanger). In case the geothermal water is corrosive, as is usually the case with the saline geothermal waters encountered in the Aegean region, a second water-water heat exchanger may be required, constructed of corrosion-resistant materials.

It appears that in Cyclades the only traditional agricultural product that can be dried is tomato, because the cultivation of other vegetables and fruits is limited. However, in Evia and the islands of Northern Aegean several fruits (apricots, prunes, figs), and vegetables (e.g. peppers, onions, garlic, asparagus, tomatoes and alfalfa – used for animal feeding) can be dehydrated using geothermal energy.

CONCLUDING REMARKS

In the summer of 2001, a new direct use of geothermal energy was demonstrated in N. Erasmio, Xanthi, dealing with the dehydration of tomatoes. It was shown that low-temperature geothermal energy can be used efficiently and reliably in heating the drying air needed in the dehydration process. With geothermal dehydration the product retains the deep-red color, the nutrients and flavors of the fresh tomatoes and high-quality "sun-dried" tomatoes are produced.

The success of the tomato drying will certainly lead to the extension of the unit regarding its capacity, drying period and drying crops (e.g. peppers, asparagus, figs and apricots). Geothermal drying of fruits and vegetables can be accomplished with water temperatures as low as 55ºC, something that is fulfilled by most low-enthalpy geothermal resources in Greece.

There is a large low-temperature geothermal potential in several Aegean Islands (Santorini, Milos, Kos, Chios, Lesvos etc.) that can be used for "sun-drying" of locally produced fruits and vegetables. In particular, geothermal energy drying of cherry-tomatoes seems to be a viable process in the Cyclades Islands, where this product is cultivated and served as a specialty. Other vegetables and fruits that can be geothermally dehydrated are apricots, prunes, figs and asparagus.

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SOL DUC HOT SPRINGS: THE RESORT THAT REFUSED TO DIE

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Figure 1. The main pool and lodge building.

Once the most noted pleasure and health resort on the Pacific Coast, Sol Duc has refused to die despite numerous disasters, including a fire that totally destroyed the resort in 1916 after only three years of operation.

However, the real story of Sol Duc Hot Springs begins in the early-1880s, when Theodore Moritz, a settler in the Quillayute Valley, found an Indian with a broken leg while out hunting. Mr. Moritz took the Indian home and cared for him until he was able to travel. Out of gratitude, the Indian told Mr. Moritz of some curative "fire chuck" (hot water) that bubbles from the ground and which the Indians had used for years to cure their ailments. After the Indian had led him to the site, Mr. Moritz returned to build a cabin and to file a claim on the property with the U.S. Land Office. Word spread rapidly and soon people were making the hard, two-day trip on horseback from Port Angeles.

In 1903, Michael Earles, owner of the Puget Sound Mills and Timber Company, accompanied a group of people to the spring--Mr. Earles had been told by his doctor that he was dying and to go to Carlsbad but he was too weak for the journey. The mineral water at Sol Duc cured him. Wanting to create a place where others could also be helped, Mr. Earles purchased the site from Mr. Moritz's heirs in 1910 and founded the Sol Duc Hot Springs Company with four other men.

The company built a road at a cost of $75,000 to make access to the site easier and constructed a health resort at a cost of over a half million dollars. The resort opened on May 15, 1912 and consisted of a four-star hotel with 165 guest rooms, each with an outside view, electric lights, hot and cold running water, telephones and steam heat. The main part of the hotel was 80 ft wide by 160 ft long with a wing 100 ft long. A sawmill had been constructed on site to supply the lumber for the hotel and other assorted buildings.

The most notable of the other buildings was the three-story sanatorium situated between the hotel and the bathhouse. There were beds for 100 patients, and facilities included a laboratory, operating room and x-ray. There was a 45-ft x 200-ft bathhouse and a gymnasium. Patients drank the mineral water and bathed in the waters in the tubs. Showers, mud or vapor baths were also available, as well as Turkish and electric baths.

Other facilities at the resort included an ice plant, powerhouse steam laundry buildings to house workers, cabins and a campground. Guests could use the golf links, tennis courts, croquet grounds, billiard rooms, bowling alley and theater, or enjoy dancing or games of poker in the evening. For the more adventurous, mountain trails were built and saddle horses, packhorses and equipment were provided to take guests on hunting or fishing trips, or just for a scenic ride.

