Energy balance of the Italian hydrothermal spa system

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ABSTRACT

After heating and cooling, thermal balneology was in 2010 the second most important sector of direct uses in Italy, with 149 thermal localities using hot water for balneotherapy, with no combination with other direct uses. This is why, in 2009 and 2010, UGI conducted regional studies on their water and energy balance to investigate the possible optimization of the heat consumption by coupling thermal bathing with other upstream and downstream direct uses. Moreover, since two thirds of the spas utilize water in part artificially heated, the studies also evaluated the energy consumption of the heating process and compared the result with the geothermal fraction of the energy used.

After an overview of the geological and hydrogeological settings of low-temperature geothermal resources, the paper describes the situation of thermal balneology in Italy at Dec. 2010, estimating the volume of hot water consumed, and the amount of heat used by the overall spa system at the regional and national level. The methodology devised to analyze the various components of the water and energy balance and its conceptual flow diagrams are described in the paper.

The paper also reviews the different types of direct uses which, depending on the temperature of the water available upstream (T > 38°C) and downstream (T < 28°C) of the thermal establishments, might be associated with the thermal balneotherapy.

Finally, the paper pinpoints the benefits that might arise from the development of multiple uses combined with the thermal balneology, in terms of: *i)* oil saved; *ii)* displaced CO_2 emissions; *iii)* higher number of spa users; *iv)* increased tourist activity in the spa areas; and *v)* creation of new production activities and jobs in the same areas.

1 GEOLOGICAL AND HYDROGEOLOGICAL BACKGROUND OF THERMAL SPRINGS

Italy belongs to the Alpine-Apennine orogen, resulting from the collision between the African and European plates, started in the Upper Cretaceous ($80x10^6$ years ago) and ended in the Upper Miocene ($10x10^6$ years ago). During this long period of time, a compression regime predominated in the south-western Mediterranean, with mantle arching, rising of igneous material from deep magma chambers, thinning of the crust, formation of anatectic bodies at relatively shallow depth, and development of a large thermal anomaly with high conductive heat flow values (100 ÷ 450 mW/m2).

A tensional regime followed in the same area during the Pliocene and Quaternary, with formation of prevailingly NW-SE horst-graben structures and fault sheaves, accentuation of thermal anomalies in correspondence with up-lifted features, and extrusion of deep and anatectic igneous materials. These phenomena occurred especially in the pre-Apennines belt from Tuscany to Campania, in the southern Tyrrhenian Sea, in central Sardinia, and in eastern Sicily (Figures 1 and 2).

Where permeable complexes overlain by impermeable covers exist in the vicinity of absorption outcrops feeding meteoric water to such complexes, confined aquifers form at more or less shallow depth. The temperature of the water hosted in these aquifers depends on their depth and on the intensity of the thermal regime of the area, reaching many tens of degrees °C at few hundreds meters depth. Favorable hydrogeological conditions thus set up and triggered a convective circulation inside the confined aquifers, with local escapes of hot waters along fractures and faults. Isolated thermal springs, or clusters of thermal springs, formed in this way at the surface along the tensional tectonic alignments of many areas.

Where the thermal anomaly is strong enough and the top of confined aquifers is rather shallow, the temperature of the escaping water may exceed 100 °C, with formation of fumaroles. These manifestations, however, occur in few places only of Italy, characterized by very recent or present volcanic activity.

On the contrary, where permeable formations of notable thickness (several hundreds meters, or more) outcrop and overlay impermeable complexes, they host unconfined aquifers whose water temperature rarely exceeds 50 °C within 2 km depth. As a consequence, albeit containing sizeable quantities of thermal energy, such aquifers form a low temperature



Figure 1: Main geodynamic domains and recent volcanism in Italy (after Cataldi et al., 2010)**.**

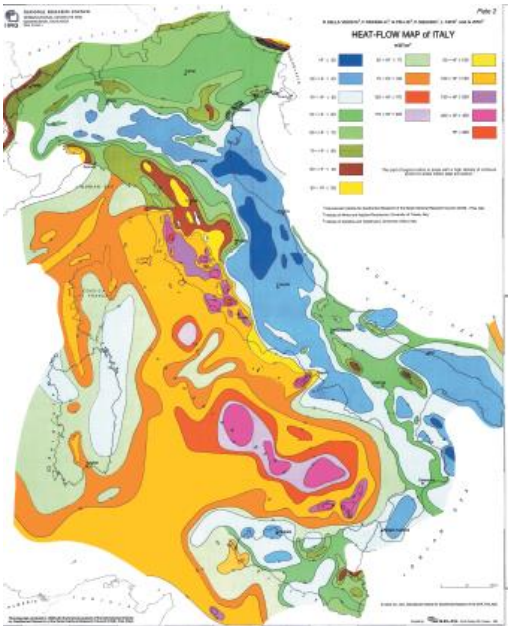


Figure 2: Conductive heat flow of Italian territory *(after Buonasorte et al, 2011.)*

resource. However, even in these situations, owing to particular hydrogeological conditions (heteropies of facies, fault contacts, lateral barriers with impermeable formations, differential porosity, belts of thick fractures, etc.), the water may escape upwards from such unconfined aquifers to form superficial springs with temperature usually lower than 50 °C.

In exceptional cases only, where the water can rise fast to surface through faults from depths above 3 km, its temperature may reach 70-80 °C.

In addition to those above, other geological factors played important roles on the formation of thermal springs in Italy. They are inversions of litho-stratigraphic sequences with doubling of series occurred in many areas of the Alps and the Apennines during their final orogenetic stages, characterized by overturned anticlinals, detachments of rock complexes from their basement, and overthrusts of thick nappes over younger terrains.

