Geothermal

Introduction

Our planet constantly produces energy in the form of heat; from the deepest areas it spreads towards the surface: this is the so called flow of heat or geothermal flow. The heat of the sun heats the Earth's surface with a flow that is almost 6,000 times greater than what is produced from inside the Earth. However the geothermal flow, that is constant and continuous, is an important source of energy, with an average of 0.06 watts per square metre; from the entire surface of the Earth, a quantity of heat, equal to approximately 30,000 billion watts is radiated.

Use of geothermal energy for domestic heating, up to only a few years ago, suffered from two severe limitations which drastically prevented its diffusion: it was possible only at relatively high temperatures (60 - 80℃) and only in the direct vicinity of the geothermal fields because it was not possible to transport the heat too far away from the source, nor use it at low temperatures.

Recent technological developments now enable, through the use of particular equipment known as heat pumps, to exploit the Earth's heat also when the temperatures are not particularly high (12-.14℃). This has dete rmined a new and very important step forward in the geothermal sector: with the new systems it is possible in any area of the Earth, in any geological or climatic condition to obtain energy that is sufficient for a normal family's domestic heating and hot water consumption.

Geothermal knowledge

What it is

Heat is thermal energy. Consequently, the heat contained inside the Earth is called geothermal energy. However, the term geothermal energy is used to define the fraction of the earth's heat which can be exploited by human beings. The earth's inner structure is similar to that of an egg. The yoke is the central core, the albumen represents the mantle, the shell is the earth's crust. The top layer of the mantello, upon which the crust rests, is made of a fluid called magma. When the magma finds a way out towards the surface, it creates volcanoes and is termed lava.

Geothermal gradient

By moving from the surface towards the core of the earth, the temperature rises by approximately 2/3℃ each 100 metres. That increase is called "geothermal gradient" and is not constant. There are areas where it amounts to less than 1℃ per 100 metres, whereas in other "hot" or "geot hermal areas" it can be 10 times higher. They include volcanic areas where magma is a more shallow depth, so that the temperature exceeds 300℃ at 500/1000 metres.

Underground study

In order to find the most suitable areas to exploit geothermal resources, surveys are conducted both on the surface and underground. The results of the survey are used to understand what are the geological, hydro-geological, thermal characteristics and the output capacity of the geothermal system.

Surface analyses include: the exam of the underground thermal conditions and the location of possible reservoirs. First of all, the geothermal gradient is measured in various points of the area and obvious signs as smoke-holes and spas are looked for. In this respect, data provided by the chemical analysis of gas and water can be very useful.

The identification of a reservoir is the most complex part of the exploration, since it calls for the integration of the results of all the geological, volcanic, geo-chemical, geo-physical (gravimetric, geo-electric, seismic, etc.) surveys previously carried out.
The underground survey is conducted by drilling a well to verify the hypotheses that have been put forward.

Where it is

With reference to the “plate tectonics” theory (according to which the earth’s crust can be divided into approximately 20 micro-areas called “plates” which every year move between zero and 18 centimetres), the hottest geothermal areas of the globe are generally positioned along the breaking and collision margins of the plates.
The breaking of a plate causes long cracks on the earth’s crust, through which the magma reaches the surface (the Iceland Rift, The Red Sea/Rift Valley system, the Baikal lake).
The collision between two plates causes the compression and lifting of the margins: in the case of oceanic plates, island arches such as the Antilles and the Japanese archipelagos; in the case of an oceanic and a continental plate, continental ranges emerge such as the Andes. If both plates are continental, the lifting of the margins leads to the formation of mountain ranges such as the Alps or Himalayas.
Important geothermal areas are “hot spots” such as Hawaii, Galapagos, Canaries and the area included between Tuscany and northern Lazio in Italy.
The continental plates include large sedimentary basins with low-temperature geothermal resources such as those in France, Hungary and China.
From the geothermal viewpoint, Italy is the hottest area in Europe although the exploitation of its geothermal resources has been so far developed only in the central and northern regions.

Where it is produced

Tuscany and the northern part of the Lazio region are well-known for their production of geothermal energy and host the largest geothermal plants in Italy (and Europe), near Piancastagnaio, at the foot of the Amiata mountain, and in Civitavecchia.
The biggest plant is “The Geysers” plant, located 140 km in the north of San Francisco in California (USA), with a total power of 750 megawatts.
Near Orbetello an important aquaculture centre was created: seawater is mixed with water at a temperature between 17℃ and 25℃ to create the optimum environment to breed sea-bass and pandoras.
Among the direct uses of heat, the most meaningful example at European level is the urban heating system in Ferrara. It is a district heating system that supplies 14,000 flats with hot water at 102℃, coming from a locatio n at 4 km from the city, from a well at 1,300 metres of depth that was originally drilled for oil search. By extracting 250 cubic metres of water, 12,000 tons of oil are saved each year. The water is then re-injected underground.
As well as saving fossil fuel, district heating reduces air pollution, bringing many benefits to urban centres.
In the Euganean Hills area (Abano Terme, Montegrotto, etc.) and to a lesser extent in Bormio, near the border to Switzerland, hot water is exploited for spas and household heating.
According to a recent study it was calculated that with the “vapour dominant” geothermal systems that are present in Tuscany and Lazio it would be possible to produce more than 5 billion kW per hour, a quantity that would satisfy the

national demand for 70 years, while the use of “water dominant” geothermal systems would lead to a huge production of electric power, which is impossible to estimate.