HISTORICAL PHOTOGRAPHS OF THE RESORT

Courtesy of U.S. Park Service,
Burt Kellog Collection.

The resort really was the place for health, fun, rest and relaxation. It attracted guests from all over the United States and from as far away as Europe. In its first year of operation, over 10,000 guests visited the resort, many of them making the six-hour steamboat trip aboard the Sioux or Sol Duc from Seattle to Port Angeles. Once in Port Angeles, they were transferred to one of several large red Stanley Steamer automobiles that drove the 19½ miles to East Beach or Lake Crescent. The passengers were then ferried across the lake on the Steamboat *Betty Earles* to Fairhaven; where, more Stanley Steamers transported them the remaining 15 miles to the resort.

Tragically, on the afternoon of May 26, 1916, after only three years of operation, sparks from a defective fire lit on the shingle roof of the main hotel building. The caretaker tried to put out the blaze but discovered that the water had been turned off for the winter. Winds blew sparks to the adjoining buildings. The fire short-circuited the organ, which played Beethoven's "Funeral March" until the wires burned out, silencing it. Within three hours, the Northwest's finest resort hotel and spa was in ashes. Insurance was insufficient to begin to rebuild and Michael Earles died in 1919.

In 1925, a gentleman by the name of Fred Martin bought the estate and constructed a lodge, two pools and 40 cabins--a far cry from the original splendor (Figure 1).

Over the years, it is reported that the site housed a successful bootlegging operation during Prohibition. At a later time, a motel was added, as were facilities for camping and recreational vehicle parking. In 1966, the resort was purchased by the National Park Service and became part of the Olympic National Park. A concessionaire was brought in to operate the resort.

By the mid-1970s, the resort was once again in trouble. This time it was the thermal waters. Flow into the hot water pool had diminished to the point that health officials required that the water be treated. Attempts to add chlorine or iodine to the water proved to be very unsuccessful due to the presence of barium that resulted in a chalky white or red precipitate. Unable to continue to use the natural thermal waters, the conservationists decided to heat fresh water in a propane-fired boiler. This proved very unsatisfactory to guests who were, after all, visiting the resort due to the therapeutic value of the natural thermal waters.

Figure 2. The geothermal soaking pool.

Attempts to locate additional sources of water also proved to be unsatisfactory and after spending hundreds of thousands of dollars in various attempts to restore the thermal water, the resort was rapidly heading toward financial ruin. In 1979, while the author was taking routine samples of the thermal waters for chemical analysis, it was discovered quite by accident that the cistern from which the thermal waters flowed was filled nearly to the surface with a vermiculite filter material. When the author inquired as to the origin and purpose, it was learned that it was simply a convenient way to dispose of a "waste product." The decision was made to see if pumping all of the material out of the cistern wall would improve the natural artesian flow into the pool. This turned out to be so successful that not only did the resort once again survive, it was totally rebuilt during the 1980s with new cabins, a new thermal pool and assorted facilities, and is yet once again one of the most popular thermal spa resorts in Washington State, having been visited by more than 50,000 per year. Unfortunately, we can only dream about the past grandeur when Sol Duc Hot Springs was the destination resort and spa.

Three main springs with temperatures up to 56ºC (133ºF) are piped into the soaking and swimming pools. The main pool is a large swimming pool, chlorinated and kept around 26ºC (79ºF) with heavy infusions of river water. There are also three small circular pools at one end of the swimming pool. These are not chlorinated and are maintained at temperatures of about 36 to 41ºC (97 to 106ºF). There are benches to hold about two dozen people and one pool is suitable for small children. The hottest pool has a little geyser sprouting out of the center (Figure 2). There is a poolside snack bar and deli on the end of the cedar built lodge. Housekeeping cabins (Figure 3) and RV hookups are available. The resort is located in the Olympic National Forest; so, there are good hiking trails and campgrounds nearby.

Addition information on Sol Duc can be obtained by calling 360-327-3583 or visiting their website at www.northolympic.com/solduc/.

Figure 3. Housekeeping cabins for rent.