This compression tectonics, with main northwards and eastwards components, preceded the occurrence in the Pliocene and Quaternary of the tensional tectonics cited before, with the above-said formation of horst-graben structures and thick faulting.

Such tensional tectonics, in turn, affected and modeled, in particular, the piedmont belt of the southern Alps, and especially the western margin of the Apennines, where the recent igneous processes shown in Figure 1 were concurrently happening during the late Pliocene and the Quaternary.

And in fact, as result of all the above, the areas with the thickest concentration of thermal springs in peninsular Italy are the Euganean district near Padua, the pre-Apennines belt of Tuscany-Latium-Campania, and the Ischia island in the southern Tyrrhenian Sea.

More detailed information on the geological background of the Italian geothermal resources and manifestations are found in Buonasorte et al (2011), in Cataldi et al. (2013), and Carlino et al (2013). For thermal springs in general, reference can be made to the papers by Cataldi et al. (2010), and by Ceccarelli A. and Ceccarelli E. (2010)

2. MAIN THERMO-MINERAL DISTRICTS

Due to its complex geological history, Italy displays a large variety of geothermal situations, resulting in the formation of over 1000 water points[1].

They are grouped in twelve thermo-mineral districts (Fig. 3) as follows: 1) northern Piedmont (Ossola Valley); 2) central-northern Lombardy (Orobian Alps and Lombard Prealps); 3) central Veneto (Pasubio Mt. and Lessini Mts.); 4) south-western Piedmont (Cuneo) and western Liguria (Ligurian Apennines); 5) western Emilia-Romagna (Parmesan Apennines) and northern Tuscany (Pistoia pied-Apennines and Mugello hills); 6) Umbria (Gualdo Tadino, Nocera Umbra, Sangemini, San Faustino) and central Marches (Sibyllin Mts.); 7) central Latium; 8) north-western Campania; 9) central Campania (Ischia Isl. and Vesuvius area) and northern Lucania (Vulture Mt.); 10) central-southern Calabria; 11) eastern Sicily (Aeolian archipelago, Etna and Hiblean Mts.); and 12) western Sardinia.

[1] *Water point* means any evidence of underground circulation of water, gas and steam escaped in recent geological times, or escaping at present to surface and leaving a "signature" of its occurrence. They include cold, warm and hot springs, hydrothermal deposits (travertine, kaolin, sulphur, etc.), hot soils, solfataras and fumaroles.When a cluster of such points occur in a small area they are grouped together as a point alone.

Each group is characterized by predominant litho-types, as specified in the sub-caption of Figure 3.

3.CLASSIFICATION AND LOCATION OF THERMAL WATERS

Out of the over 1000 *water points* mentioned above, some 50% are of the hot type, with the majority formed by thermal springs (T=15[2]÷ 80 °C). Based on temperature, their hydrogeological classification is usually made as follows:

- hypothermal waters ……...T = 15 - 30 °C;
- mesothermal waters ……T = 30 - 60 °C; and
- hyperthermal waters ……T > 60 °C.

From the medical viewpoint, on the contrary, the term "thermal water" usually designates waters at T = 20÷37°C; whereas the waters at T > 37 °C most of times are defined "hyperthermal waters".

The active hot *water-points* alone (i.e. excluding fossil manifestations and hydrothermal deposits) amount to some 350 natural springs at T >15 °C.

They are integrated by some 150 wells at depth of 100÷1000 m, tapping hot water from confined aquifers at T = 30 ÷ 80 °C.

The main thermal springs or clusters of thermal springs, and the location of the principal above-said hot water wells are found in the following areas: a) occidental Alps; b) southern Garda area to the west of Verona; c) Euganean district near Padua; d) hill piedmont of Emilia-Romagna; e) pre-Apennine belt of Tuscany-Latium-Campania; f) Ischia Isl.; g) western Sardinia; h) Aeolian archipelago; i) eastern and south-western Sicily; and j) Pantelleria Isl.

4. THERMAL BALNEOLOGY AT DEC. 2010

Over 350 spa facilities [3] were in use in that year in 149 thermal localities of Italy [4]. Those with the highest concentration of facilities were: Abano (Veneto), Ischia (Campania) and Montecatini (Tuscany), grouping together more than 50% of the Italian thermal spas.

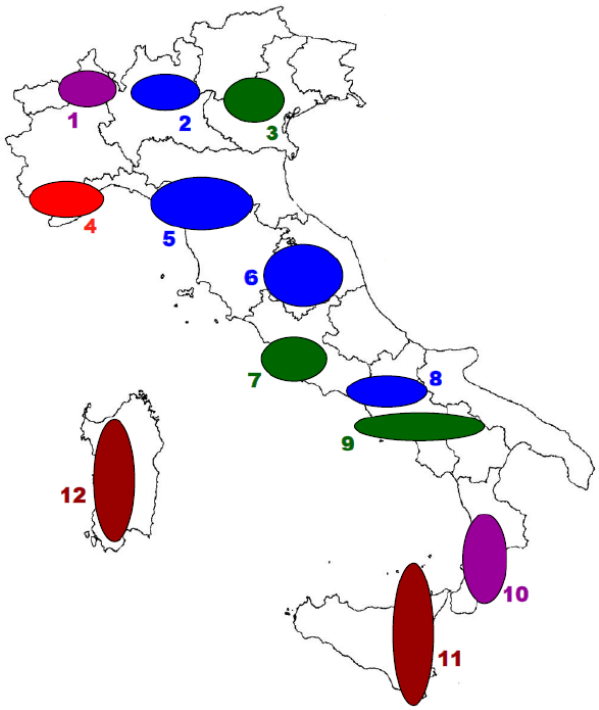


Fig. 3: Lithological characteristics of the main thermo-mineral districts of Italy *(after Cataldi et al. , 2010).*

(1 and 10, violet: *crystalline magmatic and metamorphic rocks;* **2, 5, 6, and 8**, ***blu***: *sedimentary rocks;* **3, 7, and 9, *green***: *sedimentary and volcanic rocks;* **4, *red*:** *sedimentary and metamorphic rocks;* ***11 and 12, brown*:** *sedimentary, volcanic and metamorphic rocks*)

Broken down by Region and divided in two groups with water temperature above 38 °C[5] (Group A), and below 38 °C (Group B), the thermal localities in operation in 2010 are as follows.