A bit of history

The use of geothermal waters is a very ancient phenomenon probably dating back to the higher Palaeolithic. Nevertheless, its development from a more specifically health viewpoint originated in Japan and in Italy approximately 2000 years ago. However, although in Japan it was limited at national level, Romans disseminated it from Italy to any region of their Empire (Hungary, Germany, France, Spain, Great Britain, Turkey and Arabia).
However, spas were treated in a scientific way only starting from the Renaissance, when the book De Thermis was published by Andrea Bacci (Venice 1571). Since then, between the 17th and the 18th century, numerous spa centres are built in Europe to operate as therapeutic centres to treat mind and body. Thanks to its 170 centres, the most famous country in Europe as regards spas is Italy, but mention should be made of Hungary (the Budapest centre dates back to the Roman time) and Iceland.
The exploitation of the energy of geothermal sources developed later than spas.
The first industrial plant to produce energy was built in Tuscany in 1827. At the time, Francesco Larderel, the owner of a plant producing boric acid by extracting it from the water flowing underground in the area, had a brilliant idea. Instead of making the boric water evaporate by burning the woods of nearby forests, he decided to exploit the heat contained naturally in the water. The idea was successful and, up to 1875, the chemical industry in Larderello was the most important in the world with reference to the boric products sector. In Larderello, in 1913, the first plant to produce electricity from geothermal sources was built.
Starting from the 1920s, the geothermal industry developed also in Japan, Iceland, Hungary and, starting from the 1950s, in the rest of the world.

Geothermal fields

The Earth’s energy

Our planet constantly emits energy, as heat that comes to the surface from the deepest areas: it’s the so called **heat flux**, or **geothermal flux**.
The heat from the Sun gives warmth to the Earth’s surface with a flux that is almost 6000 times bigger than the one produced inside the Earth, however the constant and continuous geothermal flux represents an important form of heating for our planet: with an average of 0,06 watt/m2, the entire surface of the Earth radiates a quantity of heat equal to about 30.000 billion watt.
The increase in temperature as you go deeper into the Earth is a well-known phenomenon to miners: in some mines and deep tunnels temperatures reach levels that are hardly bearable by human beings (this is not so in grottoes, where the natural air and water circulation lowers the temperature substantially, such that the increase in temperature with depth is hardly perceptible). The heat of the Earth is for the great part due to the liberation of energy in the decay processes of some elements’ radioisotopes such as, for example, potassium, thorium and uranium. Because of the different levels of thickness of the terrestrial crust and of the different geological situations, which can cause the seeping of hotter materials from deep zones, the geothermal gradient (that is the increase in temperature with depth) is not the same on the whole Earth’s surface: on average the temperature increases by 2-3°C every 100 m of depth, but the increase can vary from 1 to 5°C/100 m.

To measure the geothermal gradient you have to dig wells of at least 300 m of depth (so as not to be influenced by daily and yearly variations in temperature due to climate changes), where specific thermometers are lowered in order to register temperatures at different depths.
The heat flux is greater in the areas where the lithosphere's thickness is reduced, for example, along the oceanic ridges or in the areas of continental rifting, or in volcanic areas, where various geological processes cause the fusion of rocks, or in areas where the subsurface holds magma undergoing a slow cooling process.

Special zones: geothermal fields

Zones that are characterised by a high and anomalous heat flux are those where the release of energy from the ground is greater, however to be able to use this source a fundamental ingredient, together with hot rocks, is water.
Water heats up thanks to the contact with hot rocks below the surface and, if the temperature and pressure conditions allow it, it can even turn into steam. In order to understand the phenomena in these anomalously hot zones, we must recall that the temperature at which water turns into steam depends on the pressure: when pressure measures 1 atm, vaporisation temperature is, as we know, 100 degrees Celsius, but at 10 atm (equal to the pressure of a 100 m water column, o about 30 m of rock), it goes up to 180°C . In this way, therefore, high pressures keep water at the liquid state even at much higher temperatures than those 100°C that we associate with water boiling in a pan!
The areas where a high heat flux warms the subterranean waters are called **geothermal fields** and are generally distinguished in **high and low temperature geothermal systems** (also called **high and low enthalpy systems**). In these areas it is possible, with the right technologies, to exploit the Earth's natural energy to produce electricity, for domestic heating and for many other industrial uses: all in all a cheap energy source, almost unlimited and also relatively clean. Unfortunately, geothermal fields that are able to produce a good quantity of energy are not many, in the world.
How does a geothermal field look like?
All geothermal systems' structures look a bit like hydrocarbon traps and the techniques to individuate them, which use geophysical prospecting, are also very similar to the ones used in petroliferous research.
A geothermal system is constituted by:

- a **source of heat** (for example, magma undergoing a cooling process);
- an **aquifer**, that is a permeable geological formation, where water can infiltrate and circulate freely through pores or fractures;
- an **impermeable cover rock** that acts as a “trap” for the hot waters, preventing their dispersion on the surface and keeping them under pressure.

Finally, in order to allow a lasting exploitation of this energy source it is necessary to have a constant refill of water coming from the surface, generally meteoric waters, that can “refill” the aquifer, integrating the water drawn by man: where this is not so, it is necessary to input fluids artificially.

