Article “German Geothermal Congress DGK 2024”, Germany, 22. – 24. October 2024

https://doi.org/10.5281/zenodo.14844371

The thermoactive pavement: a new solution to regenerate geothermal fields

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Keywords: energy harvesting, asphalt pavement, thermoactive pavement, geothermal energy, seasonal storage

Abstract

Over the last decade, road construction companies have developed innovative solutions that integrate new functions into roads, such as the ability to generate renewable energy. One such technology involves harvesting solar thermal energy through a heat exchanger made up of pipe registers integrated into the pavement. The energy is mainly harvested during the summer, taking advantage of the large black surfaces that roads offer. However, heating needs are significantly higher in winter than in summer, making seasonal storage a critical aspect of this technology. Recent developments have focused on understanding and optimizing the storage of solar heat using shallow geothermal technologies. This paper examines the capability of thermoactive pavements to harvest solar energy and recharge a geothermal probe field. The authors present observations from two operational facilities in France, which provide renewable heat to a customer office at a toll station near to Paris and to social housing in Normandy. Two main parameters were studied: the annual energy balance between the pavement and the probe fields, and the evolution of the temperature annually and over several years. Based on these two experiences, the ability of a thermoactive pavement to recharge a geothermal probe field has been positively assessed. Like solar thermal energy, this system contributes to the regeneration of the soil. This ensures the long-term dimensioning of geothermal production and allows for optimization of the geothermal field's size. The road infrastructure, on the other hand, does not require additional space, as it is already an integral part of our urban landscapes.

1. Introduction

With the European Green Deal, the EU has set the goal for its member states to cut its greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. This represents a reduction of around 1.5 billion tonnes of CO2 annually. The ultimate objective is to achieve climate neutrality by 2050. These two targets have even been enshrined into law through the European Climate Law [1] and are supported by ambitious proposals under the “Fit for 55” package. To achieve this massive reduction in CO2 Emissions, it is crucial for Europe to drastically accelerate the transition from fossil fuels to carbon-free energy sources, alongside implementing essential energy efficiency and conservation measures across all sectors.

This paper aims to focus on the heat generation sector, which accounts for a significant share of the final energy consumption in both France and Germany. Today, in France, 42% of energy is used for heat production, 30% for transportation, and 28% for electricity. Of this 42%, the share of renewable energy in the final consumption of heat was only 22.3% in 2021 [2], according to the Renewable Heat Panorama (Renewable Energy Syndicate). The Energy Transition for Green Growth Act (LTECV) states that the national energy policy aims to increase this share to 38% by 2030. In Germany, heat consumption accounts for more than half of Germany's total final energy consumption, 57% in 2022 [3] according to the “Status Report: Heat” from Bundesverband der Energie- und Wasserwirtschaft (BDEW). Today, less than 20% comes from renewable sources. Specifically, just an 18.8% in 2023 [4] according to the Umweltbundesamt (UBA), with gas and oil remaining as the main energy sources in this sector. In the latest update of his climate plan 2030, Germany aims to increase this share in the building sector to 50% by 2030.

In this regard, one of the most promising paths is the exploitation of the energy beneath our feet: the geothermal energy. The French Haut-commissariat au Plan has published a report [5] in 2022 about this under-exploited energy and describe it like that: “It is free, inexhaustible, without any pollution, and it can advantageously complement or even replace all other heat or cold production systems, generating very significant operating savings in the short term.” Following this publication, the French government published a geothermal plan in 2023 to enhance the development of this technology with the goal to save 100 TWh/year of gas within 15 to 20 years. Similar developments can be observed in Germany, notably with the recent publication from the Bundesministerium für Wirtschaft und Klimaschutz (BMWK) to accelerate the approval procedure of geothermal plants: the geothermal energy and heat pump law (GeoWG) [6].

Among the different geothermal technologies, the authors decided to focus on surface geothermal systems and furthermore to study the seasonal thermal energy storage (STES) technologies, which are described in chapter 2.2. According to the Académie des technologies, promoting STES systems will facilitate progress toward the official target of 100 TWh of heat supplied by geothermal energy by around 2040 [7]. These specific technologies are highly relevant to the European challenge of heat supply mentioned above.

The authors have chosen to present a concrete example from STES systems through a solution developed by Vinci Construction, branded as Power Road®, which uses a thermoactive pavement as a complementary energy source for the geothermal probe field. This solution was first implemented in France and is currently being expanded to Germany. The authors share observations from two operational facilities in France supplying renewable heat to a customer office at a toll station near to Paris and to social housing in Normandy.

2. State of the art

2.1 Thermoactive pavement

Under the action of solar radiation, road infrastructures coated with black bituminous asphalt can reach surface temperatures of 60°C to 70°C in summer, with the first ten centimeters reaching around 40°C. These pavements thus function as efficient solar thermal geo-structures.