HOT SPRING RESORTS IN THE CANADIAN ROCKIES

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According to Woodsworth (1997), there are approximately 110 known hot and warm spring in Canada, most in British Columbia and the remainder in other western provinces. His preface states:

> *"These springs, which are often in spectacular surroundings, include steaming pools, reach after a long hike up a mountain valley, tide-washed streams where you can dangle your toes in the ocean while you stay deliciously warm, rustic wooden pools beside gravel roads, and fully developed commercial resorts."*

This article will describe several of the main commercial hot spring resorts located in or near the Canadian National Parks in Alberta and British Columbia, along or adjacent to the Rocky Mountains. Four of these were visited by the author and his family during the summer of 2002. Information on the Canadian Rockies Hot Springs consisting of Banff Upper Hot Springs, Radium Hot Springs and Miette Hot Springs can be obtained from their website: www.parkscanada.gc.ca/Parks/enterprice/hotsprings/english/, or by writing: Box 900, Banff, Alberta, Canada T1l 1K2. These hot spring pools and resorts are located in Banff National Park, Kootenay National Park, and Jasper National Park, respectively, and are the members of the Canadian Rockies Hot Springs group.

BANFF HOT SPRINGS

There are actually several hot springs in the city of Banff, located in Banff National Park. The local Blackfoot Indians named the area Nato-oh-sis-koom, meaning "holy springs." The name Banff was provided by Lord Strathcona, a promoter of the Canadian Pacific Railway, after his birthplace in Scotland (Woodsworth, 1997). There are four hot springs located adjacent to the Bow River in Banff. The first hot springs developed at Banff were the Cave and Basin hot springs. Cave Spring is accessed through a tunnel to a 6-m (20-foot) high cave. This circular pool, about 12 m (40 feet) across, has a maximum water temperature of 31ºC (88ºF) with a strong sulphur smell. Originally, the cave ceiling was covered with stalactites, but all have been taken by souvenir hunters. The pool is no longer used.

The Basin Spring was the original bathing pool at Banff; however, swimming has been prohibited since 1971 as the water cannot be properly chlorinated. The pools is about 8 m by 12 m (25 feet by 40 feet) with water temperature of 35ºC (95ºF). The water is a clear blue with water and gas bubbling from the bottom.

A large concrete pool as part of an aquacourt, and the largest in Canada when it was opened in 1914, was fed by water from the Cave and Basin Springs and supplemented from two small springs on the slope above the pool. It was closed in 1993, due to deterioration, decrease in attendance and policy change by Parks Canada.

These springs, first visited by Europeans in 1859, were development starting around 1883. Due to private claims to the title of the springs, the Canadian government decided to set aside the Banff springs and surrounding land as a park reserve. Thus, Banff National Park was formally created in 1887, as the result of a dispute over the ownership of the springs.

BANFF UPPER HOT SPRINGS

This is a commercial pool located above the town of Banff on the slopes of Sulphur Mountain and according to Woodsworth (1997), *"is probably the most popular hot spring pool in the Canadian Rockies."* The spring, at its maximum recorded temperature of 47ºC (117ºF) is the warmest at Banff, and the pool, kept at 40ºC (104ºF), is open daily all year round.

The Europeans first visited the Upper Hot Springs in 1884, and in 1886 the first log shack and the Grand View Villa and bathhouse, later know as the Grand View Hotel, were built. The Grand View Villa was destroyed by fire in 1901, rebuilt and burns again in 1931. The Canadian government then took over the facility and opened the present bathhouse, complete with sulphur water swimming pool, plunge baths, steam rooms, tubs, showers and dressing rooms in 1932. The bathhouse was restored in 1995 to its 1930s appearance, and period bathing suits are available for rent. Almost half a million visitors use the pool annually. Additional historical information can be obtained from the Parks Canada website: (www2.parkscanada.gc.ca/ parks/ enterprise/hotsprings/english/history_e.htm).

Water from the spring was also piped to a privately owned bathhouse and hotel near the site of the present pool building. Water also went down the hillside to Banff Springs Hotel, which opened in 1888, and to Dr. Breet's sanatorium near the bridge across the Bow River. In general, the upper springs were thought to have greater curative powers than the other springs, probably due to the higher temperature and mineral content (Woodsworth, 1997). At present, only the pool uses the spring water.