Electricity from the ground

In high temperature geothermal systems, the underground waters are very hot, usually, over 140 °C. Te mperatures can be even higher, such as, for example, in Larderello (Toscana) (260°C), Cerro Prieto (Messico) (388°C) or S. Vito (Campi

Flegrei, Campania) (400 ℃): the latter area has re gistered the highest temperature ever observed in a geothermal system. In these systems the heat flux is 3-4 times higher than normal and can generally be found in correspondence with cooling magma intrusions, between 3 and 15 km of depth.
Geothermal systems can present both an ascent of “dry” and overheated vapour, in the absence of liquid water (this constitutes the so called “**vapour-dominated systems**”), and an ascent of a mix of liquid water and vapour (“**water-dominated systems**”). Vapour, drawn through wells and systems of pipes, is used to give power to a turbine system, which in turn produces electricity. Vapour-dominated systems are the most productive, because in water-dominated systems the liquid phase has to be separated and eliminated and this entails an expenditure of energy.
Vapour-dominated systems are quite rare and there are only four, spread around the globe: Larderello and M. Amiata (Italy), The Geysers (California), Matsukawa (Japan) e Kawah Kamojang (Indonesia), while the most important water-dominated ones are in Wairakei (New Zealand) and Cerro Prieto (Mexico).
The production of electricity from geothermal fields is an Italian initiative: it started in Larderello in 1904, followed only many years after by the Wairakei plants (New Zealand) in 1958 and The Geysers (California) in 1960: Italy was a precursor in the exploitation of geothermal energy and to this day our country is one of the major world producers.
Currently the main producers of geothermal electricity are, in order of productivity, the USA, followed by the Philippines, Mexico, Italy, Japan, New Zealand, Salvador, Kenya and Iceland (see graphs and energy tables). The discovery of new geothermal fields is an exceptional event, however technological research allows a continuous increase in productivity of the existing fields.

A comfortable warmth

In low enthalpy systems, where temperatures are below 140°C, direct production of electricity from va pour is not generally convenient. However, if temperatures are above 90°C it is possible to use warm fluids to va porise a second fluid that has a lower boiling temperature (such as freon, isobuthane or ethyl cloride), thus obtaining vapour for indirect electricity production, even if the productivity level of this process is rather low.
Hot waters though lend themselves to a variety of uses, with a “cascade” scheme, that first uses hot fluids in applications that require higher temperatures, and then reuse them, in applications that require lower temperatures, as they get cooler.
Its primary application is for urban heating, for which water between 130°C and 50°C can be used. Ho t water fields are used for domestic heating in various states around the world, especially, in order of importance, in Japan, China, Hungary, ex- URSS, Iceland, Poland, France. The first experiments of geothermal heating for domestic usage took place in Iceland in 1930: in this country, a significant part of the capital’s houses heating comes from low-energy geothermal fields. In Italy this method is applied, for example, to hotels in the thermal area around Abano Terme (Colli Euganei, Veneto) and many buildings around Larderello (Tuscany).

A "cascade" of applications

After being used for electricity production and domestic heating, geothermal fluids still have a certain quantity of heat that allows their usage in a variety of ways, some of which very peculiar: in Sapporo (Japan) and Klamath Falls (USA), for example, hot waters are used for **heating the roads** during the winter to avoid the formation of ice.
Various productive processes benefit from the use of geothermal waters. For example, special absorption systems for refrigeration with ammonia or lithium bromide used for cooling and summer air-conditioning are obtained from hot waters,

if the temperatures are between 80-120 ℃.
Among the productive uses, agriculture and zootechnics are the sectors where the use of geothermal energy is more immediate and advantageous. The hot waters are used for direct heating in greenhouses: very well-known examples are the Piancastagnaio greenhouses (M. Amiata, Toscana), or the Colli Euganei (Veneto) cultivations of ornamental plants. In countries where the climate is particularly cold, such as, for example, Siberia, the hot waters are made to circulate in a system of pipes that are in contact with the ground, the so called “hot beds”, obtaining the heating of the cultivated ground, which allows cultivation even under conditions that would otherwise be prohibitive for agriculture.
The warmth that is produced by contact with hot waters is exploited for all zootechnic and agricultural processes that require a warm environment, such as, for example, mushroom cultures, fish and animal breeding and egg-hatching in poultry farms.
Other uses in the agro-alimentary sector regard wood and fish dehydration, the preparation of tinned food, the production and seasoning of dairy products or sugar refining, while more industrial uses regard the production of heavy water, aluminium, cement production processes, tire vulcanization and many others.
The waters that circulate deep underground are often rich in salts and minerals: these can represent a problems, in terms of pollution, but they can also become an important resource, as for instance for the extraction of suplhur, boron and metals.
We must not forget the therapeutic uses. The habit to go to thermal baths was spread in Europe by the Romans, who exported it in all the territories they conquered, but it has been present in Asia for centuries: only in Japan there are more than 1600 thermal centres, some of which have very ancient origins. In Italy thermal complexes are about 170 and they are exploited not only for the heat of the waters, but also for the therapeutic effects of the minerals present in them. The benefic effects of a thermal bath are wll known also by the macaque population of the Nagano springs, in Japan, who bathe there during the winter months to keep warm: the funny images of the little animals happily lying in the warm water, with the coat covered in snow and red snouts, have gone all around the world and now the Nagano macaques have become a famous tourist attraction, so much so that, in typical oriental fashion, an area of the thermal baths has been reserved for them only!