Thermoactive pavements allow the recovery of this available renewable heat while maintaining the mechanical characteristics, durability, and recyclability of conventional pavements. The renewable heat is harvested by integrating a heat exchanger into the surface layers of the pavement (under the surface layer, at a depth of 5 to 8 cm). This exchanger consists of a network of pipes through which a heat transfer fluid (usually mono-propylene glycol diluted to between 10% and 30%) circulates. Under solar radiation, this heat transfer fluid gradually heats up, reaching temperatures of up to 40°C.

The thermal energy captured can be used either immediately or with a time delay. For direct use, a heat pump extracts the necessary heat directly from the heat transfer fluid for immediate heating needs. When heating needs are delayed in time compared to the production period, the captured heat is used to recharge a geothermal probe field. In winter, the energy is extracted from the probe field via a heat pump.

Back in 2016, a state-of-the-art analysis about energy harvesting on road pavements [8] was published, highlighting a wide range of solutions. These were either based on the use of solar radiation as an energy source, or on the use of mechanical energy from vehicle loads. The thermoactive pavements are classified within the first group and named asphalt solar collectors (ASC). They are identified as the only mature technology among all others.

More recently, a review of large-scale research prototypes and actual projects involving thermoactive pavements [9] shows that this technology has led to numerous developments worldwide in recent years. Within Europe's industrial landscape, initiatives like the RES (Road engineering Systems) product from the company Ooms Producten from the Netherlands can be found [9], [10]. This thermoactive pavement solution was significantly developed between 1998 and 2006 [9], resulting in a total of nine projects completed in Europe. Following these developments, the OOMS technical solution was released in France by the company CHARIER TP under the name Hélianthe since 2018 [15]. On the other hand, the Power Road® system was developed in 2013 by the company Eurovia a subsidiary of VINCI Construction [9], [10], [11], [12], [13], [14] for two main purposes: infrastructure snow removal without the use of road salt, and low-carbon building heating. With the first two pilot projects completed in 2017, by the end of 2023, this solution will have been implemented in 20 projects, primarily in France and to a lesser extent in the UK, Czech Republic, Canada and Germany. Additionally, another solution has been implemented in Austria as part of the project “Sozial100%Erneuerbar” conducted by the Austrian Institute of Technology (AIT). In that case, a thermoactive pavement was built by the company Strabag [16], [17].

To conclude, industrial solutions have been developed and have reached full technological maturity (TRL9). However, the lack of knowledge of these solutions by engineering and design departments and contracting authorities, and of their energy efficiency, is slowing their further development and implementation.

The next chapters of this article focus on the Power Road technology, for which work sites equipped with instrumentation have been carried out and monitored over several years. This solution is based on two alternative techniques for placing tubes in the pavement, as illustrated in Fig. 1. This makes it possible to adapt this solution to any roadway geometry. In both processes, the pipes are spaced 25 cm apart and covered with 7 cm of asphalt in the nominal configuration.

Fig. 1: Power Road pipe installation - (left) Indentation installation method - (right) Grooving installation method

2.2 Seasonal thermal energy storage

Seasonal Thermal Energy Storage (STES) is a technology for storing thermal energy (heat or cold) over long periods, usually several months. The main idea is to capture thermal energy when it is available in abundance, such as solar heat in summer, and store it for later use, for example for heating in winter. By reducing the fossil fuel consumption of buildings for heating and cooling, this leads to lower energy bills for consumer, a reduced greenhouse gas footprint and improving energy independence [7].

There are numerous STES technologies covering a wide range of applications, from simple buildings to large heat networks. The thermal energy could be stored in underground reservoirs, aquifers or specific materials capable of retaining heat as shown Fig. 2. The choice of STES depends on efficiency, storage requirements (quantity of energy, storage temperature) and the specific cost of construction. During the HEATSTORE project [18], which aimed at lowering the cost, reducing risks, improving the performance of underground thermal energy storage technologies, six new demonstration pilots were built, and eight cases of existing systems were studied, including the following examples:

- Drake Landing Solar Community (2006) in Canada, where underground storage provides 97% of annual heat consumption of 52 high energy-efficiency houses.
- NIOO Wageningen (2011): This project uses a medium-temperature (45°C) heat storage system to heat the institute's buildings. It encountered initial challenges but has been optimised over time.
- University of Utrecht (1991-1999): A pioneering high-temperature (90°C) heat storage project using waste heat from cogeneration plants. Although the project was stopped in 1999, it provided valuable lessons on heat management and technical challenges.
- Hooge Burgh Zwammerdam (1998-2009): Used CHP heat to heat a care facility. The project was stopped for economic reasons but demonstrated the technical feasibility of high-temperature heat storage.
- Reichstag Berlin: The most prominent German example of an aquifer storage system, which uses a heat storage system at 70°C without water treatment, demonstrating the possibility of storing heat at high temperature without carbonate precipitation.