Abruzzo, total 4: Canistro (9 °C), Caramanico (10 °C), Popoli (10 °C), and Raiano (10 °C), *Group B.*

Basilicata, total 2: Latronico-La Calda (22 °C) and Rapolla (15 °C), *Group B.*

Calabria, total 6: Terme Caronte (39 °C) and Terme Luigiane (42-47 °C), *Group A*; and

Antonimina Terme (36 °C), Galatro Terme (37°C), Terme Sibarite (26 °C) and Spezzano (15 °C), *Group B.*

Campania, total 10: Agnano (62-70 °C), Contursi (up to 50 °C), Ischia (40-100 °C), Pozzuoli (58 °C), and Stufe di Nerone (72-74 °C), *Group A*; and

Castellammare di Stabia (30°C), Telese (19°C), Terme San Teodoro (28 °C), Torre Annunziata (15-30 °C), and Vico Equense-Scrajo (15-20 °C), *Group B.*

[2] Since the average annual air temperature of Italy is taken conventionally to be 15°C, also the lower limit of temperature for the water to be considered of the thermal type is identified with that value.

[3] Aesthetic institutes, beauty farms, fitness clubs, and other facilities not using hot natural water are not considered.

[4] Such total does not include 28 cure stations that use mineral water for cure by drinking only, with no thermal treatments. They are: Montesano (Campania); Cervarezza, Fratta, Porretta, Riccione, Salvarola and Sant'Andrea (Emilia-Romagna); Cottorella, Fiuggi and Palestrina (Latium); Gaverina, San Colombano and Sant'Omobono (Lombardy); Carignano, Montegrimano and Torre Palme (Marches); Agliano, Castagneto Po, Crodo, Monte Valenza and Vicoforte (Piedmont); Uliveto (Tuscany); Lavinia Bianca, Pejo and Rabbi (Trentino-Alto Adige); Nocera Umbra, San Faustino and Sangemini (Umbria).

[5] 38 °C has been conventionally taken as the temperature needed for the water to be used in therapeutic treatments in all thermal spas. Thus, waters of Group A can be used directly for thermal cures, whereas waters of Group B need a partial heating before thermal use.

Emilia-Romagna, total 17: Bagno di Romagna (45 °C), *Group A*; and

Bacedasco (15 °C), Bobbio (15 °C), Brisighella (15 °C), Castelsanpietro (15°C), Castrocaro (20°C), Cervia (15°C), Monticelli (15 °C), Oasis (15 °C), Punta Marina (15 °C), Rimini (15 °C), Riolo (15 °C), Salsomaggiore (16 °C), Tabiano (15 °C), Terme Agriturismo (15 °C), Terme Felsinee (15 °C), and Varano Marchesi (15 °C), *Group B*.

Friuli-Venezia Giulia, total 3: Arta (9 °C), Grado (15 °C) and Lignano Sabbiadoro (15 °C), *Group B*.

Latium, total 8: Castelforte-Suio (up to 63 °C), Stigliano (up to 56 °C), and Terme dei Papi (40-58 °C), *Group A*; and

Antrodoco (10 °C), Cotilia (15 °C), Ferentino (16-18 °C), Palombara Sabina (24 °C), and Tivoli (23 °C), *Group B*.

Liguria, total 1: Pigna (28-32 °C), *Group B*.

Lombardy, total 14: Bagni Masino (38°C), Bormio (38-41 °C), and Sirmione (69 °C), *Group A*; and

Angolo Terme (13 °C), Boario (13-15 °C), Bracca (19 °C), Franciacorta (14 °C), Miradolo (12-16 °C), Rivanazzano (15 °C), Salice (20 °C), San Pellegrino (26 °C), Tartavalle-Taceno (15 °C), Trescore (15 °C), Vallio Terme (12 °C), *Group B*.

Marches, total 7: Acquasanta Terme (38 °C), *Group A*; and

Aspio (10 °C), Pitinum Thermae (15 °C), Sarnano (10 °C), Terme di Raffaello (14 °C), Terme Santa Lucia (13-14 C), and Terme San Vittore (10 °C), *Group B*.

Molise, total 1: Sepino (15 °C), *Group B*.

Piedmont, total 6: Acqui Terme (45-73 °C), Valdieri (50-70 °C), and Vinadio (40-75 °C), *Group A*; and

Bognanco (8-10 °C), Garessio (8-10 °C), and Lurisia (15 °C), *Group B*.

Puglia *(Apulia)*, total 3: Margherita di Savoia (15 °C), Santa Cesarea (30 °C), and Torre Canne (18 °C), *Group B*.

Sardinia, total 5: Benetutti (43 °C), Casteldoria (75 °C), Fordongianis (60 °C), and Sàrdara (50-68 °C), *Group A*; and

Tempio Pausania (12 °C), *Group B*.