Our local systems

Italy, because of its geological situation, is rich in both high- and low-temperature geothermal fields. The "symbol" and flagship of the geothermal energy in our country is definitely represented by the Larderello-Travale-Radicondoli thermal field, in Tuscany.
Here electricity was produced for the first time in the world, but the exploitation of the "soffiones" goes back to the Middle Ages, for the production of sulphur and sulphuric acid, and, from 1780 onwards, for the production of boric acid. If the resource is entirely Italian, the first use of thermal energy for boric acid extraction was enacted by a Frenchman, Mr. Larderel (who gave the name to the place), since the vapours of the soffiones are rich in boric acid.
The first experiments of electricity production took place in 1904 and the first production plant was born in 1912, with a production of 250 kW, but it was only since 1930 that electricity production became an important part of the renewable energy sources of our country. With a capacity of 790 MW, exactly 100 years after the first experiments, the Larderello plant reached in 2003 its maximum productivity level, with a production of 5340 GWh. Research in this field hasn’t yet stopped: currently a 3D seismic prospecting is being realised, associated to the perforation of 11 new deep wells (of between 3.000 and 4.000 m of depth): in the last 5 years, a total of 21 wells has been realised, with an overall length of 64 km!

The second “historic” Italian geothermal field is situated not far from Larderello, on M. Amiata, where electricity is produced by an 88 MW plant.
Apart from electricity production, the Tuscan plants provide water for domestic and greenhouse heating, for dairy production and fish farming and fuel the production of CO_2 and boric acid.
Recently other interesting fields have been discovered in Lazio (Alfina e Cesano) and in the Campi Flegrei area (Napoli), apart from the Colli Euganei area (Veneto) and around Ferrara.
Fields of hot water have been discovered in the Pianura Padana subsoil, at S. Donato Milanese (Lombardia), between 1900 and 2400 m, with temperatures between 70 and 80 °C, and similar fields have been detected in the subsoil of Villaverla and Vicenza (Veneto) and Ferrara (Emilia Romagna). In the subsoil of the Casaglia area (Ferrara), where carbonated aquifers with a temperature of 100°C ha ve been found at 1200-2000 m of depth, one of the most important projects of geothermal district heating in the world is being realised, which entails the heating of tens of thousands of houses.

Clean energy?

Geothermal energy is usually considered clean energy. Its production in theory doesn’t produce dusts or toxic substances that could be dispersed in the atmosphere and there is no toxic waste to dispose of: the only subproduct of the energy process are the white plumes of the clouds of vapour that are released by the cooling towers.
However, unfortunately, things are not so simple and “clean” in nature. The waters that flow underground are rarely freshwater: in the majority of cases they are highly concentrated saline solutions, which often contain highly toxic and polluting substances. Vapour is generally associated to other gases, like H_2S and CO_2, while the waters often contain heavy metals or arsenic. This characteristic, among other things, prevents a direct use of the geothermal waters: because of the chemical characteristics combined with the high temperatures, these waters are very aggressive and rapidly erode the pipes and machinery which they touch, so it is necessary to use special materials. These types of waters obviously cannot enter in direct contact with agricultural grounds and products, animals or food and their use must necessarily be indirect.
From the environmental point of view, the quality of geothermal fluids is such that the discarded gases and fluids must necessarily be treated before they can be readmitted in the atmosphere or in the circuit of superficial waters. The best solution is to condense and separate the polluting gases before freeing the vapour and readmitting the liquids in the subsoil.
Moreover, the big cooling towers of a geothermal plant usually have a significant environmental impact from the aestethic point of view, even though, of course, this type of “pollution” is definitely preferable to that of a fossil fuel thermoelectric plant! However, natural expressions linked to the presence of geothermal fields, such as the emergence of thermal waters and phenomena lilke geysers, often make these areas particularly valuable from an environmental and landscape point of view; moreover, often in these areas there are prestigious thermal baths, of historical and economic value, therefore even the aestethic impact of the plants can represent a serious problem. The vapour turbines also produce a significant acoustic pollution, even if this problem can be easily solved through specific isolation systems. From these short considerations we can conclude by saying that geothermal energy is “clean” if some fundamental rules are followed!
Energy forever?
The Earth’s energy is, compared to the scale of human life, apparently inexhaustible, however even the use of geothermal fields has to be accurately controlled and managed. Geothermal fields tend to progressively cool down,

which diminishes their productivity: the constant input of cold waters can noticeably increase this natural process. In the same way, the excessive withdrawal of fluids from the subsoil can trigger subsidence phenomena (as happened, for example, in Wairakei), which are very dangerous in densely populated areas. To remedy to this phenomenon the fluids have to be put in the subsoil: in this way, not only the nearby areas are protected, but the life of the geothermal system is prolonged, thus minimising its utilisation problems. It is clear though that this resource is also delicate and needs to be managed with care and knowledge in order to maintain a good level of productivity without harming the surrounding environment.