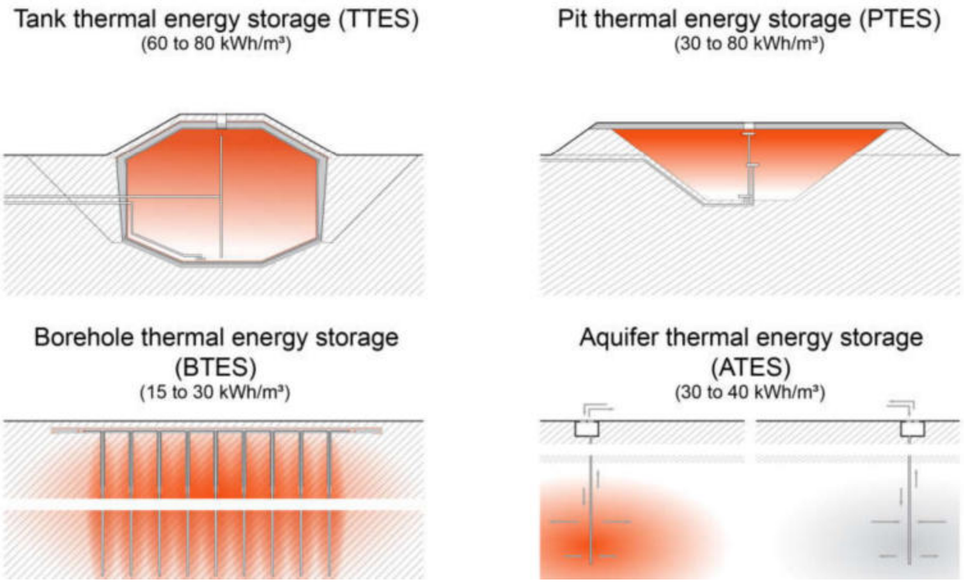

Fig. 2: different types of UTES – Underground Thermal Energy Storage

Several criteria were used to select the most appropriate underground storage technology for Power Road, leading to the selection of Borehole Thermal Energy Storage (BTES). First, BTESs can be installed throughout France (almost 100% of the country), many stakeholders have the necessary qualifications to carry out this type of installation (design offices, drillers, heat pump suppliers, etc.), and French regulations have been simplified for small-scale geothermal energy as BTES. Like in France, the situation can be assessed positively as well in Germany. According to the Roadmap on near-surface geothermal energy [19] from Fraunhofer Institute, the shallow geothermal technologies have the potential to cover up to 75% of the German heating demand. With the new geothermal energy and heat pump law (GeoWG) [6] the political and regulatory framework is moving in the right direction.

Secondly, from a technical point of view, by injecting the heat produced in summer into the subsoil (solar thermal energy, cooling…), the BTES temperature can be kept constant, or even increased, from one winter to the next, thereby maintaining or even boosting the performance of the energy system over time. This heat supply avoids the need to install long probes, which reduces the required investment. The temperature of the hot water produced by Power Road®, varies between 20 and 40°C depending on the solar flux incident on the road, as expected for boosting geothermal probes.

A numerical study carried out with the BRGM (the French Geological and Mining Research Bureau) shows that Power Road can improve the performance of a geothermal energy system, particularly if cooling requirements are not very high (less than 20% of heating requirements). It can simultaneously reduce the total cost of the system and its carbon content. This is thanks to a significant reduction in the number of probes (generally around 50% and up to 70%), even if this is partly offset by the installation of a large surface area of Power Road® [20].

3. Heating and Snow removal for a customer office at a toll station near to Paris (France)

3.1 The facility

In July 2017, Power Road® was installed on the access road to the truck parking lot from a toll station on the highway A10 at Saint-Arnoult-en-Yvelines, on the outskirts of Paris. Winner of the 2017 “Road of the Future” call for projects operated by ADEME under the Programme d'investissements d'avenir (PIA), this project was Eurovia’s first Power Road® realization, and it aimed to validate the construction principles at site scale, the pavement mechanical durability and the full-scale energy performance.

The facility was designed for two uses, with the energy produced being used to de-icing the roadway in winter, and to heat the Customer Centre Building, replacing an oil-fired boiler. The facility is made of a 500 m² thermoactive pavement which enables the active recharge from the geothermal storage (BTES) composed by a field of 20 vertical geothermal probes at a depth of 80 metres. The probe field is installed beneath the employee parking lot. Heat production for the 370 m² customer centre building is provided by a 104 kW geothermal heat pump, installed in a technical room located outside. The layout of the various elements is shown on Fig. **3** and the sizing of the facility on Fig. **4**.

For building heating, an energy need of 35 MWh/a was considered. For the de-icing function, the necessary need to warm up the road surface and remove snow was estimated at between 43 and 97 MWh/a, corresponding respectively to an average year and an exceptional year on the local weather station. In addition to the quantity of energy, the power requirement is an important parameter and, in the case of snow removal, a determining factor since high power levels are required. The installation was sized to get 200 W/m² available power for snow removal, which led to an oversizing of the geothermal probe field in relation to the building's heating requirements.

The facility was commissioned in July 2018 and has been closely monitored ever since.