Sicily, total 11: Acqua Pia (40 °C), Alì Terme (40-46 °C), Calatafimi-Segesta (51°C), Castellammare-Terme Segestane (47 °C), San Calogero Lipari (60 °C), Sciacca (56 °C), Termini Imerese (43 °C), Vulcano (40-100 °C), *Group A*; and

Acireale (22 °C), Castroreale-Vigliatore (26-36 °C), and Sclafani Bagni (30 °C), *Group B*.

Tuscany, total 26: Bagni di Lucca (40-54°C), Bagnolo (43 °C), Bagno Vignoni (51 °C), Petriolo (43 °C), Rapolano (40 °C), San Casciano (43 °C), San Filippo (52 °C), San Giuliano Terme (38-41 °C), Saturnia (38 °C), and Suvereto-Venturina (up to 45 °C), *Group A*; and

Acquaforte (20 °C), Bagni Galleraie (29 °C), Casciana (36 °C), Chianciano (18-33 °C), Equi (17-27 °C), Gambassi (34 °C), Impruneta (15 °C), Monsummano (24-35°C), Montecatini Terme (24-34 °C) , Montepulciano (20 °C), San Carlo (13 °C), San Giovanni d'Elba (15 °C), Sarteano (24 °C), Terme di Pitigliano (34 °C), Terme di Sorano (34 °C), and Versilia (17 °C), *Group B*.

Trentino-Alto Adige, total 8: Bagni Antermoia (9 °C), Bagni Salomone (8 °C), Caderzano-Val Rendena (10 °C), Levico (9 °C), Lomaso Terme (27 °C), Merano (33 °C), Pozza di Fassa (8-10 °C), and Roncegno (8-10 °C), *Group B*.

Umbria, total 4: Acquasparta (14 °C), Fontecchio (16 °C), Santo Raggio (15 °C), and Spello (14 °C), *Group B*.

Val d'Aosta, total 1: San Vincent (9 °C), *Group B*.

Veneto, total 12: Abano (70-80 °C), Battaglia (72 °C), Bibione (52 °C), Colà-Lazise (35-40 °C), Galzignano (60-70 °C), Montegrotto (60-70 °C), and Teolo Terme (75 °C), *Group A*; and

Caldiero-Terme Giunone (27 °C), Dolomiti (10 °C), Jesolo (15 °C), Recoaro (12 °C), and Scorzé (15 °C), *Group B*.

Therefore, a grand total of 149 thermal localities were in operation in Italy in 2010, out of which 47 using water of the Group A, and 102 of the Group B. However, it should be pointed out that about 10 of the waters of Group B have a temperature in the range 28÷38 °C, thus needing few degrees only of additional heating.

The volume of hot water used by the spas of the above-said 149 thermal localities is given in Table 1.

This table shows that a huge volume of hot water was used by the Italian spa system in 2010 (102×10^6 m3/yr), out of which over 50% is attributable to thermal pools for cure bathing and relax. In particular, we can note that, due to the high number of users and the resulting high number of pools available for cure and relax, almost 90% of the total volume of water was used by the spas of five Regions only: Veneto (over one third of the total), followed by Latium, Tuscany, Campania and Emilia-Romagna.

5. MASS AND ENERGY BALANCE OF THE ITALIAN SPA SYSTEM

5.1 Modeling approach

Aim of any modeling procedure is to describe numerically with an acceptable level of accuracy (and compatibly with the information available) the behavior of a complex system.

For our study, several simplifying assumptions had to be adopted as a result of the complexity and the wide variety of the spa operation parameters as the kind of treatments offered, the number and characteristics of the thermal waters available, the gathering system used to

Table 1: Total volume of hot water used by the Italian spa system in 2010, divided by Region

REGION	Total - [m^3]		*Group A - [m^3]*		*Group B - [m^3]*	
	Total spa uses	**Pools only**	***Total spa uses***	***Pools only***	***Total spa uses***	***Pools only***
Abruzzo	**150,000**	**0**	0	0	150,000	0
Basilicata	**90,000**	**20,000**	0	0	90,000	20,000
Calabria	**600,000**	**150,000**	0	0	600,000	150,000
Campania	**12,000,000**	**6,000,000**	10,800,000	5,400,000	1,200,000	600,000
Emilia Romagna	**11,000,000**	**7,000,000**	900,000	600,000	10,100,000	6,400,000
Friuli Venezia Giulia	**300,000**	**0**	0	0	300,000	0
Latium	**17,000,000**	**12,000,000**	7,000,000	3,500,000	10,000,000	8,500,000
Liguria	**100,000**	**30,000**	0	0	100,000	30,000
Lombardy	**3,000,000**	**800,000**	2,050,000	550,000	950,000	250,000
Marches	**500,000**	**120,000**	130,000	30,000	370,000	90,000
Molise	**60,000**	**0**	0	0	60,000	0
Piedmont	**1,500,000**	**400,000**	1,300,000	350,000	200,000	50,000
Puglia	**200,000**	**0**	0	0	200,000	0
Sardinia	**1,200,000**	**350,000**	1,150,000	330,000	50,000	20,000
Sicily	**2,800,000**	**390,000**	2,550,000	350,000	250,000	40,000
Tuscany	**15,000,000**	**6,500,000**	7,000,000	3,000,000	8,000,000	3,500,000
Trentino-Alto Adige	**1,300,000**	**200,000**	0	0	1,300,000	200,000
Umbria	**150,000**	**30,000**	0	0	150,000	30,000
Val d'Aosta	**50,000**	**10,000**	0	0	50,000	10,000
Veneto	**35,000,000**	**20,000,000**	34,300,000	19,650,000	700,000	350,000
TOTAL	**102,000,000**	**54,000,000**	***67,180,000***	***33,760,000***	***34,820,000***	***20,240,000***

transport hot waters from different springs and/or wells to the spa concerned; and others.