The springs flows over a small brick wall on the road up to the pool, forming an extensive orange tufa bench (Figure 1). Flowing at a maximum of 11.4 L/s (180 gpm), the temperature in late fall and winter is about 41ºC (106ºF), and during spring runoff can be as low as 33ºC (91ºF). During droughts, the flow is lower and in winter they have trouble meeting the heat demand for the pool, thus supplemental heating is then used to boost the temperature. The water is piped from the spring to the building, where it is chlorinated and filtered before going to the swimming pool. The water has about 1,677 mg/L (ppm), mainly sulphate.

Figure 1. The springs at Banff Upper Hot Springs.

The pool is outdoors in a spectacular forest setting looking down the Bow Valley and across to Mt. Rundle, which dominates the view above Banff. The irregularly shaped pool is approximately 25 m long and 10 m wide (80 ft by 30 feet) (Figure 2). The facility also has a spa with steam room, massage studios and aroma-therapy treatments, gift shop, a 35-seat restaurant and snack bar. For more information call: 1-800-767-1611 (toll-free from Canada and the U.S.), direct phone at 403-762-1498, or use the Parks Canada website.

Figure 2. Banff Upper Hot Springs Pool.

RADIUM HOT SPRINGS

The springs are located east of the town of Radium Hot Springs, about one kilometer after passing through the narrow Sinclair Canyon. The aquacourt consists of two open-air pools, one hot and the other warm (39º and 29ºC - 103º and 84ºF respectively). The springs are located in the canyon of Sinclair Creek and enter in the center of the hot pool. The water contains 700 ppm of solids, mainly sulphate, bicarbonate and calcium. The name of the springs comes from small traces of radon found in the water that is radio-active. The radioactively is too weak to be harmful, and is much less than that given off by an ordinary watch dial. At one time, in the early 1900s, a scheme to bottle and sell the water was almost carried out, as it was thought to have therapeutic and medicinal value.

These springs were used by the Kootenai Indians for centuries before the coming of the Europeans in the 1840's (Zieroth, 1978). The first recorded visit by Europeans was by Sir George Simpson, the governor of the Hudson's Bay Company in 1841. He bathed in a one-person sized pool dug out of the gravel. James Sinclair, a guide for the Hudson's Bay Company, followed Simpson on his way to Oregon with a group of Red River Settlers several weeks later. The first legally registered owner was Roland Stuart, an Englishman, who purchased the springs in 1890 for $160 and owned them until 1922. A concrete bathing pool, log bathhouse, small store and a home for the caretaker were built in 1914. The springs were key in the formation of the Kootenay National Park, adjacent to and west of Banff National Park, and were expropriated for inclusion in the park in 1922 (Parks Canada information sheets).

A new bathhouse was built in 1927 and the pool extended. The construction of the Aquacourt was begin in 1949 and completed in 1951 at a cost of almost one million dollars, after a fire that destroyed the facility in 1948. A new hot pool replaced the original 1919 pool in 1968, and the cool pool was refitted with a new smooth vinyl liner in the summer of 1996. Renovation of the main building began in 1997 and now contains Park Information and Registration, expanded food and retail services, improved spa facilities (Pleiades Massage and Spa), and the source of the spring is again visible. Presently, approximately 3,000 people use the facility a day, and 400,000 a year.

The cool pool, adjacent to the main building, is a 24-m long (79-ft) rectangle and 1 to 3 m (3 to 10 ft) deep (Figure 3). Hot water is cooled with creek water to 29ºC (84ºF), just right for lap swimming. The large hot pool, Canada's largest hot springs pool at about 100 m long, is situated at the end of the main building, is a constant 1.5 m (5 ft) deep with a concrete sloping end to relax on (Figure 4). A round fountain in the middle is the source of the spring water. The buildings and shower water are also heated with geothermal energy through two plate heat exchangers (Figure 5). Base board, ceiling forced air and radiant floor heating systems are all used in the facility. The manager , Scott Turnbull, reports that it costs $1,000 per day for heating when the geothermal system is shut down. The entire facility sits in a narrow canyon - with hiking trails that provide a beautiful view down on the pools and towards the town of Radium Hot Springs. The pools are open year round. Additional information can be obtained by calling 1-800-767-1611 (toll-free from Canada and the U.S.), direct phone at 250-347-9390, or be searching the Parks Canada website.