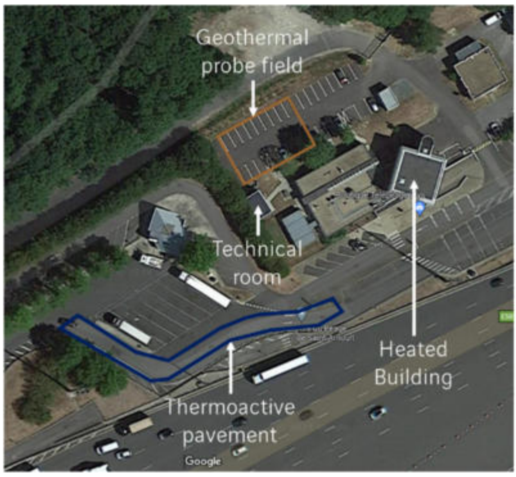

Fig. 3: Areal view, Power Road® in Saint Arnoult

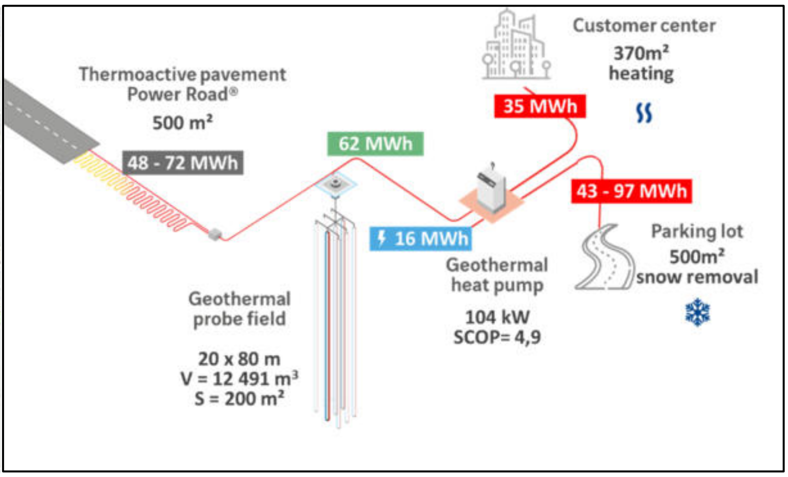

Fig. 4: System sizing, Power Road® in Saint Arnoult

3.2 Operating modes

The facility has three main operation modes:

- Energy harvesting and inter-seasonal storage: The available heat energy is harvested from the pavement and injected into the geothermal probe field. These modes take place mainly in summer and on some hot and sunny days the rest of the year.
- Building heating: The COFIROUTE Customer Centre is completely heated with the system. The heat energy is extracted from the geothermal probe field and thanks to a geothermal heat pump is adjusted to the needed temperature to heat the office.
- Snow removal: In a similar way the stored heat energy can also be used to warm up the roadway so that the road stays clear from snow and ice in winter.

3.3 Recharge geothermal probe field

3.3.1 Energy balance

As part of plant monitoring, the energy injected into and extracted from the geothermal probe field is measured. In the sizing phase a recharge rate around 1 was considered. That means that the same quantity of energy must be injected into the probe field as the extracted one. The actual facility values from 2019, 2020, 2021 and 2022 are presented in Fig. 5.

In 2019 and 2020 the recharge rates were in line with the study with values of 1.22 and 1.04, respectively. In 2021, the rate was slightly under 1, reaching only 0.92 due to a regulation malfunction in April. In 2022, it returned to 1 but a higher rate should have been reached. Indeed, a parameter setting error caused the system to operate in defrost mode during the summer, increasing the unnecessary extraction of heat from the BTES. On average over the 4 years, the recharge rate is equal to 1.04, showing a well-balanced system. Despite some occasional regulation faults, the recharge of the geothermal probe field has been working as expected.

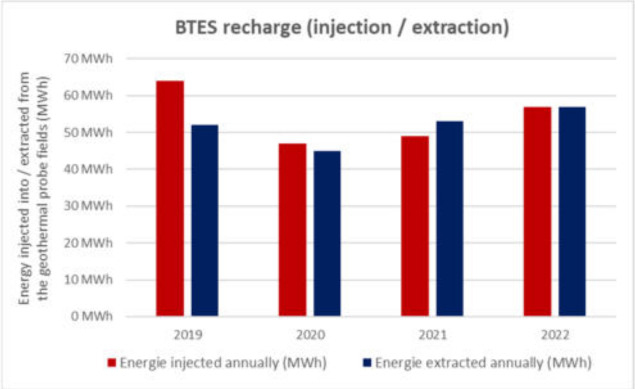

Fig. 5: Energy balance BTES, red: energy injected into / blue: energy extracted from, Power Road® in Saint Arnoult

3.3.2 Evolution of temperatures in probe field

The geothermal probe field from the facility in Saint Arnoult has been instrumented with sensors to measure temperatures from the fluid within the geothermal probes as well as temperatures from the soil in the geothermal probe field. The aim of this instrumentation is to check temperature stability after several charge/discharge phases of the probe field.