To obtain a though approximate energy balance of the Italian spa system, the following assumptions have been made:

- an average value of the water temperature at the source has been considered for each thermal district of the 20 Regions indicated in chapter 4;

- the volume of hot water used for balneological cures in each Region has been estimated on the basis of the number of users per year, the average duration of the cure per user, the yearly operation of each district, and the number and average size of the thermal pools existing in each district;

- any kind of fluids used for balneotherapeutic treatments have been considered: those used inside the cure facilities proper and the water used in the associated thermal pools, where they exist. However, due to the sizeable quantity of warm water used by these pools, their energy balance has been calculated separately as a specific sub-system of the whole spa system (see comparative Figures 4/1 and 4/2);

- a temperature drop of 10 °C (38-28 °C) has been adopted for the thermal uses inside all spas, whereas a drop of 13 °C (35-22 °C) has been conventionally chosen for the pool uses;

- since the energy balance in question is aimed at estimating the amount of geothermal heat used by the whole spa system, all waters with T < 15 °C (the average annual air temperature of Italy, as said in footnote 2) have not been considered in our calculations.

5.2 Structure of the model: conceptual flow diagram

The model adopted to calculate the energy balance of the Italian spa system is shown in Figures 4/1 and 4/2. It can be seen that both figures include three main components, as follows.

Upstream components. They refer to the gathering system from the thermal springs and/or wells to the spa facilities. As said in chapter 4, about one third of the thermal localities have at their disposal water at T≥38 °C that can be used directly for therapeutic treatments (see footnote 5). In one case only of such localities, the excess heat of the hot water available is used for space heating before therapeutic utilization (*Bagno di Romagna*, see para. 7.1).

In all other localities where the water has a temperature sizeably above 38 °C, it must be cooled to 38 °C, with resulting considerable dissipation of energy. Thus, to limit such dissipation, and increase the efficient utilization of geothermal energy, analyzing the *upstream components* one can obtain the data necessary to calculate the amount of thermal energy potentially harnessable for direct applications before thermal balneology, with no detrimental effect for it.

Thermal processing. The *temperature modification* depends on the heating equipment used to raise the temperature of the waters of Group B before their utilization for cure treatments. The energy balance of this block enables to calculate the amount of energy (other than geothermal) consumed by the spas of the Group B.

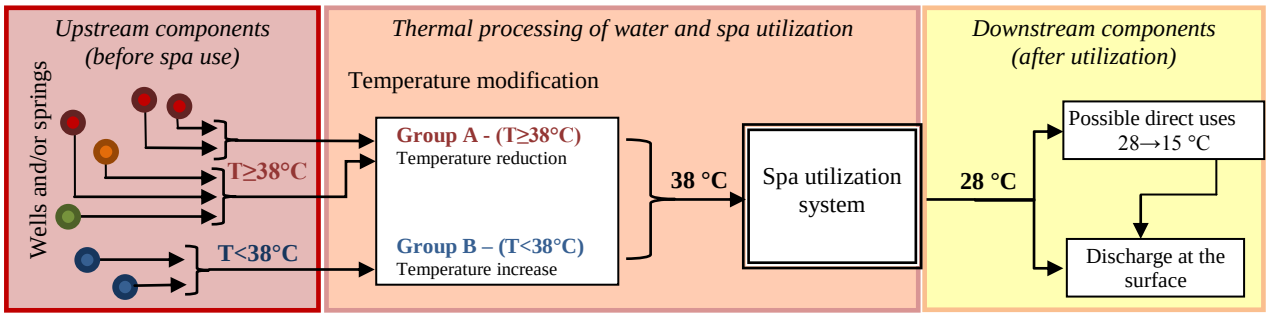


Figure 4/1: Conceptual flow diagram for water and energy balance of the Italian spa system, excluding pools

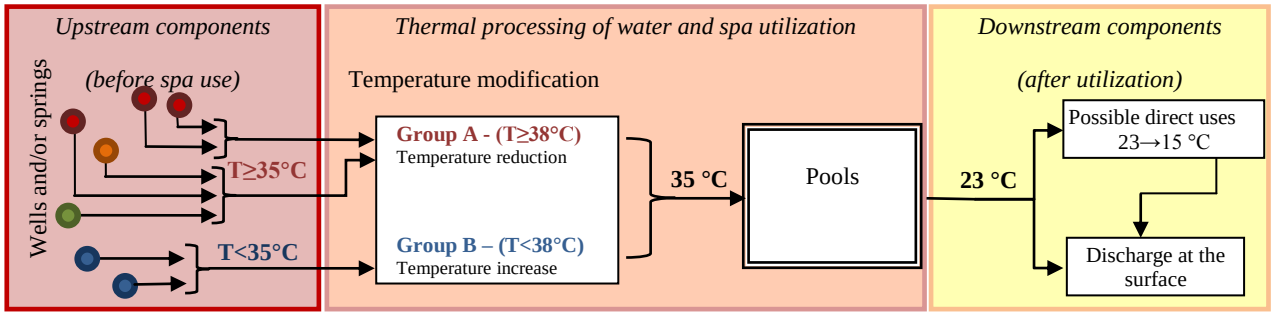


Figure 4/2: Conceptual flow diagram for water and energy balance of the pools associated to the spa system

Analyzing the central block of both figures (Fig. 4/1 for bathing cure and relax in the pools, respectively) allows one to evaluate the total amount of heat used by each thermal facility, together with its geothermal share.

