

# BALNEOLOGICAL USE OF THERMAL WATERS

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## PART 1: "TAKING THE WATERS" - INTRODUCTION TO BALNEOLOGY

### Background

People have used geothermal water and mineral waters for bathing and their health for many thousand of years. Balneology, the practice of using natural mineral water for the treatment and cure of disease, also has a long history. Based on archeological finds in Asia, mineral water has been used for bathing since the Bronze Age, about 5000 years ago. Many hot springs have been used in connection with religious rites in Egypt and by the Jews of the Middle East. The Greeks, Turks and Romans were famous for their spa development and use from Persia to England. The word "spa" traces its origin to a town near Liège in southern Belgium near the German border. Here a spring of iron-bearing water was used by an iron master in 1326 to cure his ailments. He founded a health resort at the spring called Espa (meaning fountain in the Walloon language). Espa became so popular that the word know in English as spa became the common designation for similar health resorts around the world (Lund, 1996).

Great spas have a long history, often stretching back to Roman times. Bath in England, for instance, was originally known as *Aquae Sulis*, Baden-Baden in Germany as *Aquae Aureliae*, and Aix-les-Bains in France as *Aquae Allobrogum* (Rockel, 1986).

Today, especially in Europe and Japan, the use of medically supervised spas has long been accepted. They are used for both treatment and preventive therapy. The former Soviet Union had 3500 spas and some 5000 reconditioning centers all administered and run by the state. In the former Czechoslovakia, there are 52 mineral water health spas and more than 1900 mineral springs, which every year about 220,000 citizens are granted free spa treatment for three weeks, paid by the national health insurance program. The more famous ones are Karlbád in the present Czech Republic and Piešťany in Slovakia. Many of these spas are being privatized today, and are dependent on income from visits by persons from outside the country. In Rotorua, New Zealand, the Queen Elizabeth Hospital used various mineral waters and hot springs muds to help soldiers from the WWII Pacific wars recuperate from battle injuries. In Japan there are over 1500 spas that are used by over 100 million visitors every years. Some of these international uses have been documented by Hotta and Ishiguaro (undated), Lund (1992 and 1996,) in "Stories form a Heated Earth" (1999), and the Geo-Heat Center Quarterly Bulletin (1993).

The Indians of the Americas considered hot springs as sacred places and believed in the healing powers of the heat and mineral waters. Montezuma, the great Aztec leader, spent

time at a spa, Aqua Hedionda, to recuperate from his strenuous duties; which was later developed into a fashionable spa by the Spaniards (Salgado-Pareja, 1988). Every major hot spring in the U.S. has some record of use by the Indians, some for over 10,000 years. These springs were also known as neutral ground, to which warriors could travel and rest unmolested by other tribes. Here they would recuperate from battle. Today, there are approximately 210 spas in the USA with 4.5 million persons attending a spa in 1997. Details on the U.S. use of mineral waters and hot springs can be found in Part 2: Balneological Use of Thermal Waters in the USA in this publications.

Improving your health and your appearance, and getting away from stresses to refresh and revitalize your body and your mind are the main reasons why people go to spas and why spas are becoming an increasingly important part of American life. The 7-day miracle, as some refer to a week's spa vacation, provides you with a necessary interlude to change your pace of life and your way of being, to lose weight, shape up, reduce stress, gain confidence, reassess your goals, recharge your vitality, learn new exercise and nutrition behaviors, reward yourself with time out for yourself--and have a good time, a carefree holiday (Van Itallie and Hadley, 1988)

### What is a Spa?

The word "spa" is also used as a Latin abbreviation for: S = *salud*, P = *per*, A = *aqua*, or "Health through Water." In Germany, they refer to the "Kur," which does not mean just a cure, but instead is a series of treatments over time including baths, taking (drinking) water, massage, exercise, mud baths, etc.

For the sophisticated European of the nineteenth century, a spa was much more than just a health resort. The famous spas of France, Germany and Britain were elegant social and cultural centers. Most who took the cure ["kur"] did not do so primarily for medical reasons, but to see and be seen by high society (Rockel, 1986).

Other definitions include ( DeVerville, 1998):

"The spa is the social aspect of using water therapeutically."

"The spa is a natural space and place with a perspective on time."

