# Alliance of renewable energy resources for sustainable building - algerian case

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**Abstract** - *At present, the convergence between the scarcity of fossil resources and their threat to the environment leads to considering renewable energies as an alternative in the production of heat in countries privileged by their climate and geology. These sources of energy are deemed almost inexhaustible, omnipresent, stable and clean. The Algerian construction sector is the most energy-intensive compared to other economic sectors. This unbounded energy consumption can be corrected with a more economical design of passive buildings to finally work towards buildings with net zero energy consumption. In this work, the emphasis will be on the possibility of combining geothermal energy with solar thermal power in order to exploit them in a sustainable construction project. The integration of solar thermal in a construction project has already been the subject of large studies and is still under development; therefore, we will focus, as a first step, on the integration of geothermal energy in a sustainable building.*

**Résumé** - *A l'heure actuelle, la convergence entre la raréfaction des ressources fossiles et leur menace sur l'environnement, amène à considérer les énergies renouvelables comme une alternative dans la production de chaleur dans les pays privilégiés par leur climat et leur géologie. Ces sources d'énergie sont considérées quasi-inépuisables, omniprésentes, stables et propres. Le secteur de la construction Algérien est considéré comme le plus énergivore en comparaison aux autres secteurs économiques. Cette consommation énergétique démesurée peut être corrigée avec une conception plus économique de bâtiments passifs pour enfin œuvrer vers des bâtiments à consommation énergétique nette zéro. Dans ce présent travail, on mettra l'accent sur la possibilité d'allier la géothermie au solaire thermique dans le but de les exploiter dans un projet de construction durable. L'intégration du solaire thermique dans un projet de construction a déjà fait l'objet de nombreuses études et est toujours en cours de développement, on se focalisera donc, dans une première étape, sur l'intégration de la géothermie dans un bâtiment durable.*

**Keywords**: Renewable energies - Geothermal potential in Algeria - Sustainable construction.

## 1. INTRODUCTION

Environmental and economic concerns have expressed the need for energy savings. From a climatic view, the Maghreb benefits a mild environment in the north, very cold in the highlands on winter and very harsh and dry in the south. In order to limit heating requirements while ensuring adequate internal comfort, the improvements to the envelope are therefore necessary.

In accordance with the United Nations projections, global population growth will reach 8.3 billion in 2020 and then slow down to reach 9 billion by 2050, giving rise to a significant energy supply needs. Today, though renewable energy resources are used around the world, the accessibility to renewable energy sources remains a challenge.

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The low density of solar radiation to the surface of earth and its fluctuations encourage, on one hand, the introduction of a means of storing energy by latent heat and, on the other hand, the exploitation of the geothermal resource.

The purpose of our study is to use geothermal energy for the benefit of a sustainable construction. The work, presented in this paper, is an introduction to the application of geothermal energy for heating and cooling buildings via energetics geostructures.

Figure 1 represents a sustainable building of the future that exploits photovoltaic, solar thermal and geothermal energies combined with storage elements. Our work consists, in a first step, to define renewable energies in the situation of Algeria and their applications in the building sector; more details will be given on geothermal energy.

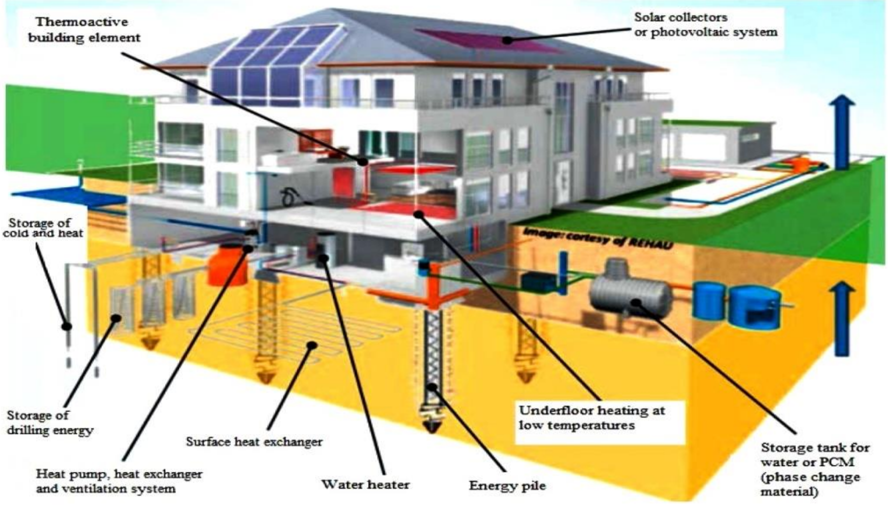



Fig. 1: Futuristic representation of a sustainable building exploiting renewable energy resources. [1]

## 2. RENEWABLE ENERGY RESOURCES SITUATION OF ALGERIA

Algeria has a considerable renewable energy potential. These clean energies produce heat through the calories of the environments of the nature such as sun, earth or air. Among these renewable resources and as part of our study, we will focus on thermal energy in its forms and more particularly to geothermal energy.