Downstream components. At present, the residual warm waters available downstream of the thermal uses (T = 28 °C for cure treatments, and 23°C for the pools, respectively) are discharged almost always into the environment with resulting considerable loss of energy. However, several direct uses other than thermal balneology can potentially be made downstream of the cure stations till the minimum temperature of 15 °C established for any kind of thermal use in the whole Italian spa system (see footnote 2).

5.3 Geothermal share of total energy used by the whole Italian spa system in 2010

As already stated, some two thirds of the spas do not have at disposal spring or well water with at least 38 °C required for thermal use, and must therefore heat it artificially to that value by means of fossils fuels and/or electricity. As a consequence, though the useful ΔT is 38-28 = 10 °C for the spa treatments and 35-22=13 °C for the pools (see Fig.s 4/1 and Fig. 4/2, respectively), not all the energy used in these spas can be ascribed to geothermal heat.

The geothermal contribution is proportional to the additional heating avoided thanks to the temperature level of the water at the source: the higher the water temperature at the source, the lower the energy consumption for additional heating.

This concept can be expressed through a specific coefficient (evaluated through equation [2]), which can be used to reduce the value of the useful ΔT shown in equation [1] and to calculate the geothermal share of the total heat used according to the equations given below and in Table 2.

5.4 Equations

The basic equation adopted is that of the well-known energy conservation principle:

$$Q = V \cdot c \cdot \Delta T \qquad \textbf{[1]}$$

where **Q, V, ΔT**, represent the thermal energy [J], the volume of water [m3], and the temperature drop [°C], respectively (with specific values given in Table 2), whereas c represents the volumetric heat capacity of thermal water, conventionally assumed to be equal to 95% of that of the pure water, [J/m3 K].

5.5 Geothermal share of energy used in Italian spa system

The evaluation of the geothermal energy used in the different spa districts must be made separately for the waters of Groups A and B. Furthermore, to evaluate the fraction of geothermal energy used in the thermal pools, a temperature drop different than that of the spa treatments proper must be adopted. Therefore, we have:

- ***Group A:*** spas and pools fed by natural water at T ≥ 38°C and T≥35°C, respectively, with no supplementary heating. In this case, the whole heat used has a geothermal origin.

Table 2: Reference values used in the energy balances

Group A	***Energy amount evaluated (Q)***	V	T_{w_in}	T_{w_out}	ΔT
	Total energy used (all geothermal)	Water volume (other than pools)	38	28	$(T_{w_in}-T_{w_out})$
		Water volume for pools	35	23	$(T_{w_in}-T_{w_out})$
	Energy potentially usable upstream of spas	Total volume of water	T'	43	$(T_{w_in}-T_{w_out})$
Group B	***Energy amount evaluated (Q)***	V	T_{w_in}	T_{w_out}	ΔT
	Total energy used	Water volume (other than pools)	38	28	$(T_{w_in}-T_{w_out})$
		Water volume for pools	35	23	$(T_{w_in}-T_{w_out})$
	Geothermal share	Water volume (other than pools)	38	28	$\alpha\cdot(T_{w_in}-T_{w_out})$
		Water volume for pools	35	23	$\alpha\cdot(T_{w_in}-T_{w_out})$
	Energy consumption for the heating up	Water volume (other than pools)	38	T'	
		Water volume for pools	35	T'	
Groups A and B	***Energy amount evaluated (Q)***	V	T_{w_in}	T_{w_out}	ΔT
	Energy potentially usable downstream of spas	Total water volume (other than pools)	28	15	$(T_{w_in}-T_{w_out})$
		Total water volume for pools	23	15	$(T_{w_in}-T_{w_out})$
Group B	Geothermal share of potentially usable downstream of spas	Water volume (other than pools)	28	15	$\alpha\cdot(T_{w_in}-T_{w_out})$
		Water volume for pools	23	15	$\alpha\cdot(T_{w_in}-T_{w_out})$

- *Group B:* spas and pools fed by water at T< 38°C and T ≤ 35°C, respectively. In this case, boilers for additional heating must be used to heat the water to 38 and 35°C; thus, a fraction only of the heat used has a geothermal origin. This fraction can be calculated by means of the dimensionless coefficient shown in equation [2]:

$$\alpha = \frac{T'-15}{\Delta T_{ref}} \qquad \textbf{[2]}$$

where:

- T' is the average temperature of the group of wells and/or springs in a given Region [6], [°C];
- ΔT_{ref} is a normalization factor to calculate the fraction of geothermal energy contained in waters of Group B. Its value is the maximum temperature difference in the absence of geothermal contribution, and corresponds to 38-15 = 23 °C for the spa treatments and 35-15= 20 °C for the pools, [°C].

6. MAIN RESULTS OF THE WATER AND ENERGY BALANCES

The regional and national water balance of the whole Italian spa system is quantitatively depicted in Table 1, whereas the regional and national values of the useful thermal energy harnessed in the same system is shown below in Table 3, with specification of its geothermal share. It can be seen from this table that the total energy consumed in 2010 by the Italian spa system has been really important (a bit little less than 4500 TJ/yr), with a high contribution of the geothermal heat: 3463 TJ/yr, or 78 % of the total. This is owed mostly to Veneto, Campania, Sicily, Sardinia, Piedmont and Tuscany, all with a specific share of the Earth's heat above 80 % compared to the total. This means that, albeit 102 over 149 Italian spas localities used in 2010 hypothermal waters needing additional (non geothermal) heat to reach the 38 °C established for use in thermal treatments (35 °C for pool uses), the Earth's heat still plays the predominant role in the sector.