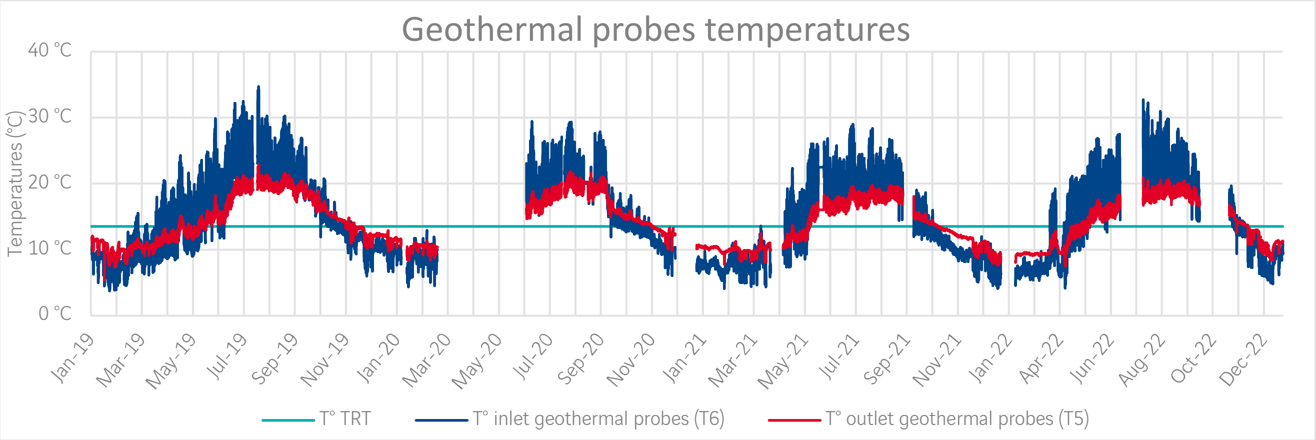

Fig. 6: Fluid temperatures in geothermal probe, Power Road® in Saint Arnoult

Fig. 6 shows the evolution of fluid temperatures over 4 years. The blue curve represents the daily inlet temperature, that means the temperature which is sent into the geothermal probe by Power Road® in summer and by the heat pump in winter, the red curve represents the daily outlet temperature. The turquoise line represents the initial temperature from the soil according to the thermal response test (TRT) realized before the site construction.

The inlet temperature lies between 4 and 35°C and thus comply with the French regulations for low impact geothermal system (GMI, Geothermie de minime importance). The average temperature over the 4 years is equal to 14°C and thus very similar to the TRT temperature, which was 13.5°C. This result shows the effect of the recharge, instead of dropping slightly year after year like in classic geothermal installation, the temperature indeed remains constant.

To illustrate this in a more concrete way, the operation of the plant was simulated by over 50 years with and without recharge of the geothermal probe field by Power Road® (requirements identical over 50 years to those achieved in the reference year 2019). Simulations were carried out by BURGEAP using the PILESIM software. The 50-year average coefficient of performance (COP) is boosted by around 20% thanks to recharge (COP of 5.1 with recharge, 4.3 without recharge). This leads to a 20% reduction in the heat pump's electricity consumption, and therefore a reduction in operating costs (OPEX). When looking at energy extraction from the subsoil over the past year, see Fig. 7, it can be observed that fluid temperatures on the probe field return are significantly higher in the case of probe field recharge (violet curve). Temperature differences are in the order of 2 to 5°C during the first year of operation; this will have a direct impact on the performance of the heat pump. Minimum fluid temperatures in the non-recharged probes fall below the minimum temperature of -3°C imposed by the GMI (-3.8°C on the flow and -2.6°C on the return of the SGV probe field) after a few years of operation.

The seasonal heat storage has a significant impact on the geothermal probes field in terms of both temperature stability and temperature level which leads for the same size of the field to a more durable and effective system.

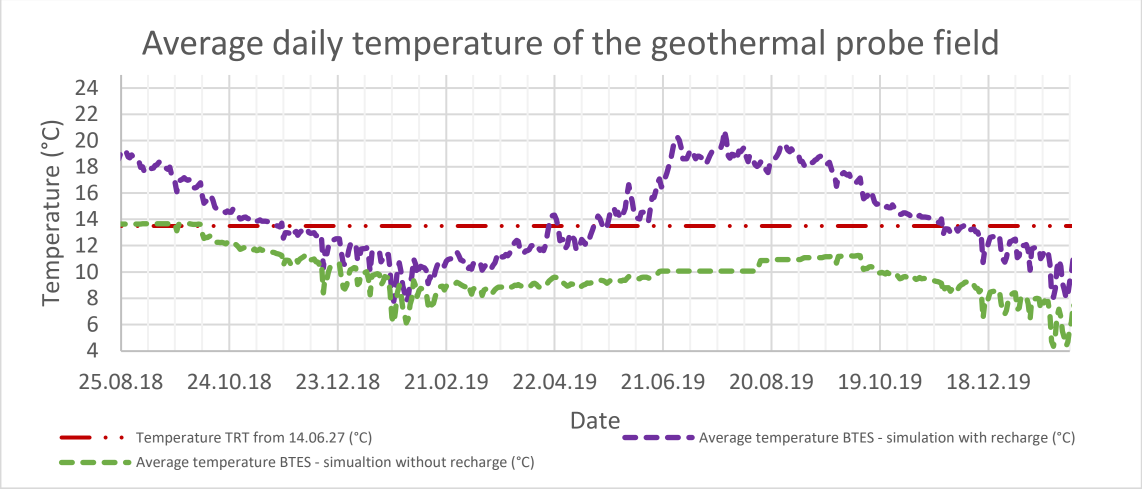

Fig. 7: Simulation daily outlet temperature in geothermal probe during the first year of operation, violet – with recharge Power Road®, green – without recharge, Burgeap