### 2.1 Solar thermal and photovoltaic energy

In addition to being inexhaustible, solar energy can both heat (solar thermal energy) and produce electricity (photovoltaic solar energy). Photovoltaic solar energy is used to supply electricity in insulated sites: rural electrification and water pumping, telecommunications and signaling, and domestic applications. For hot water production, the solar thermal is very effective in the summer, it is also useful for heating purpose in the winter when combined with other energy (fuel or electricity).

The solar potential is estimated to 169440 TWh / year. In almost the entire national territory, the duration of insolation exceeds the 2000 hours annually to reach the 3900 hours (highlands and Sahara). The energy received daily on a horizontal surface of 1 $m^2$

is about 5 kWh over most of the national territory, nearly 1700 kWh/m$^2$ in the North and 2263 kWh/m$^2$/year in the South of the country.

The integration of solar thermal in the environment and more particularly in the architecture is durable, efficient and clean, because it is used directly and is renewable [2]. In the construction industry, the choice of the site and its orientation is an essential element for its exploitation [3]. Solar radiance reaches the earth in direct form, diffuse, and reflected; it is a function that relates to cloud screen, air pollution, geographical region and season [4].

The use of this energy resource is supported by many projects: a solar-diesel power plant in Hassi R'Mel producing 150 MWe, two thermal power plants with power storage having a total capacity of 150 MWe each, a project for an integrated combined cycle power plant in Hassi R'Mel and a project for an installation of solar power plants in the south producing 1200 MWe {produced presently by four thermal power stations} [5].

### 2.2 Geothermal energy

Geothermal energy is considered as a renewable and sustainable energy source, which can replace other forms of energy consumption as well as fossil fuels, and its field of application is large and in full evolution. The geothermal studies the internal thermal phenomena of the terrestrial globe, it covers a variety of applications ranging from heating homes to heat distribution via heat networks, through the air conditioning of buildings, and heating greenhouses, fish ponds and others.

The technic, when using geothermal energy, consists of a capture of the heat flow generated by the heat of the earth and to send it to the surface. On the overall Algerian territory, the geothermal distribution is predominantly low and at medium temperature. This geothermal which is interested in aquifers temperatures between 30 and 150 °C, can be used for district heating. In addition to providing heat, geothermal energy can be used to provide cooling to buildings for very low energy consumption.

#### 2.2.1 Geothermal exploration

Geothermal exploration in Algeria began in 1967 by the national oil company Sonatrach and stopped in 1979. In 1982, the national company of electric power Sonelgaz in collaboration with the Italian company Enel began the studies of geothermal reconnaissance in the northern and eastern regions of the country.

The development program was stopped because of the relatively low prices of conventional energies as well as the national rural electrification policy [6]. According to the report of the Bureau of Geological and Mining Research, geothermal energy in Algeria was not a national priority 'the after oil' [7].

Algeria is the largest country in Africa, it has significant potential in Albian nappes occupying 80% of the territory. According to John *et al.*, Algeria has more than 240 hot springs to its assets [8]. Three geothermal regions (figure 2) have been delineated according to the distribution of thermal springs, geological and geophysical considerations (permeability and geothermal gradient). The highest temperature recorded for the western region (Tlemcenian dolomites) is 68 °C. For the central zone (carbonate formations), the highest temperature recorded is 80 °C and for the eastern region (Albian in the Sahara), it is 98 °C.

The North-Eastern zone of the country, covering an area of 15000 km$^2$, is the zone with an interesting geothermal potential, with a flow rate of 100 l/s.