"A spa is a space with a purpose, through a plan, by a purpose, for a period of time."

Spas today can have many forms and emphasize certain treatments. Sarnoff, (1989) classified American spas as follows:

1. Intensive fitness spas - where fitness buffs can trim and tone “to the max” in minimum time.
2. Rejuvenation spas - where you can take advantage of the latest beauty treatments for a younger-looking you.
3. Weight-loss spas - where you can vacation and shed those unwanted pounds at the same time.
4. Athletic camps - where excellent sports programs and exercise classes can be had at a very affordable price.
5. Mineral springs or “magic mud” resorts - where health-giving waters and the oldest, most aristocratic spa traditions await you.
6. New Age retreats - where you can renew your psychic and spiritual self as well as physical well-being.
7. Gustatory hideaways - where you can enjoy and learn about the best in healthful, nonfattening, gourmet fare.

Thus, in summary the purpose of a spa is to provide (DeVierville, 1998):

1. Water (therapeutic through heat and minerals, including muds)
2. Movement (exercise, massage and fitness)
3. Herbal (medical benefits)
4. Dietary (proper food and drink)
5. Life style pattern.

And a spa, to be successful, must have (DeVierville, 1998):

1. Hygiene (cleanliness)
2. Service
3. A unique attractions, such as scenery, special water, special mud, special cure, special food, unique location, unique facility, etc.

#### **Planning and Developing a Spa (DeVierville, 1998)**

A spa plan must have the following for a successful development:

1. Vision
2. Mission
3. Goals
4. Objectives
5. Strategies (how to accomplish the plan)

The categories and dimensions that are part of a spa and should, for the most, be incorporated into its development are:

1. Natural, environmental, ecological
2. Medical, psychological, therapeutic
3. Scientific, technical, research

4. Economical, financial, managerial
5. Planning, architectural, building
6. Social, fashionable, gastronomical
7. Artful, historical, literal
8. Spiritual, mystical, religious

Finally, the items necessary for a spa are:

1. Water
2. Food or nutrition
3. Exercise or movement
4. Massage or body work
5. Mind-body -- physiological
6. Natural therapeutic agents (muds)
7. Environment - area, climate
8. Cultural aspects
9. Management and staff (marketing)
10. Life style patterns or rhythms (time).

#### **Water and Muds**

A spa originates at a location mainly due to the water from a spring or well. The water, with certain mineral constituents and often warm gives the spa meaning from one or more of the following points of view (DeVierville, 1998):

1. Religious, mythical, symbolic
2. Social, political, economic
3. Aesthetic, artistic, literary
4. Philosophical, scientific, technological and medical.

Associated with most spas are the used of muds (peloids) which either are found at the site or are imported from special locations. As an example, at Pieštany in Slovakia, there is a special laboratory that test muds or clays for their mineral content and their therapeutic benefits. The muds are stored in tanks and “cured” for maximum benefit.

The three classification of muds are:

1. Pure mineral (fango, mud) - neutral
2. Mainly mineral (sea mud or liman) - alkaline
3. Mainly vegetable peloid (moor, peat) - acid

The spas at Calstoga, California, use a mixture of volcanic ash and peat moss for their “muds” (Lund, 1979).

The skin effects of mud are:

1. Increase the body temperature
2. Lowering of blood pressure
3. Influence on mineral metabolism and blood chemistry

Even though hot mud packs have been touted for many ailments, the recommended uses for local treatment are (DeVierville, 1998):