Figure 3. The cool pool at Radium Hot Springs.

Figure 4. The hot pool at Radium Hot Springs.

Figure 5. The plate-heat exchangers at Radium Hot Springs (Thomas Lund).

MIETTE HOT SPRINGS

These springs are the hottest in the Canadian Rockies (55°C - 131°C). Little is known of the early use of the three hot springs located in the narrow valley of Sulphur Creek, but they were likely first used by the local Indians who in turn introduced them to members of the Hudson's Bay and North West Companies in the 19th century. The coal-mining and construction town of Pocahontas was built in 1909, and a crude pack trail accessible by horse or on foot was blazed to the site in 1910. This was not a trail for the faint-hearted as several died on the trail from over exertion. A makeshift log bathhouse and sleeping shelter was built in 1913, and by 1919 a temporary bathhouse and two sweathouses were built by striking coal miners.

In 1932, a road from Pocahontas to the springs was opened to the public at infrequent times. An aquacourt was built from 1936 to 1938, and the road upgraded. Built as a Depression unemployment relief project, the aquacourt consisted of a concrete pool and bathhouse (Figure 6). Several hundred men worked on the access road, parking lot, campground and aquacourt. During WWII, use was restricted to those with a doctor's certificate, but full public access resumed in 1945 (Woodsworth, 1997).

Figure 6. Remains of the original aquacourt.

In 1984, the aquacourt was permanently closed because of unstable slopes in the narrow canyon, deteriorating concrete, over crowding, poor access, and aging equipment. The facility was moved approximately one km down to the mouth of the canyon where more space was available. The new facility, consists of three pools, changing room and café (Figure 7). There is also a private restaurant and motel just below the facility. When my family visited the pools, there were "wild" mountain sheep wandering all through the parking lot and on the grounds.

Figure 7. Miette Hot Springs building.

The water is high in dissolved solids at 1,798 mg/L (ppm), flowing at a rate of 25.7 L/s (407 gpm). The water is high in calcium, sulphate, bicarbonate and magnesium and has a strong hydrogen sulfide (rotten egg) smell. You can still walk up the narrow canyon to the ruins of the old aquacourt and see the source of the springs. The spring water is collected from three vents, the first at the old pool site, the second under the boardwalk and the third on the far side of sulphur creek (the hottest) (Figure 8). This combined water is piped into a prechlorinating tank, then sent into a precipitant tank, located in the basement, where the sulphur settles out. From there chlorine is added again and sent to the pool. The used water is then dechlorinated and sent back into the creek. The water is also passed through a plate heat exchanger and used for the domestic hot water and radiant floor heating (Figure 9).

Figure 8. ***The hottest spring in Sulfur Creek.***

Figure 9. ***Plate heat exchangers in the basement of the resort.***

There are three pools, two at 39°C (102°F), one with a handicap ramp for wheelchair access, and a cold pool (Figure 10). Due to the difficult access from the main highway, the resort is closed in the winter, and in fall and spring it is not unusual for guests to be stranded for several days due to sudden snow storms. The normal operating period is mid-May to early October. It is located 46 km (28 miles) east of Jasper on Highway 16, and then 17 km (11 miles) south on a winding paved road through beautiful country. You can call the Jasper National Park for additional information to 1-800-767-1611 (toll free from Canada and the U.S.) or access the Parks Canada website. The direct number to the resort is: 780-866-2233.

Figure 10. ***The hot pool at Miette with the handicap ramp on the right.***

FAIRMONT HOT SPRINGS RESORT

This is one of many commercial hot spring resorts in Canada, located south of Radium Hot Springs on Highway 93 on the west side of the Rocky Mountains. The hot springs water issue from two main areas: from the original bed of Fairmont Creek which is piped to the swimming and soaking pools in the resort; and a group of springs on a little knoll above the resort called the "Indian Baths." These waters average 42°C (108°F) and are cooled with creek water as needed, chlorinated and piped to the pools. The spring water has a total solid content of 2449 mg/L (ppm) consisting mainly of calcium bicarbonate, calcium sulphate, and magnesium sulfate with a small amount of dissolved radium.