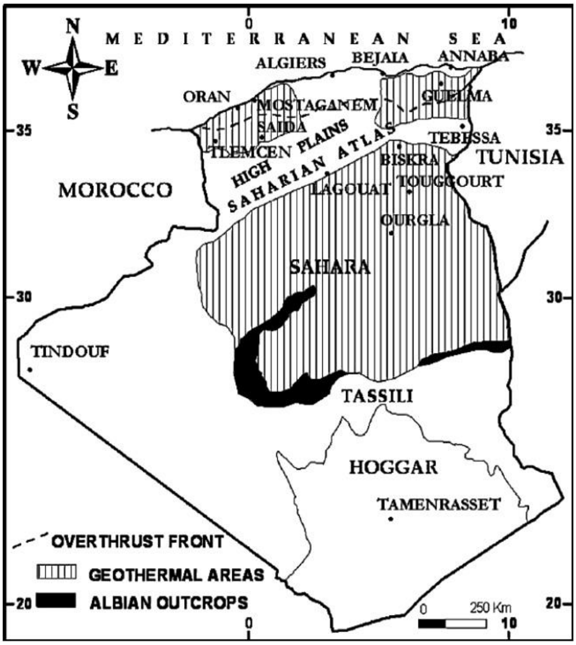



Fig. 2:Three main geothermal areas [9]

By definition, the geothermal potential of a structure is the amount of energy that can be mobilized in the ground without lasting modification of its temperature (energy resource). It is improved by the flow of a groundwater, which ensures the thermal recharge of the soil. The Algerian north has a considerable geothermal potential with low enthalpy, allowing to generate a heat discharge of 240 MWt [10].

### 2.2.2 Geothermal operation

Exploitation of a potential geothermal resource is based on data resulting from drilling already carried out as part of geological, oil or water research.

Studies performed by Saibi have developed conceptual models of northern and southern Algeria [11]. In the first model, the meteoric water follows a downward flow through the deep fractures and under the effect of a heat flux, this water is warmed up and ascended up to surface to supply the hot springs in figure 3**a**.

The temperature of the hot springs depends on: the speed of the water flow, the circulation time and the fracture characteristics.

He estimated the penetration depth of water up to 7 km, which explains the deep circulation of water. Bahri *et al.* mentioned that the thermal water extended from 780 to 2580 m depth [12]. The south of Algeria, meanwhile, is modeled by a sedimentary basin. The water in porous sedimentary rocks is heated by an ascending conductive heat flux. No water circulation occurs and the reservoir has a very high pressure in figure 3**b**.

Ferkraoui *et al* [13] performed an assessment of waste heat of the main thermal springs and the operated wells of the Albian aquifer. This assessment was performed to quantify the potential of energy that is available for direct use.

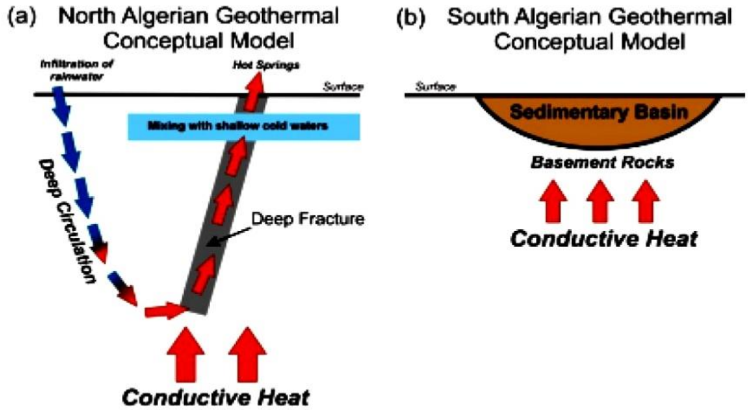
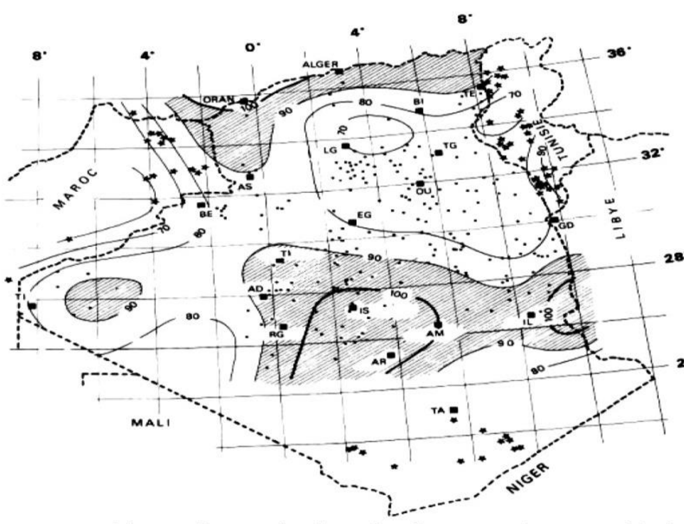



Fig. 3:Geothermal conceptual model: **(a)** Northern characterized by heating filtered meteoric water; **(b)** south characterized by basement heating of the sedimentary basin [11]

The heat flux distribution in Algeria (figure 4) reveals an average of 82 ± 19 mW/m$^2$ associated with the Sahara basin [9]. This heat flux distribution is resulting from an evaluation of heat flow in 230 oil wells with depths ranging from 500 to 5500 m, and from using temperature measurements as well as data of porosity characteristics of rocks. At the Hoggar Precambrian sub-soil boundary, the southern zone is characterized by very high heat flux values (90-130 mW/m$^2$).