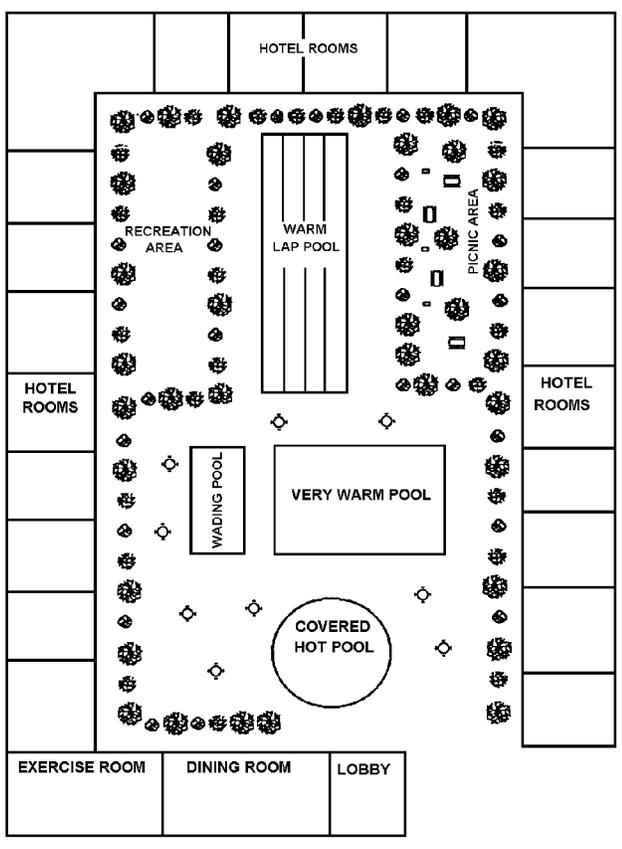
1. Chronic arthritis
2. Fibrositis
3. Neuritis, sciatic syndrome

4. After treatment of fractures
5. Sport and industrial injuries.

### Typical Spa Design

There are many types of designs for spas, depending upon the local culture, the unique character of the location, and what the developer is trying to achieve in terms of atmosphere, service and type of clientele. Two basic types, with an emphasis on the use of geothermal water will be presented here.

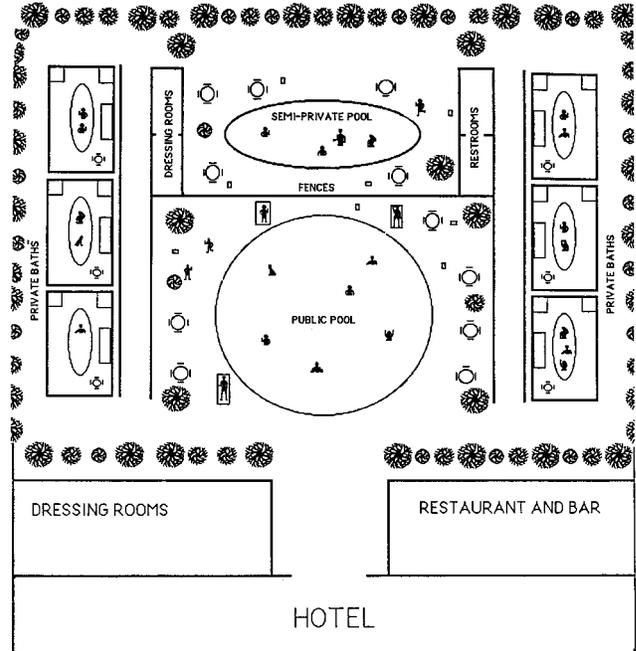
The first (Fig. 1) is one originally proposed for Hawaii (Woodruff and Takahashi, 1990) and is similar to ones in Calistoga, California. This design which includes living quarters surrounding the various bathing and soaking pool, lends itself to feature native plants and material in the landscaping and construction. Also, food and drink can be provided, along with small shops and a fitness room for a health and fitness program. The enclosed pool area would provide privacy, but also allow easy access to and from the living area.



**Figure 1.** *General scheme of a modern geothermal spa located in California (Woodruff and Takahashi, 1990).*

The second design (Figure 2) was also proposed for Hawaii (Woodruff and Takahashi, 1999). This design emphasizes private, semi-private and public bathing and soaking facilities. This is also typical of the design for the Polynesian Pools in Rotorua, New Zealand. This design does not include living quarters, but these could be added at a separate location and could be individual cottages. The semi-

private and private pools could then be used by a single family and rented on a hourly basis. This would also be appropriate in cultures where bathing in public is less accepted.



**Figure 2.** *Design for a geothermal spa offering private, semi-private, and public bathing facilities (Woodruff and Takahashi, 1990).*

Both of the above designs could be uncovered, completely enclosed or each individual pool covered with a temporary roof for use in inclement weather. Uncovered pools are extremely popular in the evening under a star-lite sky.