4. Heating and hot water supply from social housing in Normandy (France)

4.1 The facility

In January 2018, a 61-unit social housing complex in Fleury-sur-Orne, northern France, underwent thermal renovation. Inolya, the largest social housing authority in the department, used the Power Road® system to meet 70% of the heating needs for four of the five buildings.

To achieve this, half of the residents parking spaces (1,420 m² out of a total of 3,000 m²) were equipped with a thermoactive pavement. The operating principle is very simple: the collected solar heat charges a BTES of 12 vertical geothermal probes to a depth of 140 meters. Two 50 kW heat pumps then distribute the required heat to the apartments. In addition to the Power Road® system, two 180 kW gas boilers were installed. They aim to cover the remaining energy requirements, being designed as a back-up system to supply the entire energy need. The sizing of the installation is illustrated in Fig. 8.

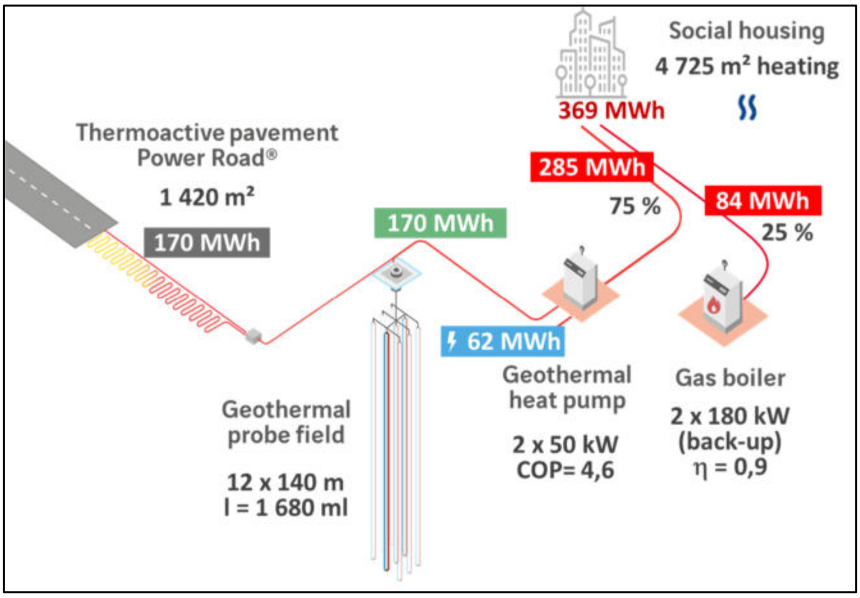

Fig. 8: System sizing, Power Road® social housing in Fleury-sur-Orne

During the feasibility study conducted by the design office Burgeap, certified by OPQIBI (a French qualification recognized by the Public Contracts Law), two scenarios were examined: a traditional geothermal heating system and the Power Road® system. The initial assessment determined that 3,400 meters of geothermal probes would be required to meet the buildings' heating needs, with a heat pump COP of 4.1. However, with the additional energy provided by the thermoactive pavement, the length of the geothermal probe field could be reduced by half to 1,680 meters. This also improved the heat pump's COP by 15%, raising it to 4.6 [21].

At this point the authors would like to stress a difference in the sizing of the two projects. By comparing this project, where 1,420 m² thermoactive pavement with 1,680 drilling meter are necessary, to the geothermal probe field from the plant in Saint Arnoult, with almost as many drilling meters (1,600 m) but a much smaller thermoactive pavement surface (500 m²), it seems not to be consistent. As explained in chapter 3.1. the facility in Saint Arnoult was designed to guarantee the necessary power for snow removal, with a lower energy requirement (132 MWh/a). The present facility has been sized to supply only the heating need of the buildings but with a much higher energy requirement of 285 MWh/a. With a similar probe field size and similar available power from the heat pumps, a much larger surface of thermoactive pavement is required to produce this higher amount of energy.

4.2 Operating modes

The facility in Fleury-sur-Orne has been initially designed for two operation modes:

- Energy harvesting and inter-seasonal storage: The available heat energy is harvested from the pavement and injected into the geothermal probe field. These modes take place principally in summer and on some hot and sunny days the rest of the year.
- Building heating and hot water production: The apartments are supplied up to 70% with the system. The heat energy is extracted from the geothermal probe field and thanks to a geothermal heat pump, it is adjusted to the needed temperature for heating and hot water for the social housing.