Fig, 4:Regional patterns of heat flow, the hatched area relates to higher values 90 mW/m$^2$ [9]

Table 1: Assessment of heat releases in Algeria [13

| Geothermal regions | Debit (Ql / s) | Heat releases evaluated (MW) |
|---|---|---|
| North West | 800 | 60 |
| North East | 700 | 79 |
| South | 4000 | 603 |
| **Total** | 5500 | 642 |

The determination of the characteristics of this energy resource is based on the following areas: geology to determine geological structures, localization of volcanic zones and structures, and hydrothermal alterations based on field data, aerial photography and satellite imagery [14].

The hydro geological investigations are required to determine the quantitative and qualitative evaluation of the resource and the fluid flows characterization within the reservoir.

Geochemistry is required to characterize the physicochemical composition of water (temperature, pH, flow) and to determine the equilibrium water-rock temperature. The analysis of dissolved elements allows to provide guidance on the course of the fluid, its age, its origin and therefore on the supply and the recharge conditions of reservoirs.

And finally, exploration geophysics involves recording physical data of the subsoil by using geophysical techniques (gravitational and seismic). The gravitational technique is used to identify the anomalies in the subsoil and to characterize the exploitability of the deposit by carrying out measurements of temperature, flow and pressure.

The seismic technique is used to locate the limits of the geological structures as well as the faults based on the observation of the reflection of the waves transmitted to the subsoil.

Not exploited, geothermal energy in Algeria is in the form of reservoirs of steam of hot water or hot rocks. The main geothermal farms concern balneotherapy, the Tilapia fish farm using the warm waters of the southern Albian aquifer (Ghardaia and Ouargla), the building equipped with a heat pump for heating and cooling installed in schools in Saida and Khenchela, electricity with a geothermal power plant in Guelma and agriculture in the Touggourt region.

In Algeria, eighteen greenhouses of a total area of 7200 m2are heated by a 57 °C, Albian geothermal water. Bellache *et al.* (1995) indicate that the geothermal potential in north-eastern of the Algerian Sahara is sufficient to heat 9000 greenhouses, with a flow rate of 3.221 l/s. The total energy consumption for geothermal energy is about 1.778.65 TJ/year [15].

**Table 2**: Annual direct geothermal use corresponding to the end of 2014 [8]

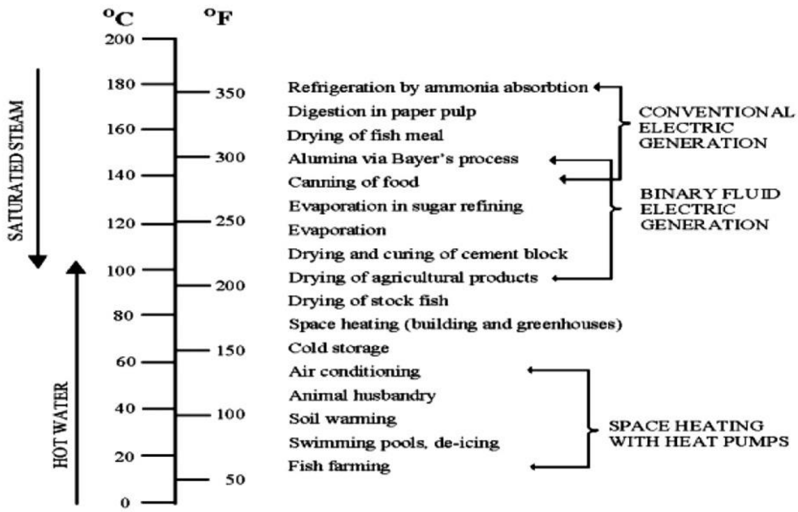
| Direct geothermal use | Installed thermal capacity (MWt) | Annual consumption (TJ/an) |
|---|---|---|
| Individual heating of permises | 1.0 | 13.05 |
| Air conditioner | 0.08 | 2.50 |
| Pisciculture | 9.02 | 279.1 |
| Swimming pool | 44.37 | 1400 |
| Geothermal heat pump | 0.17 | 5.0 |
| **Total for the country** | 54.64 | 1699.65 |

The temperature produced by a geothermal system determines the choice of the use that can be made of a geothermal resource. Three main categories of use are defined: heat to electricity conversion; direct use of geothermal heat, and application assisted by a heat pump.