### Twenty-Five Reasons to Go to a Spa

1. To live up to your potential both physically and mentally,
2. To minimize the effects of aging,
3. To establish new eating habits,
4. To feel healthier,
5. To feel happier,
6. To tone up,
7. To reduce weight,
8. To quit smoking,
9. To quit drinking,
10. To look more attractive,
11. To increase athletic skills,
12. To prevent diseases,
13. To help cure common ailments,
14. To treat specific male or female problems,
15. To stretch your body,
16. To stretch your mind,
17. To eliminate or reduce stress,
18. To have fun,
19. To meet people ("plug in" socially),
20. To achieve a better body and more balanced personality,
21. To be pampered,
22. For family togetherness,

23. For individual activity,
24. For solitude, and
25. For relaxation.

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## PART 2: BALNEOLOGICAL USE OF THERMAL WATER IN THE USA

### Introduction

In the United States, the use of natural springs, especially geothermal ones, have gone through three stages of development: (1) use by Indians as a sacred place, (2) development by the early European settlers to emulate the spas of Europe, and (3) finally, as a place of relaxation and fitness.

The Indians of the Americas considered hot springs as a sacred place of Wakan Tanka ("Great Mystery" or Great Sacredum" in the Lakota language) and thus, were great believers in the miraculous healing powers of the heat and mineral waters. Every major hot springs in the U.S. has some record of use by the Indians. They were also known as neutral ground, where warriors could travel to and rest unmolested by other tribes. Here they would recuperate from battle. In many cases, they jealously guarded the spring and kept its existence a secret from the arriving Europeans for as long as possible. Battles were fought between Indians and settlers to preserve these rights. The early Spanish explorers such as Ponce de Leon and Hernando DeSoto were looking for the "Fountain of Youth," which may have been an exaggerated story of the healing properties of one of the hot springs.

The early European settlers in the 1700 and 1800s, found and used these natural hot springs, and later realizing their commercial value, developed many into spas after the tradition in Europe. Many individual developments were successful such as at Saratoga Springs, New York; White Sulphur Springs, West Virginia; Hot Springs, Virginia; Warm Springs, Georgia and Hot Springs, Arkansas. However, the U.S. did not have the government, trade unions, social security and a national health insurance program to support these developments. Thus, in spite of the benefits of spa therapy that had been proven successful in Europe and elsewhere in the world, the U.S. lagged behind in the development of these mineral springs even though some were acquired by state and the federal government. By the 1940s, the interest in spas languished, and most of the majestic resorts went into decline and closed.

The health and fitness industry has recently been stimulated by increasing consumer interest worldwide, resulting in high growth in revenues and profits. The industry in the U.S. exceeded 835 billion in revenue in 1984. Health spas and resorts, representing a major part of the health and fitness industry, have grown in popularity and offer high investment potential in the United States. Revenues from spas in the U.S. presently are estimated at \$10 billion annually. The number of spa-goers is projected to grow from 31% of the adult population in 1987 to 45% in 1997. The most traditional type of health spa is the geothermal spa, featuring baths and pools of natural hot mineral waters.

This recent interest in hot springs soaking and physical fitness has renewed the development of spas in the United States. This natural way of healing and the "back to nature" movement has in many ways rejected formalized spa medical treatment developed in Europe. In fact, the average person in the United States knows little of spa therapy and its



Interest in spas in the U.S. was not entirely lacking after the turn of the century, as both the federal and state governments became owners and managers of several important ones. Five examples follow (Fig. 1)(Lund, 1996).

**Saratoga Springs, New York**, located 250 km north of New York City, had approximately 18 springs and hot wells discharging 13°C carbonated mineral water along a fault. The Mohawk and Iroquois Indian tribes frequented the springs during hunting trips in the area. The first written report of the springs by European settlers was in the early 1600s (Swanner, 1988). Since this time, the springs have been used for drinking and bathing, to cure everything from skin disorders to digestive problems. The water and carbon dioxide has also been bottled and sold as a commercial product. Because of use and decline in flow in the springs in the early 1900s, the state of New York formed Saratoga Spa State Park, and now manages the geothermal activity including the only spouting geyser east of the Mississippi River. Several of the older bathhouses, Lincoln and Roosevelt, have been restored providing mineral baths, hot packs and massages. Two commercially bottled water are available: Saratoga Mineral Water and Excelsior Spring Water. The present Saratoga Spa Park has 10 springs with seven other springs located in the surrounding areas of the city.