New frontiers

Technological development and the need to retrieve energy from the highest possible number of sources are contributing to the rediscovery of geothermal energy and an increase of its areas of utilisation: of the “clean and cheap” energy provided by our planet, nothing is wasted! Using systems of heat pumps, which extract heat from a fluid using small quantities of electricity, heat that is then yielded to a heat tank, waters with very low temperatures can be used for domestic heating, up to 30-40°C. The same waters c an be used directly with panel heating systems instead of heaters.
Currently there are studies concentrating on the exploitation of the so called hot dry rock fields. At high depths (around 5,000 m), even under normal heat flux conditions, the majority of the rocks is sufficiently hot to be able to fuel a geothermal system. If the warmth from the Earth is always available, sometimes though the other fundamental “ingredient” for the use of geothermal resources is missing: underground water circulation. In this case, nature has to be “helped” to create a tank that will aide the formation of a geothermal system: cold waters are artificially pumped into deep wells, after having seen to the fracturation of the surrounding rocks to allow the water to penetrate, in order to recreate an aquifer system similar to a natural geothermal field, from which it is possible to draw heated waters.
Currently they still are experimental and expensive systems, but the first attempts appear encouraging and in a few years energy production from dry rock fields could become a reality. These systems, however, are very “invasive” and their long-term effects are still not predictable: since one of the most probable side effects is to trigger subsidence phenomena on the surface, the experiments are currently undertaken in desertic or scarcely populated areas, like in the New Mexico desert.
In some areas of the Earth, such as the Mexico Gulf, geothermal systems have been discovered at a depth of 4,000 m, where hot waters are mixed with methane at very high pressures: in this case, the exploitation would yield geothermal energy as well as significant quantities of hydrocarbons. The Hawaii islands, thanks to the heat of the various active volcanoes, also constitute a formidable experimental ground. For example, there is an ongoing experiment for the production of hydrogen from very hot waters that are heated by volcanic magma, the temperatures of which are around 900-1,200°C. What however represents the ultimate frontier in this field of research is the possibility to put organic waste in contact with hot magma to produce gaseous hydrocarbons. Will man really be able to reproduce Nature’s processes to create energy?

Geothermal plants

Geothermoeletric plants

A geothermal field is the area that can be exploited within a geothermal system. A “high temperature field” can always be connected to a plant for the production of electric power. This plant is different from a thermoelectric plant only because the vapour needed to move the turbines and produce electricity is not obtained by burning fossil fuels, but it is a natural

underground product.
In a “dominant vapour” field, like in Larderello, the vapour is directly sent to the turbine. After the use, the vapour is condensed, depurated from non-condensable gases (i.e. carbon dioxide) and injected underground through special wells, so that the most adequate pressure level is kept in the tank.
In a “dominant water” field, the water/vapour mix that comes out of the geothermal well passes through a “separator”. In this way the vapour, that has to be sent to the turbine, separates from the water that will be injected again or dispersed outside.
Geothermoelectric plants can be of different types: “counter-pressure” if the vapour, after being exploited, is released into the atmosphere; “condensation” if the vapour, after being used, is condensed and injected underground through a special well.
“Flash” plants are installed in water-dominated areas and are equipped with a separator that separates the vapour to be sent to the turbine from the water that is to be eliminated. In general, the geothermal fluid is used to vaporize a second liquid (i.e. isopentane), by means of a heat exchanger, at a boiling temperature that is lower than water boiling temperature. The resulting vapour is then sent to the turbine, condensed and sent to the exchanger in a closed circuit. The geothermal fluid, instead, is injected underground again. This is closed circuit is very ecological, as the pollutants contained in the geothermal fluid are not released into the external environment.
In Italy in 2010 geothermal energy produces 5.876 GW megawatts of electric power.

Air conditioning plants

With geothermal power it is possible to supply our houses with air-conditioning. Small geothermal plants are built for small buildings, medium-sized and big buildings. A heat well is made by drilling with an adequate drill and using some coating tubes deep underground in order to prevent the land from sliding down (it can be done in a small space like a garden and small courtyard). The heat well can be built in any area, on any kind of land and regardless of the height of the aquifer. Once the drilling as been concluded, and the final depth has been reached, heat exchangers are introduced in the hole and connected to an external collector that balances the heat flow that comes from the soil and directs it to heat pump inside the building. Later the hole is filled with a mixture of cement and bentonite in order to avoid any form of pollution.
In winter the heat exchanger allows to take the free heat from underground and, through the heat pump, use it to warm up the buildings (also sanitary hot water is produced by conveniently extracting heat from underground). In the summer, the excessive heat inside the building is eliminated by transporting it underground through the heat exchanger (summer air-conditioning is particularly convenient if compared to the electric consumption of air-conditioners).

Subsoil heat for our homes

Interesting news regarding energy for our homes

A practically inexhaustible source of energy to heat our homes at a very low cost and in a clean and environment respectful manner: this is the dream of millions of families all over the world... certainly also ours!
Geothermic energy seams to answer all these requests and, since the dawn of civilization, man has learnt to use the heat inside the Earth. Initially man enjoyed the pleasure of thermal baths with naturally heated water and later on, at the beginning of the 20th century, learning to use water to produce electric energy

(5,876 GWh were produced in Italy in 2010). Moreover, water was also used to warm houses of entire cities (the first district heating plant was started in Iceland in 1925). However, until a few years ago, the use of geothermal energy for domestic heating had two important limits which strongly held back its diffusion: geothermal power could be obtained in the presence of relatively high temperatures (60 – 80 °C) and o nly in the area of the geothermal fields; the heat used was therefore endogenous: it was not possible to transport the heat too far from its source nor was it possible to use it at a low temperature (that is to say at a “low enthalpy”).