## 3. PATH TO SUSTAINABLE CONSTRUCTION

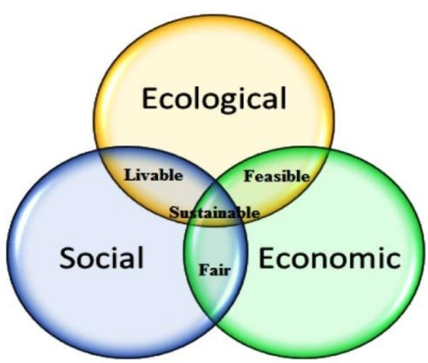
Sustainable construction is considered as the responsibility of the construction industry for the efficient use of natural resources, the reduction of negative impacts on the environment and the satisfaction of current needs in housing and infrastructure without compromising the comfort of future generations.

The sustainable development approach takes into account the life cycle of a green building and stakeholders involved in different phases. Erecting a sustainable building means then: considering the building as a whole by integrating it with external flows; developing an approach by considering issues related to sustainability, developing the project by offering an added value to its occupants and itsenvironment which surround it as a whole.




Fig, 5: Distribution of geothermal energy used as a function of temperature [16]

The United Nations Environmental Program for Sustainable Construction has defined sustainable development as a means for the construction industry to ensure sustainable development, considering ecological, socio-economic and cultural aspects (figure 6).




Fig, 6:Three foundations or spheres of sustainable development [17]

Sustainable means that development must be economically feasible and socially acceptable (fair), must be economically feasible and preserving nature, species and natural and energy resources (feasible) and must have effects on the environment that do not threaten humanity (livrable).

According to the report of the Brundtland Commission, United Nations, 1987 ‘Sustainable development is a development that meets the needs of present generations without compromising the ability of future generations to meet their own needs’.

This note focuses on the environment and social issues that are as important as economic problems and suggests that human, ecological and economic systems are interdependent.

The integration of sustainability principles in construction does not lead to a single solution but requires integrated solutions, well adapted to the goals and circumstances of the project, ensuring high quality buildings.

This is possible only through a life-cycle approach and deep analysis of alternatives in a process of optimization and finally with the integration of various actors in the process.

A sustainable construction project involves different actors such as users, residents and professionals as well as means (transport and infrastructure) of a region. Figure 7 shows the 09 themes of a sustainable building that can be closely linked.

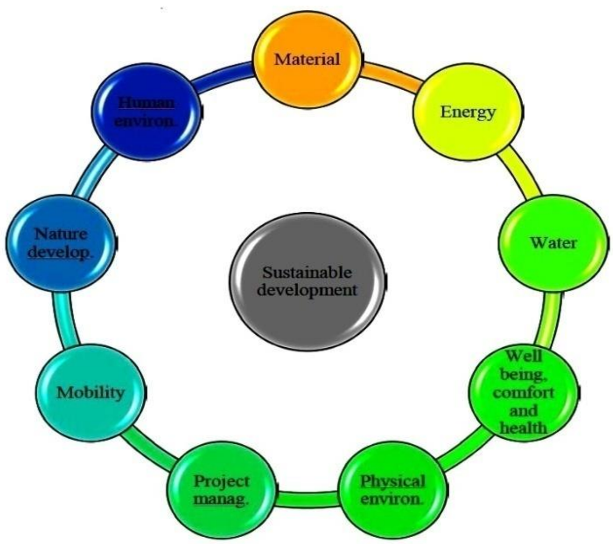


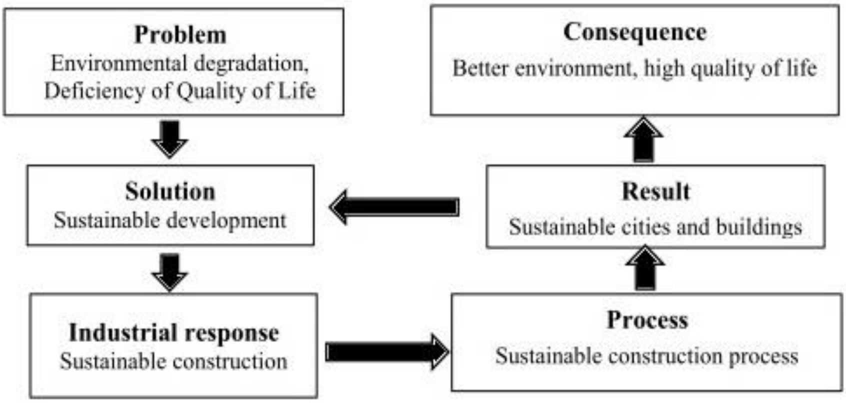

Fig. 7: Representative diagram of the 9 themes of a sustainable building

The criteria for sustainable building construction are the reduction of resource depletion, the mitigation of environmental degradation and the creation of a healthy built environment.