**Warm Springs, Georgia** is another famous mineral springs in the U.S. The springs were used by Indians from as far away as New York, as they were on a major trail system. The trails later became military and post roads, with a tavern built in the early 1800s. A number of resorts were built in the area, including the very victorian Meriwether Inn. It is know chiefly for the treatment of polio from the early 1920s to the 1960s. It was promoted by President Franklin Delano Roosevelt, who had polio and established the “Little White House” on the premises in 1932. The Georgia Warm Springs Foundation, who managed the springs, dedicated itself to the conquest of polio. It provided treatment in various pools supplied by warm springs flowing around 58 L/s at 31°C. With the advent of polio vaccines in the 1950s and 60s, use of the facility declined. Today, the Roosevelt Warm Springs Institute for Rehabilitation of the state of Georgia provides medical rehabilitation and therapy for a broad range of disabilities. The Institute also uses the water for bathing, heating and cooling, assisted by water-to-air heat pumps.

**Hot Springs, Arkansas** was one of the most popular commercial spas areas in the U.S., created to imitate the development of great spas of Europe. This natural geothermal resource consisted of about 47 springs producing a total of 4 million liters of 60°C water per day. It is estimated that these hot springs have been used by humans for at least 10,000 years. The “Valley of the Vapors” was an honored and sacred place to the Indians. This was also neutral ground, where warriors of all tribes could rest and bath here in peace--a refuge from battle. Legend reports that Hernando DeSoto, an early American explorer, visited the site in 1541. The springs were developed into a rustic bathing and resort area in the early 1800s. It became so popular with the early European

settlers, that it was made into a federal reservation in 1832. By 1878, over 50,000 people visited the springs annually. In 1921, it came under the jurisdiction of the newly formed National Park Service and was renamed Hot Springs National Park. People flocked to this new national park with its large fancy bathhouses along Bathhouse Row. Until 1949, each bathhouse needed to have its own evaporation tower in order to cool the incoming hot mineral water to below 43°C, the maximum generally tolerated by the human skin. In that year, the Park Service installed air-cooled radiators and tap-water cooled heat exchangers to supply cooled water to the system. Now the bathhouses received two supplies of water: “hot” at 62°C and “cool” at 32°C. Of the original 47 springs, only two are presently available for public viewing. Even though activity has declined over the recent years, a full range of options are still available: tub and pool baths, showers, steam cabinets, hot and cold packs, whirlpool, massage, or alcohol rub. Today, the Park leases a number of bathhouses and owns almost 2000 hectares of land.

**Thermopolis, Wyoming** is located at the mouth of the Wind River Canyon, Approximately 150 km southeast of Yellowstone National Park. The major geothermal attraction in the area is the Hot Springs State Park with the 120 L/s Big Horn Spring. Nearby is the Fountain of Youth resort using natural mineral water from the historic Sacajawea Well flowing at the rate of 60 L/s. At least eight hot springs in the area have created large terraces along the river. These terraces are composed chiefly of colorful lime and gypsum layers known as travertine. The springs, claimed to be the largest mineral hot springs in the world, flow at a temperature of between 22 and 56°C with a total dissolved solids of 2400 mg/L. The early history of the springs include use by Indians; however in 1896, a treaty was signed between the Shoshone and Arapaho Indians and the federal government which gave the public use of the hot springs. The management of the springs was later turned over to the state of Wyoming forming Hot Springs State Park. Today Hot Springs State Park consists of little over 420 hectares of irrigated lawn and developed area within the 26-square km park, providing geothermal bathing in the State Bathhouse, and free water to six other facilities. Among the facilities provided hot water is a Pioneer Center for retired state residents and the Gottsche Rehabilitation Center specializing in helping stroke victims, closed head and spinal injuries, bed sores, cellululating problems, and burn victims.