There are three outdoor public pools, covering about 930 m^2 (10,000 sq. ft.), making it the largest hot spring pool complex in Canada (Woodsworth, 1997) (Figure 11). The largest pools has lanes for swimming at a temperature of about 31°C (88°F), a diving pool at the same temperature, and a soaking pool at 40°C (104°F). Another pool, reserved for those staying at the resort, is kept at 40°C (104°F). The "Indian Baths" consists of a bathhouse set on top of a colorful tufa mound that has three individual bathing rooms, each with its own entrance (Figures 12 and 13). Each room has a bathtub and bench for changing or sitting. Water is piped into each bathtub and then drains at the other end. The temperature of the water can vary. There are also several small two-person pools dug out of the tufa on the plateau behind the bathhouse. The outflow from the bathhouse and springs (recorded as high as 49°C - 120°F) coats the hills with new tufa and orange, brown, green and blue algae.

Figure 11. ***View looking east of the Fairmont Hot Springs' pools.***

Figure 12. ***"Indian Baths" bathhouse and tufa mound.***

Figure 13. ***One of the baths in the "Indian Baths" bathhouse (Thomas Lund).***

The history of the resort development is described in the brochure: "The History of Fairmont" (undated) issued by the resort and in Woodsworth (1997). The early history of the hot springs include use by the local Indians. Recorded history first mention a visit to the hot springs by Sir George Simpson in 1841. The first homesteader in the area was George Geary, an Englishman in 1887. His vast homestead included the hot springs, but he soon tired of the lack of night life, thus in 1888 he turned his holding over to Sam Brewer from the U.S. who built a stage stop on the property. The name Fairmont was given to the place by Mr. John Galbraith, wife of a ferry operator in the area after her father's home in West Virginia. The property was then purchased by W. Heap Holland, a manufacturer from Manchester, England who operated it as a ranch and resort. In 1923 he diverted the hot springs in Fairmont Creek and built the first swimming pool on the site of the present pools. He also built a restaurant, tent camp, bungalows, and the bath house on the hill to be used by the native people free of charge. He changed the name to Radium Hot Springs. In 1957 Earl and Lloyd Wilder purchased the property with a group of investors. A major expansion resulted with a golf course in 1965, a ski hill in 1969 and the present pool and lodge built from 1969 to 1972. The name was changed back to Fairmont. Today the resort is visited by half a million people annually. The resort can be contacted toll free at 1-800-663-4979 or through their website: www.fairmontresort.com.

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NEW GEOTHERMAL SNOW MELT PROJECT IN KLAMATH FALLS, OR

Tonya L. Boyd
Geo-Heat Center

The Wall Street bridge and approach street leading to the front of Klamath Union High School is in the process of being replaced. The project is a joint effort by the Oregon Department of Transportation (ODOT) and the city of Klamath Falls. The replacement of the bridge and approach road will incorporate a deicing system using geothermal for the street, bridge and sidewalks. This is the second bridge project in Klamath Falls, which will utilize geothermal for snowmelting.

The geothermal heat will be provided by the city of Klamath Falls District Heating System. A separate heat exchanger has been installed in the city's heat exchanger building for the Wall Street Project, which will tap into the geothermal return water before it is injected into the ground. The heat exchanger will transfer heat to a 35% propylene glycol solution, which will be circulated in a closed loop to the approach road and bridge.

The geothermal water side of the heat exchanger will enter at about 150ºF and leave at 100ºF. The flow rate is 40 gpm. A 1/3-hp pump has been installed. The glycol solution side of the heat exchanger will enter at about 100ºF and leave at about 130ºF. A ½-hp pump has been installed in that side to circulate the solution.

The pipeline consists of a 4-in. high density polyethylene (HDPE) pipe when it leaves the building, then transitions into a 3-in. HDPE pipe at the approach road to the bridge. The system has been designed for further snowmelt expansion in the area. The approach road and bridge is about 1/4 of a mile from the heat exchanger building.

The glycol solution will be pumped through the tubing in the bridge deck and approach road. The tubing is Wirsbo 5/8-in ID HePEX (a cross-linked polyethylene) which was used on the other bridge deck. The system will run continuously during the winter season.

The loop system for the bridge will be placed longitudinally with the bridge on the approach road side. The loops are attached to the reinforcing steel of the bridge by wire at approximately 8 in.on center.