With the recent technological developments, it is now possible, through particular instruments known as heat pumps, to use the heat of the Earth even when temperatures are not particularly high (12 – 14 °C). This has brou ght about a new and important step forward in geothermics: with these new systems, it is in fact possible to obtain sufficient energy for a family’s everyday heating and warm water consumption, in any place of the Earth, with any geological or climatic condition. The energetic possibilities of this new technology are huge and potentially unlimited.

Energy directly from the Earth

The Earth has its own internal energy, that is responsible for the dynamics of our planet, and volcanic activity is its most evident example, however, this energy also spreads silently and continuously towards the surface in the form of heat: this occurs in every spot of the Earth, even in those areas which do not seem to have any volcanic or geologic activity. Deeper and deeper into the subsoil, the rock temperatures increase with a gradient of 1°C every 33 m in depth on average, ev en though there are areas which are particularly active, where the temperature increase is more consistent (as for example in volcanic areas): in these particular areas, the so called geothermal fields, the energy found deep in the Earth is exploited to produce electric power. However, this requires very high temperatures, so it is possible only in some fields, called high enthalpy fields (or high temperature fields). The Earth's internal heat can be exploited also when the temperatures are not very high, not for the production of electricity but to obtain heat for domestic heating or for other industrial uses (refer to the special report on geothermal energy). If special devices such as heat pumps are connected to the process to “capture” endogenous heat, an “indirect” use of thermal energy of the Earth becomes possible , and much lower temperatures of “direct” geothermal energy can be exploited: and therefore there is the possibility of a greater diffusion of this use of geothermal energy also in areas without the particular geological conditions of the geothermal fields.

The Sun's contribution

The subsoil does not only receive energy from the depths of the planet. The Sun's energy warms the Earth's surface and about 47% is directly absorbed by the soil: the temperature in the first metres of the subsoil are subjected to daily and seasonal variations according to the radiation received. These variations are more sensitive in the first decimetres or meters and weaken, until beneath about 20 m where the temperature is not affected by the external temperatures, but only by the geothermal gradient.

If there is the possibility of using even minor quantities of thermal energy, then the heat can also be obtained from this superficial layer: in this case, it is not the internal heat of the planet which is exploited but the energy provided indirectly by the Sun (so, in this case, the word "geothermics" is used incorrectly, but, as the same technology is used, usually this sector is included in the geothermal sources).

Two different sources

Low enthalpy geothermics therefore uses two distinct layers of the subsoil:

-the first layer is from 50 – 150 m to about 350 m deep, where deep geothermal heat from inside the Earth is exploited: here temperatures are constant all year round, and similar all around the planet, due to the effect of the regional geothermal gradient (on average about 12℃ at a dep th of 100 m, between 14 and 20℃ at a depth of 150 – 300 m, with the exception of the geothermal fields, where the values are much higher);

-the second layer, instead, is superficial, from few metres to 50 – 60 cm deep (just below the layer of the Earth which can freeze during winter) and exploits the heat stored by the Earth by effect of solar radiation in the warmer months, and thermal inertia of the ground in returning the energy received: in winter the soil slowly releases the heat stored in the summer months, and will therefore be warmer on the surface, instead it will be fresher in the summer.

A "domestic" energy: geothermics for homes

"Classic" geothermics uses heat directly from the Earth, using warm water extracted from the subsoil and then distributed to households or industrial installations. Now the use of special instruments, heat pumps, allows a much larger use of geothermics, independent from the particular conditions of a geothermal field. These installations are small, and can satisfy small household needs - such as household air-conditioning; and for this reason it is called "domestic geothermics".

Domestic geothermics uses natural subsoil heat through special probes positioned at various depths, using heat pumps to "multiply" the thermal energy (with a small addition of electricity), and then distribute it in the homes for the heating system in winter and air-conditioning in summer, and for the production of hot water for the bathroom.

How it works

Even though it is characterised by very high technology and very high performance, a domestic geothermal system is very simple. It consists of three principal elements:

- geothermal sensors or probes: these are simple pipes dug in the ground which have the task of absorbing the heat of the subsoil. So that the heat exchange with the ground is more efficient, the probes are filled with a so-called "thermovector" fluid, characterized by high thermal conductivity.

- heat pump, or thermopump: it is the "heart" of the system, in practice a generator that uses the heat extracted from the probes so that it can be exploited by the distribution system.

- an internal heat distribution system: this is the normal heating distribution system that is present in all the homes; however, so that the system can exploit geothermal energy in the best manner, using only a very small amount of external electricity, it is advisable that this should be a low temperature type of system (35℃), for example, radiation panels instead of normal radiators, that use water at a high temperature(60-70℃). The same system can be used for

cooling in summer by simply inverting the heat pump operation.
Additionally there is a reservoir to accumulate the hot water (very similar to a normal "boiler").

What is a heat pump?