A new operation mode was added later:

- Direct use of the heat from the thermoactive pavement supported by the heat pump: The hydraulic system underwent work in 2022 to enable the heat pump to draw calories from either the probe field or Power Road®, or both. This work was accompanied by an update of the functional and control analysis to take into account the new operating mode. It has been in operation since 2023.

4.3 Recharge geothermal probe field

4.3.1 Energy balance between pavement and probe field

Like for the first project, a recharge rate around 1 was considered in the design phase. However, this recharge rate hasn’t been reached yet. They are equal to 0.35, 0.5 and 0.7 for the three years in operation, respectively, as observed in Fig. **9**. These low rates can be explained by different factors.

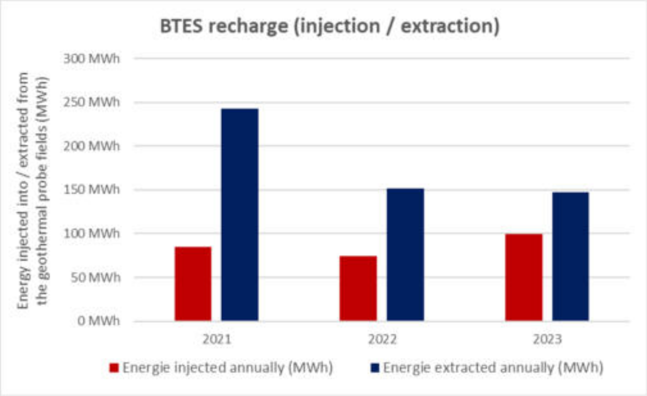

Fig. 9: Energy balance BTES, red: energy injected into / blue: energy extracted from, Power Road® in Fleury-sur-Orne

First it is necessary to focus on the heat production from the entire installation. After an extremely heavy first year with a need of 480 MWh, requirements stabilized at around 400 MWh. The initial high energy extraction from the probe field (240 MWh in 2021) reflects the significant heating requirements in the first year of operation. The landlord's strategy evolved between 2021 and 2022 which led to lower energy extraction as shown in Fig. **9**. On the one hand, it prioritized geothermal performance by reducing its coverage rate (by lowering production temperatures, the share of gas increases), and on the other, operating costs due to the low cost of gas (despite the energy crisis), to the detriment of environmental performance.

These production variances alone cannot fully explain the result. The energy harvesting from Power Road® is also significantly influenced by the design of the heat exchanger (the length of each loop is an essential parameter) and the operating points (flow rate regulation plays a key role). An optimal flow rate is necessary to maximize energy capture while limiting the electrical consumption of the circulator. Various flow regulation proposals have been evaluated for the period 2023-2024 in Fleury-sur-Orne, to increase Power Road's harnessing performance and therefore the energy injected into the BTES. By 2024, it is expected to see a better injection/extraction ratio thanks to improved plant management and control of tenant consumption.

Ultimately, the introduction of direct use, as explained in chapter 4.2, maximizes the utilization of Power Road®, capturing 25% more energy. In 2023, a total of 125 MWh was extracted from the thermoactive pavement. Of this, 100 MWh was stored in the geothermal field, as depicted in Fig. 9, and an additional 25 MWh was used immediately via the heat pump. As shown in Fig. 10 on the left, the biggest needs are mainly in winter when, in addition to hot water, it is necessary to heat the buildings. Power Road®, in its standard operation mode, produces heat primarily in summer. The direct use of the heat produced by Power Road® enable additional production mainly in the mid-season (March to May) as observed Fig. 10 on the right. From another point of view, using Power Road's energy directly also means for the installation extracting less energy from the BTES.

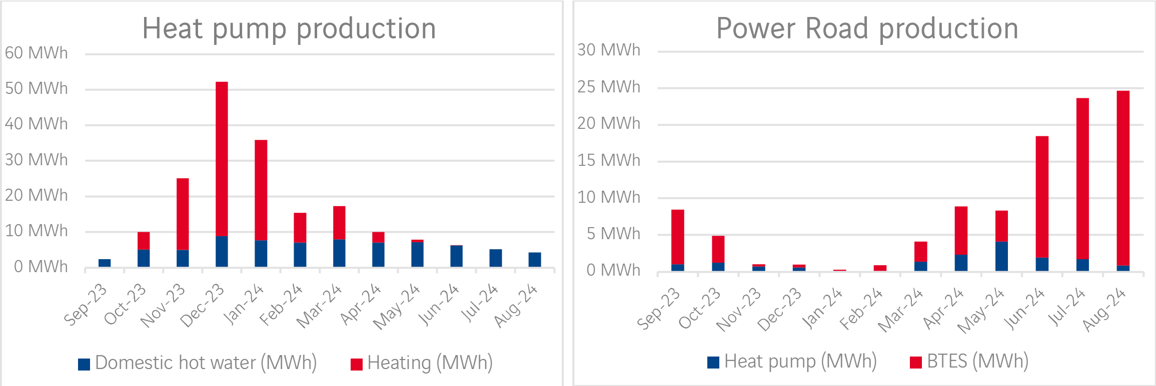

Fig. 10: left: Repartition Heat pump production between hot water and heating, right: Repartition Power Road® production between direct (blue) and indirect use (red), Power Road® in Fleury-sur-Orne

4.3.2 Evolution of temperature in probe field

Fig. 11 show the evolution of fluid temperatures over 4 years. The blue curve represents the average from the daily inlet and outlet temperatures. The grey dotted line represents the initial temperature from the soil according to the thermal response test (TRT) realized before the site construction.