### 3.2 Sustainable construction process

The construction sector is considered as a potential energy consumer. Improving quality of this sector has a significant effect on the sustainability of society as a whole [18]. According to these authors, sustainable construction is the response of the building sector to sustainable development, which has its own processes (figure 8).

Since the end of the 1980s, sustainable construction has evolved continuously to have, facing environmental exhaustion, the goal of integration of sustainability concepts into the practice of conventional construction [19].




Fig, 8:Process of sustainable construction [18]

## 4. GEOTHERMAL INTEGRATION IN THE CONSTRUCTION

The field of temperatures below 90 °C is the one that offers the greatest diversity of use {heating buildings, agriculture, horticulture and fish farming, preheating, drying, spa and seaside recreation.

For these uses, the power supplied is proportional to the flow rate produced and to the temperature difference imposed on the geothermal fluid between the outlet and the inlet of the exchanger system.

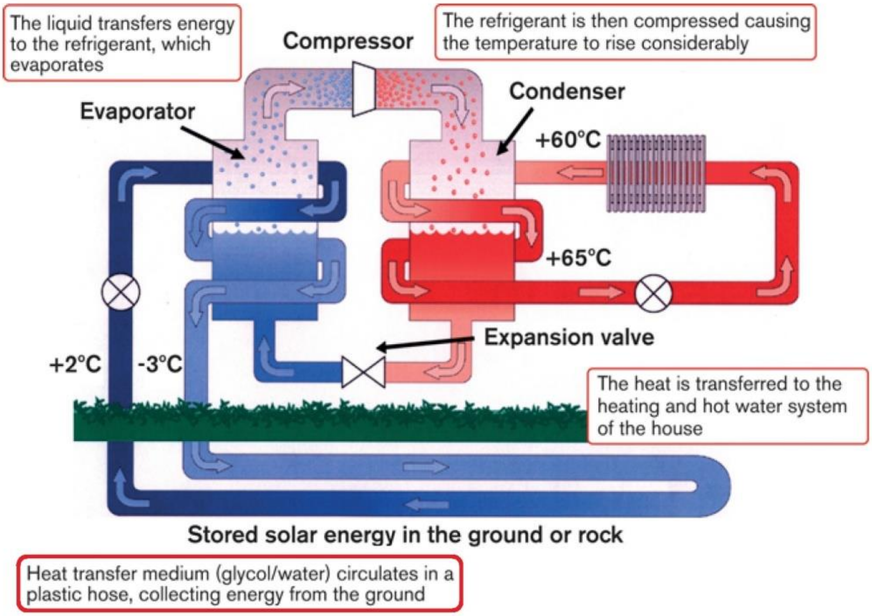



Fig. 9: Principle of the heat pump [20]

Thermal exchanges between the subsoil and the building are done via a heat pump (figure 9). In winter, the temperature extracted from the ground allows heating the building and in summer, the heat of the building is reinjected into the ground. The transport of calories is carried out by the heat transfer fluid between the soil and the heat pump to reach the heating fluid. This heat transfer fluid circulates in closed circuit between the piles and a collector connected to the heat pump.

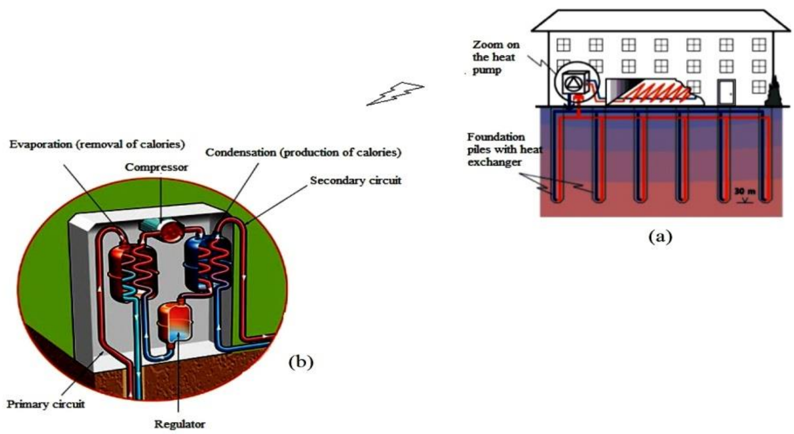
### 4.1 Geothermal energy assisted by heat pump

A heat pump is a thermodynamic device that can extract calories from the subsoil to supply a heating network (floors, walls, radiators), and it can produce cold (geocooling), by exploiting the temperature of the subsoil to refresh. The use of a reversible heat pump allows the recharge in heat of the aquifer during its use in cooling mode.