A heat pump is an instrument which allows heat exchange between a source of energy (for example the ground but also the air of the atmosphere or the water of the ground water table) and an environment with a different temperature.
It works like refrigerator, and can work both ways (for heating in winter or for cooling in summer).
A heat pump absorbs heat from the "vector" fluid in the probes, through evaporation in an evaporator, after which the temperature is increased using a compressor that releases heat into the surrounding environment through a condenser, and is connected to a distribution system that distributes heat all around the home. In a domestic geothermal installation, the heat pump can increase the water temperature from 8 - 12°C of the vector fluid to about 35 – 40 ℃ of the water that circulates in the radiant panels of the distribution system; however water temperature can be increased to much higher temperatures (approximately 70℃) if the system us es radiators. In summer, instead, water temperature for the air conditioning can be 8 – 10 ℃ lower than the tempe rature of the environment.
During this process the heat pump uses electricity, however modern heat pumps are extremely efficient systems with a very high performance, that can produce much more (thermal) energy than the (electric) energy that is consumed. The heat pump's performance is indicated by "COP", coefficient of performance, that is to say the ratio between energy produced and energy consumed. In modern pumps, COP is about 4 or 5: this means that with1 kW of electricity it is possible to obtain 4 to 5 kW of thermal energy.
The heat pump's performance is inversely proportional to the difference in temperature between the source of energy (in this case the subsoil) and the environment to be heated (or to be cooled): the greater the difference in temperature, the lesser the performance of the heat pump will be, and therefore the greater the electricity consumption will be. For this reason low temperature radiant panels are preferable (in the floor or in the wall) to the radiators, and for the same reason geothermal heat pumps are more efficient than those using heat of the air outside as a source of heat (which is much colder than the subsoil: if the air temperature is less than -5℃, air heat pumps do not work).
A heat pump for a home of approximately 100 m^2 is more or less as big as a fridge, and just as noisy, no exhaust gas or fumes are produced, no oxygen from the air is burnt (as in the case of common heating system burners) and therefore can be installed safely also inside homes. Heat pumps last about 15 years, just like heating system burners.

Different types of probes

To "capture" the heat of the subsoil, two types of probes are used, depending on how deep they are positioned.
In order to use geothermal energy, "vertical probes" are set up. These are simply a couple of U shaped pipes with a 10 - 18 cm diameter, that are positioned in wells at variable depths, between 50 and 350 m. The optimum depth for a home of approximately 100 m^2 is about 70-100 m; if the volume to be heated is greater, the probe can be positioned at depths up to 300 – 350 m, but not deeper, because drilling deeper has decidedly non competitive costs.
The pipes are made of polyethylene, a material that is inert respect to the chemical composition of the soil, it does not corrode and can guarantee good thermal conductivity. The empty space between the pipes and the walls of the well is filled in with bentonite, a special clay which guarantees good thermal contact between the

probe and the ground. The pipes are then filled with a mixture of water with 15-20% “thermovector” fluid, which is similar to the antifreeze liquid used for cars, which can absorb the heat of the ground to a higher degree than water alone. The pipes connect directly into the heat pump, and the circuit is sealed to guarantee there are no leaks: therefore there is no pollution and there is water saving, as the water is made to circulate constantly without adding more water. For the vector fluid, non-toxic substances are used, that do not damage the ozone in the atmosphere (so called “*ozone friendly*” compounds, without CFC), so also disposal , once the system closes, does not cause environmental problems.

A geothermal domestic system is installed in 3 – 4 days, the time required to dig the wells for the probes and to connect the system to the home distribution network. The probes last approximately 50 – 100 years and the system practically does not need maintenance.

Instead, in order to use energy absorbed by the ground from Sun radiation, so called “horizontal sensors” are used. The principle is the same as for the vertical probes, but instead of digging a well into the ground, a coil of pipes (made of copper or polyethylene) are laid about 60 cm underground (just under the superficial layer of the soil, which could freeze during the winter), or a series of small probes (“heat energy piles”) is positioned a couple of metres deep. For a home of approximately 100 m^2, 120 - 150 m^2 of capture surface, in contact with the soil is necessary: it is therefore an economic solution, that is easy to install if there is a small garden where it is possible to lay the sensors underground.

The only limitations linked to the use of the garden for a system with horizontal sensors are that the area above the probes must not be covered by paving or tar and tall trees cannot be planted because the roots may damage the sensors: apart from this, the garden or the orchard can be cultivated and used as usual.

Also in this case, the circuit that conveys the fluid (usually water with glycol) to the pump is closed, so there are no problems regarding emissions of gas or fumes: also this is a clean and environment respectful method.

In the presence of a water table, the so called “capture wells” can be used. These use the water directly from the water-table, which is extracted and then sent back into the ground: in this case the water is used both as a source of energy and as a the vector fluid. It is a very efficient system but it is more expensive and cannot always be used, in particular in the presence of a water table used a source of drinking water.

An analogous system can be realized, by exchanging heat and the water of a lake or of a pond close to the home: this type of system has been set up to supply air conditioning in the Palace of Nations in Geneva, using the water of Lake Geneva (Lac Léman).

Increasingly widespread

Domestic geothermic installations can entirely replace a traditional combustion plant with an autonomous and not just integrative solution (as in the case of solar panels, which do not allow a complete autonomy due to the variability of the energy supplied). They are systems which are particularly suitable to satisfy the needs of small homes, isolated villas and small groups of houses; and also schools, municipality buildings, gyms and swimming-pools. For this reason in many countries, families decide more and more often to use this type of alternative energy for heating. But this system is not used only for homes: in the last years, a true *boom* of geothermal heat pumps has been noted, also for greenhouse farming, fish farming and balneology (heating in spas and swimming pools) and in many Northern countries also to heat the footpaths and streets, keeping them free from ice in winter.