As explained in Chapter 3.3.2 without a recharge from the geothermal probe field, the average temperature would have dropped under the TRT temperature. The temperature in this project stays stable. The average temperature over the 4 years oscillates around the TRT temperature measured at 13.4°C. This reflects a good balance between the heat injected into and extracted from the geothermal probe field despite a lower-than-expected recharge rate. These results indicate that the optimal recharge ratio is not necessarily close to 1. During the first three years of operation, maintaining a ratio between 0.35 and 0.7 keeps the probe field temperature stable. Further numerical analyses are being conducted to determine the optimal ratio for the Fleury installation. This is crucial for ensuring the geothermal field long-term viability while optimizing investment costs by keeping recharge levels only as high as necessary.

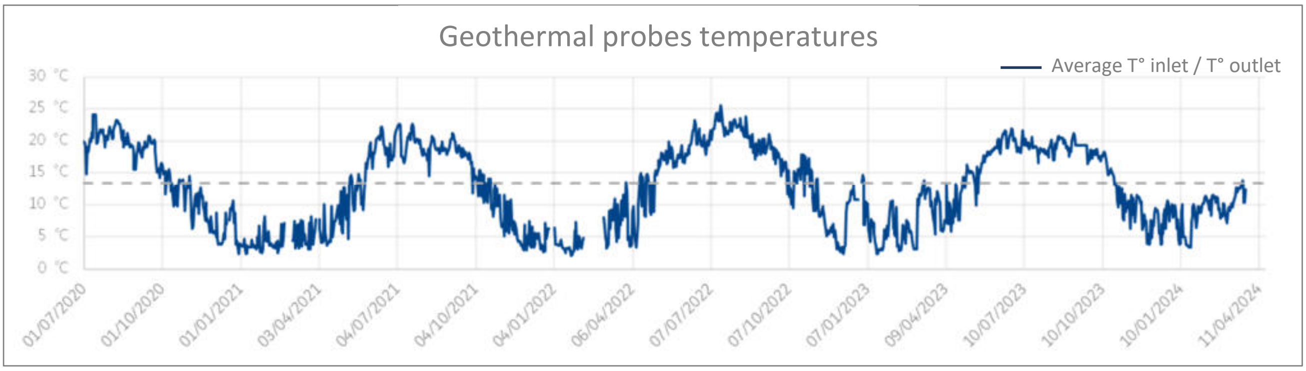

Fig. 11: Fluid temperatures in geothermal probe, Power Road® social housing in Normandy

5. Discussion and main outcomes

The proportion of renewable heat needs to be significantly increased in the coming years, with geothermal energy playing a crucial role. Seasonal thermal energy storage (STES) technologies have been recognized as essential in meeting these goals.

This paper explores the potential of thermoactive pavement as an energy source for such STES systems. Recharge rates and temperature changes in BTES were analyzed for two projects in France. In the first project in Saint Arnoult, the recharge rates remained around 1 over the four years of operation. In the second project in Fleury-sur-Orne, the recharge rates were lower, partly due to differences in design (aligned with heating requirements in terms of both power and energy) and operational parameters. In both projects, the temperatures in the geothermal probe field remained stable over the years, indicating effective recharge. Therefore, the findings suggest a positive assessment: thermoactive pavements are a relevant alternative energy source for STES technologies.

Moreover, precise regulation plays a crucial role in enhancing the harnessing performance of thermoactive pavements. As a result, the amount of renewable energy used in the Fleury plant has increased significantly over the years. First and foremost, particular attention was paid to the flow rate through Power Road®, to increase its performance. Secondly, the direct-use mode makes it possible to use available solar energy, thus limiting the amount of energy that needs to be extracted from the probe field in mid-season and during the summer.

These experimental works provide valuable insights for optimizing and refining the installation. However, identifying key parameters can be challenging, as the system is influenced by numerous factors such as weather conditions, tenants' energy demands, and system control settings. Numerical simulations offer a way to push this understanding further. In collaboration with CEA Tech (INES, Institut National de l'Énergie Solaire), a software has been developed to predict key aspects of Power Road's design - such as asphalt thickness, tube layer length, and tube spacing - based on meteorological conditions, as well as operating parameters like flow rate and fluid temperature entering the layers. These simulations allow us to compare field observations and adjust parameters one by one for better understanding. These tools also enable engineering offices to integrate Power Road® into their studies. This is essential to facilitate the wider adoption of thermoactive pavements.

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