The thermodynamic cycle allows the heat extracted from the cold source to be captured by the heat transfer fluid at the evaporator. The fluid changes state by turning into vapor. The compressor compresses this steam, increasing then its temperature.

At the condenser, the condensing vapor transmits its heat to the medium to be heated. The fluid temperature is then strongly lowered in a pressure reducer, making it ready for further heat absorption and the cycle can start again (figure 10**b**).

The production of energy via a heat pump is respectful of the environment and resulting in the reduction of $CO_2$ emissions in compared to heating or cooling using traditional energies.




Fig, 10: **(a)** Building heating in winter or cooling in summer, **(b)** heat pump merging energy resource and distribution system or storage system

### 4.2 Energy geostructure

Presenting the advantage of being an ecological solution, allowing the passive heating and cooling of buildings, thermal geostructures are structural elements buried in the ground. These elements can be presented as superficial or deep foundations (piles, bars, rafts), molded walls as retaining walls or tunnels allowing the conduction of heat.

The dual role of these structures makes their design difficult and complex. Our interest will focus on the use of energy piles; they are deep foundations supporting the loads transmitted by the structures they carry and at the same time are used as heat exchangers.

### 4.3 Principle of operation of energy piles

For reasons of bearing capacity, the construction of some buildings requires the use of deep foundations in figure 11. These concrete piles make it possible to ensure the static stability of the building by distributing its weight in the ground. As the soil temperature is higher than the average air temperature in winter and lower than the average air temperature in summer, the piles are used for heating in winter and cooling in summer. These piles exploit the energy storage capacity of the soil.

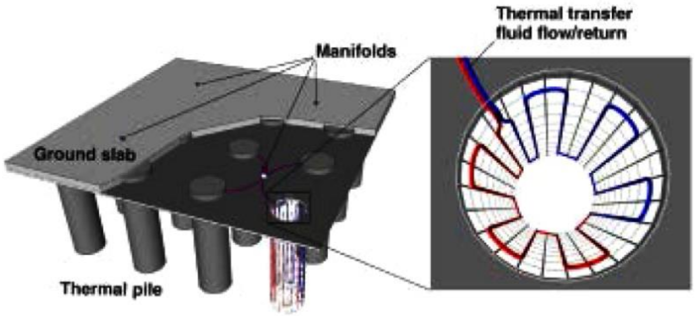



Fig. 11: Principle of a geothermal pile installation [18]

Equipped with a network of high-density polyethylene pipes in figure 12, the geothermal pile allows the thermal exchange of the building with the soil via a heat transfer fluid circulating in the tubes. This heat exchanger follows the design rules of a deep foundation. This system is only suitable for new projects and where the need for heating or cooling, depending on the season, is high.

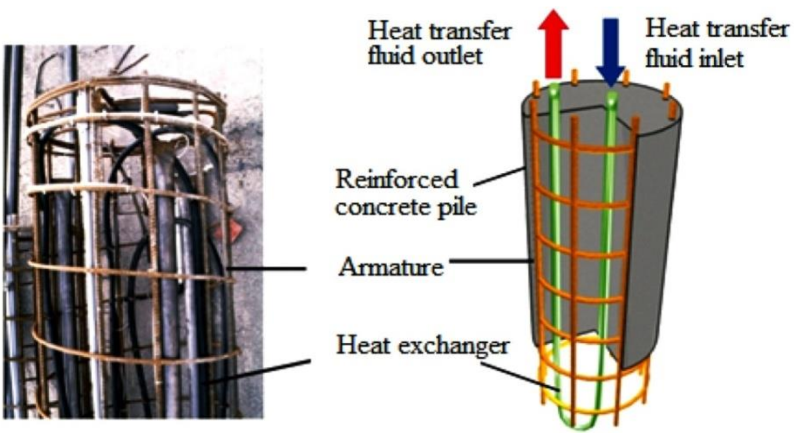



Fig. 12: Reinforcements and tubes exchanger of a geothermal pile

The heating and cooling cycles generate a contraction and expansion of the foundation in interaction with the building and the soil, caused by the soil-structure temperature variation. The resulting phenomena are: vertical displacements; variations in the vertical stress in the foundation as well as in the soil strength (axial friction and stress under the base of the pile).