**Calistoga, California** area was originally settled by the Pomos and Mayacmas Indians for at least 4000 years. These early people came from miles around to use the natural hot springs, fumaroles, and heated muds to soothe aches and pains. They also built sweat houses and used the local cinnabar for red war paint. To them, this was the “beautiful land” and “the oven place.” In the early 1800s, the Spanish explorers visited the area looking for a possible mission site. They referred to this site as “Aqua Caliente.” Samuel Brannan, in the 1850s, envisioned a resort and spa similar to Saratoga Hot Springs--and thus, the name from a combination of California and Saratoga (Archuleta, 1977). He spent an estimated half a million dollars developing the “resort,” with

his Hot Springs Hotel opening in 1862. Around the turn of the century, over 30 resorts existed in the surrounding area, including bathhouses, mineral springs, and resort hotels. By 1930, many of these resorts had closed due to financial hardship, fires and lack of maintenance. About 15 years ago, Calistoga again became a “boomtown” with six major spas and resorts in operation. All of these resorts have their geothermal water supplied from shallow wells around 60-m deep with temperature from 77 to 93°C. The water for the pools and baths is cooled to 27 to 40°C, and some have mud baths using the local volcanic ash and peat moss. Calistoga also has a mineral water industry and is adjacent to the Napa Valley wine industry.

### Conclusions

Geothermal water has been used extensively for the hot pools and baths, but not for heating or cooling the structures at these spas. Space heating was attempted in the past at many resorts, however, with mixed-to-poor results. Pipes would corrode or plug with deposits and require frequent repairs, replacement and cleaning. The expense was high and thus, “natural” space heating was usually replaced with conventional fossil fuel systems. Today, we at the Geo-Heat Center, and other geothermal experts, understand and solve these problems on a routine basis. The cost of installing the proper equipment and safeguards are more than offset by the savings in annual heating costs over fossil fuels. The Geo-Heat Center has a technical assistance program funded by USDOE to provide free preliminary engineering and economic design and analysis of any use of a resource for heating and cooling.

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## PART 3: DESIGN CONSIDERATIONS FOR POOLS AND SPAS (NATATORIUMS)

### Swimming Pools

According to ASHRAE (1999a), the desirable temperature for swimming pools is 27°C, however, this will vary from culture to culture by as much as 5°C. If the geothermal water is higher in temperature, then some sort of mixing or cooling by aeration or in a holding pond is required to lower the temperature. If the geothermal water is used directly in the pool, then a flow through process is necessary to replace the “used” water on a regular basis. In many cases, the pool water must be treated with chlorine, thus it is more economical to use a closed loop for the treated water and have the geothermal water provide heat through a heat exchanger. The water heating system in this case, is installed on the return line to the pool. Acceptable circulation rates vary from six to eight hours for a complete change of water. Heat exchangers must be designed to resist the corrosive effects of the chlorine in the pool water and scaling or corrosion from the geothermal water. This often requires, in the case of plate heat exchangers, using titanium plates.

Sizing of the system for temperature and flow rates depends on four considerations (ASHRAE, 1999a), which are also discussed in more detail in a chapter on Aquaculture Design by Rafferty (1998). These are:

1. Conduction through the pool walls,
2. Convection from the pool surface,
3. Radiation from the pool surface, and
4. Evaporation from the pool surface.

Of these, conduction is generally the least significant unless the pool is above ground or in contact with cold groundwater. Convection losses depend on the temperature difference between the pool water and the surrounding air, and the wind speed. This is substantially reduced for indoor pools and ones with wind breaks. Radiation losses are greater at night, again especially for outdoor pools, however during the daytime there will be solar gains which may offset each other. A floating pool cover can reduce both radiation and evaporation losses. Evaporation losses constitute the greatest heat loss from pools--50 to 60% in most cases (ASHRAE, 1999a). The rate at which evaporation occurs is a function of air velocity and pressure difference between the pool water and the water vapor in the air (vapor pressure difference). As the temperature of the pool water is increased or the relative

humidity of the air is decreased, evaporation rate increases. An enclosure can reduce this loss substantially, and a floating pool cover can practically eliminate the loss. Swimming and other pool uses causing waves and splashing will increase the surface area and thus the evaporation rate.