Table 3: Energy use of the Italian spa system

REGION	Total energy use *[TJ/yr]*	Geothermal share *[TJ/yr]*	*[%]*
Abruzzo	6	0	0%
Basilicata	4	1	18%
Calabria	24	16	68%
Campania	542	523	97%
Emilia-Romagna	444	52	12%
Friuli-Venezia Giulia	12	0	0%
Latium	718	418	58%
Liguria	4	3	79%
Lombardy	126	92	73%
Marches	20	6	27%
Molise	2	0	0%
Piedmont	64	56	88%
Puglia	8	1	12%
Sardinia	52	50	96%
Sicily	116	112	97%
Tuscany	632	522	83%
Trentino-Alto Adige	52	10	18%
Umbria	6	0	2%
Val d'Aosta	2	0	0%
Veneto	1 626	1 602	99%
TOTAL	**4 459**	**3 463**	**78%**

[6] The average temperature of the water in each Region has been evaluated as the arithmetic mean of the temperature of the water at the source of the different thermal districts, duly taken into account the respective flow rates.

This situation is highlighted in Figure 5, which shows that the prevalence of the geothermal share over the total energy used occurs both in absolute and relative terms of its two components, i.e. heat used by pools for bathing and relax, and heat used for thermal treatments proper.

However, Figure 5 also highlights that the amount of geothermal heat consumed by the pools (due to the high volume of water used) is some 25 % higher than that consumed for thermal treatments proper.

A part from the above, to illustrate the results of the energy balance in the spas of Groups A and B, reference can be made to Figure 6. In particular, the energy consumed for additional heating of the waters of Group B are highlighted and compared with the amounts of geothermal energy used by waters of both Groups A and B.

This figure shows that in 2010 the energy consumed for additional heating of the waters of Group B was 2344 TJ/yr, which compares with 1385 (996+389) TJ/yr of total energy used by waters of the same Group B. This means that nearly 1000 TJ (namely 2344-1385= 959 TJ), corresponding to almost 41 % of the energy consumed to heat up the waters of the Group B, is lost.

To avoid this notable loss and to improve the overall efficiency of the spa system, two solutions can be devised: *i)* develop a number of direct uses other than thermal balneology downstream of the spas; and/or *ii)* replace with other technologies the boilers presently employed to heat the waters of Group B. These aspects are discussed in para.s 7.1 and 7.2.

Figure 6 also highlights the geothermal components of the energy used (green areas), divided into waters of Groups A and B. Their total (3074 + 389 = 3463 TJ/yr) corresponds to the same amount shown in the left histogram of Figure 5.

7. FINAL REMARKS AND CONCLUSIONS

7.1 Possible direct uses other than thermal balneology

The only spa localities in Italy where the Earth's heat has been used so far for applications other than balneology, but in association with it, are *Bagno di Romagna* and *Galzignano*.

In the first of these localities a space heating system of the main spa building in winter is in operation since more than 10 years; whereas, in the second locality, an air-conditioning system of a greenhouses complex has been active until 2010. Thus, the multiple use of geothermal heat in combination with thermal balneology does not actually exist in Italy.

The reasons of such situation are mainly owed to the lack of a strategical vision in this field by the regional energy institutions concerned, and to a strong "NIMBY" position of the spa owners. Nonetheless, the data presented in this paper demonstrate that sizeable quantities of terrestrial heat are available for many uses in combination with thermal balneology, both upstream and downstream of it.

In this light, different utilization possibilities can be envisaged for spa localities in addition to system vs. energy consumed for additional heating of the waters of Group B balneological uses, which depend on whether hot natural water is available or not at a temperature sufficiently above 38 °C to not jeopardize or reduce the spa activities and business.

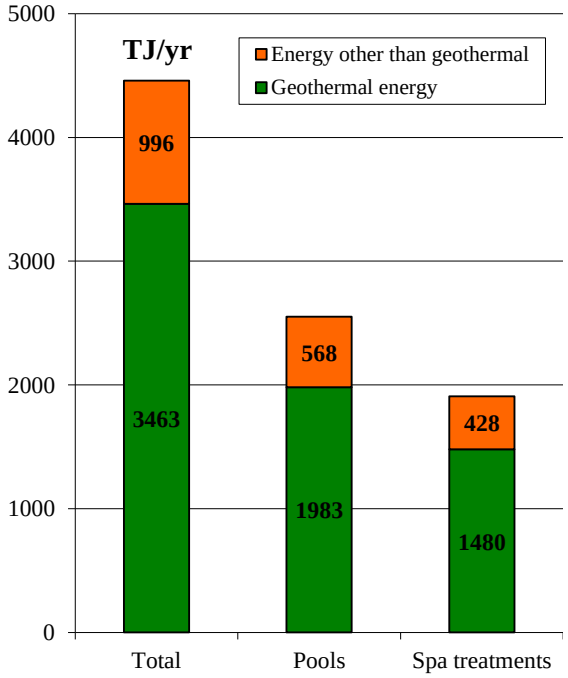


Figure 5: Thermal energy used by the Italian spa system: total broken down into pools and spa cures