The geothermal pile is surrounded by the ground, its ends are partially blocked (figure 13). It does not accept deformation in the presence of friction stresses along the envelope, but the thermal deformation portion produces additional displacements.

The distribution of the stresses and thermal deformations of the pile depends on the type of soil (friction angle) as well as the conditions of displacement imposed on its ends [15].Additional deformations of the pile due to thermal loading influence the stability and settlement of the structure.

A decrease in the temperature in an energy pile causes a soil-structure contraction preventing additional tensile stress. Therefore, the distribution of deformations along the pile tends to push the upper part downwards and to displace the lower part upwards. Increasing the temperature in the pile, in turn, prevents expansion, resulting in additional compressive stress. Therefore, the upper part of the pile is deformed upwards, while its lower part tends to be trusted downwards.

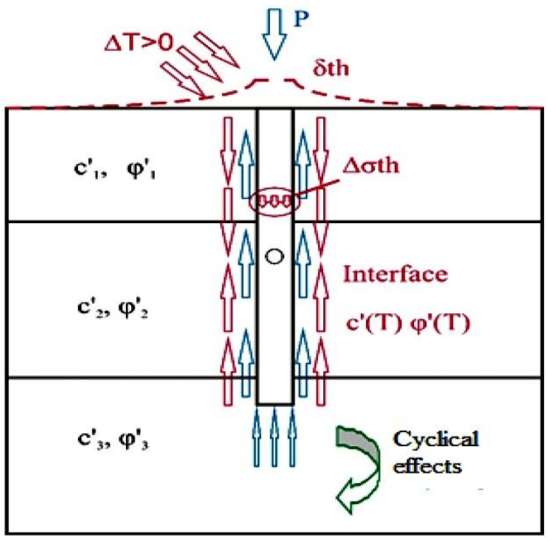



Fig. 13: Thermal effects on a pile

($\Delta T$ : Temperature variation, $P$ : Mechanical load, $\delta th$ : Displacement induced by temperature, $\Delta\sigma th$ : Additional stress induced by the temperature, $c'$ : Cohesion, $\varphi'$ : Soil friction angle) [21]

Under the effect of a thermo mechanical load, the piles are deformed. By opposition, the soil generates additional thermal stresses in the piles. These cyclical variations of the piles on the soil have an effect on the thermo mechanical behavior of the soil, in terms of deformation and shear strength. The effects of piles group play an important role in the design of energy foundations. The heating of a single pile of a group of piles causes a thermal expansion, which will be prevented by the presence of the other piles, inducing there by higher thermal stresses in this pile.

Captive of the soil that contains them, the ends of the pile are partially blocked by the presence of the building at its head and by a rigid layer located at its point. Their thermal deformation is partially prevented, resulting thereby in additional stress. In addition, the part of the thermal deformation that is not prevented results in additional displacements that concern both the foundation and the building restingon the foundation.

The distribution of the thermal stresses and deformations of the piles depends on the type of soil (angle of friction) in which they are made and the conditions of displacement that are imposed at their ends [22]. Under normal conditions, a pile subjected to a vertical stress undergoes compressive stresses causing a settlement due to the intensity of the imposed load. If this pile is subjected to a temperature decrease, it contracts, resulting in additional tensile stress.

The distribution of the deformations of the pile along its length shows that its upper part tends to thrust downwards while the lower part tends to move upwards. Therefore, there is a point on the pile length that does not move: it is the zero point.

In the upper part of the pile, the interface friction generated by the thermal movements, is in the same direction as that for the mechanical load; however, in the lower part, the friction is exerted in the opposite direction. When the pile is warmed up, the prevented expansion is giving additional compression stress.

In this case, the deformation of the pile causes the displacement of its upper part upwards and the thrust downwards of its part at the bottom. The thermal loading of the piles causes additional stresses and deformations that affect the stability and settlements of the structure.

## 5. CONCLUSION

The challenge facing the development of ecologically efficient buildings is the significant reduction of the energy footprint. In order to meet the environmental requirements, the construction of buildings is accompanied by constraints that are more and more diverse and varied. The disproportionate energy consumption of this activity sector leads to raise an emergency alarm in the Eco design policy. This article is an introduction to the application of renewable energies in sustainable building design.

The energetic geostructures support the loads transmitted by the structures, which they carry and at the same time are used as heat exchangers. The operation of this type of foundation is governed by the thermal variations (contraction and dilation) that they undergo.

In order to ensure an efficient integration of renewable energies in the design of sustainable buildings, prospects will be in a first step to integrate a design approach adapted to the need for optimization and sustainability. In a second step, determine the evolution of pile head displacements, normal stress and mobilization of soil strength including cyclic effects.

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