The same system which guarantees heating in winter can be used for cooling during the summer, and a constant production of warm water, with a thermal energy production which does not vary during the course of the year.

In our country, domestic geothermics is just beginning to take off, but in many countries it is already a well-established tradition. The countries which are presently *leaders* in this field, with the largest number of installations, are the USA (with over 3,093 MWe), Philippine (1.904 MWe) , Indonesia (1.197MWe), Mexico (958 MWe) and Italy (843 MWe).

It is estimated that a growing number of homes will plan on using domestic geothermics for the conditioning systems in the buildings: this system in fact allows the owners to save a large amount of money in terms of heating bill during the winter, it guarantees warm water and a cool house during the summer, nearly free of cost, and represents a great "global" saving for the environment, in terms of a minor consumption of fossil fuels and the consequent reduction of greenhouse gas emissions.

The price and savings

Thanks to the use of technologically advanced instruments, the performance of a geothermal domestic system is very high: in the case of heating with radiation panels (the most profitable with this type of energy), savings on costs of heating are about 60% respect to traditional heating systems using methane, and can reach 80% respect to systems using oil or LPG.

To give an idea of the possible savings, it is sufficient to examine the expense of heating for one year for every m^2 to be heated, from 4.6 to 7 € for a geothermal installation, from 9 to 13.7 € for a methane combustion system, and from 14 to 21.7 € for a LPG system.

In the production of warm water, there is a saving of about 30% in winter, while in summer the production is free, because the water is heated (to about 60 – 70℃) u sing the heat taken from the air for the air-conditioning.

For a home of 100 m^2, the cost of the installation is about 10,000 – 25,000 €, depending on the geological conditions and the type of system (vertical probes are more expensive), therefore similar to a traditional oil, methane or LPG system for the same amount of radiant surface installed. The heat pump costs little more than a good heating system boiler, and the higher price is for building he distribution system (which is necessary for every form of heating, whatever the source of energy may be).

In about five years, energy savings are able to cover the initial expense. In addition, incentives are foreseen until 2010, which consist in a tax relief of 55% on the total cost, for the substitution of winter heating systems with high efficiency heat pumps and low enthalpy geothermal systems.

Since, for the best performance the heating distribution system must be of the type with radiation panels, if the house does not already have this type of radiators, it is not convenient to substitute the traditional systems, however it is certainly convenient to choose this type of a heating/conditioning system when designing new buildings.

An inexhaustible and environment-friendly energy

The geothermal air-conditioning system is indicated in the White Paper for the Future "renewable sources of energy" COM97 of the EU as a possibility to heat and air-condition our homes in a manner that is clean and sustainable for the environment.

In fact, this system produces very low levels of CO_2 and gases which are noxious for the environment: the emissions depend on the amount of electricity required to make the heat pumps operate, however, observing the performance of the heat pumps, the thermal energy obtained from the subsoil and “increased” by the pumps, is 4 times greater than the energy consumed.

The energy obtained from the subsoil is a renewable energy, rather, it is practically inexhaustible, and very clean: the use of endogenous heat in fact does not produce emissions of any kind, neither CO_2 nor other gases (like sulphur compounds or nitrogen oxide), nor fine particles. In traditional geothermics deep fluids are brought to the surface with a resulting danger of contamination of the superficial ground water with waters coming from the deep, which often have a high content of minerals; however, in domestic geothermics this risk is not present, because no fluids are extracted from the subsoil.

Thermovector fluids, which circulate in the closed-circuit probes, never come into contact with the ground or the water of the water-table and, in any case, it is guaranteed that materials that are not toxic for the environment are used. Closed circuits allow a great water saving. The water, once put in the system, is continuously reused. The installations are quite small and their visual impact is practically inexistent: once built, all that can be seen is the heat pump, the size of a fridge, and the warm water reservoir similar to a normal “boiler”. The noise of the pumps is similar to that of a fridge, they can therefore be installed inside the homes. The only “limit” to the diffusion of this new domestic air-conditioning is its use in big buildings (as for example a large building with numerous floors), which requires the installation of various probes (or deeper wells, with consequent higher expenses) and the installation a greater number of heat pumps.

A healthier home

The environmental benefits of this new form of geothermal energy exploitation are evident, not only on a “global” scale, but also inside homes, this system helps creating a healthier atmosphere. In fact as there are no open flames, no exhaust gases, no fumes, no fine particles are produced , and no oxygen is burnt, therefore the air inside the home will be cleaner: in the houses where this type of heating is used, there will not be any problems of black deposits on the walls and on furnishings (which instead usually force us to paint our homes periodically).

Also heating with radiation panels at a low temperature is healthier: in fact it allows a better regulation of the temperature in the rooms which will have more uniform temperature, and not concentrated near the radiator, the air will be less dry and the low temperature of the panels will not create the problem of a feeling hot legs caused by the high temperature radiation panels: our floors will be pleasantly warm in winter and nice and fresh during summer.

Domestic geothermal installations are also extremely safe: there is no combustion, so no open flames, nor pipes containing gas, nor cylinders or tanks containing inflammable materials (like oil or LPG) and the possibility of an accident is practically inexistent.

Therefore, domestic geothermics seems destined to represent the future of thermal energy in our homes, and it is nice to think that while our garden fills with flowers, just a few metres below the surface, energy which will keep us warm in the winter and cool in the summer is generated, with no wastes nor pollution.