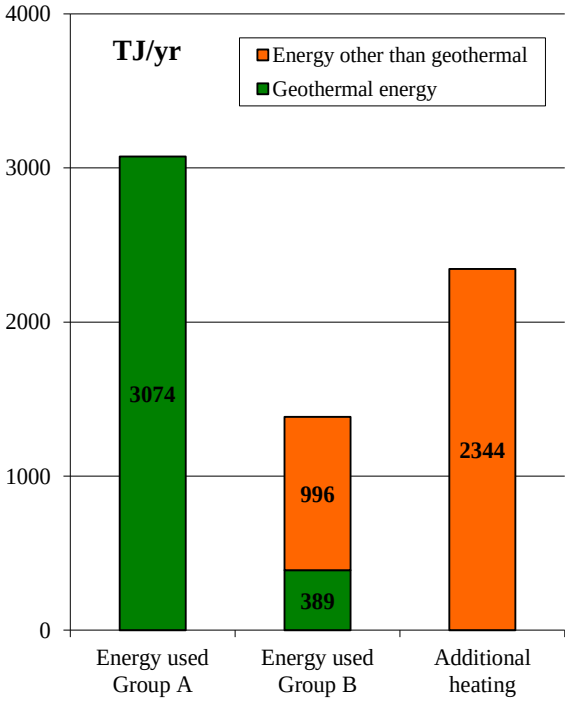


Figure 6: Thermal energy used by the Italian spa

Thus, we have hypothesized that, to be used for direct applications before thermal cures, the natural water can be cooled till no less than 43°C, i.e. 5 °C higher than 38 °C (see Table 2). The total amount of thermal energy (all geothermal) potentially usable upstream of the spas is shown in Table 4.

Conversely, for direct applications downstream of the thermal cures, the thermal energy contained in spent waters at T = 28 °C for spa treatments, and at T = 23°C for pool uses, can be considered. In fact, when discharged after the spa uses, all waters still contain a significant amount of useful energy which can be harnessed for direct applications downstream of the thermal stations. However, for spas of Group A, all such residual energy has a geothermal origin, whereas for the spas of Group B a fraction only of its energy content (proportional to coefficient of equation [2]) derives from the Earth's heat. The total amount of such residual thermal energy, and its geothermal share, are shown in Table 4.

In short, the possible multiple uses of the Earth's heat combined with balneotherapeutic cures are:

Upstream of the thermal spas (with natural hot waters at T ≥ 43 °C): *space heating; pasteurization of milk and agricultural products; maturing of cement mortars; washing of clothes and carpets; animal breeding and incubation of eggs; fast deicing of sidewalks and tracts of roads; other uses as the case may be.*

Downstream of the thermal spas (with spent warm waters at T = 28 °C for spa cures, and T = 23 °C for pool uses): *greenhousing; soil heating (gardens, orchards, etc.); fisheries and other animal breeding (turtles, alligators, etc.), biodegradation and fermentation processes; slow deicing of tracts of roads and sidewalks; other uses as the case may be*.

7.2 Benefits arising from modernization of the present equipment used for additional heating

We should recall, first of all, that the energy consumed for additional heating of the waters of Group B in 2010 was over 2300 TJ/yr for the whole Italian spa system, almost 1000 TJ/yr more than the total energy harnessed in the spas of Group B (see comments to Figure 6).

Thus, a feasibility study on re-vamping the traditional boilers with a more efficient system could be attractive for future spa development. This study would require a detailed thermo-technical engineering and economic analysis of each specific situation.

Moreover, from the general viewpoint, it is worth saying that the recovery heat exchangers coupled with residual waters, and the use of heat pumps could be considered: the former to pre-heat thermal waters at temperature close to 28 °C, and the latter (HPs) to supply the remaining amount of heat needed to reach the temperature of 38 °C.

Table 4 : Energy potentially usable upstream and downstream of the Italian thermal spas
(for energy potentially usable downstream, the geothermal share is indicated in brackets)

REGION	Upstream *[TJ/yr]*	Downstream *[TJ/yr]*
	Group A (all geothermal)	Groups A & B (geothermal share: %)
Abruzzo	0	8 *(0%)*
Basilicata	0	5 *(20%)*
Calabria	0	31 *(61%)*
Campania	1 122	620 *(95%)*
Emilia-Romagna	7	569 *(10%)*
Friuli-Venezia Giulia	0	16 *(0%)*
Latium	142	879 *(52%)*
Liguria	0	5 *(80%)*
Lombardy	0	155 *(71%)*
Marches	0	26 *(27%)*
Molise	0	3 *(0%)*
Piedmont	82	78 *(86%)*
Puglia	0	10 *(10%)*
Sardinia	77	62 *(95%)*
Sicily	86	145 *(96%)*
Tuscany	73	775 *(76%)*
Trentino-Alto Adige	0	67 *(16%)*
Umbria	0	8 *(0%)*
Val d'Aosta	0	3 *(0%)*
Veneto	2 034	1 809 *(98%)*
TOTAL	**3 623**	**5 273 *(74%)***

Still in general, a cost-benefit preliminary assessment could be made quickly and cheaply for the spa system of all the 20 Italian Regions aimed at establishing where the above-said re-vamping and/or use of heat pumps, could provide sizeable improvements from the energy and economic points of view.

7.3 Benefits arising from the development of multiple uses combined with the thermal balneology

Duly taken into account the results of the water and energy balance discussed in the previous chapters, and considering the possible uses upstream and downstream of the spas, together with the employment of heat pumps in place of fossil fuels or electricity to raise to 38 °C the temperature of the waters where necessary, the benefits in question can be quantified approximately as follows:

- oil saved: over 100,000 tonnes/yr, with a value of over 50 M€ at current oil costs;
- displaced CO2 emissions: at least 300,000 tonnes/yr;
- higher number of spa users: at least one million people, as compared to some 14.5 million users in 2010 ;
- increased tourist activity in the spa areas: in the order of hundreds M€ per year;
- creation of new production activities: in the order of hundreds M€ per year; and
- new jobs in the thermal localities: in the range of at least 20,000 people as a whole.

Taken together, all these benefits are thought to give notable impetus for a new blooming of the thermal spa system in Italy.

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