The required geothermal heating output  $q_t$  can be determined by the following two equations (ASHRAE, 1999a):

$$q_1 = \rho c_p V (t_r - t_i) / \theta \quad [1]$$

where

$q_1$	=	pool heat-up rate, kJ/h
$\rho$	=	density of water = 1,000 kg/m <sup>3</sup>
$c_p$	=	specific heat of water = 4.184 kJ/kg °C
$V$	=	pool volume, m <sup>3</sup>
$t_r$	=	desired temperature (usually 27°C)
$t_i$	=	initial temperature of pool, °C
$\theta$	=	pool heat-up time (usually 24 hours)

and

$$q_2 = U A (t_p - t_a) \quad [2]$$

where

$q_2$	=	heat loss from pool surface, kJ/h
$U$	=	surface heat transfer coefficient = 214.4 kJ/(h m <sup>2</sup> °C)
$A$	=	pool surface area, m <sup>2</sup>
$t_p$	=	pool temperature, °C
$t_a$	=	ambient temperature, °C

then

$$q_t = q_1 + q_2 \quad [3]$$

If there is no heat-up time, which is typical for geothermal pools, then equation [1] will be zero and only equation [2] will apply. Heat loss equation [2] assume a wind velocity of 5 to 8 km/h. For sheltered pools, and average wind velocity of less than 5 km/h, the second equation ( $q_2$ ) can be reduced to 75%. For wind velocity of 8 km/h, multiply by 1.25; and for wind velocity of 16 km/h, multiply by 2.0 (ASHRAE, 1999a).

### Spas (Natatoriums)

Spas or natatoriums require year-round humidity levels between 40 and 60% for comfort, energy consumption, and building protection (ASHRAE, 1999b). Any design must consider all of the following variables: humidity control, ventilation requirements for air quality (outdoor and exhaust air), air distribution, duct design, pool water chemistry, and evaporation rates.

According to ASHRAE (1999b):

“Humans are very sensitive to relative humidity. Fluctuations in relative humidity outside the 40 to 60% range can increase levels of bacteria, viruses, fungi and other factors that reduce air quality. For

swimmers, 50 to 60% relative humidity is most comfortable. High relative humidity levels are destructive to building components. Mold and mildew can attack wall, floor, and ceiling coverings; and condensation can degrade many building materials. In the worst case, the roof could collapse due to corrosion from water condensing on the structure.”

Heat loads for a spa include building heat gains and losses from outdoor air, lighting, walls, roof, and glass, with internal latent heat loads coming generally from people and evaporation. The evaporation loads are large compared to other factors and are dependent on the pool characteristics such as the surface area of the pool, wet decks, water temperature and the activity level in the pool.

The evaporation rate ( $w_p$  in kg/s) can be estimated for pools of normal activity levels, allowing for splashing and a limited area of wetted deck (Smith, et al., 1993) (ASHRAE, 1995).

$$w_p = A (p_w - p_a) (0.089 + 0.0782 V) / Y \quad [4]$$

where

$A$	=	area of pool surface, m <sup>2</sup>
$p_w$	=	saturation vapor pressure taken at surface water temperature, kPa
$p_a$	=	saturation pressure at room air dew point, kPa
$V$	=	air velocity over water surface, m/s
$Y$	=	latent heat required to change water to vapor at surface water temperature, kJ/kg

For  $Y$  values of about 2330 kJ/kg and  $V$  value of 0.10 m/s, and multiplying by an activity factor  $F_a$  to alter the estimate of evaporation rate based on the level of activity supported, equation [4] can be reduced to:

$$w_p = 4.16 \times 10^{-5} \times A (p_w - p_a) F_a \quad [5]$$

If  $p_w$  and  $p_a$  are given in bar absolute, then equation [5] becomes:

$$w_p = 4.16 \times 10^{-3} \times A (p_w - p_a) F_a \quad [6]$$

And, if  $w_p$  is given in kg/hr, then equation [6] becomes;

$$w_p = 15.0 \times A (p_w - p_a) F_a \quad [7]$$

**Table 1. Common Values for  $p_w$** 

For $p_w$ :	at 15°C water, $p_w = 0.0170$ bar (1.70 kPa)
	at 20°C water, $p_w = 0.0234$ bar (2.34 kPa)
	at 25°C water, $p_w = 0.0317$ bar (3.17 kPa)
	at 30°C water, $p_w = 0.0425$ bar (4.25 kPa)
	at 35°C water, $p_w = 0.0563$ bar (5.63 kPa)
	at 40°C water, $p_w = 0.0738$ bar (7.38 kPa)

For outdoor locations with a design dry bulb air temperature below 0°C,  $p_a$  can be taken as 0.0061 bar (0.61 kPa). For indoor locations with a design from 40 and 60% humidity, the following values of  $p_a$  can be use:

**Table 2. Common Values for  $p_a$** 

Temperature °C	40% relative humidity bar (kPa)	50% relative humidity bar (kPa)	60% relative humidity bar (kPa)
20	0.0094 (0.94)	0.0117 (1.17)	0.0140 (1.40)
25	0.0127 (1.27)	0.0158 (1.58)	0.0190 (1.90)
30	0.0170 (1.70)	0.0212 (2.12)	0.0255 (2.55)

The following activity factors should be applied to the area of specific features, and not to the entire wetted area (ASHRAE, 1999b):

Type of Pool	Typical Activity Factor ( $F_a$ )
Residential pool	0.5
Condominium	0.65
Therapy	0.65
Hotel	0.8
Public, schools	1.0
Whirlpools, spas	1.0
Wavepools, water slides	1.5 (minimum)

It is important to apply the correct activity factor for the estimation of the water evaporation rate, as for example, the difference in peak evaporation rates between private pools (residential) and active public pools of the same size may be more than 100%.

ASHRAE (1999b) recommends operating temperatures and relative humidity conditions for design, and suggests that higher operating temperatures are preferred by the elderly. Air temperatures in public and institutional pools should be maintained 1 to 2°C above the water temperatures (but not above the comfort threshold of 30°C) to reduce the evaporation rate and avoid chill effects on swimmers. The maximum water temperature that can be tolerated by the human body (for short periods of time) is 43°C. The recommendations are as shown in Table 3.

Relative humidities should not be maintained below recommended levels because of the evaporated cooling effect on a person emerging from the pool and because of the increased rate of evaporation from the pool, which increases pool heating requirements. Humidities higher than recommended encourage corrosion and condensation problems as well as occupant discomfort. Air velocities should not exceed 0.13 m/s at a point 2.4 m above the walking deck of the pool (ASHRAE, 1995).

**Table 3. Typical Natatorium Design Conditions**

Type of Pool	Air Temperature °C	Water Temperature °C	Relative Humidity %
Recreational	24 to 29	24 to 29	50 to 60
Therapeutic	27 to 29	29 to 35	50 to 60
Competition	26 to 29	24 to 28	50 to 60
Diving	27 to 29	27 to 32	50 to 60
Whirlpool/spa	27 to 29	36 to 40	50 to 60

Ventilation is important, especially if chlorine is used to treat the pool water. Ventilation is also used to prevent temperature stratification in areas with high ceilings. Since exhaust air will have chloramine from the chlorine treatment and also have high moisture contents, care must be exercised to vent this air outside and not into changing rooms, toilets and showers. In addition, pool areas should have a light negative pressure and automatic door closers to prevent the contaminated air (laden with moisture and chloramine) from migrating into adjacent areas of the building. ASHRAE (1999b) states that most codes require a minimum of six air changes per hour, except where mechanical cooling is used. With mechanical cooling, the recommended rate is four to six air changes per hour for therapeutic pools.

Natatoriums can be a major energy burden on a facility, thus energy conservation should be considered. This includes evaluating the primary heating and cooling systems, fan motors, backup water heaters (in the case of geothermal energy use) and pumps. Natatoriums with fixed outdoor air ventilation rates without dehumidification generally have seasonally fluctuating space temperature and humidity level. Since these systems usually cannot maintain constant humidity conditions, they may facilitate mold and mildew growth and poor indoor air quality. In addition, varying activity level will also cause the humidity level to vary and thus change the demand on ventilation air.

The minimum air quantity to remove the evaporated water can be calculated from the following expression (ASHRAE, 1995):

$$Q = w_p / [\rho (W_i - W_o)]$$

where:

$Q$  = quantity of air ( $m^3/s$ )

$\rho$  = standard air density = 1.204  $kg/m^3$

$W_i$  = humidity ratio of pool air at design criteria (kg/kg)(from psychrometric chart)

$W_o$  = humidity ratio of outside air at design criteria (kg/kg)(from psychrometric chart).

The number of air changes per hour (ACH) to remove the quantity of moist air ( $Q$ ) is:

$$ACH = (V/Q)/3600$$

where:

$V$  = volume of the building in  $m^3$

Normally, the air changes per hour calculated from the above expression is less than the minimum recommended of four to six per hour.

### **References**

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